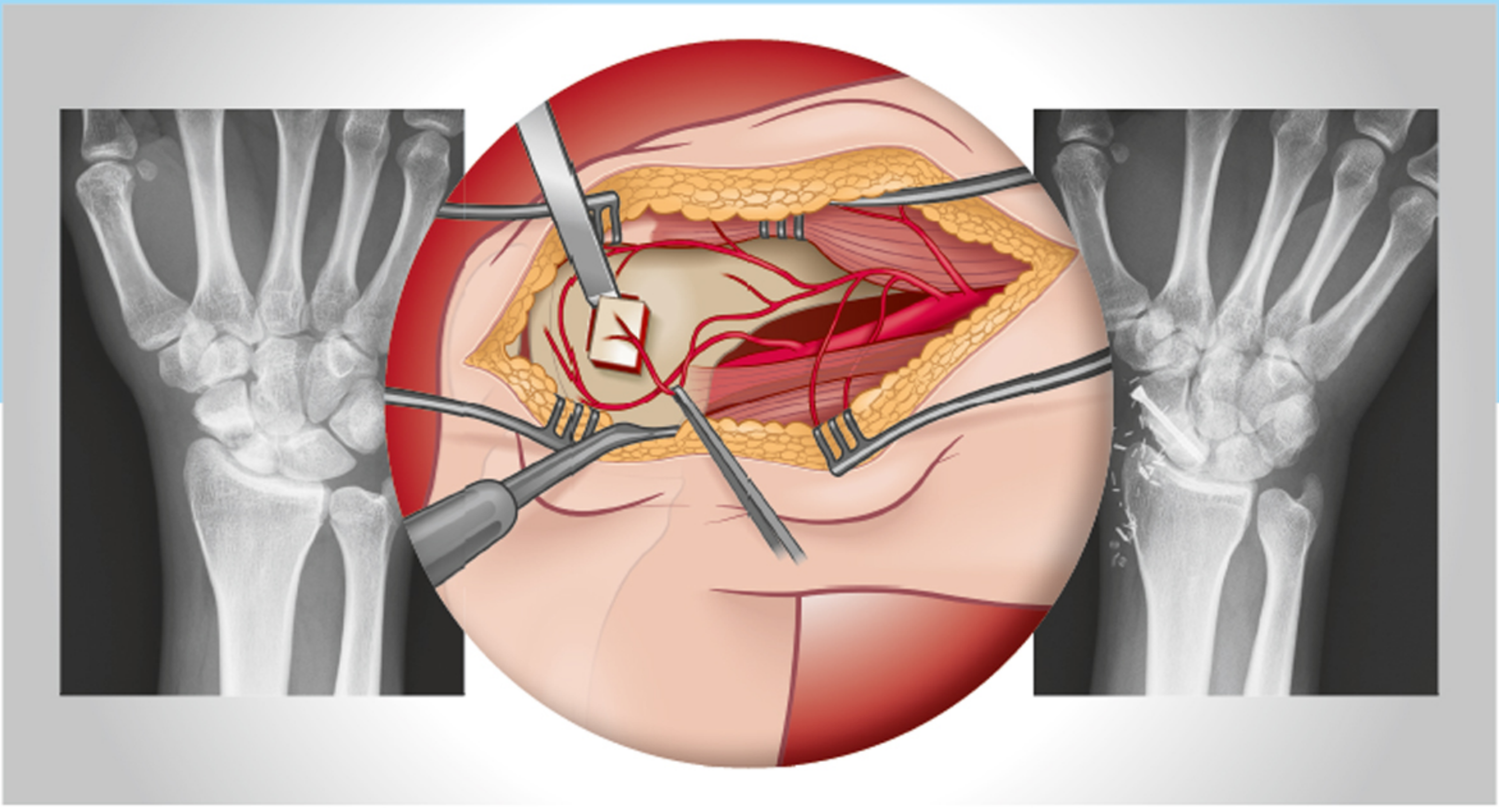
Problems in Hand Surgery

Solutions to Recover Function

Michael W. Neumeister
Michael Sauerbier



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Problems in Hand Surgery

Solutions to Recover Function

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Summary: “The intricate balance of the intrinsic and extrinsic soft tissue structure and boney scaffold of the hand, coupled with 31 articulating services in the hand and wrist can lead to significant surgical challenges. Providing surgeons with technical pearls to overcome these challenges is the primary focus of Problems in Hand Surgery by internationally renowned hand surgeons Michael W. Neumeister, Michael Sauerbier, and an impressive group of contributors. Organized by 29 sections and 90 chapters, this comprehensive book focuses on secondary hand surgeries to optimize hand form and function in patients with challenging trauma- and disorder-related hand issues. Among the many topics addressed are problems associated with nonunion, malunion, dysvascular limbs, trauma-related degenerative changes, stiffness, tendon dysfunction, joint disruption, nerve injury, neuropathy, vasospasm, fractures, and osteoarthritis”—Provided by publisher.
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We dedicate this book to our teachers and mentors who spent countless hours teaching and coaching us to become the hand surgeons we are today. We hear your words daily during our surgery and clinics. Although we spend most of our time apart from you as our practices have taken us to new areas, your presence will always be near.

Contents

Videos . . . xxiii

Foreword . . . xxiv

Preface . . . xxv

Acknowledgments . . . xxvi

Contributors . . . xxvii

Part I: Problems with Nailbed Repairs

1 Nonadherence of the Nail Plate . . . 2

Brian Mailey

1.1 Patient History Leading to the Specific Problem . . . 2
1.2 Anatomic Description of the Patient's Current Status . . . 2
1.3 Recommended Solution to the Problem . . . 3
1.3.1 Recommended Solution to the Problem . . . 3
1.4 Technique . . . 3
1.5 Postoperative Photographs and Critical Evaluation of Results . . . 4
1.6 Teaching Points . . . 5

2 Posttraumatic Split Nails . . . 6

Michael W. Neumeister

2.1 Patient History Leading to the Specific Problem . . . 6
2.2 Anatomic Description of the Patient's Current Status . . . 6
2.3 Recommended Solution to the Problem . . . 6
2.3.1 Recommended Solution to the Problem . . . 6
2.4 Technique . . . 7
2.4.1 Steps for the Procedure . . . 8
2.5 Postoperative Photographs and Critical Evaluation of Results . . . 8
2.6 Teaching Points . . . 8

3 Gentian Violet Treatment of Severe Chronic Paronychia . . . 10

Wyndell H. Merritt

3.1 Introduction . . . 10
3.2 Patient History Leading to the Specific Problem: Case A . . . 10
3.3 Anatomic Description of the Patient's Current Status: Case A . . . 10
3.4 Recommended Solution to the Problem: Case A . . . 11
3.5 Technique: Case A . . . 11
3.6 Postoperative Photographs and Critical Evaluation of Results: Case A . . . 11
3.7 Patient History Leading to the Specific Problem: Case B . . . 12
3.8 Anatomic Description of the Patient's Current Status: Case B . . . 12
3.9 Recommended Solution to the Problem: Case B . . . 12
3.10 Technique: Case B . . . 12
3.11 Postoperative Photographs and Critical Evaluation of Results: Case B . . . 12
3.12 Teaching Points . . . 12

Part II: Problems with Trigger Release

4 Bowstringing . . . 16

Loukia K. Papatheodorou and Dean G. Sotereanos

4.1 Patient History Leading to the Specific Problem . . . 16
4.2 Anatomic Description of the Patient's Current Status . . . 16

4.3 **Recommended Solution to the Problem** 16
4.3.1 Recommended Solution to the Problem 16
4.4 **Technique** 17
4.5 **Postoperative Photographs and Critical Evaluation of Results** 17
4.6 **Teaching Points** 17

Part III: Problems with Dupuytren's Disease

5 Exposed Tendons 20
Riccardo E. Giunta and Elisabeth M. Haas

5.1 **Patient History Leading to the Specific Problem** 20
5.2 **Anatomic Description of the Patient's Current Status** 20
5.3 **Recommended Solution to the Problem** 20
5.3.1 Recommended Solution to the Problem 20
5.4 **Technique** 20
5.4.1 Steps for the Procedure 21
5.5 **Postoperative Photographs and Critical Evaluation of Results** 21
5.6 **Teaching Points** 22

6 Acute Vascular Compromise after Dupuytren's Fasciectomy 23
James N. Winters, Jeffrey B. Friedrich, and Michael W. Neumeister

6.1 **Patient History Leading to the Specific Problem** 23
6.2 **Anatomic Description of the Patient's Current Status** 23
6.3 **Recommended Solution to the Problem** 24
6.4 **Technique** 24
6.5 **Postoperative Photographs and Critical Evaluation of Results** 25
6.6 **Teaching Points** 25

7 Secondary Contractures 26
M. Claire Manske and Jeffrey B. Friedrich

7.1 **Patient History Leading to the Specific Problem** 26
7.2 **Anatomic Description of the Patient's Current Status** 26
7.3 **Recommended Solution to the Problem** 27
7.3.1 Recommended Solution to the Problem 28
7.4 **Technique** 28
7.5 **Postoperative Photographs and Critical Evaluation of Results** 30
7.6 **Teaching Points** 31

8 Complications of Dupuytren's Contracture Treatment 33
Nash H. Naam and F. Thomas D. Kaplan

8.1 **Patient History Leading to the Specific Problem** 33
8.2 **Anatomic Description of the Patient's Current Status** 33
8.3 **Recommended Solution to the Problem** 33
8.3.1 Recommended Solution to the Problem 34
8.4 **Technique** 34
8.5 **Postoperative Photographs and Critical Evaluation of Results** 34
8.6 **Teaching Points** 36

Part IV: Problems with Flexor Tendon Repair

9 Flexor Tendon Rupture 38
Jin Bo Tang

9.1 **Patient History Leading to the Specific Problem** 38
9.2 **Anatomic Description of the Patient's Current Status** 38
9.3 **Recommended Solution to the Problem** 38
9.3.1 Recommended Solution to the Problem 40
9.4 **Technique** 40
9.4.1 Steps for the Procedure 40
9.5 **Postoperative Photographs and Critical Evaluation of Results** 40
9.6 **Teaching Points** 41

10 Adhesions of the Flexor Tendon 42
Donald H. Lalonde

10.1 **Patient History Leading to the Specific Problem** 42
10.2 **Anatomic Description of the Patient's Current Status** 42

10.3 Recommended Solution to the Problem 42
10.3.1 Recommended Solution to the Problem 42
10.4 Technique 43
10.4.1 Steps for the Procedure. 43
10.5 Critical Evaluation of Results 43
10.6 Teaching Points 44

11 Bowstringing of the Flexor Tendon 45
Jin Bo Tang

11.1 Patient History Leading to the Specific Problem 45
11.2 Anatomic Description of the Patient's Current Status 45
11.3 Recommended Solution to the Problem 46
11.4 Technique 46
11.4.1 Steps for the Procedure: Stage 1 46
11.4.2 Stage 1 Surgery 46
11.4.3 Stage 2 Surgery 47
11.4.4 Steps for the Procedure: Stage 2 47
11.5 Postoperative Photographs and Critical Evaluation of Results 47
11.6 Teaching Points 47

12 Ruptured Flexor Pollicis Longus Tendon 50
Florian Neubrech and Michael Sauerbier

12.1 Patient History Leading to the Specific Problem 50
12.2 Anatomic Description of the Patient's Current Status 50
12.3 Recommended Solution to the Problem 51
12.3.1 Recommended Solution to the Problem 51
12.4 Technique 51
12.4.1 Steps for the Procedure. 52
12.5 Postoperative Photographs and Critical Evaluation of Results 52
12.6 Teaching Points 52

Part V: Problems with Extensor Tendon Repair

13 Extensor Lag 54
Douglas P. Hanel and Nicholas P. Iannuzzi

13.1 Patient History Leading to the Specific Problem 54
13.2 Anatomic Description of the Patient's Current Status 54
13.3 Recommended Solution to the Problem 55
13.3.1 Recommended Solution to the Problem 55
13.4 Technique 55
13.4.1 Steps for the Procedure. 55
13.5 Postoperative Photographs and Critical Evaluation of Results 55
13.6 Teaching Points 57

14 Stiffness in the Extensor Tendon 58
Kai Megerle

14.1 Patient History Leading to the Specific Problem 58
14.2 Anatomic Description of the Patient's Current Status 58
14.3 Recommended Solution to the Problem 59
14.4 Technique 59
14.5 Postoperative Photographs and Critical Evaluation of Results 60
14.6 Teaching Points 61

15 Relative Motion Treatment of Chronic Boutonniere Deformity 62
Wyndell H. Merritt

15.1 Patient History Leading to the Specific Problem 62
15.2 Anatomic Description of the Patient's Current Status 62
15.3 Recommended Solution to the Problem 62
15.4 Technique 62
15.5 Postoperative Photographs and Critical Evaluation of Results 62
15.6 Teaching Points 63

16 Management of Chronic Sagittal Band Rupture 64
Wyndell H. Merritt

16.1 Patient History Leading to the Specific Problem 64
16.2 Anatomic Description of the Patient's Current Status 64

16.3 **Recommended Solution to the Problem** 64
16.4 **Technique** 64
16.5 **Postoperative Photographs and Critical Evaluation of Results** 64
16.6 **Teaching Points** 66

17 Posttraumatic Swan Neck Deformity 68

Jessica Frankenhoff and Jonathan Isaacs

17.1 **Patient History Leading to the Specific Problem** 68
17.2 **Anatomic Description of the Patient's Current Status** 68
17.2.1 Understanding the Problem 68
17.2.2 Evaluation 70
17.2.3 Choose the Best of the Available Treatment Options Based on Patient's Needs and Disabilities 70
17.3 **Technique** 71
17.3.1 Steps for Superficialis Sling Procedure 72
17.3.2 Steps for Oblique Retinacular Ligament Reconstruction Procedure 72
17.4 **Postoperative Photographs and Critical Evaluation of Results** 73
17.5 **Teaching Points** 73

Part VI: Problems with Vasospasm

18 Refractory Raynaud's Phenomenon 76

Collier S. Pace, Lauren Hutchinson, and Michael W. Neumeister

18.1 **Patient History Leading to the Specific Problem** 76
18.2 **Anatomic Description of the Patient's Current Status** 76
18.3 **Recommended Solution to the Problem** 76
18.4 **Technique** 77
18.5 **Postoperative Photographs and Critical Evaluation of Results** 77
18.6 **Teaching Points** 78

Part VII: Problems with Compression Neuropathy

19 A Practical Approach to Recurrent Carpal Tunnel Syndrome 80

Robert C. Russell and Franziska Huettner

19.1 **Patient History Leading to the Specific Problem** 80
19.2 **Anatomic Description of the Patient's Current Status** 80
19.3 **Recommended Solution to the Problem** 80
19.4 **Technique** 80
19.4.1 Steps for the Procedure 81
19.5 **Postoperative Photographs and Critical Evaluation of Results** 81
19.6 **Teaching Points** 81

20 Recurrent Carpal Tunnel Syndrome 83

Chye Yew Ng and Michael J. Hayton

20.1 **Patient History Leading to the Specific Problem** 83
20.2 **Anatomic Description of the Patient's Current Status** 83
20.3 **Recommended Solution to the Problem** 83
20.3.1 Recommended Solution to the Problem 83
20.4 **Technique** 83
20.4.1 Hypothenar Fat Pad Flap 84
20.4.2 Steps for the Procedure 84
20.5 **Postoperative Photographs and Critical Evaluation of Results** 84
20.6 **Teaching Points** 85

21 Failed Carpal Tunnel Release: Recognizing the Lacertus Syndrome 87

Elisabet Hagert and Catherine Curtin

21.1 **Patient History Leading to the Specific Problem** 87
21.2 **Anatomic Description of the Patient‘s Current Status** 87
21.2.1 General Appearance 87
21.2.2 Clinical Examination 87
21.2.3 Ultrasound Examination 87
21.3 **Recommended Solution to the Problem** 88
21.3.1 Recommended Solution to the Problem 88
21.4 **Technique** 89
21.5 **Postoperative Photographs and Critical Evaluation of Results** 90
21.6 **Teaching Points** 90

22 Cubital Tunnel Release at the Elbow 91
Steven T. Lanier and Jason H. Ko

22.1 Patient History Leading to the Specific Problem 91
22.2 Anatomic Description of the Patient's Current Status 91
22.3 Recommended Solution to the Problem 91
22.3.1 Recommended Solution to the Problem 92
22.4 Technique 92
22.4.1 Steps for the Procedure 94
22.5 Postoperative Photographs and Critical Evaluation of Results 94
22.6 Teaching Points 94

23 Recurrent Cubital Tunnel 96
Emily M. Krauss and Susan E. Mackinnon

23.1 Patient History Leading to the Specific Problem 96
23.2 Anatomic Description of the Patient's Current Status 96
23.3 Recommended Solution to the Problem 96
23.3.1 Recommended Solution to the Problem 96
23.4 Technique 97
23.4.1 Additional Procedures 100
23.5 Postoperative Photographs and Critical Evaluation of Results 100
23.6 Teaching Points 100

24 Recurrent Ulnar Neuropathy 101
Thomas H. Tung

24.1 Patient History Leading to the Specific Problem 101
24.2 Anatomic Description of the Patient's Current Status 101
24.3 Recommended Solution to the Problem 101
24.3.1 Recommended Solution to the Problem 101
24.4 Technique 101
24.5 Postoperative Photographs and Critical Evaluation of Results 102
24.6 Teaching Points 103

25 Radial Tunnel Release in the Forearm 104
Steven T. Lanier and Jason H. Ko

25.1 Patient History Leading to the Specific Problem 104
25.2 Anatomic Description of the Patient's Current Status 104
25.3 Recommended Solution to the Problem 104
25.3.1 Recommended Solution to the Problem 104
25.4 Technique 105
25.4.1 Steps for the Procedure 106
25.5 Postoperative Photographs and Critical Evaluation of Results 107
25.6 Teaching Points 107

Part VIII: Problems with Nerve Repair

26 End Neuroma 110
Theodore A. Kung and Paul S. Cederna

26.1 Patient History Leading to the Specific Problem 110
26.2 Anatomic Description of the Patient's Current Status 110
26.3 Recommended Solution to the Problem 110
26.3.1 Recommended Solutions to the Problem 111
26.4 Technique 111
26.4.1 Steps for the Procedure 112
26.5 Postoperative Photographs and Critical Evaluation of Results 112
26.6 Teaching Points 112

27 Pain following Nerve Repair 114
Ida K. Fox and Leahthan F. Domeshek

27.1 History 114
27.2 Anatomic Description of the Patient's Current Status 114
27.2.1 Examination Findings 114
27.2.2 Intraoperative Findings 114
27.2.3 Physiologic Explanation of Problem 114
27.3 Recommended Solution to the Problem 115
27.4 Technique for Nerve Harvest and Repair 115
27.4.1 Sural Nerve Harvest 115
27.4.2 Upper Extremity Nerve Repair 115
27.4.3 Nerve Grafting 116
27.4.4 Tendon and Muscle Repairs 117

27.5 Postoperative Care and Critical Evaluation of Results . . . 118
27.6 Teaching Points . . . 118

Part IX: Problems with Nerve Palsy

28 Finger Contractures . . . 122
Yan Chen and Peter M. Murray

28.1 Patient History Leading to the Specific Problem . . . 122
28.2 Anatomic Description of the Patient's Current Status . . . 122
28.3 Recommended Solution to the Problem . . . 122
28.4 Technique . . . 122
28.5 Postoperative Photographs and Critical Evaluation of Results . . . 123
28.6 Teaching Points . . . 123

Part X: Sarcoma

29 Incomplete Resection of Sarcoma at the Hand . . . 126
Björn Behr and Marcus Lehnhardt

29.1 Patient History Leading to the Specific Problem . . . 126
29.2 Anatomic Description of the Patient's Current Status . . . 126
29.3 Recommended Solution to the Problem . . . 126
29.3.1 Recommended Solution to the Problem . . . 126
29.4 Technique . . . 127
29.4.1 Steps for the Procedure . . . 127
29.5 Postoperative Photographs and Critical Evaluation of Results . . . 127
29.6 Teaching Points . . . 128

Part XI: Problems with Soft Tissue Coverage

30 Perfusion Problems . . . 132
Charles Yuen Yung Loh, Yu-Te Lin, and Fu-Chan Wei

30.1 Patient History Leading to the Specific Problem . . . 132
30.2 Anatomic Description of the Patient's Current Status . . . 132
30.3 Recommended Solution to the Problem . . . 132
30.3.1 Recommended Solution to the Problem . . . 132
30.4 Technique . . . 133
30.4.1 Steps for the Procedure . . . 133
30.5 Postoperative Photographs and Critical Evaluation of Results . . . 133
30.6 Teaching Points . . . 135

31 The Bulky Flap . . . 136
Kelly Currie, Evyn Neumeister, and Michael W. Neumeister

31.1 Patient History Leading to the Specific Problem . . . 136
31.2 Anatomic Description of the Patient's Current Status . . . 136
31.2.1 Management of the Defect . . . 136
31.2.2 Donor Site Problem . . . 136
31.3 Recommended Solution to the Problem . . . 137
31.3.1 Recommended Solution To The Problem . . . 137
31.4 Technique . . . 137
31.5 Postoperative Photographs and Critical Evaluation of Results . . . 138
31.6 Teaching Points . . . 138

32 Contracture after Acute Trauma Surgery of a Blast Burn . . . 141
Günter K. Germann

32.1 Patient History Leading to the Specific Problem . . . 141
32.2 Anatomic Description of the Patient's Current Status . . . 141
32.3 Recommended Solution to the Problem . . . 141
32.3.1 Recommended Solution to the Problem . . . 141
32.4 Technique . . . 142
32.4.1 Steps for the Procedure . . . 142
32.5 Postoperative Photographs and Critical Evaluation of Results . . . 142
32.6 Teaching Points . . . 144

33 Dorsal Hand Defect 145
Kelly Currie, Michael Sauerbier, Robert Russell, and Michael W. Neumeister

33.1 Patient History Leading to the Specific Problem 145
33.2 Anatomic Description of the Patient's Current Status 145
33.2.1 Donor Site Problem 146
33.3 Recommended Solution to the Problem 146
33.3.1 Recommended Solution to the Problem 147
33.4 Technique 147
33.5 Postoperative Photographs and Critical Evaluation of Results 147
33.6 Teaching Points 148

Part XII: Problems with Nonarticular Phalanx Fractures

34 Malrotation in Nonarticular Phalanx Fractures 152
Mark S. Rekant

34.1 Patient History Leading to the Specific Problem 152
34.2 Anatomic Description of the Patient's Current Status 152
34.3 Recommended Solution to the Problem 152
34.3.1 Recommended Solution to the Problem 152
34.4 Technique 152
34.4.1 Steps for the Procedure. 154
34.5 Postoperative Photographs and Critical Evaluation of Results 154
34.6 Teaching Points 154

35 Nonunion in Nonarticular Phalanx Fractures 155
A. Lee Osterman and Adam Strohl

35.1 Patient History Leading to the Specific Problem 155
35.2 Anatomic Description of the Patient's Current Status 155
35.3 Recommended Solution to the Problem 155
35.3.1 Recommended Solution to the Problem 156
35.4 Technique 156
35.4.1 Steps for the Procedure. 156
35.5 Postoperative Photographs and Critical Evaluation of Results 156
35.6 Teaching Points 157

36 Stiffness and Hardware Problems in Nonarticular Phalanx Fractures 158
Max Haerle and Tobias Del Gaudio

36.1 Patient History Leading to the Specific Problem 158
36.2 Anatomic Description of the Patient's Current Status 158
36.3 Recommended Solution to the Problem 158
36.4 Technique 159
36.5 Postoperative Photographs and Critical Evaluation of Results 162
36.6 Teaching Points 162

37 Angulation in Nonarticular Phalanx Fractures 164
Berthold Bickert

37.1 Patient History Leading to the Specific Problem 164
37.2 Anatomic Description of the Patient's Current Status 164
37.3 Recommended Solution to the Problem 164
37.3.1 Recommended Solution to the Problem 165
37.4 Technique 165
37.5 Postoperative Photographs and Critical Evaluation of Results 165
37.6 Teaching Points 165

Part XIII: Problems with Articular Phalanx Fractures

38 Angulation in Articular Phalanx Fractures 168
Marco Rizzo and Maureen A. O'Shaughnessy

38.1 Patient History Leading to the Specific Problem 168
38.2 Anatomic Description of the Patient's Current Status 168

38.3 **Recommended Solution to the Problem** 169
38.4 **Technique** 169
38.4.1 Steps for the Procedure 170
38.5 **Postoperative Photographs and Critical Evaluation of Results** 170
38.6 **Teaching Points** 171

39 Posttraumatic Bone Loss in Articular Phalanx Fractures 172
Carlos Henrique Fernandes and Jorge Raduan Neto

39.1 **Patient History Leading to the Specific Problem** 172
39.2 **Anatomic Description of the Patient's Current Status** 172
39.3 **Recommended Solution to the Problem** 172
39.4 **Technique** 172
39.5 **Postoperative Photographs and Critical Evaluation of Results** 172
39.6 **Teaching Points** 173

40 Fracture after Prior Kirschner's Wire Fixation 174
Carlos Henrique Fernandes and Rodrigo Guerra Sabongi

40.1 **Patient History Leading to the Specific Problem** 174
40.2 **Anatomic Description of the Patient's Current Status** 174
40.3 **Recommended Solution to the Problem** 175
40.3.1 Recommended Solution to the Problem 175
40.4 **Technique** 175
40.5 **Postoperative Photographs and Critical Evaluation of Results** 176
40.6 **Teaching Points** 176

41 Contractures in Articular Phalanx Fractures 178
Christian K. Spies and Frank Unglaub

41.1 **Patient History Leading to the Specific Problem** 178
41.2 **Anatomic Description of the Patient's Current Status** 178
41.3 **Recommended Solution to the Problem** 179
41.3.1 Recommended Solution to the Problem 179
41.4 **Technique** 179
41.5 **Postoperative Photographs and Critical Evaluation of Results** 179
41.6 **Teaching Points** 179

Part XIV: Problems with Metacarpal Fractures

42 Nonunion in Metacarpal Fractures 184
Carsten Surke and Esther Vögelin

42.1 **Patient History Leading to the Specific Problem** 184
42.2 **Anatomic Description of the Patient's Current Status** 185
42.3 **Recommended Solution to the Problem** 186
42.3.1 Recommended Solution to the Problem 186
42.4 **Technique** 186
42.4.1 Left Hand 186
42.4.2 Right Iliac Crest 187
42.4.3 Left Hand 188
42.4.4 Steps for the Procedure 188
42.5 **Postoperative Results and Critical Evaluation of Results** 188
42.6 **Teaching Points** 188

43 Malunion in Metacarpal Fractures 190
Richard J. Tosti and Jesse B. Jupite

43.1 **Patient History Leading to the Specific Problem** 190
43.2 **Anatomic Description of the Patient's Current Status** 190
43.3 **Recommended Solution to the Problem** 191
43.3.1 Recommended Solution to the Problem 191
43.4 **Technique** 191
43.5 **Postoperative Photographs and Critical Evaluation of Results** 192
43.6 **Teaching Points** 192

44 Angulation in Metacarpal Fractures 194
Jeffrey Greenberg

44.1 **Patient History Leading to the Specific Problem** 194
44.2 **Anatomic Description of the Patient's Current Status** 194

44.3 **Recommended Solution to the Problem** 195
44.4 **Technique** 195
44.5 **Postoperative Photographs and Critical Evaluation of Results** 196
44.6 **Teaching Points** 197

Part XV: Problems with Basilar Joint Osteoarthritis

45 Recurrent Pain in Basilar Joint Osteoarthritis 202
Michael S. Gart and Daniel J. Nagle

45.1 **Patient History Leading to the Specific Problem** 202
45.2 **Anatomic Description of the Patient's Current Status** 202
45.3 **Recommended Solution to the Problem** 202
45.3.1 Recommended Solution to the Problem 202
45.4 **Technique** 202
45.5 **Postoperative Photographs and Critical Evaluation of Results** 205
45.6 **Teaching Points** 205

46 Painful Proximalization of the First Metacarpal after Trapeziectomy 207
Martin Richter

46.1 **Patient History Leading to the Specific Problem** 207
46.2 **Anatomic Description of the Patient's Current Status** 207
46.3 **Recommended Solution to the Problem** 207
46.3.1 Recommended Solution to the Problem 207
46.4 **Technique** 208
46.4.1 Steps for the Procedure 210
46.5 **Postoperative Photographs and Critical Evaluation of Results** 210
46.6 **Teaching Points** 211

47 Metacarpal Phalangeal Hyperextension 212
Anne Argenta and Mark E. Baratz

47.1 **Patient History Leading to the Specific Problem** 212
47.2 **Anatomic Description of the Patient's Current Status** 212
47.3 **Recommended Solution to the Problem** 213
47.3.1 Recommended Solution to the Problem 214
47.4 **Technique** 214
47.4.1 Metacarpophalangeal Volar Plate Arthroplasty 214
47.4.2 Extensor Pollicis Brevis to Abductor Pollicis Longus Tendon Transfer 214
47.5 **Postoperative Photographs and Critical Evaluation of Results** 214
47.6 **Teaching Points** 214

Part XVI: Problems with Metacarpal Phalangeal Osteoarthritis after Implant Arthroplasty

48 Intraoperative Instability During Metacarpophalangeal Joint Arthroplasty for Osteoarthritis 220
Chelsea Harris, Yuki Fujihara, and Kevin C. Chung

48.1 **Patient History Leading to the Specific Problem** 220
48.2 **Anatomic Description of the Patient's Current Status** 220
48.3 **Recommended Solution to the Problem** 220
48.3.1 Recommended Solution to the Problem 220
48.4 **Technique** 220
48.4.1 Intraoperative Instability 220
48.4.2 External Fixation 222
48.4.3 Steps for the Procedure 223
48.5 **Postoperative Photographs and Critical Evaluation of Results** 223
48.6 **Teaching Points** 223

49 Revision of Subsided Pyrocarbon Implants 226
Steven C. Haase

49.1 **Patient History Leading to the Specific Problem** 226
49.2 **Anatomic Description of the Patient's Current Status** 226
49.3 **Recommended Solution to the Problem** 227
49.4 **Technique** 227
49.5 **Postoperative Photographs and Critical Evaluation of Results** 227
49.6 **Teaching Points** 228

Part XVII: Problems with Interphalangeal Osteoarthritis

50 Failed Silicone Proximal Interphalangeal Joint Arthroplasty ... 232
Elvira Bodmer and Stephan Schindele

50.1 Patient History Leading to the Specific Problem ... 232
50.2 Anatomic Description of the Patient's Current Status ... 232
50.3 Recommended Solution to the Problem ... 233
50.3.1 Recommended Solution to the Problem ... 233
50.4 Technique ... 233
50.4.1 Steps for the Procedure ... 233
50.5 Postoperative Photographs and Critical Evaluation of Results ... 234
50.6 Teaching Points ... 236

51 Stiffness in Interphalangeal Osteoarthritis ... 238
Peter M. Murray, Kimberly H. McVeigh, and Ammar Humayun

51.1 Patient History Leading to the Specific Problem ... 238
51.2 Anatomic Description of the Patient's Current Status ... 238
51.3 Recommended Solution to the Problem ... 238
51.4 Technique ... 239
51.5 Postoperative Photographs and Critical Evaluation of Results ... 239
51.6 Teaching Points ... 240

52 Contracture in Interphalangeal Osteoarthritis ... 241
Peter M. Murray, Kimberly H. McVeigh, and Ammar Humayun

52.1 Patient History Leading to the Specific Problem ... 241
52.2 Anatomic Description of the Patient's Current Status ... 241
52.3 Recommended Solution to the Problem ... 241
52.4 Technique ... 242
52.5 Postoperative Photographs and Critical Evaluation of Results ... 242
52.6 Teaching Points ... 243

53 Proximal Interphalangeal Posttraumatic Osteoarthritis ... 244
Sergio Daroda and Fernando Menvielle

53.1 Patient History Leading to the Specific Problem ... 244
53.2 Anatomic Description of the Patient's Current Status ... 244
53.3 Recommended Solution to the Problem ... 244
53.3.1 Recommended Solution to the Problem ... 244
53.4 Technique ... 245
53.4.1 Steps for the Procedure ... 246
53.5 Postoperative Photographs and Critical Evaluation of Results ... 246
53.6 Teaching Points ... 247

Part XVIII: Problems with Infection in the Thumbs, Fingers, and Wrist

54 Inadequate Drainage of Infection in the Thumbs, Fingers, and Wrist ... 250
Nikhil Agrawal and William C. Pederson

54.1 Patient History Leading to the Specific Problem ... 250
54.2 Anatomic Description of the Patient's Current Status ... 250
54.3 Recommended Solution to the Problem ... 250
54.3.1 Recommended Solutions to the Problem ... 250
54.4 Technique ... 250
54.4.1 Steps for the Procedure ... 252
54.5 Postoperative Photographs and Critical Evaluation of Results ... 252
54.6 Teaching Points ... 252

55 Salvage of Osteomyelitis of the Distal Radius after Internal Fixation of an Open Fracture ... 253
Florian Neubrech and Michael Sauerbier

55.1 Patient History Leading to the Specific Problem ... 253
55.2 Anatomic Description of the Patient's Current Status ... 253
55.3 Recommended Solution to the Problem ... 253
55.3.1 Recommended Solution to the Problem ... 254
55.4 Technique ... 254
55.4.1 Steps for the Procedure ... 256
55.5 Postoperative Photographs and Critical Evaluation of Results ... 256
55.6 Teaching Points ... 256

56 Infectious Destruction of the Wrist 259
Florian Neubrech, Michael Sauerbier, and Berthold Bickert

56.1 Patient History Leading to the Specific Problem 259
56.2 Anatomic Description of the Patient's Current Status 259
56.3 Recommended Solution to the Problem 260
56.3.1 Recommended Solution to the Problem 260
56.4 Technique 260
56.4.1 Steps for the Procedure. 261
56.5 Postoperative Photographs and Critical Evaluation of Results 261
56.6 Teaching Points 262

Part XIX: Problems with Replantation

57 Stiffness after Replantation 264
Walter Lin, Bauback Safa, and Gregory M. Buncke

57.1 Patient History Leading to the Specific Problem 264
57.2 Anatomic Description of the Patient's Current Status 264
57.3 Recommended Solution to the Problem 264
57.3.1 Recommended Solution to the Problem 265
57.4 Technique 265
57.5 Postoperative Photographs and Critical Evaluation of Results 267
57.6 Teaching Points 267

58 Failed Replant: Ray Amputation 270
Sang Hyun Woo

58.1 Patient History Leading to the Specific Problem 270
58.2 Anatomic Description of the Patient's Current Status 270
58.3 Recommended Solution to the Problem 270
58.4 Technique 270
58.5 Postoperative Photographs and Critical Evaluation of Results 271
58.6 Teaching Points 272

59 Failed Digit Replant: Toe-to-Hand Transfer 273
Sang Hyun Woo

59.1 Patient History Leading to the Specific Problem 273
59.2 Anatomic Description of the Patient's Current Status 273
59.3 Recommended Solution to the Problem 274
59.4 Technique 274
59.5 Postoperative Photographs and Critical Evaluation of Results 275
59.6 Teaching Points 275

60 Failed Thumb Replant: Great Toe-to-Thumb Transfer 277
Sang Hyun Woo

60.1 Patient History Leading to the Specific Problem 277
60.2 Anatomic Description of the Patient's Current Status 277
60.3 Recommended Solution to the Problem 277
60.4 Technique 277
60.5 Postoperative Photographs and Critical Evaluation of Results 279
60.6 Teaching Points 280

61 Failed Replant: Failed Degloving Revascularization 281
Sang Hyun Woo

61.1 Patient History Leading to the Specific Problem 281
61.2 Recommended Solution to the Problem 281
61.3 Technique 281
61.4 Postoperative Photographs and Critical Evaluation of Results 282
61.5 Teaching Points 282

62 Attempted Replantation 284
Alexandru Valentin Georgescu and Ileana Rodica Matei

62.1 Patient History Leading to the Specific Problem 284
62.2 Anatomic Description of the Patient's Current Status 284
62.3 Recommended Solution to the Problem 284
62.3.1 Multiple-Stage Reconstruction 284
62.3.2 Single-Stage Reconstruction. 285

62.4 Technique . . . 285
62.4.1 Steps for the Procedure. . . . 285
62.5 Postoperative Photographs and Critical Evaluation of Results . . . 286
62.6 Teaching Points . . . 287

63 Nonunion following Digital Replant . . . 289
S. Raja Sabapathy

63.1 Patient History Leading to the Specific Problem . . . 289
63.2 Anatomic Description of the Patient's Current Status . . . 289
63.3 Recommended Solution to the Problem . . . 290
63.4 Recommended Solution to the Problem . . . 290
63.5 Technique . . . 290
63.5.1 Steps for the Procedure. . . . 291
63.6 Postoperative Photographs and Critical Evaluation of Results . . . 291
63.7 Teaching Points . . . 291

64 Nonunion following Major Replant . . . 293
S. Raja Sabapathy and Hari Venkatramani

64.1 Patient History Leading to the Specific Problem . . . 293
64.2 Anatomic Description of the Patient's Current Status . . . 293
64.3 Recommended Solution to the Problem . . . 293
64.3.1 Recommended Solution to the Problem . . . 294
64.4 Technique . . . 294
64.4.1 Steps for the Procedure. . . . 295
64.5 Postoperative Photographs and Critical Evaluation of Results . . . 295
64.6 Teaching Points . . . 295

65 Painful Finger after Bony Nonunion . . . 296
Florian Neubrech and Ulrich Kneser

65.1 Patient History Leading to the Specific Problem . . . 296
65.2 Anatomic Description of the Patient's Current Status . . . 297
65.3 Recommended Solution to the Problem . . . 297
65.3.1 Recommended Solution to the Problem . . . 298
65.4 Technique . . . 298
65.4.1 Steps for the Procedure. . . . 299
65.5 Postoperative Photographs and Critical Evaluation of Results . . . 299
65.6 Teaching Points . . . 299

66 Stiff Fingers and Elbow after Replantation . . . 302
Chih-Hung Lin

66.1 Patient History Leading to the Specific Problem . . . 302
66.2 Anatomical Description of the Patient's Current Status . . . 302
66.3 Recommended Solution to the Problem . . . 303
66.3.1 Recommended Solution to the Problem . . . 303
66.4 Technique . . . 303
66.5 Postoperative Photographs and Critical Evaluation of Results . . . 304
66.6 Teaching Points . . . 304

67 Poor Grip or Weak Motion after Replantation . . . 305
S. Raja Sabapathy

67.1 Patient History Leading to the Specific Problem . . . 305
67.2 Anatomic Description of the Patient's Current Status . . . 305
67.3 Recommended Solution to the Problem . . . 306
67.3.1 Recommended Solution to the Problem . . . 306
67.4 Technique . . . 306
67.4.1 Steps for the Procedure. . . . 307
67.5 Postoperative Photographs and Critical Evaluation of Results . . . 307
67.6 Teaching Points . . . 307

Part XX: Problems with Complex Regional Pain Syndromes

68 Complex Regional Pain Syndrome. . . . 310
Erik Hansen and Jonathan Isaacs

68.1 Patient History Leading to the Specific Problem . . . 310
68.2 Anatomic Description of the Patients Current Status . . . 311
68.2.1 Classification and Pathogenesis . . . 312
68.3 Recommended Solution to the Problem . . . 312
68.3.1 Interventional or Surgical Treatments May Be Beneficial in Certain Patients. . . . 312
68.4 Teaching Points . . . 313

Part XXI: Problems with Scaphoid Fractures

69 Nonunion of the Proximal Pole . . . 316
Hermann Krimmer

69.1 Introduction . . . 316
69.2 Patient History Leading to the Specific Problem . . . 316
69.3 Anatomic Description of the Patient's Current Status . . . 316
69.4 Recommended Solution to the Problem . . . 316
69.4.1 Recommended Solution to the Problem . . . 317
69.5 Technique . . . 317
69.6 Postoperative Photographs and Critical Evaluation of Results . . . 317
69.7 Teaching Points . . . 317

70 Scaphoid Nonunion with Avascular Necrosis . . . 320
Nikolas H. Kazmers, Stephanie Thibaudeau, Zvi Steinberger, and L. Scott Levin

70.1 Patient History Leading to the Specific Problem . . . 320
70.2 Anatomic Description of the Patient's Current Status . . . 320
70.3 Recommended Solution to the Problem . . . 320
70.4 Technique . . . 320
70.5 Postoperative Photographs and Critical Evaluation of Results . . . 322
70.6 Teaching Points . . . 324

71 Scaphoid Revision Nonunion . . . 325
Heinz Bürger

71.1 Patient History Leading to the Specific Problem . . . 325
71.2 Anatomic Description of the Patient's Current Status . . . 325
71.3 Recommended Solution to the Problem . . . 325
71.4 Technique . . . 325
71.5 Postoperative Photographs and Critical Evaluation of Results . . . 326
71.6 Teaching Points . . . 327

72 Scaphoid Nonunion . . . 329
Mohamed Morsy, Assaf Kadar, and Steven L. Moran

72.1 Patient History Leading to the Specific Problem . . . 329
72.2 Anatomic Description of the Patient's Current Status . . . 329
72.2.1 Anatomic Etiology of Complication . . . 329
72.3 Recommended Solution to the Problem . . . 329
72.3.1 Recommended Solution to the Problem . . . 329
72.4 Technique . . . 331
72.4.1 Steps for the Procedure . . . 334
72.5 Postoperative Photographs and Critical Evaluation of Results . . . 334
72.6 Teaching Points . . . 334

73 Scaphoid Implant Malplacement . . . 336
Wesley N. Sivak and Joseph E. Imbriglia

73.1 Patient History Leading to the Specific Problem . . . 336
73.2 Anatomic Description of the Patient's Current Status . . . 336
73.3 Recommended Solution to the Problem . . . 337
73.3.1 Recommended Solution to the Problem . . . 337
73.4 Technique . . . 338
73.4.1 Steps for the Procedure . . . 338
73.5 Postoperative Photographs and Critical Evaluation of Results . . . 338
73.6 Teaching Points . . . 339

Part XXII: Problems with Scapholunate Instability

74 Failed Scapholunate Ligament Repair: Acute . . . 342
Dirck Añaños Flores, Alex Lluch Bergadà, and Marc Garcia-Elias

74.1 Patient History Leading to the Specific Problem . . . 342
74.2 Anatomic Description of the Patient's Current Status . . . 342
74.3 Recommended Solution to the Problem . . . 342
74.4 Technique . . . 343
74.5 Postoperative Photographs and Critical Evaluation of Results . . . 344
74.6 Teaching Points . . . 345

75 Failed Reconstruction with Tenodesis: Chronic 346
Dirck Añaños Flores, Alex Lluch Bergadà, and Marc Garcia-Elias

75.1 Patient History Leading to the Specific Problem 346
75.2 Anatomic Description of the Patient's Current Status 346
75.3 Recommended Solution to the Problem 347
75.4 Technique 347
75.5 Postoperative Photographs and Critical Evaluation of Results 347
75.6 Teaching Points 347

Part XXIII: Problems with the Lunotriquetral Joint

76 Problems with the Lunotriquetral Joint after Ligament Repair 352
William R. Aibinder and Alexander Y. Shin

76.1 Patient History Leading to the Specific Problem 352
76.2 Anatomic Description of the Patient's Current Status 352
76.3 Recommended Solution to the Problem 352
76.3.1 Recommended Solution to the Problem 352
76.4 Technique 352
76.4.1 Steps for the Procedure 353
76.5 Postoperative Photographs and Critical Evaluation of Results 353
76.6 Teaching Points 354

77 Problems with Lunotriquetral Fusion 355
Rocco Barbieri

77.1 Patient History Leading to the Specific Problem 355
77.2 Anatomic Description of the Patient's Current Status 355
77.2.1 General Appearance 355
77.2.2 Radiographs 355
77.3 Recommended Solution to the Problem 355
77.3.1 Recommended Solution to the Problem 356
77.4 Technique 356
77.4.1 Steps for the Procedure 357
77.5 Postoperative Photographs and Critical Evaluation of Results 357
77.6 Teaching Points 358

Part XXIV: Problems after Partial Wrist Fusions

78 Complications of Partial Wrist Fusion 362
James Higgins, Kenneth R. Means, Jr., and Kenneth L. Fan

78.1 Patient History Leading to the Specific Problem 362
78.2 Anatomic Description of the Patient's Current Status 362
78.3 Recommended Solution to the Problem 362
78.3.1 Background 363
78.3.2 Scapholunate Advance Collapse 363
78.3.3 Alternative Midcarpal Fusions 364
78.4 Technique 364
78.5 Postoperative Photographs and Critical Evaluation of Results 365
78.6 Teaching Points 365

79 Dislocated Lunar Facet Fragments and Radioscapholunate Arthrodesis 367
Christoph Pezzei

79.1 Patient History Leading to the Specific Problem 367
79.2 Anatomic Description of the Patient's Current Status 367
79.3 Recommended Solution to the Problem 367
79.3.1 Recommended Solution to the Problem 369
79.4 Technique 369
79.5 Postoperative Photographs and Critical Evaluation of Results 370
79.6 Teaching Points 370

Part XXV: Total Wrist Arthroplasty

80 Implant Migration after Total Wrist Arthroplasty 374
Brian D. Adams

80.1 Patient History Leading to the Specific Problem 374
80.2 Anatomic Description of the Patient's Current Status 374

80.3 Recommended Solution to the Problem 374
80.3.1 Recommended Solution to the Problem 374
80.4 Technique 374
80.4.1 Steps for the Procedure. 375
80.5 Postoperative Photographs and Critical Evaluation of Results 375
80.6 Teaching Points 376

Part XXVI: Problems with Triangular Fibrocartilage Complex Tears

81 Pain after Triangular Fibrocartilage Complex Tears 378
Alejandro Badia

81.1 Patient History Leading to the Specific Problem 378
81.2 Anatomic Description of the Patient's Current Status 378
81.3 Recommended Solution to the Problem 378
81.3.1 Recommended Solution to the Problem 379
81.4 Technique 379
81.4.1 Steps for the Procedure. 380
81.5 Postoperative Photographs and Critical Evaluation of Results 380
81.6 Teaching Points 381

82 Persistent Instability after Triangular Fibrocartilage Complex Tears 382
Brian D. Adams

82.1 Patient History Leading to the Specific Problem 382
82.2 Anatomic Description of the Patient's Current Status 382
82.3 Recommended Solution to the Problem 383
82.3.1 Recommended Solution to the Problem 383
82.4 Technique 384
82.4.1 Open Peripheral Repair of the TFCC. 384
82.4.2 Osteoplasty for a Deficient Sigmoid Notch 384
82.5 Postoperative Photographs and Critical Evaluation of Results 385
82.6 Teaching Points 385

Part XXVII: Problems with Ulnar Impaction

83 Arthroscopic Treatment of Ulnar Impaction 388
William Dzwierzynski

83.1 Patient History Leading to the Specific Problem 388
83.2 Anatomic Description of the Patient's Current Status 388
83.3 Recommended Solution to the Problem 388
83.4 Technique 388
83.5 Postoperative Photographs and Critical Evaluation of Results 389
83.6 Teaching Points 389

84 Nonunion after Ulnar Shortening 391
Ladislav Nagy

84.1 Patient History Leading to the Specific Problem 391
84.2 Anatomic Description of the Patent's Current Status 391
84.3 Recommended Solution to the Problem 392
84.3.1 Recommended Solution to the Problem 392
84.4 Technique 392
84.4.1 Steps for the Procedure. 393
84.5 Postoperative Photographs and Critical Evaluation of Results 394
84.6 Teaching Points 394

Part XXVIII: Problems with Distal Radial Ulnar Joint

85 Failed Bowers' Arthroplasty: Ulnar Head Prosthesis 396
Florian Neubrech and Michael Sauerbier

85.1 Patient History Leading to the Specific Problem 396
85.2 Anatomic Description of the Patient's Current Status 396
85.3 Recommended Solution to the Problem 396
85.3.1 Recommended Solution to the Problem 397
85.4 Technique 397
85.4.1 Steps for the Procedure. 397
85.5 Postoperative Photographs and Critical Evaluation of Results 398
85.6 Teaching Points 398

86 Dislocated Ulnar Head Prosthesis 401
Luis R. Scheker and Mark T. Shima

86.1 Patient History Leading to the Specific Problem 401
86.2 Anatomic Description of the Patient's Current Status 401
86.3 Recommended Solution to the Problem 401
86.3.1 Recommended Solution to the Problem 403
86.4 Technique 403
86.4.1 Overview of the Technique 403
86.5 Postoperative Photographs and Critical Evaluation of Results 403
86.6 Teaching Points 404

Part XXIX: Problems with Distal Radius Fractures

87 Distal Radius Fracture Malunion 408
Karl-Josef Prommersberger

87.1 Patient History Leading to the Specific Problem 408
87.2 Anatomic Description of the Patient's Current Status 408
87.3 Recommended Solution to the Problem 409
87.3.1 Recommended Solution to the Problem 409
87.4 Technique 409
87.4.1 Steps for the Procedure 410
87.5 Postoperative Photographs and Critical Evaluation of Results 410
87.6 Teaching Points 410

88 Distal Radius Fracture Nonunion 412
Richard J. Tosti and Jesse B. Jupiter

88.1 Patient History Leading to the Specific Problem 412
88.2 Anatomic Description of the Patient's Current Status 412
88.3 Recommended Solution to the Problem 412
88.3.1 Recommended Solution to the Problem 413
88.4 Technique 413
88.4.1 Steps for the Procedure 413
88.5 Postoperative Photographs and Critical Evaluation of Results 413
88.6 Teaching Points 414

89 Troublesome Lunate Facet 415
Hermann Krimmer

89.1 Introduction 415
89.2 Patient History Leading to the Specific Problem 415
89.3 Anatomic Description of the Patient's Current Status 415
89.4 Recommended Solution to the Problem 416
89.5 Technique 416
89.6 Teaching Points 417

90 Troublesome Lunate Facet: Treatment with Microvascular Techniques 419
Francisco del Piñal

90.1 Patient History Leading to the Specific Problem 419
90.2 Anatomic Description of the Patient's Current Status 420
90.3 Recommended Solution to the Problem 420
90.4 Technique 420
90.5 Postoperative Photographs and Critical Evaluation of Results 423
90.6 Teaching Points 425

Index 427

Videos

Video 8.1	Skin tear during the extension procedure after collagenase injection. The tear healed in one week.
Video 10.1	Preoperative movement, incision planning, and injection of the local anesthesia.
Video 10.2	Intraoperative dissection and movement obtained.
Video 10.3	Intraoperative patient impressions and postoperative movement at 4 days and 6 weeks.
Video 13.1	Patient shown at 12 weeks following surgery. Active flexion has improved. Lack of adherence to hand therapy has resulted in recurrence of his extensor lag. Flexion of the digit has improved after tenolysis.
Video 14.1	Case presenting stiffness in the extensor tendon.
Video 21.1	Preoperative clinical examination of a patient with lacertus syndrome.
Video 21.2	Surgical technique for releasing the median nerve at the level of the elbow, lacertus syndrome release.
Video 21.3	Immediate return of strength in the FPL and FDP II following division of the lacertus fibrosus and release of the median nerve.
Video 28.1	Preoperative physical examination of the patient showing prominent claw hand deformity.
Video 34.1	Video demonstrating dialing in the proper metacarpal rotation in a cadaver model using a 0.062-inch Kirschner's wire.
Video 41.1	Video demonstrating stiff PIP joint whereas MCP joint can be moved.
Video 41.2	Intraoperative testing of released PIP joint.
Video 45.1	Video depicting carpometacarpal arthroplasty with flexor carpi radialis suspension.
Video 53.1	Proximal interphalangeal vascularized transfer; surgical steps.
Video 55.1	Video demonstrating the functional result 14 months after revision surgery.
Video 57.1	Video demonstrating full composite flexion and extension in the index, middle, and ring fingers after replantation in zone 2, after completion of extensor tenolysis and dorsal capsulotomy, followed by flexor tenolysis.
Video 62.1	Long-term follow-up of the reconstructed hand demonstrating return of good function.
Video 62.2	Long-term follow-up of the reconstructed hand demonstrating return of good function.
Video 62.3	Long-term follow-up of the reconstructed hand demonstrating return of good function.
Video 70.1	Demonstration of elevating a skin paddle on the saphenous artery/vein pedicle as part of a chimeric medial femoral condyle flap.
Video 83.1	Visualization of the radial carpal joint.
Video 87.1	Corrective osteotomy for dorsal malunion of the distal radius through the palmar approach.

Foreword

Drs. Michael Neumeister and Michael Sauerbier had a unique and valuable goal at the inception of this new hand surgery book: to provide expert advice for management of challenges associated with surgical treatment of the hand. This information, assembled in one volume, will be a valuable resource for the hand specialist. The pearls contained here supplement rather than duplicate the content of standard textbooks, whose focus lies primarily on basic evaluation and surgical management of hand pathology. Management of complex reconstructive challenges and surgical complications lie beyond the scope of available texts, making *Problems in Hand Surgery: Solutions to Recover Function* an invaluable supplement to the tomes sitting on our library shelves.

The editors have carefully chosen the authors, all recognized experts in the subject matter presented. Each chapter is presented in a problem-based format, beginning with an illustrative clinical case. The anatomic basis of the problem is stated, followed by an expert author's recommended solution, including a detailed technique and analysis of the patient's result. The readers, when faced with the same clinical issue, may therefore apply the recommendations provided to these patients. While there may often be more than one potential solution to any given problem, the methods presented here have been proven reliable and effective by surgeons with extensive experience and knowledge. The level of technical details provided exceeds that which is readily available in most texts. Additional references contained in a concise bibliography at the end of each chapter allows further guidance, if desired.

Problems in Hand Surgery: Solutions to Recover Function will prove to be a valuable, unique, and niche resource for any individual interested in hand surgery. The guidance it provides makes it a required reading when faced with a challenging surgical problem.

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Preface

The practice of hand surgery has a rich history. Led by the need to improve outcomes of afflictions to the hand, surgeons gathered to deliberate over the most reliable tactics to optimize form and function of the hand and wrist after injury. Indeed, societies were spawned over conclaves of surgeons interested in finding answers for their difficult-to-treat cases. Knowledge of the management of severe hand injuries in early times was obtained through vague written descriptions and through apprenticeships of or with learned physicians. Hippocrates (460–356 BC) opined on many medical conditions, including hand injuries, such as fractures where he made note of certain reduction and stabilization techniques. Galen (131–201 AD) and Paulus Aegineta (625–690 AD) were intrigued by nerve repair and restoration of sensation. Rhazes, Avicenna, and Ali Abu Ibn Sina in the ninth and tenth centuries enhanced early awareness of nerve repair in bone stabilization in hand. Among many of their medical contributions, Andreas Vesalius (1513–1564) and the father of French surgery, Ambroise Paré (1509–1590), made tremendous advances in our knowledge of anatomy and wound care, respectively. A burst of discoveries and interest in hand surgery, in the 16th- and 17th-century medicine, are highlighted by the works of Plater, Dionis, Marechal, Gigot de la Peyronie, Petit, Camper, and Cooper. Even more interest mounted in the 18th and 19th centuries by the writings of Bon Graefe, Zeller, Pouteau, Colles, Dupryten, Weber, Duchenne, and Raynaud.

The list of contributors to the development of modern-day hand surgery could go on and on, but special mention is due of the wars of the 20th century which prompted the greatest advances in hand surgery. Sterling Bunnell, the father of hand surgery in the United States, became enamored with hand surgery during World War I. Bunnell was starting to develop specialized units for hand surgery to try to improve the function following bone and tendon injury. During the same period, the first army surgeon certified by the American Board of Orthopedic Surgery, Norman Kirk, was appointed Chief of Surgery at Walter Reed National Military medical center in Washington D.C. During World War II, President Franklin D. Roosevelt appointed Kirk as Army Surgeon General. Kirk is the only orthopaedic surgeon to be appointed to this position. Years earlier, Kirk and Bunnell had become close friends through common interests in hand surgery, hunting, and fishing. Kirk challenged Bunnell to develop hand centers of excellence and education across the country to help wounded soldiers and civilians alike. Bunnell's drive for solutions to complex issues in hand surgery and rehabilitation is the inspiration of our current book *Problems in Hand Surgery: Solutions to Recover Function*. The intricate balance of the intrinsic and extrinsic soft tissue structure and bony scaffold of the hand coupled with the 31 articulating services in the hand and wrist create a milieu that can lead to a wide variety of problems in hand surgery.

We all seek the best possible outcomes following surgery on our patients. Not all hand ailments are straightforward in their management. The complex hand problems often require some type of unique solution to optimize hand function or form. The two of us treat a wide variety of complex wrist and hand disorders. The mutilated hand has long been a common topic we speak about at various national and international meetings. It occurred to us that we rarely spoke about the treatment of nonunion, malunion, dysvascular limbs, degenerative changes after trauma, stiffness after tendon injury, joint disruption, or many other undesirable outcomes. After many dialogues, panels, and discussions at scientific meetings, we decided it was time to seek out experts in the hand surgery field who have found reliable solutions for some of these complex problems. This book represents a culmination of reliable solutions focused on difficult hand problems. While many textbooks describe techniques for primary conditions, it is rare to have a compendium of procedures of secondary hand surgeries designed to restore form and function. The scenarios within the body of this book have challenged many surgeons. This consolidation of solutions for problems in hand and wrist surgery offers a clear, step-by-step roadmap to hand surgeons confronted with difficult cases. The purpose of this was to bring "the rest of the story" to the hand surgery audience. We have provided a series of videos to help surgeons understand the details of some procedures. The accompanying videos add to the overall comprehension of the written techniques within each chapter.

It is a pleasure to see *Problems in Hand Surgery: Solutions to Recover Function* come to fruition. We hope everyone enjoys reading our book and more importantly we hope it provides some solutions for you as you encounter problems in hand surgery of your own.

Michael W. Neumeister, MD, FRCSC, FACS
Michael Sauerbier, MD, PhD

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Part I

Problems with Nailbed Repairs

1 Nonadherence of the Nail Plate *2*

2 Posttraumatic Split Nails *6*

3 Gentian Violet Treatment of Severe Chronic Paronychia *10*

I

1 Nonadherence of the Nail Plate

Brian Mailey

1.1 Patient History Leading to the Specific Problem

A 63-year-old woman presents with a nail deformity present for 2 years. She recalls a stabbing injury to her proximal nail plate while performing a self-manicure. The aesthetics of the nail was displeasing; she lacked normal nail growth and adherence (▶Fig. 1.1). She did not seek care after the initial injury and the deformity did not improve after multiple nail cycles.

Nonadherence of the nail (onycholysis) is the most common posttraumatic nail deformity. This occurs secondary to nail bed scarring and is often found immediately distal to transverse or diagonally oriented nail bed scars or bone irregularities. The scar interrupts the progressive addition of nail cells from the sterile matrix to the volar nail plate causing detachment of the nail. The nail is unable to reattach to the nail bed distally. Distal nonadherence may lead to problems with subungual hygiene, an unstable nail when picking up small objects, pain from repeat avulsions when catching the nail on objects, or simply aesthetic concerns.

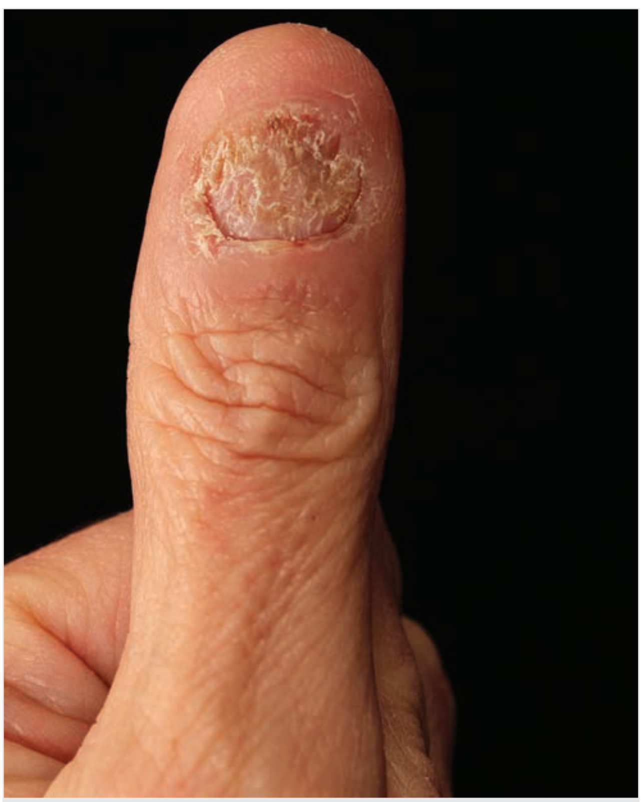

Fig. 1.1 Nonadherence of the nail plate. Right thumb nail of a 63-year-old woman. This patient suffered a sharp traumatic injury to the proximal nail bed 2 years earlier.

The rate of complete nail progression from nail fold to free margin is 70 to 140 days. Baden describes a 21-day delay in growth after injury, during which time the nail thickens proximally but does not grow distally. Distal growth of a thicker-than-normal nail proceeds for the next 50 days, followed by growth of a thinner-than-normal nail for 30 days. Nail growth is not normal for approximately 100 days after injury.

1.2 Anatomic Description of the Patient's Current Status

The hard and elastic structure of the nail plate is produced continuously by the nail matrix. The germinal matrix, sterile matrix, and dorsal roof of the nail all produce the nail, with the germinal matrix producing the majority (90%) by gradient parakeratosis. The sterile matrix adds cells to the volar surface of the nail, accounting for the attachment of the nail to the matrix. The dorsal roof of the nail fold adds flattened cells to the dorsal surface of the nail, producing shine to the nail. The nail is transparent; however, it appears pink due to the presence of vessels of the underlying nail bed. The lunula appears white due to the presence of nuclei. The nail bed consists of the germinal and sterile matrices. The germinal matrix makes up the ventral floor of the proximal nail fold. The sterile matrix consists of the soft tissue immediately beneath the nail distal to the germinal matrix. Keratinization of the nail matrix cells occurs along an oblique axis. As a result, the proximal part of the nail matrix produces the dorsal portion of the nail plate and when damaged gives rise to the development of nail plate surface abnormalities, whereas the distal part of the nail matrix produces the ventral portion of the nail plate.

The patient suffered a penetrating injury to the proximal germinal matrix, which created a disruption in the creation, growth, and strength of the dorsal nail. Injuries distal to the germinal matrix generally do very well; however, proximal nail bed injuries, in particular if unrepaired, often lead to chronic, displeasing nail plate appearance. Since the patient did not seek immediate care after injury, the differential diagnosis also includes fungal infection and skin malignancy (▶Fig. 1.2). Burn injuries to the fingertips often destroy the specialized cells of the nail matrix and result in chronic nonadherence (▶Fig. 1.3)

1.3 Recommended Solution to the Problem

This patient's problem may have been prevented by immediate repair of the injured nail bed. The patient elected to ablate the nail and cover with a skin graft from the volar wrist. Split-thickness skin grafting can be sufficient, although full-thickness grafts are straightforward to harvest and the donor site closes primarily.

1.3.1 Recommended Solution to the Problem

Options for improving this patient's nail bed include the following:

- If the scarred germinal matrix can be identified, it can be excised and closed primarily in hopes of an improved nail adherence and aesthetic.

Fig. 1.2 Nonadherence of the nail plate. Left thumb nail deformity secondary to squamous cell carcinoma.

- Split-thickness nail bed graft from the great toe.
- Application of a veneer or fake nail to disguise the deformity.
- Ablation of germinal matrix and skin grafting to the defect (one procedure or staged with a dermal substitute to improve contour).

1.4 Technique

A finger tourniquet is applied. Two radial relaxing incisions are made and the dorsal eponychial fold is exposed and turned upward. The entire dorsal and volar germinal matrices are excised (▶Fig. 1.4a). It is not necessary to remove the sterile matrix, distal to the lunula; however, the lateral gutters along the nail bed should be excised. The dorsal fold and sides of the paronychium are sutured back into place and a template is created as a guide to harvest the graft (▶Fig. 1.4b). After the full-thickness skin grafting (FTSG) is harvested from the volar wrist (▶Fig. 1.4c), the tourniquet is taken down, hemostasis obtained with an epinephrine-soaked sponge, and the graft sutured into place. It is secured with a bolster for 1 week (▶Fig. 1.4d).

1.5 Postoperative Photographs and Critical Evaluation of Results

The patient's skin graft took well and she healed without issues. She was very satisfied with the result. At about 1 year, she re-presented with a small residual nail growth (▶Fig. 1.5) along the proximal radial aspect of the nail bed. The patient elected not to have it addressed.

It is common to see nail remnants after nail bed ablation. These can be upsetting to patients as it frequently requires additional procedures and recovery times. Use of phenol to ablate the nail matrix or eliminate ingrown toenails is commonly done by podiatrists, to prevent remnant nails from occurring. The overall appearance of the skin-grafted

Fig. 1.3 Nonadherence of the nail plate. **(a, b)** Left thumb nail nonadherence secondary to prior thermal burn injury.

Fig. 1.4 Reconstruction of nailplate nonadherence with full thickness skin graft. **(a)** Radial relaxing incisions to expose the dorsal germinal matrix. **(b)** Foil template to design full-thickness skin graft. **(c)** Template transposed on to the volar wrist. **(d)** Bolster sewn over skin graft.

nail bed is generally very acceptable, even by women. The slight difference in final color of the skin graft almost appears to the casual observer as a nail or at least does not immediately catch the eye as a deformity. Alternatively, once healed, a prosthetic nail can be applied to match the other fingers.

1.6 Teaching Points

- Proximal nail bed injuries should be repaired acutely.
- Nonadherence of the nail bed can be caused by trauma, infection, burn, or malignancy. Each diagnosis should be considered in every patient, regardless of the patient's history.
- Ablation of the nail matrix for grafting only needs to include the volar and dorsal germinal matrix and lateral paronychium gutters. The sterile matrix can otherwise be left intact.
- FTSG from the volar forearm can provide good aesthetic and functional outcomes.
- Nail remnants are common after nail bed ablation; phenol can help prevent nail spikes.

Fig. 1.5 Healed full-thickness skin graft over nail bed. *Arrow* indicates area of nail remnant from retained nail bed cells.

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2 Posttraumatic Split Nails

Michael W. Neumeister

2.1 Patient History Leading to the Specific Problem

A 53-year-old man presents with a chronic splitting of his nail plate. He complained of repetitive trauma to the digit as the split nail caught on clothes (▶Fig. 2.1). He had injured the fingertip and nail bed in a door over a year and a half ago. As the nail grew out from the injury, the split in the nail plate became more apparent and more prominent. No attempt at repairing the nail bed was performed in the local emergency room at the time of his original injury.

2.2 Anatomic Description of the Patient's Current Status

The patient has an area on the sterile matrix where the nail plate is nonadherent from scar tissue within the nail bed. This also results in splitting of the nail plate. The normal nail originates from the germinal matrix under the eponychial fold. The nail plate grows distally at a rate of about 1 mm/wk. The nail plate remains adherent to the nail bed through a very specific anatomic relationship between the nail bed and the nail plate. A series of undulations in the nail bed allows the nail plate to grow around each one of these tissue peninsulas, which prevents dislodgment of the nail plate (▶Fig. 2.2). In addition, there is an adhesive-like "super glue" called the soul horn between the nail bed and the nail plate that helps the nail plate adhere to the nail bed. Scar tissue that forms between the normal junction of the nail bed and the nail plate prevents the nail plate from adhering and results in a splitting of the nail as it grows distally. The greater the amount of scar tissue, the greater the amount of nonadherence and nail plate disruption. The nail plate that does not adhere to the nail bed is subject to repetitive trauma as it catches on pockets, clothes, and other items.

2.3 Recommended Solution to the Problem

One should first realize that this problem could be prevented by the immediate repair of the nail bed at the initial time of injury. Now, however, the nail bed scar tissue needs to be removed and replaced with a split-thickness sterile matrix graft. Full-thickness grafts are not necessary and can result in donor site morbidity. If the nail bed scar tissue is isolated to a small area of the nail bed, then a split-thickness sterile matrix graft can be taken from the same finger's nail bed. Larger areas of scar tissue require the great toe to be used as a donor site to obtain a sterile matrix graft.

2.3.1 Recommended Solution to the Problem

- The nail bed scar tissue needs to be removed and replaced with a split-thickness sterile matrix graft.
- A split-thickness sterile matrix graft can be taken from the same finger's nail bed if the nail bed scar tissue is isolated to a small area.
- Larger areas of scar tissue require the great toe to be used as a donor site to obtain a sterile matrix graft.
- This problem could be prevented by immediate repair of the nail bed at the initial time of injury.

Fig. 2.1 A 37-year-old male with a posttraumatic nail deformity. The nail has a split secondary to scar tissue within the nailbed.

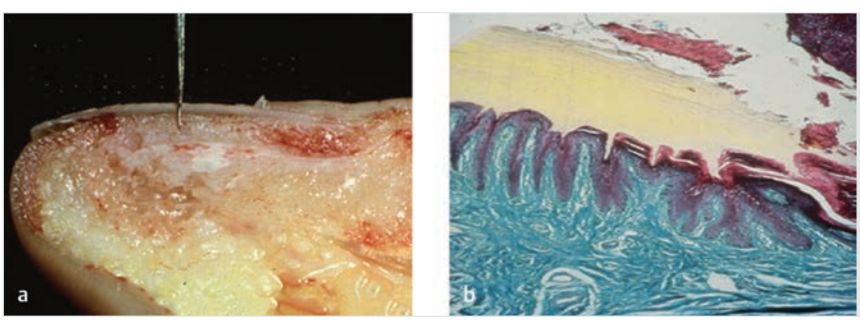

Fig. 2.2 **(a)** Cross section of a nailbed showing the anatomy behind normal adherence of the nail plate. **(b)** Undulating rugae of nailbed with the nail plate glued with a "sole horn" material keeps the nail plate adherent.

2.4 Technique

The patient is taken to the operating theater and placed in the supine position. Under a local anesthetic, with or without sedation, the digit is prepped with the appropriate sterilizing solution and a digit tourniquet is applied. The nail plate is removed from the involved finger (▶Fig. 2.3). The scar tissue is outlined and resected. The scar tissue does not need to be resected down to the bone but rather to the level that permits the sterile matrix graft to lie in precise anatomic alignment with the surrounding nail bed. This will allow the nail plate to grow out appropriately.

The split sterile matrix graft is harvested with a no. 15 Bard scalpel blade. The donor area is outlined and a partial-thickness incision in the nail bed is made to allow the scalpel blade under one edge. A sweeping motion of the scalpel blade allows the graft to be harvested without perforations. One should see the scalpel blade through this sterile matrix split graft while harvesting the graft (▶Fig. 2.4). If one is harvesting the graft that is too thick, they will not be able to see the scalpel blade through the graft during this procedure.

The graft is removed from the donor site and placed in the defect on the involved digit. The graft is secured in place with a 7–0 chromic suture using loupe magnification to make sure that the graft is anatomically aligned (▶Fig. 2.5). The previously removed nail plate is placed on top of the graft under the eponychial fold to prevent synechial scarring and protect the sterile matrix graft while it picks up a blood supply from its new bed.

The dressing is changed in 5 days. Daily dressing change follows for the next 2 weeks. The new nail plate will take 4 to 6 months to grow out. The final nail plate appearance may take up to 1 year to be fully defined (▶Fig. 2.6).

Fig. 2.3 Scar tissue in the nailbed resulted in distal non-adherence.

Fig. 2.4 The scar tissue is excised to provide a bed for the split sterile matrix graft.

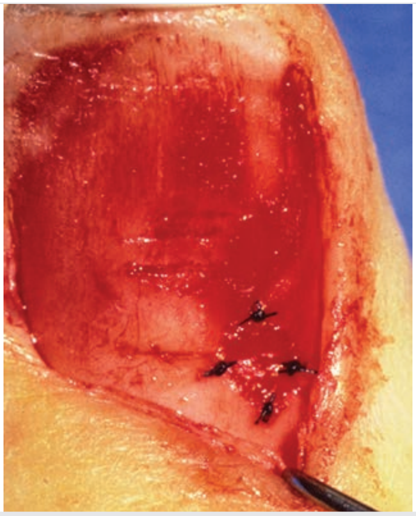

Fig. 2.5 A split sterile matrix graft is used to provide a new bed for a regenerating nail plate.

Fig. 2.6 Final outcome 1 year after grafting.

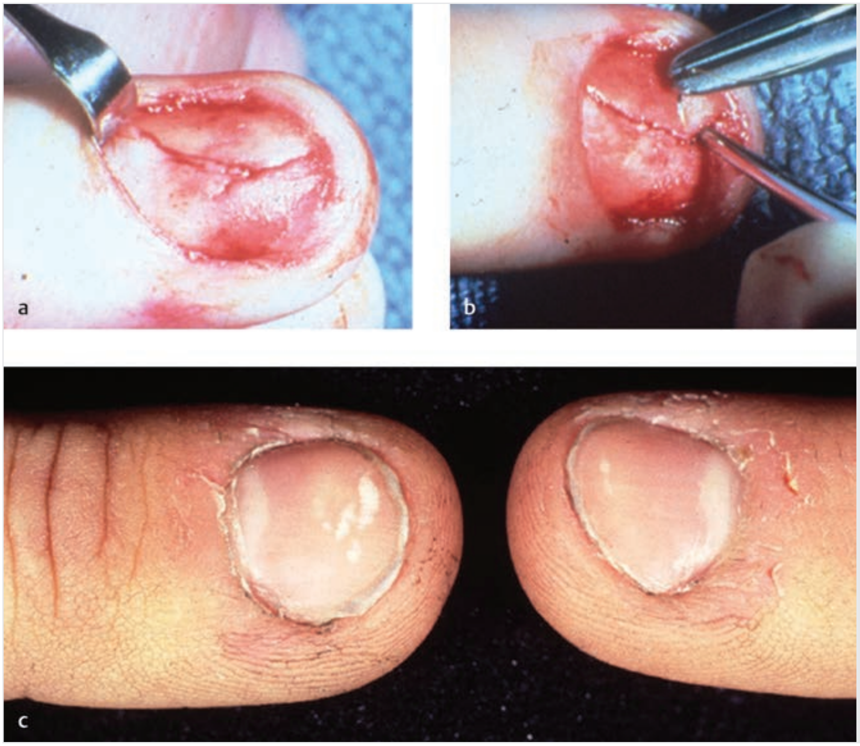

Fig. 2.7 (a–c) Primary repair of the initial nailbed injury should prevent the need for secondary grafting procedures.

2.4.1 Steps for the Procedure

1. The nail plate is removed from the involved finger.
2. The graft is secured in place with a 7–0 chromic suture using loupe magnification to make sure that the graft is anatomically aligned.
3. Final nail plate appearance may take up to 1 year to be fully defined.
4. The postoperative result is shown.

2.5 Postoperative Photographs and Critical Evaluation of Results

Performing the procedure to remove the scar tissue in the nail bed and to replace this with a sterile matrix graft mandates better results than the preoperative status. In fact if done appropriately, the nail plate can grow out and have a normal appearance relative to the other fingers. It is not uncommon to have a small area of nonadherence around the hyponychium.

This problem could be avoided by addressing the nail bed laceration at the time of injury. Anatomic meticulous suture alignment permits normal nail plate growth and adherence (▶Fig. 2.7).

Acute split grafting can also provide optimal primary results for injuries that result in the loss of nail bed substance (▶Fig. 2.8).

2.6 Teaching Points

- Primary repair of bailed lacerations.
- Meticulous attention to anatomic alignment.
- Remove entire nail plate to see the entire nail bed.
- Split nails or nonadherence requires scar excision and split sterile matrix graft.
- The split sterile matrix graft is harvested with a small scalpel blade.
- The graft is harvested so thin that one should see the scalpel blade through the graft during the elevation of the graft.
- Suture the graft in place using anatomic principles.

Fig. 2.8 Technique for harvesting the split sterile matrix graft. **(a)** The initial nailbed defect. **(b)** Harvest the normal sterile matrix bed with a 15 blade scalpel. **(c)** The graft is returned in place with 7–0 chromic suture. **(d)** Place a spacer between the eponychial fold and the nailbed. **(e)** Final outcome.

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3 Gentian Violet Treatment of Severe Chronic Paronychia

Wyndell H. Merritt

3.1 Introduction

Chronic paronychia is most commonly caused by *Staphylococcus aureus* and *Candida albicans* and is thought to be due to bits of nail beneath the eponychium, which act as a foreign body. Since the new millennium, the most common bacteria found in hand infection is methicillin-resistant *S. aureus* (MRSA).

Early gentian violet study by Churchman in 1912 showed gram-positive organisms (especially *S. aureus*) to be highly susceptible to gentian violet dye, even at marked dilution, and it was the antimicrobial treatment of choice until penicillin became popular after 1943. It has long been a favored treatment for thrush (*C. albicans*) as recommended by the World Health Organization. There is no report of resistant *Staphylococcus* to gentian violet dye, thought to be due to the dye's penetration of the bacterial cell wall and the mitochondrial membrane (thus, most gram-positive organisms are susceptible), obviating opportunity to mutate into a resistant form.

Though most surgery texts recommend one of two surgical approaches for chronic paronychia, either marsupialization or resecting the proximal nail, these have significant morbidity and often have recurrence. Topical application of the simple, inexpensive over-the-counter gentian violet treatment should be attempted. This treatment has successfully managed MRSA infections of femoral prostheses, decubitus ulcers, chronic otitis, empyema, and skin ulcerations.

Typically, we instruct our patients to topically apply 1 or 2% gentian violet liquid dye directly along the inflamed eponychium once or twice a day until it is no longer painful, usually 3 to 7 days, unless the patient has Raynaud's syndrome. In those patients, once-a-day application may be necessary for 2 to 3 weeks, because they heal so slowly. Thereafter, no further treatment is required. No antibiotics are utilized and the patient knows how to manage a recurrence or if another digit becomes involved. Additional digital involvement is frequent among the patients who have Raynaud's syndrome and scleroderma.

The author has not operated on a patient with chronic paronychia in over 30 years. Two cases are presented here to show how this noninvasive approach can help the patient avoid surgery.

3.2 Patient History Leading to the Specific Problem: Case A

This 80-year-old woman was referred by infectious disease with a request for index digit amputation. While she was in a nursing home, she developed an MRSA-infected gouty tophus of her index digit, which then led to mid-face cellulitis and MRSA sepsis. She was hospitalized, responded to intravenous (IV) vancomycin, and was discharged on oral clindamycin, but referred a month after onset with request for index amputation for recalcitrant MRSA finger infection.

3.3 Anatomic Description of the Patient's Current Status: Case A

Initial examination findings showed the patient to be weak, faint and pale, and obviously dehydrated, with a chief complaint of diarrhea and a secondary complaint of a painful index digit. Her X-ray had changes of gout, although osteomyelitis was mentioned as a possibility (▶Fig. 3.1).

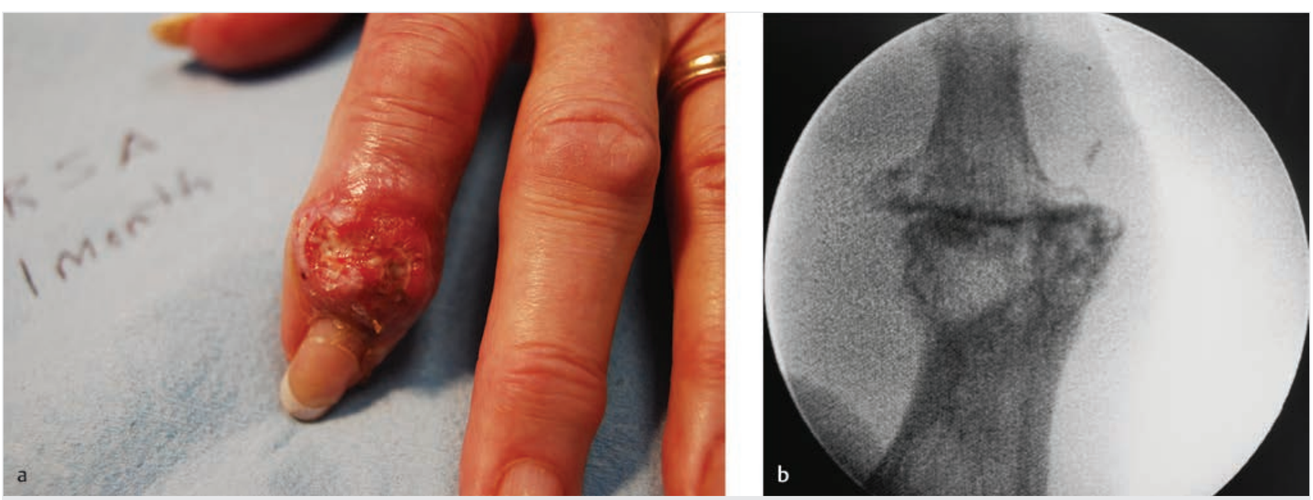

Fig. 3.1 (a, b) One month after infected gouty tophus with MRSA (methicillin-resistant Staphylococcus aureus).

3.4 Recommended Solution to the Problem: Case A

Although referred for amputation, unless there was osteomyelitis, gentian violet dye should adequately control the MRSA infection, and clindamycin discontinued due to the troublesome side effects.

3.5 Technique: Case A

This patient was given an initial treatment of 2% gentian violet dye topically in the office, told to stop taking clindamycin, and then sent to the emergency department where she was given IV fluids and loperamide (Imodium). She returned to the office in 2 days and said this was less painful, and was again treated with topical gentian violet. At 4 days on return, she stated she was pain free, and dye was reapplied with a return appointment scheduled (▶Fig. 3.2).

3.6 Postoperative Photographs and Critical Evaluation of Results: Case A

The patient did not return for her scheduled follow-up. Calls to the skilled nursing facility where she resided assured us she was well, but she continued to cancel her return appointments. Finally, the surgeon went to the facility to visit her, and she was found to be well healed, explaining that she did not return because she was told “the surgeon might cut your finger off” and it was no longer bothering her. She has had no recurrence (▶Fig. 3.3).

Fig. 3.3 Well healed 6 to 7 weeks following treatment.

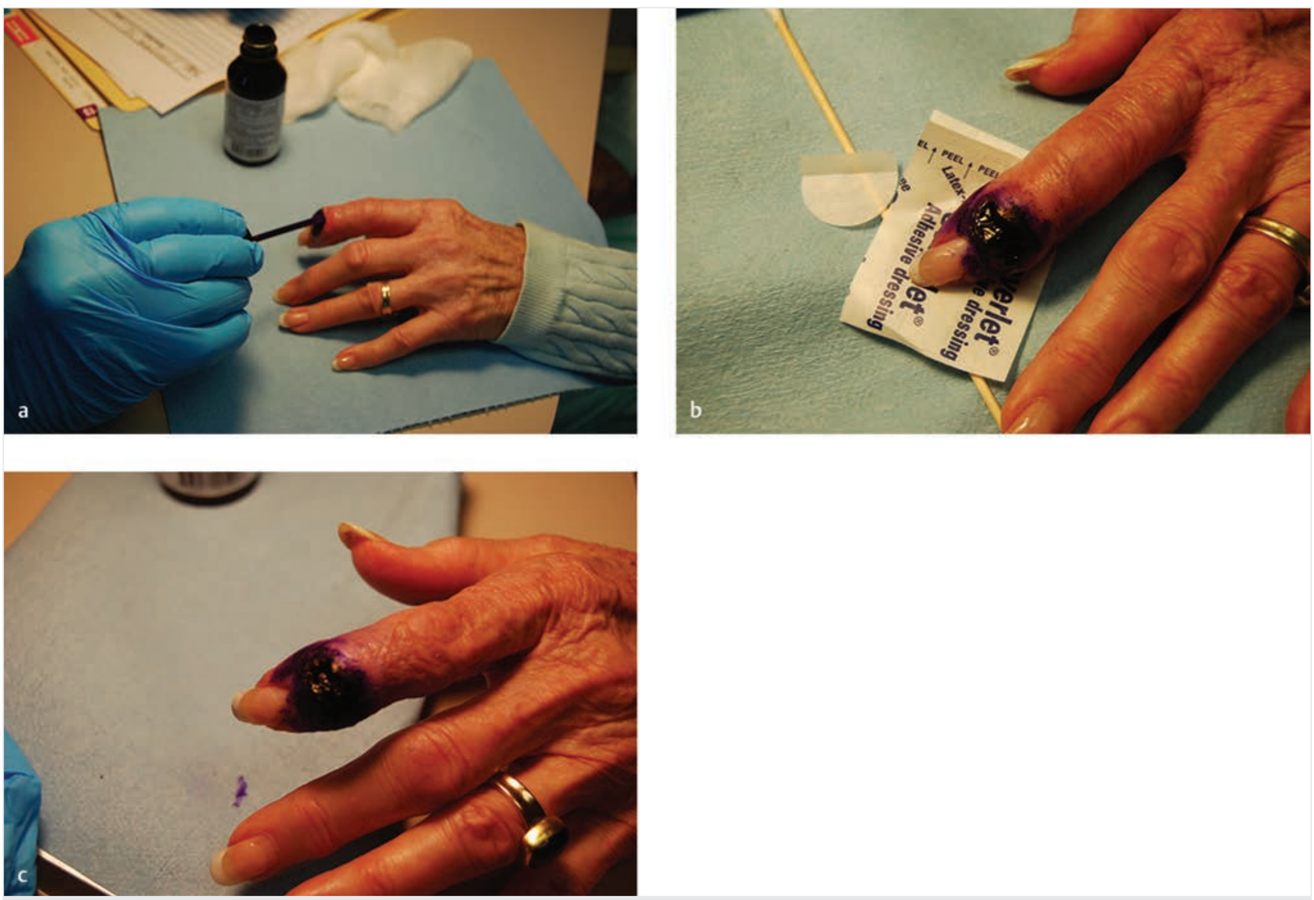

Fig. 3.2 (a, b) Antibiotics stopped and treatment initiated with 2% gentian violet dye. **(c)** Pain free after 5 days with second repainting using gentian violet dye.

3.7 Patient History Leading to the Specific Problem: Case B

This 40-year-old woman had a more typical chronic paronychia present for 10 weeks. She attributed the problem to a manicure she had 16 weeks previously.

3.8 Anatomic Description of the Patient's Current Status: Case B

The wound had been cultured and *S. aureus* and *C. albicans* were found to be present. Both recurred after a variety of antibiotics and soaks. Abnormal nail growth along the radial border of the eponychium was also present (▶Fig. 3.4). This patient had a worse infection than usually seen.

3.9 Recommended Solution to the Problem: Case B

Gentian violet dye is particularly useful for *C. albicans* and *S. aureus* organisms, and topical treatment should be instituted without need for systemic antibiotics. The patient is instructed to use this once or twice a day until all soreness has abated, then to discontinue treatment and return for follow-up.

3.10 Technique: Case B

This patient's defect was painted with 1% gentian violet and she became pain free within 5 days. She stopped the gentian violet after 1 week and began to grow a new nail within 2 to 3 weeks (▶Fig. 3.5).

3.11 Postoperative Photographs and Critical Evaluation of Results: Case B

The patient returned with normal nail growth restored after 3 months, and no recurrence (▶Fig. 3.6).

3.12 Teaching Points

- Chronic paronychia is commonly caused by *S. aureus* and *C. albicans*, and today's hand infection flora is dominated by MRSA.
- *S. aureus*, including MRSA, and *C. albicans* are highly susceptible to topical gentian violet dye, which is inexpensive and readily available over the counter.
- Gentian violet dye penetrates the bacterial cell wall and mitochondrial membrane in gram-positive organisms, so it is unlikely to develop resistance.

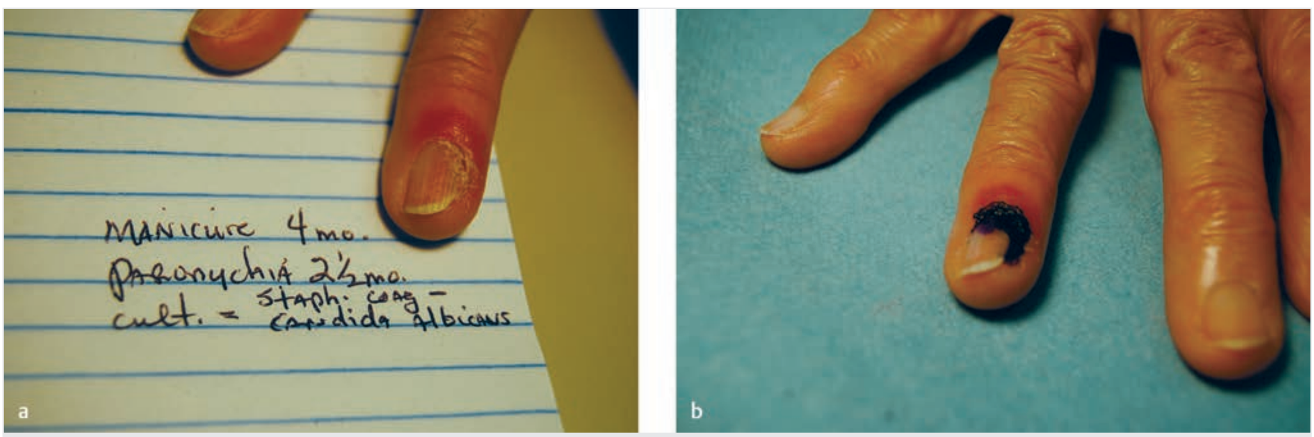

Fig. 3.4 **(a, b)** Ten-week chronic paronychia with abnormal nail growth.

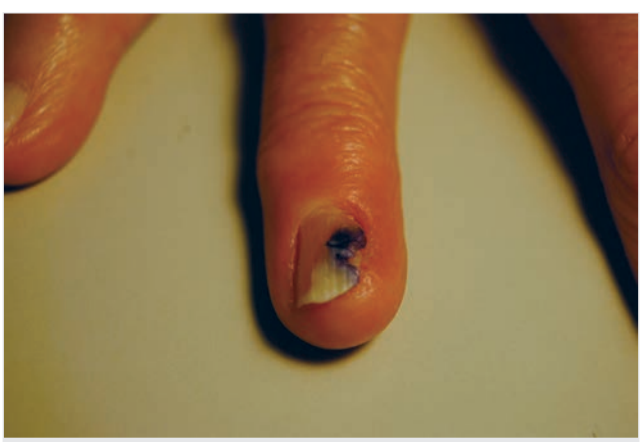

Fig. 3.5 New nail growth at 2 to 3 weeks after treatment stopped.

Fig. 3.6 Well healed after 3 months.

Fig. 3.7 (a–d) Patient with Raynaud's syndrome being treated with gentian violet. They learn to manage this themselves.

- Patients with Raynaud's syndrome are poor candidates for surgery but can usually manage their paronychial complaints with topical gentian violet, although healing takes longer (▶Fig. 3.7).
- The author initially found use of gentian violet for painful eponychial ingrown toenails among the soldiers in Vietnam as a preferred alternative to nail removal, later for ingrown fingernails, then finally for chronic paronychia. It is not useful for the typical subungual dermatophyte nail infection.

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Part II

Problems with Trigger Release

4 Bowstringing 16

II

4 Bowstringing

Loukia K. Papatheodorou and Dean G. Sotereanos

4.1 Patient History Leading to the Specific Problem

A 42-year-old professional male pianist presents with decreased active range of motion of the right long finger 2 months after a trigger finger A1 pulley release of the right long finger.

4.2 Anatomic Description of the Patient's Current Status

The patient has a painful pulling sensation in the palm with motion of his right long finger. He has limited motion of the right long finger, metacarpophalangeal (MCP) joint 0 to 60 degrees, proximal interphalangeal (PIP) joint 0 to 30 degrees, distal interphalangeal (DIP) joint 0 to 45 degrees but full passive range of motion (▶Fig. 4.1a). The flexor digitorum profundus (FDP) and the flexor digitorum superficialis (FDS) of the right long finger are intact. Bowstringing of the flexor tendons is present over the proximal phalanx during resisted flexion. Magnetic resonance imaging (MRI) reveals volar displacement of the flexor tendons (▶Fig. 4.1b). The palmaris longus tendon is present in the right wrist when the patient opposes the thumb to the small finger while flexing the wrist against resistance.

4.3 Recommended Solution to the Problem

An A2 pulley reconstruction is recommended to prevent the flexor tendons from bowstringing. Various materials and surgical techniques have been described for pulley reconstruction. Free tendon grafts, extensor retinaculum, or artificial materials can be used in the reconstruction of pulleys. Free tendon autograft options include palmaris longus and extensor tendon. Various pulley reconstruction techniques can be utilized; some encircle (loop techniques) the proximal phalanx, while others do not. The reconstructed pulley must be strong, not only maintaining the flexor tendons close enough to volar surface of the phalanx but also allowing the flexor tendons to glide freely. Biomechanical studies have shown that the pulley reconstruction with the encircling techniques is stronger than the nonencircle techniques. However, the exact mechanical strength that a flexor pulley requires for active tendon motion is still unknown. Regardless of the technique used, the goal of the pulley reconstruction should be to recreate the length, tension, and glide of the native pulley. For this patient with bowstringing after trigger finger release, an A2 pulley reconstruction is performed using palmaris longus autograft.

4.3.1 Recommended Solution to the Problem

- A2 pulley reconstruction can prevent flexor tendons from bowstringing.
- Reconstruction of pulley can be performed with free tendon autograft, extensor retinaculum, or artificial materials.
- Pulley reconstruction can be performed with encircle and nonencircle techniques.
- Achieve the appropriate tension within the flexor pulley to maintain the flexor tendons close enough to volar surface of the phalanges, but also allowing the flexor tendons to glide freely.
- It is important to recreate the length, tension, and glide of the native pulley.

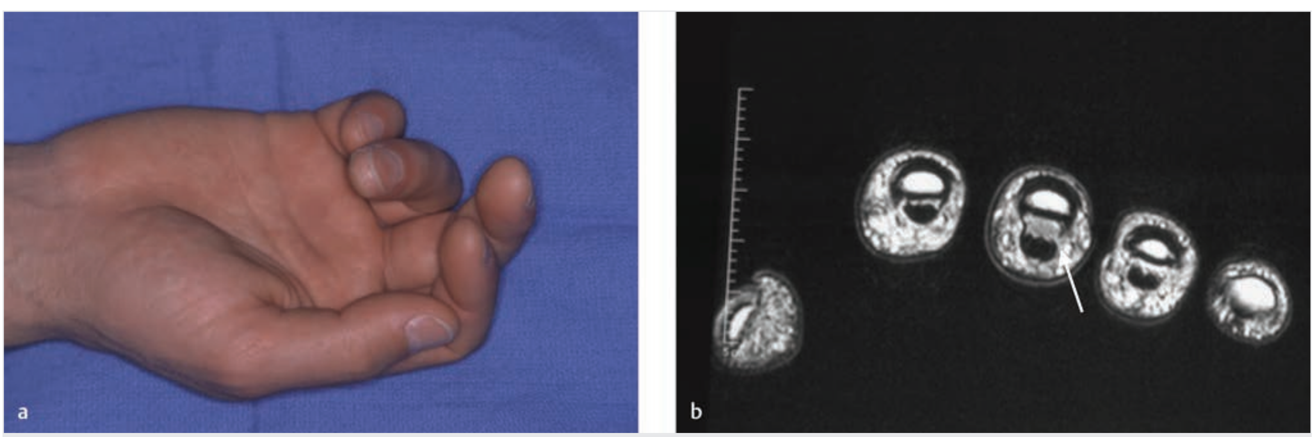

Fig. 4.1 **(a)** Clinical view 2 months after trigger release of the right long finger. **(b)** View of the right hand on MRI scan indicating volar displacement of the flexor tendons (away from the proximal phalanx) of the long finger (*white arrow*).

4.4 Technique

The procedure is performed with the patient in the supine position under general or regional anesthesia, tourniquet control, and loupe magnification. A Brunner incision is utilized at the volar aspect of the proximal phalanx of the finger to expose the flexor tendon sheath. Care is taken to identify and protect the digital neurovascular bundles. It is confirmed that the flexor tendons are intact and significant loss (almost 90%) of the A2 pulley is found (▶Fig. 4.2).

Next, the harvesting of the palmaris longus tendon graft is performed. First, a separate small transverse incision is made at the distal wrist crease and the palmaris longus tendon is identified. Care is taken to identify and protect the median nerve. After the transection at the wrist, the tendon is held with a clamp at its distal end and is mobilized proximally. Then a tendon stripper is placed along the tendon sheath. The stripper is firmly advanced proximally into the forearm with a slight twisting motion and the tendon is released from its muscle belly. Alternatively, if a tendon stripper is not available, the tendon can be harvested through a second small transverse incision over the musculotendinous level in the proximal end of the forearm.

Then, the tendon graft is used to reconstruct the A2 pulley with the "loop" technique. The tendon graft is passed around the proximal phalanx under the extensor mechanism just distal to the MCP joint (▶Fig. 4.3). The tendon graft is circumferentially wrapped around the proximal phalanx adjacent to the bone forming a double loop taking care to protect the adjacent neurovascular bundles. The passage of the tendon graft around the phalanx can be facilitated using a right-angled clamp or curved suture passer. The reconstructed pulley must be strong and it is tested under direct visualization intraoperatively by pulling the flexor tendons proximally. It is important to achieve the appropriate tension within the flexor pulley to hold the flexor tendons close enough to the volar surface of the phalanx without restricting gliding. It may be helpful to flex the finger to bring the tendons closer to the volar surface of the phalanges before securing final tension. Each loop of the tendon graft is sutured to the adjacent loop and the ends of the graft to the remaining local tissue (remaining native pulley). The tourniquet is deflated, meticulous hemostasis is obtained, and the skin is closed. Postoperatively, a static splint with the hand in resting position is utilized for 2 weeks. Then a pulley ring splint is placed over the proximal phalanx to allow gentle active range of motion exercises without resistance. The splint is removed at 8 weeks and full range of motion with progressive resistances is allowed.

4.5 Postoperative Photographs and Critical Evaluation of Results

Performing the A2 pulley reconstruction using a free tendon graft technique results in better motion of the finger than the preoperative status. To avoid flexion contracture or poor functional results, appropriate gliding of the tendons within the tendon sheath must be achieved by applying proper tension within the flexor pulley maintaining the tendons close to underlying the proximal phalanx.

At 6 months after A2 pulley reconstruction, the patient is able to make a full composite fist of the right hand and active range of motion of the right long finger is restored (▶Fig. 4.4). He returned to his previous professional activities.

4.6 Teaching Points

- A2 pulley reconstruction is performed to prevent flexor tendons from bowstringing.
- Harvest the proper length of tendon graft for loop technique pulley reconstruction (length for two to three loops).
- Place the tendon graft under the extensor mechanism at proximal phalanx.
- Do not pass the graft around the neurovascular bundles.
- The reconstructed pulley must be tested under direct visualization intraoperatively.
- Ensure appropriate tension within the flexor pulley to hold the flexor tendons close to the proximal phalanx without preventing gliding of the tendons.

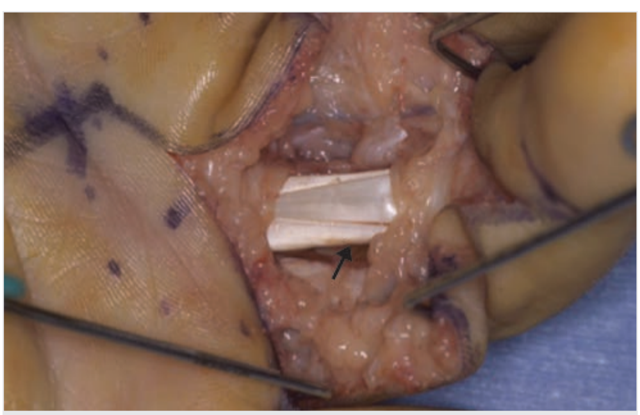

Fig. 4.2 Operative photograph during exploration of right long finger showing the significant loss of the proximal part of the A2 pulley and volar translation of the flexor tendons (*black arrow*).

Fig. 4.3 Operative photograph showing the loop pulley reconstruction with the palmaris longus tendon graft (*black arrow*).

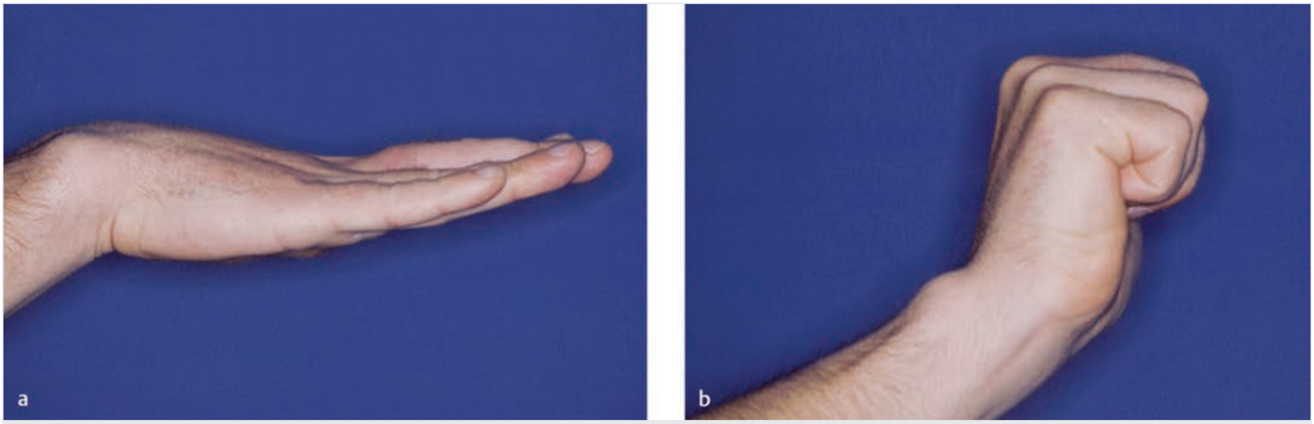

Fig. 4.4 (a, b) Clinical results at 6 months after A2 pulley reconstruction of right long finger.

- Recreate the length, tension, and glide of the native pulley.
- Protect the pulley reconstruction using a pulley ring splint for 8 weeks.

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Part III

Problems with Dupuytren's Disease

5 Exposed Tendons *20*

6 Acute Vascular Compromise after Dupuytren's Fasciectomy *23*

7 Secondary Contractures *26*

8 Complications of Dupuytren's Contracture Treatment *33*

III

5 Exposed Tendons

Riccardo E. Giunta and Elisabeth M. Haas

5.1 Patient History Leading to the Specific Problem

A 45-year-old man is seen in the outpatient clinic with an advanced stadium of Dupuytren's disease of his fourth finger (▶ Fig. 5.1). The contracture of the ring finger of the proximal interphalangeal (PIP) joint is greater than 90 degrees (Tubiana stage 3). Although he had been suffering since decades from this condition, he reported that during the last 12 months the contracture has progressed. The patient had no prior operations at this hand. He showed an aggressive type of Dupuytren's contracture with a very thick central cord. The cord was directly attached to the skin, which made the operation challenging.

5.2 Anatomic Description of the Patient's Current Status

The patient's situation is the result of a very aggressive form of Dupuytren's disease and his reluctance to see a hand surgeon.

Fig. 5.1 Preoperative appearance of Dupuytren contracture of the ring finger (Tubiana stage 3).

This case is more often seen in a recurrent disease. This condition makes the operation exceptionally complicated in terms of closing the defect after resection of the Dupuytren cord. The longer a patient with a Tubiana stage 2 or greater waits to see a surgeon, the more the skin is already retracted and the more complicated an operation. As a rule, the greater the ankle of the joint contracture, the less the skin available for closing the wound. Moreover, the older the patient, the thinner the skin and therefore the less tension tolerated by the skin during suture. One further aspect is the particular kind of Dupuytren's disease. The increased expression of collagen type I/III fiber varies in every patient. If the fibers grow extensive induratively, the dissection of the subcutis can be very difficult and the risk of damaging the latter is inevitable. This type goes less often along with strong contractures such as found in our patient.

5.3 Recommended Solution to the Problem

One should first plan operations with all surgical risks and inform the patient about the necessity of all kinds of flap surgery. If the loss of skin is too large so that Z- and VY-plasties for coverage would have a high risk for complications, a full-thickness graft or a local skin flap is the next option. Another surgical option is the "open palm" technique by McCash. In this technique, an oval area open for secondary healing is left in the palm. If the cords make up more than half of the palm, the infection risk is too high. Usually for open palm treatments, daily dressings are mandatory and wound healing should be completed after 4 to 6 weeks. For this operation type, it is necessary that the patient is extremely compliant; otherwise, there is risk of a superinfection. We determined that in the above-described case, the arising defect is too large to apply McCash's technique. Therefore, the choice for treatment was open fasciectomy with skin grafting (dermofasciectomy).

5.3.1 Recommended Solution to the Problem

- Anticipating complications due to severe skin infiltrations of Dupuytren's disease.
- Operation planning (if necessary full-thickness skin transplantation, local flap surgery).
- Tell your patient to quit smoking 4 weeks prior to the operation and until wound healing is completed.
- Do an extensive patient education with all possible complications.
- Elevate the hand to decrease swelling. Edema can also cause pressure on the skin.

5.4 Technique

The patient is planned for an operation with an inpatient stay for at least two nights. Under plexus anesthesia or general anesthesia, the arm is prepped and an upper arm tourniquet is applied. Incision is made oval shaped all around the cord until half of the proximal phalanx (▶Fig. 5.2).

Fig. 5.2 Intraoperative finding: the fibromatous cords and the overlying skin were resected (dermofasciectomy) and the flexor tendons are exposed.

The next step is complete dermofasciectomy. The cord is excised while sparing blood vessels and nerves. While preparing the cord, you have to make sure that you leave the paratenon intact. Then we plan the full-thickness skin graft. We take it from the palmar side of the forearm. Be aware of the fact that the graft shrinks and recoils. Therefore, always plan the size a bit bigger. Do not forget to incise your transplant to prevent seroma or hematoma between the graft and the wound bed. Nonadherent tie-over bolster dressings are ideal to improve adherence of the skin graft with the wound ground. Immobilization helps prevent sharing of the graft. The patient left the operation room with an extension splint.

5.4.1 Steps for the Procedure

1. Plan the operation in detail.
2. Patient should know about the difficult situation including the risk of finger loss.
3. Plan your skin graft always larger than the defect, because the graft shrinks and recoils.
4. Nonadherent tie-over bolster dressings are ideal to improve adherence of the skin graft with the wound ground.
5. Remove this pressure bolster after 5 days.
6. Start physical therapy early, but with caution of the suture and adherence of the graft.

5.5 Postoperative Photographs and Critical Evaluation of Results

The dressing was changed at the first postoperative day without removing the bolster; it will be done on the fifth day after surgery. Dressing change should be done every other day until sutures are removed after 2 weeks (▶Fig. 5.3). For prevention of infection, we apply intravenous antibiotics for a few days.

Fig. 5.3 Postoperative finding after dermofasciectomy. **(a)** Three weeks postoperative after skin grafting. **(b)** Six weeks postoperative. Graft has healed well.

5.6 Teaching Points

- Operation planning, if necessary, with full-thickness skin transplantation.
- Inform patients in advance about possible complications, for example, wound healing disorder and risk of finger loss.
- Daily follow-up to prevent infection.
- Open palm technique requires high patient compliance but is still an option.
- Begin physical therapy depending on the tensions of your suture.
- Do not discharge patients too early after operation.
- Be careful with diabetic patients, as they have a limited wound healing.
- Evaluate the indication prior to operation. Not every Dupuytren's disease requires surgery.

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6 Acute Vascular Compromise after Dupuytren's Fasciectomy

James N. Winters, Jeffrey B. Friedrich, and Michael W. Neumeister

6.1 Patient History Leading to the Specific Problem

A 51-year-old man presented with Dupuytren's contracture involving the right finger. This progressively worsened over the past 3 years and now limited his ability to perform manual labor. On examination, there were palpable cords and visible flexion contractures of 60 degrees at the metacarpophalangeal (MCP) joints and 40 degrees at the proximal interphalangeal (PIP) joint. The patient was deemed to be a candidate for surgical intervention with aggressive fasciectomy. He was brought back to the operating theater, placed in the supine position with the right arm abducted to 90 degrees, and sterile tourniquet inflated to 250 mm Hg. A longitudinal incision with designed 60-degree Z-plasty markings was utilized for access in the palm and Bruner-type incisions were designed in the finger. The neurovascular bundles were intimately involved with the cord and displaced medially. The digital nerves were easily identified and protected on either side of the cord. Palmar fasciectomy was performed with removal of pretendinous bands, digital cords, and tight spiral cords around the ring finger. The tourniquet was let down and the ring finger remained extremely white (▶Fig. 6.1). The fingers were placed back in slight flexion and warm saline-moistened laps were applied. The patient had been hemodynamically optimized to make sure hypotension was not a contributing factor. After 30 minutes of ischemia time, no change was identified in the finger. Papaverine was used to try to topically dilate the vessels and the microscope was prepped and draped to visualize each digital vessel.

Fig. 6.1 Vascular compromise observed following fasciectomy of the finger. The digital arteries were compromised during the dissection.

6.2 Anatomic Description of the Patient's Current Status

The eponym Dupuytren's contracture takes root from Baron Guillame Dupuytren's 1831 lecture on the disease. However, Plater in 1614, Cline in 1777, and Cooper in 1822 previously described the disease process and fasciotomy. Dupuytren's disease is thought to have a genetic predisposition, most commonly affecting people of Northern European descent and occurring later in life. Manual labor, trauma, alcoholism, epilepsy, and others have previously been implicated in the etiology, although conclusive evidence is lacking. Fibroblasts and myofibroblasts are thought to be the cells responsible for nodule formation, collagen deposition into cords, and progressive contracture of the digits.

A firm understanding of normal anatomical structures in the palm must first be understood to appreciate this disease process. The palmar skin and subcutaneous fat are separated from the flexor tendons by the palmar aponeurosis. This triangular-shaped fascial layer originates from the palmaris longus tendon and splits distally into pretendinous bands. The pretendinous bands further divide into three distinct layers: superficial, middle, and deep. The superficial layer attaches to the skin at the MCP crease. The deep layer extends dorsally attaching to the interosseous muscle fascia and deep transverse metacarpal ligament. The middle layer forms two spiral bands that contribute to the web-space coalescence. The natatory ligaments are transversely oriented and travel across all digits. The natatory ligaments have fibrous attachments to the flexor tendon sheath at the MCP joint and contribute to the web-space coalescence. The web-space coalescence continues distally into the finger to form the lateral digital sheet, which further splits volarly and dorsally into Grayson's ligament and Cleland's ligament, respectively. The neurovascular bundle lies deep to the palmar aponeurosis. The bundles run parallel to the flexor tendons, separated from the tendons by adipose and vertical fascial bands of Legueu and Juvara. At the palmar–digital junction, the neurovascular bundle becomes more superficial and midline, passing volar to the spiral bands. The bundle continues to travel distally in the finger encased by the lateral digital sheet (lateral), retrovascular fascia (medial), Cleland's ligament (dorsal), and Grayson's ligament (volar).

Dupuytren's disease is progressive over time and can involve any of the longitudinally oriented ligaments, as well as the transversely oriented natatory. Predictable patterns of pathologic nodules and cord formations can be based off this anatomy. Pathology typically starts with nodule formation in the pretendinous band and causes pitting of the skin due to dermal attachments. With deposition of type III collagen, this progresses to pretendinous cord formation, which is the most common. Spiral cords can also form with involvement of spiral bands, lateral digital sheet, and Grayson's ligaments. Spiral cords are responsible for MCP joint flexion and displacement of the neurovascular bundles into an abnormal superficial and medial position. The natatory ligament and lateral digital sheet may also be involved. Finally, a central cord can form over the proximal phalanx without any normal fascia precursors and contributes to PIP flexion deformity. Cleland's ligament and the transverse ligament of the palmar aponeurosis are not involved in Dupuytren's disease.

6.3 Recommended Solution to the Problem

Multiple treatment options exist for disruption of these cords including the following: physical therapy, clostridium histolyticum collagenase, needle aponeurotomy, and surgical intervention with partial or total fasciectomy. Surgery is typically reserved for more severe cases and traditional indications included MCP flexion contracture less than 30 degrees or any PIP flexion contracture. Treatment complications include skin necrosis, infection, hematoma, edema, flare pain syndromes, neurovascular injury, and recurrence. The rate of acute vascular injury is quoted at 2% in the literature with a range of 0.8 to 9%. This rate increases significantly in patients being treated for recurrence. Although the rate of vascular injury is quite low, the surgeon must be prepared to deal with this complication.

Multiple intraoperative techniques can be utilized to prevent vascular injury. Increased visualization of the vessels can be achieved by avoiding total exsanguination of the hand prior to tourniquet insufflation, along with the use of loupe magnification, and access to operating microscope. Incision should be started proximal to the area of the diseased palm. Dissection should proceed from known to unknown, proximal to distal palm, with the understanding that the nerve and artery are not always intimately associated. Damage to the neurovascular structures can occur on initial incision if starting distally at the palm–digit junction. Neurovascular bundles should be handled delicately and protected at all times during fascial excision. Avoiding aggressive passive extension of the MCP and PIP joints can prevent digital artery spasm. Additionally, during closure, care should be taken to avoid tension on vessels from skin flap inset.

If the digit remains pale and cool after release of the tourniquet, then vascular injury should be suspected. The next step is to determine the etiology of injury: vasospasm, intimal hemorrhage, traction rupture, or sharp transection. Initially, the fingers should be placed back into a slightly flexed position and warm saline-soaked gauze should be applied to the operative site and digit. Topical smooth-muscle relaxants, such as 20% lidocaine, calcium channel blockers, and papaverine, should bath the vessel directly and allow this to sit for 10 to 15 minutes prior to manipulation of the digit. Systemic anticoagulation, with heparin 5,000 U, may also be attempted if there are no contraindications. If these interventions fail to restore perfusion to the digit, then further exploration of the neurovascular bundles is warranted.

If brisk pulsatile bleeding from the proximal artery is encountered, then sharp transection likely occurred. Primary anastomosis of the vessel under operative microscope is used to restore flow. If no bleeding is encountered, then further exploration of the bundles is performed to identify rupture with intravascular thrombosis due to intimal trauma. This will require excision of the rupture site and the thrombosed portion of the vessel. Interposition vein graft will need to be harvested and anastomosed to restore flow. Postoperative revascularization monitoring and protocols should ensue.

6.4 Technique

In the above-listed case, neurovascular injury was suspected to both digital arteries. No improvement was noted in the ring finger perfusion with conservative measures, and decision was made to further explore the neurovascular bundles under microscopic assistance. Inspection of the ulnar-sided bundle showed a sharp transection to the artery, which was medially displaced near the palmar–digital junction. Inspection of the radial-sided bundle revealed a large arterial gap spanning from the palm and entirety of the proximal phalanx. The surgical plan included primary repair of ulnar-sided artery and an interposition vein graft for repair of the radial-sided artery.

Attention was first turned to the ulnar-sided digital artery. Yasargil clamps were applied, and the vessel ends were flushed and prepared by removal of adventitia. The vessel was then coapted with 9–0 nylon suture in an interrupted fashion without tension. The Yasargil clips were removed, no leak was identified, and the finger regained perfusion.

Attention was then turned to the radial digital artery. The vessel ends were trimmed, flushed with heparin, and pulsatile bleeding was restored. Yasargil clamps were applied and vessels ends prepared. The defect size was measured. Next, a vein graft was harvested through a longitudinal incision over the volar forearm. The vein was clipped proximally and distally, and then sharply transected for removal. The vein was flushed and placed in a reverse direction between the arterial ends. Again using microscopic assistance, a 9–0 nylon was used to coapt the proximal end in a simple, interrupted, tension-free manner. The added vein length was removed from the distal segment to avoid kinking. This was then anastomosed in a similar fashion. The vascular clamps were removed and good flow was observed (▶Fig. 6.2). The skin flaps were then closed in a loose fashion to avoid compression of the bypass graft. A bulky, noncompressive dressing was placed with fingers in slight flexion. The patient was admitted to the hospital and started on a daily aspirin and heparin 5,000 U thrice a day for the next 3 days.

Fig. 6.2 Interposition vein graft can be visualized on the radial aspect of the ring finger. There is bleeding from the distal tip of the finger ensuring good vascular flow.

Fig. 6.3 The finger remains vascularized and viable following vascular reconstruction.

6.5 Postoperative Photographs and Critical Evaluation of Results

The patient ultimately went on to have good range of motion without vascular compromise (▶Fig. 6.3). There was some cold intolerance for the first year.

6.6 Teaching Points

- Neurovascular bundles shifted medially and volarly due to spiral bands.
- Start proximally in the nondiseased palm to identify the neurovascular bundles.
- Loupe magnification and not exsanguinating arm entirely can help with identification.
- Aggressive extension of MCP and PIP can cause vasospasm or vessel rupture due to loss of elasticity.
- Flexed positioning, warm saline, smooth muscle relaxants for vasospasm.
- Primary anastomosis or vein graft interposition may be required if both arteries are damaged.

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7 Secondary Contractures

M. Claire Manske and Jeffrey B. Friedrich

7.1 Patient History Leading to the Specific Problem

A 70-year-old right-hand-dominant man presents for evaluation of a left small finger contracture. He was diagnosed with Dupuytren's disease of the bilateral hands 30 years ago, and his left hand has always been more severely affected than the right. Shortly following his diagnosis, he underwent partial palmar fasciectomy of the bilateral long, ring, and small fingers with good correction of metacarpophalangeal (MCP) and proximal interphalangeal (PIP) joint contractures. Twenty-five years later, he developed recurrent contracture of the left small finger PIP joint, which was treated with needle aponeurotomy with good correction. He presents now, 5 years following the needle aponeurotomy, with progressive flexion contractures of the small finger PIP and distal interphalangeal (DIP) joints, impairing his ability to golf, garden, and wear gloves (▶Fig. 7.1).

On clinical evaluation, the patient has full composite flexion and extension of all digits of the left hand, except the small finger, which has full MCP joint motion, a fixed 90-degree flexion contracture of the PIP joint, and 40-degree contracture of the DIP joint. He has full abduction of his digits without web-space adduction contractures. In addition to the pits and nodules in the palm, there is a palpable cord along the ulnar aspect of the small finger, extending distally from the MCP to the DIP joint. All digits are neurovascularly intact with brisk capillary refill and two-point discrimination to 5 mm in all digits.

7.2 Anatomic Description of the Patient's Current Status

Dupuytren's contractures result from proliferation of fibroblasts in the palmar and digital fascia, which then differentiate into myofibroblasts and cause normal fascial bands to involute into nodules and cords. The specific components of the palmar and digital fascia affected by this process determine which digits and joints become contracted (▶Table 7.1).

When Dupuytren's contractures recur following treatment, multiple anatomic structures are often responsible, including continued proliferation of pathologic palmar fascia, secondary contractures of adjacent skin and joint capsules, and scar formation resulting from the prior intervention. Although it is often difficult to differentiate which of these elements is responsible for the contracture recurrence, ideally all pathologic structures are addressed to achieve maximum correction and minimize the risk of recurrence. Occasionally, full correction of the contracture cannot be achieved due to contracted neurovascular structures limiting full extension.

Although recurrent contractures may occur in any patient following treatment of Dupuytren's disease, several risk factors have been identified. Patients meeting the modified Dupuytren's diathesis criteria of male gender, age of onset younger than 50 years, bilateral hand involvement, family history of at least one parent or sibling affected, or presence of Garrod's pad (thickenings on dorsum of MCP joints) are at increased risk in a dose-dependent fashion. Presence of all five diathesis factors increases the risk of recurrence by

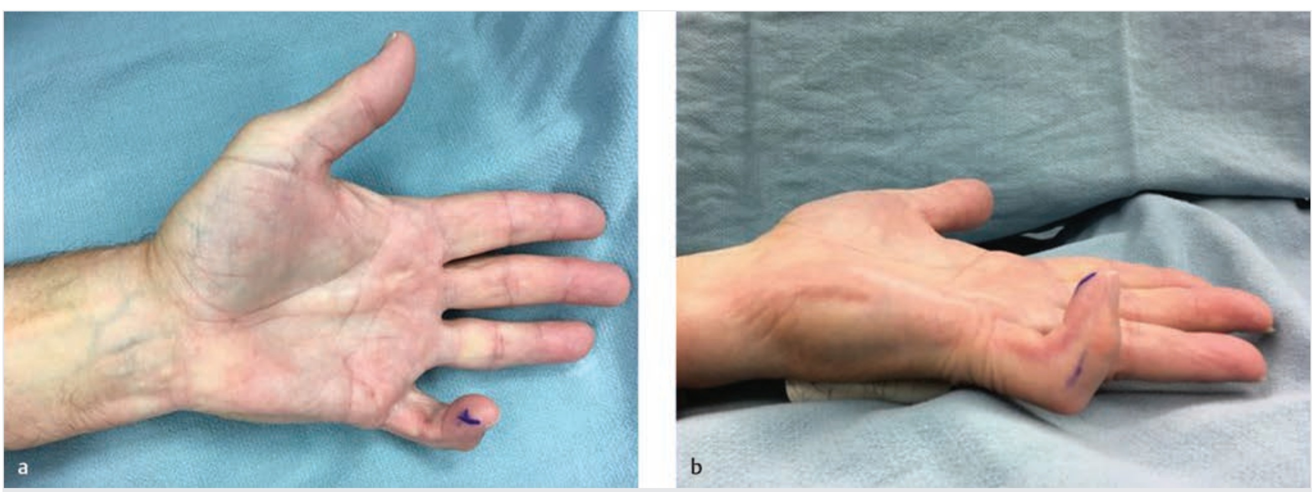

Fig. 7.1 (a, b) The patient presented for evaluation of a contracture of the small finger on his left hand.

Table 7.1 Anatomy of Dupuytren's contracture

Cord	Origin	NVB displacement	Contracture	Other
Pretendinous cord	Pretendinous band	ND	MCPJ	Commonly extends distally to become continuous with digital cords
Vertical cord	Septa linguae and Juvara	ND	No	Not common
Spiral cord	Pretendinous band, spiral band, lateral digital sheet, Grayson's ligament	Volar and medial	PIPJ	Most commonly in small finger
Natatory cord	Natatory ligament	ND	Web space	
Central cord	Extension of pretendinous cord in palm (no preexisting central band)	ND	PIPJ	Attaches into flexor tendon sheath near PIPJ or periosteum of middle phalanx on one side of digit
Lateral cord	Lateral digital sheet	Midline (because of its volume)	PIPJ and DIPJ	Attaches to skin or Grayson's ligament
ADM	ADM tendon	Sometimes	PIPJ	Can present as isolated digital cord; insertion points vary
Distal commissural cord	Distal commissural ligament	ND	Web space	Decrease in palmar and thumb abduction
Proximal commissural cord	Proximal commissural ligament	ND	Web space	Decrease in thumb abduction
Thumb pretendinous cord	Thumb pretendinous band	ND	MCPJ	

Abbreviations: ADM, abductor digiti minimi; DIPJ, distal interphalangeal joint; MCPJ, metacarpophalangeal joint; ND, no displacement; NVB, neurovascular bundle; PIPJ, proximal interphalangeal.
Source: Cheung K, Walley KC, Rozental TD. Management of complications of Dupuytren contracture. Hand Clin. 2015;31(2):345–354.

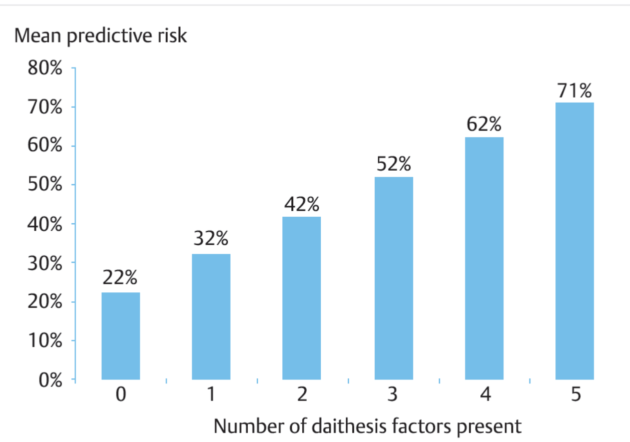

Fig. 7.2 Influence of number of Dupuytren's diathesis risk factor on contracture recurrence. (Adapted from Hindocha S, Stanley JK, Watson S, Bayat A. Dupuytren's diathesis revisited: evaluation of prognostic indicators for risk of disease recurrence. J Hand Surg Am 2006;31(10):1626–1634.)

71% compared to a baseline risk of 23% in Dupuytren's patients without these risk factors (▶Fig. 7.2).

Risk of recurrent contracture may also be influenced by the previous treatment. The rate of contracture recurrence appears to be greatest in patients undergoing needle aponeurotomy, with 85% of patients developing recontracture at 4 years and 50% requiring repeat intervention. The risk of recontracture is less with collagenase clostridium histolyticum (CCH) injection and open fasciectomy, but these too have substantial recurrence rates (▶Table 7.2).

Finally, Dias et al evaluated patterns of recurrent contracture specifically at the PIP joint and identified four patterns of recontracture: (1) minimal recontracture, (2) mild early recontracture, (3) severe early recontracture, and (4) progressive recontracture. The authors reported that worsening of contractures of more than 6 degrees between 3 and 6 months after surgery was predictive of progressive recontracture at 5 years.

7.3 Recommended Solution to the Problem

The literature does not provide clear guidance for the management of recurrent Dupuytren's contracture, as no one treatment has demonstrated superiority over another.

Given this lack of consensus regarding the optimal treatment of recurrent Dupuytren's contracture, we recommend presenting all treatment options to the patient (observation, CCH injection, needle aponeurotomy, and open palmar fasciectomy) and allow their preferences of the risk–benefit profiles of the various interventions to determine the treatment.

We tend to favor either CCH injection or open partial fasciectomy. CCH injection is recommended in patients with contractures resulting principally from a discrete, palpable cord of pathologic fascia in the palm. The benefits of CCH injection include that it is minimally invasive with a shorter recovery time compared to open fasciectomy; however, it is associated with substantial edema, hemorrhage, and ecchymosis; carries a small risk of flexor tendon injury; and has a higher recurrence rate than open surgery. In patients with less well-defined cords who are likely to have multiple structures contributing to contracture recurrence, we recommend open fasciectomy

Table 7.2 Recurrence rates following fasciectomy, needle fasciotomy, and collagenase

	Fasciectomy[a,b,c]	Needle fasciotomy[a,b,c]	Collagenase injection[d,e]
Rate of overall recurrence (%)	21	85	35
MCPJ (%)	21	57	27
PIPJ (%)	21	70	56

Abbreviations: MCPJ, metacarpophalangeal joint; PIPJ, proximal interphalangeal.
Source: Data from Cheung K, Walley KC, Rozental TD. Management of complications of Dupuytren contracture. Hand Clin 2015;31(2):345–354.
[a]Patients undergoing fasciectomy and needle fasciotomy for recurrent disease required additional procedures in 32 and 50% within 4 years, respectively.
[b]Recurrence rates for fasciectomy and needle fasciotomy ranged from 0 to 39% and 50 to 58%, respectively.
[c]Recurrence was defined as an increase of total passive extension deficit of at least 30 degrees.
[d]Recurrence was defined as an increase in joint contracture of 20 degrees or greater in the presence of a palpable cord, or the need for the joint to have further medical or surgical intervention.
[e]Overall reoccurrence rate reported at 3 years following intervention.

with joint contracture release, and possible local skin flaps as this allows all pathologic structures to be addressed and has the lowest recurrence rate. The limitations of open fasciectomy include the higher risk of neurovascular injury, wound complications, infection, and longer duration of recovery.

In this patient with a palpable cord extending in the digit who has undergone multiple previous treatments, his contracture is likely the result of recurrent Dupuytren's tissue, scar formation, and contracted joint capsule. He elected to undergo open surgical fasciectomy and joint capsule release.

7.3.1 Recommended Solution to the Problem

- There is no consensus in the literature regarding optimal treatment.
- Patient preference regarding risks and benefits of the different treatment options is paramount.
- Ideal candidates for collagenase injection have a well-defined palpable cord in the palm.
- Patients with severe contractures but without a discrete cord may achieve better correction of the contracture with open fasciectomy, which allows all pathologic structures contributing to the joint contracture to be addressed.
- Occasionally full correction of the contracture cannot be achieved due to contracture neurovascular structures limiting full extension.

7.4 Technique

The patient is positioned supine on a well-padded operating table with the operative upper extremity positioned on a hand table. A nonsterile tourniquet is placed on the proximal portion of the operative limb after it has been padded with a cotton wrap. Preoperative antibiotics are administered within 1 hour of surgical start time. We recommend a Bier block or brachial plexus block and sedation for anesthesia. The hand is placed in a holding device (i.e., lead hand, Strickland hand table, or similar) to allow for retraction of the uninvolved digits. A Bruner zigzag incision is made over the volar aspect of the digit, beginning in the palm and extending to the DIP joint (▶Fig. 7.3). Full-thickness flaps of skin and subcutaneous tissue are elevated from the palmar fascia. These may be sutured to the adjacent skin with monofilament suture to retract the skin flaps.

Fig. 7.3 A Bruner zigzag incision is marked over the volar aspect of the digit, beginning in the palm and extending to the distal interphalangeal joint.

The radial and ulnar neurovascular bundles to the digits are identified and exposed throughout their course, so they may be protected throughout the case (▶Fig. 7.4a). The diseased fascial

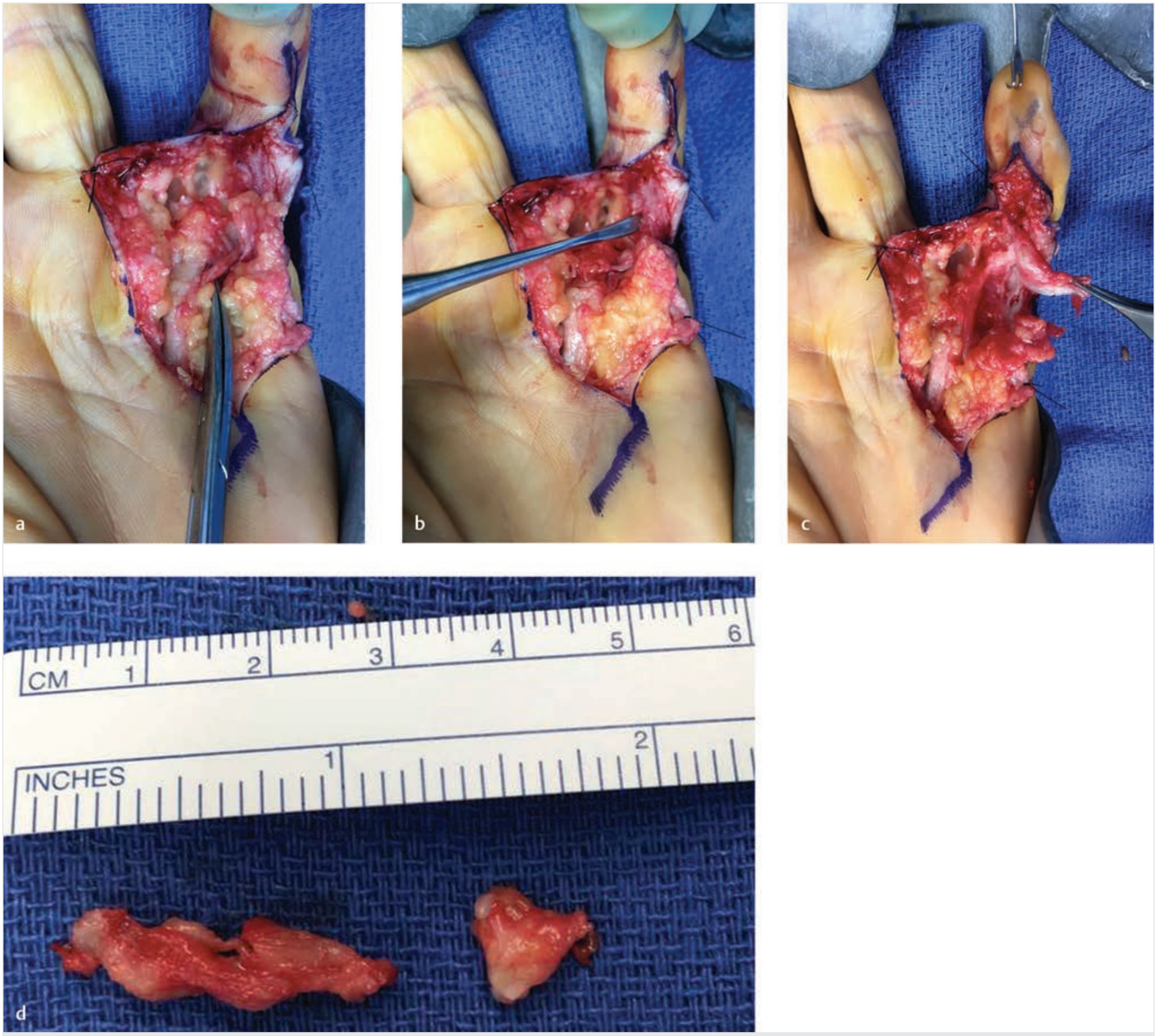

Fig. 7.4 **(a)** The radial and ulnar neurovascular bundles to the digits are identified and exposed. **(b)** The diseased fascial cords. **(c)** A lateral digital cord is dissected and excised. **(d)** A retrovascular cord was causing contracture of the distal interphalangeal joint; it was also excised.

cords are identified (▶Fig. 7.4b). This patient had a lateral digital cord that was dissected and excised (▶Fig. 7.4c). We also identified a retrovascular cord causing contracture of the DIP joint, which was also excised (▶Fig. 7.4d).

The range of motion of the digit was assessed and this patient was found to have residual PIP flexion contracture resulting from contracture of the joint capsule (▶Fig. 7.5a). The A3 pulley was opened to allow access to the PIP joint (▶Fig. 7.5b). The checkrein ligament and accessory collateral ligaments were identified and released. The passive range of motion of the PIP joint was reassessed. We were able to completely extend the PIP joint with minimal resistance (▶Fig. 7.5c).

The tourniquet is deflated and the perfusion of the digit is assessed; occasionally, the perfusion of the digit is compromised by tension on the shortened arteries, as is seen in this patient with release of a ring finger flexion contracture (▶Fig. 7.6). Decreasing the extension of the digit is often sufficient to restore perfusion. However, if it is not, we recommend evaluation of the digital artery under loupe visualization or operating microscope to ensure the artery has not been injured. After perfusion has been confirmed, meticulous hemostasis is obtained to prevent the development of a hematoma, which limits early motion of the hand and promotes scar tissue formation.

The skin flaps are then approximated and closed with nylon suture. If the skin flaps are tight, VY advancement flaps are

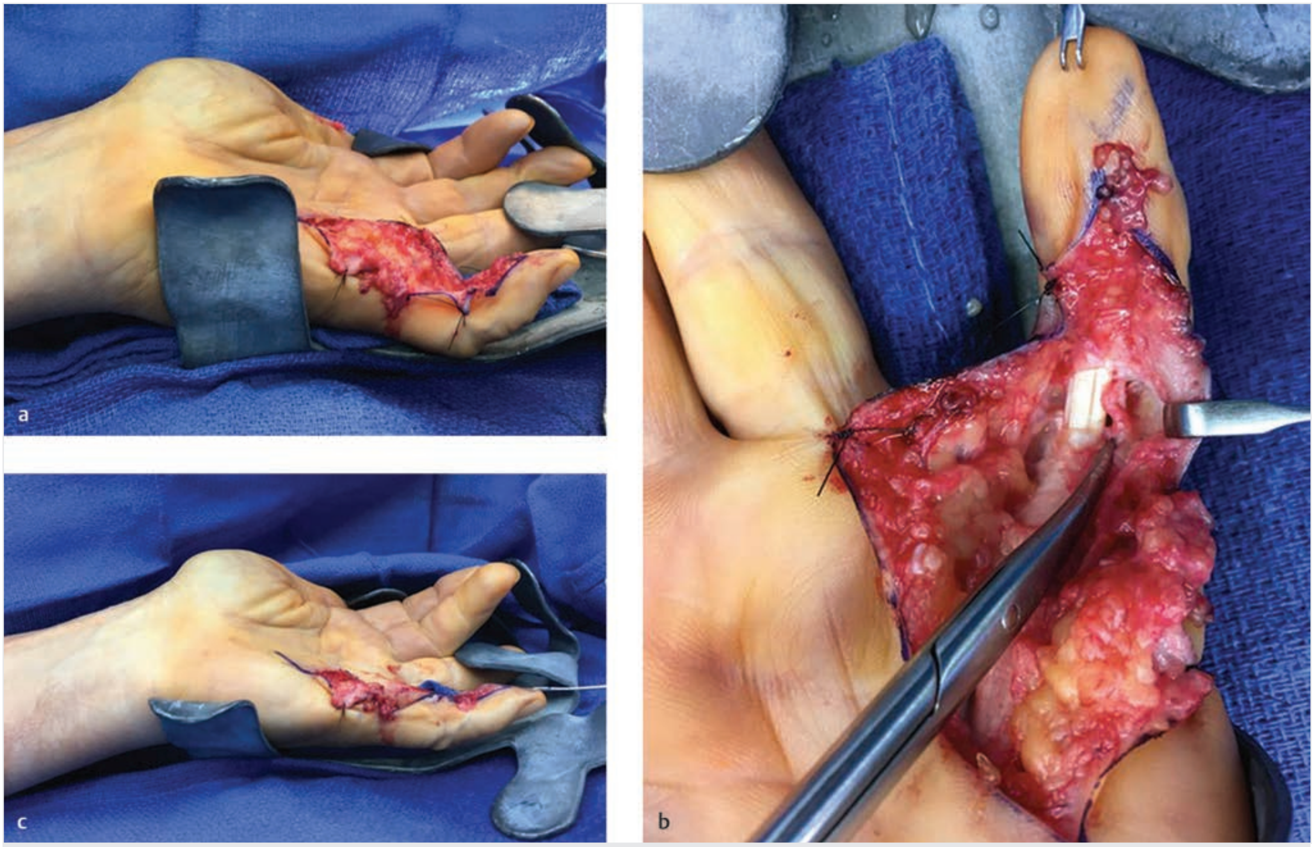

Fig. 7.5 **(a)** The patient had residual proximal interphalangeal (PIP) flexion contraction resulting from contracture of the joint capsule. **(b)** Opening of the A3 pulley to allow access to the PIP joint. **(c)** Extension of the PIP joint.

Fig. 7.6 Compromise of digit perfusion.

helpful, as were required in the case. The wound is dressed with nonadherent gauze dressing, fluff, and cotton wrap. A well-padded short-arm volar resting plaster splint is applied from the forearm to the affected and adjacent finger with the MCP joints in 20 to 30 degrees of flexion and the PIP and DIP joints in full extension, sometimes referred to as bayonet positioning.

Postoperatively, we recommend starting hand therapy within 2 to 3 days of surgery (▶Fig. 7.7a,b). At that time, the plaster splint is removed and replaced with a removable Thermoplastic splint, which the patient is instructed to wear at all times, unless performing hygiene or range of motion exercises (▶Fig. 7.7c,d). The patient is educated in wound care, edema control, active and passive range of motion exercises. The sutures are removed at 2 weeks and at this point, the splint is worn at nighttime only.

7.5 Postoperative Photographs and Critical Evaluation of Results

This patient had near full correction of his PIP joint contracture (90-degree contracture preoperatively improved to degrees postoperatively) and with less improvement of the DIP contracture (▶Fig. 7.8). He had no change in sensation in his small finger compared to his preoperative examination. He reports being very pleased with the outcome of his surgery, and already finds activities of daily living and recreational activities easier.

This patient's outcome is consistent with what is described in the literature. Patients often experience substantial improvement in range of motion following treatment and report improvement in hand function, regardless of treatment type. Nevertheless, patients rarely achieve full correction of the deformity, and many have persistent, albeit milder, functional limitations. Not uncommonly, patients experience sensory deficits following contracture release, with approximately one-third of patients reporting diminished sensation and one-third of patients reporting absence

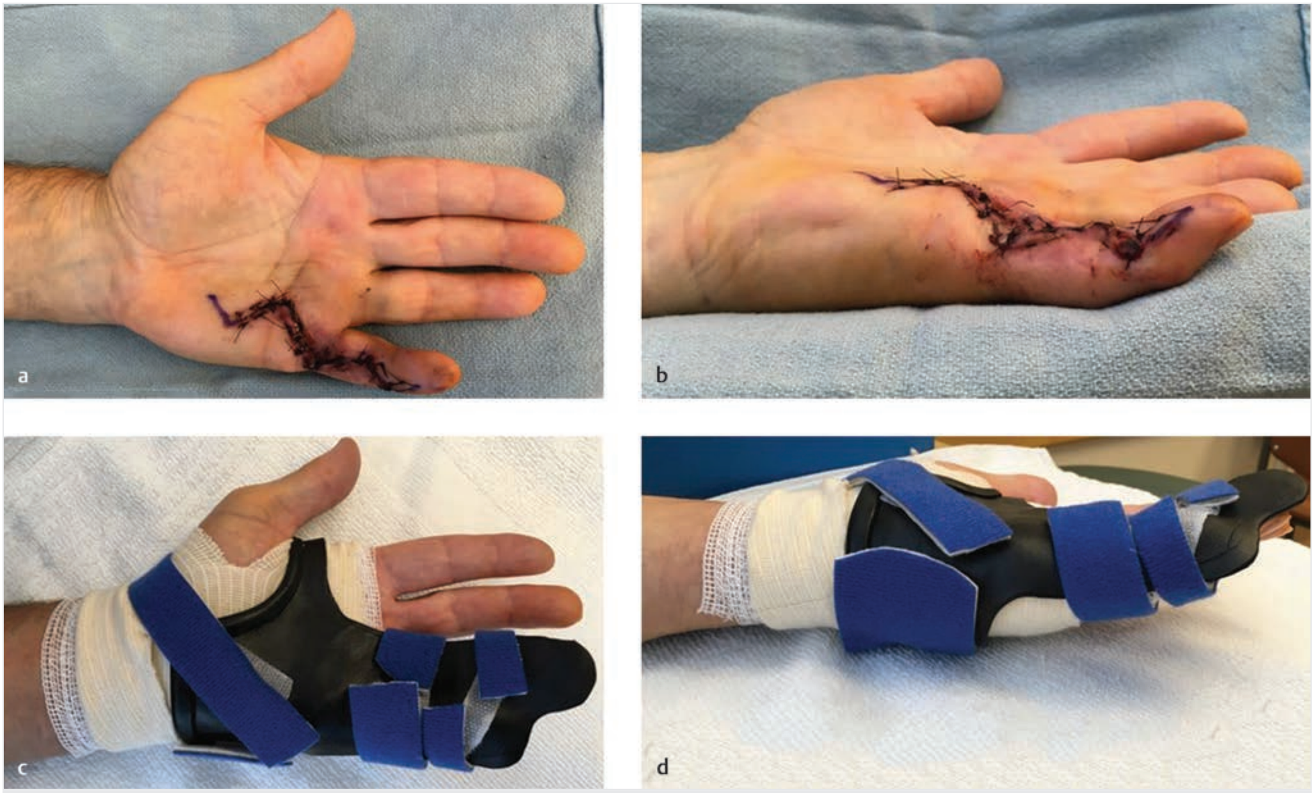

Fig. 7.7 (a, b) Result 2 days postoperative. **(c, d)** After the plaster splint is removed, a Thermoplastic splint is used.

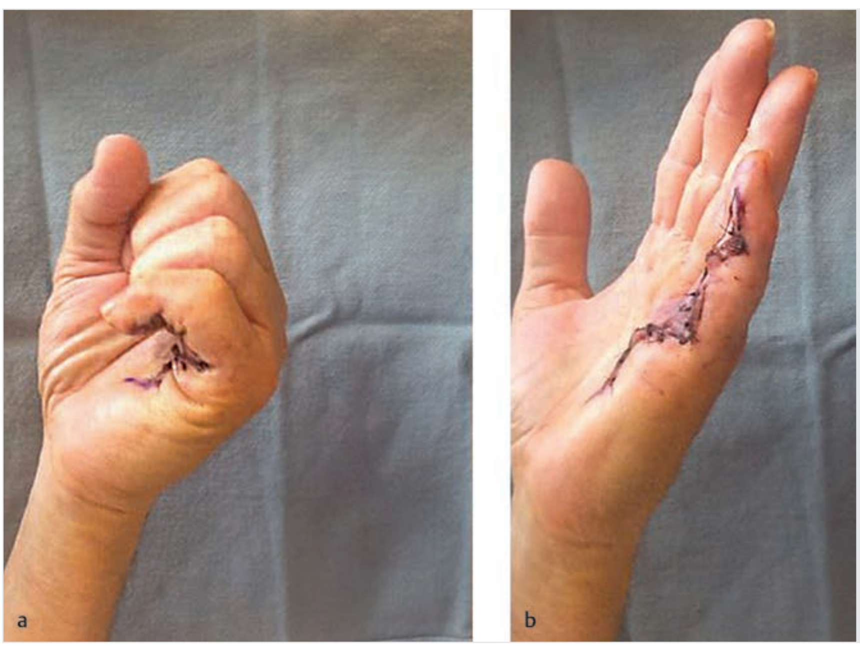

Fig. 7.8 (a, b) Result 3 weeks postoperative.

of protective sensation. Despite these limitations, patient satisfaction for revision contracture release is high. Some authors have hypothesized that the high degree of patient satisfaction following treatment of recurrent contractures is due to the fact that the patients are well educated regarding their disease, have appropriate expectations, and are appreciative of the improvements they have gained as well as avoiding of amputation.

7.6 Teaching Points

- Contracture recurrence is common following all treatment modalities for Dupuytren's contractures, although the risk appears to be higher with needle aponeurotomy and in patients with features of Dupuytren's diathesis.
- There is no evidence to support the superiority of one treatment option over another.

- Patient education regarding the high risk of recurrence as well as the risks and benefits of the various treatment options is paramount to establish patient expectations.
- Surgery for recurrent Dupuytren's contractures following previous intervention may be more technically challenging secondary to abundant scar tissue and distorted tissue planes. Identifying and protecting vital structures, including the neurovascular bundle and underlying flexor tendons, is imperative.

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8 Complications of Dupuytren's Contracture Treatment

Nash H. Naam and F. Thomas D. Kaplan

8.1 Patient History Leading to the Specific Problem

A 62-year-old steelworker presented for treatment of his right small finger contracture. The proximal interphalangeal (PIP) joint was contracted to 70 degrees, associated with an abductor digiti minimi cord. He had previously had a fasciectomy in his left ring finger and first web space, which was complicated by a flare reaction. As a result, he struggled to regain flexion of all digits and was unable to return to work for 6 months. After discussion of treatment options, he chose clostridial collagenase histolyticum (CCH) treatment for his right small finger contracture.

The injection was performed per manufacturer's guidelines, injecting 0.58 mg of clostridial collagenase into three contiguous areas of the cord. A manipulation was performed the following day, without anesthesia, resulting in cord rupture and near-full passive extension. The patient was fitted for an extension splint to wear at nighttime, and instructed in a home range of motion (ROM) exercise program. Eight days following the injection, the patient had returned to his job. While gripping a pallet jack to move a heavy pallet, he felt a pop in the treated finger.

8.2 Anatomic Description of the Patient's Current Status

Physical examination demonstrated typical sequela of collagenase injection including mild edema and mild ecchymosis (▶Fig. 8.1). Sensation was intact; however, the patient had no active flexion of the distal interphalangeal (DIP) joint, and decreased active flexion of the PIP joint. Diagnosis of rupture of the flexor digitorum profundus (FDP) tendon, with an intact flexor digitorum superficialis (FDS), was made and confirmed by magnetic resonance imaging.

Fig. 8.1 Initial examination.

8.3 Recommended Solution to the Problem

Two-stage reconstruction is the recommended option following tendon rupture, particularly when both tendons fail. It requires two surgeries, separated by 4 to 6 months, and potentially a third tenolysis procedure. This is a significant time and financial commitment, however, and is best suited for patients able to be compliant and diligent with their rehabilitation.

Acceptance of an FDS-only finger can be the best choice for many patients with isolated FDP rupture, particularly those with a preexisting stiff DIP joint. Wanting to avoid surgery, our patient initially choose observation and therapy to regain active PIP motion. Six weeks later, the patient continued to have limited PIP flexion as well as pain in the palm, and was indicated for excision of the tendon stump and FDS tenolysis, still refusing tendon reconstruction and preferring the more rapid recovery of an FDS-only finger.

The risk of tendon rupture as a result of collagenase injection, and how to mitigate against it, should be thought about during every injection. There are likely multiple factors involved in a patients' risk of tendon rupture. Location plays a key role, with all three ruptures occurring in the clinical studies following injection for PIP contracture in the small finger. Of the 26 ruptures reported in the 3 years following Food and Drug Administration (FDA) approval, 13 involved the small finger (5 metacarpophalangeal [MCP] and 8 PIP), 4 involved the ring finger MCP, and 9 were unidentified. As the cord moves distally in the finger, it becomes closer to the flexor sheath. Additionally, there is less space between the skin and the flexor sheath at the PIP joint (4 mm) compared to the MCP joint (7 mm). Extreme care should be taken while performing CCH injections. The syringe must be stabilized during the injection to prevent the needle from moving outside of the cord. During injection, a significant amount of resistance should be felt. If resistance is lost, extravasation outside of the cord is happening, and the needle should be moved to a new location in the cord. For digital cords, injections should be placed proximally whenever possible, utilizing the "safe zone" of no more than 4 mm distal to the proximal digital flexion crease. The cord can be injected so that the needle points away from the flexor sheath using a more horizontal injection aiming laterally. If the cord is particularly thin, surgeons should consider using less than the full 0.58-mg dose, particularly when injecting distal to the proximal digital flexion crease. Finally, we counsel patients to avoid forceful gripping and lifting for 3 to 4 weeks following injection, to allow for collagen remodeling.

8.3.1 Recommended Solution to the Problem

- Tendon reconstruction:
  - Primary repair not advised due to zone of injury and tendon quality.
  - Two-stage reconstruction:
    - Placement of tendon rod and FDS excision (if present).
    - Removal of rod and tendon graft after wound quiescence.
- DIP joint fusion.
- Acceptance of FDS-only finger.

8.4 Technique

Intraoperatively, the ruptured stump of the FDP tendon was found in the mid-palm (▶Fig. 8.2a,b). The FDS tendon was adhered in scar, and an area of partial thinning seen (▶Fig. 8.2c).

The stump of the FDP tendon was freed of scar tissue, and the lumbrical origin released. The tendon was excised. Tenolysis of the FDS was performed proximal to the A1 and A2 pulleys and between the A2 and A4 pulleys, until tension on the proximal FDS tendon resulted in full PIP flexion. The patient started immediate postoperative therapy for edema control and ROM exercises.

8.5 Postoperative Photographs and Critical Evaluation of Results

The patient regained full active MCP joint motion and PIP joint motion of 45 to 80 degrees. He was able to return to his manual labor job. Follow-up evaluation 3 years following treatment, the patient had lost extension at the PIP joint with ROM of 70 to 92 degrees (▶Fig. 8.3). There was no palpable Dupuytren's tissue. The recurrent flexion contracture was therefore felt to be primarily due to arthrofibrosis and extensor mechanism attenuation, two factors that lead to recurrent and residual PIP contractures in patients with long-standing severe PIP contractures regardless of primary treatment method.

CCH is a mixture of two purified bacterial enzymes that act to lyse the highly stable triple-helical type I and III collagens

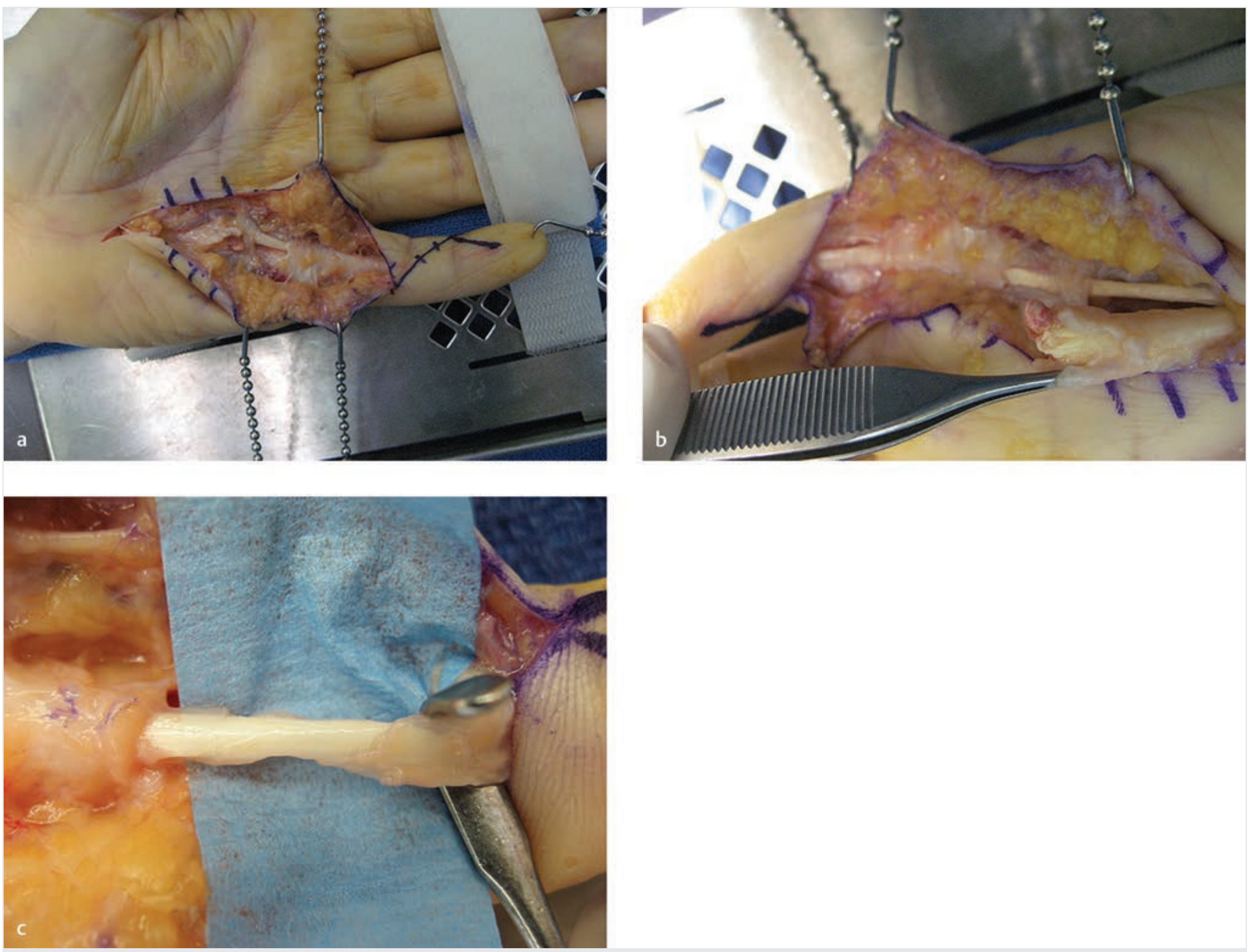

Fig. 8.2 (a, b) Ruptured stump of the flexor digitorum profundus tendon. **(c)** Area of partial thinning of the flexor digitorum superficialis tendon.

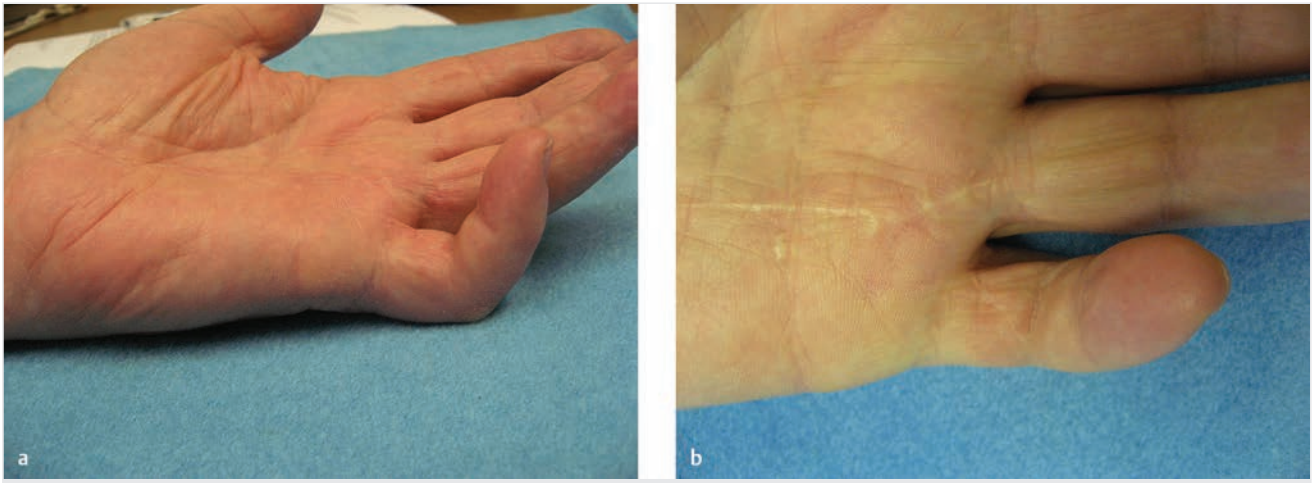

Fig. 8.3 (a, b) Follow-up examination 3 years postoperative.

comprising Dupuytren's cords. The synergistic activity of these two enzymes results in rapid degradation of fibrillar collagen tissue, weakening the cord, and allowing for subsequent elongation and rupture. The by-product of this action are small collagen fragments that trigger three characteristic physiologic responses: vascular leakage, neutrophil chemotaxis, and wound-healing response.

Complications after treatment with CCH can be broken down into side effects related to the formation of collagen breakdown products, those caused by damage to adjacent collagen-containing structures, allergic reactions to the foreign bacterial proteins, and those related to the manipulation procedure. Most patients treated with CCH demonstrate typical reactions to the collagen fragments including swelling, ecchymosis, and pain/tenderness in the treated hand. Less commonly, patients will develop itching and/or an ecchymotic rash in the medial forearm and arm (▶Fig. 8.4), or lymph node swelling and tenderness related to the elimination of the fragments. These side effects are typically short-lived, with resolution occurring within 1 to 2 weeks.

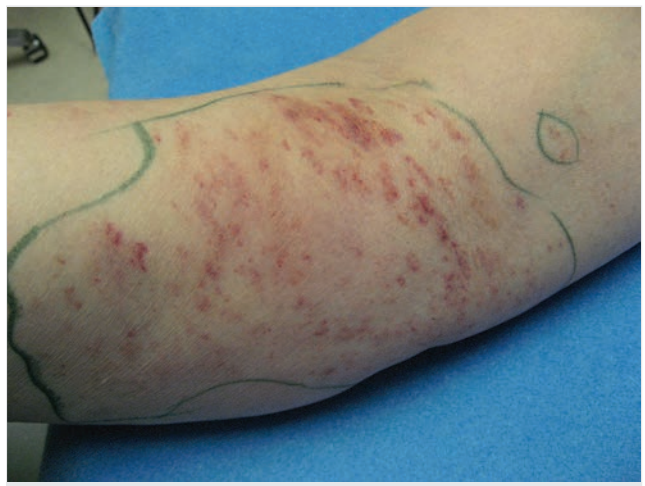

Fig. 8.4 Ecchymotic rash as a result of treatment with clostridial collagenase histolyticum.

Immunologic reactions to CCH are extremely rare. Although most subjects (>85.7%) in the preclinical trials of collagenase formed antibodies to one or both of the enzyme subtypes 30 days after their first injection, and 100% formed antibodies after their third or fourth injection, there has been only one report of an anaphylactic reaction to CCH. Though pruritus occurs in patients with no prior exposure to CCH, the incidence is higher in those patients with prior exposure, indicating a possible mild immunological response.

Injury to the finger can occur during the manipulation procedure. At this time, there have been no reports of nerve or arterial stretch injury, joint dislocation, or fracture. Skin lacerations, however, are not uncommon (▶Fig. 8.5a, ▶Video 8.1). When one injection is given, the rate of skin tears was up to 11% in the clinical trials, and 22% when two concurrent injections are given. In my experience in over 500 patients, skin tears are more likely to happen in patients with more severe contracture, those with more significant swelling, and those who form blood blisters (▶Fig. 8.5b), particularly when the finger is anesthetized prior to manipulation.

Injury to adjacent structures are the most serious complications of CCH use. Like Dupuytren's cords, tendons and ligaments are also comprised of type I collagens. They can be weakened during treatment for Dupuytren's disease if some of the injected drug extravasates outside of the treated cord, or the medicine is inadvertently injected into them. The risk of tendon and ligament injury is fortunately extremely low. In the clinical trials, out of 1,082 patients receiving 2,630 injections, there were 3 tendon ruptures and 1 pulley rupture (rate: 1.5/1,000 injections). Postmarket surveillance data reporting on the first 3 years of clinical use found 26 tendon ruptures from 49,078 injections (rate: 0.5/1,000 injections), and 1 pulley injury (rate: 0.02/1,000 injections). Surgical options for tendon rupture include tendon repair, tendon reconstruction, or salvage procedures aimed to improve the function of a tendon-deficient finger (tenolysis, DIP joint fusion). In a patient with rupture

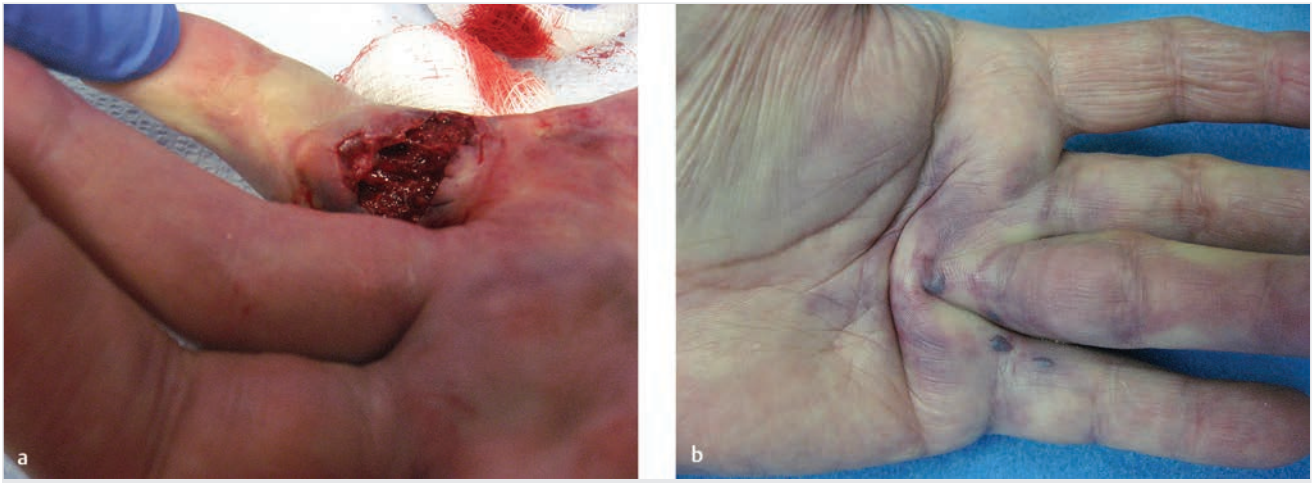

Fig. 8.5 Injuries to the finger during manipulation. (a) Skin laceration. (b) Blood blisters.

of both FDS and FDP tendons after CCH injection, Povlsen and Singh reported "disappointing" active ROM following direct tendon repair. Tendon rupture resulting from CCH damage leads to a zone of injury that likely compromises successful direct repair. Reporting on another case of FDS and FDP rupture after CCH treatment, Zhang et al chose to perform a two-stage tendon reconstruction due to "loss of tendon substance and injury to the tendon sheath." The patient regained functional motion of 0 to 110 degrees of the MCP and 25 to 80 degrees of the PIP joints at final follow-up 2.5 years after surgery (DIP motion was not reported).

8.6 Teaching Points

- Common side effects of CCH:
  - Edema.
  - Ecchymosis.
  - Injection site pain/tenderness.
  - Pruritis.
  - Lymph node tenderness/swelling.
- Complications of manipulation:
  - Skin tear.
- Major complications:
  - Flexor tendon rupture.
  - Pulley rupture.
- Surgeons must be careful during the injection procedure to ensure proper intralesional injection:
  - Avoid injection more than 4 mm distal to the proximal digital flexion crease.
  - Direct injection away from the flexor sheath.
  - Avoid extravasation—if resistance during injection is lost, stop injection and move to a new location in the cord.
- Educate patients to avoid forceful grasping for 3 to 4 weeks postinjection.
- If rupture of both tendons occurs, two-stage reconstruction is recommended.
- If rupture of only FDP occurs, an FDS-only finger may be acceptable depending on patient preference.

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Part IV

Problems with Flexor Tendon Repairs

9 Flexor Tendon Rupture *38*

10 Adhesions of the Flexor Tendon *42*

11 Bowstringing of the Flexor Tendon *45*

12 Ruptured Flexor Pollicis Longus Tendon *50*

IV

9 Flexor Tendon Rupture

Jin Bo Tang

9.1 Patient History Leading to the Specific Problem

A 36-year-old man was seen in our unit with inability of active flexion of the distal interphalangeal (DIP) and proximal interphalangeal (PIP) joints of the left index finger, 3 weeks after primary flexor tendon repair of the flexor digitorum profundus (FDP) tendon in another hospital (▶Fig. 9.1).

His FDP tendon had been repaired with the two-strand modified Kessler method and a simple running peripheral suture following a cut in the middle part of the proximal phalanx. He started active motion at the beginning of week 3 after immobilization and passive finger motion in the first 2 weeks after surgery. He noted he could not actively flex the DIP or PIP joints of the repaired finger and was diagnosed as having a rupture of the repaired FDP tendon of the left index finger.

9.2 Anatomic Description of the Patient's Current Status

The site of this patient's initial flexor tendon laceration was in anatomic zone 2 of the digital flexor tendon; the exact location is zone 2B (▶Fig. 9.2a). In this area, the tendon has to glide into zone 2C (i.e., the A2 pulley area) to flex the finger. The surgical repair of the tendon in zone 2B is particularly prone to disruption if the repair is weak, for example, a two-strand Kessler repair (as was the case in this patient), or if the repair site has no tension (which tends to allow the repair site to gap during active finger motion, easily becoming entrapped at the edge of the A2 pulley). The A2 pulley, which is rigid and narrow, 1.5- to 1.8-cm long, is located over the proximal two-thirds of the proximal phalanx. This pulley hinders the gliding of the repaired but still edematous FDP tendon after surgery and significantly increases resistance to tendon gliding. The area of the A2 pulley is the most anatomically complex in zone 2. The narrowest parts of the A2 pulley are its distal and middle portions (▶Fig. 9.2b).

During this patient's initial primary repair by relatively inexperienced surgeons, the A2 pulley was not vented. Subsequently, the repaired FDP tendon disrupted after commencement of active motion of the repaired finger.

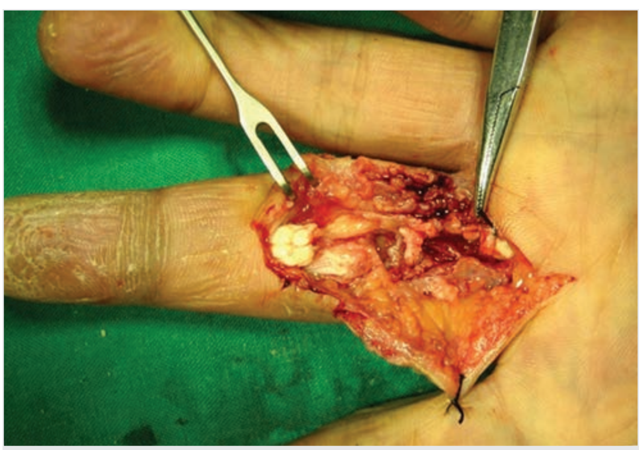

Fig. 9.1 The left index finger exposed to confirm disruption of the repair after the patient was found unable to actively flex the finger 3 weeks after initial primary repair.

9.3 Recommended Solution to the Problem

Complications of rupture of the primarily repaired tendon can be prevented by using strong repair techniques, such as a multistrand core suture, and venting of a part of the A2 pulley or the entire A4 pulley depending on the location of the tendon repair. The author prefers a six-strand core suture plus a simple running peripheral suture, though others generally recommend a core suture of four strands or more. The addition of two strands to a four-strand core repair may add only 5 minutes to the procedure, but ensures a much greater safety margin for early active digital motion. The author always uses a six-strand repair with 4–0 (or sometimes 3–0) suture, using either an M-Tang core repair (▶Fig. 9.3a) or a six-strand (three groups) asymmetric Kessler repair (▶Fig. 9.3b). The author uses the six-strand repair methods for re-repair of ruptures of primarily repaired FDP tendons.

As for the decision between re-repair of the disrupted FDP tendon and secondary tendon grafting, the author re-repairs a rupture if it occurs within 4 to 5 weeks after the initial repair. Within that period, it is possible to redo a primary repair of the disrupted tendon after proper trimming of the softened or ragged tendon ends. In the author's experience, such a re-repair is practical and a good solution. Ruptures 5 weeks after initial tendon repair are rare but should be treated secondarily with tendon grafting.

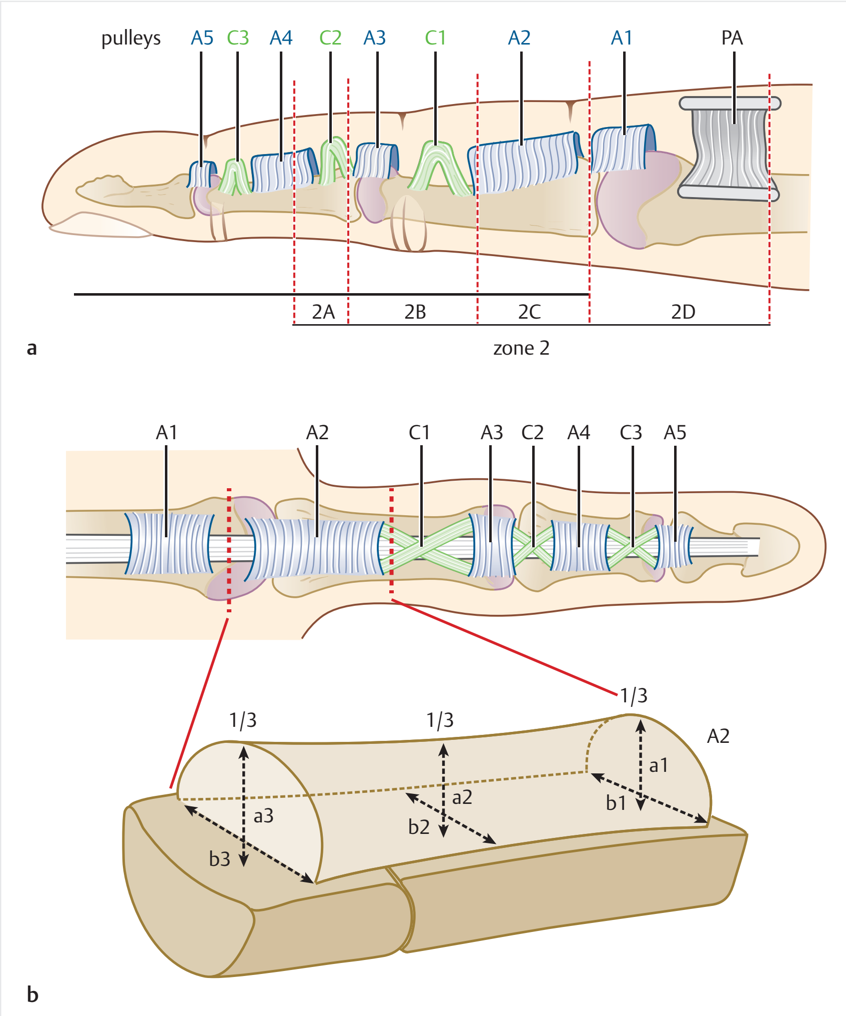

Fig. 9.2 Flexor tendons and pulleys in the fingers. **(a)** Zone and subdivisions of the zone 2 of the finger. **(b)** Anatomy of the A2 and A4 pulleys with amplified view of anatomy of the A2 pulley. The narrow parts of the A2 pulley are from a1b1 to a2b2, which are at the distal and middle portions of the A2 pulley.

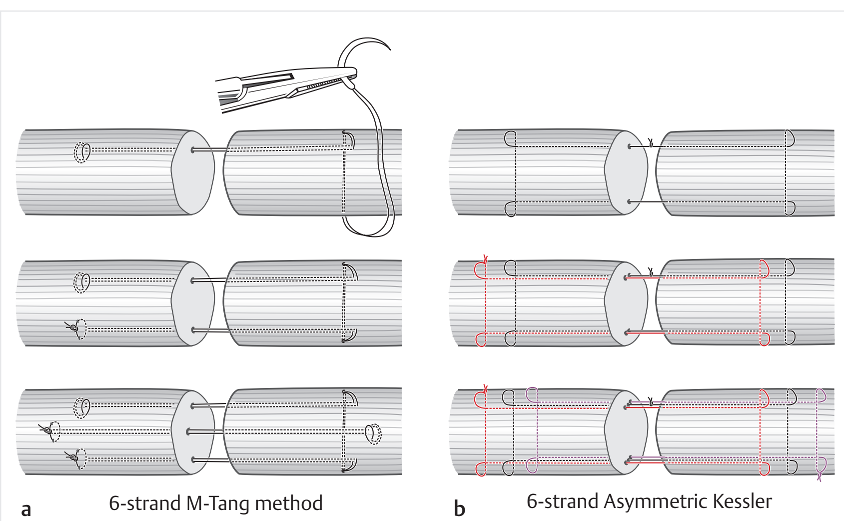

Fig. 9.3 Two repair methods that the author often uses. **(a)** A six-strand M-Tang method. **(b)** A six-strand asymmetric Kessler method.

9.3.1 Recommended Solution to the Problem

For the above patient, the author decided to perform an end-to-end FDP tendon repair soon after he was admitted, that is, 3 weeks after the initial primary repair.

9.4 Technique

The surgery was done under branchial plexus anesthesia and with tourniquet control. A Bruner incision was used to extend the original site of injury and previous surgical incision. The disrupted FDP tendon was found buried within a dense scar (▶Fig. 9.4), and the A2 pulley was collapsed, with a portion totally embedded within the adhesions. The proximal end of the tendon was retracted proximally to the A2 pulley.

The ragged ends of the FDP tendon were trimmed, with a total of 1 cm of tendon substance removed (▶Fig. 9.5). Then 70% of the A2 pulley was resected, with only a rim of the A2 pulley retained. The proximal end of the FDP tendon was advanced underneath the A2 pulley to approximate the distal end of the disrupted tendon.

The finger was then held in semiflexion to allow approximation of the tendon ends under tension, using a 25-G needle to temporarily transfix the proximal tendon end at the proximal part of the index finger. The FDP tendon was then repaired with an M-Tang core suture using two looped sutures, maintaining a core suture purchase of 1 cm in each tendon and some tension in the suture strands to avoid a loose repair. Then, a 6–0 nylon was used for a simple running peripheral suture.

The temporary needle fixation was then released from the proximal tendon. The finger was passively extended and flexed to confirm the absence of gapping at the repair site and smooth tendon gliding under the A2 pulley. The skin was then closed.

9.4.1 Steps for the Procedure

1. Ends of the FDP tendon were trimmed.
2. The scarred part of the A2 pulley was resected.
3. The proximal end of the FDP tendon was advanced under the already shortened A2 pulley.
4. The finger was held in semiflexion.
5. The FDP tendon was repaired.
6. Temporary needle fixation was released from the proximal tendon.
7. The finger was extended and flexed to confirm smooth gliding of the tendon without gapping.

9.5 Postoperative Photographs and Critical Evaluation of Results

The wrist was held in mild flexion and the metacarpophalangeal joint flexed for 40 degrees in a dorsal splint extending to the middle of the forearm. Early active digital flexion to two-thirds of the total range of motion was initiated 5 days after the surgery, progressing to a full range of active digital flexion 4 weeks after surgery. The patient's splint was discarded at the end of week 6 after surgery.

Follow-up 6 months after surgery showed excellent outcomes with full flexion and extension of the repaired finger (▶Fig. 9.6). There is no tendon bowstringing of the left index finger.

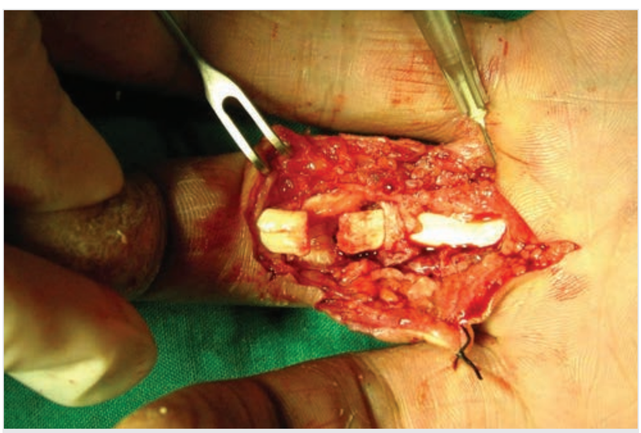

Fig. 9.4 Tendons in dense scar and disruption.

Fig. 9.5 After placement of the M-Tang core suture and preservation of a part of the intact A2 pulley. Most of the A2 pulley was embedded in the scar and had to be excised. The tendon was repaired with moderated tension.

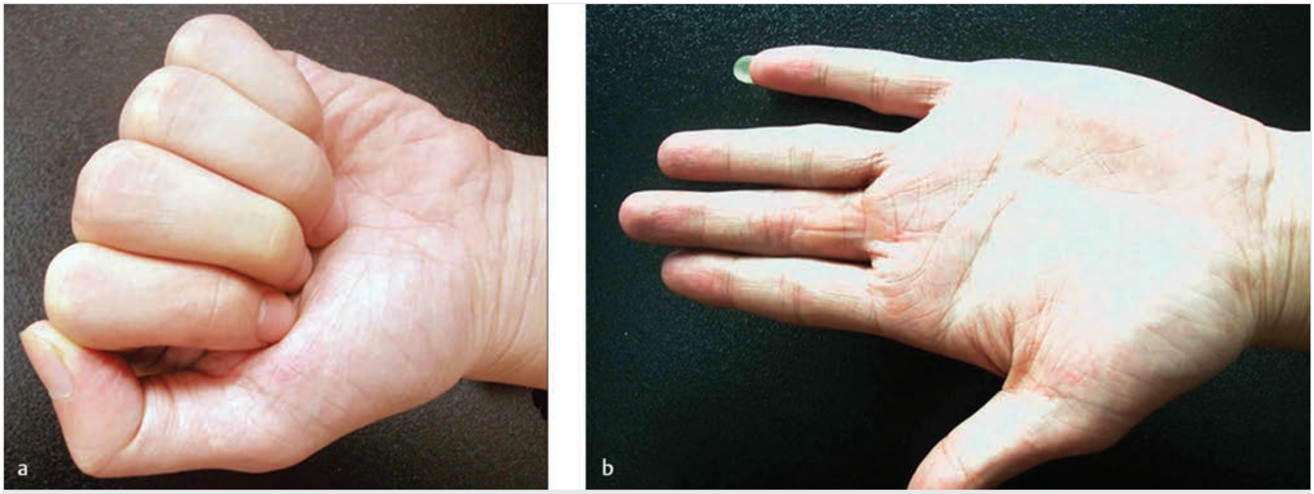

Fig. 9.6 Postoperative recovery 6 months after re-repair of the flexor digitorum profundus tendon with **(a)** full active flexion and **(b)** full active extension.

9.6 Teaching Points

- If the disruption is within 4 to 5 weeks after initial repair, perform end-to-end direct repair soon after finding rupture of the primarily repaired FDP tendon.
- The repair method can be the same as that proposed for primary tendon repair, but the author strongly recommends a stronger repair method, because the tension of the reconnected tendon is much greater after trimming the ragged tendon ends. At least a six-strand core suture repair is recommended.
- The tendon ends should be trimmed to remove the ragged edges. Usually, a 0.5-cm tendon substance should be removed from either end.
- The A2 pulley should be partially resected.
- All adhesions should be excised.
- Tension should be added to the tendon repair site, and a slightly bulky repair is fine.
- Do not attempt to repair the FDS tendon in zone 2C.
- Make sure that the repaired tendon glides smoothly under the A2 pulley and that the repair site does not gap when the surgeon passively extends the operated finger fully and then passively flexes the operated finger (called “digital extension–flexion test”) before closing the skin.
- With local anesthesia and no tourniquet, the operator can ask the patient to actively extend and flex the operated finger in order to check the gap resistance and gliding of the tendon. That is the benefit of this “wide-awake” approach to primary tendon repair.
- Encourage only partial active motion of the repaired finger in the first 3 to 4 weeks after surgery. Avoid active motion to the final one-third of the finger flexion arc, because this range creates much greater gliding resistance, making the tendon repair quite vulnerable.
- After surgery, put the wrist in neutral or slight flexion with a short forearm splint or slab for the first few weeks. Do not place the wrist in marked or extreme flexion when splinting.

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10 Adhesions of the Flexor Tendon

Donald H. Lalonde

10.1 Patient History Leading to the Specific Problem

A woman in her late 60s presents 63 years after laceration and repair of the flexor tendons of the long and ring fingers in the palm. She has full extension but only about half of normal flexion of the long and ring fingers of her right hand. She only had about one-quarter normal passive extension of the affected fingers. There are scars in the palm where the tendons are stuck in dense adhesions (▶Fig. 10.1).

Adhesions are best avoided in flexor tendon repair by performing the repair wide awake with lidocaine and epinephrine. In the absence of a tourniquet and sedation, patients can comfortably test the flexor tendon repairs to make sure they are not gapping and that they fit through the pulleys. Early protected movement with true active movement would have also prevented this if she had not been a child at the time of injury.

10.2 Anatomic Description of the Patient's Current Status

She has stiffness of the joints that limit passive flexion. She had a soft-end feel in her stiff metacarpophalangeal (MCP), proximal interphalangeal (PIP), and distal interphalangeal (DIP) joints. This means that the joints have a little spring when passively flexed, as opposed to a rock hard–end feel of a bony block that would not respond to therapy. She should not have tenolysis surgery until she has regained all passive motion of the joints with hand therapy.

10.3 Recommended Solution to the Problem

She was a cooperative patient willing to get the movement back. She was therefore sent to a hand therapist who was able to help the patient get the full passive movement back in 6 months. She was now ready for wide-awake tenolysis surgery (▶Fig. 10.2).

10.3.1 Recommended Solution to the Problem

- Get passive movement of all joints before surgery.
- Perform the tenolysis wide awake, so the patient can help you rupture the adhesions.

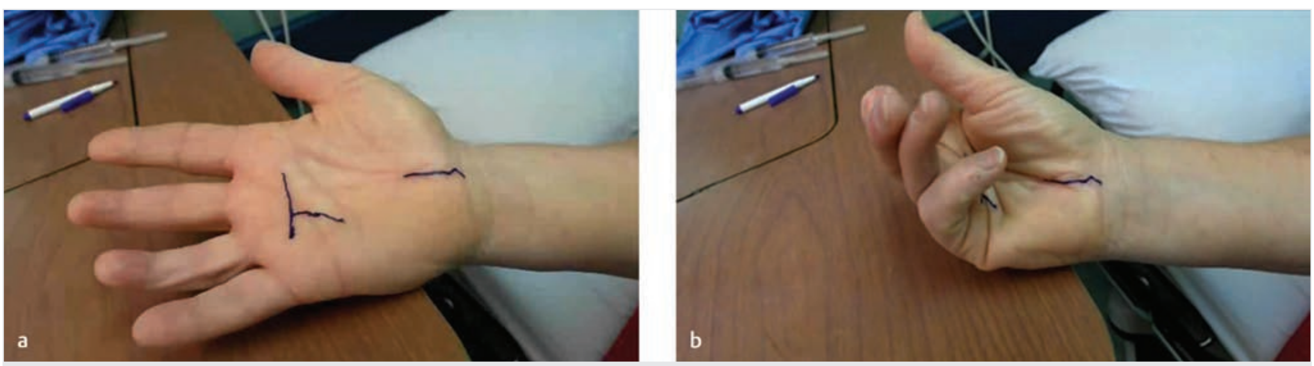

Fig. 10.1 **(a)** Preexisting scars are marked. **(b)** Full extent of the long and ring fingers' active flexion before surgery.

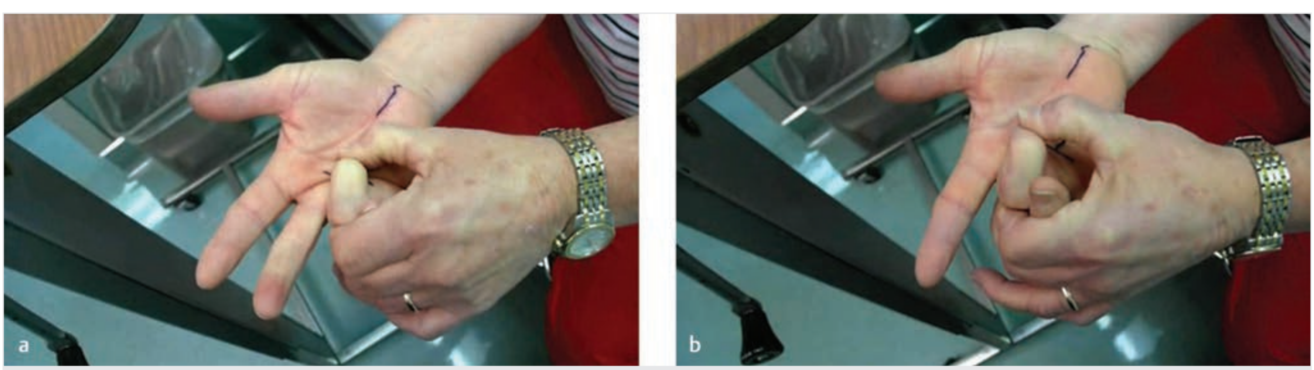

Fig. 10.2 Full passive range of motion of **(a)** the ring finger and **(b)** the long finger obtained with hand therapy before surgery.

- Perform the tenolysis wide awake, so the patient can remember the range of motion she got in the operating room. She will be motivated by that memory to get through postoperative therapy and get that intraoperative range of motion back.
- Immobilize and elevate the hand for 3 to 5 days after the surgery. Avoid immediate movement because it encourages bleeding and clots inside the wound. Blood clots need to be mopped up with vascular infiltration and scar formation, which is not good for movement. You can delay moving for 3 to 5 days because collagen formation does not even start until day 3. Before moving, let the bleeding stop, let the swelling come down, and let the work and friction of movement decrease with immobilization and elevation. The author encourages all patients to move only when they are off all painkillers.
- When you start moving at 3 to 5 days, remember that the tendon repair is very weakened. You have removed most of the collagen around the tendon, so there is very little strength left. You have also removed most of the blood supply by denuding the scar, and so your tendon is now quite avascular. If you force it, it will rupture. Instead, treat it exactly as you would a freshly repaired flexor tendon with gentle protected early true active movement. We allow up to half a fist of true active movement for the first couple of weeks. The patients can move it, but they cannot use it. They do not need a full fist in the beginning. They just do not want it to get stuck.

10.4 Technique

Before the patient comes into the operating room, inject 10 mL of buffered lidocaine with epinephrine in the palm in the most proximal place that dissection will take place (▶Fig. 10.3, ▶Video 10.1). Do not move the needle for this initial injection. The local anesthesia will find its way. Use a 27-G needle and inject very slowly to minimize pain. After the initial 10 mL, reinsert the needle distally in an area clearly white with epinephrine vasoconstriction to avoid painful needle reinsertion.

Continue tumescing until the palm is visibly swollen with local anesthetic solution, and then inject 2 mL per phalanx in the subcutaneous fat between both digital nerves. Remember that preexisting scars and creases form a natural barrier to local anesthetic solution.

Get into the sheath through transverse sheathotomies. Preserve as much pulley as possible. Use a freer elevator on the palmar and lateral sides of the tendon to separate it from the A2 pulley (▶Fig. 10.4a, ▶Video 10.2). Use tenotomy scissors on the dorsal side of the tendon to sharply dissect it from scar holding it to the bone. Dissect a little. Then, encourage the patient to rupture adhesions with active movement a little. Repeat dissection and active flexion until the patient ruptures the final adhesions. Let the patient see her own final flexion ability so she knows what to aim for with therapy in the rehabilitation (▶Fig. 10.4b).

At the end of tenolysis, tendons are greatly weakened as they are denuded of adjacent collagen and greatly devascularized with removal of scar tissue.

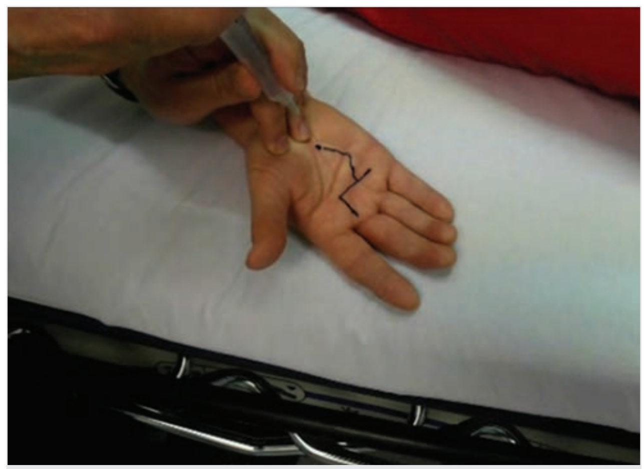

Fig. 10.3 Proposed incisions and location of initial 10 mL of local anesthetic injection. After letting the initial 10 mL work for 30 minutes, an additional 10 mL is injected in the distal palm and then 4 mL in each finger (2 mL in subcutaneous fat of the center of each ring and long proximal and middle phalanxes).

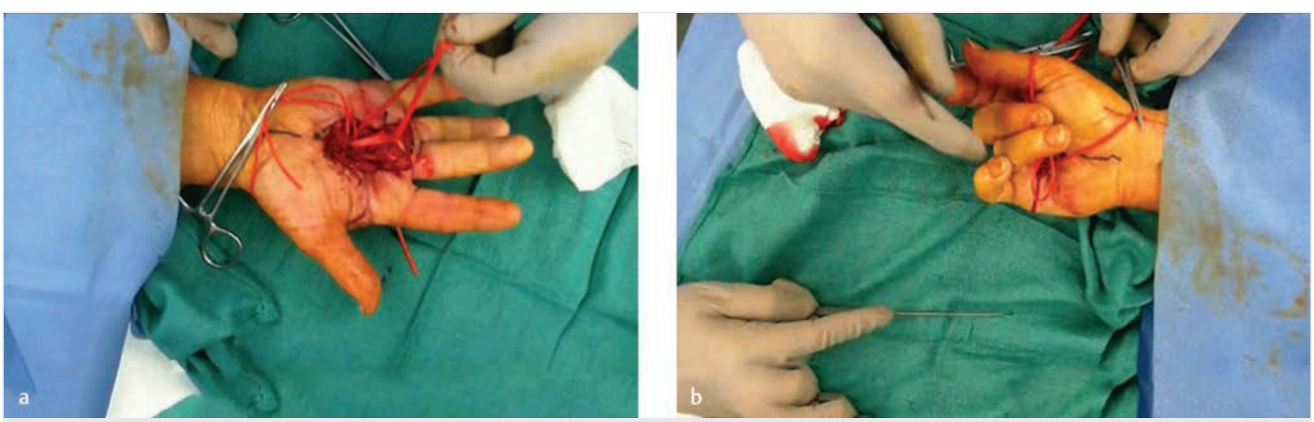

Fig. 10.4 (a, b) In the long finger, a profundus only tendon is carved out of adhesions with the patient's help as she pulls and ruptures the last few adhesions. In the ring finger, both superficialis and profundus tendons were carved out of scar. See how frail and denuded of blood supply the remaining tendon is. This is why we rehabilitate it like a freshly repaired tendon so it does not rupture.

10.4.1 Steps for the Procedure

1. Inject the local anesthesia so that it does not hurt.
2. Wait 30 minutes before making an incision to allow optimal epinephrine vasoconstriction and lidocaine numbing.
3. Dissect a little, let the patient rupture adhesions with active movement a little. Repeat until the patient ruptures the final adhesions.

10.5 Critical Evaluation of Results

The patient still does not have 100% flexion, and still remains deficient in index finger flexion as well. However, she has an almost normal functional range of motion and is much better than before the surgery (▶Fig. 10.5, ▶Video 10.3). She will likely continue to gain as she uses the hand over the next year or two.

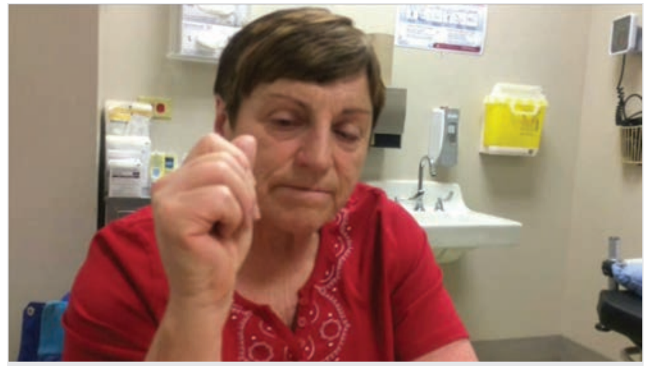

Fig. 10.5 Six weeks postoperative demonstrating extent of active flexion.

10.6 Teaching Points

- Scars need to be soft before tenolysis.
- Get full passive motion before surgery.
- Do the tenolysis wide awake.
- Preexisting scars and creases form a natural barrier to local anesthetic solution.
- Immobilize and elevate for 3 to 5 days instead of immediate aggressive movement to avoid rupture.
- Start early protected true active movement as you would for a freshly repaired flexor tendon to avoid rupture of the weakened devascularized denuded tendon.

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11 Bowstringing of the Flexor Tendon

Jin Bo Tang

11.1 Patient History Leading to the Specific Problem

A 52-year-old man was referred to the author because of sudden loss of active flexion of the index finger in the first week after repair of the flexor digitorum profundus (FDP) tendon with a two-strand modified Kessler repair. The original laceration was at the proximal interphalangeal (PIP) joint level. He lost active flexion of the distal interphalangeal (DIP) and PIP joints of that finger after starting early active digital flexion. The author decided to perform a re-repair of the disrupted FDP tendon, 4 weeks after initial primary repair. However, he developed adhesions after the second direct end-to-end repair. Tenolysis was performed twice, but he ended up with limited improvement in active finger flexion and bowstringing at the PIP joint (▶Fig. 11.1). He was diagnosed as having adhesions, pulley destruction, and tendon bowstringing. According to the clinical presentation, the A4 pulley had to be reconstructed.

After detailed discussion with the patient, we decided to proceed with staged tendon reconstruction and pulley reconstruction. The plan was that in stage 1 of the surgery, the frayed FDP tendon would be removed from zones 1 and 2 and replaced with a Hunter rod, with reconstruction of the pulleys over the rod. In stage 2 of the surgery, the Hunter rod would be replaced with a palmaris longus tendon graft.

11.2 Anatomic Description of the Patient's Current Status

An important feature of the digital flexor tendon system is the presence of annular pulleys (▶Fig. 11.2), of which the A2 and A4 pulleys are the largest and functionally most important. Therefore, if all annular pulleys have been destroyed, these two pulleys should be reconstructed; if only one remains, the other should be reconstructed. The A2 pulley is located at the proximal and middle portions of the proximal phalanx and the A4 locates at the center of the middle phalanx.

For this patient, re-repair of the disrupted FDP tendon would increase the risk of adhesions, and severe adhesions tend to destroy the entire sheath—including most or all of the annular pulleys; this is a possible cause of destruction of the A4 pulley and its adjacent structures. At least the A4 pulley needed to be reconstructed for this patient.

Fig. 11.1 Bowstringing of the flexor digitorum profundus tendon at the proximal interphalangeal joint after primary repairs of the tendon. (This image is provided courtesy of Jin Bo Tang, MD.)

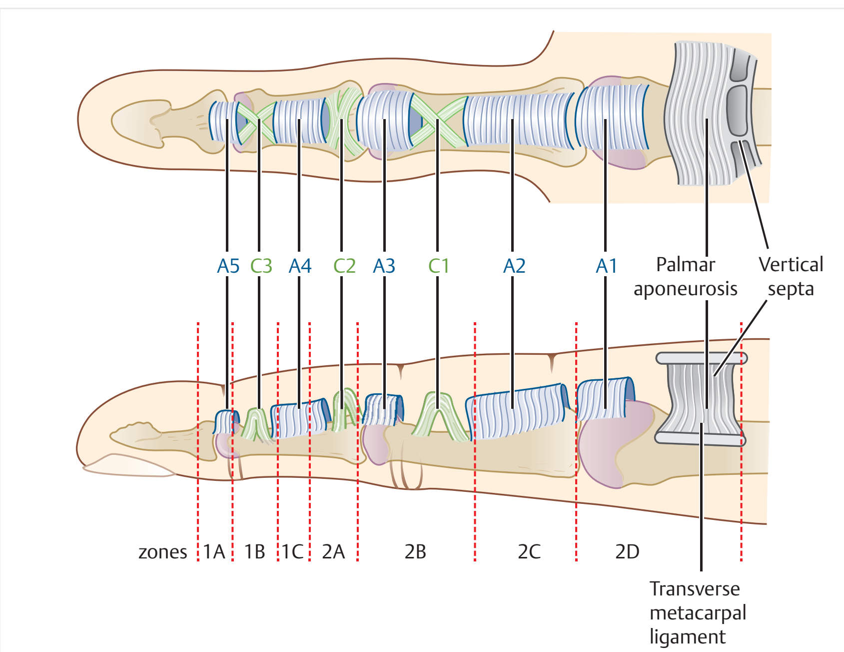

Fig. 11.2 Locations of the annular pulleys in a finger. Note the A2 and A4 pulleys are the largest and critically located among all pulleys.

The A3 pulley, functionally less insignificant than the A2 or A4 pulley, is located palmar to the PIP joint. However, surgeons should consider a broader A4 pulley or add a slip of reconstructed pulley over the PIP joint, which helps minimize tendon bowstringing at the PIP joint.

11.3 Recommended Solution to the Problem

The pulley should be reconstructed together with placement of a Hunter rod; this is a standard approach for such a complex case. The pulley reconstructed over the Hunter rod will not develop adhesions between the pulley and the rod. It is not proper to perform a pulley reconstruction over a frayed tendon during tenolysis, because adhesions will recur, and early active finger flexion disrupts the reconstructed pulley.

At the time of single-stage tendon grafting, the pulleys can also be reconstructed, but the author prefers to do tendon grafting with pulley reconstruction when only one pulley needs to be reconstructed and adhesions are confined. If both A2 and A4 pulleys need to be reconstructed, the scar is usually extensive. A Hunter rod should be placed first to stimulate pseudo-sheath formation. In a finger with extensive scarring, one-stage tendon grafting combined with pulley reconstruction does not yield a movable finger, and outcomes would be disappointing. A staged tendon reconstruction would be preferable to a single-stage tendon grafting for a finger with extensive scarring.

11.4 Technique

The surgery was performed under branchial plexus anesthesia and tourniquet control.

11.4.1 Steps for the Procedure: Stage 1

1. Frayed FDP tendon is resected.
2. The distal A2 pulley is preserved.
3. Adhesions are cleaned and flexor digitorum superficialis (FDS) tendon slips are excised.
4. A Hunter rod is inserted under the A2 pulley and connected.
5. A segment of the FDP tendon is used as a graft to reconstruct the A4 pulley.
6. The graft is anchored to the remnants of the pulleys.
7. Suture strength is confirmed.

11.4.2 Stage 1 Surgery

An extended Bruner incision made from the fingertip to the mid-palm was used to extend the previous surgical incisions. The frayed FDP tendon was found buried in the scar (▶Fig. 11.3) and was resected over the entire finger length. A short stump (0.5 cm) of the FDP tendon was kept at its insertion.

The A2 pulley was found collapsed and partially embedded in the adhesions. The distal A2 pulley was excised, but the proximal part was found intact, with dense fibers that could be freed from the adhesions. The proximal A2 pulley was thus preserved. Adhesions were thoroughly cleaned and FDS tendon slips were excised. Since the A1 pulley was intact, that pulley was kept as well.

After we placed trail rods confirming the size of the rod to be used, the Hunter rod was then inserted under the preserved part of the A2 pulley, and the distal end of the rod was connected to the residual part of the FDP tendon at the insertion site. A segment (2 cm) of the excised FDP tendon that had smooth surfaces was used as a graft for pulley reconstruction. The tendon segment was lassoed from the A4 pulley to the distal A2 pulley in the middle and the proximal phalanges. This tendon segment was firmly anchored to the rim of the residual A4 pulley and periosteum with a number of interrupted sutures with 3–0 Ethilon (▶Fig. 11.4).

We confirmed that sutures of the reconstructed pulley to the residual parts of the A4 pulley and periosteum were secure. We also confirmed that the new pulley was not too tight for the gliding of the Hunter rod, through passively moving the finger from full extension to semiflexion. It is not usually necessary to check the gliding of the Hunter rod up to full passive flexion

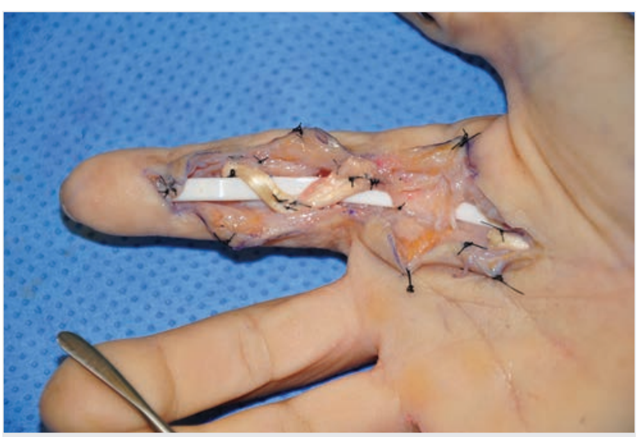

Fig. 11.3 Placement of the Hunter rod to the index finger after excision of adhesions and scar. (This image is provided courtesy of Jin Bo Tang, MD.)

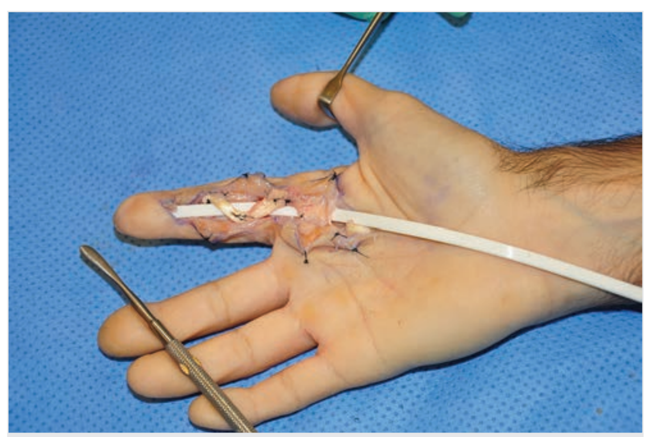

Fig. 11.4 Reconstruction of the A4 and A3 pulleys together with a segment of the excised flexor digitorum profundus tendon. The tendon segment was securely sutured to the remnants of pulleys and periosteum. (This image is provided courtesy of Jin Bo Tang, MD.)

Fig. 11.5 In stage 2 surgery, the Hunter rod was replaced with a palmaris longus tendon graft.

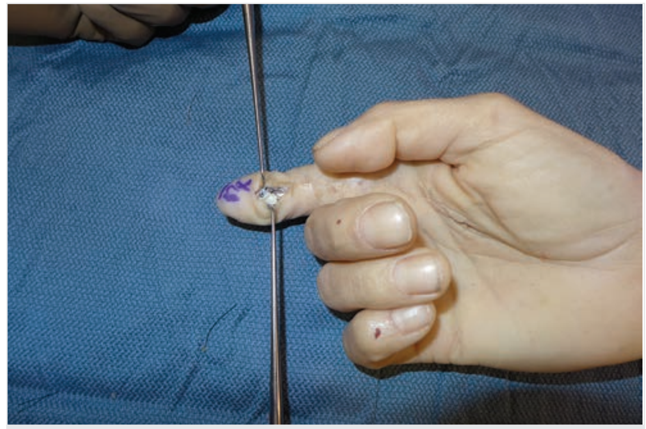

Fig. 11.6 The distal tendon junction method: direct reinforced suture repair. (This image is provided courtesy of Jin Bo Tang, MD.)

of the finger. The proximal end of the Hunter rod was left free, rather than being sutured to the end of the FDP tendon in the palm. The skin was closed.

Postoperative Care after Stage 1 Surgery

The wrist was held in semiflexion and the metacarpophalangeal joint flexed for 40 degrees in a dorsal splint extending to the middle of the forearm for only 3 weeks. Passive finger flexion and active extension were performed starting the first week after surgery.

The stage 2 surgery was performed 3 months after stage 1.

11.4.3 Stage 2 Surgery

The stage 2 surgery was performed 3 months after stage 1 surgery.

11.4.4 Steps for the Procedure: Stage 2

1. The palmaris longus tendon is harvested.
2. The palmaris longus tendon graft is connected to the Hunter rod.
3. The Hunter rod is pulled out.
4. The graft is laid.
5. The graft is sutured to the FDP tendon stump distally.
6. The graft and tendon are connected proximally with a suture after setting the finger in semiflexion.

For the stage 2 surgery, a palmaris longus tendon was harvested. Only a distal incision in the fingertip and an incision in the palm were made to expose the distal junction of the Hunter rod. Then a proximal incision of about 3 cm was made in the palm to expose the proximal end of the Hunter rod. The palmaris longus tendon graft was connected with the proximal end of the Hunter rod at the palm. Through the distal incision, the Hunter rod was pulled out (▶Fig. 11.5) and the entire graft was laid inside the new sheath from the palm to the distal fingertip.

The graft tendon was directly sutured to the residual part of the FDP tendon and any soft tissues around that site with multiple reinforced sutures with 4–0 Ethilon (▶Fig. 11.6), which is currently the author's routine method. The author does not pull the suture out through the nail of the finger. In the incision in the palm, a Pulvertaft weave suture was used to connect the graft with the FDP tendon end after setting the finger in semiflexion.

Postoperative Care after Stage 2 Surgery

The wrist was held in semiflexion and the metacarpophalangeal joint flexed for 40 degrees in a dorsal splint. Early active digital flexion to two-thirds of the total motion was initiated 5 days after surgery, progressing to full range of active digital flexion 4 weeks after the surgery. The splint was discarded at the end of week 6. The postoperative care is similar to conventional one-stage tendon grafting, but the author usually starts active finger motion about 5 days to 1 week after surgery so the tendon can glide early. There is little risk of repair rupture after tendon grafting as both ends of the graft are repaired with strong repair methods, which are very secure during early motion exercise.

11.5 Postoperative Photographs and Critical Evaluation of Results

The patient had good recovery of active finger motion of the right index finger after the above staged surgeries with pulley reconstruction (▶Fig. 11.7). No bowstringing was found during follow-up.

11.6 Teaching Points

- Two pulleys should be reconstructed if both A2 and A4 pulleys are damaged.
- If the scar is extensive, the best way is to reconstruct a pulley is over a Hunter rod. If the scar is limited, one pulley can be reconstructed over a tendon autograft.

Fig. 11.7 Functional recovery after two stages of surgeries; no tendon bowstringing is noted. (This image is provided courtesy of Jin Bo Tang, MD.)

- Always use a long graft and place the proximal junction in the mid-palm. It is incorrect to do a short graft or to place the proximal junction of the graft with the FDP tendon at the distal palm (that is still in zone 2, and adhesions easily occur).
- Sutures in the reconstructed pulley should be secure. The author prefers a tendon graft wrapping over the Hunter rod with secure sutures to the residual A2 or A4 pulleys. Other methods that the author used are shown in ▶Fig. 11.8. The residual part of the A4 pulley is often difficult to find or confirm. In that case, the periosteum should be used for anchoring as well.
- The author does not use pullout sutures for the distal junction and has found that strong direct suture is sufficient.
- Postoperative rehabilitation is the same as after primary tendon repair, except that after stage 1 surgery, only passive finger motion is possible. A pulley ring should be used to protect the reconstructed pulley during rehabilitation after pulley reconstruction.

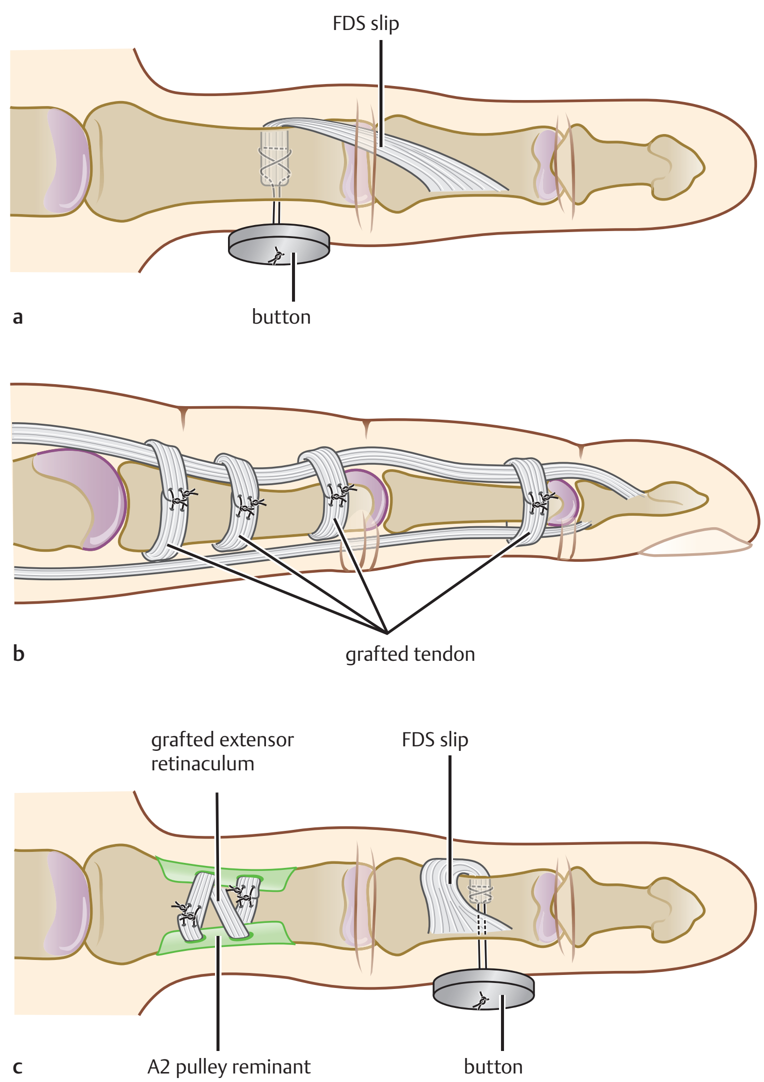

Fig. 11.8 Three other methods of pulley reconstructions. **(a)** flexor digitorum superficialis tendon slip, **(b)** tendon grafts around the phalanges, and **(c)** tendon graft anchoring to the remnants of the A2 pulley.

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12 Ruptured Flexor Pollicis Longus Tendon

Florian Neubrech and Michael Sauerbier

12.1 Patient History Leading to the Specific Problem

A 49-year-old man presented with missing active flexion of the interphalangeal joint of the left thumb. Three months ago, the patient sustained a palmar cutting injury at the distal proximal phalanx with a hunting knife. A repair of the flexor pollicis longus tendon in T1 zone (Verdan) was performed in an outside department for hand surgery. The patient reported that after splinting for 6 weeks there was no return of active movement of the interphalangeal joint.

12.2 Anatomic Description of the Patient's Current Status

The flexor pollicis longus tendon not only provides active flexion of the interphalangeal joint of the thumb but also stabilizes the joint together with the antagonistic extensor pollicis longus tendon (▶Fig. 12.1). After chronic rupture, drag of the extensor pollicis tendon outweighs and hyperextension of the joint, often together with painful osteoarthritis in the long term, may result. A feeling of instability of the thumb is common. Furthermore, active flexion of the interphalangeal joint of the thumb is essential for a precise pinch grip. Hence, tendon repair should be preferred instead of arthrodesis or tenodesis of the interphalangeal joint.

In patients with chronic rupture or re-rupture, the proximal part of the tendon retracts and extensive scaring of the tendon stump, slide bearing, and tendon pulleys occurs (▶Fig. 12.2). As a result, simple secondary suture of the tendon is only possible in very rare cases after a few weeks.

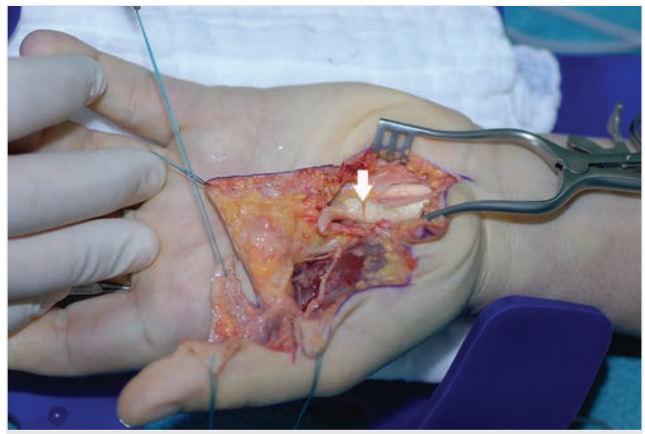

Fig. 12.2 The proximal stump of flexor pollicis longus tendon (*white arrow*) was retracted up to the carpal tunnel and flipped over. There was extensive scaring. The tendon pulleys were lost.

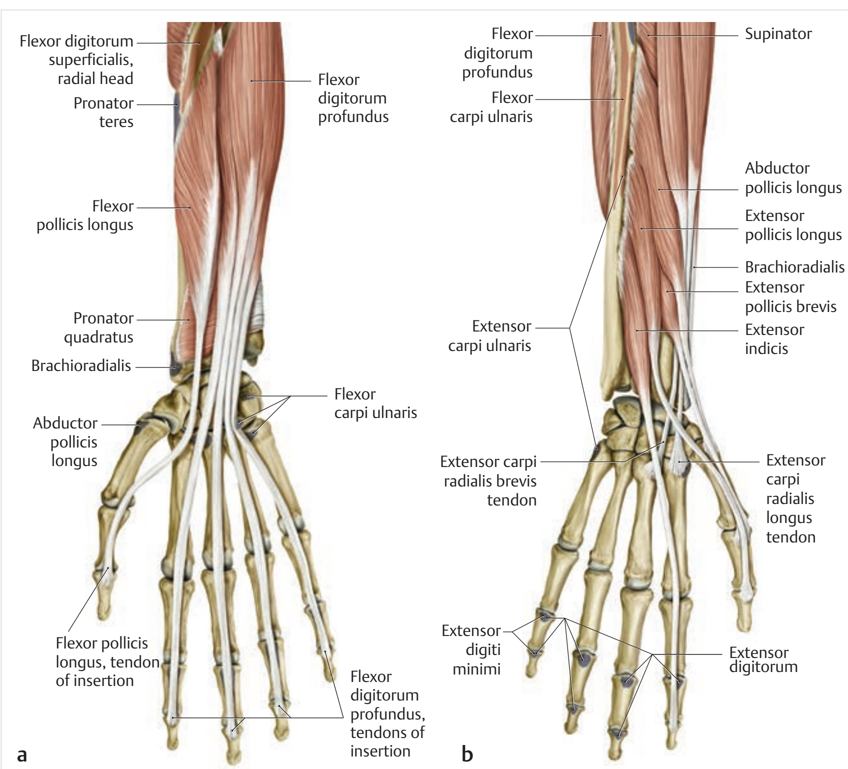

Fig. 12.1 Anatomy example. (Reproduced from Schuenke M, Schulte E, Schumacher U. THIEME Atlas of Anatomy. General Anatomy and Musculoskeletal System. Illustrations by Voll M and Wesker K. 2nd ed. New York: Thieme Medical Publishers; 2016)

12.3 Recommended Solution to the Problem

A secondary suture of the shortened and adhered tendon stumps may not be possible after a couple of weeks, but there are several therapeutic options. First, the slide bearing of the tendon must be inspected. If it is destructed, the best option is to insert a silicon rod first that is sutured to the distal stump and lays loose in the carpal tunnel with its rounded end. After 8 weeks of passive motion under the guidance of a physical therapist, a neoformation of the tendon channel can be seen. This should provide adequate tendon gliding, and tendon grafting can be performed. In the presented case, there was a sufficient tendon route for a single-stage procedure. Established techniques for the replacement of the flexor pollicis longus tendon are the transfer of the flexor digitorum superficialis tendon of the ring finger or the interposition of the palmaris longus tendon if there is no atrophy of the muscle motor. Of course, the availability of the palmaris longus tendon has to be checked preoperatively. In the presented case, the use of a functional tendon was rejected by the patient; therefore, the interposition technique was used.

Force transmission of the flexor tendons requires intact tendon pulleys. In several positions, they are indispensable. For sufficient active flexion of the thumb, the Y pulley or the A1 and the A2 pulleys in combination are necessary. In the presented case, a pulley in the Y position was reconstructed. In two-stage cases, the pulley reconstruction should always be performed in the first stage.

Secondary flexor tendon reconstruction is challenging and comes along with a protracted subsequent treatment. Physiotherapy and occupational therapy are necessary for several months. Some patients withdraw these expenses. Arthrodesis of the interphalangeal joint of the thumb and tenodesis of the distal tendon stump connecting it to the distal tendon pulley are alternative options that can be considered in low-demand patients.

12.3.1 Recommended Solution to the Problem

- Inspection of the tendon route with decision for single- or two-stage tendon reconstruction.
- Interposition of the palmaris longus tendon between proximal and distal tendon stumps.
- Reconstruction of a flexor tendon pulley.

12.4 Technique

Operation is performed under regional or general anesthesia with use of a tourniquet with 300 mm HG in a bloodless field. The use of magnifying loupes is mandatory.

A Bruner-type incision is performed; an arteriolysis and a neurolysis of both neurovascular bundles follow. The tendon stumps are identified and tenolysed, and the vital ends are resected sparely. It is usually required to open the carpal tunnel to find the proximal tendon stump. In these cases, a neurolysis of the median nerve is part of the operation. Parts of the flexor retinaculum or of the palmar aponeurosis can be used for reconstruction of a tendon pulley as well as the palmaris longus tendon. The palmaris longus tendon is harvested through an extra incision just proximal of the distal wrist crease using a tendon stripper. It is of utmost importance to distinguish the tendon from the median nerve first. The graft is interposed in the Pulvertaft technique using resorbable sutures. In the presented case, PDS 3–0 (Ethicon, Somerville, New Jersey, United States) was used. Care should be taken that the reconstructed tendon has the appropriate extend of pretension. The thumb should be just a little bit more in flexion compared to its neutral position. It has to be ensured that the interphalangeal joint can be extended fully in the neutral position of the wrist (▶Fig. 12.3).

A diversity of techniques is described for tendon pulley reconstruction. In this case, a strip of the palmar aponeurosis was sutured to remaining parts of the Y pulley with PDS 3–0 sutures. Postoperatively, a dorsal forearm splint is used in mild flexion of the wrist and the thumb. Dynamic treatment starts on the second postoperative day. Additionally, a protection of the reconstructed flexor pulley using a Velcro textile ring is necessary. Full load is not allowed for 12 weeks postoperatively.

12.4.1 Steps for the Procedure

1. Bruner-type incision.
2. Arteriolysis and neurolysis of both neurovascular bundles.
3. Identification and debridement of both tendon stumps.

Fig. 12.3 (a–c) The flexor pollicis longus tendon was reconstructed using a palmaris longus graft in the Pulvertaft technique. Y-pulley was reconstructed with a strip of the palmar aponeurosis. Carpal tunnel release was required to find the proximal stump of the tendon. Note the correct extent of pretension of the reconstructed tendon.

Fig. 12.4 (a–c) Functional results 18 months after secondary reconstruction of flexor pollicis longus tendon of the left thumb by interposition of a palmaris longus graft with additional flexor tendon pulley reconstruction.

4. Carpal tunnel release.
5. Harvest of the palmaris longus tendon.
6. Interposition of the graft using the Pulvertaft technique.
7. Reconstruction of a tendon pulley.

12.5 Postoperative Photographs and Critical Evaluation of Results

A clinical follow-up after 18 months was feasible. Hand function in daily life was unrestricted. The patient was able to work (office job) and rediscover his manual hobbies and interests (hunting and handicraft work). Active range of thumb motion was nearly equal sided. There was no "bowstring phenomenon" under load. Fist closure was unlimited. ▶Fig. 12.4 demonstrates excellent functional results.

12.6 Teaching Points

- The flexor pollicis longus tendon facilitates active movement of the interphalangeal joint of the thumb. After loss, a chronic hyperextension of the joint with instability often occurs.
- In closed, secondary or chronic tendon rupture, the surgeon should not consider finding the tendon stumps ready for direct suture.
- Treatment options are tendon grafting, tendon transfer, two-stage tendon reconstruction using a silicon rod in the first stage, and tenodesis or arthrodesis under exceptional circumstances.
- Only an anatomic routing of the tendon enables its correct functioning.
- The surgeon should be prepared for reconstruction of the flexor tendon pulleys not only in secondary reconstruction but also in primary repair.
- Correct pretension of the tendon is essential in secondary reconstruction.

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Part V

Problems with Extensor Tendon Repair

13 Extensor Lag *54*

14 Stiffness in the Extensor Tendon *58*

15 Relative Motion Treatment of Chronic Boutonniere Deformity *62*

16 Management of Chronic Sagittal Band Rupture *64*

17 Posttraumatic Swan-Neck Deformity *68*

V

13 Extensor Lag

Douglas P. Hanel and Nicholas P. Iannuzzi

13.1 Patient History Leading to the Specific Problem

A 23-year-old man presents with extensor lag of his index finger approximately 10 weeks after primary repair of the extensor indicis proprius and extensor digitorum communis to the index finger. The patient initially sustained an injury to the dorsum of the hand while using a grinding apparatus (▶Fig. 13.1). The wound demonstrated some mild contamination and tendon ends that were somewhat ragged with a relatively long zone of injury. A repair was effected using a combination of Krakow and horizontal mattress sutures. Following repair of the extensor tendon and closure of the skin, a forearm-based splint was placed with the index through small fingers in extension. At 10 weeks, and despite regular hand therapy, the patient was noted to have an extensor lag of approximately 30 degrees at the metacarpophalangeal (MCP) joint in addition to extrinsic stiffness of the index finger, preventing flexion of the proximal interphalangeal (PIP) joint beyond approximately 10 degrees with the MCP fully flexed (▶Fig. 13.2).

Fig. 13.1 Upon initial presentation, the patient demonstrated a laceration overlying the second metacarpal with a long zone of injury including approximately 3 cm of the extensor indicis proprius and extensor digitorum communis to the index finger.

13.2 Anatomic Description of the Patient's Current Status

The patient's dorsal soft tissues are healed without excessive edema, inflammation, or immature scar (▶Fig. 13.3). The scar demonstrates some hypertrophy as well as firmness at the middle of its length consistent with adhesions. Individually, the joints of the index finger and the wrist may be taken through a nearly full passive range of motion. Actively, the patient is able to extend the proximal and distal interphalangeal joints fully but is unable to extend the digits beyond 30 degrees at the MCP joint with the wrist positioned in neutral. Extension at the MCP joint improves to 5 degrees short of full with the wrist in approximately 40 degrees of flexion. There is palpable contraction of the extensor muscles within the forearm, and at the level of the scar, the skin demonstrates tethering between the extensor tendon and the skin with attempt at passive flexion of the finger.

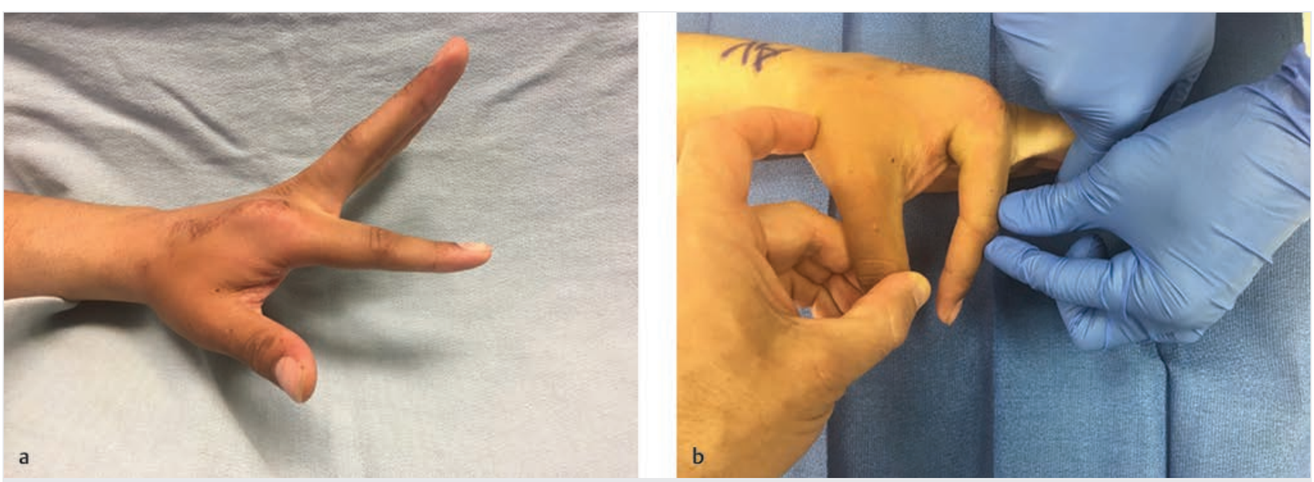

Fig. 13.2 **(a)** At follow-up at 10 weeks, the patient demonstrates an extensor lag at the metacarpophalangeal (MCP) joint of approximately 30 degrees upon attempted extension. **(b)** In addition to the extensor lag, there is extrinsic tightness of the proximal interphalangeal (PIP) joint with inability to flex the PIP joint beyond approximately 10 degrees with the MCP fully flexed.

Fig. 13.3 At 10 weeks, the prior incision is well healed. There is some evidence of hypertrophy of the scar. The surrounding tissues are without significant edema or signs of inflammation.

13.3 Recommended Solution to the Problem

One should first realize that supervised hand therapy can minimize extensor lag after extensor tendon repair. Appropriate therapy provides limited motion to minimize adhesion formation while preventing gapping at the repair site. If adhesions do form and formal hand therapy is unable to improve active motion for a period of approximately 12 weeks, tenolysis may be considered. Examination of the patient is critical to determining the presence of tendinous adhesions within the digits, hand, wrist, or forearm. Adhesions ultimately limit tendon excursion, and total active range of motion of the involved portion of the extremity is decreased. Passive range of motion may be nearly normal.

Other causes of extensor lag should also be ruled out. Flexor tendon adhesions, associated fracture shortening, bow stringing of extensor tendons over the wrist, or sagittal band rupture may also cause extensor lag. Once other causes of extensor lag have been ruled out and adhesions have been localized, tenolysis may be performed. Use of local anesthesia and wide-awake surgery allows the surgeon to verify intraoperatively that all adhesions have been addressed and that active motion has been restored. Following tenolysis, meticulous hemostasis may limit postoperative swelling and inflammation, which facilitates early motion of the digits and helps prevent further adhesions. The patient should begin formal hand therapy no more than 1 week following surgery to prevent recurrence of adhesions.

13.3.1 Recommended Solution to the Problem

- Adhesions between the tendons and surrounding soft tissues require tenolysis to improve active motion if therapy fails.
- Physical examination will help localize the likely area of adhesions.
- Ideally, surgery should be performed using wide-awake, local anesthesia to allow the patient to demonstrate active motion of the involved tendons to confirm improvement intraoperatively.
- Obtaining meticulous hemostasis following repair can help minimize edema and inflammation, which may help prevent further adhesions.
- Though it is difficult to prevent extensor lag entirely, appropriate hand therapy reduces adhesions and prevents gapping of tendon repairs, minimizing the chance of extensor lag after tendon repair.

13.4 Technique

The patient is taken to the operating theater and placed into a supine position using a hand table. Surgery can be performed under local anesthetic to allow the patient to participate in an examination during and after the tenolysis. Anesthetic with epinephrine can be used to minimize bleeding in lieu of using a tourniquet. If a tourniquet is used, the procedure should be performed expediently to permit an evaluation prior to development of tourniquet-associated paralysis. An incision is made over the dorsum of the digits, hand, wrist, or forearm, in line with the tendons to be dissected. If multiple tendons are involved, the skin and subcutaneous tissues can be elevated radially and ulnarly over the dorsum of the wrist. The tendons should be identified proximal and distal to the area of adhesions to ensure that the tendons are dissected in their entirety from the surrounding tissue and intratendinous dissection is prevented. The extensor retinaculum over the wrist and the sagittal bands must be preserved to prevent bow stringing of the tendons or lag associated with sagittal band rupture.

In our case, once the tenolysis was complete, an area of attenuated tendon was noted where the repair appeared to have gapped. This was imbricated using a combination of figure-of-eight and horizontal mattress sutures (▶Fig. 13.4).

Once the tendons are freed from the surrounding tissue, the patient is asked to actively range the digits and wrist in order to confirm that the tenolysis is complete (▶Fig. 13.5). After active motion of the affected digits has been restored, attention is turned to obtaining excellent hemostasis within the wound bed. Closure is then performed and a sterile dressing is applied along with a splint with the digits in a resting position. The splint and dressings should be removed within a week to permit hand therapy with a focus on active motion and prevention of further adhesions.

13.4.1 Steps for the Procedure

1. An incision is made over the suspected site of adhesions.
2. The tendon is dissected from surrounding tissues beginning proximal and distal to the affected area to prevent intratendinous dissection, which can lead to tendon rupture.

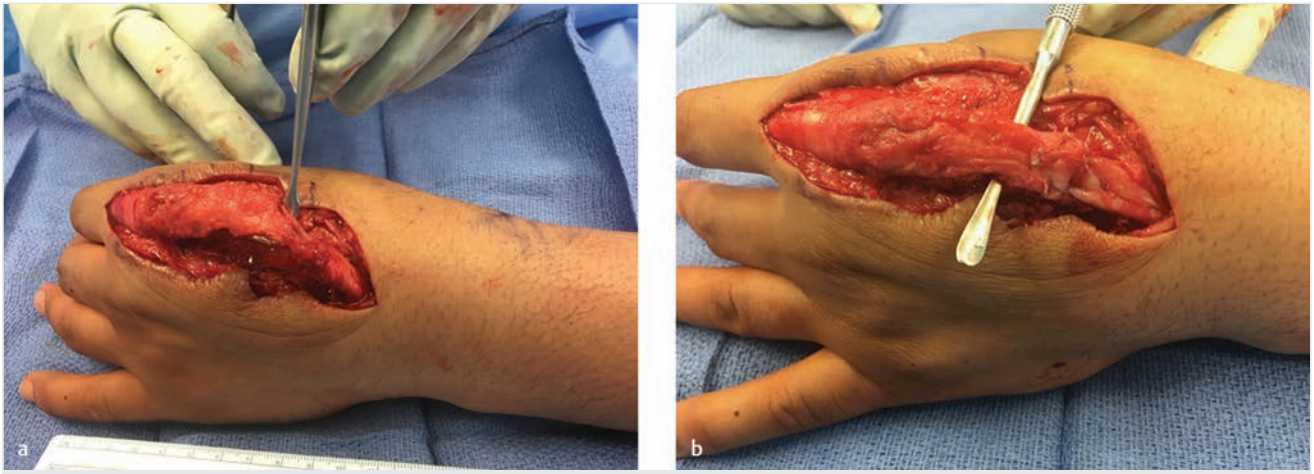

Fig. 13.4 (a) Tendons to the index finger have been freed from surrounding tissue and overlying skin. At the site of the freer elevator, there is an area of attenuated tendon where the tendon repair appears to have gapped somewhat. **(b)** The tissues at the site of attenuation were imbricated and sutured together with a combination of figure-of-eight and horizontal mattress sutures.

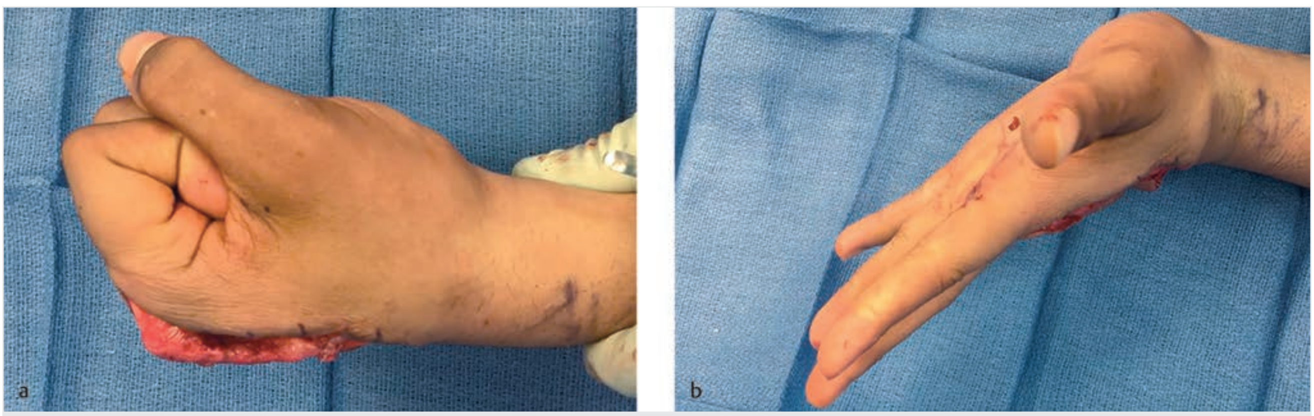

Fig. 13.5 (a) Following tenolysis of the tendon from surrounding tissues, the finger is able to achieve near full composite grip with the wrist in neutral **(b)** as well as full extension with the wrist extended.

3. If performed under wide-awake anesthesia, the patient may actively range the digits and hand to demonstrate adequate tenolysis.
4. The postoperative result is shown.

13.5 Postoperative Photographs and Critical Evaluation of Results

If extensor lag is appropriately diagnosed and extrinsic causes such as sagittal band rupture, bony shortening, and bowstringing of tendons are ruled out, then performing a tenolysis for extensor tendon lag should improve motion of the affected extremity. While obtaining full range of motion is possible, it is not uncommon for some extensor lag to remain, though this is often less than what was experienced prior to tenolysis. Fetrow documented his results of tenolysis in eight patients treated for extensor lag of the fingers following primary extensor tendon repair and reported an improvement in the extensor lag from 15 to 45 degrees to 0 to 15 degrees in seven. The remaining patient required arthrodesis of the distal interphalangeal joint due to inadequate tendon quality to permit tenolysis. In another group, Creighton and Steichen evaluated 25 patients who sustained metacarpal and phalangeal fractures and developed extensor lag. In patients requiring only a tenolysis to improve active motion of the digits, extensor lag improved 50%, from 16 to 8 degrees on average.

In our patient, at the time of surgery, we were able to obtain full extension of the digits with the wrist in full extension as well as good composite grip, as noted in ▶Fig. 13.6 and the ▶Video 13.1.

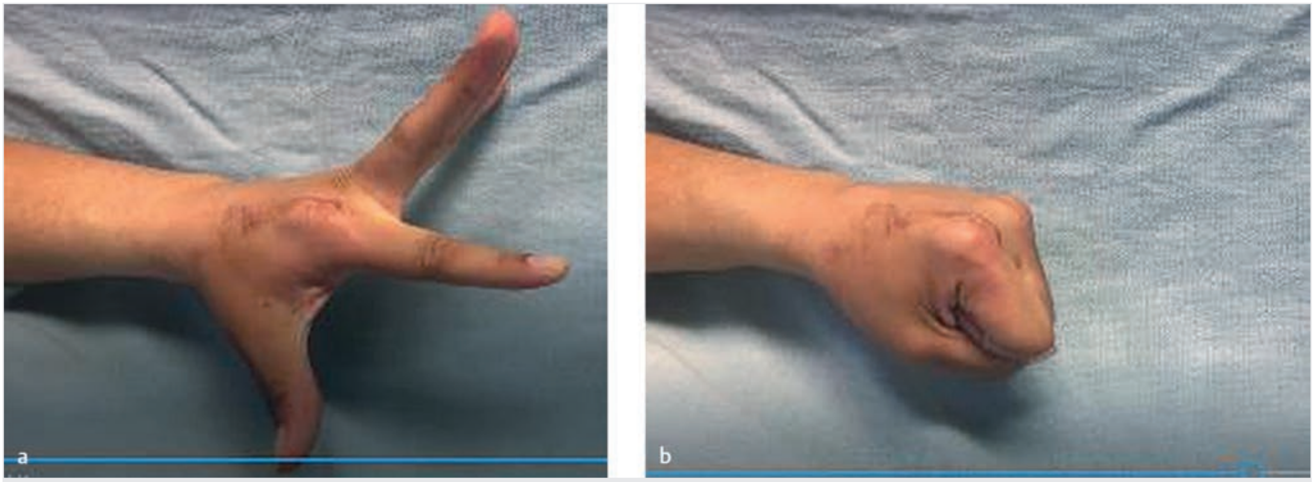

Fig. 13.6 (a, b) Patient shown at 12 weeks following surgery. Active flexion has improved. Lack of adherence to hand therapy has resulted in recurrence of his extensor lag. Flexion of the digit has improved after tenolysis.

13.6 Teaching Points

- Therapy following extensor tendon repair or reconstruction may limit or prevent adhesions.
- Determination of the cause and site of extensor lag is key to adequate treatment.
- Tenolysis should be performed under wide-awake anesthesia if possible to help confirm adequate release of adhesions.
- Begin tenolysis proximal and distal to site of adhesions to prevent intratendinous dissection.
- Meticulous hemostasis may limit inflammation and swelling, which can slow postoperative therapy.
- Hand therapy should begin within 1 week following surgery to prevent recurrence of adhesions.

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14 Stiffness in the Extensor Tendon

Kai Megerle

14.1 Patient History Leading to the Specific Problem

A 44-year-old male patient presents with a stiff left index finger. He had suffered an injury with a circular saw about 3 months earlier. The middle slip of the extensor tendon of the finger had been avulsed together with some bone fragments. The fragment had been reattached and the extensor tendon as well as the surface of the proximal interphalangeal (PIP) joint had been reconstructed (▶Fig. 14.1). Despite extensive postoperative physical therapy, range of motion was severely reduced in the proximal interphalangeal (PIP) and distal interphalangeal (DIP) joints, respectively (▶Fig. 14.2).

14.2 Anatomic Description of the Patient's Current Status

Stiffness of finger joints is one of the most common complications after any type of injury or surgery of the hand. Detailed knowledge of tendon and joint anatomy and a thorough analysis of the individual situation are mandatory to develop a treatment plan for any patient presenting with stiffness of the fingers.

There are many reasons for limited flexion of the PIP joint such as edema, lack of or contractures of the overlying skin, adhesions of the extensor tendons to skin or bone, contracture or adhesions of the palmar plate, and incongruence of the

Fig. 14.1 (a, b) Preoperative X-ray studies immediately after injury. Notice the boutonniere deformity after detachment of the central slip. **(c, d)** X-ray studies 12 weeks after the initial injury. The central slip was reattached and the joint surface was reconstructed.

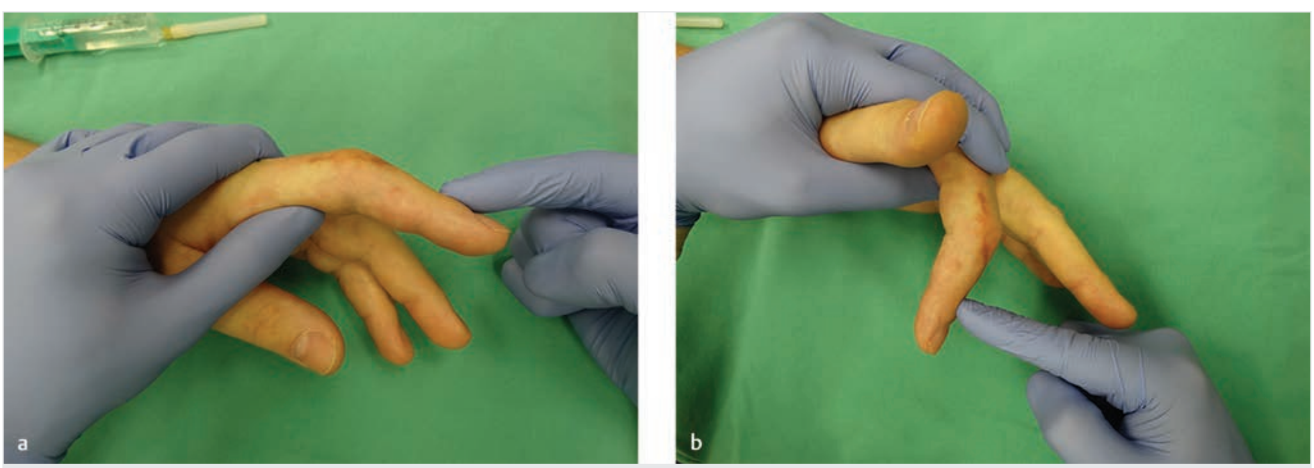

Fig. 14.2 (a) Clinical findings after the initial procedure with bony healing but stiffness of proximal interphalangeal joint in extension contracture. **(b)** Test for intrinsic tightness. Range of motion does not change with the metacarpophalangeal joint held in flexion, indicating the lack of intrinsic tightness.

joint surfaces or mechanical blocks such as exostoses. Most of the times, combinations of these will be present; therefore, it is often very hard to determine the full extent of a possible operative procedure beforehand. While alterations of the bony structure can easily be detected by common X-ray studies, soft tissues must be assessed by clinical examination. At times, it can be even quite difficult to determine whether the pathology is located on the flexor or extensor side of the finger, or both.

Most importantly, active and passive ranges of motion of the PIP joint must be examined in different positions of the metacarpophalangeal (MCP) joint. Range of motion was determined as 0/25/35 degrees for the PIP joint according to the neutral-0 method for both, active and passive movements. There was no substantial movement of the DIP joint. Because the patient had suffered an injury to the extension side of the finger and demonstrated similar active and passive range of motion, adherence of the extensor tendon and possible extension contracture of the PIP joint were the most probable causes of the limited range of motion. Since the injury involved both substantial soft-tissue trauma and fractures of the middle phalanx, broad adhesions of the extensor tendon with the overlying skin and underlying bone had developed. Range of motion for the PIP joint was independent of the position of the MCP joint, indicating the lack of intrinsic tightness (▶Fig. 14.2).

Correct timing of secondary surgery on stiff fingers is of utmost importance. Rather than relying on rigid time frames, one should make sure that a number of requirements are met before attempting revision surgery. There must be adequate soft-tissue coverage allowing for the preparation of well-perfused flaps above tendons and joint surfaces. Swelling must be gone and scars should be supple. Splinting, physical therapy, and other conservative therapy options should have been exhausted and the patient should have reached a plateau of range of motion with no further improvement. These requirements are usually not met before 3 to 6 months after surgery. Furthermore, the patient must be aware of and willing to perform extensive postoperative physical therapy for several weeks after the operation. It has been indicated that surgery after a delay of a year or more will lead to less favorable results, possibly because of more rigid joint contractures.

Wide-awake or WALANT (wide-awake local anesthesia, no tourniquet) surgery describes an operative technique in which anesthesia is achieved only by lidocaine and epinephrine. Patients are able to move their fingers throughout the procedure and do not have to endure a tourniquet. This form of surgery is ideal especially for tenolysis, because the success of the procedure is immediately visible to both surgeon and patient.

14.3 Recommended Solution to the Problem

- WALANT surgery to intraoperatively check for active range of motion.
- Separation of adhesions between the central slip and both overlying skin and underlying bone.
- Possibly arthrolysis of the PIP joint.

14.4 Technique

See ▶Video 14.1.

Approximately 30 minutes before the operation, an appropriate amount of tumescent local anesthetic is administered (▶Fig. 14.3). Usually, we prefer a mix of 1% lidocaine with 1:100,000 or 1:200,000 epinephrine injected directly into the presumed operative field. A combination of nerve blocks and direct infiltration may be used. It is important to estimate the maximum extent of surgery beforehand, because vasoconstriction takes about 30 minutes to properly set in. You can always numb up additional regions during surgery, but most of the time there won't be sufficient vasoconstriction and surgery can become exceedingly difficult in regions such as the palm of the hand because of diffuse bleeding. If possible, additional sedation should be avoided to ensure a fully cooperative patient during tenolysis. The patient is then placed in a supine position and prepped appropriately.

The skin is incised and skin flaps are created by dissection in the plane between the tendon or peritendineum and subcutaneous tissues (▶Fig. 14.4a). It is important to stay in the correct plane, because otherwise either skin viability will be compromised or the tendon is weakened or damaged. The integrity of the tendon is assessed and cautiously protected as well as its insertion at the middle phalanx. In a similar fashion, the tendon is separated from the underlying bone (▶Fig. 14.4b). After freeing the tendon proximal to the PIP joint, the tendon is assessed and, if necessary, released distal to central slip insertion (▶Fig. 14.4c). Dissection should be continued until all adhesions around the extensor tendon are released. Passive range of motion is assessed. If the PIP joint is contract, stepwise release of the PIP joint must be performed. The extensor tendon is elevated and the dorsal joint capsule and collateral ligaments are exposed. The first step is to incise the dorsal joint capsule. If easy flexion of the PIP joint is still not possible, both accessory collateral ligaments are carefully incised in a dorsal-to-palmar fashion, until easy passive

Fig. 14.3 Injection of solution for WALANT (wide-awake local anesthesia, no tourniquet) surgery.

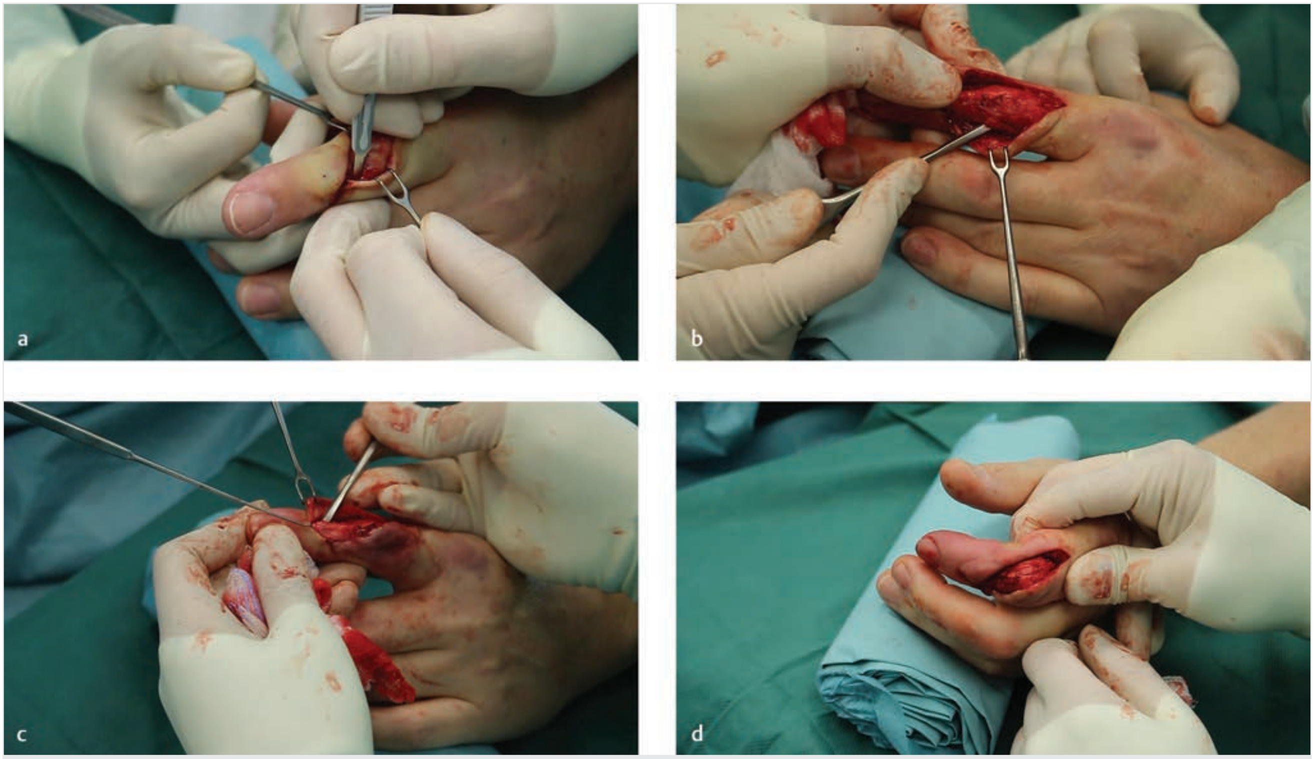

Fig. 14.4 **(a)** Separation of tendon and skin. **(b)** Separation of tendon and bone. **(c)** Release distal to the central slip. **(d)** Intraoperative active motion.

flexion is achieved. The patient is then asked to actively flex the joint (▶Fig. 14.4d). In this way, minor adhesions that still limit function can be ruptured. At the end of the procedure, active and passive flexion should be as close to full range of motion as possible. Sometimes, patients will have difficulties moving a numb finger without visual control. If possible, the drapes should be lowered and the resulting range of motion demonstrated to the patient. Most of the time, the patient will be very impressed. We strongly encourage demonstrating the results to the patient, because it helps motivate postoperative therapy. The skin is closed with narrow interrupted sutures and range of motion is finally assessed one more time before putting a light bandage on. The patient is encouraged to move the joint right away.

Fig. 14.5 Result after 8 weeks.

14.5 Postoperative Photographs and Critical Evaluation of Results

At 8 weeks postoperatively, the patient obtained an active range of motion of 0/5/60 degrees for the PIP joint and was satisfied with this result (▶Fig. 14.5).

Stiff fingers are often difficult problems and tenolyses of finger tendons can be very frustrating endeavors. Most of the time, long-term range of motion is improved, but the intraoperative result is not preserved. This is due to postoperative edema and subsequent scarring of the tendon and joints, despite all postoperative efforts. With improper postoperative therapy, there is a risk that patients may even lose function after the procedure. Immediate, high-intensity postoperative hand therapy is key to preserve as much motion as possible after arthrolysis and tenolysis. During the early postoperative phase, continuous axillary nerve blocks may be helpful for pain control.

In patients with impaired finger perfusion, arthrodesis or even amputation instead of tenolysis may be warranted.

Postoperative stiffness can be reduced by early motion protocols. Active and passive motion exercises should be started as early as possible.

14.6 Teaching Points

- Early mobilization after tendon injuries or fractures may reduce or prevent postoperative stiffness.
- All conservative treatment measures should be exhausted before revision surgery.
- Correct timing of tenolysis is essential; special attention should be paid to the surrounding soft tissues.
- The exact cause of stiffness and full extent of the procedure may be hard to estimate preoperatively.
- WALANT surgery is ideal for tenolysis.
- Intensive postoperative hand therapy is mandatory; during the early postoperative phase, continuous nerve blocks may be helpful for pain control.
- Procedures may be technically demanding and long-term results may be disappointing for both the patient and the surgeon.

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15 Relative Motion Treatment of Chronic Boutonniere Deformity

Wyndell H. Merritt

15.1 Patient History Leading to the Specific Problem

A 48-year-old woman had a 6-month fixed flexion contracture of her middle digit that was swollen, painful, and had lost flexion in both interphalangeal (IP) joints as well as extension of her proximal interphalangeal (PIP) joint following a jam-type injury in a fall. She explained it had been diagnosed initially as an "occult fracture" and then as a "volar plate injury" that was "unresponsive to hand therapy." She complained about discomfort and loss of motion.

15.2 Anatomic Description of the Patient's Current Status

The patient was distressed due to chronic pain and swelling of her PIP joint and had lost flexion in her distal interphalangeal (DIP) joint from hyperextension remodeling of her dorsal capsule, and had also lost some flexion in her PIP joint as well as extension, with a fixed PIP flexion contracture of –45 degrees of active extension and –35 degrees of passive extension ("fixed contracture") due to volar joint capsule remodeling. A Boyes' test was distinctly positive. Her Elson's and modified Elson's tests were equivocal because of her decreased motion and fixed flexion contracture. Her X-ray was normal (▶Fig. 15.1).

15.3 Recommended Solution to the Problem

There are numerous proposed operations for chronic boutonniere deformity, all of which have uncertain, usually poor, results. This is especially true if the contracture has been present for 3 months or more, initially presents with greater than –30 degrees of active extension, and if the patient is older than 45 years; this patient had all of these characteristics with greater than 50% probability of a poor surgical result. All patients with fixed contractures from chronic boutonniere deformity need serial casting to recover full passive extension when possible and we believe nonsurgical management techniques should be attempted.

15.4 Technique

In this patient, we utilized serial casting with progressive forced extension changed twice a week, with minimal padding (▶Fig. 15.2a, b). When –5 degrees was obtained, improvement plateaued, and relative motion flexion splinting was initiated, with therapy attention directed toward recovering full PIP flexion and the achieved extension maintained in the splint full time while using her hand for normal functional activities. This is accomplished by placing the injured digit in 15- to 20-degree greater flexion relative to the adjacent metacarpophalangeal joints and encouraging active motion and digit functional use (▶Fig. 15.2c, d). When she became almost able to touch her palm, she was encouraged to resume all her normal previous activities in the splint (▶Fig. 15.2e, f).

15.5 Postoperative Photographs and Critical Evaluation of Results

After 3 months, she maintained her −5 degree PIP extension, and recovered 90 degrees of PIP flexion, and the splint was discontinued, though she still lacked full DIP flexion (▶Fig. 15.3a, b). At 3 years, her extension is slightly improved, and she now has full composite flexion. She is pleased with her final result (▶Fig. 15.3c, d).

Fig. 15.1 **(a)** Progressive fixed boutonniere deformity at 6 months. **(b, c)** Positive Boyes' test with resistance to passive flexion of the distal interphalangeal (DIP) joint when the proximal interphalangeal (PIP) joint is maximally extended. DIP easily flexes passively when PIP is flexed (both DIP and PIP also have decreased flexion passively).

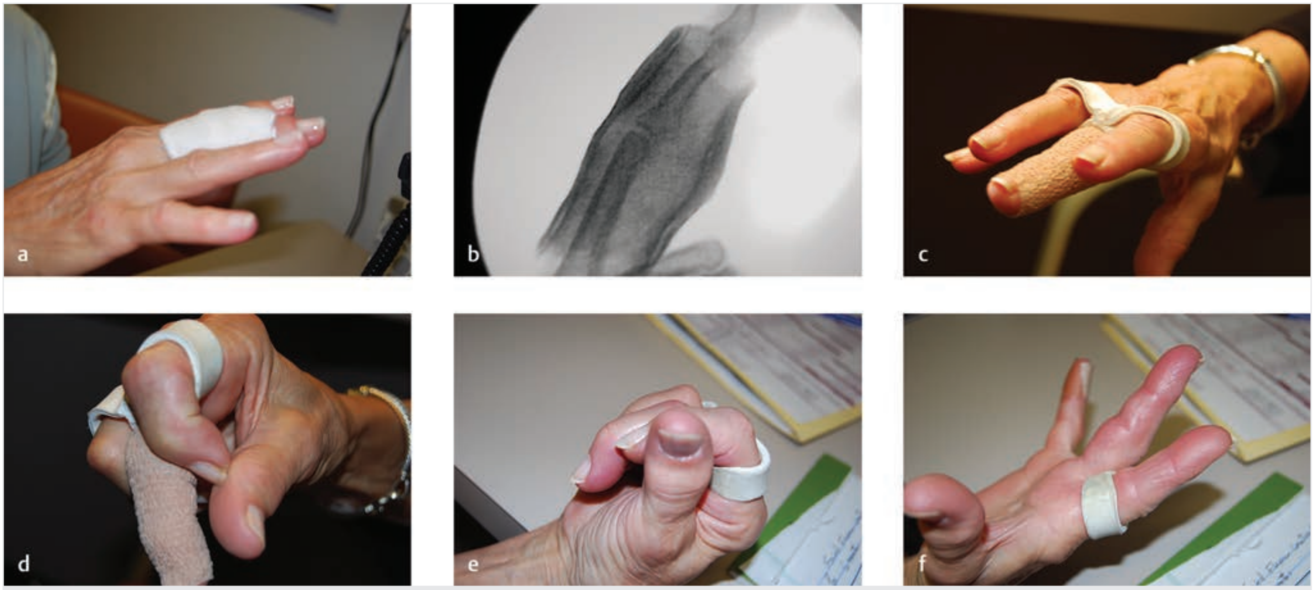

Fig. 15.2 (a, b) The patient is serially casted to as much passive extension as possible. **(c, d)** The first month after serial casting, the patient must recover interphalangeal joint flexion (early after splinting). **(e, f)** One month after splinting, the patient is encouraged to resume full activity in the relative motion orthosis.

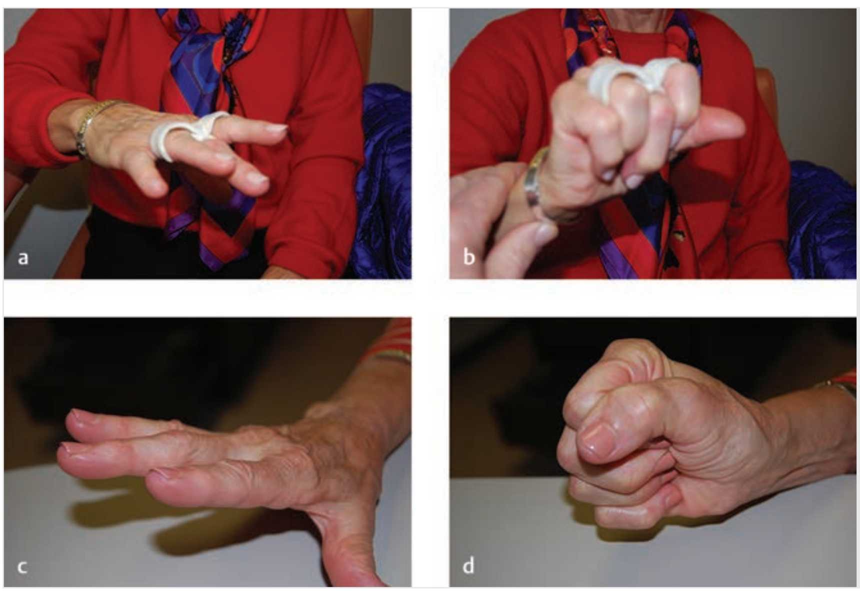

Fig. 15.3 (a, b) At 6 weeks, the patient has almost recovered full composite flexion and has maintained the extension achieved by casting. **(c, d)** Final result is full flexion and −5 degrees of extension at 2 years following treatment.

15.6 Teaching Points

- The best way to avoid chronic boutonniere deformity is to prevent deformity in the first place with early diagnosis and treatment using relative motion flexion orthoses.
- Because an extensor hood rupture often does not become initially apparent, it is imperative to diagnose the suspected patient with an Elson test, the modified Elson test, or the Boyes test, and if doubtful, ultrasonic or MRI study can confirm whether the problem is boutonniere or a flexor tendon "pseudo-boutonniere" deformity.
- The chronic boutonniere deformity patient is splinted with relative motion flexion splints for 3 months in 15 to 20 degrees of relatively greater MP joint flexion. If the patient cannot be serially casted to less than −30 degrees of flexion contracture, surgical release of the lateral bands and volar joint contracture and reconstruction of the central hood will be necessary, and should be done under local anesthesia with epinephrine to be sure the intrinsic–extrinsic balance is restored. We recommend 6 weeks of relative motion flexion splinting to see that it is maintained. However, the author has not found it necessary to attempt this yet due to results as described in this patient.

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16 Management of Chronic Sagittal Band Rupture

Wyndell H. Merritt

16.1 Patient History Leading to the Specific Problem

This 80-year-old man fell off of his tractor 6 months prior to examination, with a resultant chronic subluxation of his fifth digit due to radial sagittal band rupture.

16.2 Anatomic Description of the Patient's Current Status

This healthy 80-year-old man had ulnar deviation and inability to extend his fifth digit unless he relocated it to an extended position by using his other hand. He was pain free, but found this embarrassing and functionally awkward (▶Fig. 16.1).

16.3 Recommended Solution to the Problem

The use of relative motion extension splinting for sagittal band rupture was first described in 2001 and in a series of patients successfully treated for acute sagittal band rupture in 2005. Although there are several proposed operations for chronic sagittal band rupture, all recommend immobilization postoperatively for 6 to 10 weeks. The morbidity is significantly greater with immobilization than with early active motion and function in a relative motion extension splint, placing the repaired digit in 15 to 20 degrees relatively greater MP extension than adjacent digits. Although this would likely work for any of the techniques utilized for chronic sagittal band rupture, we prefer local anesthesia with epinephrine to verify successful correction and to confirm the value of the splint to maintain correction, and we create a tendon graft pulley to avoid relying on the questionable strength of a repaired or reconstructed sagittal band. The validity of the splint protection of repair is demonstrated in a video with only a single 6–0 nylon suture placed initially to test the result without and then with a ribbon retractor relative motion extensor splint.

16.4 Technique

Creating a tendon graft pulley attached through bone in the head of the metacarpal successfully centralizes the long extensor tendon and relative motion extension splinting preserves motion without adherence or rupture. Tendon grafts have been used successfully for this purpose from the extensor indicis proprius, juncturae tendinum, extensor retinaculum, palmaris longus, and one half of the flexor carpi radialis. The author has preferred the latter two as seeming the easiest, especially the palmaris longus, when available. Burr holes are made through the dorsal cortical surface of the metacarpal head, and the tendon graft passed through bone, surrounding the extensor tendon in a centralized position and secured with a Pulvertaft weave of the tendon graft and 4–0 Prolene suture. The suture line is then rotated so it is then within the bone. A few days after surgery, the patient is placed in a relative motion extension splint and active hand use is encouraged. A video illustrates the technique, done under local anesthesia, using only an initial 6–0 nylon suture to illustrate force on the graft, without and with a ribbon retractor relative motion extensor splint.

16.5 Postoperative Photographs and Critical Evaluation of Results

We have successfully used nonsurgical relative motion extensor splinting as late as 6 weeks after closed sagittal band rupture if the patient is still inflamed and symptomatic while collagen remodeling is still possible, recovering lost motion and becoming pain free in the splint. The patient is splinted full time for 6 weeks and encouraged to functionally use their hand. However, when the patient develops chronic subluxations without pain or swelling, a surgical solution is necessary.

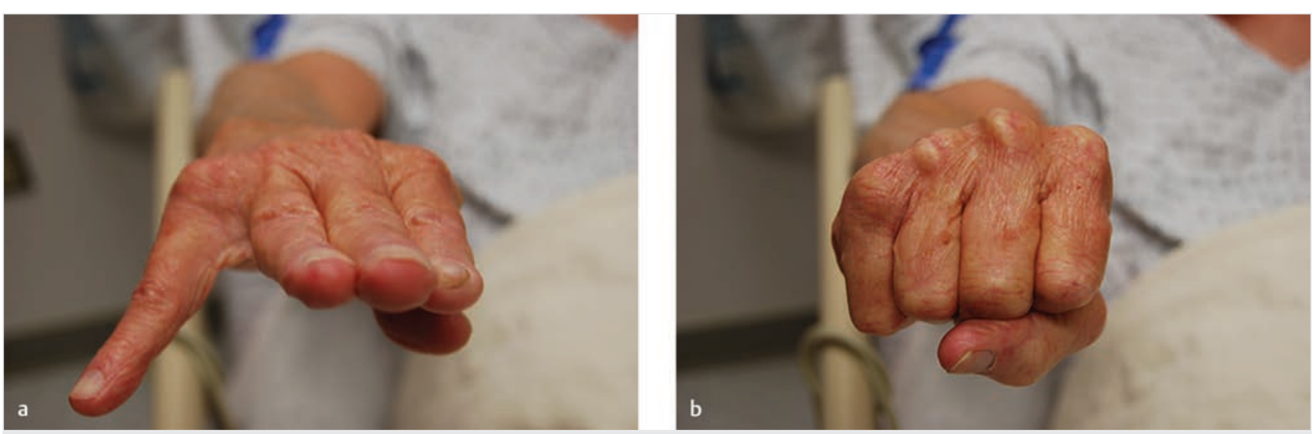

Fig. 16.1 (a, b) Six-month chronic fifth digit sagittal band rupture.

Any of several techniques will likely work equally well with relative motion extensor splints and have far less morbidity than with immobilization (▶Fig. 16.2). We prefer the security of creating a tendon graft pulley, because our first patient was an elderly rheumatoid arthritis patient who had subluxation to either side of her metacarpophalangeal (MCP) joint, depending on the direction of her finger, due to steroid injections from misdiagnosis (▶Fig. 16.3). The tendon graft obviates concern about the attenuated fragile sagittal band and the splint provides immediate active motion with functional use, and full range of motion quickly, usually providing normal range of motion after 6 weeks of splinting (▶Fig. 16.4). This has become our favored surgical technique for this problem, with no failure or ruptures thus far (▶Fig. 16.5). The patient demonstrated normal amplitude of motion with full flexion and extension at 8 weeks after surgery, as illustrated in the video.

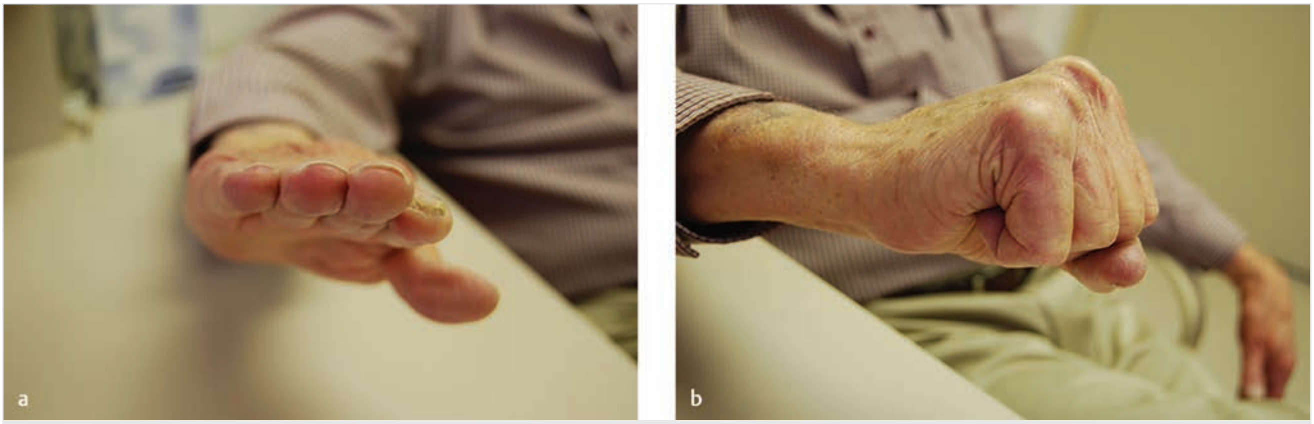

Fig. 16.2 (a, b) Range of motion 8 weeks after surgery.

Fig. 16.3 (a–c) A 75-year-old rheumatoid patient with subluxation in both ulnar and radial directions after sagittal band rupture and steroid injections.

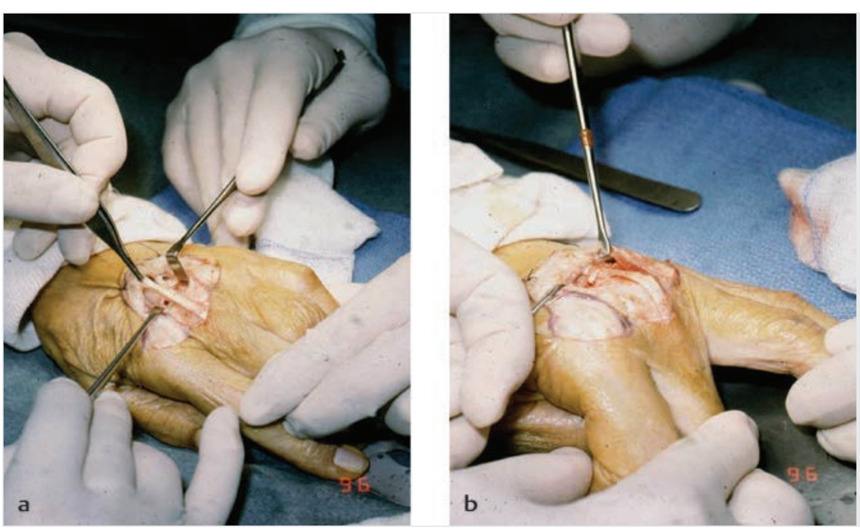

Fig. 16.4 (a, b) Drill hole placed in the metacarpal head and juncturae tendinum graft used to create a pulley over the tendon.

Fig. 16.5 (a, b) Range of motion a few days after surgery. **(c, d)** Final range of motion at 7 weeks.

16.6 Teaching Points

- Often sagittal band ruptures are misdiagnosed because the extensor returns to a centralized position if the patient avoids flexion, but becomes stiff, usually has some degree of angulation with flexion, is tender with palpation on the ruptured side, and will probably experience immediate pain relief in a relative motion extensor splint. Buddy splints, which are popular, will usually remain painful.
- If early diagnosis and treatment is not achieved, the patient will need surgical correction to securely centralize the chronically subluxing extensor tendon.
- Use of relative motion extensor splinting within a few days after surgery will provide protection for the repair (whichever technique) and permit active motion and functional use with the expectation of full range of motion after 6 weeks. This is preferable for acute, nonsurgical, or later surgical management of sagittal band rupture.

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17 Posttraumatic Swan Neck Deformity

Jessica Frankenhoff and Jonathan Isaacs

17.1 Patient History Leading to the Specific Problem

A 24-year-old right-hand-dominant laborer presented with a crushing/twisting injury to his dominant hand after he caught his hand in machinery at a sawmill. Among other joint, bone, and tendon injuries to multiple digits, he sustained an open, extra-articular proximal phalanx fracture of the small finger, which was pinned (▶Fig. 17.1). The pins were pulled 3.5 weeks after the operation, and he began hand therapy. Three months after the operation, he had developed a swan neck deformity (SND) of the small finger. He could bend the digit actively but suffered a painful snapping as the extensor mechanism generated enough tension to force the joint past the fulcrum point from hyperextension to flexion.

17.2 Anatomic Description of the Patient's Current Status

The SND was mostly correctable passively. However, the small finger could not be passively flexed fully to the distal palmar crease, indicating some extensor tendon adhesions as well. The finger was neither tender nor swollen. Bunnell's test was negative for intrinsic tightness. The proximal interphalangeal joint (PIPJ) was hyper-extended to 30 degrees and the distal interphalangeal joint (DIPJ) was flexed to 25 to 30 degrees. He had independent flexor digitorum profundus (FDP) and flexor digitorum superficialis (FDS) function. The difficulty initiating flexion of the small finger and the swan neck posture impeded his grasp and fine motor skills. X-rays indicated a malunion of the proximal phalanx fracture of about 10 degrees apex dorsal angulation (▶Fig. 17.2). The PIPJ and DIPJ were congruent and without arthritis.

17.2.1 Understanding the Problem

To understand the problem, one must determine the etiology of the SND and then choose the best of the available treatment options based on the patient's needs and disabilities.

The term SND refers to a finger with a posture of hyperextension at the PIPJ and concomitant flexion at the DIPJ. Although the appearance of the finger is the same in all instances of SND, the etiology varies. The functional loss associated with this deformity is related to the loss of PIPJ motion. In some patients, the deformity has only minor clinical consequences, and it

Fig. 17.1 Trauma films showing P1 fracture of the small finger.

Fig. 17.2 Films from 3 months post-op showing swan neck deformity and malunion.

is mostly a cosmetic issue. Some may only be bothered by a mechanical snapping into flexion. For others, it can adversely affect function, decrease grip strength, and cause pain.

The extensor mechanism is made up of both extrinsic and intrinsic tendons (▶Fig. 17.3). The extrinsic tendons originating from the extensor digitorum communis (EDC) in the forearm travel over the dorsum of the metacarpophalangeal (MCP) joints into the digits. Over the proximal phalanx, each EDC tendon splits into a central tendon, which inserts onto the base of the middle phalanx, and two lateral slips, which join with the lateral bands to form the conjoined tendon just distal to the PIPJ. The conjoined lateral band continues until its insertion onto the base of the distal phalanx, at which point it is known as the terminal tendon. The intrinsic extensor mechanism has contributions from both the lumbricals and the dorsal interossei. The lumbricals originate from the radial aspect of the corresponding FDP tendons. The deep head of the dorsal interossei passes superficially to the sagittal band and contributes to both the transverse fibers of the extensor hood over the middle aspect of the proximal phalanx (to provide a flexion moment arm to the MCP joint) and to the medial band of the interosseous, which blends with the central slip and helps extend the PIPJ. The transverse retinacular ligaments originate from the flexor tendon sheath and insert onto the palmar aspect of the lateral bands to prevent their dorsal subluxation, while the triangular ligament distally binds the lateral bands into the conjoined lateral band and prevents the slips from subluxing palmarly. The extrinsic extension system normally extends the MCP joint (via the extensor hood volar connections), while the intrinsic system flexes the MCP joint and extends the PIPJ and DIPJ. When both systems work in synergy, the digits have coordinated and controlled extension through all three joints.

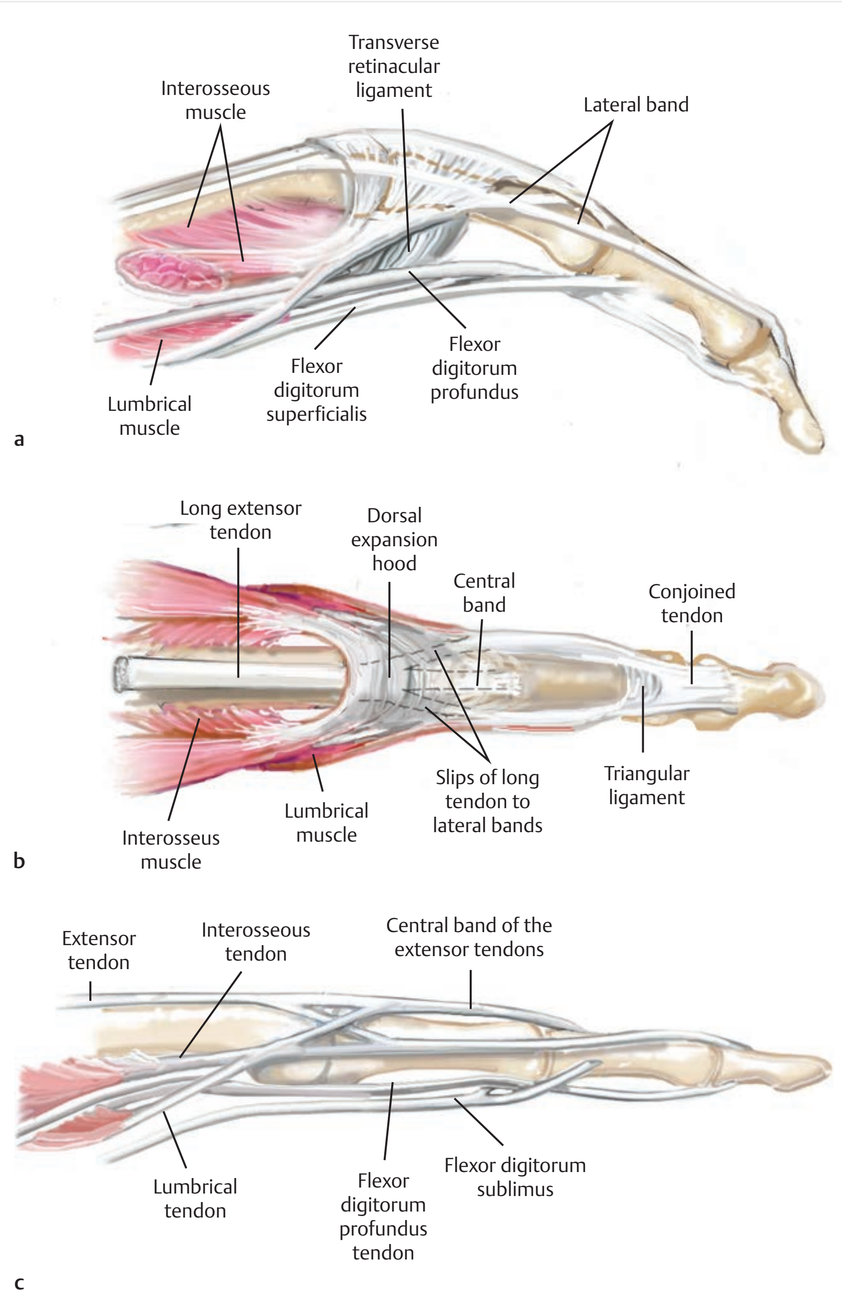

Fig. 17.3 (a–c) Extensor tendon anatomy.

SND is caused by an imbalance in this extensor mechanism. That imbalance originates in one, or sometimes more, of three areas: (1) extrinsically, at the level of the forearm, wrist, or MCP joint; (2) intrinsically, from the intrinsic extensor tendon system; or (3) at the articular level of the PIPJ or DIPJ themselves. For example, a wrist or MCP joint flexion contracture increases extrinsic EDC tension. This increased tension is transmitted to the base of the middle phalanx via the central slip insertion and can result in hyperextension of the PIPJ. Alternatively, contracture or spasticity of the intrinsic system can flex the MCP joint and hyperextend the PIPJ (via the lateral bands) resulting in the same deformity. A loss of PIP flexion tone from a disruption to the superficialis tendon (which inserts onto the volar base of the middle phalanx) can have the same result though by creating an intrinsic extension/extrinsic flexion force imbalance that allows the PIPJ to hyperextend. Finally, proximal migration of the extensor mechanism due to terminal tendon disruption at the DIPJ (mallet finger) can increase extensor force to the central slip and hyperextend the PIPJ by yet a different mechanism, while laxity (or stretching) of the volar plate of the PIPJ can independently contribute to the SND.

17.2.2 Evaluation

The diagnosis of SND is based just on physical appearance of the digit and functional complaints. The pathophysiology of the tendon imbalance, the presence of arthritis in the joints, and the quality of the soft-tissue envelope and tendency for tendon adhesions must all be considered in designing a successful treatment strategy. A history of known disease states (e.g., rheumatoid arthritis, cerebral palsy) or trauma (e.g., mallet deformity, volar plate avulsion fracture) can direct the workup, and radiographic evaluation of the joints should reveal degenerative and posttraumatic joint conditions.

The passive and active range of motion of the wrist, MCP, and IP joints should be evaluated both with the hand in its resting posture and with the SND passively corrected. This can allow the identification of a chronic mallet injury from either traumatic disruption or gradual attenuation of the terminal slip insertion. Extrinsic tightness can be assessed by evaluating changes in extrinsic extensor tendon tension related to wrist position. Extension of the wrist would allow more finger flexion in the presence of extrinsic tightness. Intrinsic tightness, on the other hand, can be determined utilizing the Bunnell test. The Bunnell test is performed by holding the MCP joint in extension and then in flexion while actively or passively flexing the PIPJ. Decreased passive PIPJ flexion with the MCP joint in extension is compatible with intrinsic tightness (lateral bands run volar to MCP joints and dorsal to the IP joints).

The SND can be classified into one of four types as devised by Nalebuff and Millender:

- Type I: full range of motion of the joints with no significant functional limitations.
- Type II: intrinsic tightness as shown by a positive Bunnel test; the PIPJ can be ranged fully with MCP joint held in flexion only.
- Type III: the PIPJ is stiff both actively and passively irrespective of the position of the MCP joint.
- Type IV: the same as type III, but with radiographic arthritic changes at the PIPJ.

17.2.3 Choose the Best of the Available Treatment Options Based on Patient's Needs and Disabilities

Type I

For a type I deformity, only the PIPJ hyperextension needs to be addressed. This can be done by decreasing the amount of skin volarly with a dermodesis or by creating a mechanical restriction to extension with an FDS sling, an oblique retinacular ligament (ORL) reconstruction, or a lateral band rerouting procedure. Excising and closing an ellipse of skin from the volar aspect of the PIPJ is only helpful for very mild deformity (and can stretch out with time). A stronger restraint to hyperextension can be achieved using the FDS to create a restraint sling known as the "sublimis sling." This was performed on our patient, and is described later under the section "Technique." These strategies only address the PIP hyperextension and not the DIPJ extension lag. If this appears to be a persistent problem even with the PIP passively corrected than one of the following reconstructions can be used. In the ORL reconstruction, the ulnar lateral band is freed from the extensor mechanism proximally at the level of the MCP joint, passed volar to Cleland's ligament and volar to the PIPJ axis of rotation, and sutured radially either to the flexor tendon sheath or passed through the proximal phalanx via a bone tunnel. Alternatively, a palmaris free graft can be used, sutured to the terminal tendon, then following the same path as the ulnar lateral band as described earlier. Finally, one or both lateral bands are freed from their dorsal attachments, translocated palmarly, then either sutured to the ipsilateral FDS slip and volar plate or placed into a flap made in the flexor tendon sheath at the PIPJ level.

Type II

For a type II deformity, the same procedures as in type I are available for the PIPJ deformity, but the MCP joint needs to be addressed as well. Often, this is done with just an intrinsic release. However, any MCP joint or wrist disorder that aggravates the imbalance of the finger such as subluxation or deviation must be corrected as well.

Type III

For a type III deformity, in addition to the intrinsic release, the PIPJ needs to be released. There is often a paucity of skin dorsally that may need to be addressed. A formal joint release with transection of the collateral ligaments, volar translocation of the lateral bands, and possible step-cut lengthening of the central slip may be necessary. Also, due to the prolonged lack of range of motion, there may be flexor tendon adhesions, which need to be freed simultaneously. This approach is obviously more complex and the results tend to be less predictable.

Type IV

For a type IV deformity, the PIPJ needs to be addressed most commonly with an arthrodesis.

The Presented Case

Our patient had a type 1 SND, complicated by the proximal phalanx malunion and extensor tendon adhesions. His biggest problems were initiating flexion and keeping his small finger from catching on objects in its resting swan posture. Dermodesis was unlikely to be sufficient or lasting in a young laborer. This left the superficialis sling surgery, the lateral band translocation procedure, and the ORL reconstruction. The final option also helps correct DIP flexion deformity. His DIP flexion deformity was not severe enough to warrant correction especially in the small finger and because of the crush nature of his initial injury, there were concerns about the propensity for adhesions and stiffness with a more complex procedure.

17.3 Technique

The patient was taken to the operating room after administration of regional anesthesia and placed in the supine position on the operating table. An upper extremity tourniquet was inflated to 250 mm Hg. Wide-awake surgery local anesthesia without tourniquet (WALANT) is also an option and is normally the author's preference as it allows for visualization of the range of motion in real time and allows for any necessary modifications at the time of surgery. However, this was not possible in this case due to the necessity of performing several concomitant procedures.

There are multiple approaches to exposing the flexor tendon sheath, and many variations in technique for creating the sling (e.g., using one or both slips of FDS, securing the tendon through the A1 or the A2 pulley or to the proximal phalanx).

In this case, a Brunner incision was made from the level of the A1 pulley to the level the A3 pulley. Skin flaps were created and held to the side with 4–0 silk retention sutures. A beaver blade and freer were slid under the extensor mechanism from both the radial and ulnar sides, freeing the extensor mechanism from the proximal phalanx where it was adherent in the region of the fracture. The A3 pulley was then incised, exposing the distal end of the flexor superficialis tendon toward its insertion at the base of the middle phalanx (▶Fig. 17.4a). To make

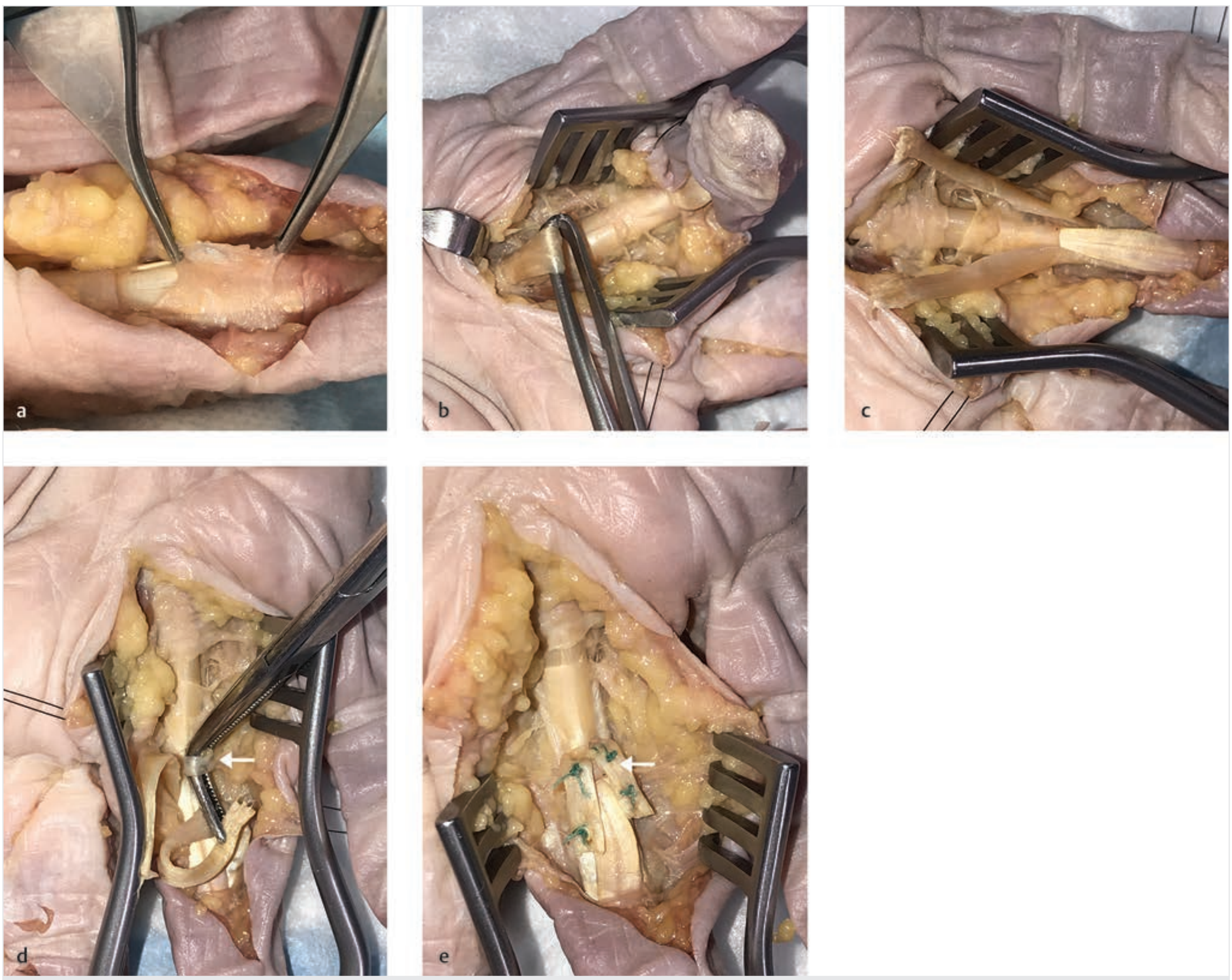

Fig. 17.4 (a) Venting the A3 pulley. **(b)** Isolating the flexor digitorum superficialis (FDS) proximal to the A1 pulley. **(c)** Both slips of the FDS freed to the level of their insertion. **(d)** Pulling the FDS slips through the transverse rent in the A2 pulley (*white arrow* at distal edge of A2 pulley). **(e)** FDS slip sutured to the edge of the A2 pulley and to itself (*white arrow*).

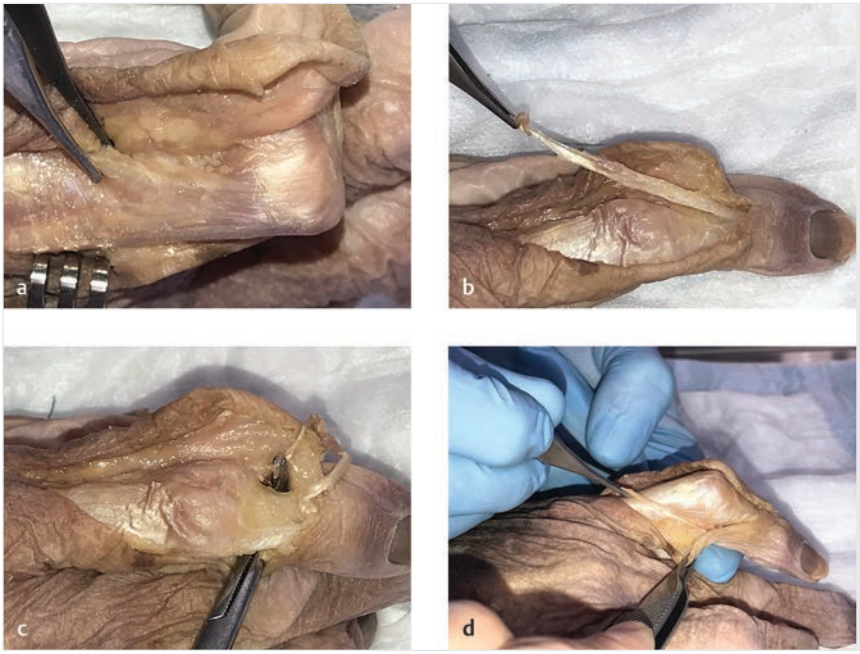

Fig. 17.5 Cadaver depiction of an oblique retinacular ligament reconstruction. **(a)** Identify the ulnar lateral band. **(b)** Transect the ulnar lateral band proximally and free to the level of the distal interphalangeal joint. **(c)** Pass the lateral band volar to the flexor tendons at the level of the proximal interphalangeal joint. **(d)** Tension the translocated lateral band and secure proximally at the level of the proximal phalanx.

sure there were no flexor tendon adhesions, an Allis was placed around the profundus and superficialis tendons proximal to the A1 pulley and used to gently twirl the tendons around it. This simulated active flexion of the tendons. Each was tested independently. There was a bit of catching of the profundus and a freer was placed between the profundus and the bone, releasing the adhesion.

The superficialis was then isolated just proximal to the A1 pulley (▶Fig. 17.4b). The slips of the tendon were very small, so both slips were taken. The tendon ends were pulled proximally and the chiasm cut. Then, through the opening previously made in the A3 pulley, both of the tendon ends were pulled distally (▶Fig. 17.4c). The slips of the FDS were then passed through a small transverse opening made with a beaver blade in the distal one-third of the A2 pulley. The ends of the tendon were grasped with a right angle that was then fed underneath the distal edge of the A2 pulley and popped through the rent in the pulley in a dorsal to volar direction (▶Fig. 17.4, d). The superficialis was looped back distally, the PIPJ pulled down into 20 degrees of flexion and the slip was sutured to itself and to the distal edge of the A2 pulley with 4–0 Ethibond (▶Fig. 17.4e). The profundus tendon was then located proximally, grasped with an Allis, and the tendon was twirled again, confirming good excursion of the profundus tendon. The wounds were irrigated with normal saline. Interrupted 4–0 nylon suture was used to approximate the skin edges. A dorsal blocking splint was placed, preventing hyperextension of the PIPJ. The patient was encouraged to flex the digit actively within the confines of the splint.

17.3.1 Steps for Superficialis Sling Procedure

1. Expose flexor tendon sheath.
2. Isolate one or both slips of the FDS either proximal to the A1 or between the A1 and A2 pulleys.
3. Cut one or both slips of the FDS proximally leaving at least a 5-cm tail.
4. Pull the tendon distally, then from distal to proximal, pop the tendon slip through the mid to distal one-third of the A2 pulley with a right angle.
5. Secure the FDS slip back to itself and the edge of the A2 pulley with a 4–0 nonabsorbable stitch, making sure to keep the PIPJ in 20 to 30 degrees of flexion.
6. Close and place a dorsal blocking splint.

Another alternative to the FDS sling is the ORL reconstruction. In this procedure, a curvilinear incision is made over the dorsal aspect of the finger exposing the extensor mechanism from the base of the proximal phalanx to the DIPJ. The ulnar lateral band is identified (▶Fig. 17.5a), cut proximally, and freed to the level of the DIPJ (▶Fig. 17.5b). The mobilized band is pulled proximally, extending the DIPJ, and is then passed volar to the Cleland ligament just distal to the PIPJ with a large right angle (▶Fig. 17.5c). This creates a pull volar to the axis of rotation of the PIPJ, thus flexing the PIPJ. The band is tensioned to flex the PIPJ roughly 30 degrees and secured to the mid-proximal phalanx through a drill channel in the phalanx, a suture anchor, or suture fixation to the edge of the flexor tendon sheath (▶Fig. 17.5d). Once healed, active extension of the PIPJ will be restrained by the rerouted lateral band though subsequent tension of this band will simultaneously extend the DIPJ.

17.3.2 Steps for Oblique Retinacular Ligament Reconstruction Procedure

1. Expose the extensor mechanism from P1 to P3.
2. Identify the ulnar lateral band and transect at the level of P1.
3. Free the lateral band to the level of the DIPJ.

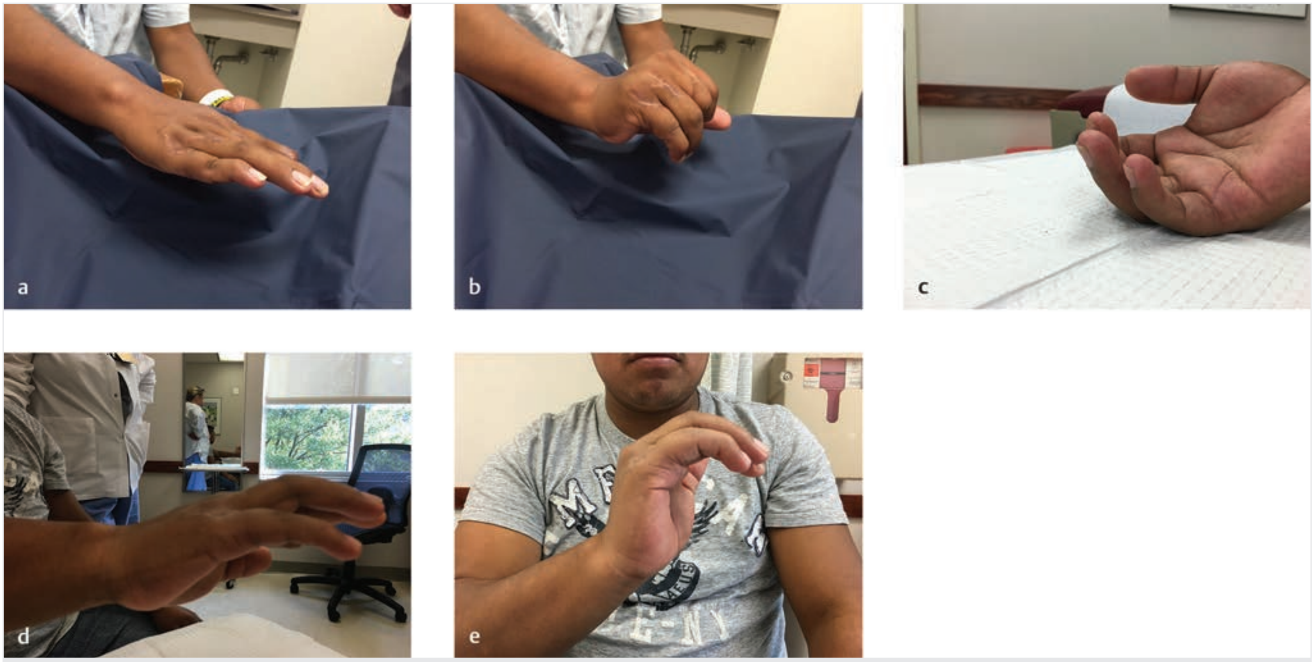

Fig. 17.6 **(a, b)** Before sublimis sling surgery. **(c–e)** After sublimis sling surgery.

4. Pass the lateral band volar to Cleland's ligament from ulnar to radial just distal to the PIPJ.
5. Secure the lateral band to the radial side of P1 with the PIPJ in 30 degrees of flexion.
6. Close and place a dorsal blocking splint.

17.4 Postoperative Photographs and Critical Evaluation of Results

A goal of hand surgery is to make the patient's postoperative function better than their preoperative function. The patient's resting posture was better than preoperatively, and his initiation of flexion was no longer problematic (▶Fig. 17.6a, b). At last follow-up, he was quite pleased with his progress. However, his ultimate flexion never returned to normal and he never regained as much passive flexion as was demonstrated in the OR nor active flexion as simulated by pulling on his FDP intraoperatively (▶Fig. 17.6c–e). His postoperative course was hindered by his distance from our facility, making therapy follow-up with our certified hand therapists difficult but validating our concerns regarding more complex reconstructive options.

17.5 Teaching Points

- Assess if the swan neck is secondary to disease (rheumatoid or cerebral palsy, etc.) versus a trauma.
- Determine the cause of the SND.
- Remember that other structures other than the obvious PIPJ may be involved (e.g., the MCP joint) and that all abnormalities must be addressed for an optimal outcome.
- Keep the joint in flexion postoperatively with a dorsal blocking splint to protect the repair.

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Part VI

Problems with Vasospasm

18 Refractory Raynaud's Phenomenon *76*

VI

18 Refractory Raynaud's Phenomenon

Collier S. Pace, Lauren Hutchinson, and Michael W. Neumeister

18.1 Patient History Leading to the Specific Problem

A 42-year-old woman presents with severe ischemia to bilateral hands. She has had a long-standing diagnosis of Raynaud's disease with no diagnosis of an autoimmune disorder. She previously had proximal sympathectomies as well as palmer and digital sympathectomies. The progressive ischemia resulted in amputation of the thumb, index, and long finger (▶Fig. 18.1). Her current presentation involves severe ischemia to all fingers of the right hand as well as the remaining digits on the left hand. She was extremely worried about losing the remaining fingers on the left hand as well as digits on the right as this was her primary hand for daily activities. Proximal sympathetic blocks did not work and the discussion with the patient hinged around repeat palmer and digital sympathectomy or Botox (or onabotulinumtoxinA) injections.

18.2 Anatomic Description of the Patient's Current Status

Raynaud's phenomenon is a painful vasospastic condition of the digits usually induced by stress or exposure to the cold. The vasospasm produces a characteristic triphasic color change in the hands that begins with pallor, cyanosis, and finally hyperemia. If prolonged, arterial vasospasm can lead to digital ischemia resulting in ulcerations and gangrene.

While the definitive etiology for Raynaud's phenomenon has yet to be elucidated, several theories have been proposed. The majority of the theories are centered around a dysfunctional local sympathetic nervous system. However, other studies implicate abnormal platelet function or red blood cell morphology or dysregulation of neuropeptides.

18.3 Recommended Solution to the Problem

Initial treatment of Raynaud's phenomenon is nonoperative and characterized by behavior modifications including smoking cessation and reducing cold exposure and stress. In addition to lifestyle changes, pharmacologic agents directed at altering the abnormal arterial vascular response seen in Raynaud's phenomenon are the primary mainstay for treatment. Calcium channel blockers are utilized most commonly; however, phosphodiesterase-5 inhibitors and endothelin antagonists are also frequently used. If a patient fails conservative management, additional interventions should be considered.

Cervical dorsal sympathectomy, digital sympathectomy, and arterial bypass grafting are all accepted surgical techniques to treat refractory Raynaud's phenomenon. However, these interventions can be associated with significant morbidity and have varying results.

There continues to be much debate regarding the location and extent of dissection for digital sympathectomies. Proximal, or thoracic, sympathectomy has fallen out of favor by most due to the disappointing long-term results. Sympathectomy is most effective if performed closer to the location of symptoms, with a more extensive palmar dissection to improve long-term outcomes. Extended periarterial sympathectomy, which includes the adventitia of the ulnar artery, superficial arch, common digital vessels past their bifurcation, along with the radial artery as it courses dorsally, improves ischemic pain in 95% of patients and will allow digital ulcers to completely heal in almost 80% of cases.

However, surgical sympathectomy may not result in long-term improvement as well. Also, some patients may be unwilling to undergo surgery. Botox injections are an excellent option in these situations. While the exact mechanism of action for

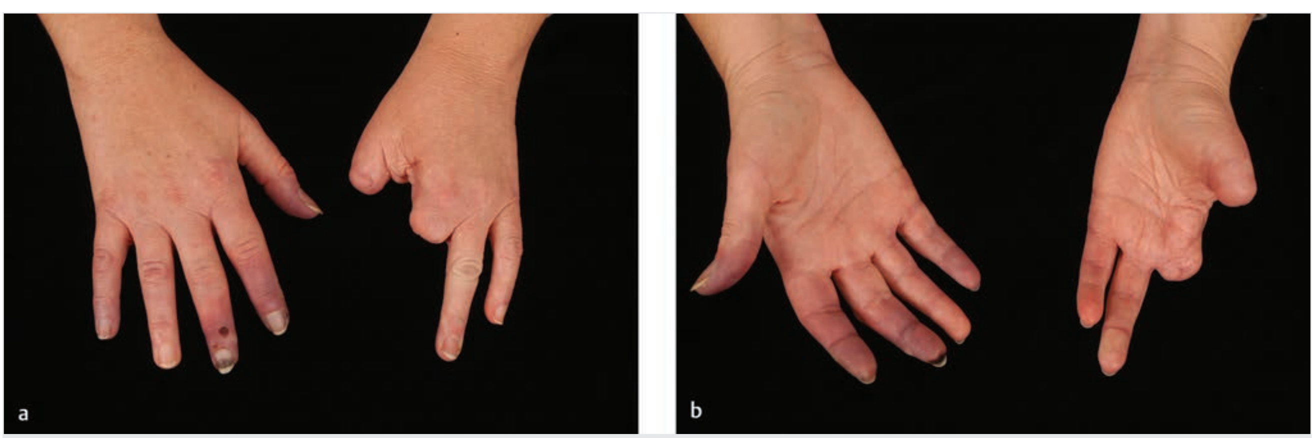

Fig. 18.1 (a, b) Patient on presentation. Note the discoloration of distal digits and evidence of ischemic ulceration.

botulinum toxin has yet to be clarified, a number of clinical studies have demonstrated excellent results. Botox may work by blocking ectopic sodium channels or specific chronic pain receptors such as transient receptor potential vanilloid 1 (TRPV-1) or it may work through the sympathetic blockade or even through modulation of neurotransmitters such as substance P, calcitonin gene–related peptide, norepinephrine, and glutamate.

Palmar injection of botulinum toxin type A has been shown to increase tissue perfusion, significantly reduce or even eliminate pain, and result in complete resolution of digital ulcers with minimal associated morbidity.

Our patient elected to undergo botulinum toxin injection. Her previous palmar sympathectomies had failed. Botox injections involve very little downtime, as patients can resume their normal activities the same day.

18.4 Technique

This procedure can be performed in the office. A wrist block should be performed prior to the procedure to eliminate the pain and burning sensation associated with the onabotulinumtoxinA injection (▶Fig. 18.2). One hundred units of onabotulinumtoxinA is reconstituted with 20 mL of injectable, preservative-free normal saline, resulting in a final concentration of 5 U/mL. The 20 mL is divided between both hands with 2 mL or 10 U per each neurovascular bundle. The patient's volar hands are cleansed with alcohol wipes over the planned injection areas. Under aseptic technique, 2 mL is injected just proximal to the A1 pulley for each neurovascular bundle.

Fig. 18.2 Injection technique for Botox. (Adapted from Neumeister MW. Botulinum toxin type A in the treatment of Raynaud's phenomenon. J Hand Surg Am 2010;35(12):2085–2092.)

18.5 Postoperative Photographs and Critical Evaluation of Results

The patient noted improved warmth, decreased pain, and better range of motion of her fingers (▶Fig. 18.3). A laser perfusion scan demonstrated the increased blood flow to the left hand as a result of the Botox injection (▶Fig. 18.4). The patient remains symptom free 4 years out from the Botox injections.

Available clinical data demonstrate that Botox injection improves ischemic pain in greater than 75% of patients, and the majority go on to heal digital ulcerations within 3 months. While many patients experience a dramatic improvement in their symptoms, 20 to 45% require additional injections and some simply do not benefit from this modality. Further research will help clarify patient selection for surgical or chemical sympathectomy, and allow us to better understand this challenging disease process.

18.6 Teaching Points

- Side effects are minimal and include pain with injection, anhydrosis, and temporary intrinsic muscle weakness.
- Local anesthetic application in the form of wrist block for the median and ulnar nerves prior to the onabotulinumtoxinA injection can eliminate pain associated with the multiple injections.
- Injections should be carefully placed at the bifurcation of the common digital nerves and vessels just proximal to the A1 pulley with the goal of bathing the neurovascular bundle.
- Make sure to aspirate before injection to ensure needle location is not intravascular.
- Pain relief can occur as quickly as 5 minutes but often takes several days or weeks.

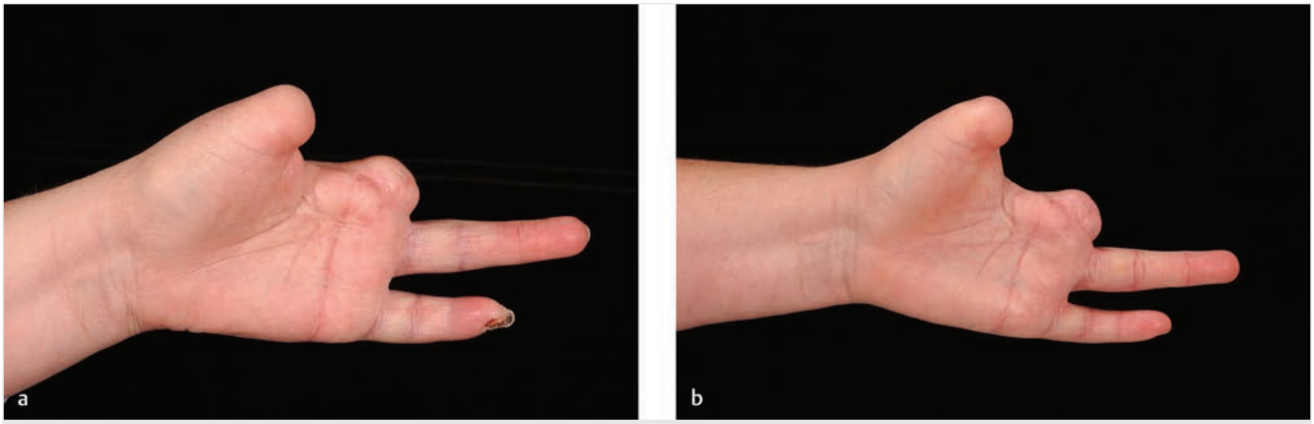

Fig. 18.3 **(a, b)** Preoperative compared to postoperative photographs. Note the improved and uniform digit coloration postoperatively, along with healing of digital ulceration of the small finger.

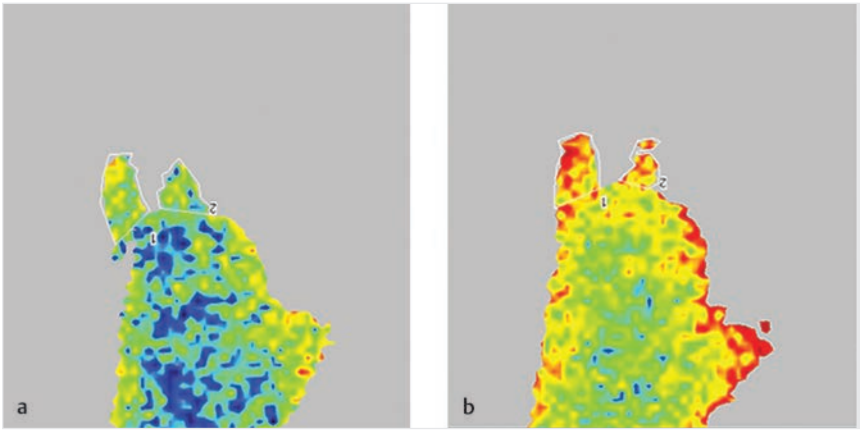

Fig. 18.4 (a, b) Preoperative versus postoperative laser Doppler analysis demonstrating improved perfusion. (Adapted from Neumeister MW. Botulinum toxin type A in the treatment of Raynaud's phenomenon. J Hand Surg Am 2010;35(12):2085–2092.)

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Part VII

Problems with Compression Neuropathy

19 A Practical Approach to Recurrent Carpal Tunnel Syndrome *80*

20 Recurrent Carpal Tunnel Syndrome *83*

21 Failed Carpal Tunnel Release: Recognizing the Lacertus Syndrome *87*

22 Cubital Tunnel Release at the Elbow *91*

23 Recurrent Cubital Tunnel *96*

24 Recurrent Ulnar Neuropathy *101*

25 Radial Tunnel Release in the Forearm *104*

VII

19 A Practical Approach to Recurrent Carpal Tunnel Syndrome

Robert C. Russell and Franziska Huettner

19.1 Patient History Leading to the Specific Problem

A 37-year-old man had a left carpal tunnel release 6 years ago. The symptoms of numbness and tingling improved but never completely resolved after the surgery. Over the past 6 months, the symptoms had become more pronounced to the point where they now interfered with the activities of daily living. Repeat nerve conduction study (NCS)/electromyogram (EMG) revealed severe median nerve compression neuropathy at the carpal tunnel.

19.2 Anatomic Description of the Patient's Current Status

Carpal tunnel release is the most frequent surgical procedure performed by hand surgeons around the world. The prevalence of carpal tunnel syndrome in the United States is estimated to be up to 3.72% with approximately 500,000 releases performed annually. The majority of patients do well after surgery without complications or recurrent symptoms. Major complications such as permanent injury to branches of the median nerve are rare (0.01–0.12%), as is injury to the nerve proper (0.06%). A small percentage of patients (usually less than 3%, and also as high as 20%), however, experience persistent or develop recurrent symptoms after release. Despite the small number of patients who require reoperation, the surgeon is faced with the dilemma of deciding which patients may benefit from re-exploration of the median nerve at the wrist, the timing of reoperation, and exactly what to do differently to adequately release the nerve and/or prevent another recurrence.

There appears to be a number of reasons for recurrent symptoms at re-exploration. Some patients had what appeared to be an intact or reformed transverse carpal ligament, which required division a second time. Persistent symptoms in these patients may have been caused by either incomplete release of the flexor retinaculum or the antebrachial fascia. More often, the median nerve was encased in thick extraneural scar, which appeared to cause compression and/or prevented gliding of the nerve during finger and wrist motion or appeared to decrease the nerve's blood supply within the carpal tunnel. In a few patients, the nerve was found to course outside the carpal canal and was lying in a superficial position directly under the skin. Pressure from a knife or tool handle could easily produce nerve symptoms in such patients.

The patients who develop recurrent symptoms are a more difficult problem. The author usually tries to manage them with hand therapy modalities, including massage, nerve desensitization, active and passive range of motion exercises, neural glides, Kinesio tape, deep heat, etc., for some time before agreeing to re-explore a compressed or irritable nerve. It is generally better to wait for at least 6 to 8 months after the original release and attempt therapy measures before agreeing to re-explore a symptomatic patient.

In general, simple decompression and external neurolysis alone is not favored for revision surgery due to inferior outcomes. One should not expect a better outcome by using the same operative approach for a second time, or as Dr. L. Vasconez would say: "If plan A doesn't work, don't make plan B the same as plan A." A wide range of options used for revision surgery have been described. They include, but are not limited to, the use of a vascularized hypothenar fad pad flap; muscle flaps, like the palmaris brevis turnover flap, the pronator quadratus muscle flap, or abductor digiti minimi muscle flap; a radial artery perforator fascial flap, a tenosynovial flap, vein wrapping, and even the use of omentum as free flap. There are advantages and disadvantages to each of these options.

19.3 Recommended Solution to the Problem

The author's preferred choice for patients with difficult recurrent carpal tunnel syndrome or with a scarred nerve with pale segments after tourniquet release is to wrap the nerve in well-vascularized adipofascial flap harvested as a distally based ulnar artery perforator flap from the volar wrist.

This flap has several advantages:

- Use of the previous incision.
- Extension of the incision into forearm, instead of more visible palmar hand.
- No sacrifice of a hand muscle.
- Little risk of injury to the palmar cutaneous branch.
- A reliable blood supply.
- No additional remote donor site.
- No use of microscope.
- Technically feasible without need for a specialty center.

19.4 Technique

The transverse carpal ligament is incised, and, as in primary releases, a 1- to 2-mm segment of the ligament is excised (▶Fig. 19.1a). Nerves encased in thick scar are freed by sharply

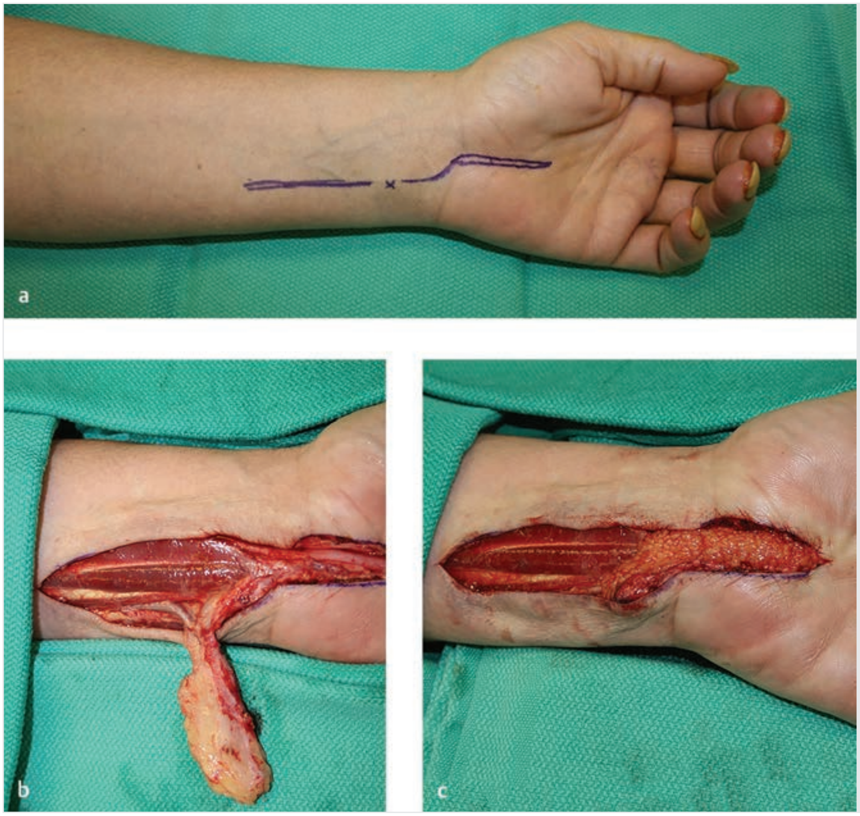

Fig. 19.1 **(a)** The old carpal tunnel scar is excised and the incision extended proximally over the flexor carpi ulnaris. **(b)** The skin edges are elevated in a subdermal plane. The fascia/fat flap is elevated from proximal to distal preserving the most distal ulnar artery perforator. **(c)** The flap is turned over and around the median nerve providing vascularized soft-tissue coverage.

excising the scar under magnification with a scalpel. The canal of Guyon is opened if not previously done. The ulnar artery fat/fascial perforator flap is dissected by extending the palmar carpal tunnel incision proximally in a zigzag or an **S**-shaped incision over the ulnar artery. The skin is elevated at a level just below the deep dermis, and a fat and fascial flap of approximately 2 × 4 cm is outlined over the ulnar artery. Beginning in the middle of the distal forearm, the fat and deep muscle fascia is incised and carefully elevated toward the ulnar artery. The ulnar side of the flap is similarly elevated radially toward the artery. In some larger flaps, the dorsal branch of the ulnar nerve should be identified in the proximal portion of the dissection and preserved. The fat/fascial flap is then elevated from proximal to distal toward the distal wrist crease, preserving the most distal perforating vessel from the ulnar artery, which arises approximately 1 to 1.5 cm proximal to the pisiform bone (▶Fig. 19.1b). The flap is dissected under tourniquet control, which is released prior to turning the flap over on the nerve in the carpal tunnel. Occasionally, some subcutaneous fat, synovium, or palmar fascia may be excised to provide adequate space for the transposed flap (▶Fig. 19.1c), permitting a loose palmar skin closure, again over a 19-G butterfly drain. The flap places vascularized soft tissue around the nerve and has prevented further recurrences in our patients. Occasionally, the donor site incision skin edges have experienced delayed wound healing, but none have required reoperation.

A small drain is left in place for the first 3 to 5 days post-op. A butterfly needle can be used where the needle end is inserted into a red rubber top blood collection tube. The patient has the wrist splinted for 10 to 14 days. Therapy is thereafter initiated for range exercises.

19.4.1 Steps for the Procedure

1. Rerelease and reposition of median nerve with neurolysis.
2. Ulnar artery fat/fascial perforator flap.
3. Drain ×24 hours.
4. Splint in wrist extension for 5 days.

19.5 Postoperative Photographs and Critical Evaluation of Results

The patient had complete resolution of the carpal tunnel symptoms. At 6 months, there was no evidence of recurrence. The scars and range of motion are documented in ▶Fig. 19.2.

19.6 Teaching Points

- The procedure is performed through the previous scar and extended proximally just radial to the flexor carpi ulnaris tendon.
- All scar tissues are removed within the carpal tunnel.
- The adipofascial flap is elevated based on a perforator from the ulnar artery.

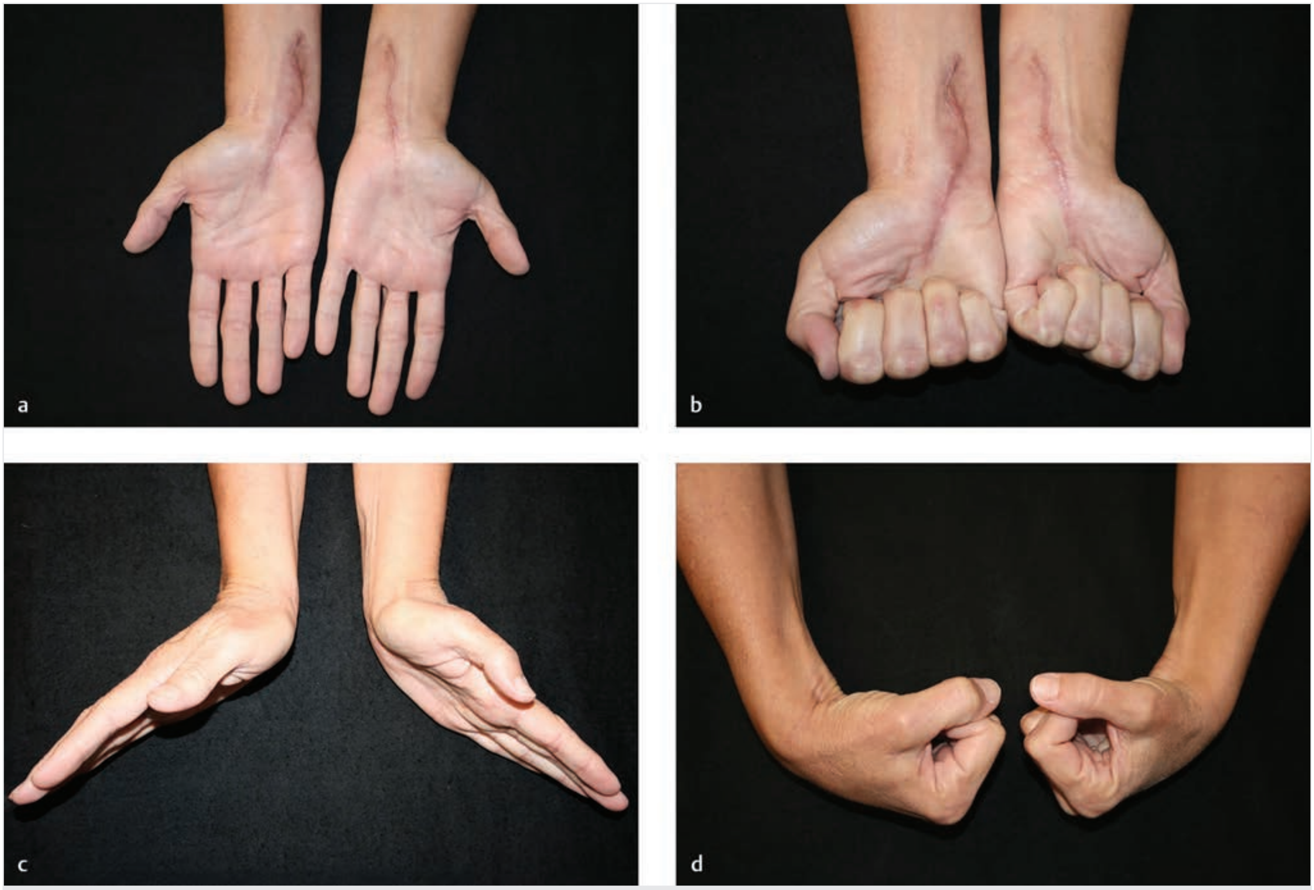

Fig. 19.2 (a–d) The patient has full finger and wrist flexion and extension without nerve symptoms.

- The flap is designed proximal enough to reach the distal end of the carpal tunnel.
- The pivot point of the flap is just proximal to the feeding perforator.
- The flap is inset without tension.

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20 Recurrent Carpal Tunnel Syndrome

Chye Yew Ng and Michael J. Hayton

20.1 Patient History Leading to the Specific Problem

A 55-year-old woman who suffers from type 2 diabetes mellitus underwent a left carpal tunnel release (CTR) under local anesthesia 3 years previously. Postoperatively, she enjoyed 6 months of complete relief of paresthesia and the nocturnal symptoms in her hand. Since then, the tingling sensation has gradually recurred. She then underwent repeat nerve conduction studies, which showed slowing of conduction velocities across the wrist although still marginally better than the preoperative values. This was considered a true recurrent carpal tunnel syndrome (CTS) given the defined period of resolution of the initial symptoms.

20.2 Anatomic Description of the Patient's Current Status

The patient has a well-healed open carpal tunnel scar. She has reduced sensation in the radial three digits. Thenar eminence has preserved muscle bulk and abductor pollicis brevis power is medical research council grade 5. Tinel's and Phalen's signs are positive. By asking the patient to flex and extend the fingers and wrist repetitively, shooting tingling sensation into the radial three digits could be reproduced. This implies tethering and restricted excursion of the median nerve. This clinical finding has been named "traction Tinel sign." In addition, she complains of subjective digital stiffness, which is not a symptom often volunteered by patients and we believe it should be specifically enquired in such cases. Chronic diabetic patients are known to develop diabetic cheiroarthropathy with the classic moon shape to the hand and digits. However, one should also consider the possibility of scarring surrounding the flexor tendons and tenosynovitis in revision situation as a contributory cause to the digital stiffness and recurrent CTS. In this patient, the potential of background diabetic neuropathy contributing to some of her symptoms needs to be acknowledged.

Following division, the transverse carpal ligament (TCL) heals in a more convex shape within 6 weeks. As a result, there is anterior displacement of the carpal contents (~3.5 mm) and an increase of the carpal canal volume (~24%). The commonest cause of persistent symptoms following CTR is believed to be due to incomplete release of the TCL. Recurrent CTS is often attributed to circumferential fibrosis around the median nerve. New symptoms, particularly worsening pain or neurological deficit, may imply iatrogenic injury to the nerve.

20.3 Recommended Solution to the Problem

Accurate clinical assessment remains the key in approaching the problem. First and foremost, the diagnosis of CTS needs to be confirmed. More proximal causes of neural compression, such as cervical radiculopathy and pronator syndrome need excluding. Systemic conditions (such as diabetes mellitus and alcoholism) that could be confounding factors need recording. Establish if the CTS is persistent, recurrent, or a new phenomenon. Patients with suspected iatrogenic injury should be explored urgently. The other patients may benefit from a period of hand therapy. Occasionally, steroid injection could help in indeterminate cases, but the response should not be taken as absolute indication or contraindication to further surgery. Patients who do not respond to conservative measures are offered revision surgery.

During revision surgery, a methodical approach should be adopted. The median nerve is carefully explored from proximal to distal in the carpal tunnel. An external neurolysis ± epineurotomy of the median nerve is then performed. Internal neurolysis is not recommended, as it tends to lead to more neural scarring. Flexor tenosynovectomy has not been shown to offer additional benefit in primary CTR, but can improve digital stiffness in revision cases. In addition, it would also debulk the carpal canal contents creating space for any secondary nerve coverage procedure.

Multiple nerve wrapping options have been described, which can be grouped under autologous tissues or synthetic materials. The need for such intervention is yet to be supported by a prospective randomized controlled trial. However, when faced with a heavily scarred median nerve during revision situations, it would seem logical to devise a strategy to prevent further recurrence after neurolysis. Hypothenar fat pad flap is our preferred option due to its local availability and provision of vascularized tissue coverage.

20.3.1 Recommended Solution to the Problem

- Perform a thorough decompression and external neurolysis of the median nerve, followed by flexor tenosynovectomy.
- Options of nerve wrapping for autologous tissues are:
  - Hypothenar fat pad flap.
  - Synovial flap.
  - Muscle flap.
  - Fascial flap.
  - Vein wrapping.
- Options for synthetic wraps (commercially available) are:
  - Type I collagen.
  - Submucosal extracellular matrix.

20.4 Technique

The procedure is performed under a regional or general anesthesia, with loupe magnification. The healed scar is utilized and extended proximally (▶Fig. 20.1a). The median nerve is first identified within normal tissues at the distal forearm by releasing the antebrachial fascia. Dissection then proceeds in a

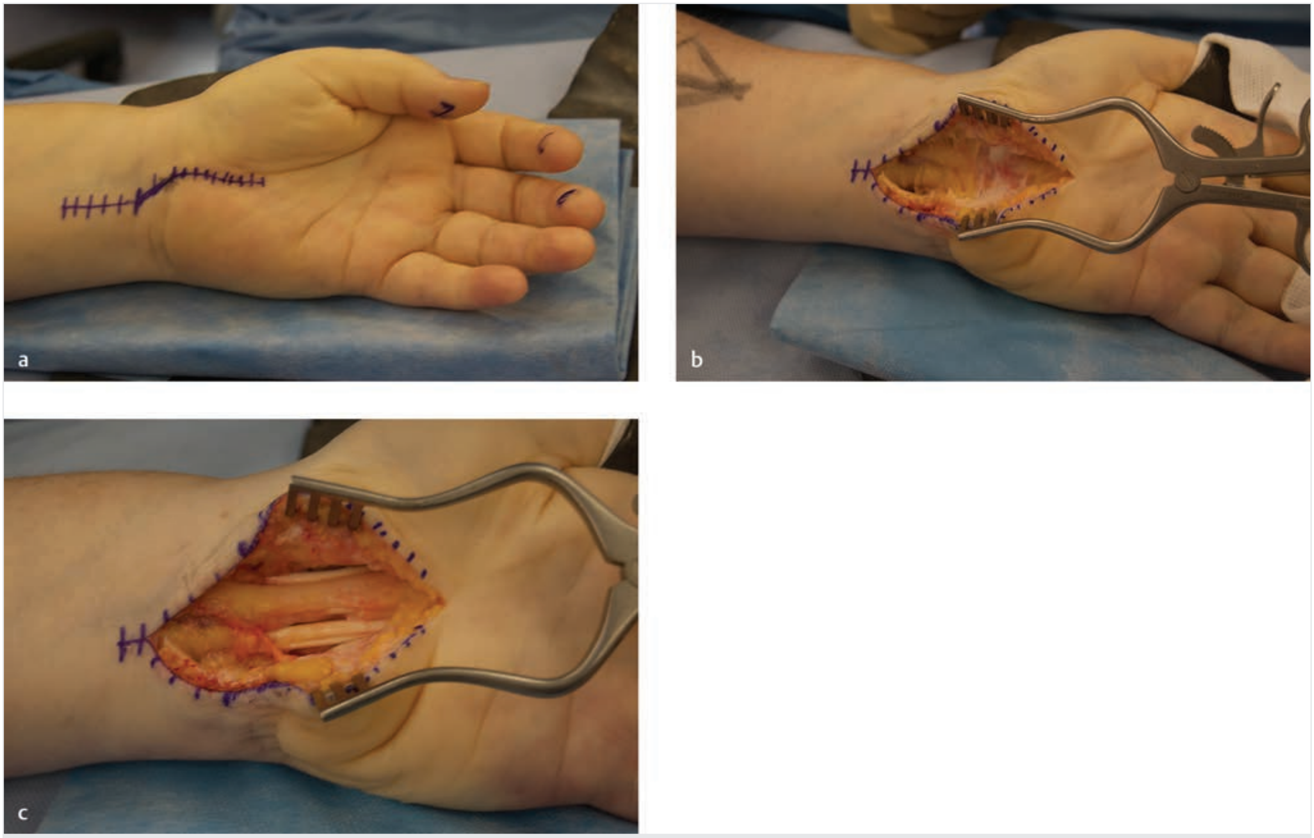

Fig. 20.1 **(a)** Incision is marked over the existing scar (and extended proximally and distally). **(b)** The transverse carpal ligament is divided revealing extensive scarring. **(c)** The appearance after median nerve neurolysis and flexor tenosynovectomy. Note the focal constriction and ischemia of the median nerve.

proximal-to-distal direction. The reconstituted TCL is divided under direct vision (▶Fig. 20.1b). If there is extensive scarring, the median nerve may be separately explored in the palm and dissected in a distal-to-proximal direction until the nerve is fully released. Beware of the nerve of Berrettini and the superficial palmar arterial arch, which are at risk of being injured at the distal margin of the carpal tunnel. Any extrinsic scar on the median nerve is excised. The use of microscope is recommended for challenging neurolysis. If appropriate, a flexor tenosynovectomy is performed (▶Fig. 20.1c).

20.4.1 Hypothenar Fat Pad Flap

Through the proximal incision (which is angled in an ulnar direction) at the distal forearm, the ulnar artery and nerve are identified just before they enter Guyon's canal. The volar carpal ligament is released, which will facilitate subsequent mobilization of the hypothenar fat pad flap. The flap is raised by sharp subcutaneous dissection from the ulnar border of the carpal tunnel incision. Superficial dissection starts from beneath the subdermal plexus and continues ulnar to the dermal attachment of palmaris brevis. Potential pitfall of the distal margin dissection is injury to the digital nerves to the ring and small fingers. Care is also taken to ensure that the overlying skin is not excessively thinned. Deep dissection then proceeds to elevate the flap from the remnant of the ulnar leaf of the TCL until the ulnar neurovascular bundle is encountered (▶Fig. 20.2a). The ulnar leaf of the TCL is excised to allow greater reach of the flap (▶Fig. 20.2b). The flap is inset with three mattress sutures to the radial wall of the carpal tunnel (▶Fig. 20.2c). Care is taken to ensure that the flexor pollicis longus tendon and median nerve have not been inadvertently sutured to the flap. The wound is closed with interrupted sutures and the wrist is splinted for 10 days postoperatively (▶Fig. 20.2d).

20.4.2 Steps for the Procedure

1. Explore the median nerve from normal to scarred tissues.
2. Perform external neurolysis ± epineurotomy of the median nerve.
3. Perform flexor tenosynovectomy.
4. Identify the ulnar neurovascular bundle and decompress Guyon's canal.
5. Raise the hypothenar fat pad flap through the superficial and deep dissections, while the delicate perforators from the ulnar artery are preserved.
6. The flap is inset and the wound is closed.

20.5 Postoperative Photographs and Critical Evaluation of Results

Postoperatively, digital exercises commence immediately. The volar slab is kept for 10 days for pain relief and also to allow the wound to settle down. After this time, simple range of motion exercises of the wrist are performed under

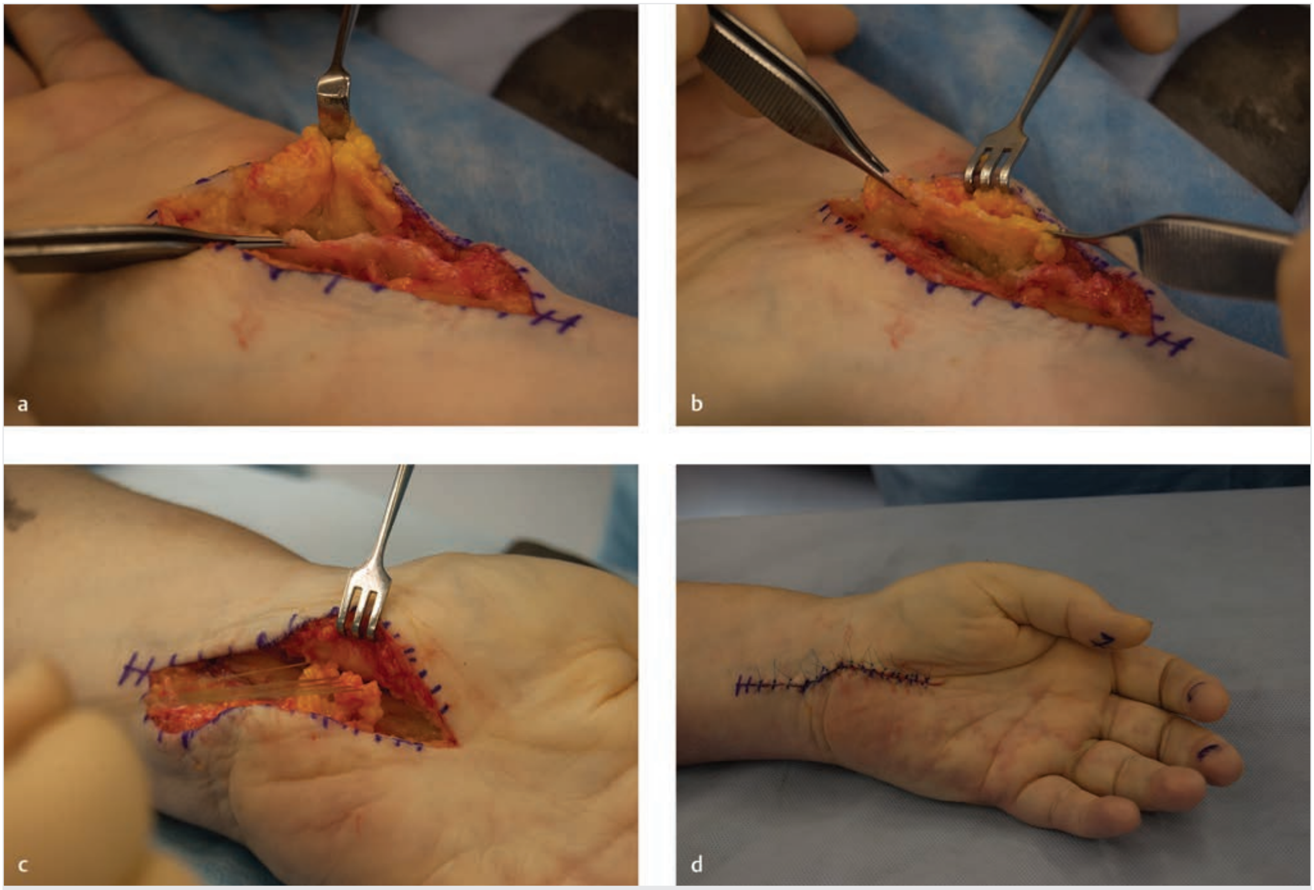

Fig. 20.2 **(a)** The flap has been raised and the ulnar leaf of the transverse carpal ligament (TCL) is isolated (held by the forceps). **(b)** The ulnar leaf of the TCL has been excised, allowing greater mobility of the flap (which is held by the pair of forceps). **(c)** Inset of flap to the radial wall of the carpal tunnel, taking particular care not to suture flexor pollicis longus and the median nerve. **(d)** Closure of the wound with interrupted sutures.

Fig. 20.3 Fingers flexion at 4 weeks postoperatively.

the supervision of the hand therapist. The appearance of the wound at 4 weeks is shown in ▶Fig. 20.3. In the early postoperative period, the patient reported resolution of paresthesia, akin to the experience following a successful primary CTR. The subjective sensibility returned to virtually normal over several weeks. She also noticed significant ease in the digital motion. The improvements were maintained at 1-year review.

Another case example of revision CTR (she also underwent index finger A1 pulley release concurrently) is included here with final appearance at 16 months postoperatively (▶Fig. 20.4).

20.6 Teaching Points

- The surgical aim of the CTR should be complete division of the TCL (including the most distal antebrachial fascia), without causing any iatrogenic injury.
- When faced with a failed CTR, establish if it represents a persistent, recurrent, or new issue.
- Clinical assessment remains the key in approaching the problem, with neurophysiology providing supplementary information.
- During revision CTR, perform a meticulous exploration and external neurolysis of the median nerve.
- Flexor tenosynovectomy is recommended as it could improve digital stiffness and reduce the carpal canal contents.
- Devise a strategy to prevent further scarring around the median nerve.
- The hypothenar fat pad flap is our preferred option.

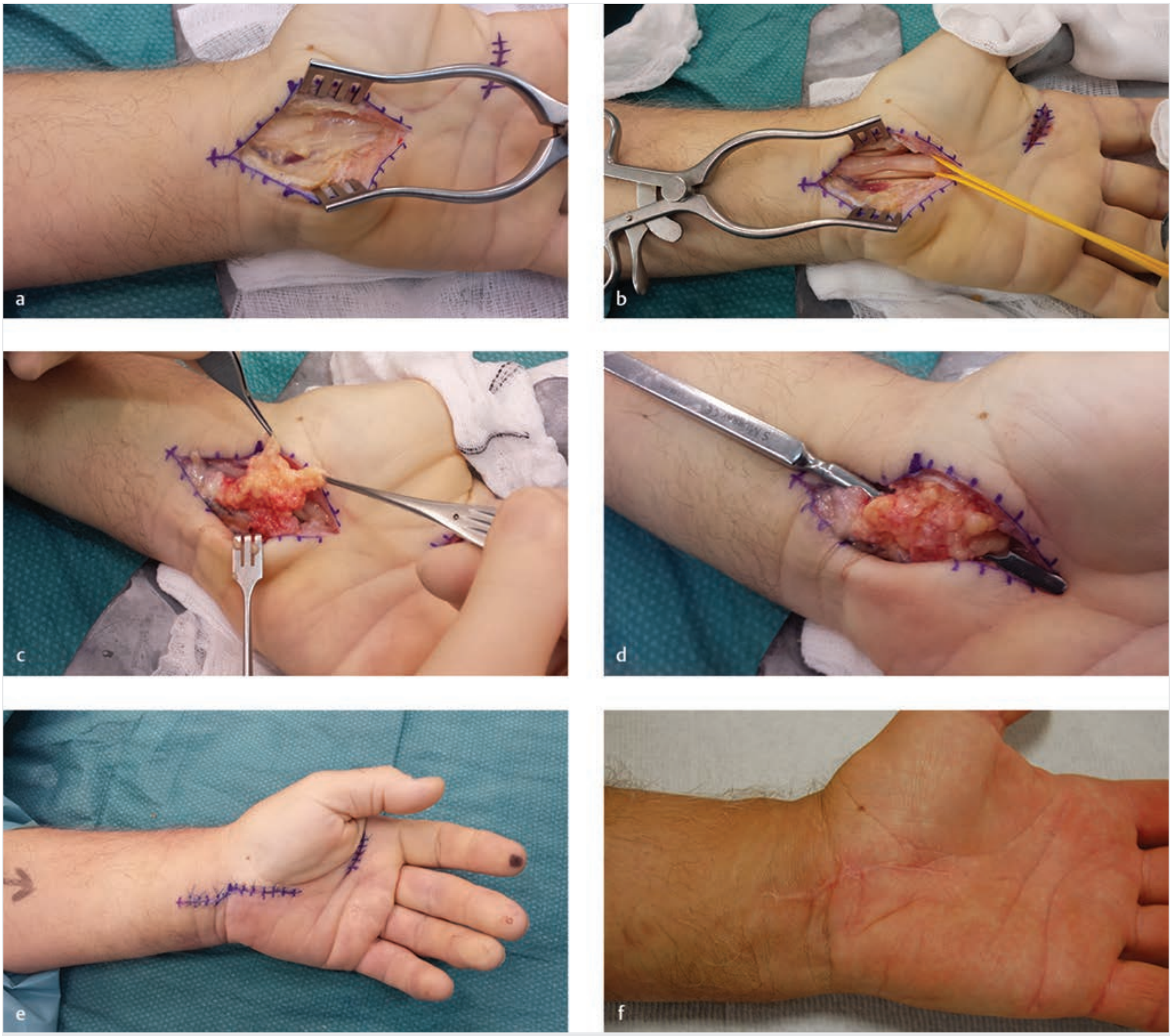

Fig. 20.4 **(a)** Following division of the reconstituted transverse carpel ligament (TCL), extensive scarring around the median nerve and the flexor tendons were shown. **(b)** Following external neurolysis of the median nerve and flexor tenosynovectomy. Note the hourglass constriction of the median nerve. **(c)** Hypothenar fat pad flap is raised. **(d)** After inset of the flap, a MacDonald dissector is passed under the flap to ensure that there is no secondary compression on the median nerve. **(e)** The wound is closed. **(f)** Appearance at 16 months postoperatively.

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21 Failed Carpal Tunnel Release: Recognizing the Lacertus Syndrome

Elisabet Hagert and Catherine Curtin

21.1 Patient History Leading to the Specific Problem

A 45-year-old right-handed woman presented with bilateral numbness within her median innervated areas of both hands. She had been diagnosed with bilateral carpal tunnel syndrome (CTS) a year prior to the visit, with positive nerve conduction studies and clinical examinations indicating CTS of a moderate degree on her right side and lesser degree on her left side. She subsequently underwent endoscopic carpal tunnel release (ECTR) of her right hand. Postoperatively, she has experienced a reduction in the nocturnal paresthesias of her right hand, but 9 months after ECTR she still complains of numbness at the tips of her thumb, index, and long fingers. She holds an office job, and also owns horses and works frequently in the stables. In addition to her persistent numbness, she complains of right hand weakness and lack of endurance, both while working at the computer and during everyday chores and manual work. She still has occasional nocturnal paresthesias in her left hand. She has no history of diabetes or thyroid disease, she is normotensive, not obese, and a nonsmoker.

Since the failure rate of surgical CTS is approximately 10 to 20%, it is important to ask the following questions when investigating a patient with residual median nerve problems:

- Was the surgery done correctly (complete/incomplete release)?
- Was the diagnosis correct?
- Was the nerve healthy enough to recover from surgery?

21.2 Anatomic Description of the Patient's Current Status

21.2.1 General Appearance

The right hand is examined with a small transverse scar at the level of the volar wrist crease (▶Fig. 21.1). The scar is pale, has healed uneventfully, and without hyperesthesia or hyperkeratosis. There is no sweating of the skin in the palm of the hand, nor hyperemia and thus no suspected pain syndrome. There is no visible swelling over the carpal tunnel or visible wasting of the thenar muscles.

21.2.2 Clinical Examination

When testing the patient for possible residual CTS, Tinel's test was negative over her right and operated carpal tunnel, and positive over her nonoperated left carpal tunnel. Similarly, Phalen's and Durkan's tests were negative on her right, operated, side but positive on her left.

Using manual muscle testing to screen for proximal median nerve involvement, she was found to be weak when testing her right flexor carpi radialis (FCR), flexor pollicis longus (FPL), and flexor digitorum communis II (FDP II; ▶Video 21.1).

Scratch collapse test (SCT) was found to be positive over the median nerve at the level of the right lacertus fibrosus (LF), with pain upon compression at the same level (▶Video 21.1).

The findings of (1) weakness of proximal median nerve innervated muscles, (2) positive SCT, and (3) pain over the median nerve at the level of the LF indicate that the patient is suffering from a proximal median nerve entrapment, so-called lacertus syndrome.

21.2.3 Ultrasound Examination

Ultrasound (US) is a valuable tool to investigate the potentially failed (or untreated) CTS. Using a transverse view and a nerve examination program, the median nerve can be readily identified proximal to the volar wrist crease.

The patient had a normal median nerve US appearance on the operated right side, with a slightly elliptical nerve without hyperechogenicity (▶Fig. 21.2a). Contrarily, on her left side, where she has clinical symptoms of CTS, the median nerve was found to be enlarged in diameter and cross-sectional area, as well as hyperechogenic, indicating endoneurial edema (▶Fig. 21.2b).

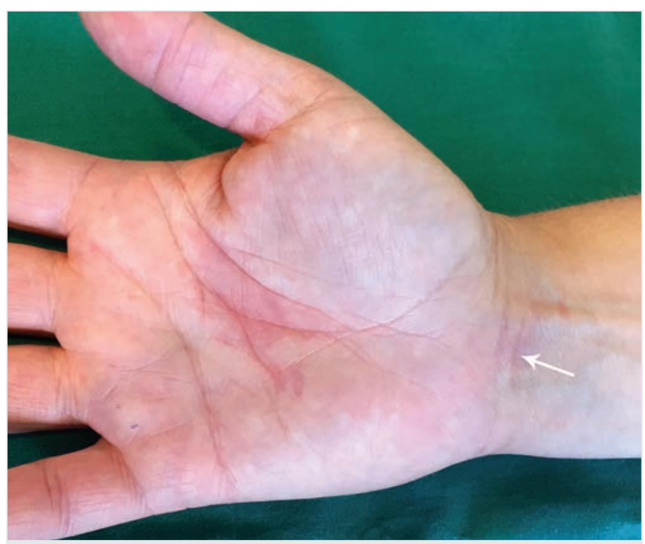

Fig. 21.1 General appearance of the hand. Arrow points to the scar from the endoscopic carpal tunnel release.

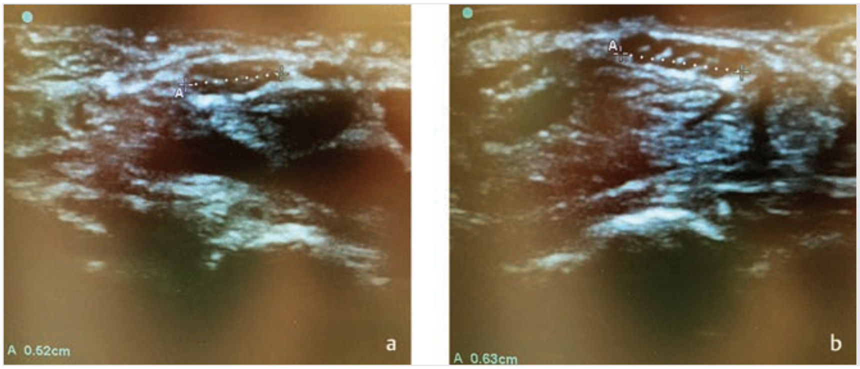

Fig. 21.2 **(a)** Transverse ultrasound view of the carpal tunnel, showing the median nerve with a normal appearance and a diameter of 0.52 cm. **(b)** Ultrasound appearance in the same patient, symptomatic carpal tunnel. Note the hyperechogenicity of the median nerve as well as increased diameter, 0.63 cm.

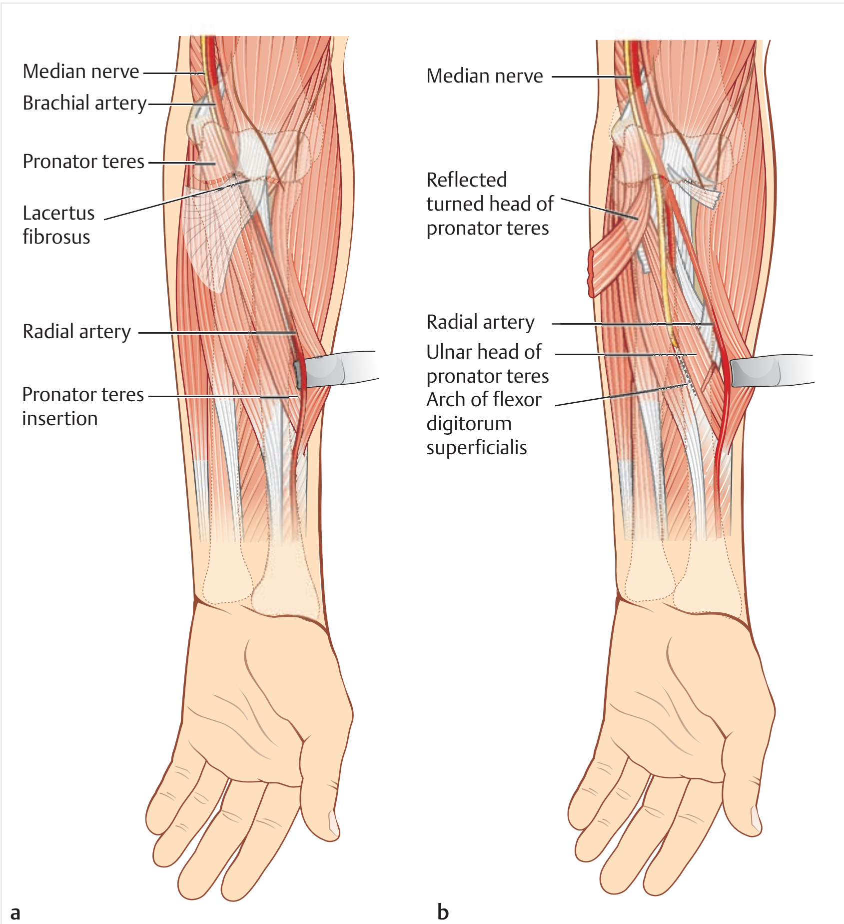

Fig. 21.3 Anatomy of proximal median nerve entrapments. **(a)** In the lacertus syndrome, an entrapment of the median nerve occurs at the level of the lacertus fibrosus, resulting in weakness in the flexor carpi radials, flexor pollicis longs and the deep flexor of the index finger. During surgery, the lacertus should be completely transected. **(b)** In the event of a concomitant superficialis syndrome, the median nerve is additionally compressed at the arch of the flexor digitorum superficialis (FDS) with resulting weakness in the FDS IV and sometimes paresthesias in the median nerve distribution in the hand. In this instance, a release of the FDS arch also needs to be completed during surgery.

21.3 Recommended Solution to the Problem

It is important to recognize that median nerve entrapment proximal to the carpal tunnel is generally not found using nerve conduction studies or electromyography. Double-crush syndrome is also an important factor to recognize chronic nerve compression syndromes, and any patient presenting with a "classic" CTS may also have more proximal median nerve involvement (▶Fig. 21.3). This patient would have benefited from a more thorough clinical examination before her first ECTR to rule out a proximal entrapment as cause and/or contributor of her median nerve symptoms.

21.3.1 Recommended Solution to the Problem

- Patients with early signs of lacertus syndrome may benefit from a local cortisone injection at the proximal edge of the LF.
- In addition to cortisone, a regime of nerve gliding exercises and evaluation of work ergonomics may be part of a conservative treatment strategy.

- In patients with distinct weakness in the FCR-FPL-FDP II (with or without sensory symptoms), a release of the LF is indicated.
- Surgical treatment of the lacertus syndrome is generally done in wide-awake anesthesia, to allow for perioperative control of muscle strength following the proximal median nerve release.

21.4 Technique

The surgery is scheduled as an outpatient case and generally performed using a wide-awake technique. Some patients prefer an addition of sedation, but general anesthesia is rarely needed.

About 20 to 30 minutes preoperatively, the patient is anesthetized using 20 to 30 mL 1% lidocaine (10 mg/mL) with epinephrine (5 µg/mL), buffered with 2- to 3-mL sodium bicarbonate (50 mg/mL) solution to neutralize the pH of the lidocaine.

Using a 27-G needle, the anesthesia is slowly infiltrated from the medial elbow crease and obliquely over the area of the LF, about 4 cm distal and central to the elbow crease (▶Fig. 21.4).

The skin incision is placed transversely in the volar medial elbow crease to give good postoperative aesthetics. A 2- to 3-cm transverse incision is placed in the flexion crease, from 1 to 2 cm medial of the biceps tendon to 2 cm lateral of the medial epicondyle (▶Fig. 21.5a). Careful dissection is made subcutaneously so that the medial antebrachial cutaneous nerve can be identified and protected, before reaching the pronator teres (PT) fascia (▶Fig. 21.5b). The PT fascia is incised and the PT retracted slightly medially. The LF is readily identified laterally and centrally (▶Fig. 21.5c). Lift the proximal edge of the LF to make sure the underlying neurovascular bundle is not injured while dividing the LF completely (▶Fig. 21.5d). The median nerve can then be identified underneath the split lacertus (▶Fig. 21.5e), at times within the muscle belly of the PT. At this point, the strength of the FPL and FDP II is again tested intraoperatively before the skin is closed, as return of muscle strength is usually immediate after proper release of the nerve (Video 21.2).

After adequate hemostasis, the wound is closed with intradermal 4–0 monocryl sutures, the incision covered with surgical strips, a small soft dressing applied, and immediate

Fig. 21.4 Infiltration anesthesia with lidocaine-epinephrine on the volar aspect of the elbow, showing the pallor of the skin where the epinephrine effect is evident. (BT, biceps tendon; ME, medial epicondyle.)

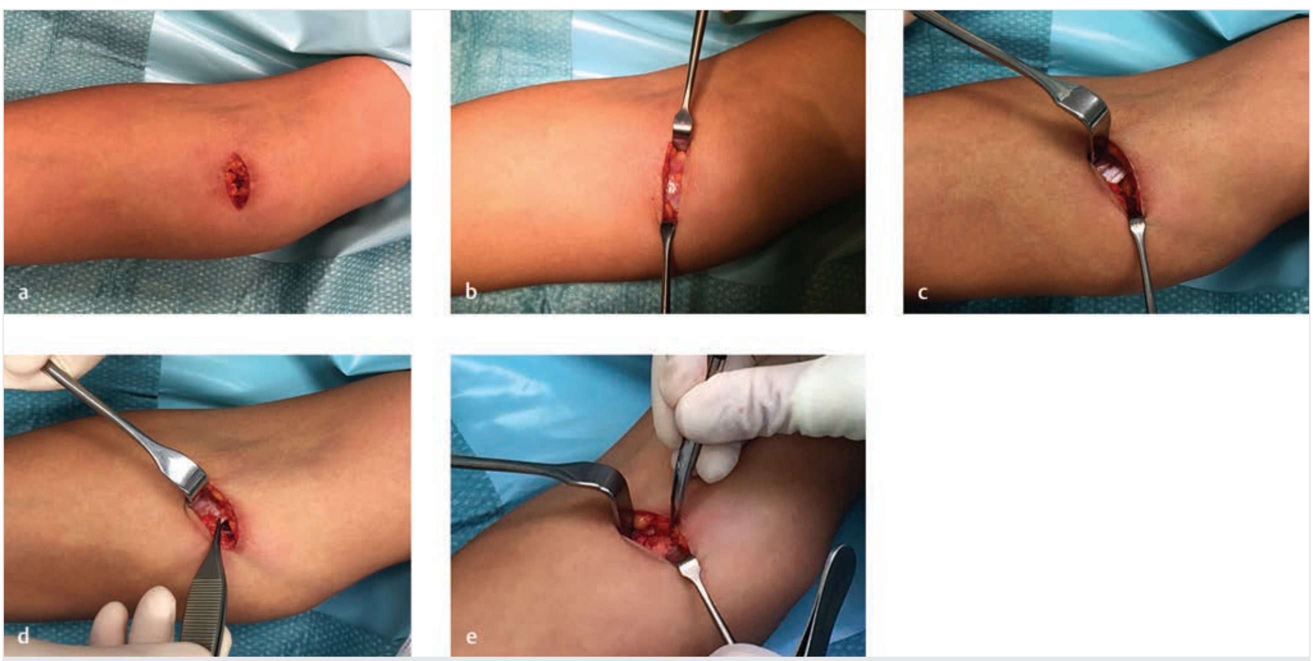

Fig. 21.5 **(a)** Transverse skin incision in the ulnar volar elbow crease. **(b)** Blunt dissection to the pronator teres fascia that is incised to allow retraction of the pronator teres muscle belly medially. **(c)** The thick lacertus fibrosus (LF) is seen in the lateral aspect of the wound. **(d)** Lift the proximal edge of the LF to make sure the underlying neurovascular bundle is not injured while dividing the LF completely. **(e)** Following release of the LF, the median nerve is clearly seen (scissors pointing to nerve).

Fig. 21.6 The incision at 1 week post-op. The patient is allowed to wash and instructed to tape the wound for healing and aesthetics.

mobilization is encouraged. Patients with no manual labor return to work within 1 to 2 days postoperatively, but are encouraged to abstain from lifting more than 1 kg for the first 2 weeks as well as avoid physical exercise. Heavier lifting and manual work are allowed after 4 weeks.

21.5 Postoperative Photographs and Critical Evaluation of Results

One of the advantages of doing the lacertus release in wide-awake anesthesia is the possibility to test the return of strength in the FPL and FDP II as soon as the release is complete (▶Video 21.2). Since the majority of chronic nerve compression cause changes in neural circulation and saltatory conduction, rather than actual axonal damage, return of strength and/or elimination of paresthesias will be evident as soon as the cause of the nerve compression is eliminated.

If the patient is sedated during surgery, it is advised to check the return of strength at the first postoperative follow-up. At this time, the SCT can be rechecked. If the median nerve has been adequately released, the patient will have good return of strength as well as a negative SCT over the median nerve at the elbow (▶Video 21.3).

Although power is often back on the table, patients with a long duration of symptoms and/or pronounced weakness preoperatively may experience that restoration of endurance takes several months. During this time, it is common to experience periods of soreness in the volar forearm muscles.

The scar will generally heal with pleasing aesthetics over time (▶Fig. 21.6). Some patients will have a hard scar and swelling for about 6 to 8 weeks postoperatively due to the characteristics of the skin in the volar elbow crease.

21.6 Teaching Points

- Always test the strength of the FPL, FDP II, and FCR in patients presenting with CTS to screen for possible lacertus syndrome.
- When testing the strength in the FPL and FDP II, isolate the interphalangeal and distal interphalangeal II joints while testing and flex the wrist to avoid compensatory tenodesis effect that may occur with wrist extension.
- Perform the scratch-collapse test first on the healthy side to see the effect on the patient, before performing the test over the entrapped nerve. Also, in patients with median nerve symptoms, always test the SCT over both the carpal tunnel and the LF.
- Entrapment may also occur at the level of the superficialis arcade. In these patients, the FCR strength will be normal, but weakness will be evident in the FPL, FDP II, and FDS IV.
- In the case of lacertus syndrome, expect nerve conduction studies and electromyography tests to be negative.

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22 Cubital Tunnel Release at the Elbow

Steven T. Lanier and Jason H. Ko

22.1 Patient History Leading to the Specific Problem

The patient is a 44-year-old right-hand dominant woman who presented with a 12-month history of paresthesias and numbness in the ring and small fingers of the left hand. She also noticed some clumsiness in her left hand and reported dropping objects occasionally over the past 3 months. She had tried conservative measures, including activity modifications, nonsteroidal anti-inflammatory drugs (NSAIDs), and elbow braces at night, with no appreciable improvement.

On examination, the patient's symptoms were reproduced by holding the elbow in flexion for 1 minute, and Tinel's signs were elicited over the cubital tunnel both proximal and distal to the medial epicondyle. No intrinsic wasting was apparent, and abduction strength of the first dorsal interosseous muscle was symmetric to the unaffected hand. Froment's sign was negative, and static 2-point discrimination was 5/7 mm in the ring finger and 9/9 mm in the small finger. Strength of the flexor digitorum profundus (FDP) to the ring and small fingers and flexor carpi ulnaris (FCU) were 5/5, and there was diminished sensation to light touch on the dorsal–ulnar aspect of her hand. No ulnar nerve subluxation was appreciated with passive flexion and extension of the elbow.

Based on these findings, a diagnosis of cubital tunnel syndrome was made, which was confirmed with electrodiagnostic testing. Although we consider cubital tunnel syndrome a primarily clinical diagnosis, we routinely obtain either electrodiagnostic testing or ultrasound studies to confirm the diagnosis. Results of electrodiagnostic studies can frequently be negative in symptomatic patients, particularly those with less chronic compressive symptoms for which dynamic ischemia occurs, but there has not been extensive demyelination or axonal loss. Electrodiagnostic testing is especially helpful for patients with an atypical presentation and equivocal diagnosis, or those patients with a history of known cervical pathology that may be contributing to a double-crush phenomenon. While these patients may still benefit from cubital tunnel release, knowledge of cervical compression helps set expectations and referral for management of cervical pathology. Ultrasound provides the additional benefit of assessing static and dynamic views of the ulnar nerve within the cubital tunnel in elbow extension versus flexion.

We discussed treatment options with the patient, including continued conservative measures and close follow-up or surgical decompression, and the patient opted for surgery, as she felt the symptoms significantly affected her quality of life.

22.2 Anatomic Description of the Patient's Current Status

The patient had no external stigmata of injury over the course of the ulnar nerve and no appreciable wasting of ulnar-innervated musculature. On clinical examination, there was no appreciable ulnar nerve instability or subluxation out of the epicondylar groove. However, based on the patient's clinical examination, we could deduce that the ulnar nerve was being compressed within the cubital tunnel, especially when the elbow was flexed.

The anatomic borders of the cubital tunnel are the medial condyle anteriorly, epicondylar groove of the ulna and medial collateral ligament of the elbow on the deep surface of the nerve, the olecranon posteriorly, and a roof consisting of aponeurotic fascia connecting the humeral head of the FCU muscle, which arises from the medial epicondyle anterior to the nerve, and the ulnar head of the FCU, which arises from the olecranon and dorsal–ulnar border posterior to the nerve. The proximal fibers of this aponeurotic connection between the two heads of the FCU is known as Osborne's ligament, while more distally into the proximal forearm this aponeurosis is known as the arcuate ligament. Proximal to the elbow, the arcade of Struthers is a fascial band spanning from the medial intermuscular septum anterior to the nerve to the fascia of the medial head of the triceps muscle posterior to the nerve. The arcade of Struthers is located approximately 6 to 8 cm proximal to the medial epicondyle. An additional potential cause of ulnar nerve compression is the anconeus epitrochlearis (▶Fig. 22.1), a congenital accessory muscle spanning the medial epicondyle to the olecranon that is present in approximately 34% of the population.

22.3 Recommended Solution to the Problem

For patients presenting with early signs of compression and no motor weakness, conservative measures can be attempted initially for a period of at least 3 months. These efforts are directed primarily at avoiding excessive flexion of the elbow that elicits symptoms, as the area inside the cubital tunnel decreases up to 50% with elbow flexion, while pressure within the cubital

Fig. 22.1 Anconeus epitrochlearis identified over the ulnar nerve.

tunnel increases. This includes orthotics for elbow extension at night and modification of workplace activities to avoid acute flexion of the elbow at rest. Positional modification can be supplemented with NSAIDs. However, corticosteroid injection into the cubital tunnel has not been proven to be efficacious. Surgery is indicated if conservative measures fail, if the patient's symptoms have a significant negative impact on work and leisure activities, or if there is evidence of intrinsic muscle weakness indicating a more severe compression neuropathy.

When surgical intervention is indicated, our preferred solution to cubital tunnel syndrome is a minimally invasive in situ release of the ulnar nerve in the cubital tunnel. Advantages of in situ decompression compared to more invasive methods include reduced risk of iatrogenic nerve injury or transient devascularization of the ulnar nerve by sacrificing ulnar collateral arterial branches, decreased operative time, and expedited patient recovery without the need for postoperative immobilization. More invasive approaches, including anterior nerve transposition with subcutaneous, intramuscular, or submuscular placement, are better reserved for recalcitrant cubital tunnel symptoms following an in situ release. Medial epicondylectomy can be performed, but this is not recommended by the authors. Other contraindications to an in situ release include a failed prior in situ release, elbow arthritis, and ulnar nerve instability diagnosed either preoperatively or intraoperatively. In this case, a primary ulnar nerve transposition with subcutaneous or submuscular placement is indicated.

22.3.1 Recommended Solution to the Problem

- In situ decompression of the ulnar nerve in the cubital tunnel, consisting of the following:
  - Division of Osborne's ligament over the cubital tunnel.
  - Division of the aponeurosis between the humeral and ulnar heads of the FCU distally (the arcuate ligament).
  - Division of the aponeurotic fascia overlying the epicondylar groove and arcade of Struthers proximally.
  - Ensuring no subluxation of ulnar nerve following unroofing of the cubital tunnel.
  - Allowing early active range of motion of the arm immediately with no splint immobilization.

22.4 Technique

The patient is taken to the operating room and placed supine on the operating table. For in situ cubital tunnel release, anesthesia can vary depending on surgeon, anesthesiologist, and patient. General, nerve block, intravenous regional, or local anesthesia with sedation are all options for this procedure. The arm is abducted 90 degrees and placed on a hand table. If a tourniquet is used, it can be placed in a nonsterile or sterile fashion. The arm is then prepped and draped with chlorhexidine in the standard fashion.

The surgeon sits medial to the patient's arm with an assistant lateral to the arm. The assistant externally rotates the patient's shoulder and flexes the elbow to expose the medial epicondyle of the humerus and olecranon process of the ulna. The skin incision is marked in a line halfway between the medial epicondyle and olecranon, extending from this interval to approximately 2 to 3 cm distal over the FCU muscle, directly over the course of the ulnar nerve (▶Fig. 22.2). If a tourniquet is used, then the arm is raised and exsanguinated using an Esmarch bandage. The tourniquet is then inflated to 250 mm Hg and the Esmarch bandage is removed.

An incision is made with a no. 15 blade through skin and superficial subcutaneous tissue (▶Fig. 22.3). Tenotomy scissors are then used to spread the subcutaneous tissue in a direction perpendicular to the incision in order to identify posterior branches of the medial antebrachial cutaneous (MABC) nerve that course through the plane of dissection. Dissection with scissors continues to the deep fascia overlying the flexor/pronator origin, and skin flaps are mobilized sufficiently to expose this fascia.

The ulnar nerve can be palpated posterior to the medial epicondyle and courses posterior to the medial intermuscular septum. The leading edge of the FCU (Osborne's ligament) is visualized proximally along with the medial intermuscular septum distally. An incision is made carefully with a no. 15 blade in the fascia overlying the nerve. Release is then continued proximally above the medial epicondyle to include aponeurotic fascia overlying the epicondylar groove and the arcade of Struthers, ending at the medial border of the medial head of the triceps muscle (▶Fig. 22.4).

Fig. 22.2 The incision is designed directly over the course of the ulnar nerve, midway between the medial epicondyle and olecranon.

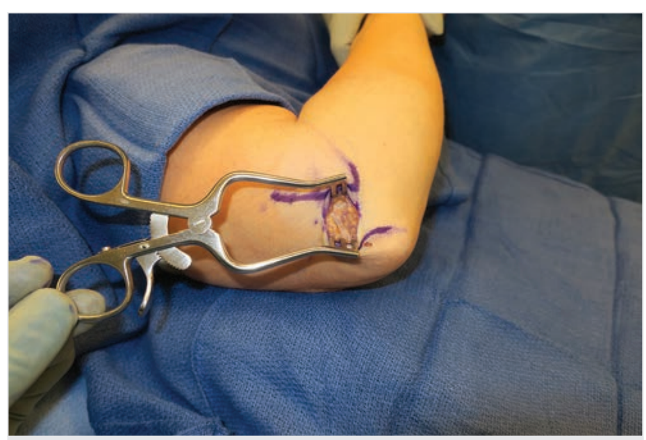

Fig. 22.3 Tenotomy scissors are used to dissect the subcutaneous plane, spreading in the direction of medial antebrachial cutaneous nerve branches.

Circumferential neurolysis of the nerve within the epicondylar groove should not be performed—this will increase the chances of ulnar nerve instability and subluxation. The ulnar nerve is then identified and protected distally, and division of Osborne's ligament and the FCU fascia is completed distally using tenotomy scissors (▶Fig. 22.5).

Division of the fascia is performed posteriorly, closer to the olecranon than medial epicondyle in an effort to create an anterior "flap" of fascia that helps prevent ulnar nerve subluxation. Care is taken to release both the superficial and the deep fasciae of the FCU overlying the ulnar nerve to release all distal compression points (▶Fig. 22.6).

The elbow is then ranged from full extension to full flexion to identify any residual points of compression and ensure that the ulnar nerve is not destabilized by decompression, which would manifest as subluxation of the nerve out of

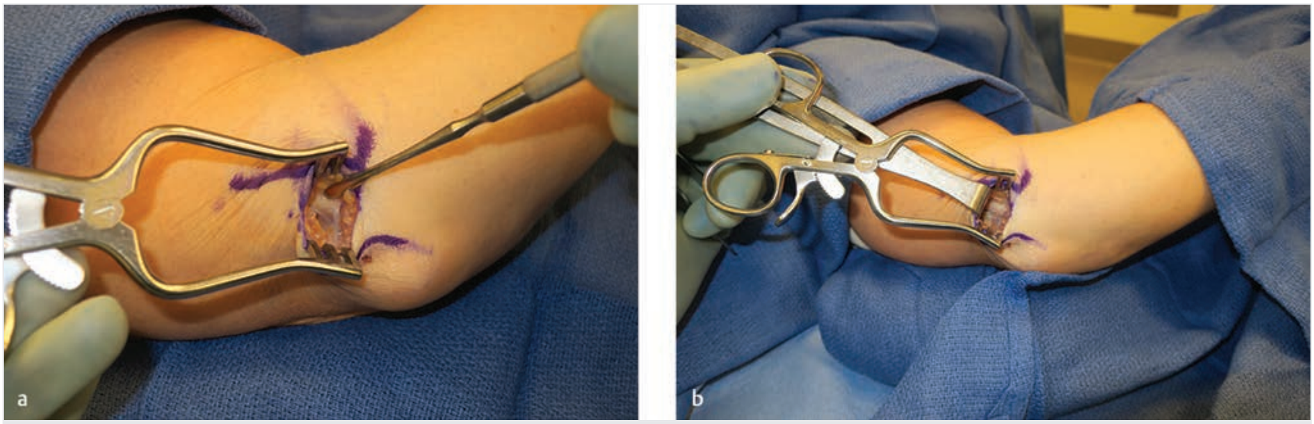

Fig. 22.4 (a) The ulnar nerve can be palpated posterior to the medial epicondyle and courses posterior to the medial intermuscular septum. **(b)** The proximal release of the ulnar nerve from the investing fascia. All sharp fascial edges are removed.

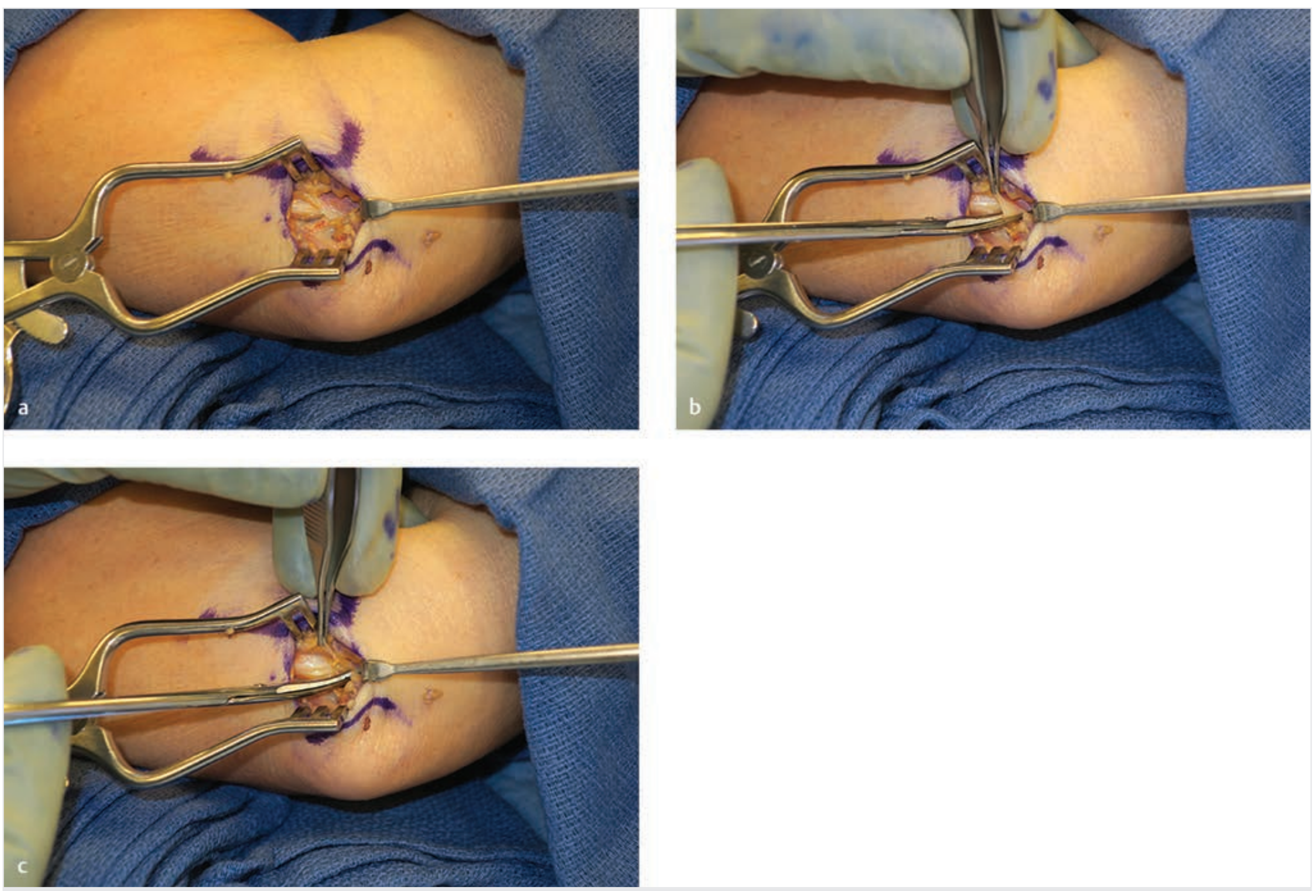

Fig. 22.5 (a) Osborne's ligament, the leading edge of the flexor carpi ulnaris (FCU) fascia, is visualized distally. **(b)** The ulnar nerve is released from Osborne's ligament and the FCU fascia. The division of the fascia and muscle are kept posterior to prevent the nerve from volar subluxation with elbow flexion. **(c)** Both the superficial and deep fascia of the FCU overlying the ulnar nerve to release all distal compression points.

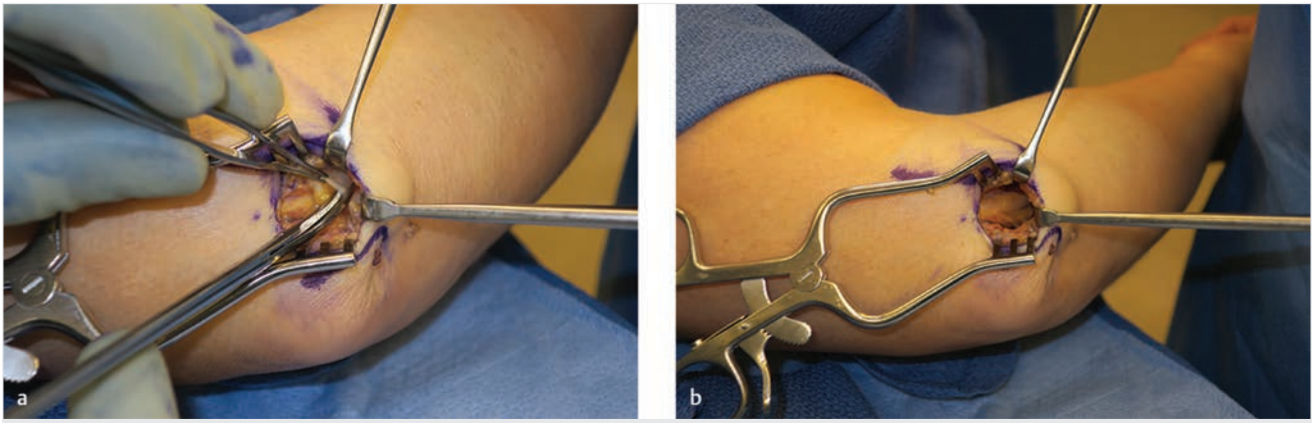

Fig. 22.6 (a, b) Complete release of the ulnar nerve distally is ensured.

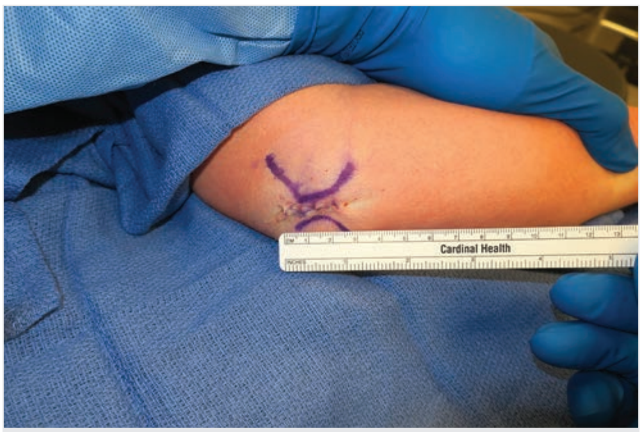

Fig. 22.7 A layered closure is performed with deep dermal and subcuticular sutures.

the epicondylar groove. The tourniquet is then deflated and hemostasis obtained with bipolar electrocautery.

The skin is closed in layers with interrupted, buried-deep dermal 3–0 absorbable sutures and a 4–0 monofilament subcutaneous suture (▶Fig. 22.7). The incision can be covered with either Steri-Strips or skin glue. A strip of Owen's gauze is placed over the incision, covered by bulky fluff gauze, and a gentle compressive ACE wrap. Active range of motion is allowed immediately, and this dressing can be removed after 24 to 48 hours for hygiene. Compression is recommended for 2 weeks postoperatively to minimize edema.

Potential sites of ulnar nerve compression not addressed by an in situ release include the medial head of the triceps muscle and the medial intramuscular septum.

22.4.1 Steps for the Procedure

1. Mark an approximately 2- to 3-cm incision halfway between medial epicondyle and olecranon.
2. If a tourniquet is used, exsanguinate the arm with Esmarch and inflate tourniquet.
3. Incise skin and subcutaneous tissue with a no. 15 blade.
4. Spread with tenotomy scissors and protect posterior branches of the MABC nerve.
5. Identify and incise the deep fascia between the humeral and ulnar heads of the FCU muscle.
6. While protecting the ulnar nerve, sharply incise Osborne's ligament and the arcuate ligament distally along their posterior borders. Then divide the epicondylar aponeurosis and fascia overlying the ulnar nerve proximal to the medial epicondyle, including the arcade of Struthers.
7. Range the elbow to identify any sites of residual compression or ulnar nerve subluxation.
8. Deflate tourniquet and obtain hemostasis.
9. Close skin in layers and apply bulky dressing.

22.5 Postoperative Photographs and Critical Evaluation of Results

The patient reported full resolution of her symptoms. Her incision healed well, and there were no postoperative complications.

22.6 Teaching Points

- Cubital tunnel syndrome is a clinical diagnosis characterized by a history of paresthesias and numbness of the ring and small fingers of the affected side, and when chronic and severe, intrinsic muscle weakness or atrophy of the hand. Electrodiagnostic testing and ultrasound are helpful diagnostic tests.
- Conservative measures are attempted prior to surgery for early cases without evidence of motor weakness. These consist primarily of orthotics to avoid excessive flexion of the elbow during sleep, activity modification, and NSAIDs.
- Failure to respond to conservative measures with significant interference with daily activities or severe symptoms with motor weakness are indications for surgical decompression of the ulnar nerve at the elbow.
- In situ release is the first-line surgical treatment as it involves reduced risk of iatrogenic nerve injury or devascularization of the ulnar nerve, decreased operative time, and expedited patient recovery without the need for postoperative immobilization.
- Recalcitrant cubital tunnel syndrome following in situ decompression can be addressed with more aggressive surgical measures, including anterior nerve transposition with subcutaneous, intramuscular, or submuscular placement.

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23 Recurrent Cubital Tunnel

Emily M. Krauss and Susan E. Mackinnon

23.1 Patient History Leading to the Specific Problem

A 28-year-old man presented to the office with complaints of severe pain and numbness in the ring and small fingers of his nondominant hand. The patient had three ulnar nerve operations for recurrent symptoms: first, a subcutaneous transposition, followed by a submuscular transposition, and finally by an ulnar nerve vein wrap. Immediately after the third surgery, he experienced severe pain in the ulnar nerve distribution, dense numbness in the ring and small fingers, and developed weakness, intrinsic atrophy, and clawing of the ulnar digits.

23.2 Anatomic Description of the Patient's Current Status

An old surgical scar is present posterior to the medial epicondyle. The patient has pronounced ulnar intrinsic atrophy on the left hand. A marked Wartenberg's sign is noted in addition to clawing of the ring and small fingers. Motor examination illustrates minimal lumbrical function and no first dorsal interosseous function or bulk is visible when the patient is asked to pinch. A pronounced Froment's sign is present. Ulnar-sided flexor digitorum profundus has marked weakness. Pinch and grip strengths are 6.34 and 37.7 kg, respectively, on the involved side compared to 12.7 and 56.8 kg, respectively, on the uninvolved extremity.

The involved ulnar nerve distribution has no functional 2-point discrimination on sensory testing, compared to 4 mm in the contralateral hand. Pronounced Tinel's signs and hierarchical Scratch Collapse Tests are present first at the elbow, then Guyon's canal, and proximally in the medial arm where an arcade of Struthers is located.

Fig. 23.1 Mark the previous incision with visual cues to notify you of the previous zone of surgery. The incision is extended proximally and distally in the shape of a smile.

The patient has completed a visual analog scale (VAS) for pain, depression, anger, frustration, and negative impact on quality of life (▶Fig. 23.1). The patient describes his pain as burning and crushing along the ulnar border of his hand, small, and ring fingers, with an average to worst pain level of 7 to 8 out of 10. The pain has had an 80% negative impact on his quality of life.

23.3 Recommended Solution to the Problem

Indications for revision cubital tunnel surgery can be classified as persistent, recurrent, or new symptoms. Recurrent cubital tunnel is a difficult problem requiring a systematic approach to the identification of the nerve and surgical decompression. Patients presenting with recurrent cubital tunnel may have different spectrums of symptoms related to the previously performed operation. The required surgical procedure differs slightly for each scenario; however, the overall approach is to turn the revision procedure into our primary operation: a transmuscular ulnar nerve decompression avoiding any kinking of the nerve and ensuring that all proximal and distal compression points are released (▶Table 23.1).

23.3.1 Recommended Solution to the Problem

Treatment priorities should focus on pain relief and restoration of ulnar nerve function:

- Pain relief.
- Protecting the ulnar nerve.
- Complete decompression of the ulnar nerve (Box 23.1).
- Restoring function (motor, sensory, possibly with distal transfers).
- Treating any medial antebrachial cutaneous (MABC) neuromas.

Box 23.1 Compressive Structures in Recurrent Cubital Tunnel Syndrome

1. Tight fascial band from previous subcutaneous transposition.
2. Medial intermuscular septum (PMIS).
3. Flexor carpi ulnaris (FCU) fascial septum between median-innervated forearm flexors and FCU (distal intermuscular septum DIMS.
4. Thin but strong FCU fascia overlying the ulnar nerve.
5. Distal crossing vessels in the FCU, kinking the nerve when transposed.
6. Intermuscular septa in the flexor mass from previous submuscular transposition.
7. Arcade of Struthers.

Table 23.1 Anticipated symptoms, operative findings, and surgical procedure by previous ulnar nerve operation

Previous ulnar nerve operation	Common symptoms	Anticipated operative findings	Surgical procedure
Decompression	Persistent or recurrent ulnar nerve numbness, tingling, possible pain, and weakness ± subluxation across elbow	Intact MABC Subluxation + scarring	Limited neurolysis Flexor pronator slide Standard transmuscular transposition with fascial flaps
Subcutaneous transposition	Recurrent or new symptoms: Recurrent ulnar nerve numbness, tingling, possible neuropathic pain	Distal (proximal) kink Tight band at transposition site + scarring MABC neuroma	Release all "kinks" Limited neurolysis Place ulnar nerve "transmuscular" ± fascial flaps
Learmonth's submuscular transposition	Persistent or new symptoms: ++Neuropathic pain (ulnar distribution) Intrinsic weakness Ulnar extrinsic weakness Numbness	Intramuscular fibrous bands and fascial septa compressing ulnar nerve ++ scarring Distal double right angle kink	Release distal kink Remove fibrous bands and septum within the muscle compressing the nerve Option to leave muscle intact/remove tendinous tissue
"Submuscular" transposition	Persistent or new symptoms: ++neuropathic pain (ulnar distribution and MABC distribution) Intrinsic weakness and atrophy Ulnar extrinsic weakness Numbness	+++ Scarring Ulnar nerve in variable location, usually right on or against medial epicondyle Distal kink MABC/MBC neuroma	Release distal kink Decompress nerve Limited neurolysis
MABC neuroma	New symptoms: ++ Neuropathic pain and hypersensitivity in the medial forearm Tinel's sign in forearm in MABC distribution	Incision crossing 3.5 cm distal to median epicondyle Painful sensitivity medial forearm Proximal Tinel's sign into MABC territory	Evaluate after ulnar nerve is identified and protected Identify MABC in mid-arm with basilic vein Follow distally. If neuroma present, crush proximal, cauterize distal, transpose proximal, keeping in place with fibrin glue

Abbreviations: MABC, medial antebrachial cutaneous; MBC, medial brachial cutaneous.

23.4 Technique

With the operative arm prepped to the axilla, abducted to 90 degrees, and a high above-elbow sterile tourniquet in place (to enable removal later in the procedure to check for an arcade of Struthers), mark the previous incision including a visual reminder of the zone of scarring (see ▶Fig. 23.1). Extend the incision proximal and distal. Identify the ulnar nerve widely proximal to the area of previous surgery; the ulnar nerve lies directly posterior to the remaining intermuscular septum between the biceps and triceps (▶Fig. 23.2a). The entire length of the proximal intermuscular septum (PIMS) is removed. Then identify the ulnar nerve far distal to the previous operative site by dividing the skin and dissecting down to expose the flexor carpi ulnaris (FCU) fascia. There is a thick superficial fascial band (the "unnamed" septum) that is always present in the forearm fascia, even in revision surgery, that divides the median-innervated forearm flexors laterally from the FCU medially (▶Fig. 23.2b). This distal septum and its relationship to the ulnar nerve mimics its proximal counterpart (PMIS) and it can similarly be used as a helpful anatomic landmark to identify the unscarred distal nerve. The ulnar nerve lies directly under this unnamed distal intermuscular septum (DIMS), and deep to the FCU fibers.

In the primary operation after identification of the ulnar nerve, we dissect to identify the medial antebrachial cutaneous nerve (MABC). In revision cubital tunnel surgery, we ignore the MABC until the entire ulnar nerve is exposed in order to prevent inadvertent injury to the ulnar nerve in its unpredictable course through scar tissue. After identification proximally and distally, we carefully dissect the ulnar nerve into the previous zone of surgery, understanding that the nerve, scar tissue, and fascia are all white in appearance, making it imperative to work from "known to unknown." The "tug test" can be used to anticipate the course of the ulnar nerve and ensure that it is in continuity within the scarred surgical field.

After a previously performed simple decompression, the ulnar nerve will lie posterior to the medial epicondyle, or on the epicondyle as it subluxes across the bony prominence (▶Fig. 23.3a). A circumferential decompression is performed until the entire ulnar nerve is identified and mobile. The flexor–pronator origin is then exposed. Fascial flaps are created with the flexor–pronator fascia. A central "T" of thick fascia between the forearm flexors is identified and excised to prevent an area of kinking or compression on the ulnar nerve when it is transposed to this new anterior location. A flexor muscle slide is performed for at least 1 inch distally using bipolar cautery (▶Fig. 23.3b). Distally where the ulnar nerve courses through the FCU, the "unnamed" septum (DIMS) is removed. Very thin but tight fascia overlies the ulnar nerve within the FCU and must be released. Also within the FCU, small crossing vessels superficial and perpendicular to the ulnar nerve are routinely encountered and must be divided to prevent kinking of the nerve when transposed. Small motor branches to the FCU should be neurolysed proximally off the main ulnar nerve to enable a tension-free transposition while preserving the critical motor innervation to the FCU. Once transposed anteriorly, the nerve should lie tension free, straight, within the trough created by the flexor slide. The fascial flaps should be very loosely approximated over the ulnar nerve (▶Fig. 23.3c).

In patients with a previous subcutaneous transposition, the dissection through the zone of injury can be very difficult as the nerve and subcutaneous scar will look the same. Often after a subcutaneous transposition, there is a tight compressive band over the ulnar nerve usually from the strategy used to keep the nerve anterior. In this scenario, the medial

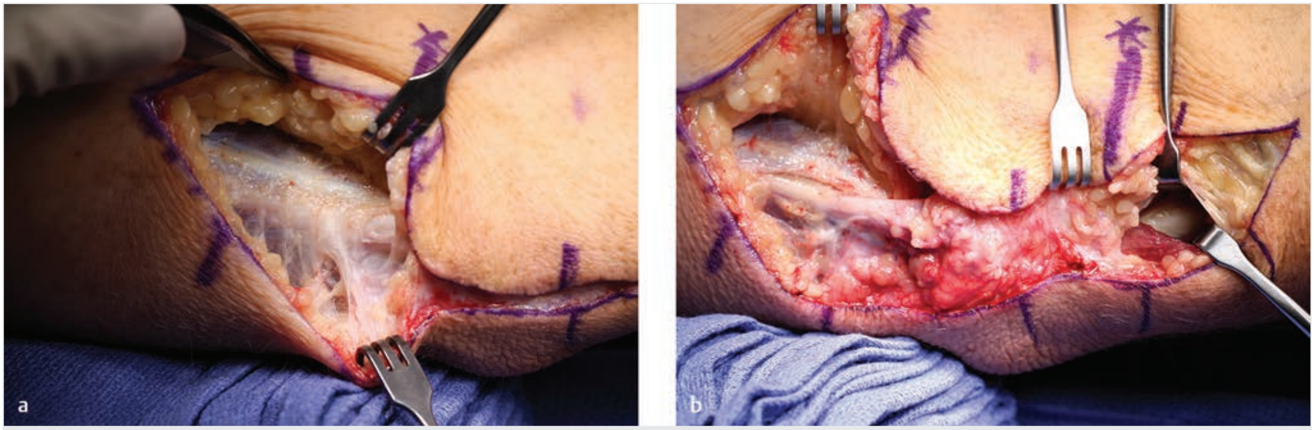

Fig. 23.2 **(a)** Locating the ulnar nerve far proximally to the previous zone of surgery, lying just posterior to the medial intermuscular septum. **(b)** Locating the ulnar nerve distal to the previous zone of surgery, lying directly under the "unnamed" septum and flexor carpi ulnaris fibers.

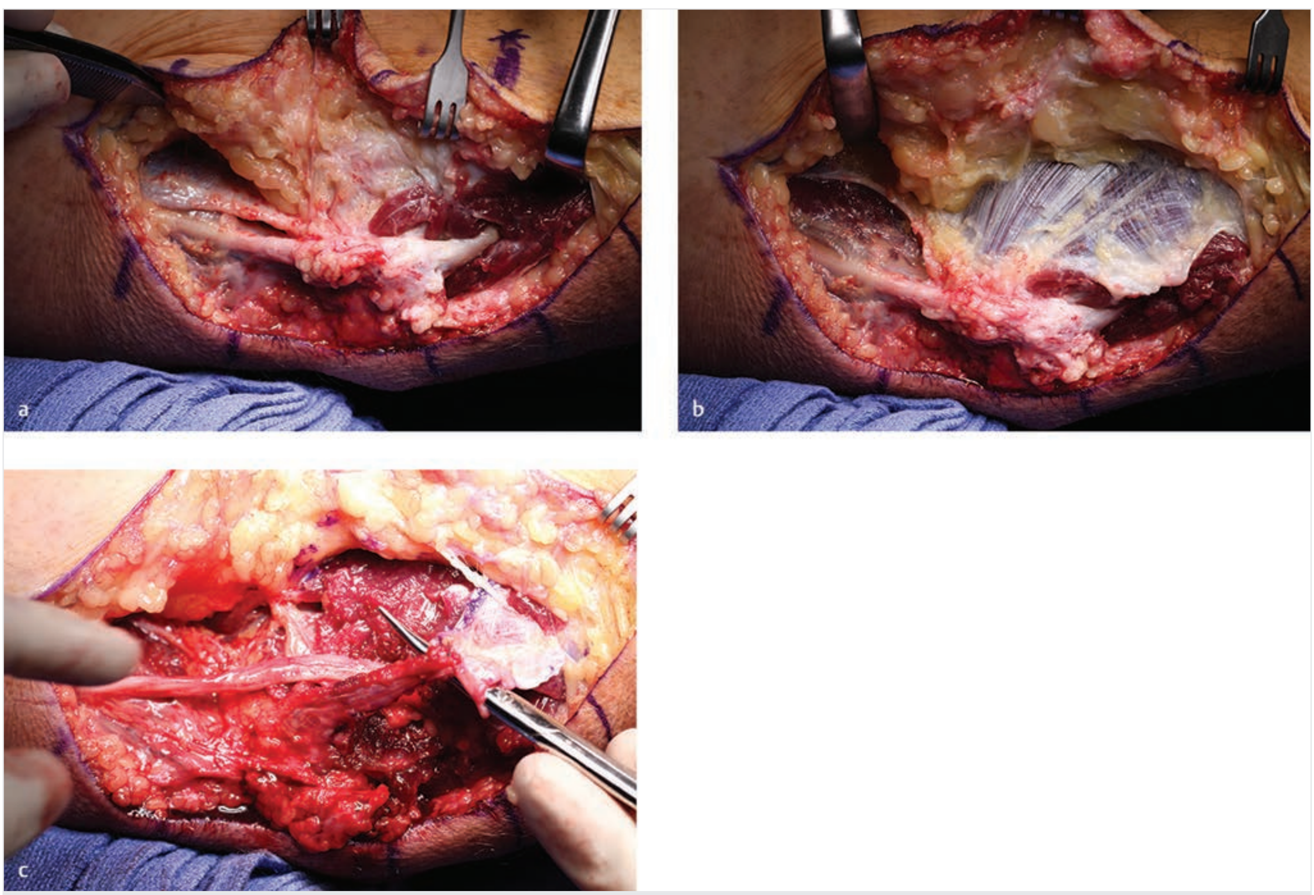

Fig. 23.3 **(a)** Ulnar nerve position, scarred and subluxing over the medial epicondyle, after a previous simple decompression. **(b)** Ulnar nerve, and fascia of the forearm flexor origin that will be used to create fascial flaps, with a flexor muscle slide of the fibers at least 1 inch distally. **(c)** Ulnar nerve transmuscular transposition, with loose fascial flaps and the nerve lying in a straight line.

intermuscular septum (PIMS), unnamed septum (DIMS), and distal crossing vessels are often intact and must be released or removed. The flexor slide is performed. This allows the nerve to sit gently in an anterior trough with no kinking or compression. Typically, the nerve has “memory” and does not require fascial flaps to maintain its anterior position. A limited neurolysis is performed only on the anterior surface of the nerve to release any compressive scarred epineurium.

In patients with a previous Learmonth or submuscular transposition, releasing intramuscular septal fascia located in the flexor mass is essential to decompression the transposed nerve (▶Fig. 23.4). Patients who have had a submuscular transposition may need release of muscle fibers as well, which is performed by working from proximal and distal along the course of the ulnar nerve. All other compressive or kinking structures as described earlier are released. A limited neurolysis of the anterior surface of the nerve is also performed.

Finally, removing the tourniquet and inspecting proximally is essential to identify an arcade of Struthers for release. The arcade of Struthers is a fascial noose of triceps fascia that arises posterior and medial to the nerve traversing laterally toward the intermuscular septum that actively compresses the nerve with elbow extension (▶Fig. 23.5).

23.4.1 Additional Procedures

Identification of an MABC neuroma is treated with proximal neurolysis of the branch with the neuroma (▶Fig. 23.6). The branch is then crushed proximally using a hemostat to create a second-degree injury and to move the front of regenerating nerve fibers proximally. The neuroma is then excised and the distal end is capped using cautery or a long acellular nerve allograft. The nerve is proximally transposed loosely and tension free within the intermuscular plane.

Consider an anterior interosseous nerve (AIN) transfer to the ulnar motor nerve as an supercharged end to side (SETS), using the branch to pronator quadratus, to allow for early distal reinnervation in severe proximal nerve injury or compression. A distal nerve transfer is particularly indicated in the case of ulnar intrinsic atrophy and if electrodiagnostic studies illustrate

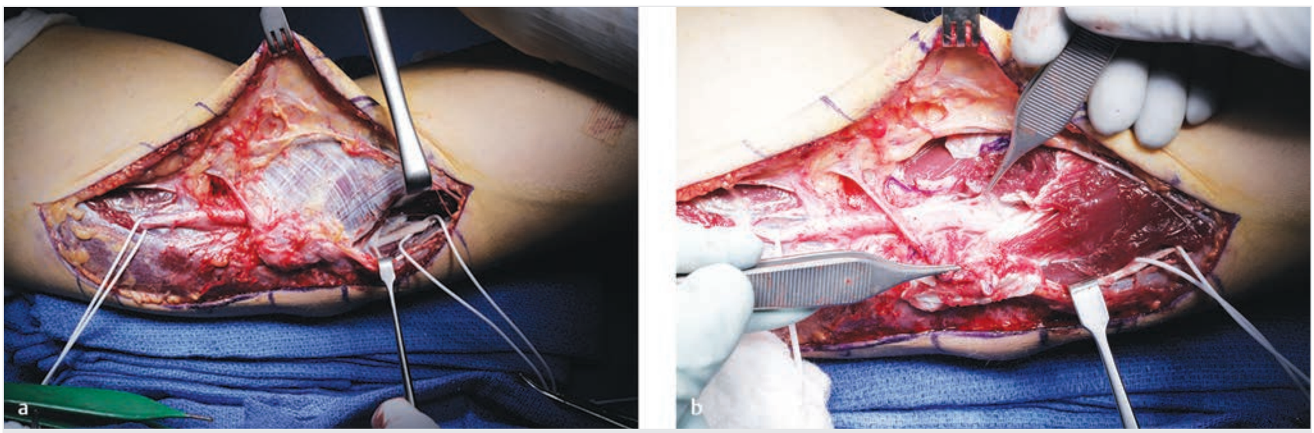

Fig. 23.4 Previous submuscular transposition. **(a)** The ulnar nerve underlying the flexor-pronatormass with two nearly 90-degree turns in the nerve and **(b)** with thick fascial bands in the flexor mass requiring excision to create a transmuscular transposition.

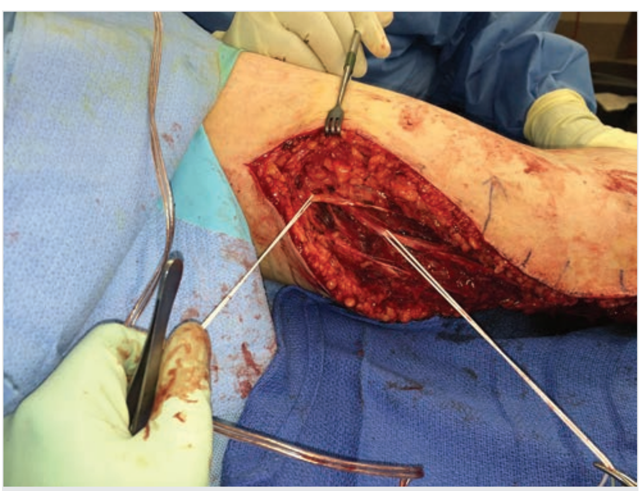

Fig. 23.5 Proximal intermuscular septum over ulnar nerve, and arcade of Struthers posterior to the ulnar nerve in a revision cubital tunnel operation.

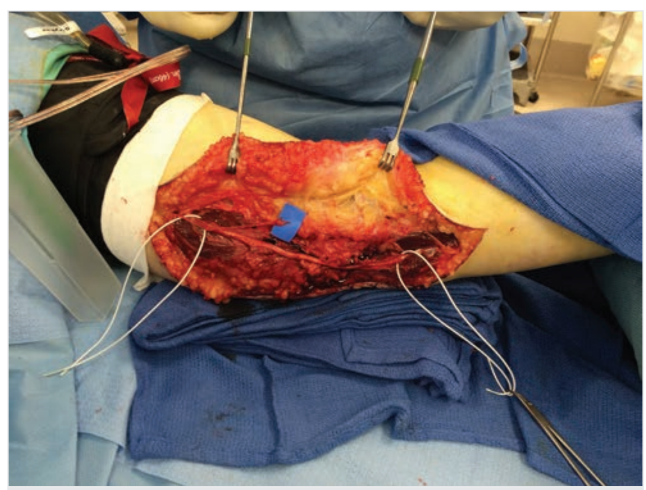

Fig. 23.6 Medial antebrachial cutaneous neuroma (*blue background*) identified beside the decompressed and anteriorly transposed ulnar nerve.

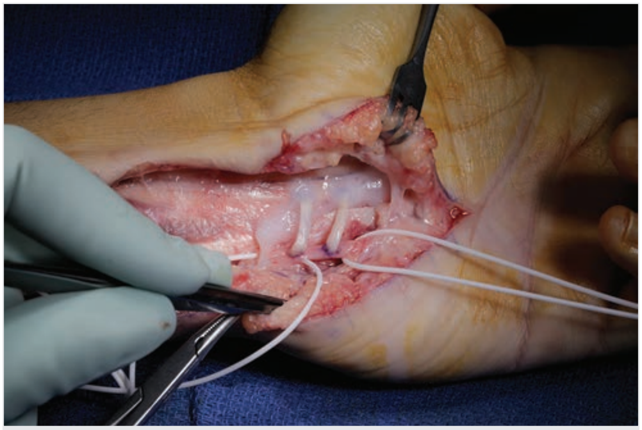

Fig. 23.7 Distal cross-cross grafts, using acellular nerve graft, from the third web-space fascicle of the median nerve to the ulnar sensory nerve at the level of the carpal tunnel and Guyon's canal.

fibrillations and decreased compound motor action potential indicating axonal injury and axonal loss. The motor transfer is often accompanied by a profundus tenodesis in our revision cubital tunnel patients.

Consider distal sensory transfers to restore ulnar digital sensation earlier, especially in patients with severe proximal scarring. We perform these transfers using nerve grafts to bridge from the median third web-space fascicle to the ulnar sensory fascicles in a side-to-side fashion (what we refer to as a cross-cross graft; ▶Fig. 23.7). Ensure that any neurolysis of the median nerve takes only the fascicle to the third web space and protect the remaining median nerve, so as not to create another injury.

23.5 Postoperative Photographs and Critical Evaluation of Results

The patient is placed in a well-padded volar splint with the elbow at 90 degrees of flexion and the forearm pronated and wrist in neutral for 48 hours. A drain and pain pump are used. Early gentle range of motion is initiated when the splint is removed at 48 hours and is critical to prevent further scarring of the ulnar nerve. Patients also benefit from desensitization and strengthening exercises directed by a hand therapist.

A recent evaluation of the results of our preferred technique for recurrent cubital tunnel syndrome indicated higher preoperative VAS scores for pain than primary cubital tunnel syndrome patients. Patients undergoing our preferred technique for recurrent cubital tunnel syndrome had significant improvements in postoperative pain and impact of pain on quality of life. The magnitude of improvement was not statistically different from the improvement reported in the primary ulnar nerve transposition cohort.

23.6 Teaching Points

- General surgical consideration:
  - Plan 4 hours of operating room time (anticipate scarring).
  - General anesthesia/intravenous regional anesthesia with Precedex if pain a key component.
  - Sterile tourniquet.
  - Delay distal surgeries if there is severe pain (Guyon's, SETS, profundus tenodesis).
- Surgery:
  - Extend previous incision proximal and distal.
  - Proximally identify PMIS—the ulnar nerve is posterior.
  - Distally identify fascial septum (DIMS) between median and ulnar muscles—the ulnar nerve is posterior.
  - Work slowly following ulnar nerve, move proximal/distal, and distal/proximal.
  - Use the tug test to confirm continuity and location of the ulnar nerve.
  - Focus on identifying the ulnar nerve (not MABC).
  - Dissect "wide on the ulnar nerve if significant scarring."
  - Limited graded neurolysis but remove all kinks—transpose—transmuscular.
  - MABC neurolysis or transposition.
  - Check for arcade of Struthers when tourniquet deflated.

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24 Recurrent Ulnar Neuropathy

Thomas H. Tung

24.1 Patient History Leading to the Specific Problem

A 54-year-old man is referred with persistent ulnar neuropathy following decompression and transposition over 1 year ago. His symptoms began about 1.5 years ago when he began to notice weakness and clumsiness in his right hand. A diagnosis of severe cubital tunnel syndrome was made, followed by ulnar nerve transposition. Postoperatively, however, he has continued to experience progressive loss of ulnar nerve function and severe ulnar nerve pain for which he takes nortriptyline. He complains of hypersensitivity along the ulnar aspect of his forearm, hand, and ring and small fingers.

24.2 Anatomic Description of the Patient's Current Status

The patient has a well-healed longitudinal curvilinear scar behind the left medial epicondyle extending approximately 6 cm. He has marked ulnar intrinsic atrophy of the left hand, very little ulnar intrinsic function, and a very positive Froment's sign (▶Fig. 24.1). He has very weak ulnar extrinsic function as well. His pinch and grip strengths on the right are 9 and 55 lb, respectively, compared to 20 and 110 lb, respectively, on the left. His 2-point discrimination in the median nerve distribution is between 4 and 5 mm, but no detectable 2-point discrimination or even light touch sensation in the ulnar nerve distribution. He has a strong Tinel's sign at the right elbow and especially at the distal end of his scar where it seems his enlarged ulnar nerve is almost palpable.

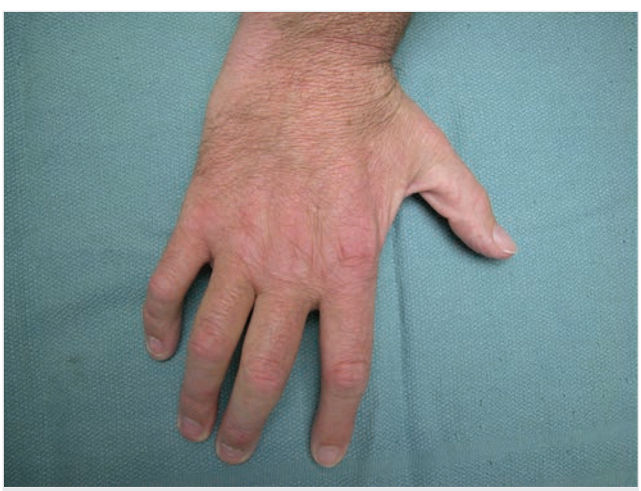

Fig. 24.1 Intrinsic wasting secondary to ulnar nerve neuropathy. The first dorsal interosseous muscle is most notably deficient.

24.3 Recommended Solution to the Problem

A common problem after ulnar nerve transposition is insufficient release and mobilization of the nerve at the most proximal and distal extent of dissection that leads to an acute angle of turn of the nerve both proximally and distally after transposition. Insufficient soft tissue and fascial release will also cause a firm edge against which the nerve will press as its course changes in its transposed location. All of these areas will need to be released and the ulnar nerve further mobilized both proximally and distally so its course is more gradual and smooth as it transitions from its anatomic location to the transposed position. His symptoms are also suspect for injury to one or more branches of the medial antebrachial cutaneous (MBAC) nerve, which will need neuroma excision and proximal transposition into muscle away from the scar.

Finally, he has significant muscle atrophy after a prolonged period of chronic denervation. An appropriate and thorough decompression at this point will be helpful, especially for his pain and sensation, but muscle reinnervation may be more limited because of the chronic duration of his problem. As such, a nerve transfer from the distal anterior interosseous nerve (AIN) should be considered to provide a source of motor axons in closer proximity to the intrinsic muscles and allow faster reinnervation. If done in a reverse end-to-side (RETS) or supercharge end-to-side (SETS) fashion, any reinnervation from his recovering ulnar nerve would still be possible and additive.

24.3.1 Recommended Solution to the Problem

- MABC nerve branches and neuromas need to be identified, excised, and the proximal nerve transposed proximally away from scar.
- The ulnar nerve should be more extensively mobilized to release all scar and existing or potential compression points, including all fascial and septal edges.
- There should be easy transposition of the nerve without sharp bends or pressure points at the proximal and distal endpoints of dissection.
- SETS nerve transfer from the distal AIN should be done to optimize intrinsic muscle reinnervation and supplement the recovering ulnar nerve.

24.4 Technique

His previous scar is excised, reopened, extended both proximally and distally, and skin flaps re-elevated. Branches of the MABC should be identified and any neuromas excised, mobilized, and transposed proximally into innervated muscle to minimize the risk of recurrent neuroma formation. The transposed ulnar nerve is identified, and any overlying scar is released, especially if a fascial sling was constructed to keep it in a transposed position and is now causing any compression. At the proximal and distal exposures, the nerve is remobilized, and the muscle and fascial planes dissected and released to ensure that the nerve takes a smooth curving course to and from its transposed position without any kinking or palpable fascial edges against it. If a submuscular transposition was done before or is being done, intermuscular septa between the forearm muscles under the transposed nerve should also be excised to provide a smooth, soft bed for the nerve without ridges or firm edges that may become more pronounced with scarring. If a new fascial sling needs to be constructed to keep the nerve transposed, it should be very loose and ideally any fascial suturing should be kept away from the nerve and not directly over it if possible (▶Fig. 24.2). Nerve branches coming off the nerve within the cubital tunnel, usually articular and flexor carpi ulnaris (FCU) branches, should be neurolysed from the nerve proximally to gain sufficient length to allow easy anterior transposition without tethering.

For the distal nerve transfer, a separate longitudinal incision should be made in the distal volar forearm. This should be extended onto the proximal palm with a zigzag across the wrist crease to expose and release Guyon's canal. The deep motor branch should be identified and neurolysed from the sensory ulnar nerve as proximally as possible. The distal AIN is identified just proximal to the pronator quadratus muscle, which is then split longitudinally to follow the intramuscular course of the nerve (▶Fig. 24.3a). This will maximize the length of the AIN to facilitate transposition to the ulnar nerve. Once the motor fascicle of the nerve is identified at this level, a RETS transfer of the terminal AIN to the side of the ulnar motor fascicle is constructed with interrupted 9–0 nylon and/or fibrin glue, if preferred (▶Fig. 24.3b). We prefer to make an epineurial/perineurial window at the site of intended coaptation to the motor fascicle, but we do not believe additional significant intentional axonal injury is necessary. The skin is closed over an indwelling drain and a pain pump catheter. A posterior elbow splint is applied for immobilization for no more than approximately 5 days and then movement begun to maximize nerve gliding and minimize scarring.

Fig. 24.2 A fascial sling is employed to maintain the ulnar nerve in its desired, transposed position.

24.5 Postoperative Photographs and Critical Evaluation of Results

At 1.5-year follow-up, his symptoms are significantly improved. His pain is essentially gone and he has stopped taking nortriptyline. His visual analog scales for quality of life, depression, frustration, and anger are all down to 0 from a maximum of 5. His 2-point discrimination in the ulnar nerve distribution is 8 and the Semmes-Weinstein testing in the small finger is 2.83 compared to no sensation preoperatively. Pinch and grip strengths on the right are 9 and 80 lb, respectively. The first dorsal interosseous muscle contraction is visible with pinch.

Many of the problems this patient had can be avoided with careful attention to these details at the time of his initial surgery. Branches of the MABC should be identified and preserved whenever possible. If they cannot, then they should

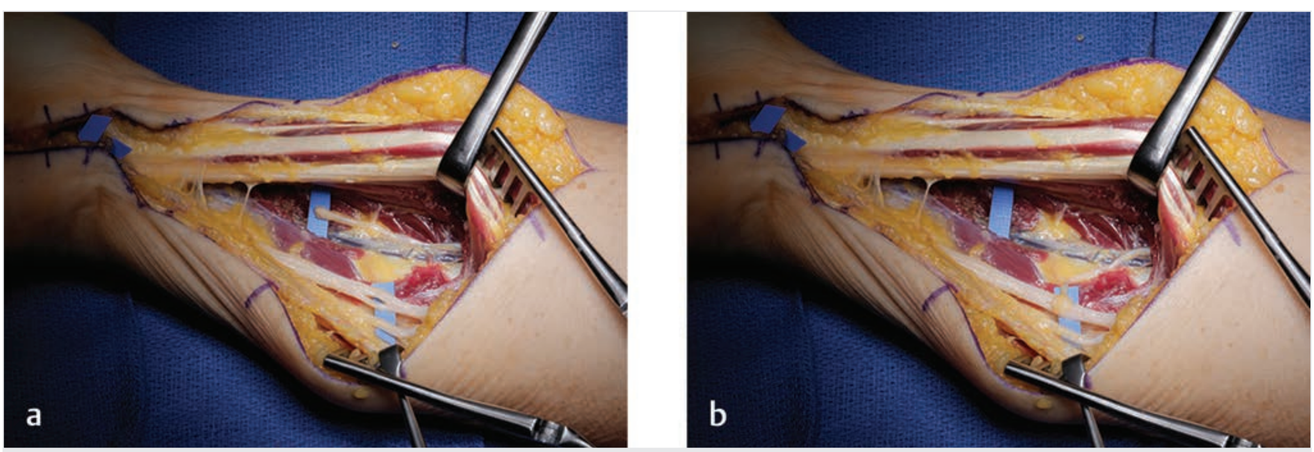

Fig. 24.3 **(a)** The distal anterior interosseous nerve (AIN) is identified just proximal to the pronator quadratus muscle, which is then split longitudinally to follow the intramuscular course of the nerve. **(b)** Once the motor fascicle of the nerve is identified at this level, a reverse end-to-side transfer of the terminal AIN to the side of the ulnar motor fascicle is constructed with interrupted 9–0 nylon and/or fibrin glue, if preferred.

be crushed high (for fourth degree injury) and the end cauterized and transposed proximally away from the scar. Care should also be taken to ensure a sufficient exposure and mobilization of the ulnar nerve so that the transposition does not cause new entrapment points at the proximal and distal ends where the nerve emerges and then courses down again into deeper muscle and fascial planes. The mobilization should be sufficient enough so that the nerve remains in the transposed position easily by itself without tension. Any fascial sling to hold it there should be loose and fascial sutures kept away from the nerve if possible to minimize scarring onto the nerve.

The SETS nerve transfer provides an option to improve muscle reinnervation and function but still allow spontaneous recovery and innervation from the proximal ulnar nerve after thorough decompression. Without this, we believe muscle reinnervation following such prolonged denervation will remain more limited.

24.6 Teaching Points

- Short skin incisions with limited exposure are counterproductive to a thorough nerve mobilization and transposition.
- MABC nerve branches should be respected or can otherwise cause a significant postoperative pain problem.
- All potential compression points should be considered including new ones that arise from dissection and transposition. These often involve fascial or septal bands that form firm edges after scarring and healing.
- SETS nerve transfer is a good option when some nerve function is present but weak, and will benefit from supplementing with additional axonal input.
- Early mobilization will limit nerve scarring, which can contribute to long-term pain and disability.

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25 Radial Tunnel Release in the Forearm

Steven T. Lanier and Jason H. Ko

25.1 Patient History Leading to the Specific Problem

The patient is a 35-year-old right-handed woman who presented with a 3-year history of pain along the dorsoradial aspect of the proximal forearms bilaterally, with the left arm being more symptomatic than the right. She also reported some weakness of finger extension on the left compared to the right, along with intermittent numbness and tingling in the dorsoradial aspect of her left hand and wrist. She worked as a nurse and had trouble performing some of her job duties due to the pain.

On examination, the patient endorsed focal tenderness over the area of the posterior interosseous nerve (PIN) on the left dorsoradial forearm approximately 5 cm distal to the lateral epicondyle, along with a positive Tinel's sign over the radial tunnel. Scratch-collapse test was positive for radial neuropathy in the left dorsal forearm. Symptoms were exacerbated with resisted forearm supination. She had 5/5 muscle strength of the wrist extensors, but 4–/5 strength of the extensor digitorum communis (EDC) compared to the contralateral side, with slightly diminished sensation to light touch in the radial sensory nerve distribution. Palpation of the lateral epicondyle elicited minimal to no tenderness, and there was no appreciable increase in pain with resisted wrist extension, making lateral epicondylitis a less likely diagnosis. Based on these findings, a diagnosis of radial tunnel syndrome was made. Nerve conduction studies and electromyogram (EMG) were not obtained as these are often normal in the cases presenting with radial tunnel syndrome, and the diagnosis is considered a clinical one.

Prior to presentation, the patient had been unsuccessfully treated by an outside surgeon for presumed lateral epicondylitis with nonsteroidal anti-inflammatory drugs (NSAIDs) and therapy exercises. She had attempted to avoid activities that exacerbated the pain, but she was still working without restrictions and dealing with persistent pain. Conservative measures had failed to provide any relief, and upon learning of the diagnosis of radial tunnel syndrome, the patient desired surgical intervention on the left upper extremity with the hope of returning to work pain free.

25.2 Anatomic Description of the Patient's Current Status

The patient has no external stigmata of injury of the proximal dorsoradial forearm or lateral epicondylar region. Based on her history and physical examination findings, however, we can deduce that the radial nerve is being compressed within the radial tunnel. The radial nerve courses anterior to the lateral intermuscular septum in the distal arm. After giving branches to the brachialis and brachioradialis muscles, it enters the dorsoradial aspect of the forearm anterior to the lateral epicondyle. After branching to the extensor carpi radialis longus (ECRL), extensor carpi radialis brevis (ECRB), and supinator muscles, the radial nerve bifurcates into the radial sensory nerve and the PIN, which immediately courses deep to the proximal edge of the superficial head of the supinator muscle into the radial tunnel. The radial tunnel is bordered radially by the ECRB muscle, medially by the biceps tendon and brachialis, with a floor formed by the radiocapitellar joint proximally, and deep head of the supinator muscle distally. The roof of this tunnel consists of the superficial head of the supinator muscle, the most proximal extent of which forms the arcade of Frohse. Potential compression points of the radial nerve include the fibrous bands of the radiocapitellar joint, recurrent leash of Henry (radial recurrent vessels), the proximomedial edge of the ECRB, the arcade of Frohse, and the distal edge of the supinator.

25.3 Recommended Solution to the Problem

For patients presenting with early signs of nerve compression and no motor weakness, conservative measures are attempted first for a period of at least 3 months, including activity modification, NSAIDs, and corticosteroid injection (CSI). In a series by Sarhadi et al, 16 of 23 patients experienced 2 years of pain relief with a single injection of 40 mg of triamcinolone. We offer surgical decompression of the radial nerve if conservative measures fail, if the patient's symptoms have a significant negative impact on work and leisure activities, or if there is evidence of PIN-innervated extensor muscle weakness when compared to the contralateral side. The three commonly used surgical exposures are the volar approach (referred to as the Henry approach), the brachioradialis-splitting approach, and the dorsal approach. Our preferred surgical technique is the dorsal approach, which develops the interval between the brachioradialis and the ECRL. Reported success rates of surgical decompression of the radial nerve vary from 67 to 92%. A recent series of patients by Simon Perez et al treated with the dorsal approach reported that approximately 50% of patients achieved symptom-free "excellent" results and an additional 37% achieved "good results," with only occasional symptoms with prolonged activity.

25.3.1 Recommended Solution to the Problem

- Surgical decompression of the radial nerve in the radial tunnel via a dorsal approach between the brachioradialis and the ECRL interval.
- Full release of the arcade of Frohse and the superficial head of the supinator muscle.
- Ligation of the leash of Henry if there are visible signs of anatomic compression.

25.4 Technique

The patient is taken to the operating room and placed supine on the operating table. The arm is abducted 90 degrees and placed on a hand table, and a tourniquet is placed on the upper arm. The arm is then prepped and draped in the standard fashion.

The surgeon sits facing the dorsal aspect of the patient's arm with an assistant facing the volar surface of the arm. The forearm is pronated and placed on the hand table with the extensor surface up. The skin incision is marked along the groove between the brachioradialis radially and the ECRL ulnarly (▶Fig. 25.1).

The proximal extent of the incision begins approximately 2 cm distal to the lateral epicondyle and extends obliquely along the medial border of the mobile wad for approximately 8 cm. The arm is exsanguinated, and the tourniquet is then inflated. The incision is made with a scalpel through the skin, and tenotomy scissors are used to dissect the superficial subcutaneous tissue (▶Fig. 25.2a). The posterior antebrachial cutaneous nerve (PACN) of the forearm may be encountered during the dissection and should be protected. The PACN lies dorsal to the interval between the brachioradialis and the ECRL and can be used as a landmark for this intermuscular interval (▶Fig. 25.2b).

Fig. 25.1 Positioning and marking: the forearm is pronated and the incision is marked along the groove between the brachioradialis and the extensor carpi radialis longus.

A difference in thickness of the fascia overlying the brachioradialis and the ECRL is typically noticeable, and this fascial interval is incised with a scalpel. The interval is developed with a combination of tenotomy scissors and mostly blunt dissection (▶Fig. 25.3a). A self-retaining retractor is then placed in this interval to expose the radial nerve and its overlying structures (▶Fig. 25.3b).

The vascular leash of Henry can be ligated with vascular clips, and further dissection will expose the PIN and radial sensory nerve (▶Fig. 25.4). The supinator muscle and its thick fibers will be visible running obliquely at the base of the field, and the PIN will be seen diving deep to the thickened proximal aponeurotic border of the supinator, also known as the arcade of Frohse.

The radial sensory nerve can be seen radial to the PIN, and the arcade of Frohse and the entirety of the superficial head of the supinator muscle overlying the PIN are then divided (▶Fig. 25.5).

Complete decompression of the PIN is confirmed visually and manually, and proximal release of any potential fibrous bands of the radiocapitellar joint is performed to complete the nerve decompression (▶Fig. 25.6).

The tourniquet is then deflated and hemostasis obtained with bipolar electrocautery. The skin is closed in layers with interrupted, buried-deep dermal 3–0 absorbable sutures and a 4–0 monofilament subcutaneous suture. The arm is then placed in a soft dressing, consisting of gauze and a gentle compressive ACE wrap. This dressing is kept in place until 48 hours after the procedure; active and passive range of motion can begin immediately postoperatively.

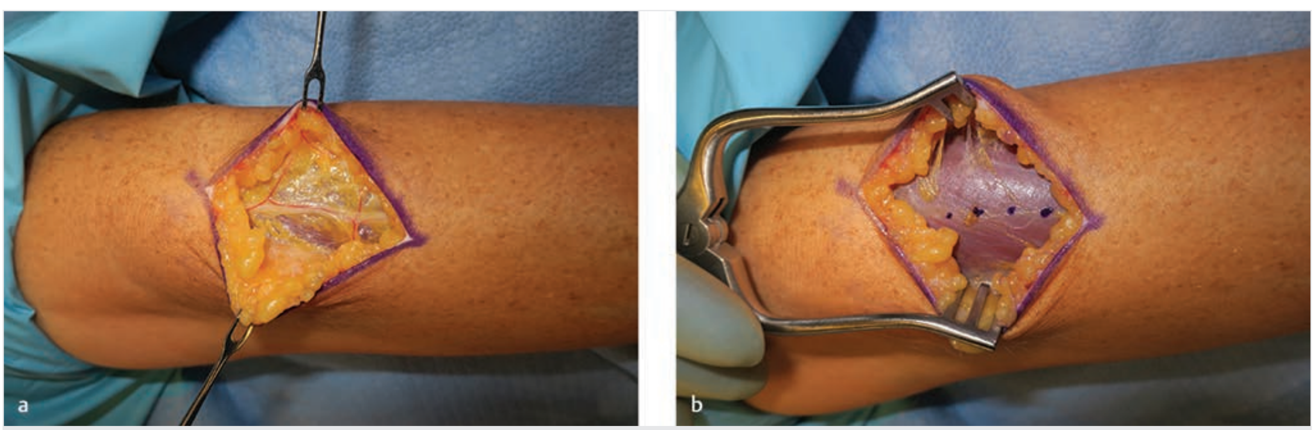

Fig. 25.2 **(a)** Dissection of subcutaneous tissue reveals the posterior antebrachial cutaneous nerve (PACN). **(b)** The PACN serves as a landmark for the interval between the brachioradialis and the extensor carpi radialis longus (*black dots*).

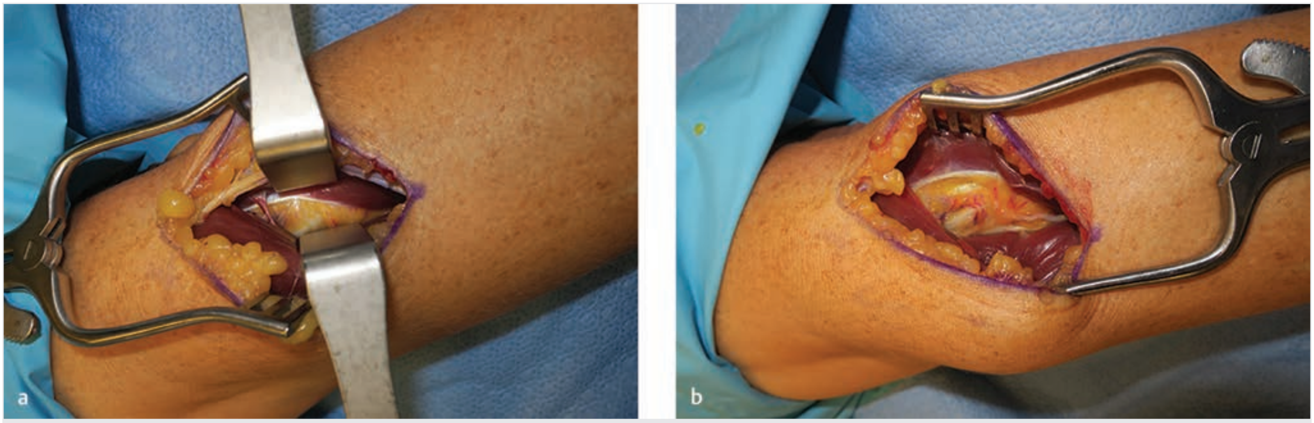

Fig. 25.3 Exposure of the radial nerve. **(a)** Fascial interval is developed with tenotomy scissors and blunt dissection. **(b)** A self-retaining retractor is used to expose the radial nerve and the overlying structures.

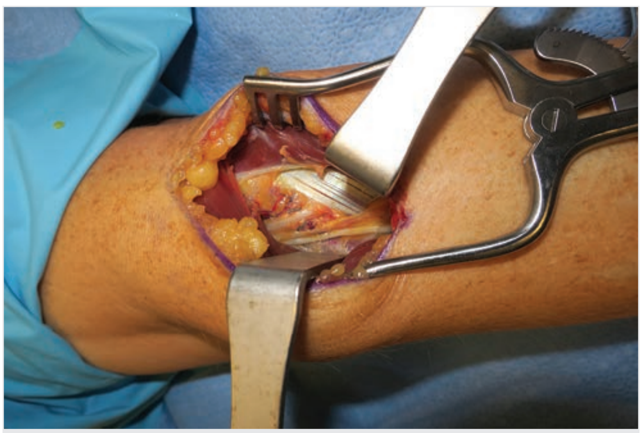

Fig. 25.4 Ligation of the vascular leash of Henry and exposure of the posterior interosseous nerve.

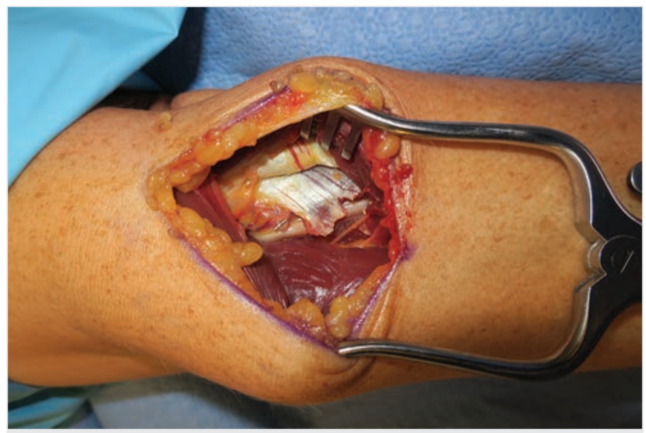

Fig. 25.5 Division of the superficial head or the supinator muscle overlying the posterior interosseous nerve.

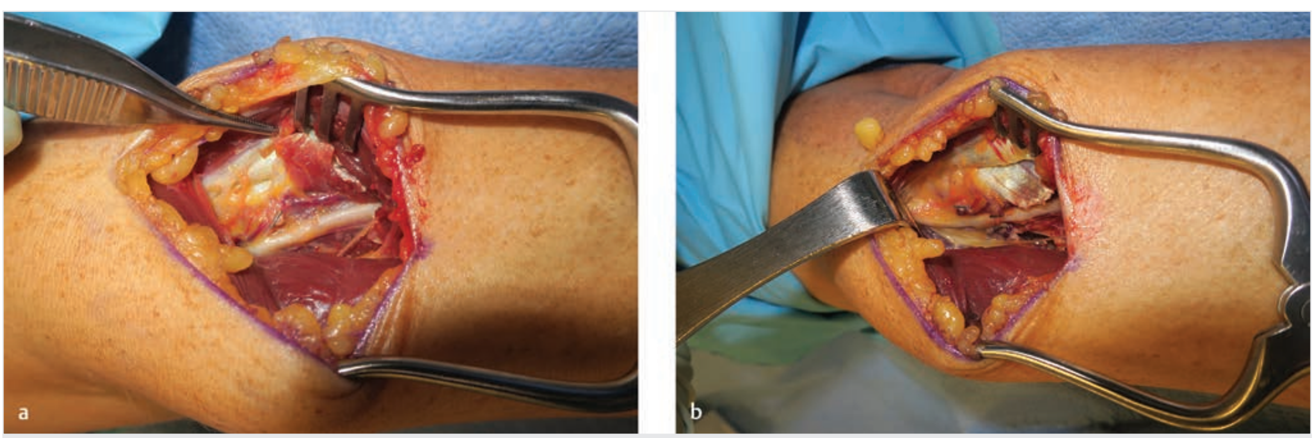

Fig. 25.6 Complete release of the radial nerve is ensured both **(a)** distally and **(b)** proximally.

25.4.1 Steps for the Procedure

1. Mark incision that begins approximately 2 cm distal to the lateral epicondyle and extends obliquely along the medial border of the mobile wad for approximately 8 cm.
2. Exsanguinate the arm with Esmarch and inflate tourniquet.
3. Incise skin and dissect to the fascial interval between the brachioradialis radially and the ECRL ulnarly, protecting the PACN of the forearm anteriorly.
4. Retract the brachioradialis and ECRL to visualize the superficial head of the supinator muscle with the PIN along the anterior border.
5. Overlying vessels (leash of Henry) should be ligated with vascular clips.
6. While protecting the PIN, incise the arcade of Frohse and release the entire superficial head of the supinator muscle using bipolar electrocautery.
7. Ensure decompression by observing the PIN with the arm in pronation and supination, and confirm there are no additional compression points of the radial sensory nerve.
8. Explore the radial nerve proximally and release any fibrous bands of the radiocapitellar joint region.
9. Obtain hemostasis and perform a layered closure of the skin.
10. Apply a soft dressing that is taken down in 48 hours and begin range of motion immediately as tolerated.

25.5 Postoperative Photographs and Critical Evaluation of Results

The patient reported full resolution of her symptoms. Her incision healed well, and there were no postoperative complications.

25.6 Teaching Points

- Radial tunnel syndrome is a clinical diagnosis of compression of the PIN in the dorsoradial forearm, resulting in primarily pain localized to this region, with occasional extensor muscle weakness. A presentation consisting of primarily motor weakness without pain is referred to as the PIN syndrome, though the site of compression and anatomic structures involved are the same.
- Radial tunnel syndrome needs to be differentiated from lateral epicondylitis.
- The radial tunnel is bordered radially by the ECRB muscle, medially by the biceps tendon and brachialis, with a floor formed by the radiocapitellar joint proximally, and deep head of the supinator muscle distally.
- Conservative measures including activity modification, NSAIDs, and CSI may be tried for a period of 3 to 6 months prior to surgical intervention. Anecdotal evidence suggests potential effectiveness of CSI, though further study is needed.
- Failure to respond to conservative measures with significant interference of daily activities—or any motor weakness—is an indication for surgical decompression of the radial nerve in the dorsoradial forearm.
- Volar and dorsal approaches with various intervals of access to the radial tunnel have been described. Our preferred surgical approach is the dorsal approach in the interval between the brachioradialis and the ECRL.
- A soft dressing is applied postoperatively, and active and passive range of motion is begun immediately.

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Part VIII

Problems with Nerve Repair

26 End Neuroma *110*

27 Pain following Nerve Repair *114*

VIII

26 End Neuroma

Theodore A. Kung and Paul S. Cederna

26.1 Patient History Leading to the Specific Problem

A 47-year-old man presented several years after sustaining a traumatic transfemoral amputation of the left lower extremity and subsequent above-knee revision amputation. He reports intense neuropathic pain that emanates from a consistent location along the posterior aspect of his left residual thigh. Direct pressure over this specific point exacerbates his symptoms and as a result the patient has considerable difficulty wearing his prosthesis to ambulate. Upon exploration, a large-end neuroma involving the distal sciatic nerve was discovered (▶Fig. 26.1).

26.2 Anatomic Description of the Patient's Current Status

After a peripheral nerve is severed (neurotmesis), Wallerian degeneration occurs distal to the site of injury, followed by axonal sprouting and elongation that is guided by a multitude of local neurotrophic factors. When the distal end of the severed peripheral nerve is available, the optimal intervention is to perform end-to-end neurorrhaphy in order to allow the regenerating axons to reestablish contact with the distal nerve segment. However, in the setting of amputation, the distal nerve segment is absent and consequently the regenerating axons are prone to form an end neuroma consisting of a disorganized mass of axonal spouts, Schwann cells, fibroblasts, and capillaries. Symptomatic neuroma occurs in up to a third of patients with major limb amputation. In patients who experience traumatic amputation injury, the incidence of residual limb pain can be as high as 70%.

Although the experience of neuroma pain itself can be quite debilitating, a serious functional consequence of persistent pain in the residual limb is the inability to wear a prosthetic device. This leads to considerable limitations in a patient's capacity to perform activities of daily living and a significantly decreased quality of life. As a result of neuroma pain, patients with a major upper extremity amputation frequently forego the functional advantages of an artificial limb and may not even tolerate a passive, cosmetic prosthesis. Those with a lower extremity amputation may suffer even more significant morbidity due to the loss of ambulation. Therefore, all patients with limb loss should be carefully evaluated for symptomatic neuromas. If present, the neuromas should be surgically addressed to allow the patient to comfortably wear a prosthesis.

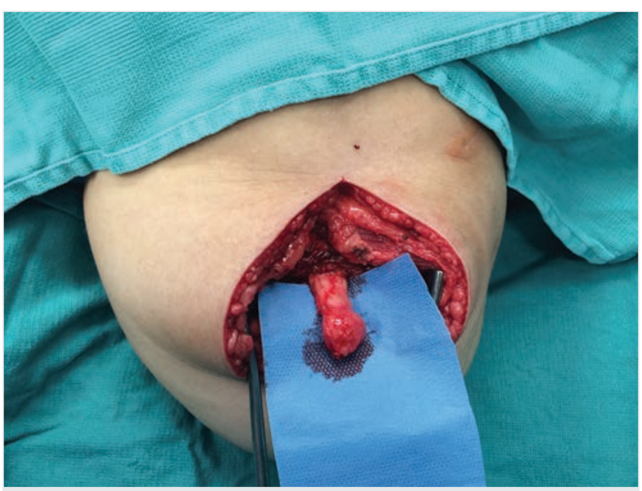

Fig. 26.1 Large end neuroma involving the distal sciatic nerve.

26.3 Recommended Solution to the Problem

Various nonsurgical therapies for neuroma pain have been described, including desensitization therapy, injection of the neuroma with chemicals that attempt to inhibit axonal regeneration, and numerous medications such as antidepressants, anticonvulsants, and narcotics. However, definitive treatment involves surgical exploration, excision of the neuroma bulb, and an effort to either to reduce the pain of a recurrent neuroma or to prevent the reformation of a recurrent neuroma. The most commonly performed option to address recurrent neuroma pain is to bury the end of the nerve into normal muscle tissue after neuroma excision. With this method, the end neuroma is expected to reform, but the muscle serves as a biological cushion that mitigates the incitement of painful neuroma symptoms.

More recently, investigation into novel strategies to control neuroprosthetic limbs has led to techniques that inhibit neuroma formation. These approaches prevent the development of a disorganized and hyperexcitable neuroma bulb by promoting guided axonal regeneration and subsequent reinnervation of denervated muscle. For example, targeted muscle reinnervation (TMR) is a method whereby a nerve transfer is performed to provide sprouting axons a distal target for reinnervation in order to prevent reformation of an end neuroma. After the neuroma bulb is excised from the symptomatic nerve, a specific recipient motor branch is selected and divided, which results in selective denervation of the target muscle. Coaptation is then performed between the proximal nerve (which formerly had the neuroma) and the distal recipient motor branch, allowing the axons to regenerate toward and subsequently reinnervate the denervated muscle.

The regenerative peripheral nerve interface (RPNI) is a novel strategy to prevent neuroma formation in transected peripheral nerves. The RPNI consists of a residual peripheral nerve that is implanted into a free skeletal muscle graft either at the time of limb amputation or after excision of a neuroma bulb (▶Fig. 26.2). Because the muscle fibers within the

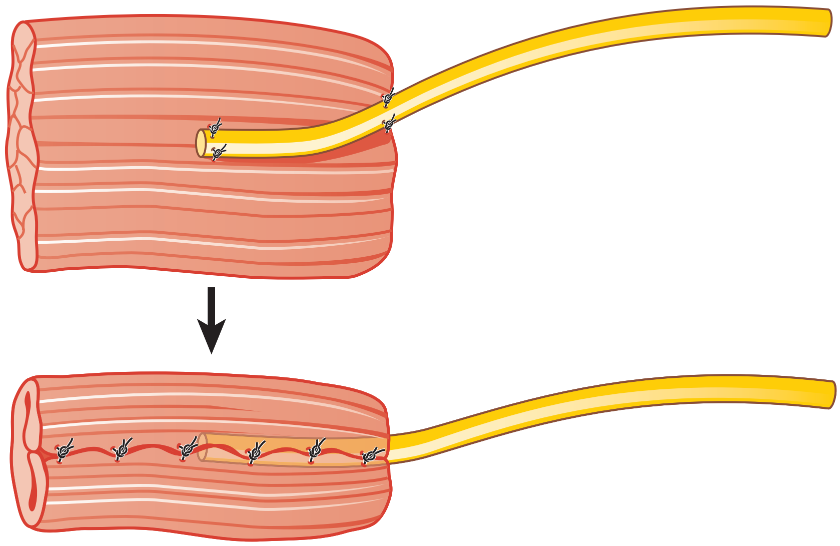

Fig. 26.2 Regenerative peripheral nerve interface.

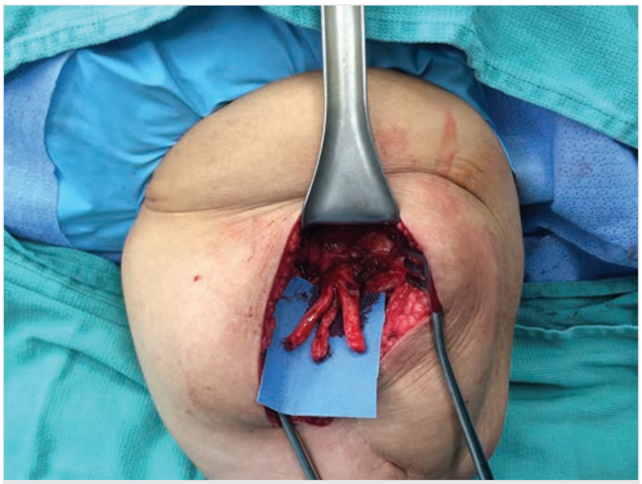

Fig. 26.3 Intraneural dissection of fascicles.

free graft are both nonvascularized and denervated, they will undergo a process of degeneration followed by regeneration and are subsequently reinnervated by the sprouting axons of the implanted nerve. In this manner, the RPNI encourages the formation of new neuromuscular junctions within the free muscle graft, thereby greatly reducing the number of aimless axons at the end of the nerve and reducing the chance of neuroma recurrence. Multiple RPNIs can be performed at the site of limb amputation using a piece of free muscle graft for each available peripheral nerve end.

26.3.1 Recommended Solutions to the Problem

- Implantation into muscle.
- Targeted muscle reinnervation.
- Regenerative peripheral nerve interface.

26.4 Technique

The end neuroma is identified under tourniquet control and the symptomatic nerve is dissected proximally for several centimeters to free it from any surrounding adhesions. If the neuroma is located in an unfavorable location, such as the weight-bearing aspect of the residual limb, the nerve is repositioned so that ultimately the RPNI is protected from external pressure. The neuroma bulb is sharply excised with a blade. An end neuroma involving a small sensory nerve can be addressed using a single RPNI. However, larger mixed nerves such as the sciatic nerve contain several major fascicles that can be meticulously separated by dividing the epineurium and performing intraneural dissection (▶Fig. 26.3). This allows for construction of several RPNIs, which optimizes the ratio of regenerating axons to denervated muscle fibers. Additionally, splitting of the fascicles within a large nerve also permits future detection of discrete electromyographic motor signals from these fascicles if the RPNIs are to be used for controlling a prosthetic device.

One free muscle graft for each RPNI is harvested sharply using a knife. Electrocautery is avoided in order to preserve the viability of muscle fibers. The donor muscle tissue is usually taken from the surrounding musculature within the distal amputation stump, but can also be harvested from a distant location, such as the vastus lateralis muscle. To facilitate muscle regeneration and reinnervation, tissue scissors are used to remove as much fat and fascia as possible from the graft. The size of the free muscle graft varies with the size of the nerve or fascicle and generally maintains a 2:1 length-to-width ratio (▶Fig. 26.4a). The nerve is then implanted into the central portion of the free muscle graft and the epineurium is secured to the epimysium using two 6–0 nonabsorbable monofilament sutures. Subsequently, the edges of the muscle graft are wrapped completely around the nerve and closed with sutures (▶Fig. 26.4b). In most cases, the cylinder of muscle measures approximately 3 to 4 cm in length and 1.5 to 2 cm in

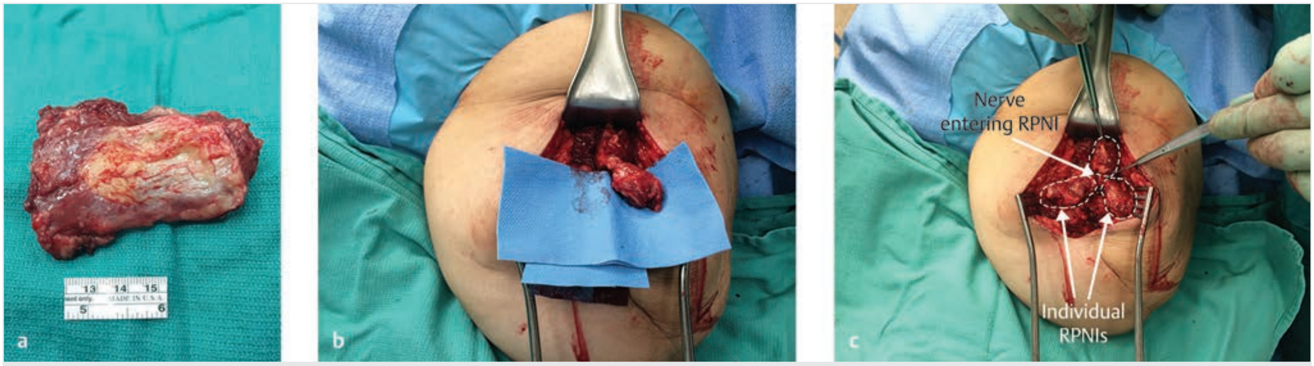

Fig. 26.4 (a) Free muscle graft for regenerative peripheral nerve interface (RPNI). **(b)** Muscle graft wrapped around the nerve and sutured closed. **(c)** Multiple RPNIs located adjacent to each other within the residual limb.

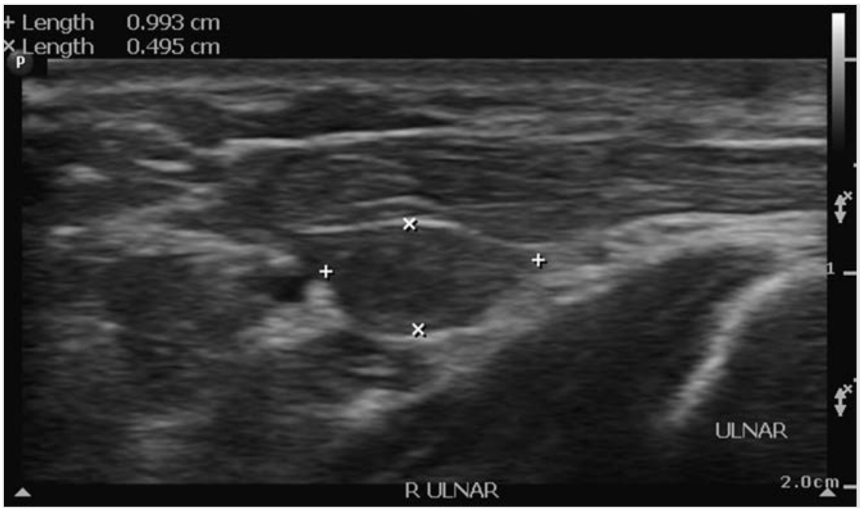

Fig. 26.5 Ultrasound evaluation of the free muscle graft.

diameter. Multiple RPNIs can be located adjacent to each other within the residual limb (▶Fig. 26.4c). The surgical site is then closed in layers.

26.4.1 Steps for the Procedure

1. Identify the end neuroma and free the nerve from scar tissue.
2. Sharply excise the neuroma bulb.
3. Determine if one or more RPNIs are to be performed. Large nerves can be separated into major fascicles.
4. Harvest a free muscle graft for each nerve fascicle.
5. Nerve is implanted and the muscle is wrapped around the nerve and secured with 6–0 nonabsorbable monofilament sutures under loupe magnification.

26.5 Postoperative Photographs and Critical Evaluation of Results

Immediately after RPNI surgery is performed, patients often report improvement of their neuroma symptoms and this is likely a direct result of excising the hyperexcitable neuroma bulb. Further pain relief can be expected throughout a period of about 3 to 4 months as sprouting axons begin to reinnervate the regenerated free muscle grafts. A mature RPNI can be evaluated by ultrasound imaging to confirm the presence of the free muscle graft (▶Fig. 26.5). After RPNI surgery, patients should proceed with prosthetic rehabilitation.

Amputees with symptomatic neuromas frequently also suffer from chronic pain that arises from both peripheral and central nervous system mechanisms. These patients may depend on multiple medications for pain management, including chronic opioid therapy, which may further complicate central neural sensitization pathways. Due to the complex pathophysiology of neuropathic pain, treatment of the end neuroma may not completely relieve pain within the residual limb. For example, phantom limb pain largely derives from central neural mechanisms that can be exacerbated by the presence of neuromas. Surgical treatment of the neuromas may eliminate the peripheral trigger of phantom limb pain but will not affect the root cause, which originates from the central nervous system.

26.6 Teaching Points

- Symptomatic neuromas can result in abandonment of prosthetic devices, which leads to decreased functional capacity and quality of life for amputees.
- Sprouting axons from a divided peripheral nerve seek to reestablish physiologic connections with end organs. Without reinnervation, these free axons are prone to forming an end neuroma.

- Surgical treatment of a symptomatic neuroma within an amputation site involves sharp excision of the neuroma bulb and addressing the residual nerve end to either reduce the pain of a recurrent neuroma or to prevent the reformation of a recurrent neuroma.
- The RPNI is a novel treatment for end neuromas. Sprouting axons are guided to denervated free muscle grafts and subsequent reinnervation prevents the formation of a neuroma.

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27 Pain following Nerve Repair

Ida K. Fox and Leahthan F. Domeshek

27.1 History

A 40-year-old right-hand-dominant woman was accepted in transfer with subacute left, greater than right, neuropathic arm pain. Five days prior to presentation, the patient had fallen on the stairs and sustained bilateral upper extremity lacerations from broken glass. She sustained bilateral arterial, nerve, and tendinous injuries and presented to an outside facility for emergent management. Perfusion was restored, tendons were repaired, and major nerve branches were temporarily coapted using conduit. On transfer, she presented with tachycardia and 10 out of 10 pain.

27.2 Anatomic Description of the Patient's Current Status

27.2.1 Examination Findings

The left arm had a stapled transverse laceration spanning the antecubital fossa with significant edema, no signs of infection, intact distal perfusion, pain with attempted elbow flexion, and absent distal median and radial nerve function. There was exquisite sensitivity to light touch at the medial and lateral aspects of the proximal staple line with loss of sensation in the medial antebrachial (MABC) and lateral antebrachial (LABC) cutaneous nerve distributions. Distal ulnar nerve function was preserved.

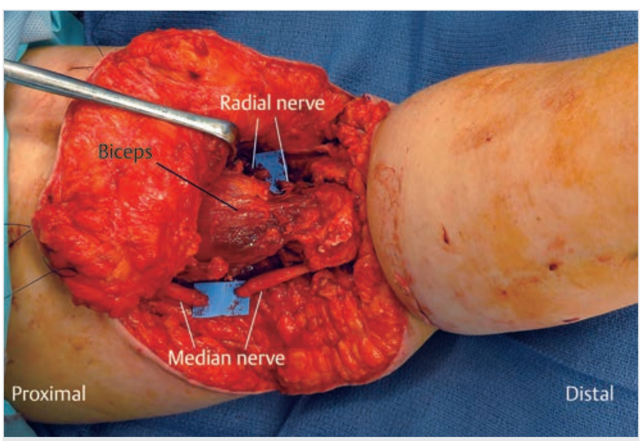

Fig. 27.1 Left upper extremity after extension of the laceration, exposure and removal of the previously interposed nerve conduits. The transected median and radial nerves are visible. The biceps was transected at the musculotendinous junction; the brachialis was partially transected; the proximal muscle bellies were coapted under tension to the distal brachialis muscle. The distal biceps tendon had not been included in the repair. The nerve stumps are contused and show some evidence of a more avulsive mechanism of injury. (Reproduced with permission of nervesurgery.wustl.edu)

The right arm had a stapled oblique laceration that crossed the ulnar aspect of the forearm. Distal function of the ulnar nerve was absent.

27.2.2 Intraoperative Findings

In the left upper extremity, after extending the previous laceration significantly to allow for better exposure, the ends of the transected left median and radial nerves were exposed. They had been approximated, under moderate tension, with nerve conduits (▶Fig. 27.1). In addition, after meticulous and tedious dissection through the subcutaneous tissue, the proximal ends of the transected LABC and MABC were identified; the distal stumps could not be easily identified. A laceration through the biceps musculotendinous junction and brachialis muscle belly was also noted.

In the right upper extremity, the previous laceration was extended slightly, and the transected ulnar nerve (with interposed conduit) was exposed. The muscle bellies of the flexor digitorum superficialis (FDS) and flexor carpi ulnaris (FCU) were partially transected (▶Fig. 27.2).

27.2.3 Physiologic Explanation of Problem

Following laceration, the proximal nerve end undergoes axonal sprouting, and, if left unrepaired, it can generate a traumatic neuroma. Stimulation of this traumatized proximal stump leads to pain and paresthesias. If the proximal end is appropriately approximated to a recipient scaffold for ingrowth (i.e., distal stump of the transected nerve, autograft, allograft, etc.), regeneration occurs, preventing neuroma formation and its accompanying pain.

Furthermore, when a traumatized nerve is repaired, the coapted ends must be healthy, and outside of the zone of injury.

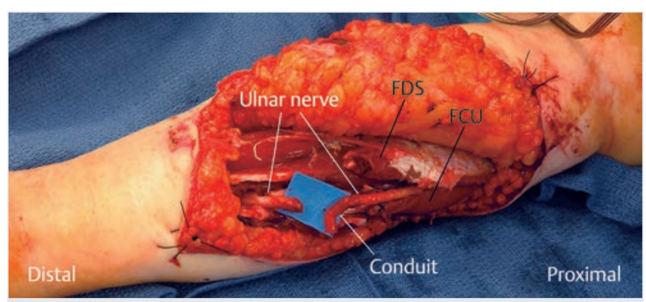

Fig. 27.2 Right upper extremity. The transected ulnar nerve is visible, still attached to the previously interposed conduit proximally. Lacerated flexor digitorum superficialis (FDS) and flexor carpi ulnaris (FCU) muscle bellies are noted. The distal nerve stump appears to be of poor quality—ecchymotic, with evidence of an avulsive mechanism. (Reproduced with permission of nervesurgery.wustl.edu.)

Coaptation of damaged fascicles will prohibit healthy nerve regeneration, resulting in a segment of abnormal fascicular sprouting and scar (neuroma in continuity). Tension across a nerve repair also inhibits axonal outgrowth and promotes gapping, both of which further contribute to neuroma-in-continuity formation. For these reasons, acute repair of nerve injuries requires aggressive trimming of traumatically transected nerve ends and, often, interposition grafting to avoid tension.

27.3 Recommended Solution to the Problem

Anticipating and addressing the potential for neuropathic pain at the time of nerve injury, through pharmacologic, surgical, and therapeutic interventions can help prevent this problem. Nerves of critical function must be repaired, tension free, with interposed graft material if a tension-free primary repair is not possible. Distal compression points, which add additional insult to an injured nerve (the double-crush phenomenon), should be released to assist distal regeneration and potentially decrease pain or dysfunction.

There must be a high index of suspicion for injured cutaneous nerves (such as the LABC and MABC), which can also lead to painful neuroma formation. Diligent dissection to identify at least the proximal nerve end is important. If the distal ends cannot be found, then the proximal end should be cauterized, crushed proximally (to move the regeneration front away from the cut end), and transposed in a loose loop, deeper into a relatively immobile muscle plane. These injured cutaneous nerves may also be harvested for use as “spare parts” graft material for repair of nerves of more critical function.

Neuropathic pain medications, such as gabapentin, nortriptyline, or pregabalin, should be started at the time of injury and titrated as needed to control pain after surgery. These should be used in conjunction with anti-inflammatories, muscle relaxants, and narcotics. Early referral to a pain specialist can be helpful not only for medication management but also for performance of both pre- and postoperative nerve blocks. Indwelling supraclavicular catheters can also be placed for instillation of continuous local anesthetic perioperatively. Later, stellate (sympathetic) ganglion blocks can provide significant pain relief and even help prevent progression to complex regional pain syndrome (CRPS).

Finally, physical therapy can be a powerful adjunct. Techniques such as desensitization and graded motor imagery can assist with pain control. Additionally, following repair, institution of early nerve gliding exercises (even within the limited movement required to protect muscle and/or tendon repairs) helps ensure that newly repaired nerves do not heal encased and tethered in scar.

27.4 Technique for Nerve Harvest and Repair

27.4.1 Sural Nerve Harvest

The patient may be positioned prone for bilateral harvest (supine may be used for one-sided harvest or in children/smaller patients). The sural nerve is identified, through an incision posterior to the lateral malleolus (▶Fig. 27.3) running with the lesser saphenous vein, just lateral to the Achilles tendon. Harvest is performed with the assistance of a nerve stripper (do not substitute the tendon stripper, which will transect the nerve) to free the nerve from surrounding tissues without requiring an extensive incision along the posterior leg. Several small incisions may be needed proximally along the course of the sural nerve to free branches that prohibit smooth use of the stripper. The proximal end of each harvested nerve is marked.

Fig. 27.3 Bilateral sural nerve harvest. Incisions are noted posterior to the lateral malleoli, anterior to the Achilles tendons. Prone positioning of the patient facilitates harvest when bilateral sural nerves are to be obtained. Later, proximal incisions were made to allow harvest of both sural nerves to the level of the posterior knee. (Reproduced with permission of nervesurgery.wustl.edu.)

27.4.2 Upper Extremity Nerve Repair

Left Upper Extremity

The identified, transected MABC and LABC nerves are noted to be of excellent quality and are harvested for use as autograft. The new proximal stump of each nerve is cauterized, crushed proximally with a hemostat clamp, and transposed to lie loosely in a proximal muscle belly. The proximal and distal stumps of the median and radial nerves are prepared for cable grafting by bread-loafing until healthy fascicular patterns are visualized on cross-section (▶Fig. 27.4).

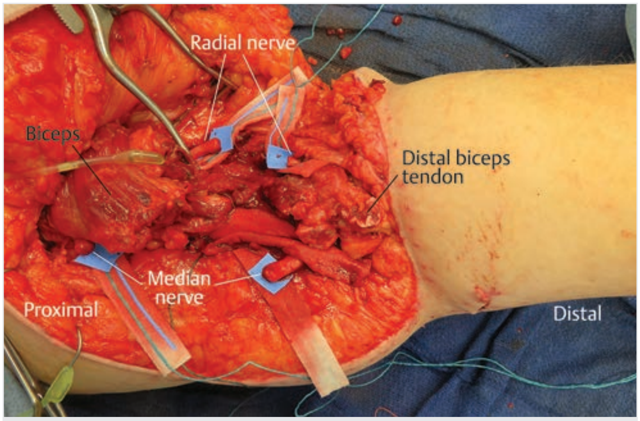

Fig. 27.4 Left upper extremity following muscle and nerve debridement. Proximal and distal median and radial nerve stumps have been serially bread loafed back until soft, nonecchymotic nerves ends with clear fascicular patterns are identified. (Reproduced with permission of nervesurgery.wustl.edu.)

Right Upper Extremity

The proximal and distal stumps of the ulnar nerve are prepared for cable grafting by bread-loafing until healthy fascicular patterns are visualized on cross-section (▶Fig. 27.5). Aggressive trimming is critical.

27.4.3 Nerve Grafting

Given their size, the median, ulnar, and radial nerves must be repaired using multiple cable grafts (▶Fig. 27.6). For each, the

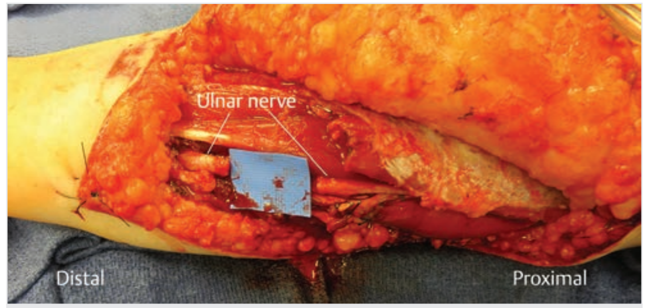

Fig. 27.5 Right upper extremity following muscle and nerve debridement. The proximal and distal nerve ends have been serially bread loafed back. (Reproduced with permission of nervesurgery.wustl.edu.)

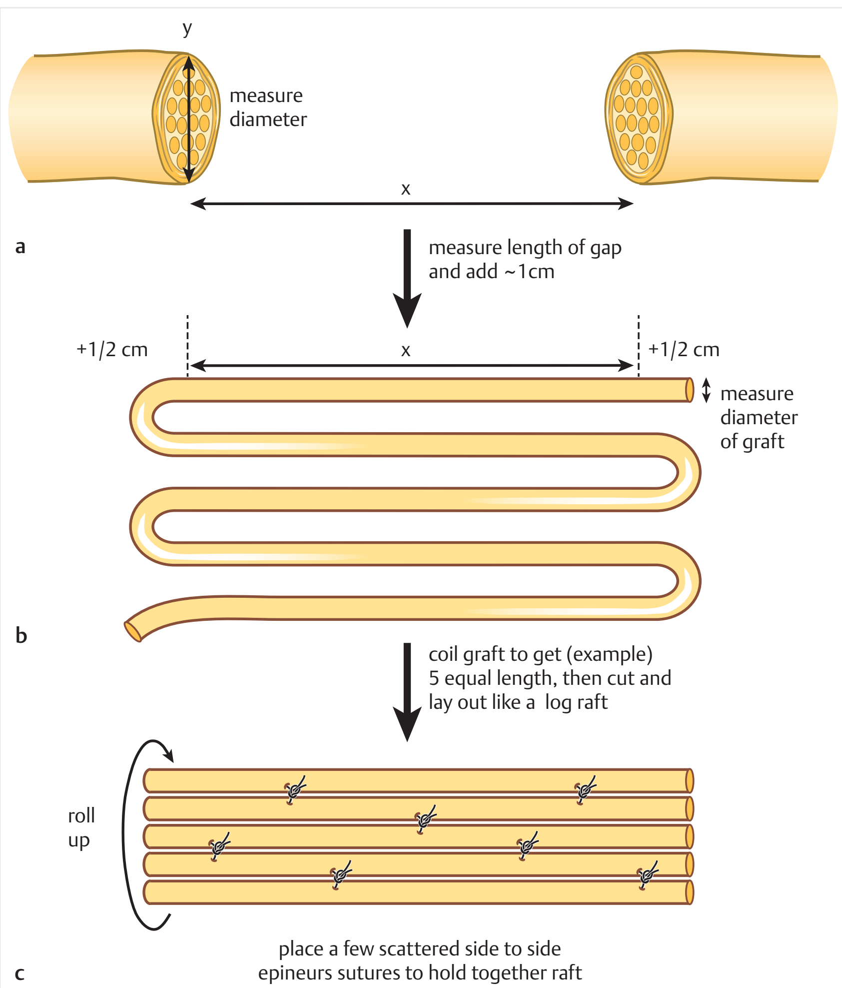

Fig. 27.6 Schematic of preparation of cable grafts. The cable grafts can be prepared on a back table by one team while the other team flips a patient from prone to supine (in the case of sural nerve harvest) or while the second team is preparing the in vivo nerve stumps for coaptation. **(a)** Measure gap distance between proximal and distal nerve stumps (x) and add approximately 1 cm. **(b)** Fold nerve graft back on itself in equal lengths of x + 1 (generating, in this schematic, five cables). The number of cables required to match the diameter of the injured nerve (y) can be best estimated by temporarily placing the autograft folded on itself next to the native nerve to see how they approximate one another in size. **(c)** A few scattered 9–0 nylon epineurial stitches can be used to keep cables approximated to one another side by side. (*Continued*)

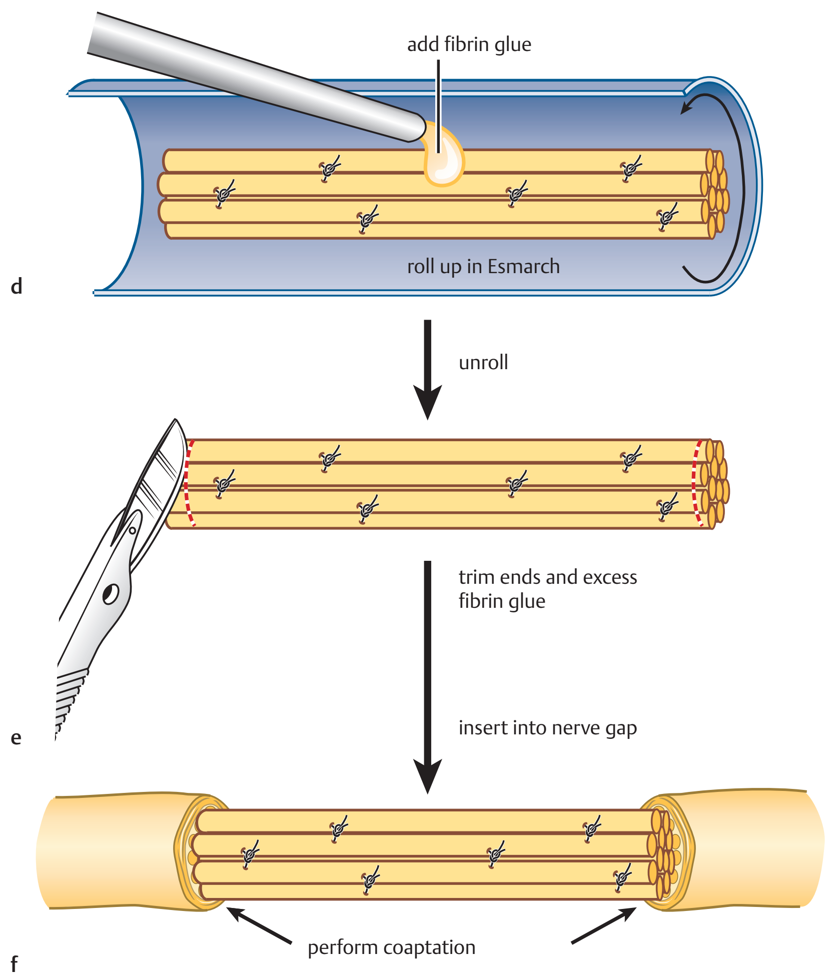

Fig. 27.6 (*Continued*) **(d)** Roll up cables in a piece of Esmarch. Add fibrin glue to hold cables in the newly created tubular construct. Ensure that cables remain parallel, such that they do not cross or twist around one another. **(e)** Unroll Esmarch and trim ends of cable construct, removing excess fibrin glue. **(f)** Insert construct into nerve gap, avoiding twisting of cables to ensure that proximal and distal topography of native injured nerve is aligned as accurately as possible. Following coaptation of cable construct to proximal and distal stumps of injured nerve, reinforce coaptation sites with additional fibrin glue. Keeping a piece of Esmarch or blue background underneath the coaptation sites until the fibrin glue has set will help prevent the graft from adhering to surrounding structures.

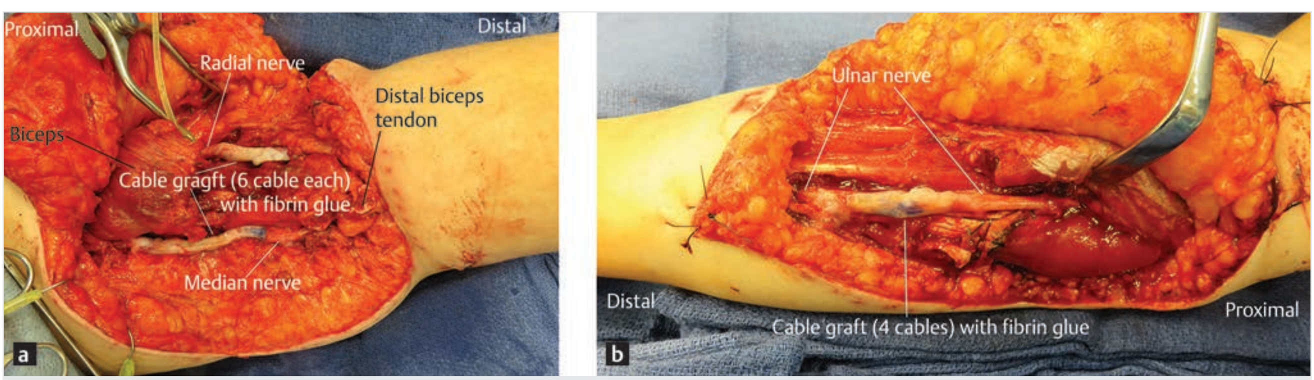

Fig. 27.7 **(a)** Left and **(b)** right upper extremity nerve repairs. **(a)** The left median and radial nerves have each been repaired with an interposed six-cable grafts. **(b)** The right ulnar nerve has been repaired with an interposed four-cable graft. All proximal and distal coaptations were performed with 9–0 nylon suture and reinforced with circumferential application of fibrin glue following suture repair. (Reproduced with permission of nervesurgery.wustl.edu.)

number of cables required to match the diameter of the injured nerve is determined.

The prepared cables are interposed in the nerve gaps, reversed such that the proximal ends of each segment of autograft is coapted to the distal stump of the nerve being repaired. This is done to avoid loss of regenerating axons that may occur through branching that may be present on the donor autograft. Coaptations are performed using 9–0 nylon epineurial sutures, careful to avoid bunching or escape of fascicles. Coaptations are reinforced with fibrin glue (▶Fig. 27.7). Prior to final trimming and coaptation in the left upper extremity, the elbow is moved through its full range of motion with the cable graft laying in place to ensure that there will be no tension on the repair even with the elbow in full extension.

27.4.4 Tendon and Muscle Repairs

The right FDS and FCU muscle bellies were not repaired. This was done to allow the patient use of at least one hand and to decrease postoperative pain by institution of nerve gliding exercises. On the left, the biceps was repaired at the musculotendinous junction and the brachialis muscle belly was coapted (not depicted).

27.5 Postoperative Care and Critical Evaluation of Results

The patient is maintained on neuropathic pain medication and a physical therapy regimen as detailed earlier. Physical therapy is continued for pain control (desensitization and graded motor imagery) and, after 48 to 72 hours of postoperative immobilization to permit some resolution of edema, passive range of motion is started. Due to the biceps repair, the left elbow should be ranged from 90 degrees of flexion to full flexion, within a protective splint, to promote nerve gliding while protecting the musculotendinous repair. Range of motion of the right upper extremity is also begun, but with fewer restrictions.

Meticulous nerve repair (tension-free repair with the use of cable grafts, interposed between nerve stumps outside of the initial zone of injury), combined with initiation of neuropathic pain medication at the time of injury may help avoid neuropathic pain following nerve repair. Additionally, a pre- and/or postoperative stellate ganglion block may be beneficial for preventing significant postoperative neuropathic pain. Early postoperative physical therapy for desensitization or graded motor imagery as well as referral to a pain specialist should be considered for patients at the first sign of neuropathic pain.

After treatment (▶Fig. 27.8), this patient had minimal pain on the right; distal ulnar nerve function had not yet appeared on last examination (clawing of the right small finger can be appreciated in the follow-up photograph). The left side continued to show evidence of evolving CRPS—hyperemia, diffuse swelling, and shiny smooth skin. The condition was slowly responding to intensive therapy and stellate blocks. Further distal decompression at known sites of nerve compression is planned once regeneration progresses and will be dependent on her work schedule. She has successfully returned to work and some leisure activities.

27.6 Teaching Points

- Nerve pain is challenging and requires a multimodal treatment approach. This includes surgery, medication, therapy, and other strategies.

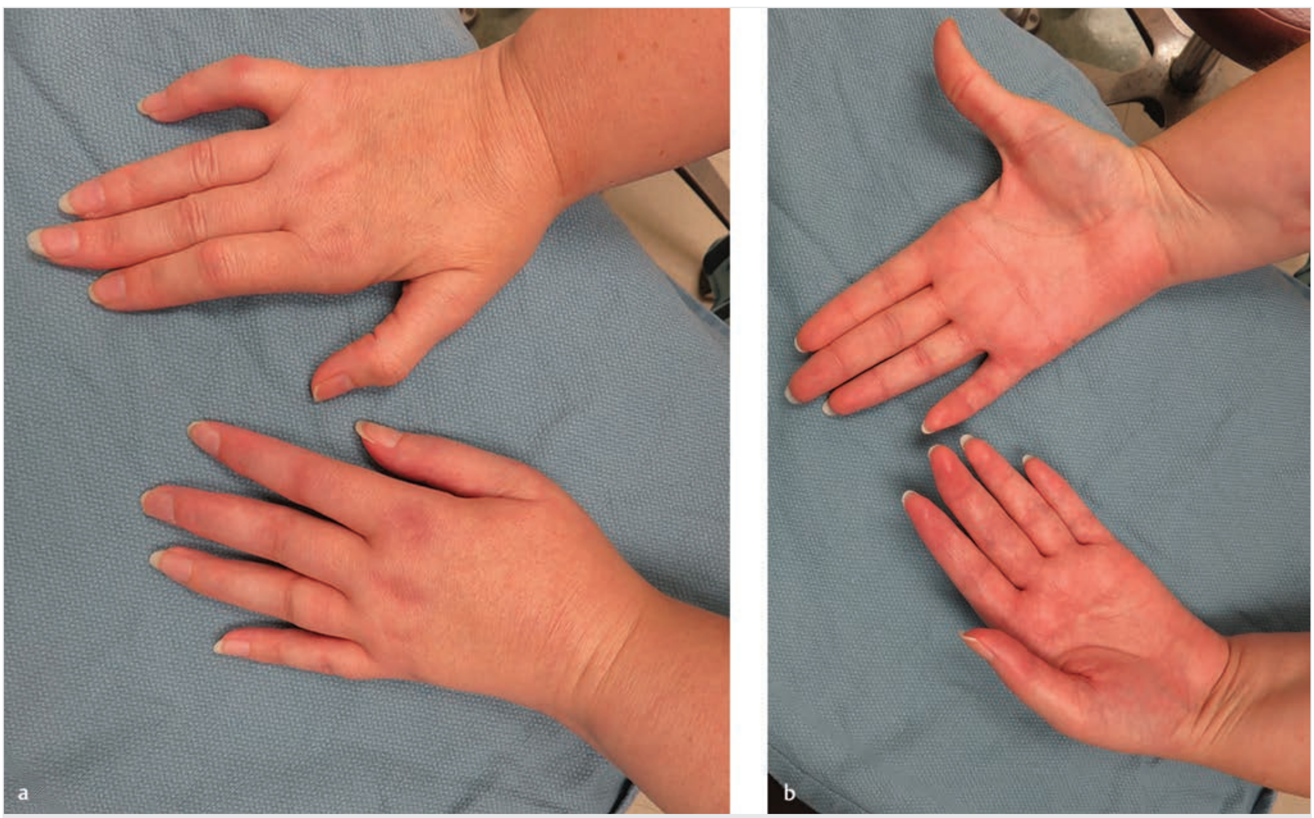

Fig. 27.8 Postoperative images of **(a)** dorsal and **(b)** volar bilateral hands at 4 months. Clawing of the right small finger is evident, as expected given the right ulnar nerve transection. The left hand depicts common clinical signs of complex regional pain syndrome (CRPS): hyperemia, diffuse edema, and shiny slick skin. Note the loss of the rhytids at the joints on the left. There is also profound stiffness of the left side with decreased passive and active range of motion (not depicted). (Reproduced with permission of nervesurgery.wustl.edu.)

- Do address “minor” sensory nerve injuries in the setting of major upper extremity trauma (e.g., look for and address transection of the medial and lateral antebrachial cutaneous and other nerves); prevention of painful neuromas is critical.
- Be patient—nerve regeneration, motor and sensory reeducation, and strengthening can take years to plateau.
- Plan carefully—book all day in the operating room for most major nerve repair cases. Graft harvest and preparation along with the primary injury site exploration, trimming the damaged nerve ends, inset of graft, and microsurgical repair are tedious and take time if done well.

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Part IX

Problems with Nerve Palsy

28 Finger Contractures 122

IX

28 Finger Contractures

Yan Chen and Peter M. Murray

28.1 Patient History Leading to the Specific Problem

The patient is a 23-year-old man who was involved in a motorcycle accident sustaining a left femur fracture, left bone forearm fracture, and left brachial plexus palsy. Physical examination as well as neurophysiologic studies and CT/myelogram indicated avulsion injury of nerve roots C5, C6, and C7. After a period of observation, the patient recovered 4/5 function of the C8 and T1 nerve root (lower trunk) innervated muscles. At 6 months postinjury, the patient underwent a left brachial plexus exploration and spinal accessory to suprascapular nerve transfer as well as a partial ulnar nerve to biceps branch of the musculocutaneous nerve (Oberlin's transfer).

At 18 months postsurgery, the patient has regained only limited elbow and shoulder animation (▶Video 28.1) while developing a claw deformity of index, long, ring, and small fingers. The patient is limited functionally by the claw deformity in that he has little functional use of the hand and is unable to grasp objects, despite his ability to flex the digits.

28.2 Anatomic Description of the Patient's Current Status

On physical examination, the patient demonstrates prominent claw deformities of the index, long, ring, and small fingers. He has flexor digitorum profundus function but no interosseous muscle function, owing to the incomplete nature of his lower trunk injury (▶Video 28.1).

The metacarpophalangeal (MCP) joints of index, long, ring, and small fingers are fixed in 40 degrees of hyperextension, while the proximal interphalangeal (PIP) joints have range of motion as follows:

- Index finger: –60/100 degrees.
- Long finger: –45/100 degrees.
- Ring finger: –45/100 degrees.
- Small finger: –45/105 degrees.

28.3 Recommended Solution to the Problem

- Full passive motion of the PIP joints should be restored preoperatively through a structured hand therapy program.
- Due to the relative weakness of the flexor digitorum sublimis (FDS) muscles, transfer of the FDS to the lateral bands of the individual digits will not achieve the desired result of PIP extension with MCP flexion.
- Volar MCP joint capsulodesis is performed to prevent MCP joint hyperextension and improve grip.

28.4 Technique

Through a volar transverse incision in the palm at the level of the distal palmar crease, the flexor tendon sheath is isolated. The A1 pulley is released, the flexor digitorum profundus and FDS tendons are retracted, and the volar capsule of the MCP joint is identified. A distally based flap of the volar capsule of the MCP joint is created. A single suture anchor is placed in the metacarpal neck with attached a 2–0 braided suture. The distally based flap is advanced to the extent that the MCP joint is placed in the resting position of 0-degree extension. The distally based flap is then secured to the neck of the metacarpal using the 2–0 braided suture attached to the previously placed suture anchors (▶Fig. 28.1). The procedure is repeated for each of the MCP joint indicated for claw deformity correction. In this case, the index, long, ring, and small finger MCPs were corrected.

28.5 Postoperative Photographs and Critical Evaluation of Results

At 3 months postoperative, the distal palmar incision was well healed. The MCP joints of the index, long, ring, and small fingers had been maintained to 0-degree extension (▶Fig. 28.2). The patient had the ability to flex the digits at PIP in order to grasp as an assisting hand, which was the goal of surgery. The patient's grasp has been made more functional with the correction of the MCP hyperextension

28.6 Teaching Points

- Ulnar nerve palsy or lower trunk palsy is a severe injury.
- Clawing of the digits resulting from ulnar nerve palsy or lower trunk palsy creates a functionally compromising hand deformity.
- Correction of the MCP joint hyperextension can be accomplished by advancement of the volar MCP joint capsule.
- The goal of claw deformity correction is to restore func-tional use of the hand for assistance in activities of daily living.

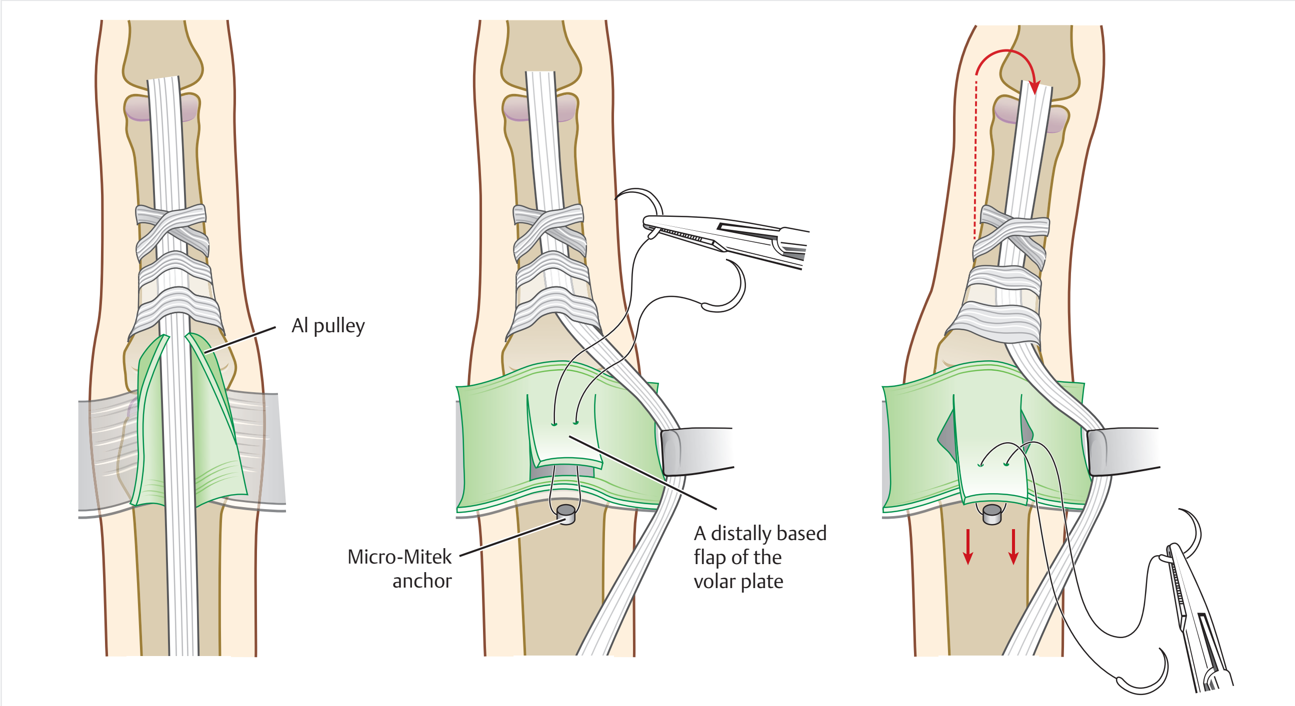

Fig. 28.1 Surgical technique of volar capsular advancement.

Fig. 28.2 (a, b) Post-op appearance of the left hand following capsular advancement with correction of claw deformity.

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Part X

Sarcoma

29 Incomplete Resection of Sarcoma at the Hand *126*

X

29 Incomplete Resection of Sarcoma at the Hand

Björn Behr and Marcus Lehnhardt

29.1 Patient History Leading to the Specific Problem

An 88-year-old woman presented in our clinic with a painless lump in the proximal phalanx of her left ring finger. She reported that, because of the tumor, she was operated on the same finger 3 months previously in an outpatient setting. During the previous procedure, the team attempted to remove the tumor, but were interrupted. The swelling did not disappear and increased since the intervention. Recently, the finger started to become painful. The previously excised tissue was histologically analyzed. The diagnosis of a chondrosarcoma with G2 grading was established. Surgical margins were not evaluated; therefore, the resection status was unclear.

29.2 Anatomic Description of the Patient's Current Status

The patient presented with a 2 × 3 × 1 cm large mass at the radial aspect of the proximal phalanx of the left ring finger (▶Fig. 29.1a, b). At inspection, there was an apparent ulnar displacement of the finger because of the tumor. There was an oblique scar on the ulnodorsal border of the finger from the previous surgery. Circulation and sensitivity of the finger were intact. On X-ray examination of the finger in anteroposterior and lateral views, the proximal phalanx showed a pathological fracture, signs of osteolysis, and a potential invasion of the soft-tissue tumor in the bone (▶Fig. 29.1c, d). In the MRI scan, which was performed before the initial surgery, the tumor semicircumferentially enclosed the proximal phalanx from dorsally (▶Fig. 29.1e, f).

29.3 Recommended Solution to the Problem

When treating patients with sarcoma of the hand and forearm, we typically aim to receive clear (negative) margins. Moreover, we routinely check for distant metastasis, which usually occurs in the lungs. Thus, initially a pulmonary CT scan was performed. Given the destruction of the proximal phalanx, the size of the tumor and the accompanying pain, we recommended to perform an amputation by exarticulation of the ring finger at the level of the metacarpophalangeal joint. The patient demanded a simple solution, so we did not discuss and evaluate in detail techniques such as a ray transposition in order to reduce the generated gap. Transpositions have mixed results in many hands; therefore, we aim to adapt our recommendations according to the patient's situation. When performing an exarticulation, we wanted to ensure we had sufficient skin and soft tissue for defecting coverage; otherwise, a local flap such as a reversed dorsal metacarpal artery would have been necessary. Intraoperatively, there was a moveable layer surrounding the tumor, thus ensuring an excision without the necessity of flap coverage.

29.3.1 Recommended Solution to the Problem

- Confirming the diagnosis with biopsy.
- Staging of the patient and presentation of the case in an interdisciplinary tumor board.
- Tumor resection with clear margins.
- Exarticulation of the affected finger at the level of the metacarpophalangeal joint.
- Sufficient soft-tissue coverage.

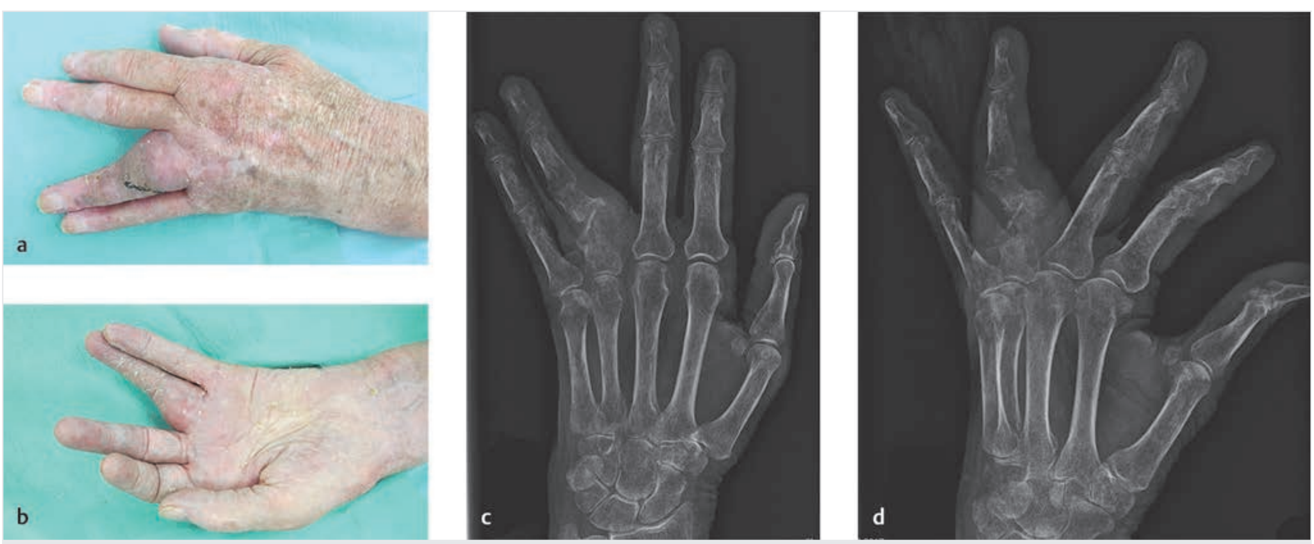

Fig. 29.1 **(a, b)** Preoperative photos of the patient showing a large mass on the radial aspect of the proximal phalanx of the left ring finger. **(c, d)** Preoperative X-rays of the mass. (*Continued*)

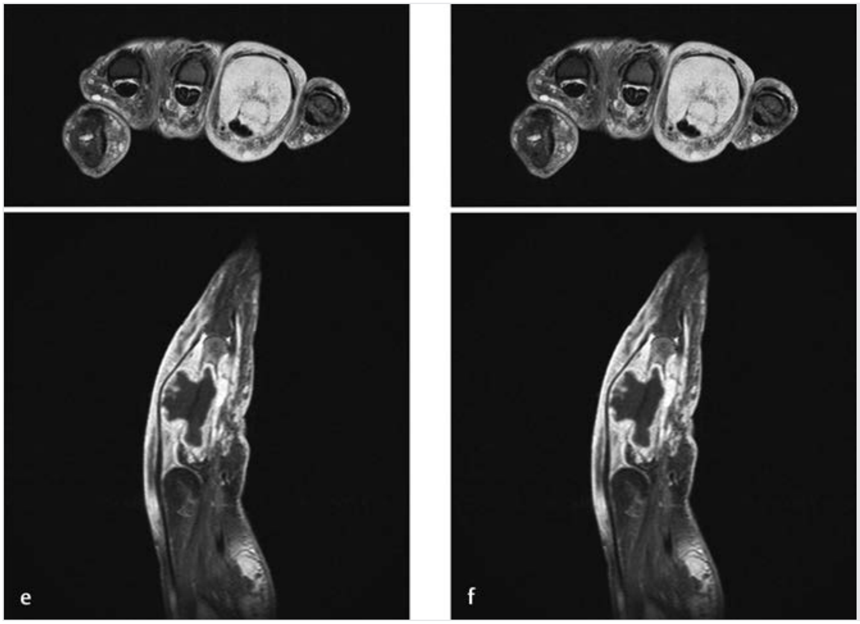

Fig. 29.1 (*Continued*) **(e, f)** Preoperative MRI of the involved area.

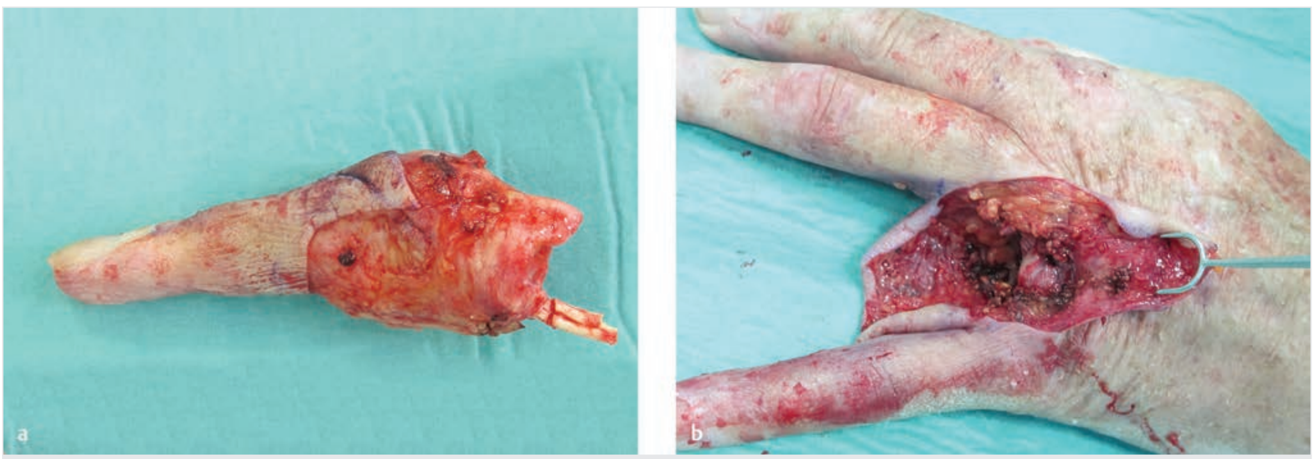

Fig. 29.2 **(a)** The resected ring finger. **(b)** Intraoperative situs after exarticulation of the ring finger in the metacarpophalangeal joint.

29.4 Technique

The patient was operated in the supine position and under tourniquet control. Incisions were planned in order to have a sufficient palmar soft-tissue filet to close the resulting defect. The exarticulation was approached from dorsally by dividing the extensor tendon and incising the collateral ligaments. Then, the palmar incision was performed, the neurovascular structures were sacrificed, and both flexor tendons grasped and shortened (▶Fig. 29.2). In the cases that do not require amputation, the relationship of the tumor to the surrounding tissue cannot be as easily assigned as in the current case. Pinning of the resected tissue on a labeled corkboard may be advisable in these cases. Importantly, the instruments and gloves are changed at this point, the tourniquet is opened, and hemostasis is achieved. Then, the wound is closed and a dressing is applied.

29.4.1 Steps for the Procedure

1. Dorsal incision and division of the extensor tendon.
2. Incision of the collateral ligaments.
3. Palmar incision (with preservation of a palmar filet) and sacrifice of the neurovascular bundles.
4. Shortening of the flexor tendons.
5. Hemostasis.
6. Wound closure with the palmar filet.

29.5 Postoperative Photographs and Critical Evaluation of Results

After histological evaluation of the finger, the diagnosis of a chondrosarcoma with G2 grading was confirmed. Clear

Fig. 29.3 (a–d) The patient is seen here 3 months postoperative.

margins were confirmed by the pathologist. The wound healed uneventfully and the patient regained full range of motion of the remaining fingers. Fortunately, postoperative complications such as neuroma or phantom pain did not occur. Scaring was uneventful (▶Fig. 29.3). The interdisciplinary tumor board recommended adjuvant radiation, which was declined by the patient.

The patient was then scheduled for regular follow-ups: clinical examination every 3 months, as well as MRI scans with contrast imaging to control local recurrence and chest X-ray to evaluate occurrence of distant lung metastasis. In our department, the interval is prolonged to semiannual in case of tumor-free survival after 2 years for an additional 3 years.

29.6 Teaching Points

- Preoperative imaging (MRI of the local tumor, chest CT or X-ray to evaluate for distant metastasis) is necessary for sufficient planning of the operation. We recommend CT for initial examination and X-ray for follow-up.
- Negative margins are the most important prognostic factor and should be tried to achieve.
- However, resection does not have to be wide.
- Functional aspects, especially when operating at the upper extremity, need to be carefully evaluated and should be tailored to the patient-specific condition.

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Part XI

Problems with Soft Tissue Coverage

30 Perfusion Problems *132*

31 The Bulky Flap *136*

32 Contracture after Acute Trauma Surgery of a Blast Burn *141*

33 Dorsal Hand Defect *145*

XI

30 Perfusion Problems

Charles Yuen Yung Loh, Yu-Te Lin, and Fu-Chan Wei

30.1 Patient History Leading to the Specific Problem

A 53-year-old man previously sustained a crush injury to his dominant right hand, resulting in soft-tissue lacerations to the zone 2 region of his right index finger. After initial repair of his flexor digitorum profundus (FDP) of the index finger, he developed severe tendon adhesions that necessitated tenolysis shortly after. Unfortunately, he developed a secondary FDP rupture during mobilization at home later. This was treated with a tendon graft procedure, followed by an A3 pulley reconstruction. After several months of rehabilitation, the range of motion (ROM) at his proximal interphalangeal joint (PIPJ) remained poor with a flexion contracture (▶Fig. 30.1a). A decision was made to surgically release the dense scarring over the PIPJ as part of a flexion contracture release. After surgical excision of scar tissue and adhesions, a 3 to 4 cm × 2 cm soft-tissue defect was formed over his zone 2 right index finger (▶Fig. 30.1b).

30.2 Anatomic Description of the Patient's Current Status

The zone 2 region of a finger was affectionately known as "no man's land" by hand surgeons. This is due to the numerous structures contained within the section of the finger directly over the PIPJ. The decussation of the flexor digitorum superficialis (FDS) and passing of the FDP occur at this region, along with bilateral neurovascular bundles and a thick fibrous structure known as the volar plate. All these structures contribute to its bulky contents that make soft-tissue coverage over this region particularly tricky.

The complex nature of this case comes from multiple previous soft-tissue repair procedures along with tendon grafting and pulley reconstruction. As a result, tendon adhesion and dense fibrosis occur, necessitating surgical release. Flexion contracture release requires excision of all fibrotic scar tissue in order to adequately straighten the joint, allowing for smooth tendon excursion. The result is a full-thickness defect with exposure of vital structures including the radial and ulna neurovascular bundles.

30.3 Recommended Solution to the Problem

Reconstructive options should take the above into consideration to provide adequate coverage that should ideally also contain supple tissue to avoid recurrence of adhesions and contracture. Local flaps, homo- or heterodigital in this case, were unlikely to provide the soft-tissue quality or quantity required for adequate coverage. A free medialis pedis flap may be considered in reconstructing such a defect, but it will create new donor site wounds on the foot. A thin, pliable free flap would be most suited for this case and we chose to use a free venous flap harvested from the ipsilateral forearm.

Conventional venous flaps are notorious for their unreliable perfusion. We utilize a technique of "shunt restriction" and apply them to venous flaps, which increases their reliability and perfusion to the whole flap.

30.3.1 Recommended Solution to the Problem

- Adequate soft-tissue coverage is required over zone 2 finger defects.
- A venous flap fulfills the requirements needed in this case—thin, pliable, and adequate in size, often similar in thickness to soft tissue over a finger.

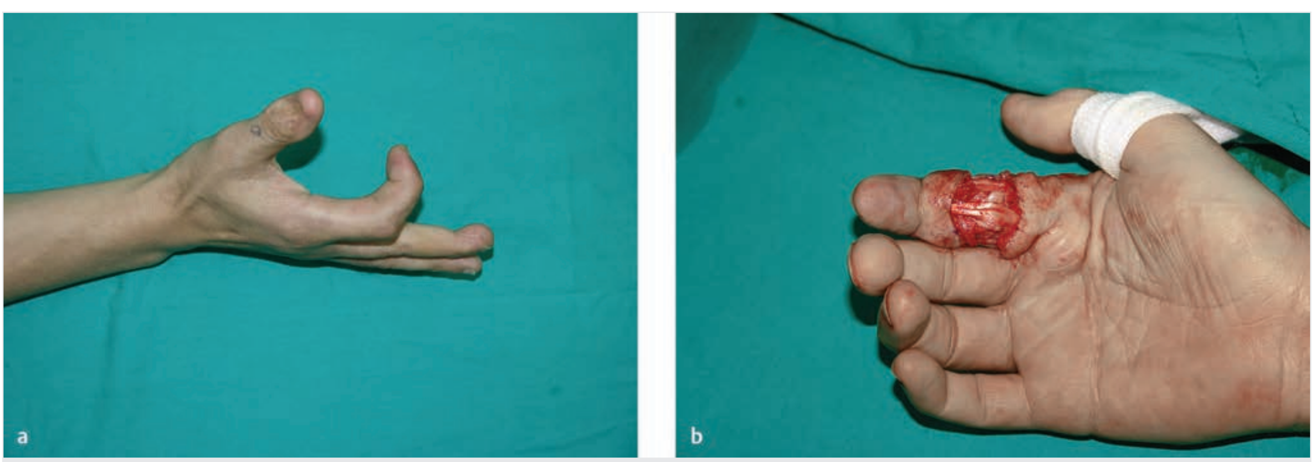

Fig. 30.1 (a) Fixed flexion contracture of the right index finger over his proximal interphalangeal joint (PIPJ). **(b)** Intraoperative photograph following release of the fixed flexion contracture and dense scarring of soft tissue impairing PIPJ movement. A resulting soft-tissue defect over the zone 2 region is seen.

- There is minimal size mismatch between distal forearm veins and the digital arteries and veins.
- Donor site can be kept to the ipsilateral forearm with minimal donor site morbidity.
- Reliability of venous flaps can be enhanced using a technique known as "shunt restriction."

30.4 Technique

Venous flaps are designed conveniently in the forearm of the patient. They most likely can be closed primarily with minimal donor site morbidity. Careful planning of the venous pattern can be done preoperatively with the aid of near-infrared scanners.

An afferent vein refers to the vein that carries blood entering the flap, whereas an efferent vein refers to the veins that carry blood away from the flap. An efferent vein and an afferent vein to the flap have to be established and, if needed, an added efferent vein can be anastomosed. In order to prevent arteriovenous (AV) shunting of blood within the venous flap, "shunt restriction" using a hemoclip within the flap should be performed (▶Fig. 30.2). AV shunting results in bypass of arterial blood directly through the flap without perfusion of the flap. When a buildup of blood occurs within the flap, it cannot drain through the efferent end of the flap due to the high intravascular pressure resulting from the AV shunting of blood. When "shunt restriction" is applied, the distal 50% or so of the venous network collapses initially. Arterialized blood from the afferent end enters the flap and is forced through the flap tissue. When buildup of blood occurs, pressure within the flap forces blood to flow through the low-pressure valveless venules within the venous network and exits the flap via the efferent vein after tissue perfusion.

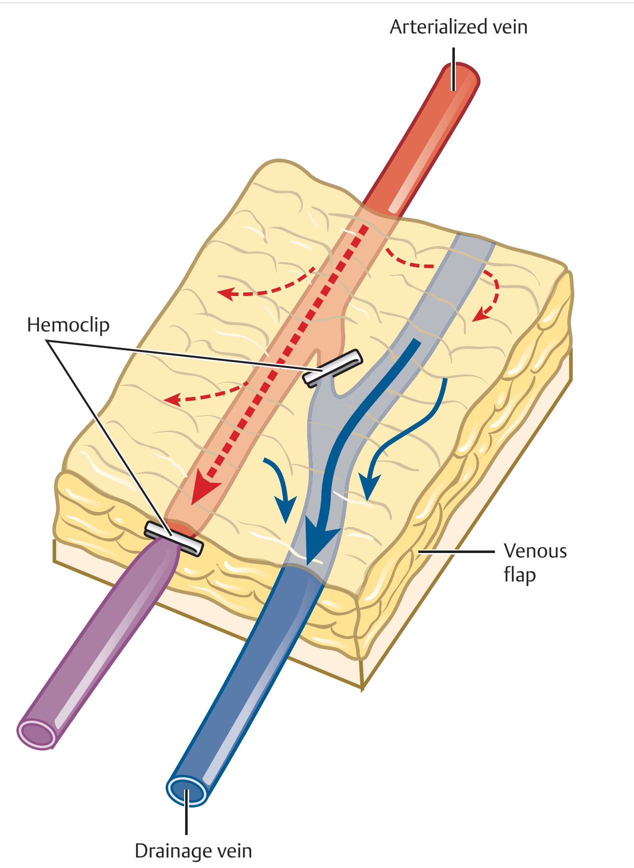

Fig. 30.2 Schematic diagram of "shunt restriction" of H pattern–type venous flaps as shown in the case. A hemoclip is placed between the connecting branches of the superficial veins.

30.4.1 Steps for the Procedure

1. Preoperative marking of superficial veins in the forearm required (▶Fig. 30.3). Design of skin paddle should incorporate the various types of superficial vein patterns. The use of commercial near-infrared scanners can help locate veins and facilitate flap design. A template of the defect can be first drawn on a sheet of Surgilon. The template, which is made of translucent material, can then be placed on the marked venous network of the forearm. The orientation of the flap can then be adjusted according to the pattern of the veins where as many veins as possible are included within the flap design.
2. The afferent and efferent veins should be identified in the flap and within the flap itself, the vein should be examined and "shunt restriction" using a hemoclip can be performed at roughly 30 to 40% of the total intraflap distance of the venous network (afferent to efferent) within the flap (▶Fig. 30.4). By clipping and preventing shunting of arterialized blood, venous return is encouraged into the remaining portion of the draining vein as arterial blood is forced into the flap and its only path of return would be through the collapsed distal venous network and through the efferent vein of the flap.
3. A temporary K-wire is placed across the PIPJ to keep the joint in extension, which is crucial in the recovery phase to prevent kinking of vessels.
4. A digital artery is then chosen and anastomosed to the afferent end of the venous flap. With the use of shunt restriction, only one afferent and efferent vein each are required normally. A second efferent vein may be considered where the venous flap serves a flow-through purpose where distal perfusion of the digit is required (▶Fig. 30.5).

30.5 Postoperative Photographs and Critical Evaluation of Results

Arterialized "shunt-restricted" venous flaps can be monitored as per any other free flap. During the immediate postoperative

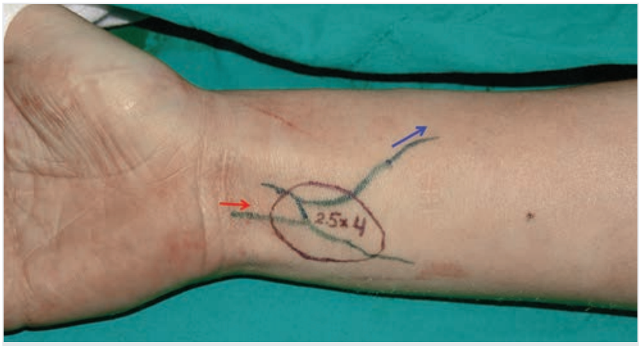

Fig. 30.3 Photograph demonstrating the preoperative venous flap design with an H pattern of superficial veins within the flap of size 2.5 cm × 4 cm.

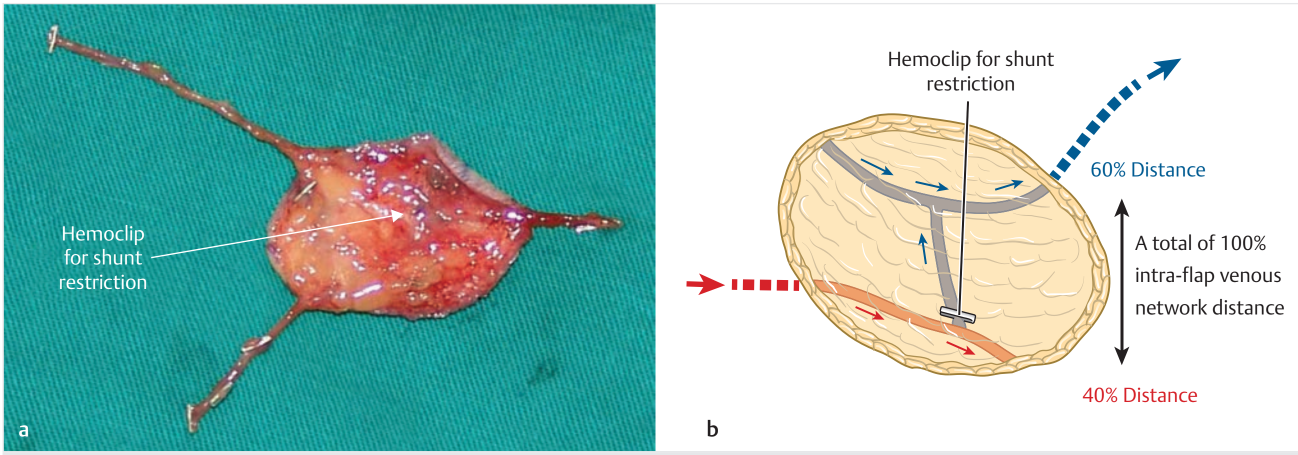

Fig. 30.4 **(a)** Design of the harvested venous flap. **(b)** Schematic diagram explaining the intraoperative design of the venous flap for "shunt restriction" and where to place the hemoclip according to intraflap total vessel length division.

Fig. 30.5 Inset of the venous flap into the zone 2 defect post contracture release with arterialized vein bridging the ulna digital artery of the index and the outflow of the flap connected to a superficial vein.

Fig. 30.6 A pale arterialized venous flap with no bleeding, suggestive of an arterial problem. The patient was taken back for a re-exploration immediately.

period, it was found that the venous flap had turned pale without any inflow (▶Fig. 30.6). The patient was immediately taken back to the operating room for re-exploration under an axillary block to relieve vasospasm. It was found that the arterial anastomosis had inadequate blood flow and a segment of the ulna digital artery was resected and re-anastomosed to the venous flap. The segment was found to have signs of intimal separation possibly from the crush injury previously, which affected the blood flow across the anastomosis. After a redo, the venous flap was well perfused immediately with a capillary refill of 2 seconds and restoration of a pinkish hue.

For a small venous flap, a flow-through pattern (along the valve) has been recommended by other study in the literature. The arterial flow may bypass the flap through the AV shunting, which reduces peripheral perfusion resulting in increased flap ischemia. On the other hand, the venous return is impeded due to the high intravascular pressure of the venous network within the flap, resulting in flap congestion. Monitoring is also subsequently difficult as there is uncertainty regarding usual flap monitoring methods or Doppler perfusion imaging. In order to circumvent this, the technique of "shunt restriction" disrupts the AV shunting of arterial blood, forcing blood through the venous flap, which in turn increases perfusion of the flap. When so, the blood collected within the flap will be forced to exit the flap through the now-collapsed distal portion of the venous network within the flap. This will encourage venous return and hence allow one to more easily monitor the flap with a lesser degree of venous congestion, normal capillary refill times, and with normal parameters of any other arterial free flap (▶Fig. 30.7). A slight degree of epidermolysis can be expected during the immediate stages postoperatively but resolves when the flap remodels in its neosite.

A free venous flap can provide a thin and pliable soft tissue that allows "like-for-like" tissue reconstruction of hand defects. With adequate rehabilitation, improved and acceptable ROM can be achieved (▶Fig. 30.8).

30.6 Teaching Points

- Venous flaps can provide "like-for-like" replacement of soft-tissue defects in the hand.
- They are thin and pliable, which allow for unimpeded ROM.
- Veins within the forearm are a similar match in terms of size to digital arteries and veins.

Fig. 30.7 Photograph demonstrating some minor epidermolysis secondary to slow venous drainage in the immediate postoperative period. This was a temporary phenomenon and the flap remained pink with good balance between inflow and drainage.

- "Shunt restriction" can improve the reliability of venous flaps by increasing flap perfusion and encouraging venous return.
- Flap monitoring of "shunt-restricted" venous flaps is as per any other free arterial flap, which is an improvement over conventional venous flaps.

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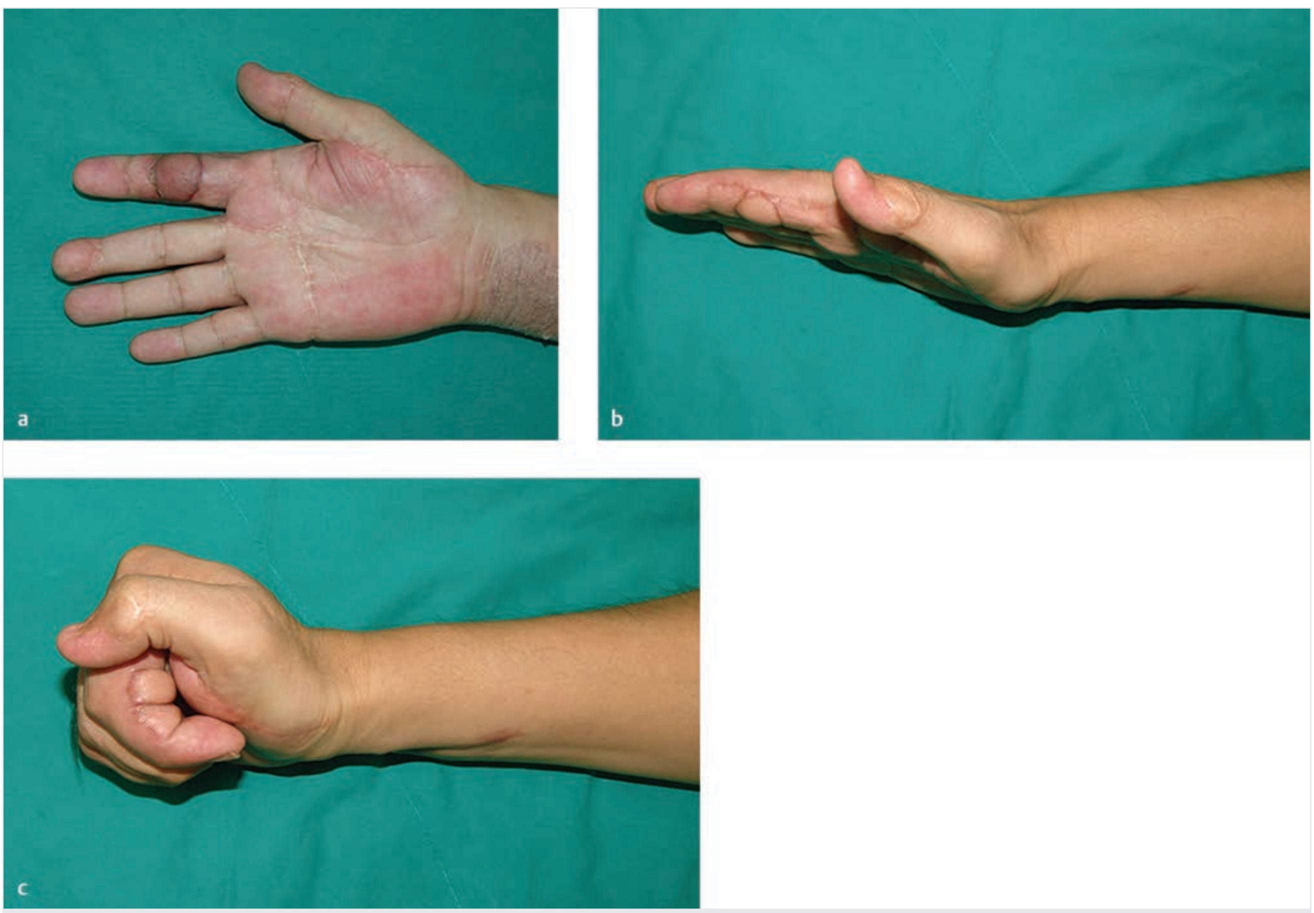

Fig. 30.8 (a–c) Photograph taken postoperatively during follow-up clinic visits 6 months later. Note the thin pliable nature of venous flaps particularly suited for defect coverage over the proximal interphalangeal joint with acceptable range of motion as a result.

31 The Bulky Flap

Kelly Currie, Evyn Neumeister, and Michael W. Neumeister

31.1 Patient History Leading to the Specific Problem

A 38-year-old woman suffered a left upper extremity injury from motor vehicle collision. The skin was severely traumatized and much of the flexor mass was avulsed. The medial elbow joint was exposed. After debridement and thorough irrigation, the wound on the forearm and upper arm was extensive. The median nerve was intact but exposed. The flexor digitorum profundus muscle was intact. The proximal radius was fractured and temporarily fixated with an external fixator

31.2 Anatomic Description of the Patient's Current Status

The traumatic injury to the patient's left forearm required serial debridements of nonviable tissue prior to coverage. The debridement of skin, subcutaneous fat, and muscle (mostly flexor digitorum superficialis) created a defect with exposed vital structures including the median nerve and the medial elbow joint (▶Fig. 31.1). The tissue loss was largely volar, from the antecubital fossa to the volar wrist flexion crease, leaving the median nerve exposed lying on top of the flexor digitorum profundus muscle bellies. The anterior capsule of the elbow was avulsed, exposing the joint. An external fixator was needed for elbow joint stabilization, spanning from the distal humerus to the proximal radius. Soft-tissue coverage was required. The extent of the coverage mandated an enormous amount of tissue reconstruction.

31.2.1 Management of the Defect

Due to the large area requiring coverage, a fasciocutaneous free flap was selected for reconstruction. The flap needed to be very large, limiting the plausible choices for donor sites. An anterolateral thigh flap was chosen, providing satisfactory wound closure (▶Fig. 31.2). The flap was debulked three times over the ensuing 3 years to improve forearm contour.

31.2.2 Donor Site Problem

Inability to close the donor site primarily, due to the need for such a large flap to cover the forearm defect, necessitated split-thickness skin grafting to the right leg. This created a large contour deformity of the anterior thigh (▶Fig. 31.3). Other than a less-than-ideal aesthetic outcome, the nonpliable scar created discomfort for the patient during ambulation. The patient was not able to wear shorts without feeling self-conscious.

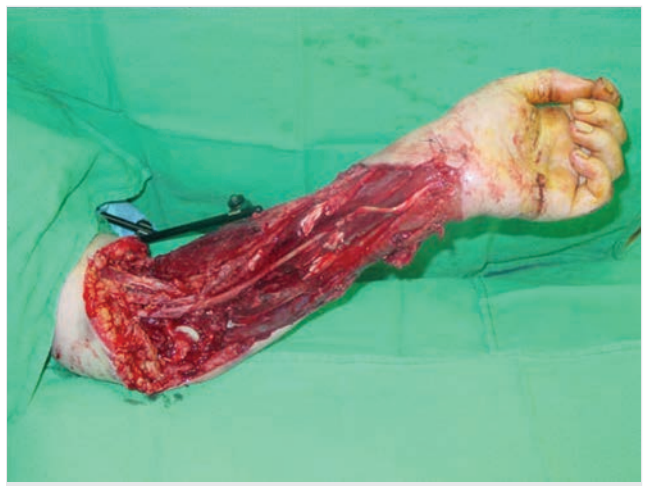

Fig. 31.1 A large soft-tissue defect in the forearm with exposed elbow joint and median nerve.

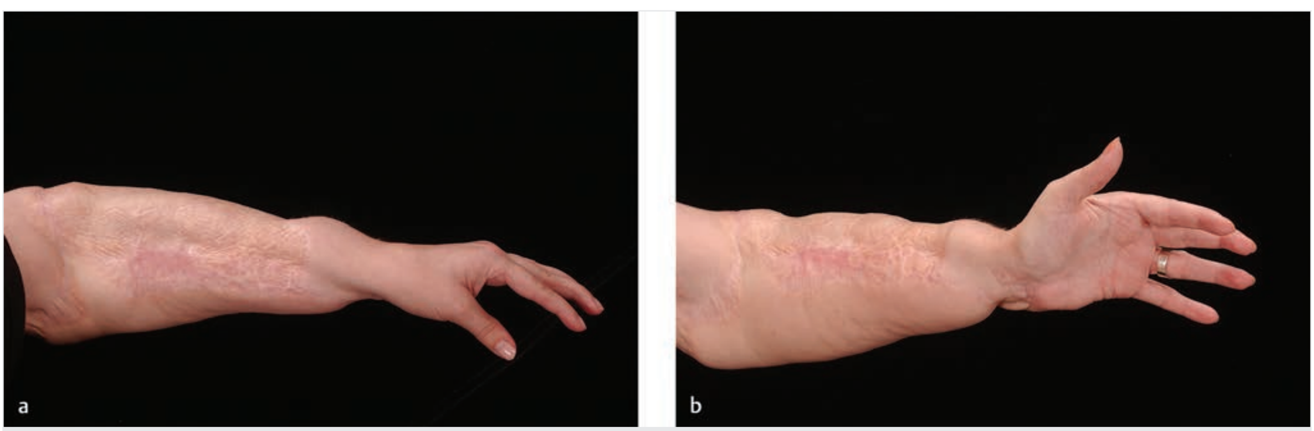

Fig. 31.2 (a, b) An anterolateral thigh flap was used to close the large defect on the forearm.

Fig. 31.3 The anterolateral thigh donor defect on the leg is unacceptable in patients with large body mass index.

31.3 Recommended Solution to the Problem

Management of a large soft-tissue defect of the forearm with exposed vital structures requires free tissue transfer. Local and regional pedicled flap options, such as a large pedicled abdominal flap, are not adequate for providing complete coverage or would require a two-stage approach. A fasciocutaneous free flap is a great option for such a defect. When considering the potential need for subsequent operations for functional improvements, that is, tendon transfers and tenolysis, a fasciocutaneous flap is easier to elevate than a muscle flap. The fascial component provides a "fresh" plane of dissection. Additionally, the cutaneous portion of the flap provides a more aesthetically pleasing reconstruction when compared to muscle free flap with a split-thickness skin graft.

The choice of fasciocutaneous flap should take the donor site into consideration. Given the vast array of different flaps available today, donor sites that leave disfiguring defects need to be

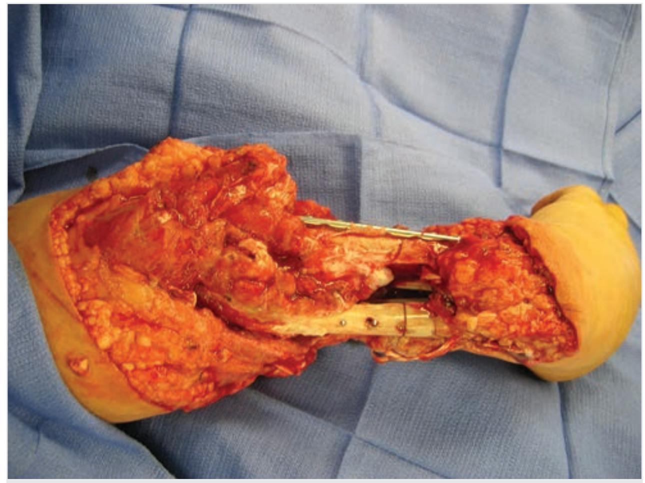

Fig. 31.4 An 18-year-old girl sustained a mutilating injury to the forearm with fractures to the ulna and radius. There is massive extensor muscle loss.

avoided. We present next a similar forearm defect from a motor vehicle collision, although dorsal, in an 18-year-old female patient (▶Fig. 31.4). There is exposed hardware fixation of the radius and ulna after thorough debridement of the extensor muscle. The size and depth of the wound necessitate free tissue transfer, preferably with a fasciocutaneous flap for reasons mentioned previously. When executing any type of flap procedure, whether free or pedicled, primary closure of the donor site is ideal. There are not many other fasciocutaneous free flap options that are located in areas that usually have enough laxity to close as in the deep inferior epigastric artery perforator (DIEP) flap. This flap was used for forearm reconstruction in this patient.

31.3.1 Recommended Solution To The Problem

- Free tissue transfer needed for large surface area coverage.
- Fasciocutaneous flap is the best if additional reconstructive procedures are planned; it provides a more aesthetically pleasing reconstruction and it can be debulked.
- Choose flap where donor site can be closed primarily (i.e., DIEP flap).

31.4 Technique

Perforators to the skin can be identified with a Doppler preoperatively and marked on the skin. There is typically a lateral and medial row of cutaneous perforators that come off of the deep inferior epigastric artery. The flap's dimensions and the decision to use a hemiflap versus the entire lower abdomen are dependent on the defect, as it is not difficult to close a donor defect spanning from 2 cm above the umbilicus to just cephalad to the pubis (▶Fig. 31.5a). Dissection is

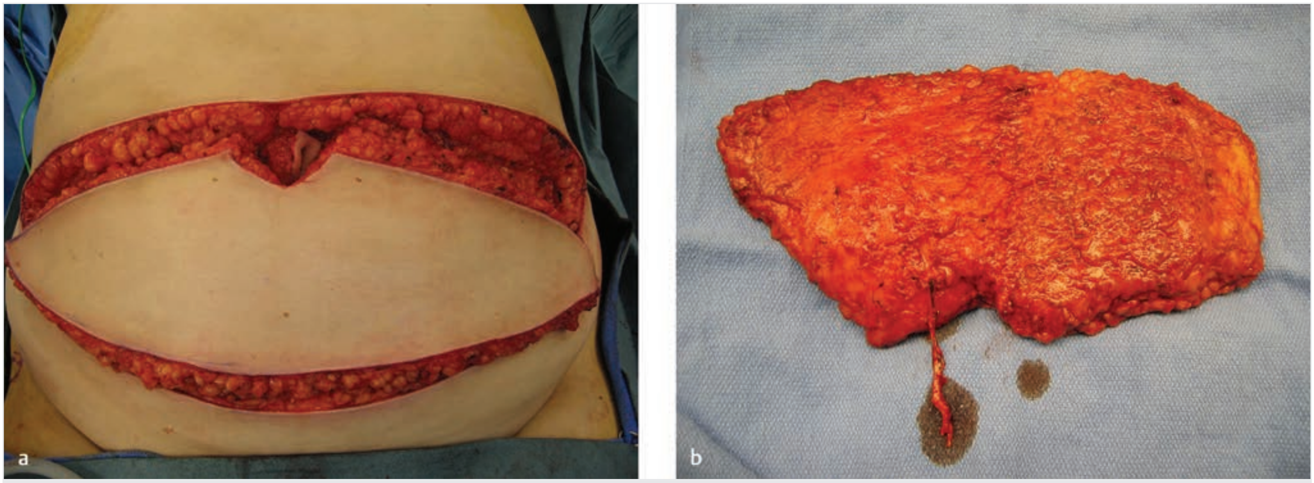

Fig. 31.5 (a) A deep inferior epigastric perforator (DIEP) flap was designed on the lower abdomen to minimize the donor morbidity. The DIEP flap allows the donor site to be closed primarily. **(b)** The entire lower abdominal flap was elevated on a single perforator.

Fig. 31.6 The lower abdominal donor site is closed primarily leaving an acceptable donor site.

performed through skin and fat and down to the fascia. The flap is elevated off of the fascia in a lateral-to-medial direction. Perforators to the skin are identified and preserved. Once the perforators are chosen that are adequate to perfuse the flap, they are dissected down through the anterior rectus sheath and muscle to the pedicle. The deep inferior epigastric pedicle is traced back to its origin off of the external iliac vessels where it is ligated for flap removal (▶Fig. 31.5b). The superior abdominal flap is dissected off of the fascia to the costal margin and advanced inferiorly to meet the inferior skin for closure. The donor site is closed in layers with interrupted absorbable sutures in Scarpa's fascia and the deep dermis, followed by an absorbable monofilament suture in the subcuticular layer.

31.5 Postoperative Photographs and Critical Evaluation of Results

The donor site is much more acceptable than severe scarring to the exposed extremity (▶Fig. 31.6). The lower abdominal tissue is redundant in most individuals. Closure of any wound with a free tissue transfer should take the morbidity of the donor site into consideration. The reconstructed forearm shows tissue excess, but wound closure was easily achieved (▶Fig. 31.7). Another benefit of the fasciocutaneous flap is that it can be serially debulked until a pleasing contour has been achieved. She underwent two debulking surgeries (▶Fig. 31.8), followed by a free functioning gracilis muscle transfer 7 months after injury to regain active extension (▶Fig. 31.9). Debulking procedures are generally a minimal intervention. It is easier to remove tissue than to manage a tissue deficiency (▶Fig. 31.10).

31.6 Teaching Points

- Extensive soft-tissue defects often require reconstruction with free tissue transfer.
- The choice of flap should respect the resulting donor site morbidity while achieving the goals of coverage.
- Fasciocutaneous flaps are easier to elevate when secondary reconstruction is anticipated.
- Anterolateral thigh flaps are robust and can provide a large amount of tissue, but they can leave a "shark bite" appearance to the thigh.
- The DIEP flap also provides an enormous amount of tissue, but it offers an acceptable donor site scar in a rather inconspicuous area of the lower abdomen.

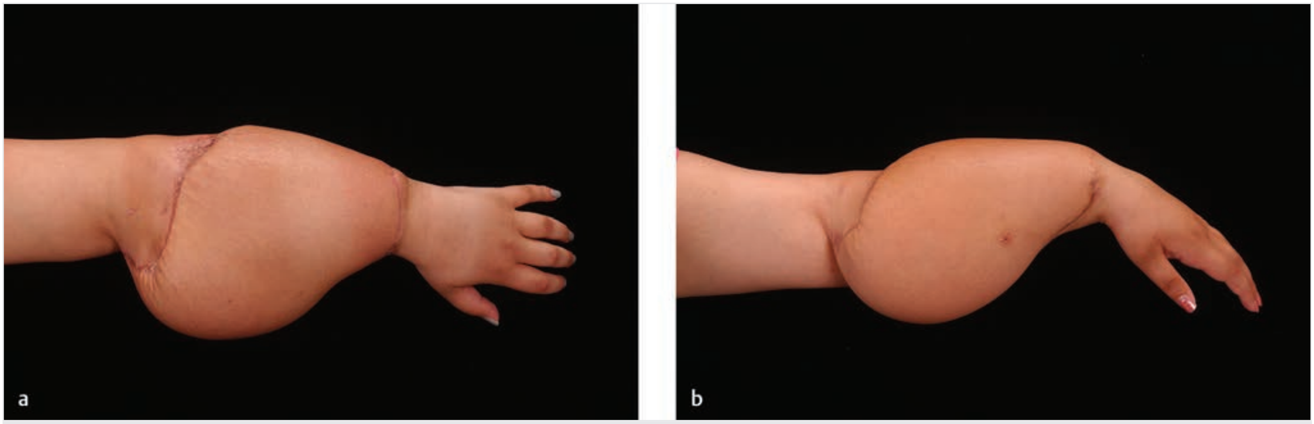

Fig. 31.7 (a, b) The deep inferior epigastric perforator flap has been inset on the forearm. The flap is very bulky. It is always easier to remove tissue than to bring more tissue into a defect.

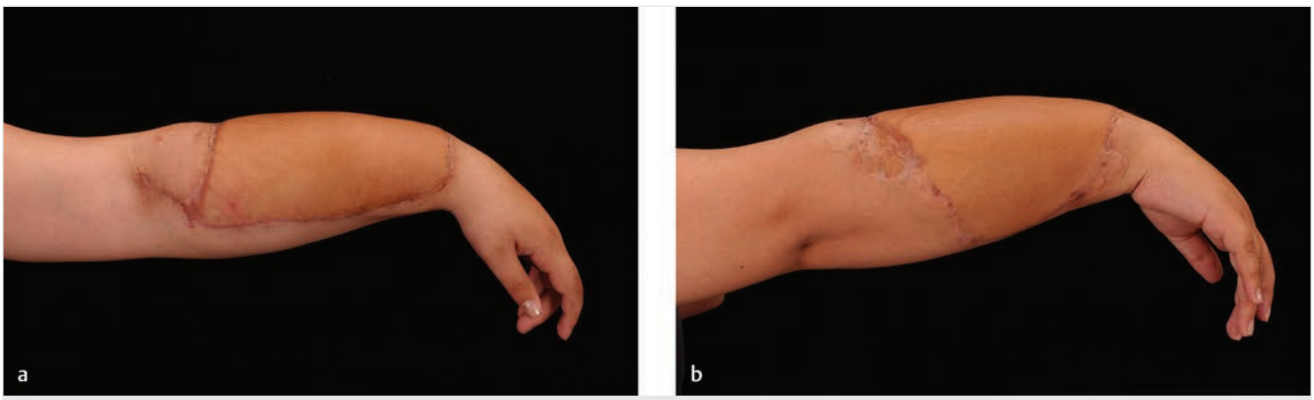

Fig. 31.8 (a, b) The fat has been debulked with liposuction and direct excision for fat and skin. Contour has been restored.

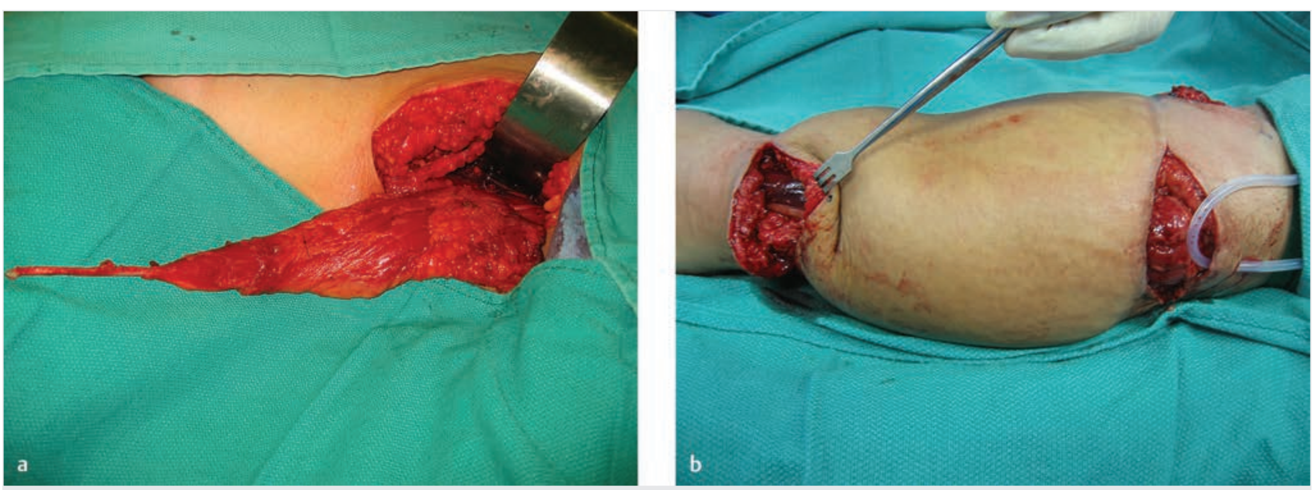

Fig. 31.9 (a, b) A functioning muscle transfer was tunneled under the flap to provide extension to the digits.

- Employ soft-tissue coverage that minimizes donor site morbidity but will optimize recipient site form and function.
- Wait for 3 months to debulk flaps to allow tissue to soften and scars to mature to some degree.
- Debulk the flap with liposuction and direct tissue excision.
- Do not debulk more than 50% of the flap at any one sitting.
- Multiple contouring procedures may be required to get the final form.

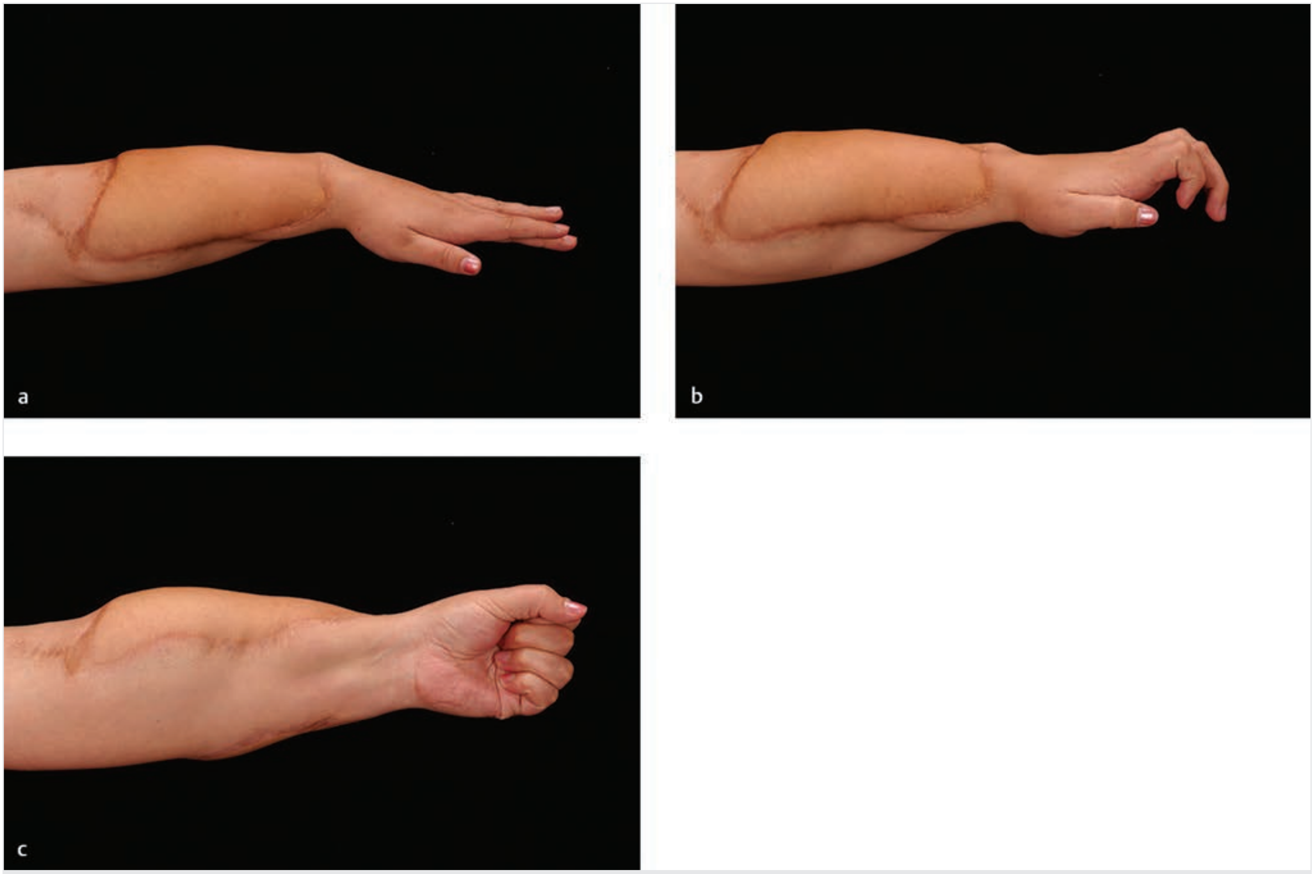

Fig. 31.10 (a–c) The final outcome following flap debulking and functioning muscle transfer demonstrating good extension of the fingers and thumb. The patient returned to her regular activities.

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32 Contracture after Acute Trauma Surgery of a Blast Burn

Günter K. Germann

32.1 Patient History Leading to the Specific Problem

A 30-year-old man presents after having suffered an explosion trauma to his left hand a few months ago. The initial treatment consisted of wound debridement and partial closure of the wound. The remaining wound healed on secondary intention.

Despite the acute trauma surgery treatment in the local emergency department and postoperative rehabilitation, the explosion trauma resulted in a massive deformity of the left thumb and a contracture of the first web space between the thumb and the index finger.

Furthermore, the patient complained about neuroma pain in the digital nerves III and IV as well as pain in the remaining distal part of the index finger resulting from inappropriate soft-tissue coverage (▶Fig. 32.1).

32.2 Anatomic Description of the Patient's Current Status

The patient showed with a severe skin and soft-tissue contracture of the first web space (so-called web-space syndactyly) and concomitant injuries including adduction deformity of the thumb, limitation of the thumb extension and opposition function, and carpometacarpal contracture. Being the only opposing digit against the others, the thumb has a major contribution to the overall hand function. When the thumb is involved, functional loss of the whole hand is severe. Therefore, the correction of the thumb's deformity constitutes the most important part for a beneficial functional outcome. Adequate length, mobility, stability, and sensation are the goals of a functional thumb reconstruction.

Fig. 32.1 Preoperative view of the hand showing severe deformity of the thumb in the interphalangeal and base joint 4 months after trauma.

32.3 Recommended Solution to the Problem

One should notice that it is very important for a successful outcome after burn or explosion injury that early measures, such as early debridement, edema and infection control, early wound coverage, and early mobilization, be performed. With these simple principles applied correctly, the most difficult postburn complications such as flexion contracture and finger deformities can be minimized or even prevented.

Superficial burns usually heal spontaneously within 10 days. Full-thickness wounds would only heal slowly on secondary intention and would result in restricted function and mobility because of scar tissue formation. On the other hand, the early motion that is required to prevent joint stiffness and reduce edema formation may inhibit the healing process. Deeper wounds would take more than 2 weeks to heal on their own; therefore, these should be treated by excision and coverage with a graft or flap. Placement of full- or split-thickness skin grafts has been used successfully in treating both superficial and partial-thickness burns of the hand.

In cases of full-thickness burns, after excision and debridement, exposed deeper structures (i.e., free-lying tendons) rarely accept skin grafts and therefore require flap coverage.

Flap coverage is an excellent option in injuries of the hand because of the ability to cover the wound while providing a smooth surface for joint and tendon motion and the potential for early mobilization with hand rehabilitation therapy.

When early adequate treatment is lacking, contractures and deformities such as seen in our patient, appear. In order to achieve a better functional outcome, secondary surgical revision and correction is needed.

Mild to moderate contractures involving the thumb and adjacent web-space area can be corrected simply by contracture release combined with the basic reconstructive techniques including skin grafting, variations of Z-plasty flaps, and Y-V advancement techniques.

A severe contracture that causes a major deformity like the one seen in our case, however, requires a more complex procedure such as local or regional flaps for soft-tissue defect coverage.

In our case, we chose a distally based radial forearm flap as it presents an optimal solution for defect coverage.

32.3.1 Recommended Solution to the Problem

- Explosive trauma often causes severe contractures.
- Severe contractures leading to massive deformity of the thumb and great functional loss of the hand require secondary revision and scar contracture release.

- Defect coverage after release of severe contractures as shown in our case requires a more complex procedure. A distally based reverse radial forearm flap is an ideal option for defect coverage.

32.4 Technique

Prior to the operative intervention, before deciding to use a radial forearm flap, an Allen test was performed to ensure that retrograde flow through the ulnar artery would maintain blood flow to the hand.

The patient was then taken to the operating theater. The surgery was performed under general anesthesia. The arm was exsanguinated and a tourniquet was raised to 250 mm Hg.

At first, the patient was treated with a subtotal palmar and digital scar contracture release on the left hand. The neurovascular bundles were identified and protected. Tenolysis of the flexor pollicis longus tendon was then performed.

At the conclusion of the procedures, complete correction was obtained at both the metacarpophalangeal and interphalangeal (IP) joints of the thumb. Contracture release in the first web space allowed a free abduction of the thumb.

The new sculptured thumb was then stabilized by means of K-wire in a proper position to achieve a maximum surface for defect coverage.

The next step included further exploration and neurolysis of the digital nerves I to IV and of the median nerve. The painful neuroma of the digital nerve IV was identified and removed, followed by a nerve reconstruction by transplantation of a sensory nerve graft harvested from the left forearm (nerve cutaneous lateralis).

After scar contracture was completely released, soft-tissue defect on the left hand was repaired by incorporating the fasciocutaneous distally pedicled reverse radial forearm flap of the same size as the defect (3 × 8 cm). The flap included the radial artery and an accompanying vein (▶Fig. 32.2). As the tourniquet was deflated, excellent capillary refill in the skin paddle of the flap was noted immediately.

The flap was then placed and secured into position and the donor site was partially closed by undermining the soft tissue medially and laterally to allow tension-free approximation of the wound edges. The area on the donor site that was unable to be closed primarily required a split-thickness skin graft (harvested from the left thigh).

The surgery was completed by removal of the remaining distal phalanx of the left index finger, followed by stump coverage with an advancement flap and removal of the remaining explosive particles out of the left hand (▶Fig. 32.3).

32.4.1 Steps for the Procedure

1. An Allen test has to be performed prior to the surgical intervention to ensure adequate retrograde blood supply to the hand through the ulnar artery.
2. Scar contracture release allowed free range of motion of the thumb.
3. Soft-tissue defect coverage was done with the fasciocutaneous distally based reverse radial forearm flap.
4. Donor site closure partially requires a split-thickness skin graft harvested from the left thigh.

32.5 Postoperative Photographs and Critical Evaluation of Results

The surgical intervention and the patient's postoperative inpatient stay were uneventful (▶Fig. 32.4).

A rehabilitation regime with a certified hand therapist, consisting of active, active-assisted, and passive range-of-motion exercises was initiated on the second day after surgery. After K-wire removal on the fourth day after surgery, the patient was given a more intense physical therapy, with increasing active, active-assisted, and passive range-of-motion exercises in the IP and base joint of the thumb, fingers, and wrist. To reduce postoperative edema in the flap, lymphatic treatment was initiated.

Wound healing during inpatient stay was uneventful. Daily dressing changes of the hand followed for the next 2 weeks after surgery. The dressing on the forearm donor site was left on for 1 week to promote healing of the skin graft.

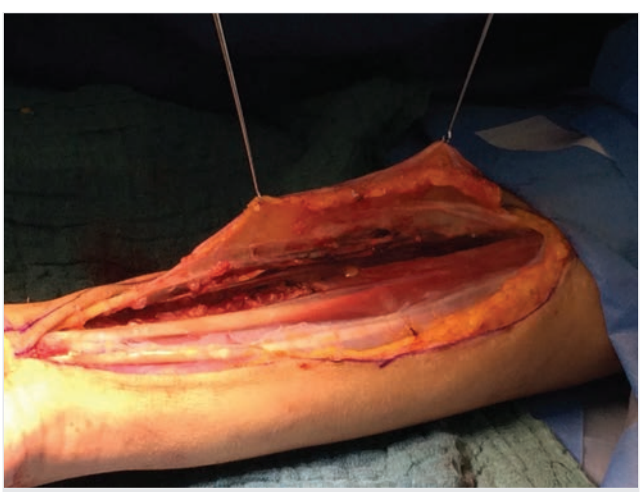

Fig. 32.2 Intraoperative view of the forearm after flap elevation.

Fig. 32.3 Intraoperative view after scar resection and view on the remaining explosive particles.

Fig. 32.4 (a) Postoperative view of the hand on the second day after surgery showing the flap covering parts of the palmar surface. **(b)** Showing the flap also covering the first web space between the thumb and index finger as well as ulnar parts of the thumb. **(c–f)** Postoperative view of the hand on the fifth day after surgery.

The patient could be discharged from the hospital after 5 days. The early postoperative period was uneventful.

A follow-up examination after 2 weeks revealed that the donor site skin graft had taken and the flap was healing well. No donor site complication was encountered.

The flap was shown to provide adequate soft-tissue coverage for the exposed vital structures.

The neuroma pain had nearly disappeared. The patient reported no signs of lack of sensation.

Suture removal was performed and a light dressing was applied on day 11 postsurgery.

The patient went back to his home country, after 2 weeks where he will proceed with the intense rehabilitation treatment.

The 2-week follow-up revealed that the deformity of the thumb has successfully been treated with a satisfactory functional recovery (▶Fig. 32.5). The thumb's function has improved significantly in flexion and extension, adduction, abduction, and opposition. The patient is able to make a fist and showed normal wrist function. The patient is satisfied with the result.

Defect coverage with distally based flaps is not without potential complications such as postoperative venous congestion that may require a second operation for venous anastomosis for adequate flap drainage.

Our patient showed to have sufficient vascular supply, as any distally based flap requires sacrificing one of the major vascular supplies of the hand that can lead to arterial insufficiency in an inappropriate patient (such as a patient with poor peripheral circulation).

As in our case, complete closure of the donor site necessitated the use of a split-thickness skin graft. In case the cosmetic result in the donor site area is disturbing the patient, a second procedure to repair might be required later. Further correction steps like flap debulking can also be performed later if required.

Fig. 32.5 **(a)** Two-week clinical follow-up after the operation. **(b, c)** Full extension. **(d)** Full flexion.

Despite the potential complications, the distally based radial forearm flap proved to be an ideal solution for coverage as shown in our case. The advantage of the flap is that it can cover large defects, provide skin with characteristics similar to the recipient site, does not require staged procedures or immobilization, and does not require extensive dissection or, in many cases, vascular anastomoses.

32.6 Teaching Points

- Burn injuries require adequate early principles such as early surgical debridement and mobilization to a successful outcome.
- Adherence to these simple principles will likely prevent or minimize the most difficult postburn complications such as flexion contractures and deformities.
- Functional loss of the whole hand is severe when the thumb is involved. Correction of the thumb's deformity thus constitutes the most important part for a beneficial functional outcome.
- In large defects such as in our case, with exposing tendons after scar excision and debridement, flap coverage is required.
- If planned well, the distally based radial forearm flap is an excellent option providing the potential of early mobilization with physical therapy and it has low donor site morbidity.

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33 Dorsal Hand Defect

Kelly Currie, Michael Sauerbier, Robert Russell, and Michael W. Neumeister

33.1 Patient History Leading to the Specific Problem

A 29-year-old man sustained a dorsal hand injury while working on an assembly line. Following debridement and dressing changes, definitive coverage required a thin flap as bone and tendon were exposed. The extensor tendons to the index finger had a segmental defect that would need grafting to restore function (▶Fig. 33.1).

33.2 Anatomic Description of the Patient's Current Status

The patient has a dorsoradial full-thickness skin defect of the left hand. The wound extends from the wrist to the level of the proximal interphalangeal joint of the long finger, mid-proximal phalanx of the index, and to the first web space. Extensor tendon is exposed and there is a segmental defect of extensor tendons over the second metacarpal. The majority of the wound bed has healthy granulation tissue.

A pedicled fasciocutaneous radial forearm free flap with palmaris tendon was chosen for reconstruction. A template of the defect was created and used to design the skin paddle to be transferred (▶Fig. 33.2a,b). The flap fitted nicely into

Fig. 33.1 A full-thickness wound to the dorsum of the left hand. Tendons are exposed and there is a segmental defect in the extensor indicis proprius and the extensor digitorum communis to the index finger.

Fig. 33.2 **(a)** A reverse radial forearm flap is designed on the volar forearm. A template is used to harvest the exact skin paddle required for the dorsal defect. **(b)** The reverse radial forearm flap is harvested on the distal radial artery. The palmaris longus tendon is also harvested in continuity with the flap to provide a vascularized tendon graft for the extensor tendon reconstruction. **(c)** The flap is tunneled and inset providing stable coverage for form and function.

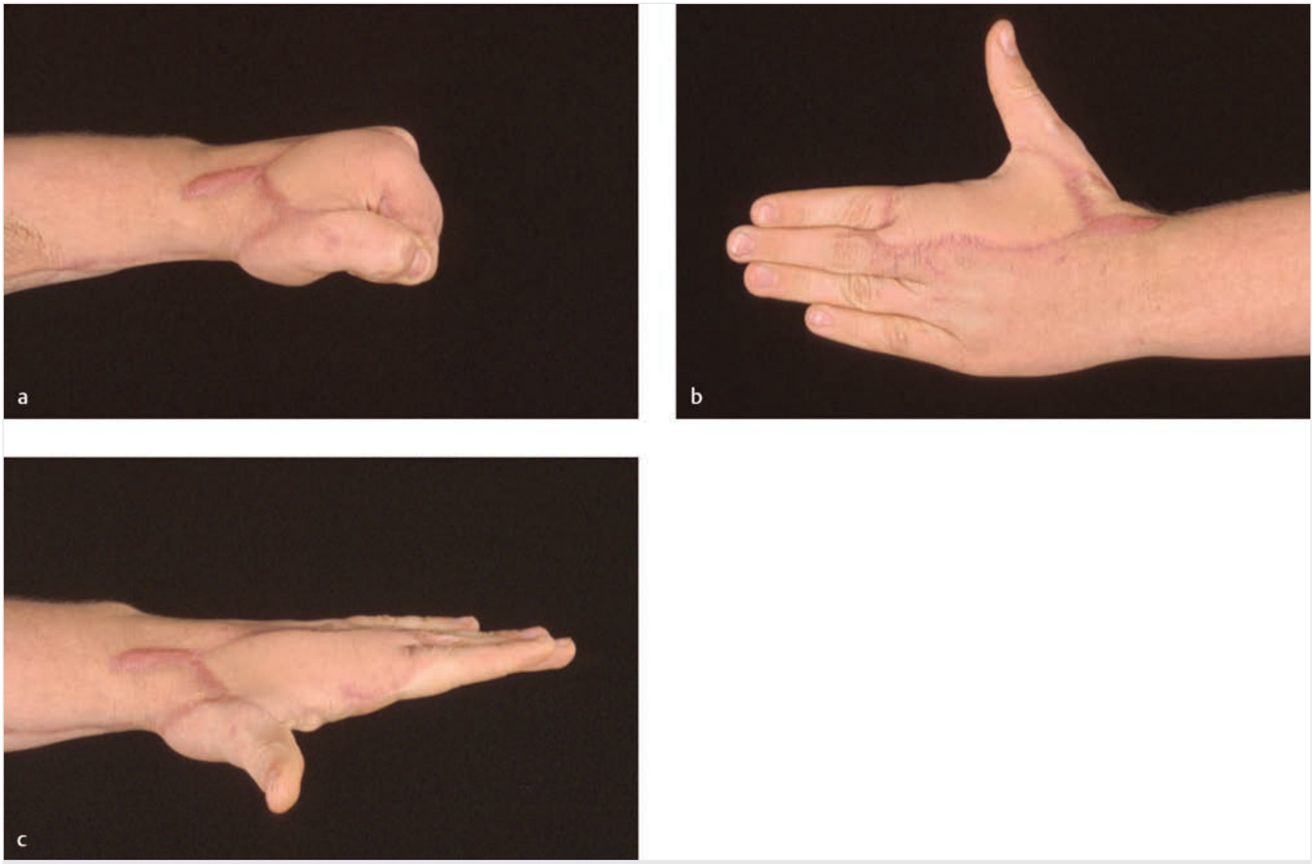

Fig. 33.3 (a–c) The recipient site on the dorsum of the hand has great long-term contour and excellent finger extension.

the defect (▶Fig. 33.2c) and excellent function was obtained postoperatively (▶Fig. 33.3).

33.2.1 Donor Site Problem

Although good function was obtained, the use of a fasciocutaneous radial forearm flap can leave the donor site with quite an unappealing defect. Due to the paucity of excess skin in this area, the donor site can rarely be closed primarily, necessitating a skin graft for closure (▶Fig. 33.4). The skin graft requires healthy muscle and paratenon to heal, often with a period of immobilization, and is prone to skin graft shearing from movement of these structures. Tethering of the scar to the underlying tendons and muscle bellies can lead to pain and limitations of tendon excursion, in addition to the poor aesthetic outcome.

Fig. 33.4 The forearm donor site can be very unsightly and occasionally painful because of antebrachial nerve neuromas.

33.3 Recommended Solution to the Problem

Dorsal hand defects present a unique reconstructive dilemma. The ideal tissue for coverage requires several specialized properties. First, it should be thin, so it does not hinder placement of the hand into small places like pants pocket. Thin tissue should also maintain the aesthetic contours in this location. Second, it should be pliable to accommodate the large arch of motion at the wrists and fingers. Next, it should allow smooth gliding of the extensor tendons underneath it. And, finally, it should have an aesthetic donor site that limits morbidity.

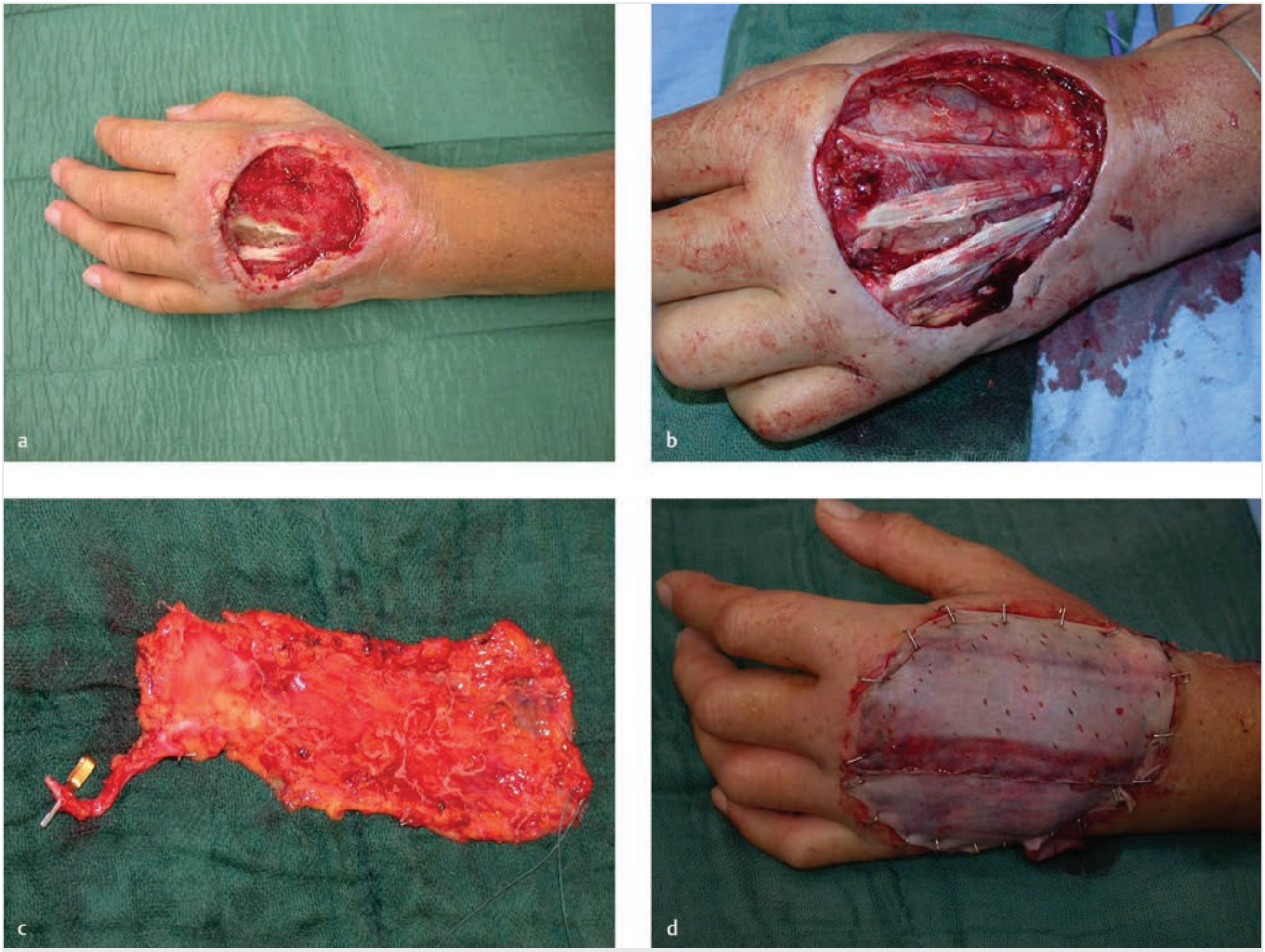

Fig. 33.5 (a) A dorsal hand wound with exposed tendon requires flap coverage. **(b)** Following debridement, multiple tendons are exposed. **(c)** A serratus anterior fascia flap is harvested. The flap is very thin and will provide a good gliding surface for the extensor tendons. **(d)** The fascia flap is covered with a split-thickness skin graft. The anastomosis was performed to the radial artery and cephalic vein.

Fascial flaps, without any cutaneous component, possess all of these properties. Even with a skin graft on top of these flaps, they tend to provide a very aesthetically pleasing result. We present a patient with a dorsal hand wound (▶Fig. 33.5a) that has several extensor digitorum communis tendons exposed after debridement (▶Fig. 33.5b). A free serratus fascial flap was chosen for coverage (▶Fig. 33.5c). The fascial flap was covered with a nonexpanded split-thickness skin graft (▶Fig. 33.5d).

33.3.1 Recommended Solution to the Problem

- Donor tissue properties for dorsal hand coverage:
  - Thin.
  - Pliable.
  - Allow for extensor tendon glide.
  - Minimal donor site morbidity.
- Nonexpanded skin graft for best aesthetic outcome.

33.4 Technique

With the patient in the lateral decubitus position, or 45-degree anterior oblique to facilitate a two-team approach, a longitudinal incision is made from the axilla for 10 to 15 cm inferiorly, anterior to the latissimus. The latissimus is dissected off the lateral thoracic fascia. This fascia is elevated off of the serratus muscle, from an inferior-to-superior direction, taking care not to injure the long thoracic nerve. It may be helpful to begin dissection at the “crow’s foot” (superior-to-inferior dissection) where the long thoracic nerve crosses the dominant serratus artery branch. The nerve is left

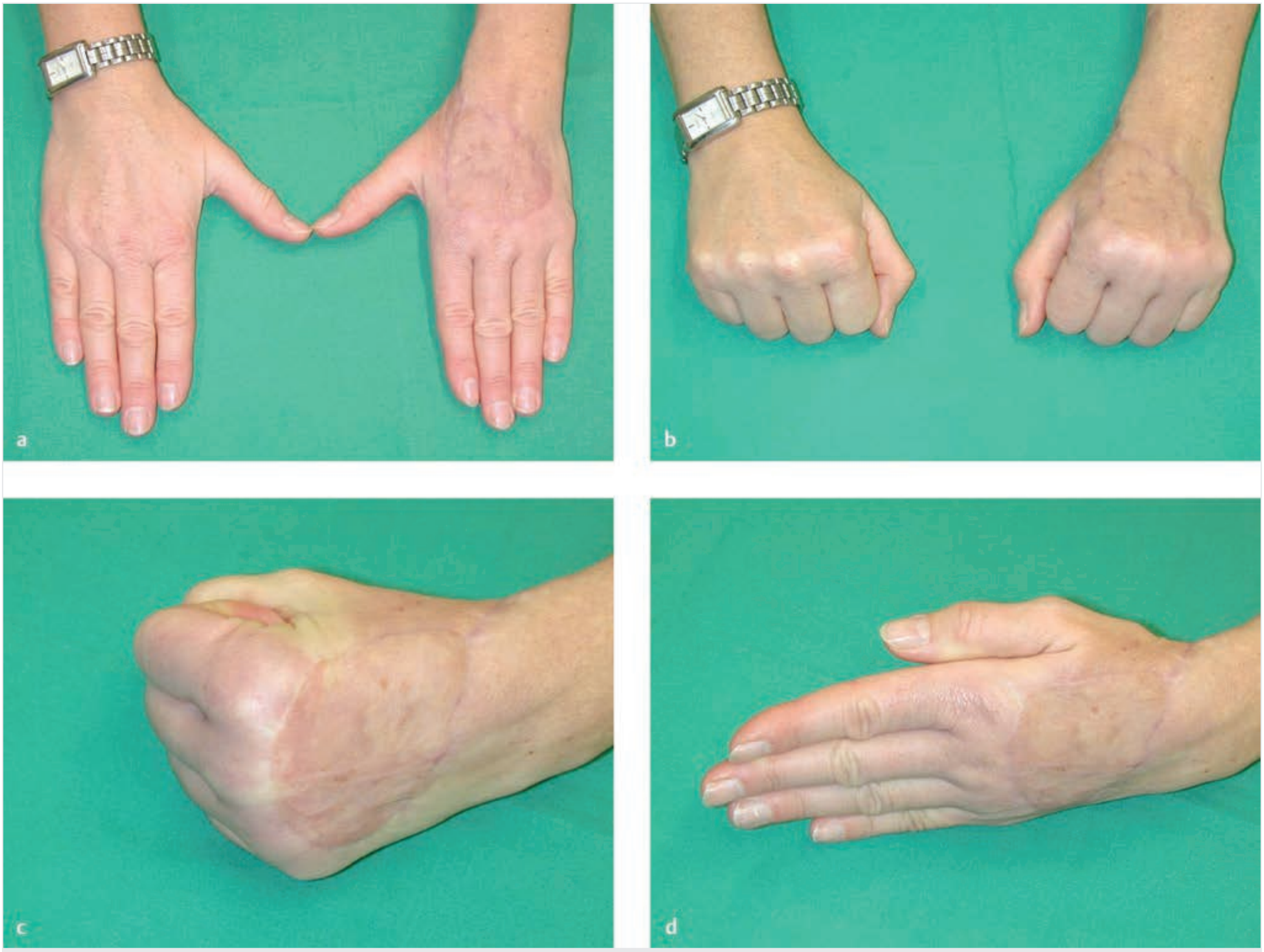

Fig. 33.6 (a–d) The final appearance and function after 1 year following the serratus anterior fascial flap to the dorsum of the hand.

down on the serratus muscle to prevent scapular winging. The vascular branch to the latissimus dorsi muscle is divided and the fascial flap is elevated on the thoracodorsal pedicle. The pedicle can be 12- to 15-cm long. The donor site is closed over a drain.

33.5 Postoperative Photographs and Critical Evaluation of Results

At 1 year postoperatively, the patient maintained excellent range of motion of her digits and wrist, without extensor tendon adhesion to the flap limiting her function (▶Fig. 33.6). The donor site scar was linear and easily hidden under her arm (▶Fig. 33.7).

33.6 Teaching Points

- The dorsum of the hand has very thin skin.
- Loss of the dorsal hand skin with associated exposed tendons requires a flap that is thin yet provides adequate glide of the tendons.

Fig. 33.7 The donor site from the serratus anterior fascia harvest can only be seen when the patient removes their shirt.

- Regional flaps such as the reverse radial forearm may provide adequate dorsal hand coverage but may have poor donor site contour and scarring.
- The serratus anterior fascia provides a very thin flap and permits excellent tendon glide.
- The donor site morbidity of the serratus anterior fascia flap is minimal.

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Part XII

Problems with Nonarticular Phalanx Fractures

34 Malrotation in Nonarticular Phalanx Fractures *152*

35 Nonunion in Nonarticular Phalanx Fractures *155*

36 Stiffness and Hardware Problems in Nonarticular Phalanx Fractures *158*

37 Angulation in Nonarticular Phalanx Fractures *164*

XII

34 Malrotation in Nonarticular Phalanx Fractures

Mark S. Rekant

34.1 Patient History Leading to the Specific Problem

A 28-year-old female bank teller presents with continued difficulty making a right fist and a "crooked finger." She reports having a hand fracture 14 months ago during a motor vehicle collision for which she required an extensive hospitalization. The fracture was treated in a splint for 4 weeks at the time followed by occupational therapy. Despite therapy, the patient complains that her finger gets in the way of the other fingers when grabbing items.

34.2 Anatomic Description of the Patient's Current Status

The patient has a normal-appearing hand without scars or wounds. There are no areas of tenderness. Upon making a fist, there is scissoring noted on the right ring finger that limits full flexion to the distal palmar crease with rotational malalignment (▶Fig. 34.1). The patient has full passive range of motion. Total active motion (TAM) of the right ring finger measures 226 degrees (left ring finger 260 degrees).

34.3 Recommended Solution to the Problem

Surgical management of proximal phalanx fractures is challenging. Current described techniques of direct repair maybe complicated by ongoing stiffness, pin infection/loosening, deep infection, hardware irritation, extensor lag, malunion, and nonunion. The flexion force of the interossei insertion on the proximal fragment and the extension force of the central slip on the base of the middle phalanx often lead to an apex volar deformity. Other times, fracture pattern and injury mechanism may cause malrotation at the fracture site. Despite appropriate management, malrotation of both nonoperative and operatively treated proximal phalanx fracture may occur.

Rotational malunion is often a disabling complication of proximal phalanx fractures. After swelling and pain subside, and active motion is advanced, subtle malunion on radiographs may produce a pronounced malrotation deficit noted most in mid-fist. If active and passive motion of the digit is within acceptable range, bypassing the zone of injury with a metacarpal osteotomy to correct the malrotation is a good option.

34.3.1 Recommended Solution to the Problem

- Prevention is the best treatment. Provide passive motion or observe early active motion when possible to check for malrotation after proximal phalanx fractures.
- If operative intervention is required, consider wide-awake or local anesthesia/monitored anesthesia care. Patients can then make a fist in the operative suite to ensure rotation is correct and fixation is adequate to allow for some protected early motion.
- Away from the tight soft-tissue confines of the proximal phalanx, an osteotomy at the metacarpal metadiaphyseal region provides for better bony fixation and less soft-tissue problems.

34.4 Technique

Prior to entering the operating theater, both hands of the patient are evaluated critically for subtleties in rotation. Critically

Fig. 34.1 This patient presents with scissoring of the right ring finger.

evaluating the angulation and position of the nail plate through active range of motion of both the injured and normal hands helps guide the correction necessary.

The patient is taken to the operating theater and placed in the supine position with a hand table. Using local, regional, or general anesthesia with sedation and an arm tourniquet, the arm is prepped and draped. The carpometacarpal (CMC) joint of the affected joint is palpated, and fluoroscopy can be used to confirm location. Beginning at the CMC joint a 4-cm skin incision is made extending in line with the metacarpal of the affected digit. Extensor tendons are identified and retracted, while sharp dissection is used to expose the metadiaphysis of the metacarpal in a subperiosteal fashion. Once exposed, care is used to further expose the base and diaphysis of the metacarpal in preparation for plate placement.

After proper exposure, a T-style 2.4-mm plate (2.0-mm plate in smaller females) is utilized to allow for two-screw fixation both proximal and distal to the osteotomy (▶Fig. 34.2a). The plate is applied to the intact metacarpal using only the two screws in the metacarpal base and fluoroscopy is used to confirm placement and to mark the osteotomy site. A 0.062-inch K-wire is placed distal to the plate to serve as a rotation lever and guide (▶Fig. 34.2b).

After confirmation, the plate is removed and the transverse osteotomy is performed using a saw blade with copious amounts of irrigation. It is helpful to score and mark the metacarpal with ink longitudinally prior to the osteotomy to recall the initial bony alignment. The 0.062-inch K-wire is used to rotate the metacarpal, helping dial in the correct rotation (▶Video 34.1). With satisfactory correction, a separate 0.045-inch K-wire is placed from an adjacent metacarpal into the distal segment to maintain the correction and serve as provisional fixation of the osteotomy. To further confirm correct rotation, use wrist motion and pressure on the proximal muscle bellies to check for a normal cascade and rotation with tenodesis or have the patient gently move their fingers if using wide-awake surgery. After securing the proximal plate using the predrilled holes, the distal holes are filled using bicortical cortical screws in a compression technique. Radiographs are used to confirm proper fixation and the wound is then irrigated and closed (▶Fig. 34.3). The hand is splinted in the intrinsic plus position. Protected motion is started after the first follow-up visit and the patient is weaned from a splint at 4 to 6 weeks.

The metacarpal 0.062-inch K-wire is essential to evaluate the true bony correction. Manually rotating the finger or using a wire further distally in the phalanx will rotate through some articulation where soft tissues may account for some rotation. This will underestimate the true correction.

There is a limit to correction. With maximum rotation of the metacarpal, a 20-degree correction can be achieved with the exception of the small finger, in which a 30-degree pronation deformity can be corrected (rotates away from the scaphoid tubercle prior to correction). The deep metacarpal transverse ligaments limit rotation, but we have not seen problems with flexion limitation, unsatisfactory correction, or saddle syndrome in patients after correction.

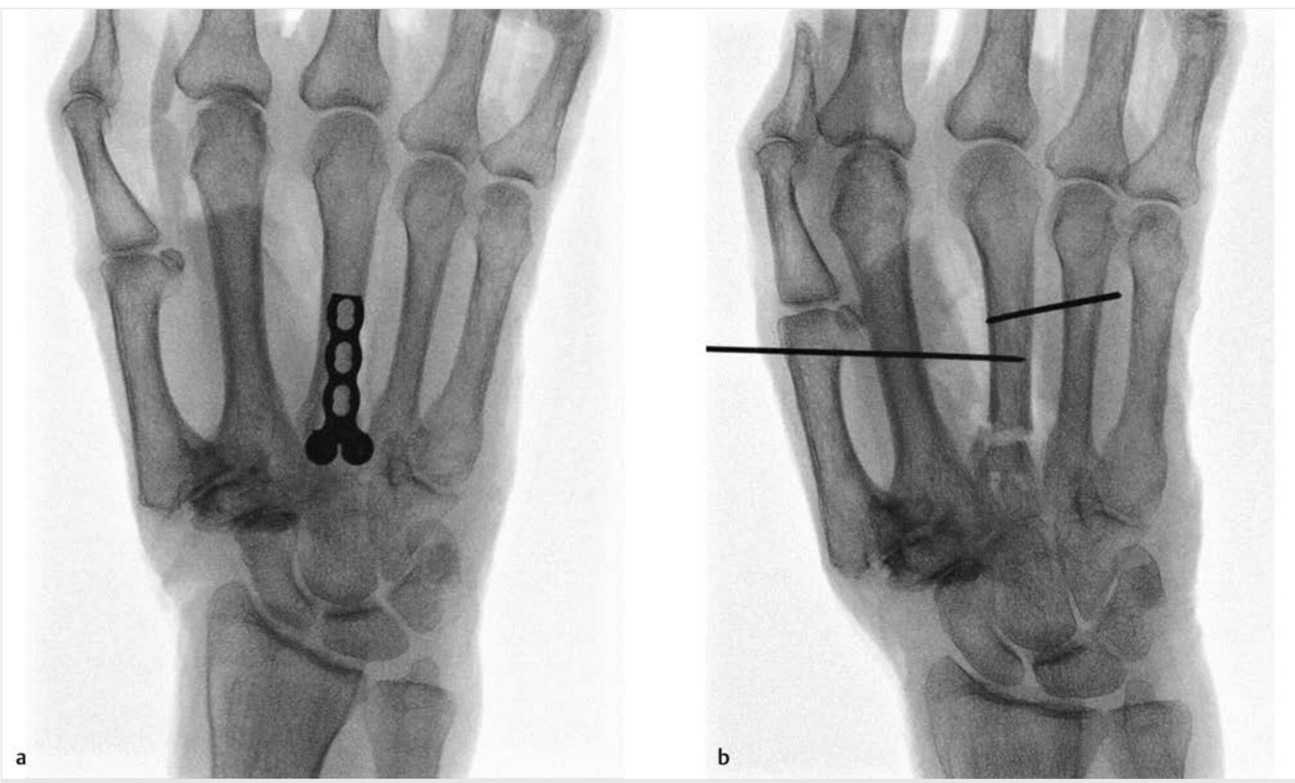

Fig. 34.2 (a) The T-plate is placed at the base of the metacarpal and the two proximal holes are secured into place. Care is taken to mark the site of the osteotomy. **(b)** With the 0.062-inch rotation wire in place, the osteotomy is made and the malrotation is corrected. A transmetacarpal wire is used for temporary fixation. Tenodesis is used to confirm satisfactory correction.

Fig. 34.3 Postoperative radiograph shows a realigned long metacarpal shaft. Notice the two distal screws were placed distally in the compression hole to allow for additional compression at the osteotomy site.

34.4.1 Steps for the Procedure

1. Identify the metacarpal base using palpation and fluoroscopy and make a 4-cm incision just distal to the CMC joint.
2. Expose the metadiaphyseal junction and prepare the metacarpal for a 2.4-mm T-plate.
3. Apply the plate to the metacarpal using only the two proximal holes. Mark the site for osteotomy at a screw site. Place a 0.062-inch K-wire just distal to the plate.
4. Check with fluoroscopy.
5. Remove the plate, perform osteotomy, and replace the plate.
6. Use 0.062-inch K-wire to correct the deformity. Secure rotation with a 0.045-inch K-wire transmetacarpal wire as provisional fixation.
7. Confirm rotation with tenodesis.
8. Secure the plate using compression technique in the distal segment.
9. Close and splint the hand for comfort.

34.5 Postoperative Photographs and Critical Evaluation of Results

The patient underwent surgical correction of her phalangeal malunion using a metacarpal osteotomy. Intraoperative tenodesis confirmed rotation correction. After suture removal 11 days post-op, the patient was placed into a custom thermoplastic splint and gentle range of motion exercises were begun. At 6 weeks, the patient returned to work without restrictions with a TAM of 230 degrees and grip strength of 80% of the uninvolved hand.

34.6 Teaching Points

- Compression plating is important to prevent nonunions. After securing the plate proximally, place a cortical screw into an oblong hole away from the osteotomy site to nsure compression. Remove all temporary fixation before final tightening of the screw so as not to impede compression.
- There are limits to correction of rotation, but this is rarely an issue. The deep transverse metacarpal ligament in the primary restraint to rotation, but it should not be released in order to obtain more correction. This will cause instability.
- Measure twice, cut once. Tenodesis using wrist motion and forearm pressure on the flexor muscle bellies given an accurate measure of rotation.
- The fourth metacarpal has a very narrow diaphysis. Be sure to have the place centered distally prior to screw placement in order to avoid unicortical screws and extra drill holes that may lead to fracture.
- Do not attempt correction using manipulation of the digit. Manipulation of the 0.062-inch K-wire in the distal metacarpal will ensure proper correction.
- Preservation of paratenon, placement of a subperiosteal plate, and gentle early digital motion all help prevent stiffness in the hand after surgical correction.
- Corrections greater than 20 degrees cannot reliably be made and patient expectations should reflect this shortcoming to an otherwise reliable technique.

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35 Nonunion in Nonarticular Phalanx Fractures

A. Lee Osterman and Adam Strohl

35.1 Patient History Leading to the Specific Problem

A 25-year-old right-hand-dominant man presents with a left painful, stiff index finger. Four years earlier, he sustained a closed injury to the proximal phalanx that was treated elsewhere with open reduction and internal fixation. His injury resulted from an altercation in which he struck another individual. He underwent revision corrective osteotomy for malunion 1 year ago. Since then, he complains about persistent pain in the digit and inability to completely extend the digit. He acknowledges deformity of the digit, but tells you, “it is more straight than it was before last surgery.” Medical records do not indicate any history of infection.

35.2 Anatomic Description of the Patient’s Current Status

The patient has a 3-cm slightly hypertrophic, linear over the dorsum of the proximal phalanx of the left index finger. There is obvious ulnar deviation of 15 degrees at the proximal interphalangeal (PIP) joint. There is mild tenderness to palpation over the proximal phalanx without any gross instability, motion, or crepitus. No erythema, warmth, or drainage is seen. Capillary refill is present and there is no sensory deficit at the radial or ulnar tip of the finger.

Active range of motion (ROM): metacarpophalangeal (MCP): H30 to 80 degrees; PIP: 25 to 50 degrees; distal interphalangeal (DIP): 0 to 65 degrees.

Passive ROM: MCP: H50 to 85 degrees; PIP: 0 to 70 degrees; DIP: 0 to 65 degrees.

With finger flexion, the index finger overlaps the long finger (▶Table 35.1).

Radiographs of the left index finger reveal transverse lucency in the mid-diaphysis of the proximal phalanx (▶Fig. 35.1). There is no hardware present. The anteroposterior view shows ulnar translation as well as ulnar angulation (30 degrees) of the distal fragment. The lateral view shows dorsal angulation (45 degrees) of the distal fragment. Diagnosis is chronic nonunion of a left index finger nonarticular, proximal phalanx fracture.

35.3 Recommended Solution to the Problem

One must consider possible causes for nonunion of this fracture such as infection or inadequate fixation. In addition to the initial fracture and surrounding soft-tissue injury, this patient has already had two surgeries involving open reduction and internal fixation, which led to scar and tendon adhesions. Tenolysis and sometimes joint release maneuvers may need to be considered.

Table 35.1 Hand grip strength dynamometer testing

Jamar dynamometer	Right	Left
I	75	35
III	105	100
IV	95	85

Fig. 35.1 Patient X-ray showing transverse lucency in the mid-diaphysis of the proximal phalanx with extension and angulation deformities.

Rigid fixation is important to allow early motion and prevent future adhesions, as well as careful consideration of approach and hardware position. Lateral, instead of dorsal, placement of hardware can prevent extensor tendon adhesion. The lateral approach will also allow adequate exposure of extensor and flexor tendons for tenolysis. If dorsal approach is chosen, then additional volar incision may be needed for additional procedures.

35.3.1 Recommended Solution to the Problem

- Adequate debridement of all fibrous tissue at the nonunion site until normal-appearing bone is paramount to successful healing.
- Infection of the nonunion must be considered and appropriately treated with adequate debridement and antibiotic suppression. Sometimes antibiotic cement spacer may be needed.
- Nonunions are often associated with high-energy, crush, and/or open injuries as well as multi-injury.
- Tenolysis and joint contracture release may need to be done at the time of nonunion correction.
- Intercalating corticocancellous bone graft may be needed for structural support and correction of shortening and/or angulation.
- If chronic infection, inadequate coverage, insensate, or extensive bone loss, consider joint fusion or amputation

35.4 Technique

The patient is placed in the supine position with their hand abducted on a hand table with a pneumatic tourniquet placed proximal to the surgical field. Anesthesia choice ranges from regional to general to wide awake (if a tenolysis is considered). Addition surgical sites for obtaining autologous bone graft, such as the distal radius, proximal ulna, or iliac crest, are exposed and similarly prepped. Administration of antibiotics is delayed until bone cultures are obtained from the nonunion site. Intraoperative use of fluoroscopy is indicated.

A mid-lateral incision is designed and the full-length of the proximal phalanx is marked. The apex of the PIP flexion crease and palpable proximal phalanx base are used as landmarks for this marking. The upper extremity is exsanguinated with an Esmarch bandage and the pneumatic tourniquet inflated to appropriate pressure for its position.

A no. 15 scalpel is used to incise along the previously made skin marking. Blunt dissection is performed with a dissecting scissor. Any cutaneous nerves should be protected and gently retracted as thick skin flaps are raised dorsally and volarly. The neurovascular bundle should be identified volarly and protected at all times.

The lateral band of the extensor tendon will next be identified. It will need to be dissected from the underlying periosteum and retracted dorsally. Alternatively, the lateral band may be sharply excised to allow maximal exposure without resultant deficit, assuming the other lateral band is intact.

The dissecting scissor can be used to free the extensor tendon mechanism from any adhesions to the periosteum and overlying dorsal skin scar. Dense scarring may be noted overlying the site of nonunion. An additional incision may be needed on the contralateral side of the digit to complete the tenolysis.

The flexor tendons can next be identified and assessed for adhesions. The annular pulleys should be identified. At the proximal phalanx, the A3 pulley may be sharply incised and sacrificed to gain access to the flexor sheath and tendons. A freer elevator or tenolysis knives can be used to free the tendons from each other and adhesions. Palmar incisions may be necessary if additional tenolysis is deemed necessary.

A scalpel is then used to sharply incise the periosteum longitudinally, and periosteal elevators are used to preserve as much periosteal cuff as possible. The nonunion site is widely exposed, and the intervening fibrous tissue is identified. Using a scalpel, curettes, and rongeurs, all fibrous tissue is debrided until native, cortical bone can be identified. Bone loss at the fracture site must be assessed, as shortening leads to extensor lag.

Cancellous bone graft is generally sufficient, but if there is a large gap, an intercalating, corticocancellous bone graft can be used. A cancellous graft is harvested between the second and third extensor compartments using a Craig needle or curette .To harvest an iliac crest graft, an incision over the iliac crest is made, and blunt dissection continues through the subcutaneous tissues directly to bone. Deep, right-angle retractors may be needed to maintain exposure. The periosteum is sharply divided and a periosteal elevator is used to raise periosteal flaps. A graft is measured and marked on the bone. The graft can be harvested using a combination of K-wire outline, osteotome, and saw.

The fracture needs to be reduced as angulation and rotation corrected by visual inspection and intraoperative fluoroscopy. Lateral placement of an appropriately templated plate is secured to the fracture fragments. The intercalating bone graft is placed in its position and if large enough can be secured by screw to the plate or compressed using the plate construct (▶Fig. 35.2). Final radiographs are obtained and inspection for malrotation is performed by evaluating distal nail bed orientation and passive ROM of the digit with the MCP joint flexed.

The periosteal flaps are repaired over the plate if possible. Hemostasis is obtained following release of the tourniquet. The skin is closed with skin sutures. A splint is placed on the hand.

35.4.1 Steps for the Procedure

1. Exposure of fracture nonunion under tourniquet control.
2. Tenolysis of flexor and/or extensor tendons, as needed.
3. Debridement of fibrous nonunion site to normal-appearing bone ends.
4. Maintain phalanx height despite bony gap, and measure the defect.
5. Obtain corticocancellous or cancellous bone graft, as indicated.
6. Apply appropriate hardware fixation with intercalating bone graft.
7. Inspect digit for malrotation and/or angulation deformities.

35.5 Postoperative Photographs and Critical Evaluation of Results

The phalangeal height and bow have been restored with stable fixation utilizing three screws distally and proximally, seen in radiographs taken 3 months postoperatively (▶Fig. 35.3).

Fig. 35.2 Internal fixation performed following debridement of the nonunion site with an intercalating corticocancellous wafer placed in bony defect.

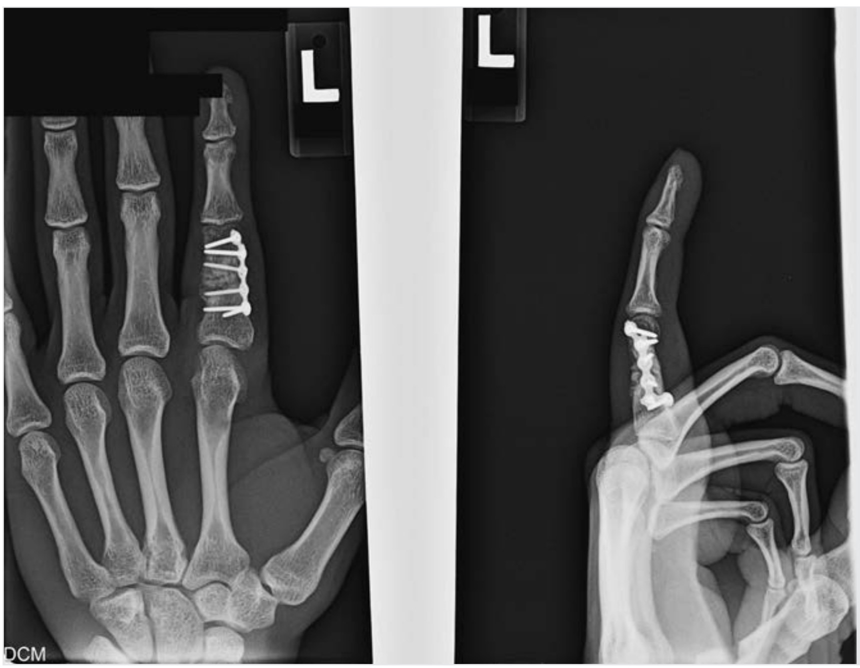

Fig. 35.3 Three months postoperative radiographs reveal continued bone growth without deformity.

35.6 Teaching Points

- Often high-energy, multi-injury, crush, open injury.
- Hypertrophic nonunions usually occur secondary to instability of fracture fragments and improper immobilization. Atrophic nonunions occur secondary to bone loss from trauma or infection. If bone loss is present after debridement, intercalating bone graft with rigid fixation is needed.
- Ensure infection is cleared before definitive correction.
- Adequate debridement of fibrous tissue.
- Tenolysis if necessary.
- If chronic infection, inadequate coverage, insensate, or extensive bone loss, consider joint fusion or amputation.

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36 Stiffness and Hardware Problems in Nonarticular Phalanx Fractures

Max Haerle and Tobias Del Gaudio

36.1 Patient History Leading to the Specific Problem

A 34-year-old right-hand-dominant woman presented to our department complaining of pain and persistent stiffness of her right small finger after open reduction and plate fixation of a proximal phalanx fracture 3 months prior elsewhere (▶Fig. 36.1). After surgery, the patient was immobilized over 2 weeks in an intrinsic plus splint. Then, after radiological follow-up control (▶Fig. 36.2), the patient was advised to look after physical therapy.

36.2 Anatomic Description of the Patient's Current Status

A hypertrophic scar was found on the dorsal aspect of the proximal phalanx of the small finger. Range of motion (ROM) of the small finger was severely decreased with painful stiffness and fixed flexion of 20 degrees in metacarpophalangeal (MCP) joint and almost 50 degrees in proximal interphalangeal (PIP) joint, while good ROM was preserved in all other small joints.

36.3 Recommended Solution to the Problem

In many patients, the trauma, the operation, and the postoperative immobilization are by themselves apt to create tendon adherences and joint stiffness. Measures of prevention are several and they aim to keep tendon irritation as low as possible to prevent tendinous adhesions through early postoperative mobilization.

Once the stiffness occurred, the condition should be treated early and aggressively, if allowed by the situation. In such situations, our first approach consists of a multimodal conservative treatment model, including physical and occupational therapy several times a day, special pain management, and, if indicated, psychological support. Goal of treatment is both the—at least partial—restoration of ROM and a sufficient pain management.

Fig. 36.1 **(a, b)** Radiographs after trauma.

Fig. 36.2 (a, b) Radiographs after plate fixation.

Then, once ROM is consistently improved and maintained over few weeks and indication for surgery persists (e.g., irritating plate, fixed contraction), decision-making in between different surgical strategies is mainly influenced by following two factors: the underlying cause of stiffness/joint contracture (scarred contraction, adhesions of the tendon, ligamentous/capsular shrinking) and the affected bone/joint itself (e.g., MCP vs. PIP, malrotation).

Contracted scars are treated by excision and corrected through Z-plasty or local flap plasty. Tendinous adhesions are treated by extensive adhesiolysis, while treatment of ligamentous/capsular shrinking is based on release techniques, which differ in between MCP and PIP joints because of their different anatomical structures.

ROM in the PIP joint is limited through the collateral ligaments, the palmar plate (which as a quite inelastic complex reinforces—stabilized through checkrein ligaments—the palmar joint capsule) and the accessory collateral ligaments, which insert on the palmar plate (▶Fig. 36.3). Consequently, the most common cause of PIP joint contraction is caused by a shrunken palmar plate and subsequently shortened accessory collateral ligaments. Typically, an identical extension deficit is found in active and passive ROM examination.

In contrast, the MCP joint contraction is characterized by shrinkage of the posterior collateral ligaments and, because of different anatomical course of these ligaments, contraction is often in hyperextension of the joint.

If a motion-related, intra-articular pain condition persists, an additional joint denervation should be taken into consideration.

36.4 Technique

Surgery is performed in regional anesthesia and upper arm tourniquet. A dorsal S-shaped incision under excision of hypertrophic tissue is made over the proximal phalanx from the MCP to the PIP joint (▶Fig. 36.4a). The subcutaneous tissue is gently prepared, exposing extensor tendon system, detaching subcutaneous adhesions, while dorsal veins and sensory nerves are preserved (▶Fig. 36.4b). The lateral extensor band is then identified at the PIP joint level and the extensor hood is gently lifted with a blunt dissector (▶Fig. 36.4c). The underneath lying plate is exposed dissecting gently adhesive tissue between the plate and the tendon. Subsequently, the screws and the plate are removed.

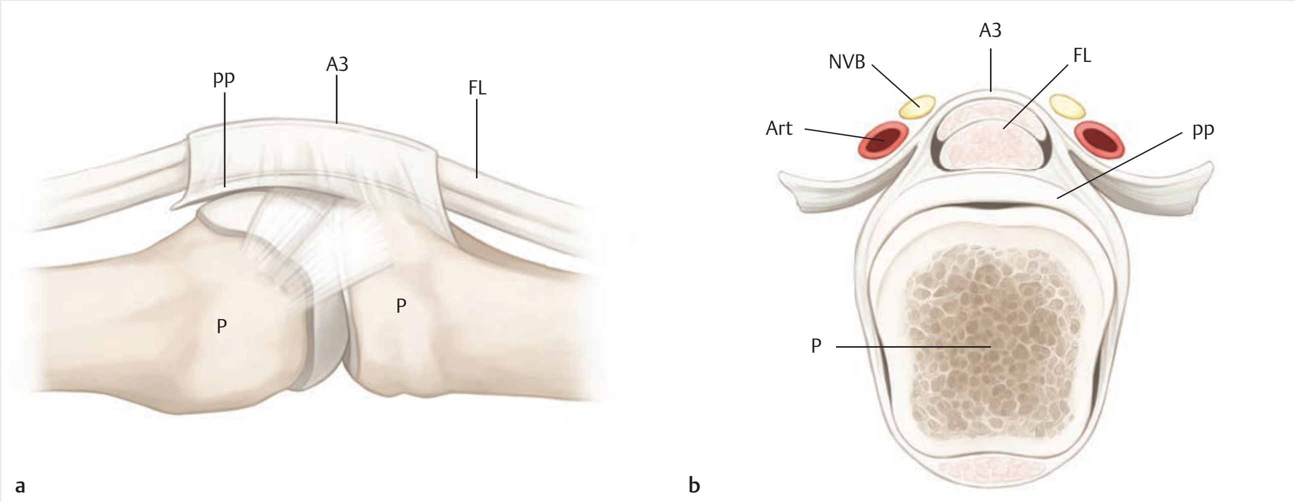

Fig. 36.3 (a, b) Palmar complex composed of palmar plate, checkrein ligaments, and collateral ligaments. A3, A3 pulley; Art, artery; FL, flexor tendons; P, proximal phalangeal NVB, neurovascular bundles; pp, palmar plate. Modified from Fowler J, Rawool N. Ultrasound of the Hand and Upper Extremity. 1st Edition. Thieme; 2017.

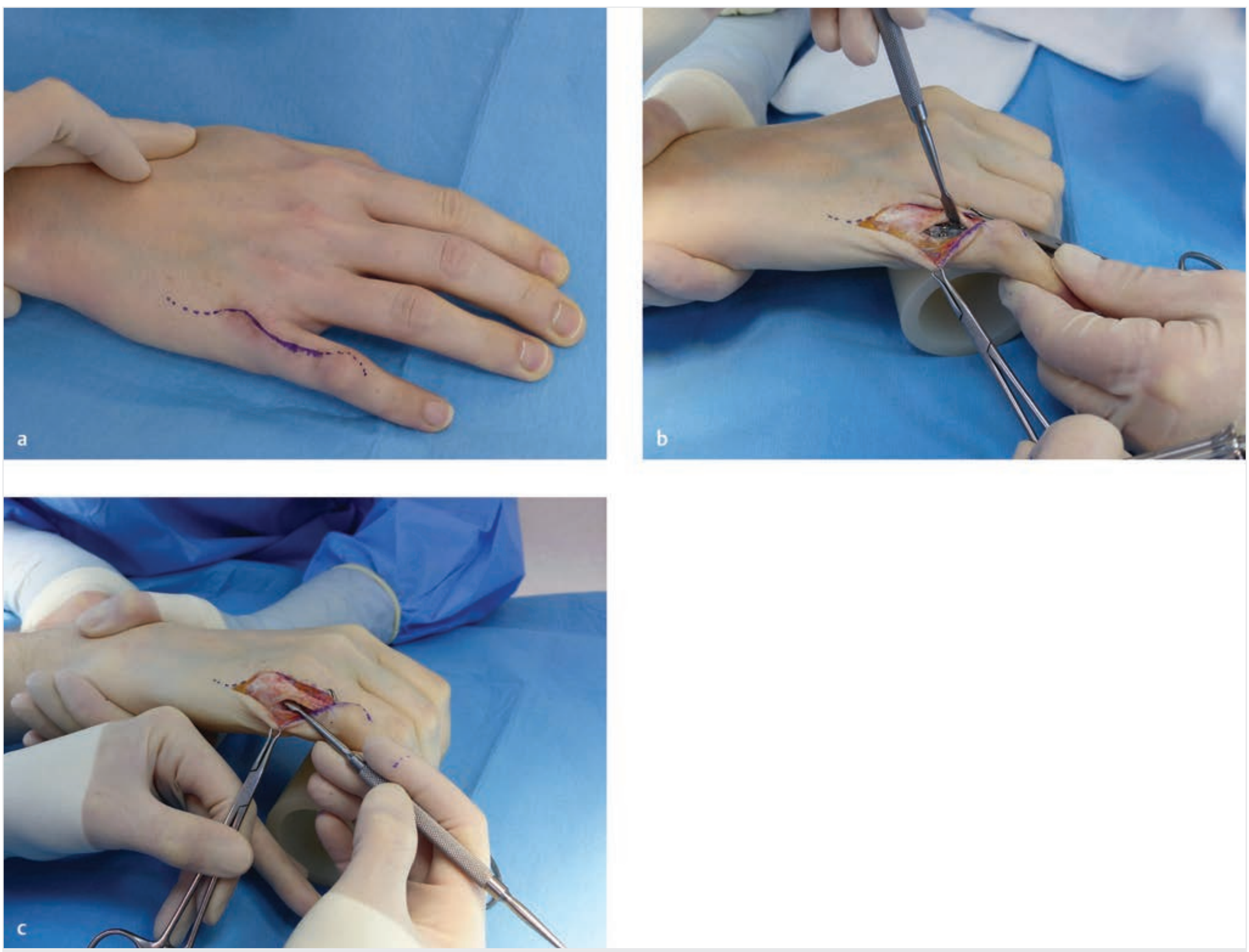

Fig. 36.4 (a) Dorsal incision over metacarpophalangeal and proximal interphalangeal joints. **(b)** Exposition of extensor hood and exposition of the plate. **(c)** Lifting of the extensor hood through a lateral approach.

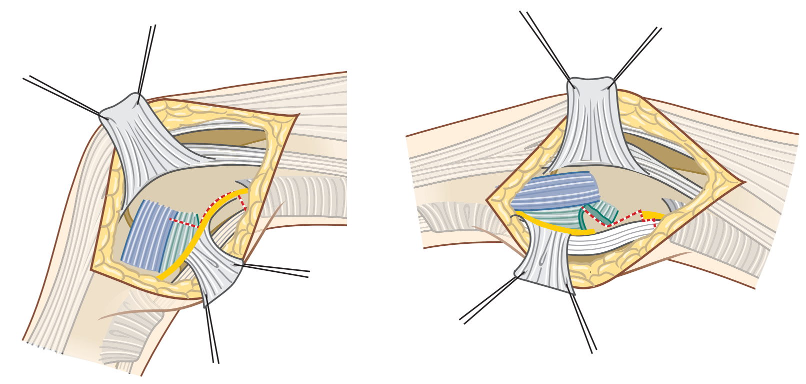

Fig. 36.5 Dissection plane of accessory collateral ligaments and palmar plate.

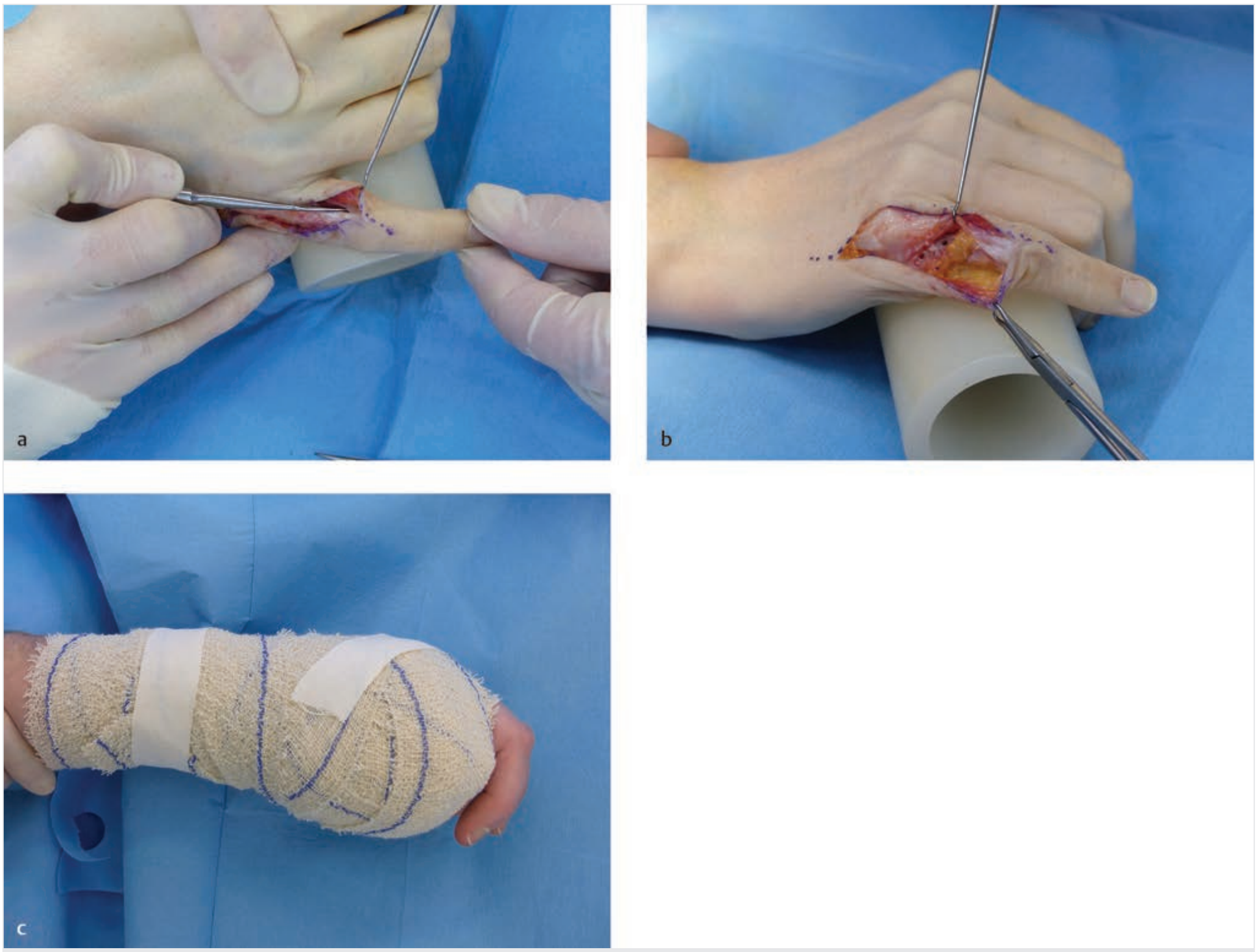

Fig. 36.6 (a) Lifting of palmar plate in flexion of proximal interphalangeal joint. **(b)** Fat paddle is placed between bone and extensor tendon. **(c)** Fist dressing.

The blunt dissector is then inserted under the extensor tendon hood and the tendon is prudently lifted (▶Fig. 36.4c and ▶Fig. 36.5). By doing so wide proximal up to the MCP joint level, the tendon is released from further adhesions.

Tenolysis of the extensor complex at the level of the PIP joint is proceeded with the blunt dissector, taking care to avoid a disinsertion of the central slip. Through that dorsal approach of the PIP joint, two flaps can be formed and the PIP joint can be exposed in its dorsal and lateral parts. Following the capsule, the flexor tendon and the palmar plate can be reached easily avoiding a double approach. Hereby arthrolysis is reached through transection of the accessory collateral ligaments and proximal detachment of the palmar plate. Attention is given to avoid collateral ligament damage.

Finally, the palmar plate is lifted up from bone in slight flexion of the PIP joint (▶Fig. 36.6a). At this point, in case of painful condition, by choosing this approach to the PIP joint, not only all structures can be handled in a single approach but also a beneficial denervation effect is obtained. Under loupe magnification, the regular proximal dorsoulnar and dorsoradial nerve branches to the joint are coagulated and transected. Passive ROM mobility in the MCP and PIP joints is then ascertained. To provide for a better gliding of the extensor apparatus, a periosteal pedicle flap with fat paddle may be sculptured and placed in between the bone and the extensor tendon from ulnar to radial (▶Fig. 36.6b). The flap is then fixed with resorbable 5–0 sutures. After wound closure, a fist dressing is applied (▶Fig. 36.6c).

36.5 Postoperative Photographs and Critical Evaluation of Results

We immediately started with intensive physical therapy treatment several times per day; the patient was discharged after surgery with a preserved ROM, followed by intensive outpatient treatment. At the controls, MCP joint mobility could be restored in large scale, while flexion contracture of the PIP joint recurred slightly. A dynamic extension splint was applied. At the final control, ROM was significantly improved, as compared to the initial status. A mild extension deficit of 25 degrees recurred in the PIP joint, which was pain free (▶Fig. 36.7).

36.6 Teaching Points

- Through a dorsal approach, the palmar plate and the accessory ligaments can be reached easily.
- Detachment of the palmar plate and transection of the collateral ligaments are mandatory to obtain full extension in the PIP joint.
- Denervation of the PIP joint may be obtained through the same approach.
- A periosteal pedicle flap with fat paddle may increase tendon gliding, preventing early adherences.
- Immediate postoperative physical therapy is mandatory to preserve ROM.

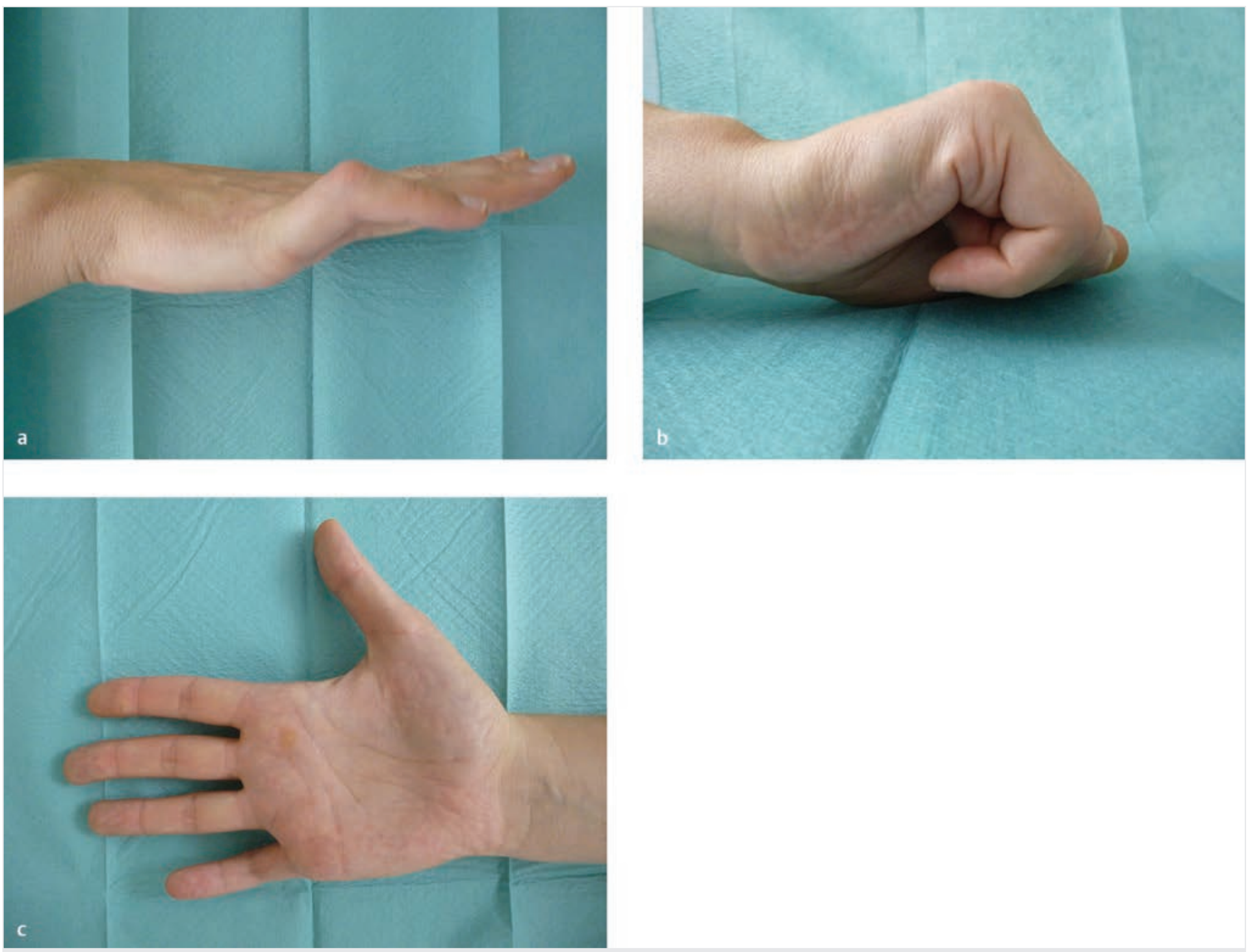

Fig. 36.7 (a–c) Results after 2-year follow-up.

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37 Angulation in Nonarticular Phalanx Fractures

Berthold Bickert

37.1 Patient History Leading to the Specific Problem

A 19-year-old man presented with an angular deviation of his left index finger toward the long finger. In early childhood, at the age of 2 years, he had suffered an injury to his left hand when it was caught in the V-belt drive of a sawmill on his parents' farm. His left thumb was completely destroyed and had to be amputated. It could be reconstructed 3 years later by a free microvascular great toe transplantation. The proximal phalanx of the left index finger had suffered an open phalangeal neck fracture and was treated by K-wire fixation.

37.2 Anatomic Description of the Patient's Current Status

The left thumb-toe shows an almost normal appearance with full sensitivity and function. The index finger has an angulation of 15 degrees, near the proximal interphalangeal (PIP) joint, toward the ulnar side, impeding the function of the long finger (▶Fig. 37.1). Additionally, there is a significant lack of extension in the index PIP joint, with active and passive motion being limited to 0 to 40 to 65 degrees (extension–flexion).

37.3 Recommended Solution to the Problem

In complex hand injuries, it may be difficult for the hand surgeon to shift his focus of interest from the major problem (thumb amputation) to the minor one (open phalangeal neck fracture or the index finger). Yet, early correction of what is possible may improve late function.

Actual treatment should first address the impairment of the long finger by the deviated index finger and then the function of the index finger itself. The index finger can be improved either by an attempt of flexor and extensor tenoarthrolyses (17 years after injury) or by corrective PIP joint arthrodesis.

As the patient has got used to the limited—and appreciates the remaining—PIP joint motion of the index finger, he only wants the long finger to be freed from the impairment by the index finger. So a corrective osteotomy at the neck of the proximal phalanx of the index finger has been consented.

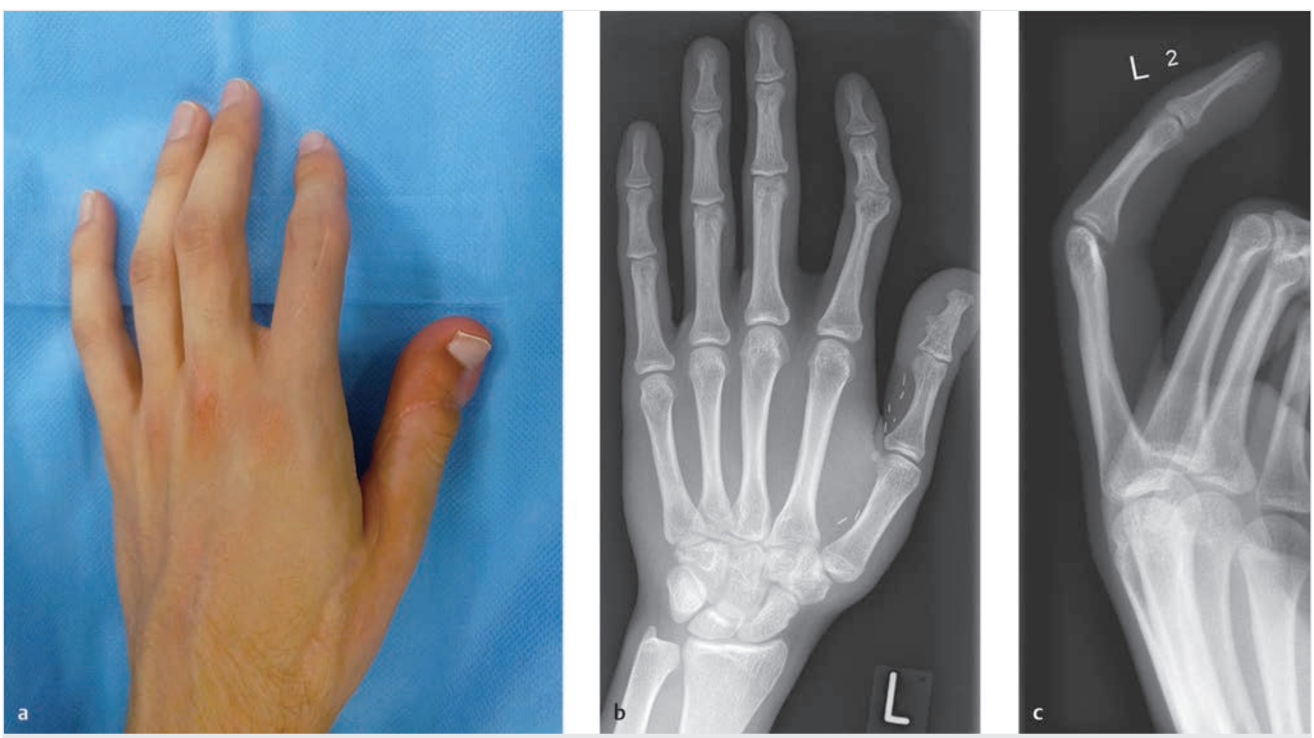

Fig. 37.1 **(a)** Lateral angulation of the left index finger in a 19-year-old young man after a V-belt injury and K-wire osteosynthesis at the age of 2 years. (Also note the thumb that had been reconstructed by microvascular great toe-to-thumb transplantation at the age of 5 years.) X-rays show the lateral angulation at the fracture site at the phalangeal neck of the index finger in **(b)** posteroanterior and **(c)** lateral views.

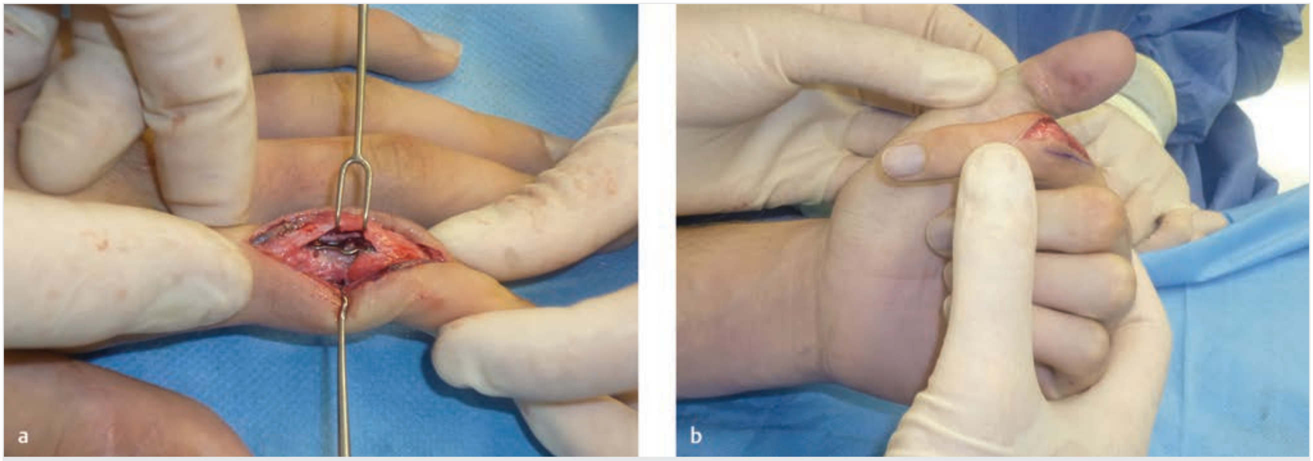

Fig. 37.2 (a) Intraoperative view of the alignment of the osteotomy site and the locking plate stabilization. (b) Check for correct axial and rotational alignment.

37.3.1 Recommended Solution to the Problem

- In complex hand injuries, do not forget the minor injuries.
- Corrective osteotomy may further restrict active joint motion.
- Be aware of the patient's needs and wishes.
- Plan the osteotomy as subtractive or additive osteotomy at the site of deviation.
- Stabilization is best achieved by 1.5-mm locking plate osteosynthesis.

37.4 Technique

From a dorsal approach, the extensor hood is mobilized and incised. A distal subtractive wedge osteotomy of the proximal phalanx is done and stabilized with a 1.5-mm locking T-plate (▶Fig. 37.2a). The correct alignment of the axis and, in palmar flexion of all fingers, the rotation are thoroughly checked (▶Fig. 37.2b). Finally, the extensor apparatus is repaired with a longitudinal absorbable running suture.

Fig. 37.3 X-rays taken 6 days postoperative.

37.5 Postoperative Photographs and Critical Evaluation of Results

The osteotomy healed uneventfully (▶Fig. 37.3), and the PIP joint motion has remained unchanged. So far, the patient has not requested an attempt to functionally improve the index finger by plate removal and extensor tendon tenolysis.

37.6 Teaching Points

- In pediatric fractures, there is a good tendency for remodeling in the direction of finger flexion or extension (i.e., in the sagittal plane).
- In pediatric fractures, do not accept any mediolateral angulation (i.e., angulation in the coronal plane).
- Correction of a healed, but malaligned fracture can be gained by closing wedge or by opening wedge osteotomy. The osteotomy should be performed at the former fracture site.
- Stabilization of the osteotomy can be achieved by the use of K-wires or of a small joint locking plate, both having their specific advantages and disadvantages.
- At operation of finger fractures, the surgeon should not look at only the fluoroscopic image.
- Also check the clinical appearance to ensure a correct axial and rotational alignment of the finger during passive flexion and extension.

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Part XIII

Problems with Articular Phalanx Fractures

38 Angulation in Articular Phalanx Fractures *168*

39 Posttraumatic Bone Loss in Articular Phalanx Fractures *172*

40 Fracture after Prior Kirschner's Wire Fixation *174*

41 Contractures in Articular Phalanx Fractures *178*

XIII

38 Angulation in Articular Phalanx Fractures

Marco Rizzo and Maureen A. O'Shaughnessy

38.1 Patient History Leading to the Specific Problem

A 14-year-old adolescent boy presented to our clinic 5 months after undergoing treatment at an outside facility for a right small finger proximal phalanx fracture with intra-articular extension (▶Fig. 38.1). He was treated with open reduction and pin fixation. He initially did well; however, upon returning to competitive baseball, he was hit by a ball and refractured his finger approximately 4 months after initial injury. Follow-up films showed poor position and he was referred to our clinic. At the time of examination, the patient has some pain at the proximal phalanx, but the primary complaint was stiffness. He finds it difficult to hold a baseball bat properly and notes decreased grip strength.

38.2 Anatomic Description of the Patient's Current Status

Inspection of the right small finger reveals radial deviation at the proximal interphalangeal (PIP) joint. The digit is swollen with mild tenderness of the proximal phalanx. There

Fig. 38.1 (a–d) Films at the time of presentation to clinic. Note the rotational deformity of the proximal phalanx with step-off at the joint line and loss of height of the radial condyle.

is a well-healed previous dorsal incision. Motion at the PIP joint is 30 to 55 degrees with an intact neurovascular examination.

38.3 Recommended Solution to the Problem

The patient presents with a postoperative intra-articular angulated proximal phalanx malunion. Articular malunions can result in pain, deformity, joint stiffness, and progressive degenerative joint disease as highlighted by this case.

Phalangeal extra-articular malunions of significant amount may lead to rotational deformity of the fingers, pain due to distortion of the joint, alteration of the musculotendinous balance, and/or reduction of grip strength. Intra-articular malunions may cause joint surface irregularities, synovitis, capsule laxity or stiffness, and ultimately arthritis.

Weighing the clinical significance of a malunion should take into account these factors. Of note, malunion of the thumb, middle, and distal phalanges of the fingers usually yields lesser problems than those located in the proximal phalanx. A young, active patient may require a different management strategy than an older or sedentary patient. Malunions requiring surgical correction are usually infrequent in any one surgeon's practice; therefore, management and technical preferences often rely on the individual surgeon's judgment.

Options for surgical correction include an extra-articular versus intra-articular osteotomy. Extra-articular osteotomy can correct the alignment, but lacks the ability to address articular incongruity. Intra-articular osteotomy can yield powerful correction of articular deformity; however, it can be a complex procedure with increased risk for stiffness or arthritis.

Timing of osteotomy varies. For extra-articular fractures, an osteotomy through the fracture plane should be addressed at weeks 6 to 8 from injury. Once the patient has passed the 8-week mark, osteotomy outside of the fracture plane should be considered. Articular osteotomies made through the plane of fracture should be done as soon as possible and ideally sooner than 6 months. Articular osteotomy outside of the fracture plane is difficult and not typically recommended.

Various osteotomies to correct articular malunion have been described. A few notable descriptions include extra-articular osteotomy by Pieron, Froimson, and Harness et al, and intra-articular correction as described by Light and Teoh et al.

This patient was treated with intra-articular sliding advancement osteotomy technique, a modification of the technique described by Teoh et al. Stabilization was achieved with the use of allograft bone and Kirschner's wires (K-wires) for fixation.

38.4 Technique

Regional block can be considered. The patient is placed supine and the operative extremity prepped in the usual fashion. Tourniquet is elevated to improve visualization. In this case, previous dorsal longitudinal incision was used over the PIP joint. Thick soft-tissue flaps are raised. The extensor mechanism is visualized. An extensor tendon–splitting technique can be used with a longitudinal split in the midline. Subperiosteal dissection is taken to the distal proximal phalanx and proximal middle phalanx for visualization of the joint line and the malunion (▶Fig. 38.2a). Any nonunion evident should be debrided gently using rongeur and curette (▶Fig. 38.2b). Consider sending a sample of the nonunion for culture to rule out occult infection as a source of non- or malunion.

The articular segment is gently mobilized (▶Fig. 38.3a). If fracture has healed, a small osteotomy is made proximally to slide the malreduced articular segment distally. Tricks include using a 0.035-inch K-wire in the fragment as a joystick, as well as a piercing reduction clamp to reduce the articular segment anatomically. Another trick is to look down the joint line in the "shotgun" approach to visualize the overall articular reduction. The reduction is held with multiple K-wires to ensure appropriate stability (▶Fig. 38.3b). Alternatively, small screws could be considered as described by Teoh et al.

Allograft bone is used to backfill the void and provide additional support for the articular reduction. Check the final fixation construct with direct visualization and fluoroscopy (▶Fig. 38.4). K-wires can be cut under the skin to allow for potential removal at a later date. The extensor mechanism is closed using nonabsorbable suture and skin is closed in an

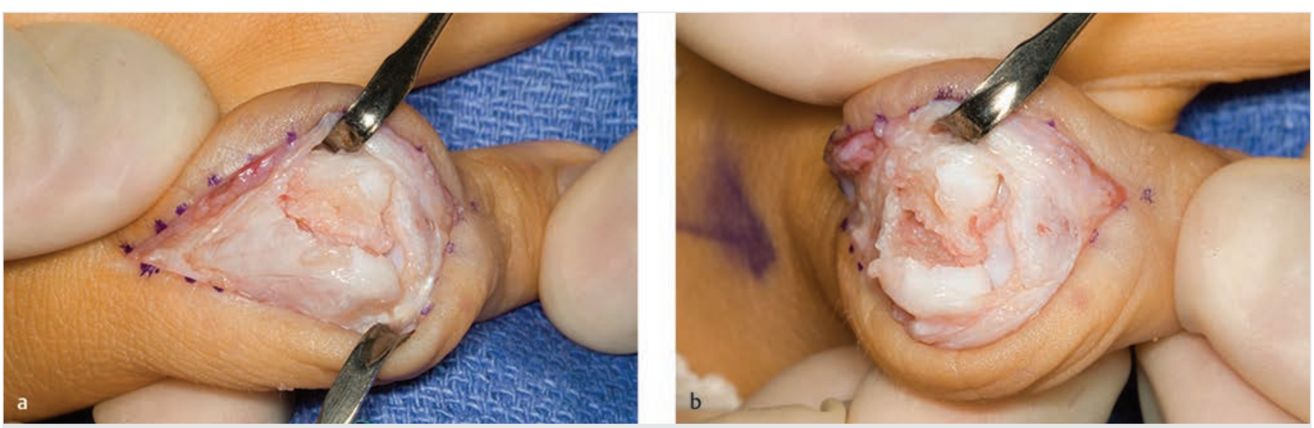

Fig. 38.2 (a, b) After the extensor tendon splitting approach, the malunion is visualized and gently debrided.

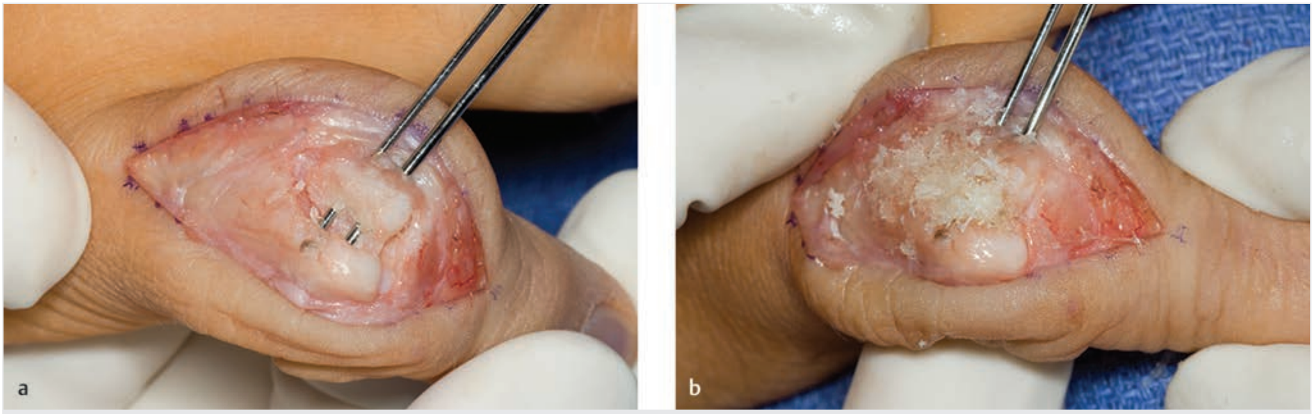

Fig. 38.3 Case presenting angulation. **(a)** Using sliding osteotomy, the malreduced articular segment is brought out to length for anatomic intra-articular reduction. This is held in place with two 0.045-inch K-wires. **(b)** Bone graft is used to fill void from osteotomy to help support fracture reduction.

Fig. 38.4 Final fluoroscopy image shows articular reduction.

interrupted fashion. The patient is immobilized for 4 to 6 weeks to allow osteotomy healing and then early motion is begun.

38.4.1 Steps for the Procedure

1. Expose malunion with meticulous subperiosteal dissection at the joint line.
2. If any suspicion, rule out acute inflammation by sending nonunion material for pathologic analysis and/or culture.
3. Gently mobilize malreduced segment using a 0.035-inch K-wire as joystick.
4. If fracture healed, make proximal sliding osteotomy using a small osteotome.
5. Take care to ensure anatomic reduction of the articular segment.
6. Consider bone graft to backfill void and support reduction.
7. Fixation construct should be secure to avoid collapse or fixation failure; consider multiple 0.045-inch K-wires versus small screws.

38.5 Postoperative Photographs and Critical Evaluation of Results

Postoperative follow-up films show healed fracture and improved articular alignment (▶Fig. 38.5). Although not full, the patient's range of motion increased to 20 to 75 degrees (pre-op 30–55 degrees). The patient was sent to a certified hand therapist after 4 weeks of immobilization to begin working on motion. The patient healed well and returned to competitive baseball without difficulty.

This patient's result is in keeping with similar recent reports. Teoh et al's series found final average total digit range of motion of 155 degrees, with two patients having residual PIP extension lags of 10 and 20 degrees. There were no fixation failures or postoperative infections. Büchler et al evaluated a series of 57 corrective osteotomies for posttraumatic malunions and noted improved motion in 89% of patients and healing in all, although only 76% achieved a satisfactory correction. Harness et al report on a series of five patients treated with extra-articular osteotomy for condylar malunion. Their outcomes include healing in all patients with average

Fig. 38.5 (a, b) Six-month follow-up anteroposterior and lateral radiographs show healed osteotomy and improved articular alignment. Final pin was removed after the radiograph was obtained.

correction from 25-degree angulation pre-op to 1-degree angulation post-op. Average arc of motion improved from 40 to 86 degrees postoperatively.

Overall, osteotomies have the power to correct articular malunions, although motion gains may be modest, particularly in the PIP joint. Patients should be counseled on the risks associated with surgery, including infection, nonunion, stiffness, and potential for pain syndrome after surgery. The benefits include improved articular congruity and phalangeal height to potentially avoid the pitfalls of deformity, reduced motion, stiffness, and progressive joint deformity. Individual patient factors such as age, medical comorbidities, physical demands, and personal preference should be considered. Ultimately, decision regarding malunion management should be made jointly between patient and surgeon for optimal outcomes and satisfaction.

38.6 Teaching Points

- Consider intra- or extra-articular osteotomy to correct intra-articular malunion to avoid pain, stiffness, deformity, and progressive joint degeneration.
- Appropriate preoperative imaging should be obtained to plan osteotomy and determine optimal fixation construct and final alignment.
- Utilize prior incisions if necessary. Adequate visualization is imperative for anatomic articular reduction.
- Gently debride mal-/nonunion. Consider sending specimen to pathology to rule out acute inflammation and/or sending multiple cultures.
- Use proximally based slide osteotomy to reduce depressed fracture segment.
- After osteotomy, take the finger through range of motion of all joints to ensure no impingement prior to final fixation.
- Secure with pins or screws. Liberal use of bone graft to support construct is advised.
- Check cascade of digits after fixation to ensure appropriate final alignment.
- Immobilize appropriate amount of time to ensure healing, then early referral to hand therapist to reduce stiffness inherent to PIP injuries.

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39 Posttraumatic Bone Loss in Articular Phalanx Fractures

Carlos Henrique Fernandes and Jorge Raduan Neto

39.1 Patient History Leading to the Specific Problem

A 46-year-old man presented 1 week after sustaining an open injury to the right thumb. He had injured the thumb while using a saw to cut a flagstone. He had received emergency care in a community hospital, where intravenous antibiotics had been promptly administered, and debridement and irrigation had been performed in the operating room. The wound had been sutured and the thumb was splinted. The patient was then referred to our hospital.

39.2 Anatomic Description of the Patient's Current Status

The wound margins appear to be healed and closed. There are no signs of infection. The thumb tip is warm and well perfused. Normal sensation was noted. The digit was very unstable because of the fracture. Tendon function was poor.

Initial radiographs reveal a fracture of the proximal phalanx of the thumb with segmental bone and articular surface loss, leaving the proximal half of the proximal phalanx (▶Fig. 39.1).

39.3 Recommended Solution to the Problem

One should first realize that this problem could have been treated by immediate internal or external fixation at the initial time of injury. However, large segmental bone defects in a viable digit may require structural bone grafting. The use of a free vascularized bone graft requires microsurgical expertise, which may not be readily available. A nonvascularized structural bone graft within the same extremity as the injury has the advantage of only involving a single surgical field, allowing the use of regional anesthesia. Nonvascularized bone graft from the iliac crest has been used successfully for structural purposes in the phalanges.

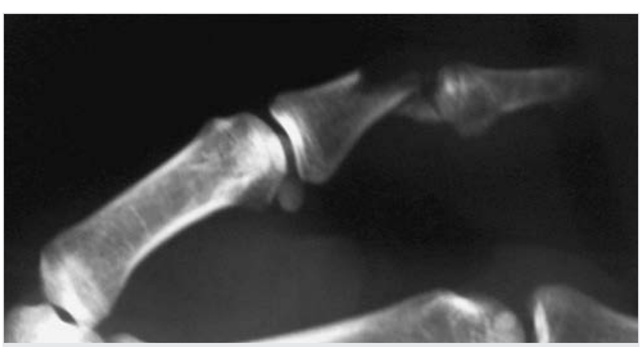

Fig. 39.1 Radiograph taken at first presentation showing the bone loss.

Arthrodesis of the distal interphalangeal joint and thumb interphalangeal joint is an effective surgical procedure for restoring hand function and joint stability. Arthrodesis can be done using cannulated headless screws; these have the theoretical benefit of being completely intraosseous, thus avoiding hardware prominence while providing interfragmentary compression. As the distal phalanx of the thumb is larger than that of the other digits, we can use larger diameter implants for bone fusion in the thumb.

39.4 Technique

The patient is placed in the supine position, using a hand table. A dorsal longitudinal incision is made directly over the thumb. After exposing the base of the distal phalanx, the cartilage is curetted out, exposing the subchondral bone. A small K-wire is advanced in an antegrade fashion through the flexed distal phalanx, exiting through the tip of the finger in the midline. This wire is then advanced until the tip is just proximal to the surface of the distal phalanx. A nonvascularized rectangular corticocancellous anterior iliac crest bone graft is aligned with the distal phalanx, and the wire is advanced proximally into the bone graft. A cannulated headless screw of appropriate length is inserted to approximately half the length of the bone graft, taking care to maintain reduction of the fusion site. The proximal portion of the bone graft is aligned with the fragment of proximal phalanx. A small K-wire is then advanced in an antegrade fashion through the dorsal phalanx base until it reaches the bone graft. A second cannulated headless screw is inserted distally (▶Fig. 39.2).

Final fluoroscopic images are then taken, before wounds are closed with 5–0 nylon sutures. Bandages and a splint are then placed.

39.5 Postoperative Photographs and Critical Evaluation of Results

Sutures are removed at 10 days postoperatively. Hand therapy is not typically necessary. The patient is monitored until bony union occurs (▶Fig. 39.3). Thumb grip is restored and the patient returns to his professional activities (▶Fig. 39.4).

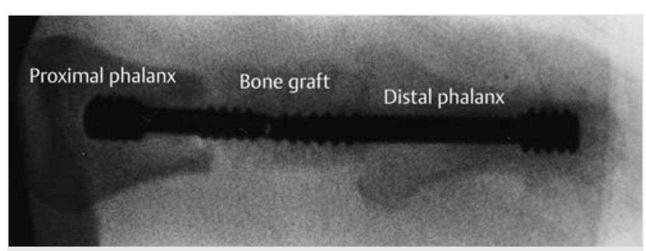

Fig. 39.2 Fluoroscopic image taken after fixation of the bone graft.

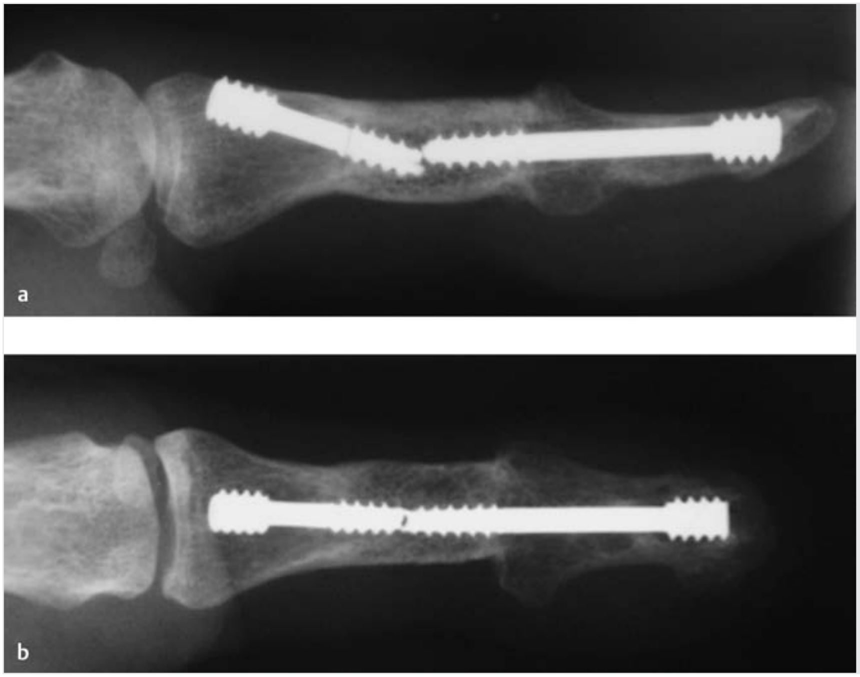

Fig. 39.3 **(a, b)** Radiograph showing bony union between the graft and the phalanx.

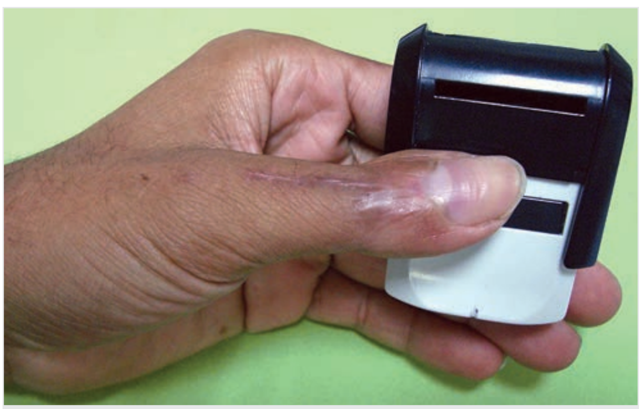

Fig. 39.4 The patient performing the precision grip.

39.6 Teaching Points

- Trauma resulting in severe comminution, bone loss, and articular involvement of the fingers is a challenging injury.
- Effective wound debridement with skeletal stabilization and bone grafting and early wound closure or coverage provide the most favorable circumstances for healing and functional recovery of the seriously damaged hand and wrist.
- Finger arthrodesis can be performed via intraosseous cerclage wires, K-wires, tension band wiring, cannulated headless screw, and plates.
- The delayed primary bone grafting promote primary bone healing, a shorter rehabilitation period, fewer operations, avoidance of wound contracture, and bone grafting in a well-vascularized scar-free bed.

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40 Fracture after Prior Kirschner's Wire Fixation

Carlos Henrique Fernandes and Rodrigo Guerra Sabongi

40.1 Patient History Leading to the Specific Problem

A 26-year-old man sustained a closed fracture of the third and fourth metacarpals due to a motorcycle accident (▶Fig. 40.1). The fourth metacarpal transverse shaft fracture was treated by intramedullary fixation with two 0.045-inch Kirschner's wires (K-wires), while the third metacarpal articular base fracture was treated by intermetacarpal fixation with two 0.062-inch K-wires directed from the second to the third metacarpal (▶Fig. 40.2).

The K-wires and protective splint were maintained for 6 weeks. Ten weeks after the injury, the patient reported an acute onset of pain while holding a cutting board of approximately 4.5 lb with key pinch.

40.2 Anatomic Description of the Patient's Current Status

Static inspection of the right hand demonstrated moderate edema. Surgical wounds from the previous surgery were healed. He was able to actively move his fingers with restriction of range of motion (ROM) of all metacarpophalangeal (MCP) joints, related to prior immobilization period. A visible deformity was evident with and apex dorsal angulation and radial rotation of the index finger with flexion (▶Fig. 40.3).

Radiographic images revealed a transverse fracture on the diaphysis of the second metacarpal (▶Fig. 40.4). The fracture was related with K-wire track. There were angulations of 20 degrees in the coronal plane and 5 degrees in the sagittal plane. There was evidence of consolidation of the previous third and fourth metacarpal fractures.

Fig. 40.1 Radiographs from the fracture of the third and fourth metacarpals.

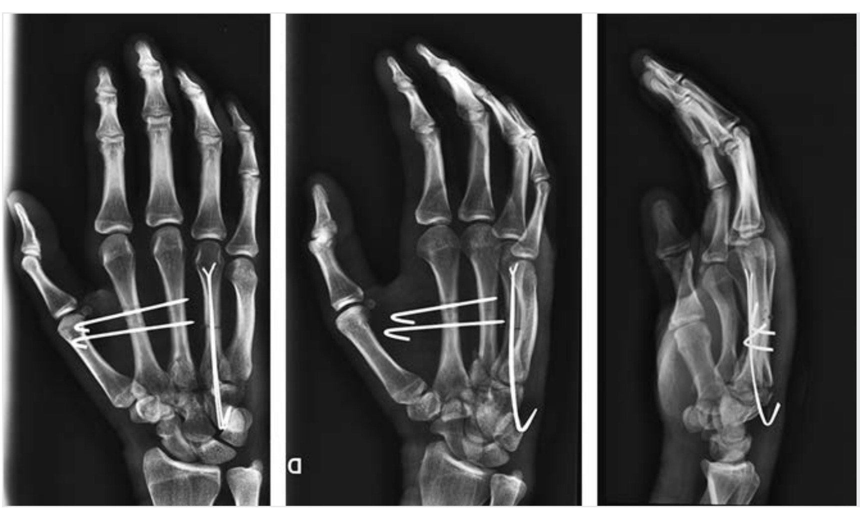

Fig. 40.2 Postoperative radiographic follow-up of the fixation of the third and fourth metacarpals with K-wires.

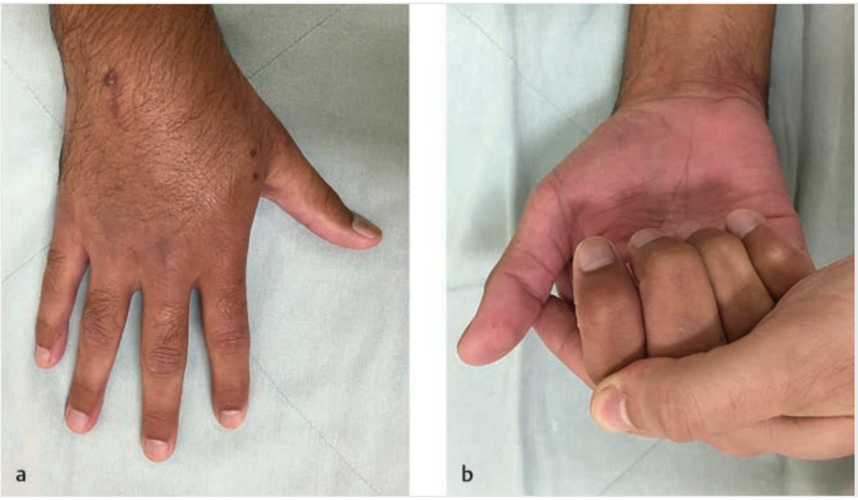

Fig. 40.3 **(a, b)** Clinical appearance of the right hand with moderate swelling and rotational deformity.

Fig. 40.4 Fracture through the second metacarpal related to prior K-wire fixation.

40.3 Recommended Solution to the Problem

More common complications following metacarpal fractures may be associated, such as stiffness and pin track infection. To avoid stiffness, the fracture should be addressed with a plan of early ROM. Fracture fixation with plates and screws may provide immediate stability while granting anatomic reduction. An open reduction and internal fixation may potentially cause soft-tissue damage. This is a shortcoming of this approach. Nonetheless, the benefits from a stable construct may outweigh this disadvantage. Care must be taken with plate positioning in order to avoid potential complications, such as tenosynovitis, scar formation, tendon adhesions, and tendon ruptures. Meticulous dissection and minimal stripping of periosteum are critical to prevent delayed union or nonunion.

40.3.1 Recommended Solution to the Problem

- Take into account associated complications (stiffness or infection).
- Early ROM to avoid longer immobilization time.
- Larger implants and rigid construct for intensive hand therapy.
- Plates and screws may provide immediate stability.

40.4 Technique

After consent for the procedure, the patient was taken to the operative room and placed in the supine position with the right upper limb in a radiolucent table. A dorsal longitudinal incision over the second metacarpal was performed. Dissection was carried out with attention to retract the sensory nerve branches and the dorsal venous system. The extensor tendons were retracted ulnarly.

Anatomic reduction was accomplished with the aid of bone clamps. Fluoroscopic confirmation of the alignment was performed, as well as clinical evaluation of rotation. A two-row titanium 2.0-mm plate was used for the fixation. The plate was positioned on the dorsal aspect of the metacarpal shaft, in such a way that at least three screws could be placed in each fragment. Four screws were placed proximally and three distally, and the index finger was taken through full ROM while the fracture was observed. No movement of

Fig. 40.5 Radiographic follow-up from the second metacarpal fixation with plate and screws.

the plate or the fracture site was detected. The closure was conducted with monofilament sutures. A bulky dressing was applied and the hand was placed in a forearm-based plaster splint.

40.5 Postoperative Photographs and Critical Evaluation of Results

Optimal pain management was obtained with simple analgesics. The patient was evaluated a week after the procedure; at the time control radiographs were obtained (▶Fig. 40.5), the immobilization was removed and protected ROM exercises begun. He was instructed to wear a resting orthosis and warned not to use his injured hand even for minor activities. Hand therapy continued for 2 months where the patient sustained painless full ROM. He returned to his activities with no limitations and without complaints at the surgical site.

K-wires are largely used for several hand injuries, being responsible for bone fracture fixation or stabilization in soft-tissue repairs and reconstructions. They are inexpensive multipurpose implants that have a relatively easy application with minimal damage to surrounding soft tissue. One main drawback of this type of fixation is related to its lack of stability, which may require a period of postoperative immobilization. In an effort to increase stability, multiple pins, thicker-diameter wires, and numerous geometric configurations can be adopted.

Although largely applied for several hand injuries, K-wires may be associated with up to 14% of complications. The majority are related to several degrees of infection or minor complications, such as wound redness, drainage, delayed healing, skin overgrowth, pin loosening, and migration. Fracture through the pin tract is an uncommon complication associated with smooth K-wire fixation in the hand. It can be related with implant thickness, relation to other wires, and a number of perforation attempts. Careful preoperative planning can minimize the risk of weakening on fixation sites. The K-wire path can be marked on the skin after fluoroscopy guidance during the procedure and the number of passes and attempts close to each other must be avoided. Furthermore, the patient should be warned that after pin removal the bone may be fragile and strenuous activity with the injured hand must be avoided for several weeks.

40.6 Teaching Points

- Metacarpal fractures are common and result in significant economic impact.
- Proper treatment must be guided in context with age, activity level, occupation, and soft-tissue status.
- Associated complications may be present, such as stiffness, infection, delayed wound healing, malunion, and nonunion.
- Careful preoperative planning of the osteosynthesis and type of implant, followed by meticulous surgical technique is fundamental to avoid complications.
- K-wires are the workhorse of hand fractures but are not exempt from complications.
- Plate and screw fixation may provide rigid fixation when the clinical picture demands early ROM.
- Hand therapy and good patient communication are essential to produce successful clinical outcomes.

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41 Contractures in Articular Phalanx Fractures

Christian K. Spies and Frank Unglaub

41.1 Patient History Leading to the Specific Problem

An 81-year-old man presents with stiffness of the proximal interphalangeal (PIP) joint of the left small finger after open reduction and internal fixation of a transcondylar intra-articular fracture of the head of the proximal phalanx using K-wires and a dorsal locking plate. The patient had injured his small finger as he tried to avoid a fall 12 weeks ago. The finger was immobilized for 2 weeks after surgery. Then active mobilization was encouraged while buddy-tape bandage with the neighboring finger was applied. At the time of referral, the PIP joint was completely stiff and the patient complained of irritation caused by the osteosynthesis. Plain radiographs verified osseous consolidation 11 weeks after reduction (▶Fig. 41.1).

41.2 Anatomic Description of the Patient's Current Status

The small finger was slightly swollen (▶Fig. 41.2). Scar tissue at the dorsal aspect of the proximal phalanx and PIP joint was consolidated but firmly adhered to the underlying tissue. The K-wires were palpable percutaneously at the ulnar aspect of the PIP joint. The PIP joint was completely stiff (▶Video 41.1). The distal interphalangeal (DIP) and metacarpophalangeal (MCP) joints were not restricted passively. Active flexion and extension of the MCP joint was possible, whereas active mobilization of the DIP joint was not. The extensor plus test for zone 6 tendon adhesion did not reveal pathological findings. This examination evaluates zones 5 and 6, while unrestricted flexion of the MCP joint is feasible with PIP joint flexion regardless of wrist position physiologically. Pathologically,

Fig. 41.1 (a, b) This patient presented with stiffness of the proximal interphalangeal joint of the left small finger after fracture repair with K-wires and dorsal locking plate.

Fig. 41.2 Stiff proximal interphalangeal (PIP) joint of the small finger.

the MCP joint flexion entails extension of the PIP joint or vice versa. Whereas pulp-to-pillar and tiger claw tests were positive for tendon adhesions at the proximal phalanx, the former test examines zones 4 to 6 and is physiological whenever the proximal palm can be reached by the fingers flexed in the MCP and PIP joints while the DIP joints are extended. The latter examination evaluates zones 1 to 3 and is physiological whenever flexion in the PIP and DIP joints of the same finger are possible.

41.3 Recommended Solution to the Problem

After a thorough clinical examination, we concluded that the PIP joint contracture is caused by extensor tendon adhesions at zones 3 to 5. It ought to be pointed out that “invasive” osteosynthesis is to be prevented in the first place whenever possible. Based on the anatomic region, dorsal placement of plates will eventually promote tendon adhesion and consecutively joint stiffness. Surgical treatment of contractures demands a stepwise approach with evaluation of joint motion after each operative maneuver in order to prevent destabilization.

As a prerequisite, tissue should be consolidated and conservative therapy should have reached a plateau.

41.3.1 Recommended Solution to the Problem

- Removal of the osteosynthesis.
- Tenolysis of the extensor tendon.
- Arthrolysis of the PIP joint.

41.4 Technique

Facilitating the former incision, sharp dissection and identification of the extensor tendon was performed (▶Fig. 41.3a, b). Longitudinal incision of the central slip revealed the underlying plate (▶Fig. 41.3c). The extensor tendon was released from the underlying hardware using a scalpel. After screw loosening, the plate was removed and debridement of the phalanx was performed (▶Fig. 41.3d–f). Adhesions of the extensor tendon were identified in zones 3 to 5. Before tenolysis was done using an elevator, the remaining K-wires were removed through a separate skin incision. After extensor tenolysis, the PIP joint motion was assessed. Gained range of motion was 20 degrees. The transverse retinacular ligaments were dissected in order to mobilize the extensor apparatus (▶Fig. 41.3g). Then a dorsal capsulotomy allowed arthrolysis of the PIP joint. The dorsal capsule was incised transversely and the elevator was introduced into the joint (▶Fig. 41.3h). It was crucial to release the palmar plate and palmar pouch since adhesions limited joint motion significantly (▶Fig. 41.3i). After closure of the central slip, the PIP joint was released successfully with joint motion from 10 to 100 degrees (▶Fig. 41.3j, ▶Video 41.2).

41.5 Postoperative Photographs and Critical Evaluation of Results

The gained intraoperative motion from 10 to 100 degrees was excellent. It is imperative to instruct the patient to start physical therapy immediately. Patient education is crucial. We recommend intensive physical therapy immediately after surgery while sufficient analgesia is guaranteed (▶Fig. 41.4).

41.6 Teaching Points

- Precise clinical examination in order to identify the pathology.
- Stepwise surgical approach using loupe magnification.
- Sufficient identification of all anatomic structures beginning at the site of normal tissue planes.
- Sharp dissection and preparation of the extensor apparatus using scalpel and elevator.
- After each surgical step, examination of tendon gliding and joint motion is imperative.
- Immediate postoperative physical therapy is recommended, and sufficient analgesia ought to be provided.
- Edema containment is of utmost importance.
- Strict exercises may last for 6 months in order to maintain joint motion.

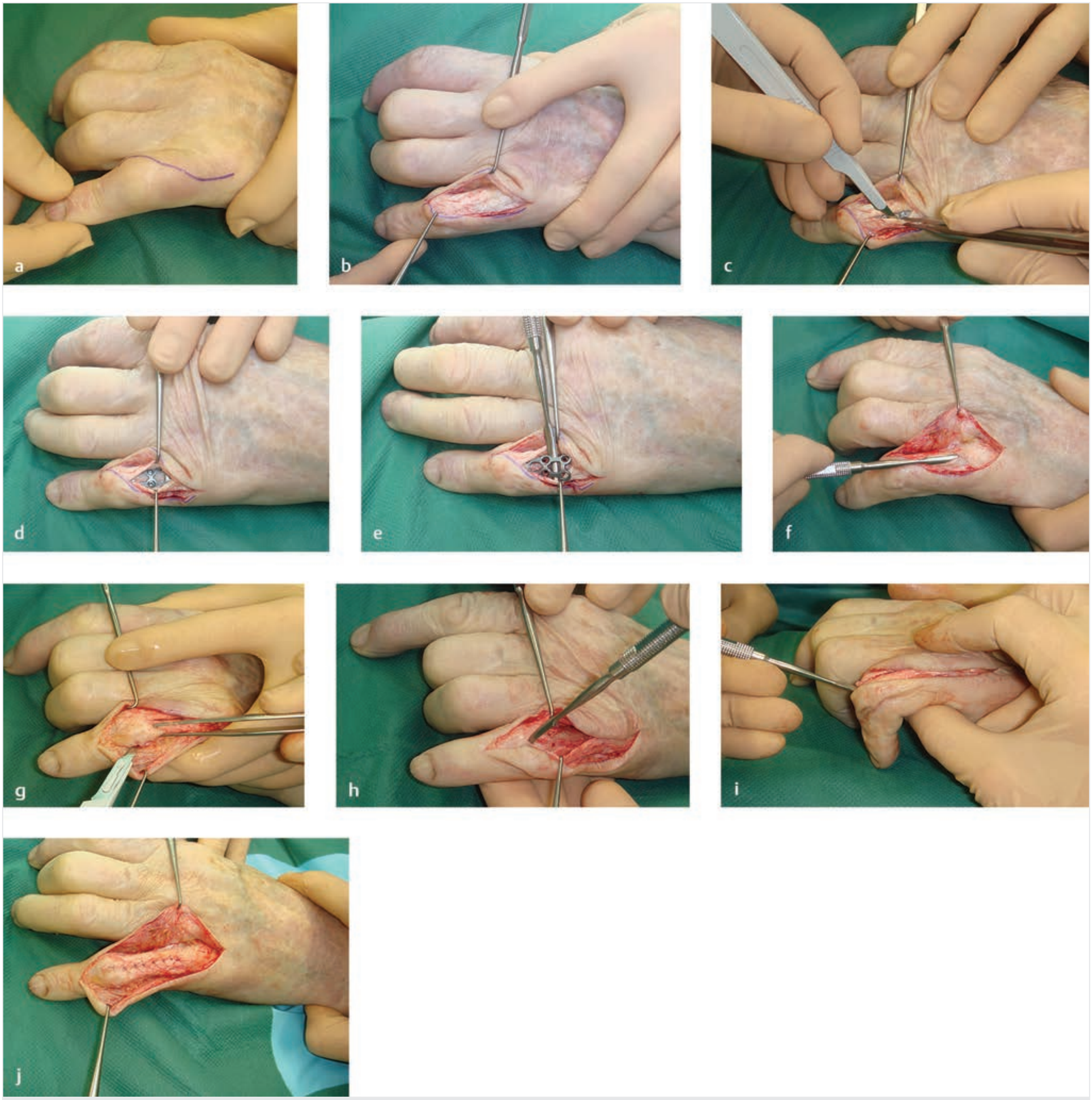

Fig. 41.3 (a–c) Sharp dissection and identification of the extensor tendon was performed. **(d)** Reveal of the underlying plate. **(e)** Removal of the plate using a dissector. **(f)** Tenolysis in zone 4 using a dissector. **(g)** Transverse retinacular ligament was dissected. **(h, i)** Dorsal capsule being incised transversely and introduction of the elevator into the proximal interphalangeal (PIP) joint. **(j)** Situs after closure of the central slip.

Fig. 41.4 Result 6 months postoperative, with extension deficit of 10 degrees.

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Part XIV

Problems with Metacarpal Fractures

42 Nonunion in Metacarpal Fractures *184*

43 Malunion in Metacarpal Fractures *190*

44 Angulation in Metacarpal Fractures *194*

XIV

42 Nonunion in Metacarpal Fractures

Carsten Surke and Esther Vögelin

42.1 Patient History Leading to the Specific Problem

A 28-year-old patient suffered an avulsion amputation of the third ray when catching his left hand in a dough mixer. The patient was a heavy smoker. At admission to the emergency department, he showed a complete avulsion of soft tissue of the middle finger. Initial treatment was carried out by primary mid-shaft metacarpal ray resection of the third ray and transposition of the second ray onto the third metacarpal. Stabilization was performed via a 2.0-mm nonlocking plate osteosynthesis (▶Fig. 42.1a) using three screws distally and two screws

Fig. 42.1 X-rays of a patient suffering an avulsion amputation of the third ray after **(a)** initial treatment by resection of the third ray and transposition of the second ray. **(b)** Failure to heal resulted in a nonunion and **(c)** a reosteosynthesis was performed using a stronger 2.7-mm plate. **(d)** No bone healing could be achieved and a reosteosynthesis using a 2.4-mm plate with interposition of autologous cancellous bone graft from the iliac crest was performed.

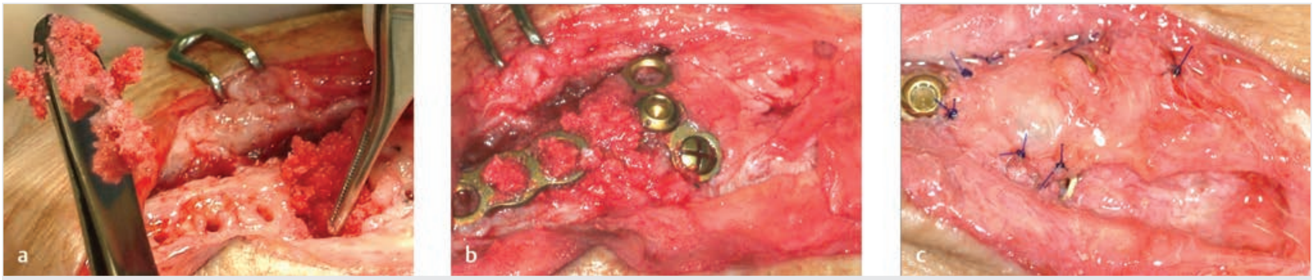

Fig. 42.2 Case presenting nonunion in metacarpal fractures. Intraoperative photographs 19 months after initial treatment. After resection of the nonunion, **(a)** a combination of Osigraft (rhBMP-7) and Vitoss (Beta TriCalciumPhosphate-Matrix) was applied and **(b)** the nonunion again stabilized with a 2.4-mm plate. **(c)** The area of the defect was then covered with a local periosteal transposition flap.

Fig. 42.3 Case presenting nonunion in metacarpal fractures. For additional stability, an external fixator was applied as shown on postoperative X-rays.

proximally to the osteotomy site. The patient developed a painful hypertrophic nonunion (▶Fig. 42.1b) and a reosteosynthesis had to be performed using a four-hole 2.7-mm stainless steel plate 6 months after primary treatment (▶Fig. 42.1c). Another half year later, the patient presented again with a persistent hypertrophic nonunion in the proximal third of his third metacarpal, rendering motion painful. Again, the pseudarthrosis was resected and a reosteosynthesis was performed using an eight-hole 2.4-mm titanium T-plate and filling the defect with an autologous bicortical corticocancellous bone graft from his left iliac crest (▶Fig. 42.1d) 7 months later.

In due course, the bone failed again to heal. In order to induce bone healing after careful resection of the nonunion, a combined application of Osigraft (rhBMP-7) and Vitoss (Beta TriCalciumPhosphate-Matrix) as well as a local viable periosteal transposition flap covering the area of the defect as well as the plate was used (▶Fig. 42.2). Osteosynthesis was performed with an eight-hole 2.4-mm titanium locking plate. In addition, an external fixator, bridging the third carpometacarpal (CMC III) joint and the nonunion was applied for optimal stability for 5 months (▶Fig. 42.3). ▶Table 42.1 summarizes the patient's surgical history prior to definitive treatment.

Table 42.1 Summary of the surgical history

Number of treatments		Time course after last surgery	Problem
1	Osteosynthesis of transposed MC II on MC III, 5-hole 2.0 mm non-locking plate		
2	Re-osteosynthesis with 4-hole 2.7 mm non-locking plate	+ 6 months	Painful hypertrophic nonunion
3	Re-osteosynthesis with8-hole 2.4 mm T-plate + bone graft left iliac crest	+ 7 months	Painful hypertrophic nonunion
4	Osigraft (rhBMP-7) + Vitoss (ßtriCaPh Matrix), periosteal flap, re-osteosynthesis with 8-hole 2.4 mm titanium locking plate + external fixature for 5 months	+ 6 months	Hypotrophic nonunion

42.2 Anatomic Description of the Patient's Current Status

After his last operation (26 months after the accident and 7 months after the fourth attempted osteosynthesis), the patient was able to perform full flexion and extension of his fingers. In due course, an inadequate trauma caused a cracking noise in the hand according to the patient.

At admission, the patient presents with painful swelling of the proximal third metacarpal. Closing the fist and opening the fingers is impaired due to pain. Conventional radiography and CT scans reveal a persistent hypotrophic pseudarthrosis in the proximal third of the metacarpal and a failure of the titanium plate. The site of antecedent grafting is almost completely absorbed.

Fracture healing is known to be a complex process. Mutual interaction of cellular, molecular, environmental, and mechanical factors influences bone regeneration. Impairment of only one of these factors at any point of healing will have a negative impact on the consolidation of the fractured bone and may lead to development of a nonunion.

Nonunions of the metacarpals are extremely uncommon and are usually associated with open fractures, severe soft-tissue injury, or infection. Excessive development of heat when sawing the bone can lead to cell death of osteoblasts, increasing the risk of nonunion.

Nonunions can be subdivided into hypertrophic and hypotrophic pseudarthroses. In hypertrophic nonunions, healing usually is prevented by increased interfragmentary motion due to insufficient fixation or inadequate immobilization. In hypotrophic nonunions, impaired nutrition, for example, due to limited vascularization, prevents the bone from healing. In addition, smoking adversely influences bone healing by prolongation of healing in long bones and can increase of the rate of nonunions. In metacarpals, mostly hypotrophic nonunions are found.

An unrestricted hand function depends on sufficient stability of osseous structures as well as the integrity of surrounding tissue especially gliding structures. Due to initial soft-tissue damage, futile attempts of bridging the gap, and sometimes repeated surgical measures, nonunions almost always lead to severe impairment of hand function. Even after bony healing, a limited function of the hand can be expected.

42.3 Recommended Solution to the Problem

According to radiographic findings, the patient moved from a repetitive hypertrophic nonunion to a hypotrophic pseudarthrosis, leading to implant failure. In due course of treatment, the main focus moved from just improving stability by using a stronger type of osteosynthesis to additional improvement of nutrition and blood supply at the osteotomy site by introducing growth factors and a local vascularized periosteal flap. Eventually, these attempts failed to demonstrate bony union.

In order to achieve bone healing, a different approach has to be chosen. Healthy bone with independent blood supply has to be introduced to the site of the nonunion. This can be achieved by transplanting a free vascularized corticocancellous bone graft. These grafts can be harvested from the iliac crest or other sources such as the medial femoral condyle, fibula, scapula, or humerus. The inclusion of a skin flap additionally enables the monitoring of vascularization of the graft.

First, the site of nonunion has to be debrided without any compromise. Any macroscopically identifiable necrotic tissue has to be removed. Bony ends of the metacarpal have to be debrided until bleeding spots are seen. The size of the defect and the distance to the appropriate donor vessel have to be measured and accordingly an appropriate vascularized graft has to be chosen. When choosing a graft from the iliac crest, it has to be ensured that the donor site is unscathed. In this specific case, the contralateral right side is chosen, because previously a corticocancellous graft has been harvested from the left side in prior surgeries. A free microvascular osteocutaneous graft is planned to monitor the vascular supply.

42.3.1 Recommended Solution to the Problem

- Treatment shall focus on the underlying problem—vascularization and stability.
- Complete resection of the pseudarthrosis and replacement with a vascularized graft.
- Large defects or persistent nonunions can be bridged by a free vascularized bone graft taken from the iliac crest, fibula scapula, or humerus.
- In order to monitor vascularization, an osteocutaneous graft can be chosen.

42.4 Technique

The patient is taken to the operating theater and placed in a supine position with his left arm and hand placed on an arm table. Under general anesthesia, the left arm and the right iliac crest are prepared with sterilized solution and an upper arm tourniquet is applied.

42.4.1 Left Hand

The preexisting scar along the transposed index finger is incised, followed by exposure of the broken titanium plate (▶Fig. 42.4a,b). If the finger position is acceptable prior to surgery, its orientation should be held by temporarily transfixing the third to the fourth metacarpal using two 1.25-mm K-wires. The broken plate is then removed. Subsequently, the pseudarthrosis is resected taking care to remove all scar tissue (▶Fig. 42.4c).

The bony ends of the metacarpal are exposed followed by step-by-step resection with a burr and/or an oscillating saw with open tourniquet until cancellous bone and bleeding spots are identified, making sure scar tissue and sclerotic bone are resected completely. Care is to be taken to avoid excessive heat development by continuous cooling with water. The dimension of the resulting bony defect is measured. The incision is then extended radially and proximally toward the radial artery in the snuffbox. Care has to be taken not to damage branches of the superficial branch of the radial nerve. The dorsal branch of the radial artery and the cephalic vein are identified and marked with vessel loops.

42.4.2 Right Iliac Crest

An incision over the inguinal ligament reaching from the palpable femoral artery along the inguinal ligament toward the superior anterior iliac spine is carried out and advanced along the iliac crest retaining a skin flap according to the expected cutaneous defect on the left hand, advancing through the lower border of the internal abdominal muscle using the fiber-splitting technique. Subsequently severing the internal oblique and transverse abdominal muscles, the pedicle of the deep circumflex iliac artery is identified (▶Fig. 42.5a). The skin flap is incised medially and the pedicle developed along its craniolateral course. The iliac muscle is lifted off the ilium and the bone resection is planned. The most ventral site of the osteotomy should be about 3 cm dorsal of the superior anterior iliac spine, in order to prevent fracture of the iliac bone. Incision of the flap and preparation of

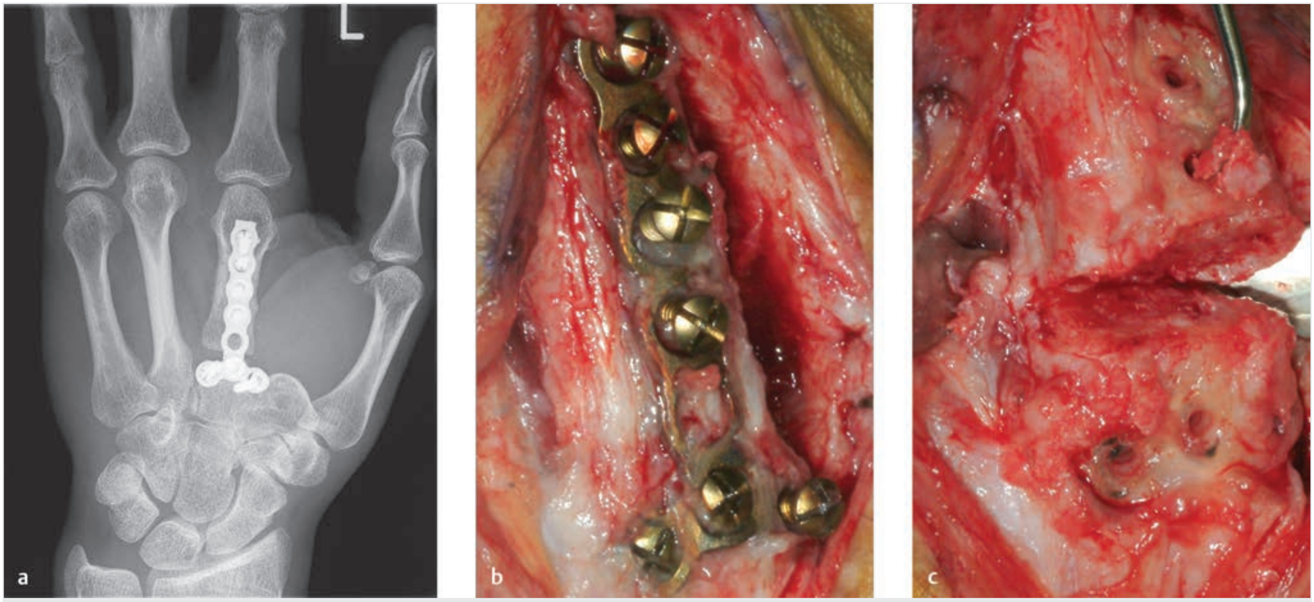

Fig. 42.4 Case presenting nonunion in metacarpal fractures. **(a)** X-ray and **(b)** intraoperative documentation of the persisting nonunion after implant failure. **(c)** Plate removal and complete resection of the nonunion is necessary.

the iliac bone from laterally, followed by osteotomy and harvest of the osteocutaneous flap (▶Fig. 42.5b). Care has to be taken of the cutaneous branch of the lateral femoral nerve.

42.4.3 Left Hand

The bone graft is trimmed to the appropriate size according to the bony defect in the metacarpal ray, taking care not to injure either the pedicle or the skin flap. When trimming the bone graft, the periosteum should be preserved. It is important to properly orientate the graft, so the corticocancellous bone of the graft will get in contact with the corticocancellous bone of the metacarpal. After fitting the graft into the defect, a 2.0-mm bridging plate is added at the radial border of the metacarpal and fixed distally to the transferred second and proximally to the remaining third metacarpal bone. Additional fixation of the graft may be achieved by using either K-wires or screws. Remaining small bony defects can be filled with cancellous bone.

The blood vessels are shortened to the proper length to avoid kinking as well as strain. Subsequently, the vein of the graft is sutured to the cephalic vein using 10–0 suture material under the microscope and the corresponding artery is sutured to the dorsal branch of the radial artery in an end-to-end or end-to-side manner. Blood flow in the graft can now be monitored via the skin flap (▶Fig. 42.6). The remaining periosteum can be used to envelope the graft and cover the osteosynthetic material. Skin closure is performed by single-button sutures avoiding stress to the flap. Finally, easy-flow drains are applied, in order to avoid compression by hematoma. The dressing is fashioned to monitor the osteocutaneous flap.

42.4.4 Steps for the Procedure

1. Stabilizing the metacarpals in correct axial and rotational position by transmetacarpal K-wires.
2. The pseudarthrosis has to be completely resected (usually much larger defect than anticipated).
3. Preparing bony ends by removing sclerotic bone until fresh bleeding is seen.
4. Preparing adequate vessels near the defect.
5. Raising the graft from the iliac crest.
6. Trimming the graft to the appropriate size and implantation into the defect.
7. Microanastomosis of the blood vessels.
8. Use of drains prevents compression of the graft by hematoma.
9. Continuous monitoring of vascularity of osteocutaneous flap by color, recapillarization and temperature for 5 days

42.5 Postoperative Results and Critical Evaluation of Results

Performing the procedure by resection of the nonunion and transplanting an osteocutaneous graft from the iliac crest lead to bony consolidation of the transposed border ray. Stable healing of fracture in the hand improves the pain situation of the patient, allowing active mobilization with hand therapy (▶Fig. 42.7).

Nonunions in metacarpals and phalanges are very uncommon and fracture lines can remain apparent for as long as a year, finally healing uneventfully. In the presented case, a hypertrophic nonunion develops, forming hypertrophic callus around the osteotomy site. Insufficient stability of fixation of an osteotomy may cause too much interfragmentary motion, leading to nonunion. During the initial surgery, only two screws were inserted proximal to the osteotomy site. Using a longer plate, temporarily even transfixing the CMC III joint might have provided sufficient stability. This problem furthermore might have been avoided by choosing a more proximal osteotomy site during initial surgery. While cortical bone

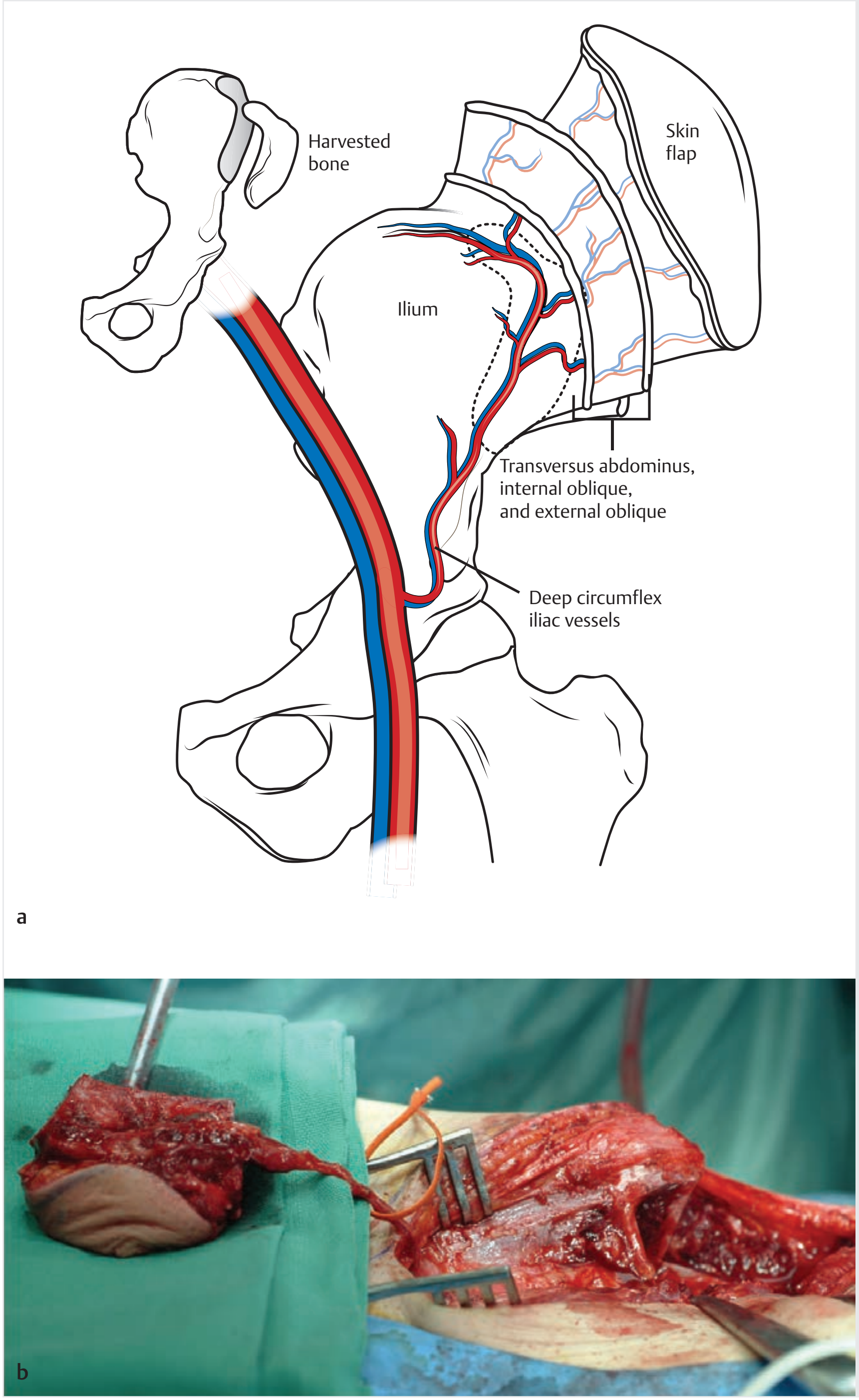

Fig. 42.5 Case presenting nonunion in metacarpal fractures. **(a)** Schematic drawing and **(b)** intraoperative photo documentation of the raised free vascularized corticocancellous bone graft from the iliac. (**Source:** Cheney M, Hadlock T. Facial Surgery. Plastic and Reconstructive. 1st Edition. Thieme; 2014)

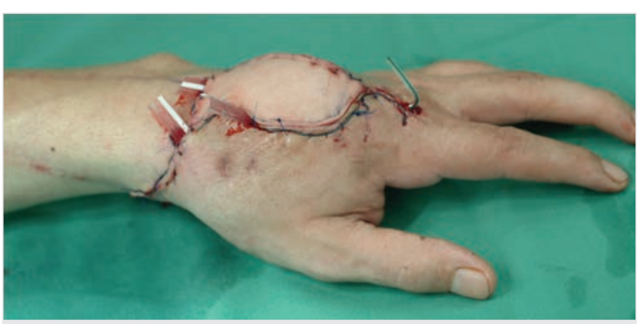

Fig. 42.6 Case presenting nonunion in metacarpal fractures. Intraoperative photograph of the transplanted iliac crest flap. The viability of the graft can monitored via the skin flap.

heals by means of intraosseous and endochondral ossification, cancellous bone heals by membranous ossification where woven bone is formed directly in the bone marrow, which seems to allow a faster consolidation. This leads to a persistent hypertrophic nonunion after three consecutive surgical interventions despite the addition of nonvascularized bone grafts. Due to nutritional depletion and instability, further surgical attempts to heal the bone with the addition of growth factors and local vascularized periosteum failed and resulted in an atrophic nonunion.

In the course of treatment, nutrition of the bone was increasingly impaired by repeated surgeries, promoting the formation of scar tissue, which could only be overcome by adequate debridement and introduction of a free vascularized bone graft.

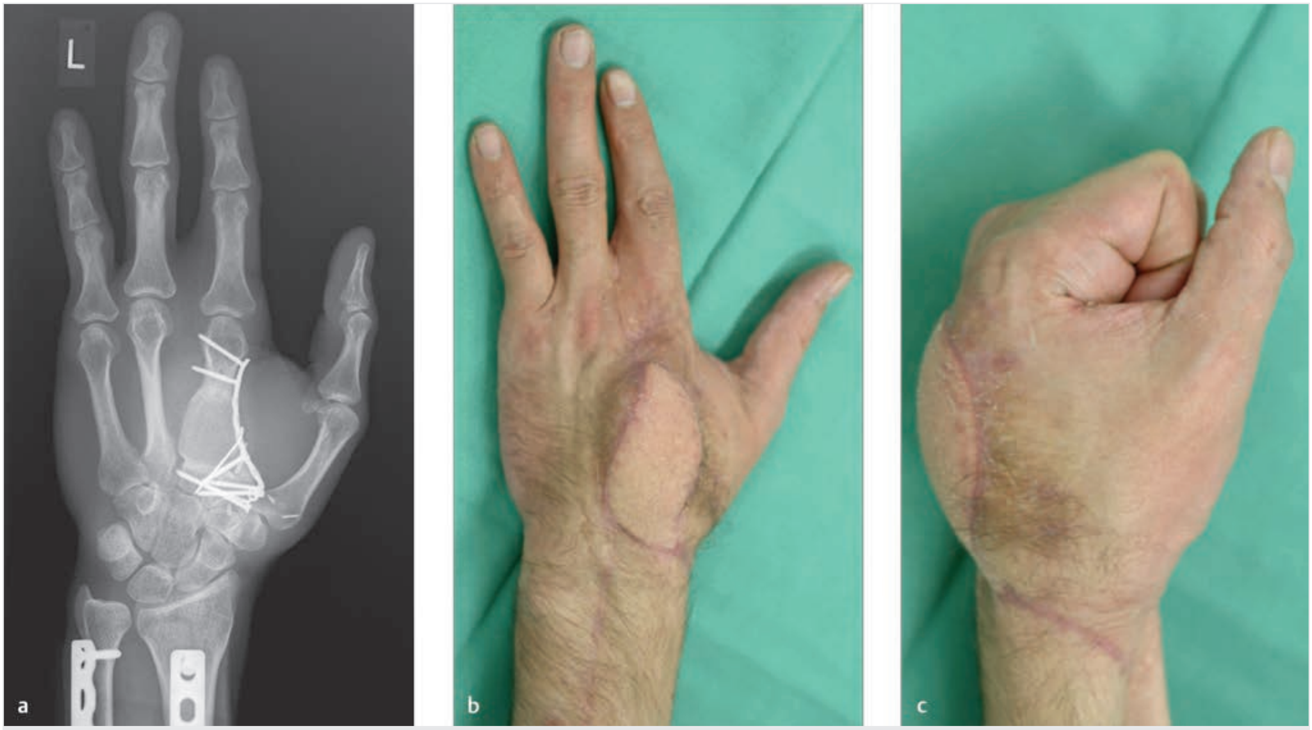

Fig. 42.7 Case presenting nonunion in metacarpal fractures. **(a)** X-ray and **(b, c)** photo documentation of the function of the left hand 1 year postoperatively.

We have chosen the vascularized iliac crest flap compared to the femoral condyle flap, because a skin flap of 7 × 3 cm was required. The size of the osteocutaneous flap matched well with the chosen option of the iliac crest.

42.6 Teaching Points

- Understanding the underlying problem:
  - Hypertrophic nonunion—increase stability.
  - Hypotrophic nonunion—improve vascularization/nutrition.
- Complete resection of nonunion.
- Harvest graft according to size of defect (cancellous graft, corticocancellous bone graft, vascularized corticocancellous bone graft and periosteum).
- Meticulous trimming of the graft according to size and alignment.
- Stable fixation of the graft without impairing vascularization.
- Assessment of optimal length of the pedicle of the graft.
- Osteotomies should be placed in the metaphysis if feasible.
- Smoking impairs healing.

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43 Malunion in Metacarpal Fractures

Richard J. Tosti and Jesse B. Jupiter

43.1 Patient History Leading to the Specific Problem

A 26-year-old, right-hand-dominant man suffered an injury to the left (non-dominant) ring finger after falling from standing height. He suffered a fracture of the ring finger metacarpal base with minimal angulation and displacement on radiographs (▶Fig. 43.1a). He was treated with cast immobilization. Upon release of the cast, he noticed the ring finger overlapped over the long finger when making a composite fist (▶Fig. 43.1b). Buddy taping was unsuccessful. He admitted to significant limitations with grip.

43.2 Anatomic Description of the Patient's Current Status

This patient has an extra-articular, rotational malunion of the metacarpal. Malunions may be classified by the bone involved, the type of deformity (angular, shortening, rotatory, combination), location (intra-articular vs. extra-articular), adult versus pediatric, and with or without combined soft-tissue injury. In the metacarpal, a surgeon should give consideration for correction of a malunited fracture if the deformity is anticipated to limit function. Intra-articular malunions cause painful range of motion, stiffness, and accelerated degeneration of the articular cartilage. Metacarpal neck malunions most often present with apex dorsal angulation and are less functionally limiting. Although cadaveric models have shown that for every 2 mm of shortening a 7-degree extensor lag occurs, clinical trials have reported well-tolerated apex dorsal angulation in the small and ring fingers. However, angulation of the index or middle finger metacarpal neck exceeding 10 degrees may cause pain during grip from a prominent metacarpal head. Additionally, diaphyseal angulation greater than 20 degrees may reduce strength and cause intrinsic tightness. A rotational malunion at any level greater than 10 degrees often causes adjacent digits to overlap and interfere. Often a combination of rotational,

Fig. 43.1 **(a)** Radiograph of rotational malunion of metacarpal. **(b)** Clinical photo of scissoring.

shortening, or angular deformities is present; however, usually only one component is dominant and requires surgical correction to restore function.

43.3 Recommended Solution to the Problem

Early identification and correction of rotational deformity may prevent malunited fractures. Radiographs may look relatively benign, as rotation of the fracture fragments may be difficult to define on plain films. All patients with metacarpal fractures should have a clinical examination out of cast to examine the rotational plane of the fingernails. In a painful hand, using the tenodesis effect (extending the wrist to observe passive flexion of the digits) can help the patient to make a composite fist. When flexing the fingers, the tips should point toward the scaphoid; overlapping of adjacent digits is usually more obvious at the midpoint of finger flexion. In addition, buddy taping a malunited fracture may appear to correct the deformity at first glance; however, this technique only rotates the digit through the metacarpophalangeal joint, which is promptly derotated when the straps are released.

Evaluation of the deformity should include the malunion classification, soft-tissue injury, joint contracture, skeletal fixation, and rehabilitation plan. Radiographs should include posteroanterior, lateral, and oblique views; a CT scan is useful especially for intra-articular fractures. Tracing the fragments on the radiographs and comparing them to the normal side can be helpful for planning fixation. Ideally, the correction should be made when a healthy soft-tissue envelope is present and the original fracture lines are still visible, which is often within 3 to 4 months from the injury. The type of osteotomy depends on the type of malunion, location, tendon balance, and joint mobility (▶Table 43.1). Simple intra-articular malunions may be treated with a corrective osteotomy; however, late deformities with degenerative disease or complex malunions are better treated with arthroplasty or arthrodesis. Angular deformities in the radial–ulnar plane are usually treated with an incomplete closing wedge osteotomy, which hinges on an intact far cortex; radial–ulnar malunions in the metacarpals are rare unless associated with bone loss. Angular deformities in the dorsal-to-volar direction are more common and often require an opening wedge osteotomy with wedge autograft and plate fixation to restore length for tendon balance; however, a closing wedge osteotomy may still be acceptable if significant shortening is not present. If shortening is the primary deformity, the surgeon's options are either immediate lengthening with plate fixation and bone graft or progressive lengthening via distraction osteogenesis. Rotational malunions can be treated with a transverse derotation osteotomy or with a step-cut osteotomy as described by Manktelow and Mahoney. We prefer the step-cut osteotomy for a variety of advantages: bone contact is larger, control over the osteotomy is easier, deformity correction is more precise, and less internal fixation is required. Some surgeons may still prefer the transverse derotation osteotomy at the metacarpal base described by Weckesser; however, the healing surface and precision of correction are less and plate fixation may cause tendon adhesions.

Table 43.1 Techniques of corrective osteotomies

Deformity type	Osteotomy type	Technique
Angular	Incomplete	Closing vs. opening wedge
Rotation	Complete	Derotation
Length	Complete	Immediate vs. progressive lengthening
Combined	Complete	Combination

43.3.1 Recommended Solution to the Problem

- Identify the type, location, and soft-tissue status of the malunion.
- Offer corrective surgery for functional limitation.
- Template the osteotomy using the contralateral metacarpal as a reference.
- Perform either a transverse or a step-cut derotational osteotomy.

43.4 Technique

Measure the amount of deformity at its largest margin, which is most often at the midpoint of finger flexion. The required deformity correction is used to calculate the amount of dorsal bone resection; a 20-degree (or 2-cm) correction is achieved with 2 mm of dorsal cortical wedge resection. The metacarpal is approached through a longitudinal dorsal incision. The extensor tendon is mobilized and protected. The step cut is planned to create a "Z osteotomy" with two hemitransverse cuts and a dorsal wedge using an oscillating saw. The direction of the hemitransverse cuts dictates the direction of rotation (▶Fig. 43.2a–c). It is easiest to visualize the distal hemitransverse cut on the same side as the deformity. Placing the cuts in the reverse orientation will rotate the fragment in the reverse direction. The hemitransverse cuts are made 2 to 3 cm apart (▶Fig. 43.2d). Then a dorsal wedge is resected from the dorsal cortex using two longitudinal cuts separated by the amount of correction calculated preoperatively. The volar cortex is left intact. Pointed reduction forceps can be used to close the dorsal gap; the volar cortex may crack, but the volar periosteum should still be intact (▶Fig. 43.2e). Clinical assessment of rotation confirms the correction; occasionally, more bone may need to be resected if more rotation is required. The osteotomy is secured using two 1.5- or 2.0-mm interfragmentary lag screws (▶Fig. 43.2f).

43.5 Postoperative Photographs and Critical Evaluation of Results

Finger motion may be allowed in the first postoperative day. A splint is provided for comfort. Release to full activities occurs when radiographic healing is evident usually around 3 to 4 months (▶Fig. 43.3).

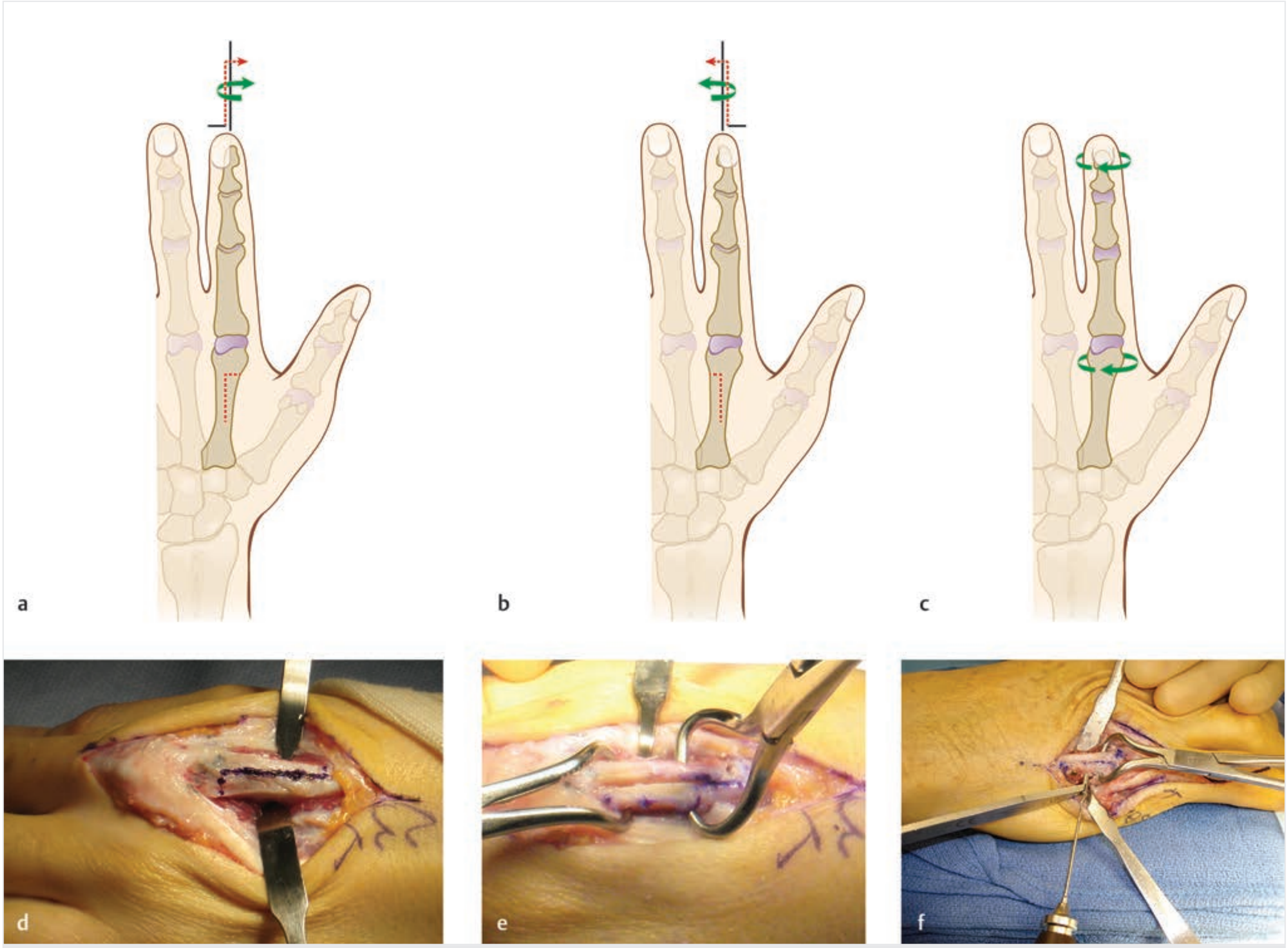

Fig. 43.2 **(a–c)** Illustration of step cuts and direction of rotation. Intraoperative photos showing **(d)** incision, **(e)** cuts, and **(f)** fixation.

The optimal treatment for metacarpal malunion is still debated, as case series reporting outcomes for corrective osteotomies are few. Manktelow and Mahoney were the first to describe the step-cut osteotomy, reporting on 22 cadaveric digits and 10 patients. They noted reliable, large-surface bone healing and precise correction. They reported that 1 mm of dorsal resection resulted in 8.6 ± 2 mm of correction. Gross and Gelberman found that rotational correction in cadaveric digits was limited to 19 degrees in the index, middle, and ring fingers, and 30 degrees in the small finger; the limiting structure was thought to be the deep transverse metacarpal ligament. More recently, Jawa et al reported on 12 patients treated with step-cut osteotomy for metacarpal and phalangeal rotational deformity. All patients had successful correction, united osteotomies, and had improved total arc of motion; one patient required a flexor tenolysis.

43.6 Teaching Points

- Approach the metacarpal through a dorsal incision.
- Measure the deformity and calculate the proportional dorsal cortical resection.
- Make the step-cut osteotomy in an orientation in which the distal hemitransverse cut faces the direction of the deformity.
- Secure the osteotomy with small caliber lag screws.

Fig. 43.3 Postoperative **(a)** X-ray and **(b)** clinical appearance.

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44 Angulation in Metacarpal Fractures

Jeffrey Greenberg

44.1 Patient History Leading to the Specific Problem

A 20-year-old man presents 2 weeks after an injury to his right hand (▶Fig. 44.1). He reports punching a wall and experiencing immediate pain over the ulnar hand. Pain, swelling, and inability to extend his fingers have led to decreased function of his hand. He is subsequently diagnosed with displaced right ring and small finger metacarpal fractures.

44.2 Anatomic Description of the Patient's Current Status

The patient has displaced metacarpal fractures of the ring and small fingers. Angulation is 10 degrees in the coronal plane and 45 degrees in the sagittal plane. This patient exhibits the most common pattern of displacement in regard to angulation in metacarpal shaft fractures. Volar angulation or apex dorsal angulation is caused by the pull of the intrinsic and extrinsic muscle tendon units. While sagittal angulation is tolerated better than rotational and coronal angulation in the setting of metacarpal shaft fractures, this patient was considered for surgery for multiple reasons. The coronal angulation due to the pull of the hypothenar musculature is measured at 10 degrees. Failure to correct coronal angulation in metacarpal fractures may negatively alter function. Nonanatomic coronal alignment may lead to overlapping of the fingers upon making a composite fist, compromising functional grip. Sagittal angulation in the setting of metacarpal fractures may lead to extensor lag and/or cosmetic deformity of the hand. Acceptable sagittal angulation in metacarpal shaft fractures can be reviewed in ▶Table 44.1. In isolated central metacarpal fractures, the adjacent intact metacarpals may help prevent displacement due to intact intermetacarpal ligaments and structural stability of the carpometacarpal (CMC) joints. Surgery was ultimately recommended for this patient to correct both coronal and sagittal malalignment to restore metacarpal cascade, alignment, active extension, and maximize recovery of function.

Table 44.1 Acceptable sagittal alignment of metacarpal shaft fractures

Index	10–20 degrees
Middle	10–20 degrees
Ring	20–30 degrees
Small	30–40 degrees

Fig. 44.1 (a) Lateral radiograph showing transverse metacarpal fractures of the ring and small fingers with 45 degrees of angulation. **(b)** Posteroanterior radiograph showing 10 degrees of coronal malalignment and translation of the fractures.

44.3 Recommended Solution to the Problem

- Coronal, sagittal, and rotational alignment must be corrected.
- Stability for fracture healing must be maintained.
- Reduction and application of instrumentation should be performed in the least invasive way necessary.
- Instrumentation should not interfere with intrinsic or extrinsic mobile muscle–tendon units.
- Options for this patient include the following:
  - Closed reduction and percutaneous fixation.
  - Open reduction and percutaneous fixation.
  - Open reduction and intramedullary fixation.
  - Open reduction and plate fixation.
- Wire fixation construct options:
  - Tension band.
  - Cross-pinning.
  - Transverse pinning.
  - Intramedullary wire fixation.
- Due to the delay in presentation, an open technique was used to obtain reduction of both fractures, followed by fixation using multiple intramedullary wires.

44.4 Technique

The patient is placed supine on the operating table with the arm on a radiolucent arm board. In this patient, regional anesthesia with sedation was used; however, surgeon preference dictates anesthetic choice. A nonsterile tourniquet is placed on the upper arm and the arm is prepped and draped in the usual sterile manner. The incision was made between the fourth and fifth metacarpals from the metacarpal base to the fracture site. If exposure of the fracture site is not needed, the incision is generally smaller and over the metacarpal base. Blunt dissection is used to ensure protection and retraction of the extensor tendons and the periosteum is exposed. The intrinsics attached to the metacarpal shaft are released, the periosteum is incised and elevated at the level of the fracture, and the fracture ends are exposed.

After fracture exposure, early callus is debrided until an adequate reduction can be obtained. In addition, the medullary canals are opened. Next, the base of the metacarpal is exposed. A 3.5-mm drill is then used to enter the intramedullary canal at the metacarpal base (▶Fig. 44.2a). Intraoperative imaging can be used at this point to assist in obtaining an accurate starting point. The starting point for the index, middle, and ring metacarpals is in line with the shaft on the metacarpal base distal to the CMC joint. The starting point for the small finger is along the ulnar border of the metacarpal base, again distal to the CMC joint. In order to facilitate wire passage, the drill is started perpendicular to the dorsal surface of the metacarpal. The drill is run at full speed and as the drill gains traction in the dorsal cortex, the bit is aimed distal by slowly lowering the drill to the dorsal forearm in line with the metacarpal (▶Fig. 44.2b). Once the dorsal cortex is breached, the drill should be at a 30-degree angle to the dorsal cortex. The unicortical hole is elongated with the drill on full speed to prevent iatrogenic fracture. Once access to the intramedullary canal has been obtained, wire selection and preparation for fracture stabilization can begin.

The ring finger metacarpal has the smallest isthmus and thus fewer and smaller diameter wires are used. In general, the intramedullary canal can accommodate between two and five wires in the canal and sizes vary from 0.028 to 0.045 inches. Wire preparation starts by cutting off the sharp tips to prevent engagement and inadvertent cortical penetration (▶Fig. 44.3). One end of the wire is bent slightly at the tip to facilitate passage of the wire and fragment manipulation.

Once the wire is prepared, a T-handle chuck or heavy needle driver is used to hold and manipulate the wire. The wire is then inserted in antegrade fashion into the entry point with the bent tip pointing dorsally (▶Fig. 44.4a). The small bend allows for the wire to glance off the volar cortex and facilitates passage down the medullary canal without embedding into the cortex. Intraoperative imaging is used to ensure wire passage across the fracture site and engagement into the distal fragment (▶Fig. 44.4b). Both manual manipulation of the fractures and rotation of the wire will assist in passage of the wire.

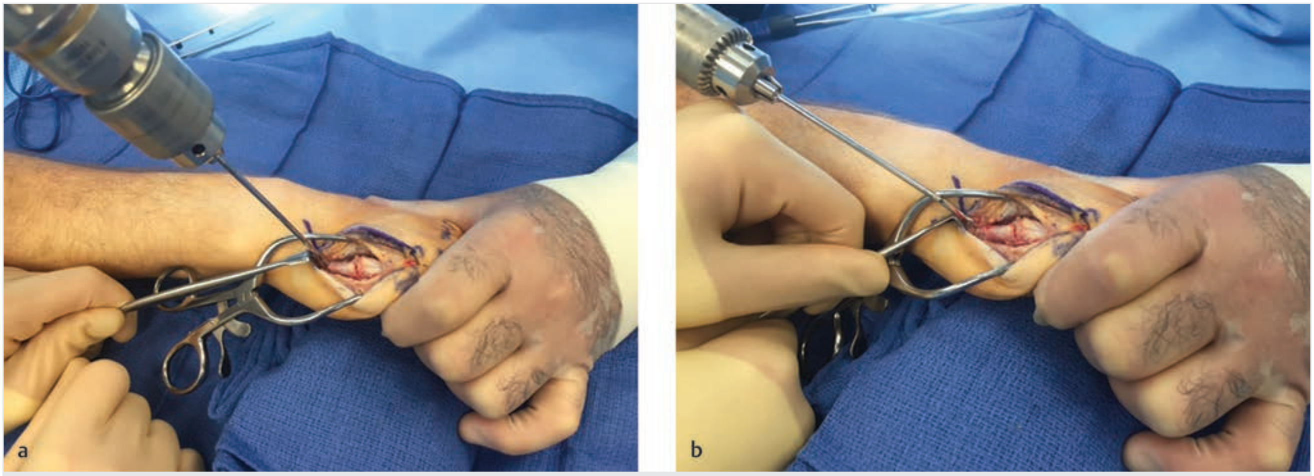

Fig. 44.2 **(a)** Starting the drill bit more perpendicular to the shaft of the metacarpal. **(b)** Gradually dropping the drill toward the forearm allows for breaching of the near cortex in this position. This angle allows for easy passage of the wires.

The wire is seated against the subchondral bone of the metacarpal head. At this point, the chuck or needle driver is removed and the end of the wire is left at its original length. Fracture reduction frequently improves with insertion and manipulation of additional wires. At least one additional wire, preferably the same size, is prepared and inserted (▶Fig. 44.5a). Each wire that is inserted is driven into the subchondral bone of the metacarpal head in a different location: ulnar, radial, volar, dorsal, and central. Once the canal is filled, the reduction should be acceptable; minor adjustments may be made by rotating the individual wires or by manipulating the fracture fragments. Proximally, each wire is backed out enough to cut the wire and then re-impact the wire into the medullary canal without breaching the metacarpal head (▶Fig. 44.5b). After all the wires are cut and re-impacted, fluoroscopy is utilized to ensure that the wires are not prominent over the dorsal metacarpal base to prevent extensor tendon irritation. Critical evaluation of the articular surface of the metacarpal head must also be performed using fluoroscopy to prevent intra-articular wire penetration into the metacarpophalangeal joint. Prior to wound closure, clinical assessment of rotation is also performed to endure adequate reduction.

Fig. 44.3 Prepared wire with tips removed and slightly bent distally.

Postoperatively, patients are encouraged to perform range-of-motion exercises of unencumbered joints in their initial surgical dressing. At their first postoperative visit, usually 10 to 14 days after surgery, suture removal is performed and patients are placed in a hand-based safe position splint allowing unrestricted interphalangeal motion. Despite the constructs' lack of "rigid" internal fixation, intramedullary wire fixation is stable enough to allow early range of motion. Clinical healing and functional range of motion are usually achieved by 6 weeks postoperatively.

44.5 Postoperative Photographs and Critical Evaluation of Results

In practice, good results have been achieved with intramedullary pinning of metacarpal shaft fractures (▶Fig. 44.6). In acute fractures, closed reduction and intramedullary

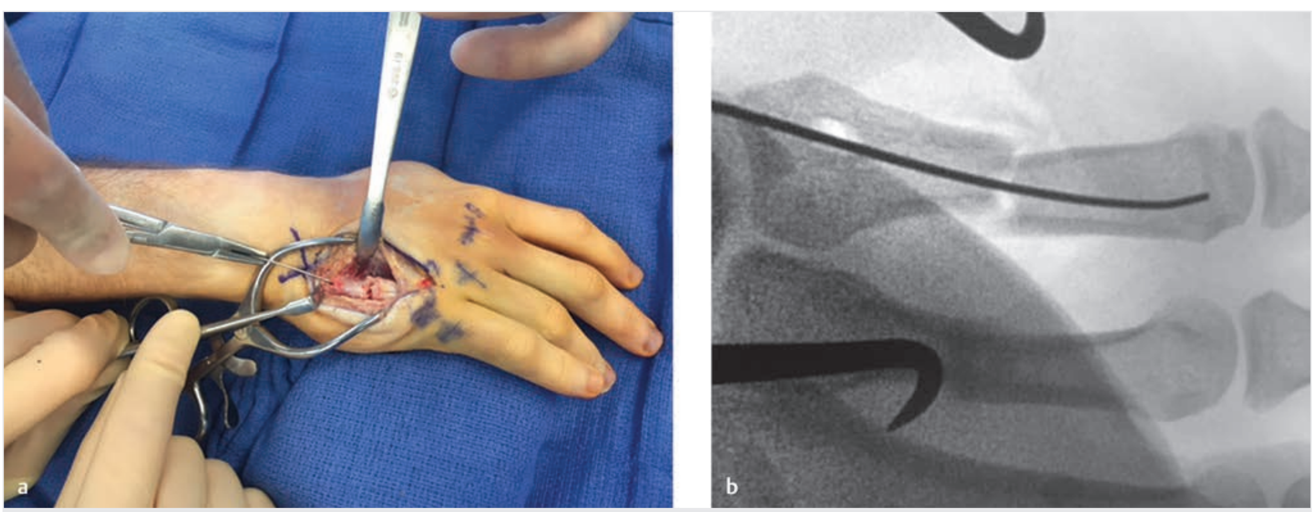

Fig. 44.4 **(a)** Insertion of the first wire across the fracture site. **(b)** Radiographic appearance after insertion of the first wire.

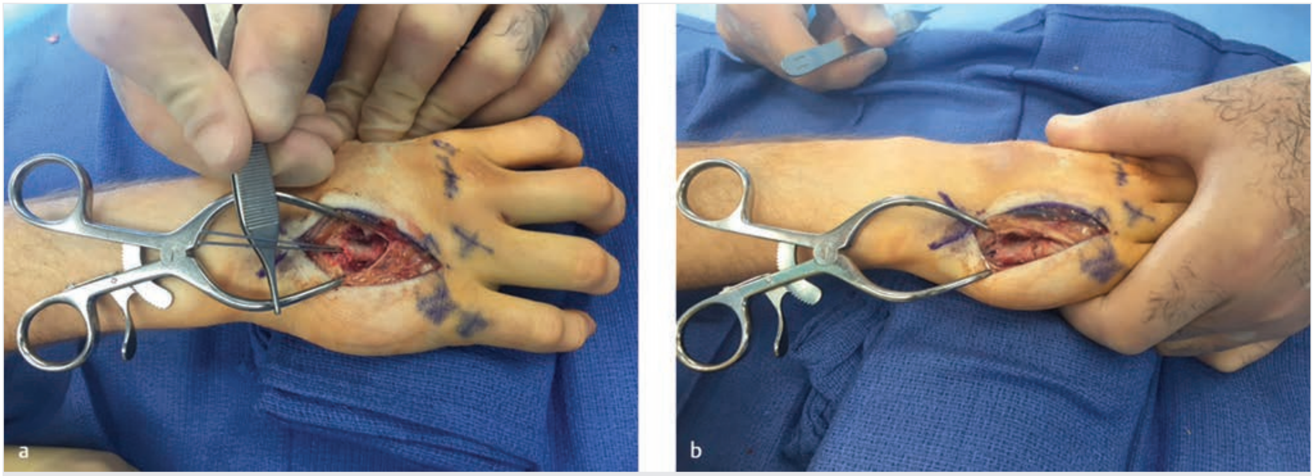

Fig. 44.5 (a) After insertion of the second wire. **(b)** After cutting, the wires have been re-impacted to be flush with the dorsal cortex.

Fig. 44.6 (a) Postoperative lateral to confirm reduction and correction of sagittal deformity. **(b)** Postoperative X-ray confirming correction of coronal angulation and translation.

fixation without opening the fracture site is usually possible (▶Fig. 44.7). If reduction is unsatisfactory, or difficult, a mini-open technique is performed as described (▶Fig. 44.8). Unique complications of this technique are wire penetration into the metacarpophalangeal joint and dorsal extensor tendon irritation. Hardware removal is generally performed with a corticotomy if necessary to withdraw the wires from the medullary canal; however, close examination of the intraoperative fluoroscopic films and direct visualization of the proximal ends of the wires are critical steps to avoid these problems.

44.6 Teaching Points

- Use fluoroscopy to identify the appropriate starting point and ensure good coronal alignment for opening the intramedullary canal at the metacarpal base. The starting point should not violate the CMC joint proximally and should be centered over the intramedullary canal.
- Start the drill or awl perpendicular to the dorsal cortex and slowly lower the hand to be more collinear with the canal that facilitates passage of the intramedullary wire(s).
- Remove sharp points and prebend one end of the wire.
- Use intraoperative imaging, manual manipulation, and the bend of the wire to help with passage of the wires across the fracture site.
- Use two to five wires to gradually improve reduction of the fracture and enhance rotational stability.
- Smaller diameter wires are necessary for ring finger metacarpal fractures due to the narrow isthmus.
- Slightly back out wires to cut to length, followed by re-impaction with a tamp to prevent dorsal prominence of the proximal portion of the wire.
- Critical fluoroscopic evaluation is necessary to ensure there is no violation of the metacarpophalangeal joint distally.
- This technique is not applicable to comminuted metacarpal fractures or fractures with bone loss as longitudinal stability may not be achieved.

Fig. 44.7 An 18-year-old man with closed, displaced, ring finger metacarpal fracture. **(a, b)** Preoperative views. **(c–e)** Two weeks postpercutaneous intramedullary wire fixation. Note early and exuberant callus consistent with indirect fracture healing response. **(f–h)** Six weeks postpercutaneous intramedullary wire fixation. The patient has already achieved full composite range of motion.

Fig. 44.8 Unstable index finger metacarpal fracture with volar angulation and translation. **(a)** Preoperative view. **(b)** Alternative method of wire fixation of the index finger metacarpal shaft fracture to correct angulation.

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Part XV

Problems with Basalar Joint Osteoarthritis

45 Recurrent Pain in Basilar Joint Osteoarthritis *202*

46 Painful Proximalization of First Metacarpal after Trapeziectomy *207*

47 Metacarpal Phalangeal Hyperextension *212*

XV

45 Recurrent Pain in Basilar Joint Osteoarthritis

Michael S. Gart and Daniel J. Nagle

45.1 Patient History Leading to the Specific Problem

A 47-year-old, right-hand-dominant woman presents with recurrent right thumb pain following surgery at another institution for trapeziometacarpal arthritis. Her initial trapeziectomy and suspension arthroplasty, using the flexor carpi radialis (FCR) tendon, was complicated by postoperative instability and she underwent a revision arthroplasty with reconstruction of the intermetacarpal ligament using the abductor pollicis longus (APL) tendon. At the time of her presentation, she complained of pain at the base of her right thumb and difficulty in performing activities of daily living, including pinching and grasping.

45.2 Anatomic Description of the Patient's Current Status

Examination revealed scars from previous surgery. There was no pain with manipulation of the thumb metacarpophalangeal (MCP) joint. The first metacarpal had migrated proximally and the thumb was held in a zigzag posture with 25 degrees of hyperextension at the MCP joint. This hyperextension was correctable with anatomic reduction of the first metacarpal. A residual slip of the FCR tendon and a well-defined palmaris longus tendon were palpable at the wrist.

Following her first operation, radiographs were consistent with trapeziectomy and FCR ligament reconstruction. Notably, the first metacarpal had migrated proximally to impinge on the scaphoid and no arthritis was appreciated at the MCP joint (▶Fig. 45.1a–c). Immediately following her revision arthroplasty, the metacarpal–scaphoid space had been restored, with bone anchors from her APL ligament reconstruction noted (▶Fig. 45.1d–f). However, at 6 months, her first metacarpal had again migrated proximally and lay in contact with the scaphoid (▶Fig. 45.1g–i).

45.3 Recommended Solution to the Problem

Although her first two operations were performed at another institution, we can assume they were technically well executed, as the patient did have temporary relief of symptoms and improvements in her radiographic appearance. Recurrent proximal migration of the first metacarpal following appropriately performed surgery was strongly suggestive of a loose ligamentous habitus. However, there were no other systemic findings to suggest classic Marfan's or Ehlers–Danlos syndrome. Given her age and functional status, we elected to reconstruct the intermetacarpal ligament and remove the arthritic base of the first metacarpal. Given that the FCR and APL were no longer present, we elected to reconstruct the intermetacarpal ligament using the palmaris longus tendon as a free graft.

45.3.1 Recommended Solution to the Problem

- Excision of the proximal first metacarpal base is key to increase the metacarpal–scaphoid space.
- The tendon graft must be secured firmly to the first metacarpal base.
- The palmaris longus is an excellent local option for tendon graft in this patient with previous harvest of her FCR and APL tendons.
- In the absence of a palmaris longus tendon, one can use other free tendon grafts (plantaris) or transfer of the extensor carpi radialis longus to reconstruct the intermetacarpal ligament.
- A prolonged period of postoperative immobilization and close supervision of gentle range-of-motion exercises are essential to allow healing when a free tendon graft is used. All phases of the rehabilitation program are delayed by 2 weeks.

45.4 Technique

A periclavicular regional block is performed in the preoperative holding area with an indwelling catheter for postoperative pain relief. The patient is taken to the operating room and placed in the supine position with the extremity on a hand table. The arm is prepped and draped in the standard sterile fashion, exsanguinated, and a proximal arm tourniquet is inflated to 250 mm Hg. The technique is described in ▶Video 45.1.

A Wagner incision is used to access the thumb carpometacarpal (CMC) joint with a small proximal extension to facilitate palmaris longus tendon retrieval. A Z-plasty is incorporated into the longitudinal aspect of the incision to prevent scar contracture across the wrist joint (▶Fig. 45.2). Dissection is carried down to the level of the thenar musculature, taking care to protect the branches of the superficial radial sensory nerve and the radial artery. The thenar muscles are incised along their fascial insertion of the first metacarpal and reflected ulnarly, allowing access to the first metacarpal and CMC joint capsule. A longitudinal capsulotomy is performed in the interval between the APL and the extensor pollicis brevis (EPB) tendons or slips of the APL, and thick capsular flaps are elevated radially and ulnarly. Care must be taken to preserve the integrity of these flaps for subsequent closure.

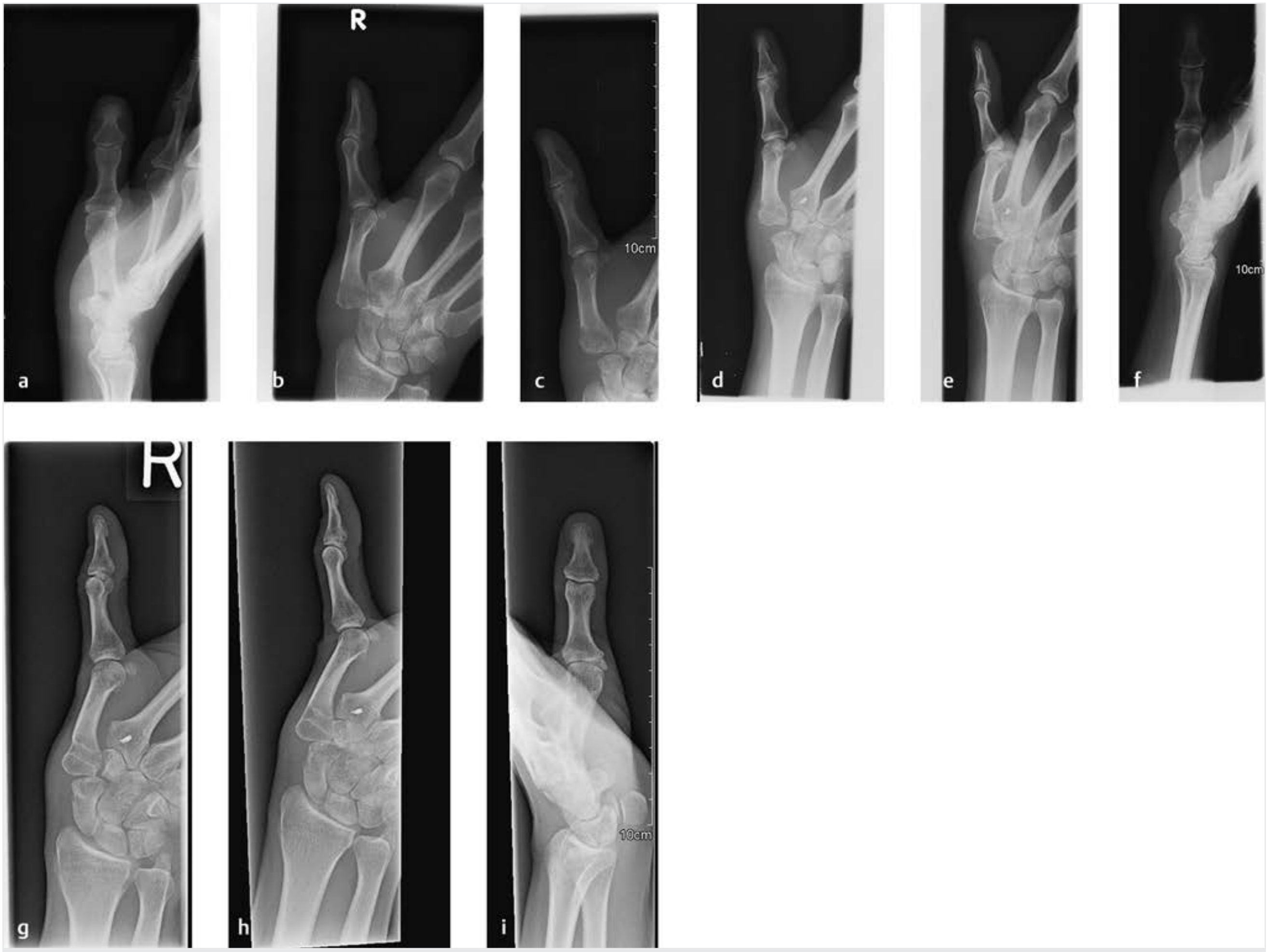

Fig. 45.1 **(a–c)** Radiographic appearance following trapeziectomy and flexor carpi radialis suspension arthroplasty. Note the bone tunnel in the base of the first metacarpal as well as proximal migration of the first metacarpal with scaphoid impingement. **(d–f)** Radiographic appearance following revision arthroplasty. Initial appearance, demonstrating good preservation of the trapezial space. **(g–i)** Six-month postoperative view, demonstrating proximal migration of the first metacarpal with scaphoid impingement.

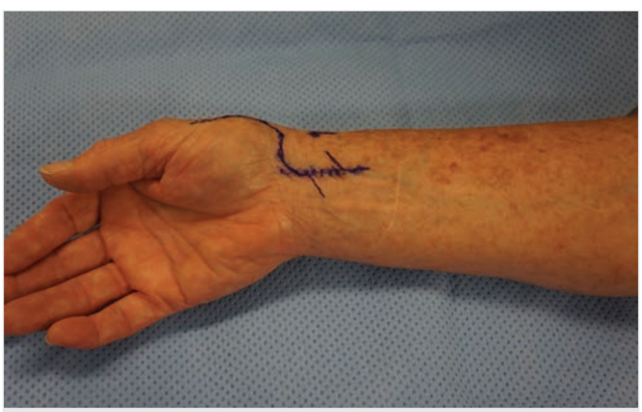

Fig. 45.2 Modified Wagner's incision with small proximal extension for PL tendon retrieval.

The metacarpal base is excised using a sagittal saw. The osteotomy is performed at the junction of the most distal extent of the joint surface and the metaphyseal–diaphyseal junction (▶Fig. 45.3). All osteophytes surrounding the base of the first metacarpal must be removed to prevent postoperative impingement on the second metacarpal.

The harvested palmaris longus tendon is anchored to the base of the second metacarpal at the FCR insertion site using a mini-Mitek anchor.

Using sequentially larger drill bits, a hole of sufficient caliber to pass the tendon is drilled from the radial border on the dorsal aspect of the proximal metacarpal, exiting out the ulnar aspect of the osteotomized surface, in the direction of the second metacarpal base (▶Fig. 45.4). An additional drill hole is made in the base of the metacarpal to intersect the first hole in a "T" fashion, to facilitate passage of an anchoring suture needle to secure the PL tendon graft. Finally, a mini-Mitek anchor is placed along the

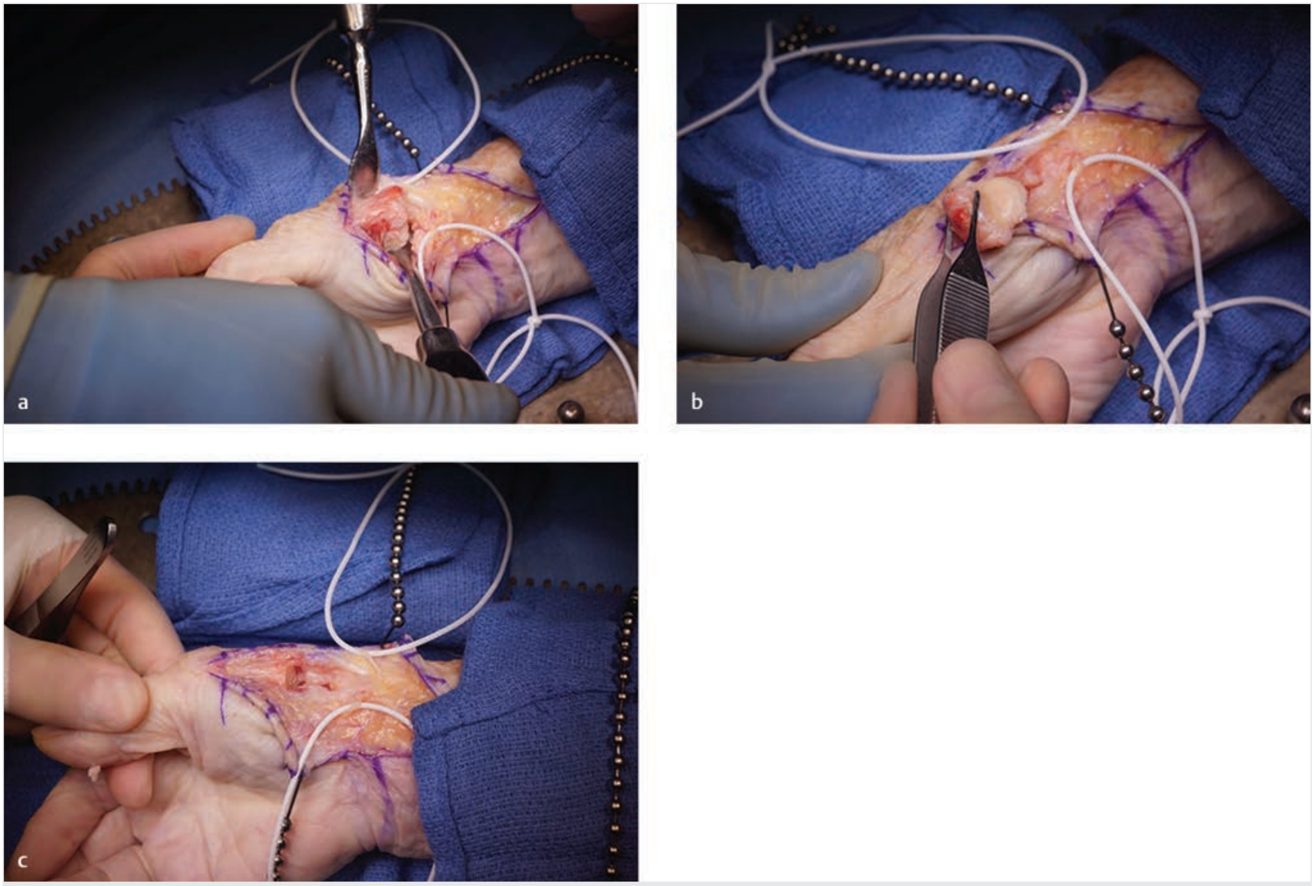

Fig. 45.3 **(a)** Excision of the first metacarpal base. Presenting the base of the first metacarpal for excision. **(b)** Segment of the first metacarpal base removed. **(c)** Appearance of metacarpal–scaphoid interval following excision of metacarpal base.

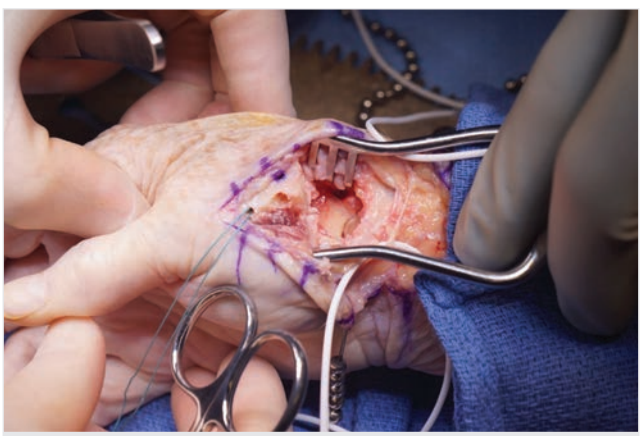

Fig. 45.4 Base of the first metacarpal, showing the drill hole for pollicis longus tendon passage, the mini-Mitek anchor in place along the radial crest, approximately 1 cm distal to this, and the marking for the second drill hole, where the anchoring suture needle will be passed.

radial crest of the metacarpal, approximately 1.5 to 2 cm distal to the first (PL) drill hole.

A no. 67 beaver blade is used to ensure that the bony tunnel is free from jagged edges or bony spicules that may cause the tendon to fray or rupture over time. Next, a Hewson suture passer is used to retrieve the PL tendon through the base of the first metacarpal, passing the tendon from proximal to distal. One half of a blue towel is rolled up and placed in the hand to hold the thumb in the "clenched-fist" position (▶Fig. 45.5). The assistant uses forceps to hold the base of the first metacarpal in contact with the base of the second metacarpal at the insertion of the FCR tendon, taking care not to apply direct pressure over the bony tunnels to avoid inadvertent fracture. (This maneuver has not led to impingement between the first and second metacarpals.) The tension is applied to the PL tendon perpendicular to the second metacarpal base. A 3–0 PDS suture is passed through the previously drilled suture hole, catching the tendon substance securing the PL to the first metacarpal base. Great care must be taken to not translate the metacarpal proximally or distally while placing this suture. Doing so will lead to instability of the reconstruction. The tendon is then further secured to the distal first metacarpal using the previously placed Mitek anchor.

Next, a 4–0 PDS suture is placed in the soft tissue at the base of the former trapezial space for closure of the joint capsule (this technique draws the capsule into the metacarpal–scaphoid space and helps stabilize the repair and prevent

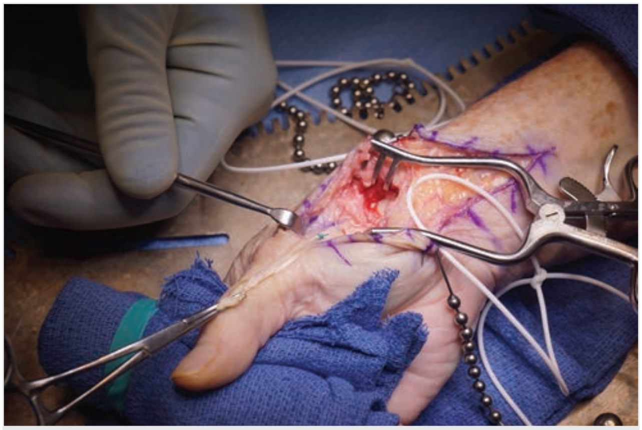

Fig. 45.5 With the thumb in the "clenched-fist" position, the 3–0 PDS anchoring suture and Mitek sutures are secured with the pollicis longus tendon graft under tension, taking care not to translate the metacarpal proximally or distally.

Fig. 45.7 Thumb spica cast applied at the first postoperative visit.

proximal migration). The joint capsule is closed in a vest-over-pants fashion using this deep 4–0 PDS suture.

A side-to-side tenodesis is then performed from the EPB tendon to the CMC joint capsule to convert the EPB into an abductor of the thumb, helping stabilize the repair and decrease the likelihood of MCP hyperextension deformity. Distal to the tenodesis, approximately 1 to 1.5 cm of the EPB tendon is excised to prevent scar bridging.

The thenar fascia is then repaired with 4–0 PDS suture, taking great care to protect the branches of the superficial radial nerve. The tourniquet is deflated and hemostasis obtained. The skin is closed using a running subcuticular 4–0 Prolene suture, incorporating the previously marked Z-plasty (▶Fig. 45.6). A thumb spica splint is applied.

The patient is maintained in the thumb spica splint until their first postoperative visit, typically 3 days after surgery, at which time a thumb spica cast is applied for 6 weeks due to the use of free tendon graft (▶Fig. 45.7). At 6 weeks, the patient is transitioned to a hand-based splint allowing thumb range of motion while avoiding adduction. At 8 weeks, full range of

Fig. 45.6 Skin closure incorporating previously marked Z-plasty.

motion is allowed, and gentle strengthening begins at 10 weeks using the hand-based thumb spica splint as needed. Sutures are removed at 3 weeks.

45.5 Postoperative Photographs and Critical Evaluation of Results

Postoperatively, the metacarpal–scaphoid space has been restored and the metacarpal base has been resected (▶Fig. 45.8). No proximal migration of the metacarpal is noted. Within 14 weeks, the patient had discontinued use of her splint and returned to all activities of daily living without pain.

45.6 Teaching Points

- Shorten the first metacarpal to remove arthritic bone and to help preserve the metacarpal–scaphoid space.
- To avoid postoperative instability, the tendon used for reconstruction must be securely attached to the first metacarpal base while being sure not to translate the metacarpal proximally or distally.
- Tenodesis of the EPB to the joint capsule converts this muscle into an abductor of the thumb and excision of the distal EPB helps prevent MCP joint hyperextension.
- Capsular repair in a vest-over-pants fashion with the suture placed in the depths of the trapezial excision site adds stability to the reconstruction and also acts as a spacer to prevent impingement or proximal migration of the first metacarpal.
- Patients with multiple failed tendon reconstructions for the first metacarpal suspension may have loose ligamentous habitus that may predispose them to stretching and ultimate failure of suspension.
- Prolonged immobilization and gradual return to activity is critical to the long-term success of this procedure.
- Patients must be advised preoperatively that the superficial branch of the radial nerve is at risk in revision CMC arthroplasty surgery and postoperative paresthesias should be expected for several months. Every step should be taken to avoid injury to this nerve.

Fig. 45.8 (a–c) Radiographic appearance following resection of the first metacarpal base with reconstruction of the intermetacarpal ligament using the palmaris longus tendon.

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46 Painful Proximalization of the First Metacarpal after Trapeziectomy

Martin Richter

46.1 Patient History Leading to the Specific Problem

A 71-year-old woman suffered from a painful stage III osteoarthritis of the basal thumb according to the Eaton and Littler classification. As surgical treatment, a trapeziectomy was performed. In the postoperative course, there were no complications. Six months after initial surgery, the patient still complained of pain at the base of the first metacarpal. This pain intensified especially with a firm pinch grip and power grip. The active elderly patient was restricted during her sports in the gym as well as in activities of daily living (ADLs) and wanted to get her condition improved.

46.2 Anatomic Description of the Patient's Current Status

The clinical examination shows pressure pain over the base of the first metacarpal bone. The range of motion was unrestricted. Constant pain occurred over the former first carpometacarpal (CMC 1) joint when the patient performed a pinch or forced grip. The examination reveals a subluxation of the base of the first metacarpal bone. Under tension and pressure, the base of the first metacarpal bone moves 1 cm distally and proximally (▶Fig. 46.1). The Grind test is painful, increasing under pressure and disappearing under tension.

Plain X-rays of the CMC 1 joint show the proximalization of the first metacarpal without direct contact to the scaphoid bone (▶Fig. 46.2a). In a scan, contact between the ulnopalmar edge of the first metacarpal and the oblique surface of the trapezoid is confirmed (▶Fig. 46.2b).

46.3 Recommended Solution to the Problem

Revision surgery was performed. For this purpose, the oblique surface of the trapezoid to the former trapezium is vertically osteotomized (▶Fig. 46.3) in order to avoid contact with the base of the first metacarpal. In order to prevent a re-proximalization, the implantation of a piece of rib cartilage was carried out, which was implanted in the left trapezium space and fixed with a bone anchor on the distal scaphoid bone.

46.3.1 Recommended Solution to the Problem

- Partial horizontal resection of the trapezoid to avoid impingement of the first metacarpal.
- Maintain trapezial space height with the rib cartilage graft.
- Avoid dislocation of the graft with a suture anchor and 4 weeks of immobilization.

Fig. 46.1 Unstable base of the first metacarpal under **(a)** traction and **(b)** load.

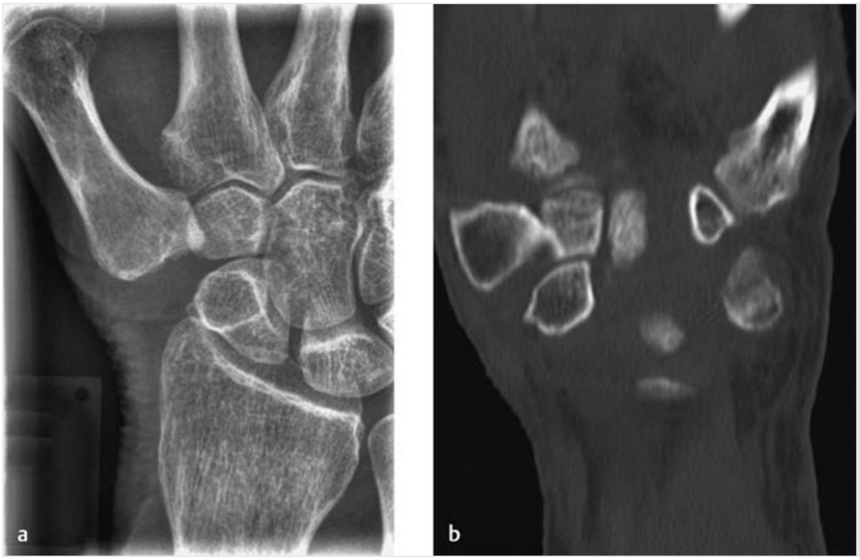

Fig. 46.2 **(a)** Proximalization of the first metacarpal without direct contact to the scaphoid bone. **(b)** Impingement between the ulnopalmar edge of the first metacarpal and the oblique surface of the trapezoid.

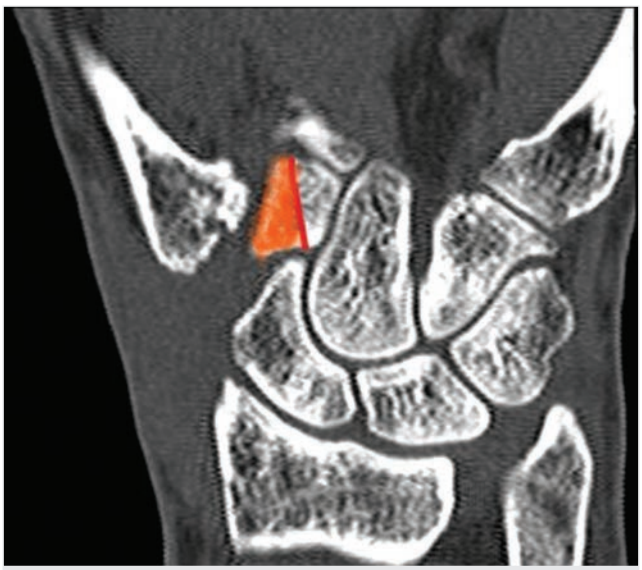

Fig. 46.3 CT scan of the wrist. The red area demonstrates the amount of resection of the trapezoid to avoid impingement.

46.4 Technique

The old scar is excised on the radiodorsal aspect over the CMC 1 joint. The incision is then widened to the proximal and distal direction (2 cm each). In the scar tissue, two sensory branches of the superficial radial nerve have to be microsurgically neurolysed. For this purpose, surgical loupes are highly recommended. This is followed by the exposure of the radial artery. Once these structures are secured, a longitudinal incision of the scar tissue between the base of the first metacarpal bone and the scaphoid bone is performed. The scar tissue is dissected to the side and the left trapezium space is exposed. If the first metacarpal bone is difficult to move, use scissors to dissect the base of the first metacarpal bone out of the scar tissue to mobilize the entire first ray distally. It is important to ensure that the insertion of the abductor pollicis longus (APL) muscle tendon is not detached in this case. After exposure, the oblique articular surface of the trapezoid can be inspected; often a cartilage wear can be seen (▶Fig. 46.4). If so, the trapezoid should be partially resected vertically, leaving a small amount of articular surface to the scaphoid on the ulna side. This prevents contact between the bones.

Fig. 46.4 After opening the previous trapezial space, the cartilage defect due to impingement of the first metacarpal is visible on the trapezoid surface at the bottom of the trapezial space.

Subsequently, an approximately 1 × 1 cm large rib cartilage graft is removed from the opposite medial costal arch (▶Fig. 46.5). Therefore, an incision of about 3 to 4 cm over the costal arch at the level of the insertion of abdominis muscle is made in the transverse direction. After subcutaneous dissection, the anterior rectus sheath is opened transversely and the rectus abdominis muscle is split in longitudinal direction and pushed apart. Under the rectus abdominis muscle, the lower costal arch is exposed. Here the perichondrium is opened and the cartilage is exposed ventrally and dorsally with a sharp dissector. It is important not to slip too deep with the dissector to avoid an intrathoracic injury. After passing through the cartilage, it can be resected either with scissors or with small scaphoid chisels. The wound closure is done in layers.

The harvested cartilage is formed to the size of the trapezium space (▶Fig. 46.6a). To prevent later dislocation of the cartilage, a bone anchor is placed into the distal articular surface of the scaphoid next to the capitate. The graft is fixed in the

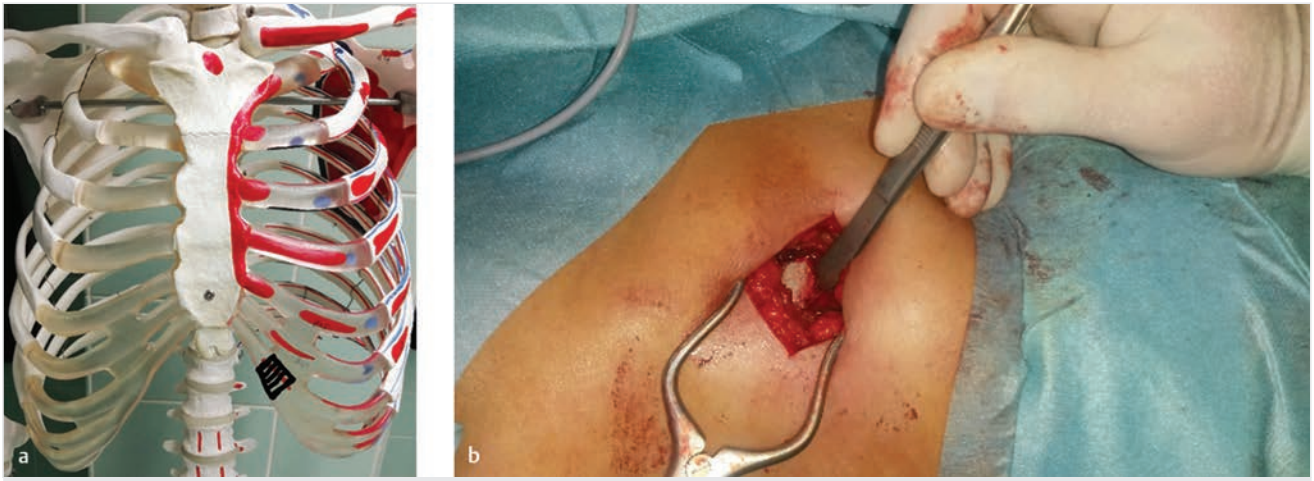

Fig. 46.5 **(a)** Site and amount of cartilage resection is outlined in black at the left costal arch. **(b)** Dissection of the costal arch through a transverse skin incision and vertical M. rectus abdominis split.

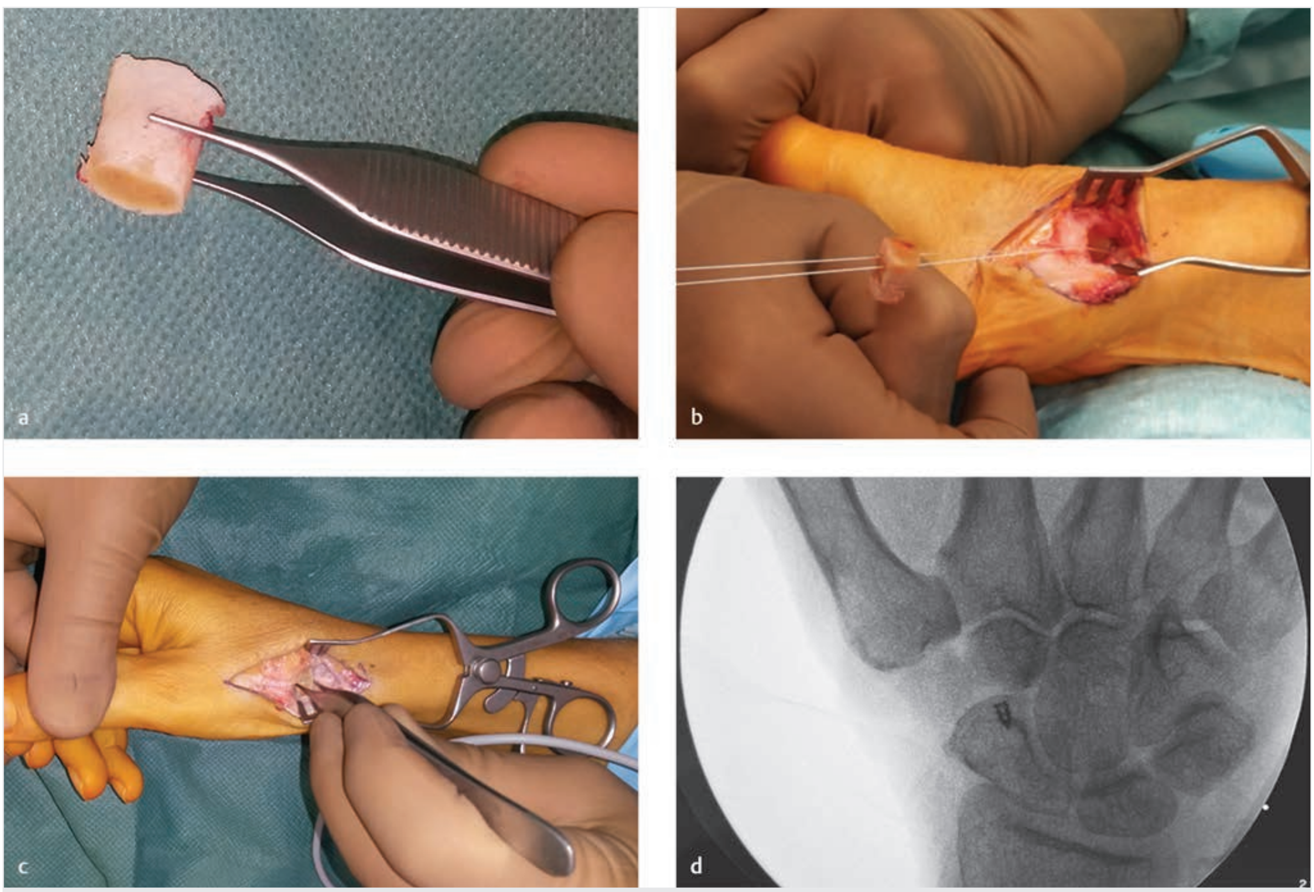

Fig. 46.6 **(a)** The rib cartilage graft. **(b)** Suture anchor in the distal scaphoid with the graft threaded. **(c)** Graft in the trapezial space between the branches of the forceps. **(d)** X-ray during surgery suture anchor and graft in place.

cavity (▶Fig. 46.6b,c). The closure of the joint capsule is done with a 2–0 Monofile absorbable suture. An attempt should be made to close the joint capsule. Radial artery and the sensory nerve branches have to be protected in this step. The exact position of the first metacarpal bone has to be verified in an intraoperative X-ray control (▶Fig. 46.6d). A thumb forearm splint is used for immobilization first; after removal of the skin sutures, a CMC 1 joint orthosis can be applied. Immobilization is necessary for 4 weeks. Forced manual mobilization of the former CMC 1 joint is not allowed until completion of the eighth postoperative week.

46.4.1 Steps for the Procedure

1. Expose the sensory nerves and the radial artery first.
2. Longitudinal incision of the scar and sufficient mobilization of the first metacarpal base.
3. Carefully remove the rib cartilage with the Rasparatorium after opening the perichondrium.
4. Longitudinal resection of the oblique portion of the trapezoid.
5. Fixation of the rib cartilage graft with a suture anchor on the ulnar distal scaphoid.
6. Tight suture of the joint capsule (2–0 PDS) with protection of nerves, the artery, and tendons.
7. Four weeks of immobilization of the CMC 1 joint.
8. No forced passive mobilization 8 weeks after surgery.

46.5 Postoperative Photographs and Critical Evaluation of Results

The intraoperative and postoperative X-rays show a restoration of the height of the first ray. Free range of motion of the former CMC 1 joint is obtained after 3 to 6 months (▶Fig. 46.7).

The proximalization after trapeziectomy is an occasionally detected problem in the treatment of the CMC 1 joint osteoarthritis. While in failed CMC 1 joint prostheses most authors recommended a trapeziectomy, revision after trapeziectomy remains controversial. A silastic spacer was often used in the past, but these implants may dislocate and lead to silicone synovitis. Restabilizing them was extremely difficult. Revision surgery with suspension arthroplasty by various tendons such as flexor carpi radialis, APL, and extensor carpi radialis is still the most commonly used method. However, the results of these methods are not always satisfying. Up to 30% disappointing results were found in the literature. In an own series with revision surgery and subsequent APL ligamentoplasty, Brunelli et al found disappointing results in only 2 of 14 patients. However, the proximalization could not be corrected radiologically with a proximalization of 6 mm on average in most cases. The use of rib cartilage grafts to repair the proximalization after trapeziectomy was first described by Glard et al. They used the method in four patients with success. Therefore, we increasingly use rib cartilage grafts for revision surgery after trapeziectomy. We can survey a series of 10 cases now with only 1 disappointing result. However, it must be noted here that we had problems with dislocation of the rib cartilage before we used a bone anchor for fixation. Nevertheless, radiologic proximalization could be improved compared to postoperative. Ever since we started performing the operation as described earlier, we have not seen dislocation any more.

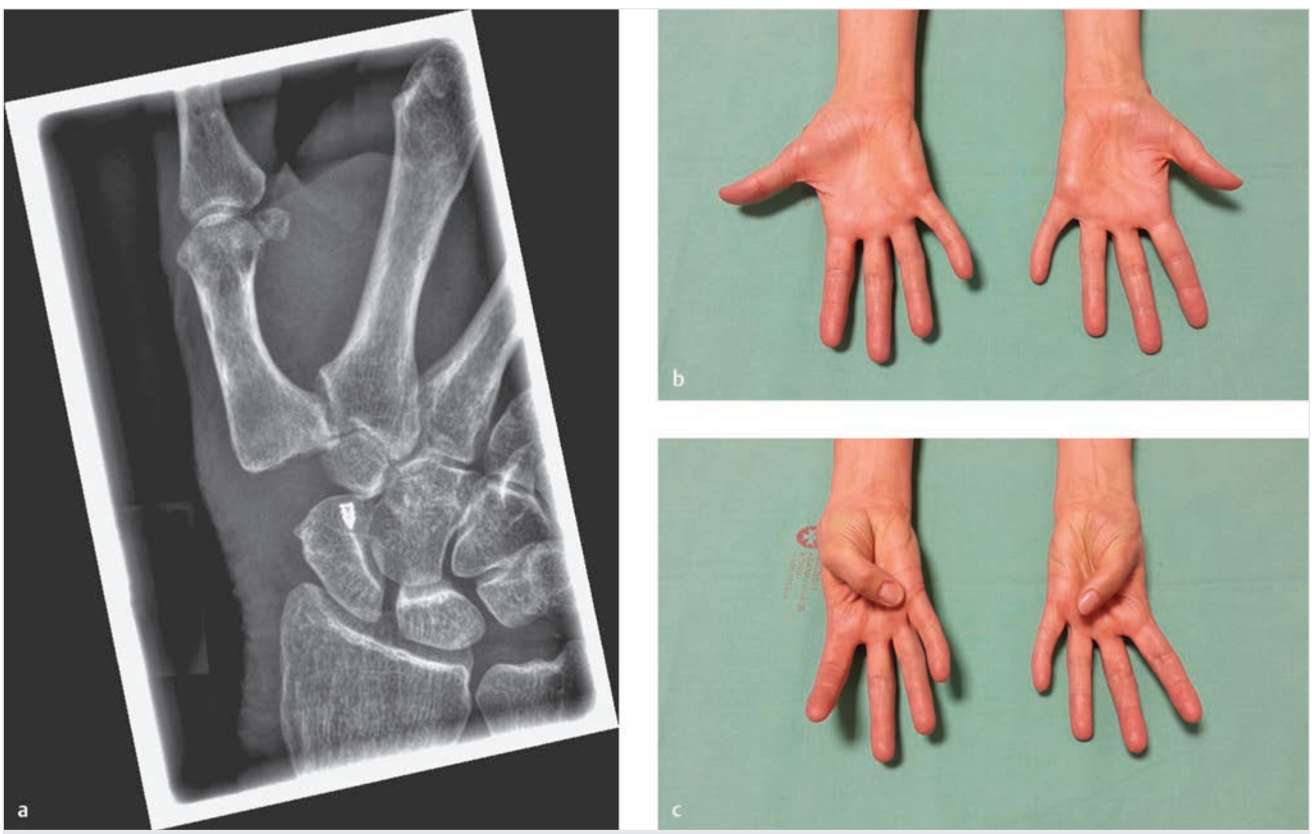

Fig. 46.7 **(a)** X-ray after surgery shows almost normal trapezial height. **(b,c)** Functional results 1 year after implantation of a rib cartilage.

46.6 Teaching Points

- Impingement on trapezoid level is often a cause of pain in failed trapeziectomy even if there is still space between the first metacarpal and the scaphoid.
- Maintaining trapezial space height with a graft avoids recurrence of impingement.
- Partial horizontal resection of the trapezoid avoids recurrence of impingement as well, even if some proximalization occurs again.
- Dislocation of the graft is an issue and must be managed by fixing it, that is, with a suture anchor.
- Neurolysis of sensory nerve branches and dissection of the radial artery are mandatory as the first step of surgery to avoid pitfalls related to neuromas or diminished perfusion.

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47 Metacarpal Phalangeal Hyperextension

Anne Argenta and Mark E. Baratz

47.1 Patient History Leading to the Specific Problem

A 54-year-old, right-hand-dominant woman presents with pain localized to the base of her right thumb. She describes the pain as “aching” and worse with movement. It has gradually progressed over the past 3 years and now wakes her at night. She works as a nurse and cashier, and notes pain with writing and opening twist-top pill containers. She takes ibuprofen and aspirin for the pain. She has worn a thumb brace for 6 months, without improvement of symptoms.

Examination of the right hand demonstrates a shoulder deformity at the base of thumb and adduction of the thumb metacarpal (▶Fig. 47.1a, b). Her metacarpophalangeal (MCP) joint rests in approximately 25 degrees of hyperextension; this can be passively stretched to 45 degrees of hyperextension (▶Fig. 47.1c). She has pain with both passive flexion and extension of the thumb metacarpal. A grind test is positive. Sensation and vascularity of the thumb is normal. Radiographs demonstrate an Eaton stage 4 carpometacarpal (CMC) arthritis and an MCP hyperextension deformity of 30 degrees. There is no evidence of MCP joint arthritis (▶Fig. 47.2).

47.2 Anatomic Description of the Patient’s Current Status

In addition to pain and difficulty with fine motor skills (twisting caps, using scissors, etc.), patients with basal joint arthritis will often complain of a visible thumb deformity. Attenuation of the CMC ligaments results in progressive dorsoradial subluxation of the metacarpal head on the trapezium and adduction of the thumb metacarpal. Concurrently, the extensor pollicis brevis (EPB) contributes to compensatory MCP joint hyperextension. This is commonly referred to as a zigzag or thumb collapse deformity. Key pinch will accentuate this deformity.

Compensatory MCP hyperextension is a pathologic component of basal joint arthritis that can lead to MCP arthritis and persistent pain after CMC arthroplasty. Addressing the MCP hyperextension deformity at the same time as CMC arthroplasty is important for an optimal surgical outcome. ▶Fig. 47.3 demonstrates a patient who underwent a prior CMC arthroplasty without addressing the MCP joint; postoperatively, she complains of persistent pain and deformity at the MCP joint.

Fig. 47.1 (a, b) Preoperative photographs of the right hand demonstrating a classic “shoulder deformity” and MCP hyperextension. **(c)** Accentuation of the MCP hyperextension with passive range of motion.

Fig. 47.2 Preoperative radiograph of the right hand demonstrating an Eaton stage 4 carpometacarpal arthritis with preservation of the MCP joint.

47.3 Recommended Solution to the Problem

The thumb MCP joint needs to be preoperatively evaluated in all cases of CMC arthritis. The degree of resting and passive MCP hyperextension should be measured. Pain and instability at the MCP joint should be examined clinically. Radiographs taken to stage the CMC arthritis can also be used to evaluate the integrity of the MCP joint and presence of MCP collapse.

There is no evidence that surgical intervention for mild MCP hyperextension (<25 degrees) offers any functional advantage. Surgical intervention for more severe deformity (>25 degrees) is generally accepted, but it remains controversial as to whether long-term outcomes demonstrate a significant benefit. Treatment options for MCP hyperextension address soft tissue and/or bone. There are limited data on each procedure and there are no randomized controlled trials that show superiority of one technique compared to another, or compared against nonoperative management.

In the cases where the MCP joint is preserved with minimal arthritis and passively reducible, soft-tissue procedures help reposition the thumb and place the MCP in a position that may be more functional and cosmetic. The more universally accepted soft-tissue procedures include tendon rebalancing and/or MCP volar plate arthroplasty. Both are outlined in the Technique section. We recommend that these procedures be done at the same time as CMC arthroplasty. Some degree of recurrence should be anticipated as the tendons and volar plate stretch over time.

In the cases of concomitantly advanced MCP and CMC joint arthritis, pain may originate from both joints. An arthritic thumb MCP joint is best managed with a combined MCP arthrodesis and CMC arthroplasty.

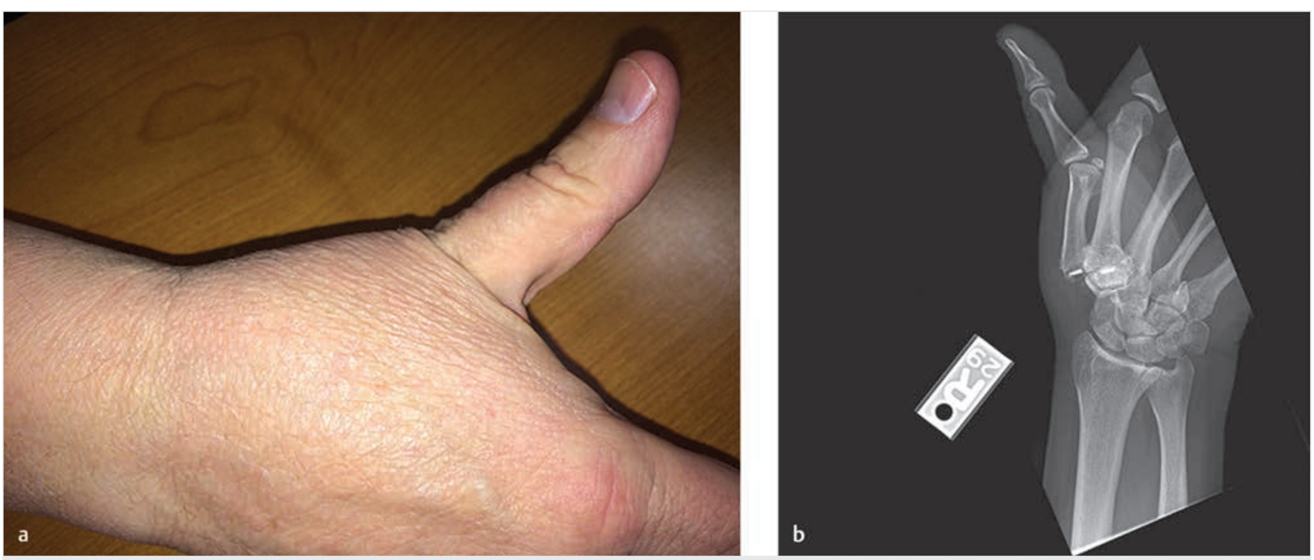

Fig. 47.3 **(a)** Failure to address the MCP joint during carpometacarpal (CMC) arthroplasty in the case resulted in persistent pain, deformity, and patient dissatisfaction. **(b)** Postoperative radiograph of CMC arthroplasty demonstrating hyperextension and early arthritis at the MCP joint.

47.3.1 Recommended Solution to the Problem

- Perform a preoperative evaluation of the MCP joint with clinical examination and radiographs.
- Consider surgical treatment for MCP hyperextension deformities of 30 degrees or greater.
- If the MCP joint has minimal arthritis, consider soft-tissue reconstruction (volar plate arthroplasty ± tendon transfer).
- If the MCP joint has advanced arthritis, consider an MCP fusion.

47.4 Technique

47.4.1 Metacarpophalangeal Volar Plate Arthroplasty

When done in combination with a CMC arthroplasty and ligament reconstruction, MCP volar plate arthroplasty should be performed after trapeziectomy and before tensioning of the flexor carpi radialis (FCR) or other donor tendons. The CMC arthroplasty technique used in this patient is a trapeziectomy with suspension of the metacarpal using the FCR graft sutured to the metacarpal base, along with a slip abductor pollicis longus (APL) sutured to the extensor carpi radialis longus at the base of the index metacarpal. The trapeziectomy is performed first and sutures are placed for the suspension. Prior to tying these suspension sutures, the MCP volar plate arthroplasty is performed.

Exposure of the thumb MCP joint is made using a two-limb Brunner incision (▶Fig. 47.4a). The flexor sheath is incised, taking care to preserve the oblique pulley (▶Fig. 47.4b). The FPL tendon is retracted with a Ragnell retractor. A proximally based, U-shaped flap in the volar plate is designed and raised (▶Fig. 47.4c, d). This flap is advanced distally and secured to the base of the thumb proximal phalanx using a suture anchor (▶Fig. 47.4e, f). Prior to securing the volar plate flap with the suture anchor, the thumb is stabilized in approximately 30 degrees of MCP flexion using a 4.5-inch K-wire, inserted from the metacarpal head to mid-shaft of the proximal phalanx (▶Fig. 47.4g, h). Intraoperative fluoroscopy can confirm acceptable position of the pin in the MCP joint and suture anchor in the proximal phalanx. Once the volar plate is secured with the suture anchor and the pin is determined to be in good position, the remainder of the CMC arthroplasty is completed. In order to protect the volar plate arthroplasty while tensioning the tendons at the CMC level, we recommend using a double hook to pull on the 4.5-inch K wire, rather than pulling direct traction on the thumb (▶Fig. 47.4i).

47.4.2 Extensor Pollicis Brevis to Abductor Pollicis Longus Tendon Transfer

Our patient had a congenitally absent EPB, preventing a planned tendon transfer in addition to the volar plate arthroplasty above. Therefore, ▶Fig. 47.5 demonstrates an EPB to APL tendon transfer in a different patient with CMC arthritis and an MCP hyperextension deformity. A first dorsal extensor compartment release is performed during the exposure for the CMC arthroplasty (▶Fig. 47.5a). Transfer of the EPB to the APL is performed by transecting the EPB distally. It is brought out to full excursion and then relaxed to 50% of full excursion (▶Fig. 47.5b, c) and sutured to the APL, using two 3–0 braided, nonabsorbable sutures in a mattress-type fashion (▶Fig. 47.5d). In this patient, the combination of the CMC arthroplasty with tendon rebalancing successfully repositioned the thumb MCP joint into approximately 20 degrees of flexion.

47.5 Postoperative Photographs and Critical Evaluation of Results

A variable amount of recurrent MCP hyperextension has been reported with volar plate arthroplasty and EPB to APL transfers, likely due to soft-tissue stretch. At her 1-month postoperative visit, our patient noted satisfaction with the position of her thumb (▶Fig. 47.6a). Radiographs demonstrated good positioning of the pin and suture anchor, with the MCP joint stabilized in 35 degrees of flexion (▶Fig. 47.6b). Her pin was removed in the office at 6 weeks, at which time she reported minimal pain. She was maintained in a cast or splint full time until 8 weeks postoperatively, and then allowed to gradually increase her weight-bearing activities. Her 4-month follow-up is documented in ▶Fig. 47.7.

At this time, she is also 1 year out from the identical procedure (CMC arthroplasty and MCP volar plate arthroplasty) on her left hand (▶Fig. 47.8). Her MCP rests in approximately 10 degrees of hyperextension, demonstrating mild recurrence. She reports painless range of movement, sustained improvement in dexterity postoperatively, and satisfaction with the cosmesis of her left hand.

47.6 Teaching Points

- Compensatory MCP hyperextension is a pathologic component of basal joint arthritis.
- Addressing MCP hyperextension deformity at the same time as CMC arthroplasty seems to be important for an optimal surgical outcome.
- Most literature recommends only intervening for hyperextension deformities beyond 25 to 30 degrees, although there is no firm cutoff.

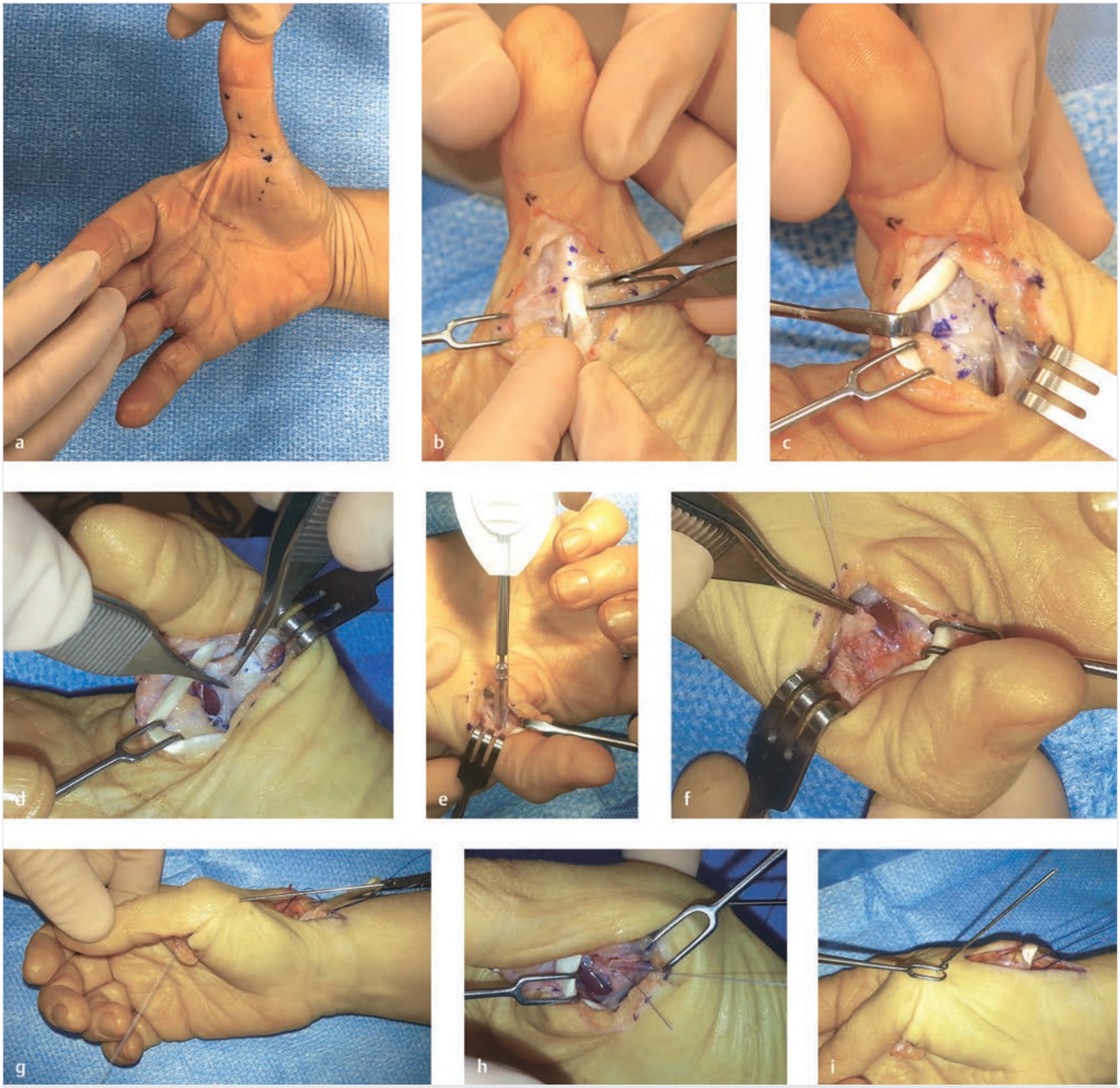

Fig. 47.4 Volar plate arthroplasty. **(a)** Two-limb Brunner's incision for exposure of MCP volar plate. **(b)** Exposure of the flexor sheath. Oblique pulley is dotted. **(c)** Proximally based **U**-shaped flap of volar plate is marked. **(d)** The flap is lifted and held up with forceps. **(e)** Placement of the suture anchor at the base of the thumb proximal phalanx. **(f)** Advancing the volar plate distally to the suture anchor. The volar plate is lifted with the forceps. **(g)** With the MCP flexed in approximately 30 degrees, a 4.5-inch K-wire is inserted from the metacarpal head into the shaft of the thumb proximal phalanx. **(h)** The final position of the volar plate, sutured down to the proximal phalanx. **(i)** To protect the volar plate arthroplasty while finishing the CMC arthroplasty, use a double hook to pull on the 4.5-inch K-wire, rather than direct traction on the thumb.

- MCP hyperextension deformity can be addressed with soft-tissue procedures (volar plate arthroplasty, EPB to APL transfer) or MCP joint fusion. There is minimal evidence supporting one procedure over another, or any procedure over nonoperative management.
- Variable recurrence of MCP hyperextension should be anticipated after volar plate arthroplasty and/or EPB to APL transfer.

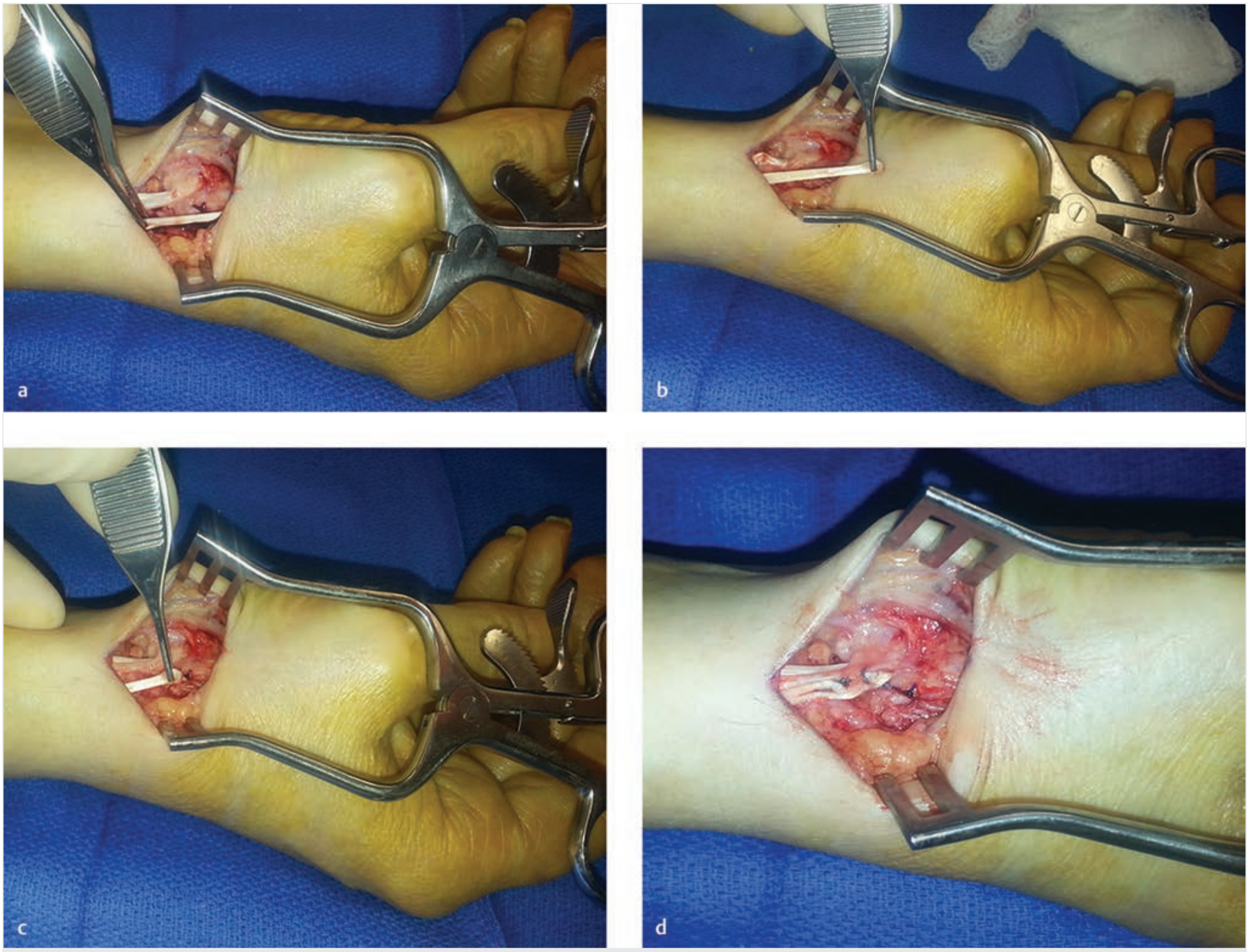

Fig. 47.5 Steps for extensor pollicis brevis (EPB) to abductor pollicis longus (APL) tendon transfer. **(a)** First dorsal compartment is released. **(b)** Transected EPB is pulled to full excursion. **(c)** Transected EPB is pulled to 50% excursion. **(d)** EPB is sutured to APL at 50% excursion.

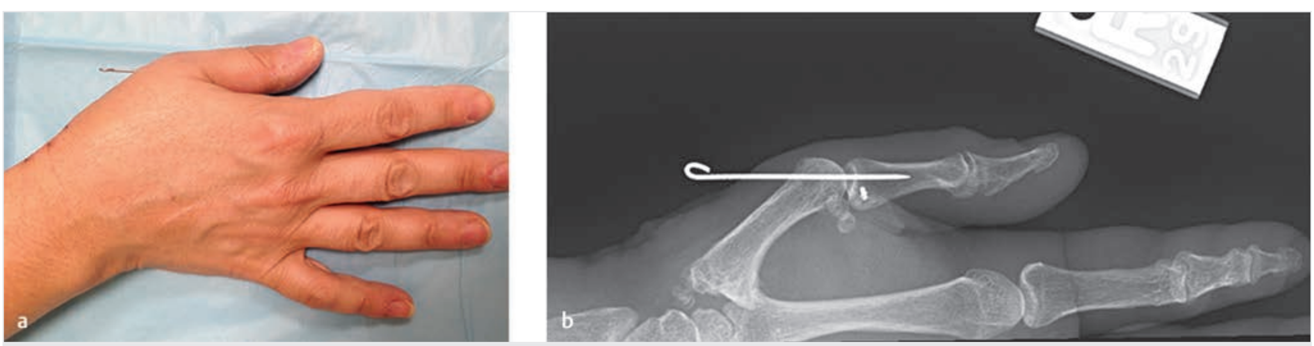

Fig. 47.6 One-month postoperative **(a)** photograph and **(b)** X-ray after carpometacarpal (CMC) arthroplasty and MCP volar plate arthroplasty.

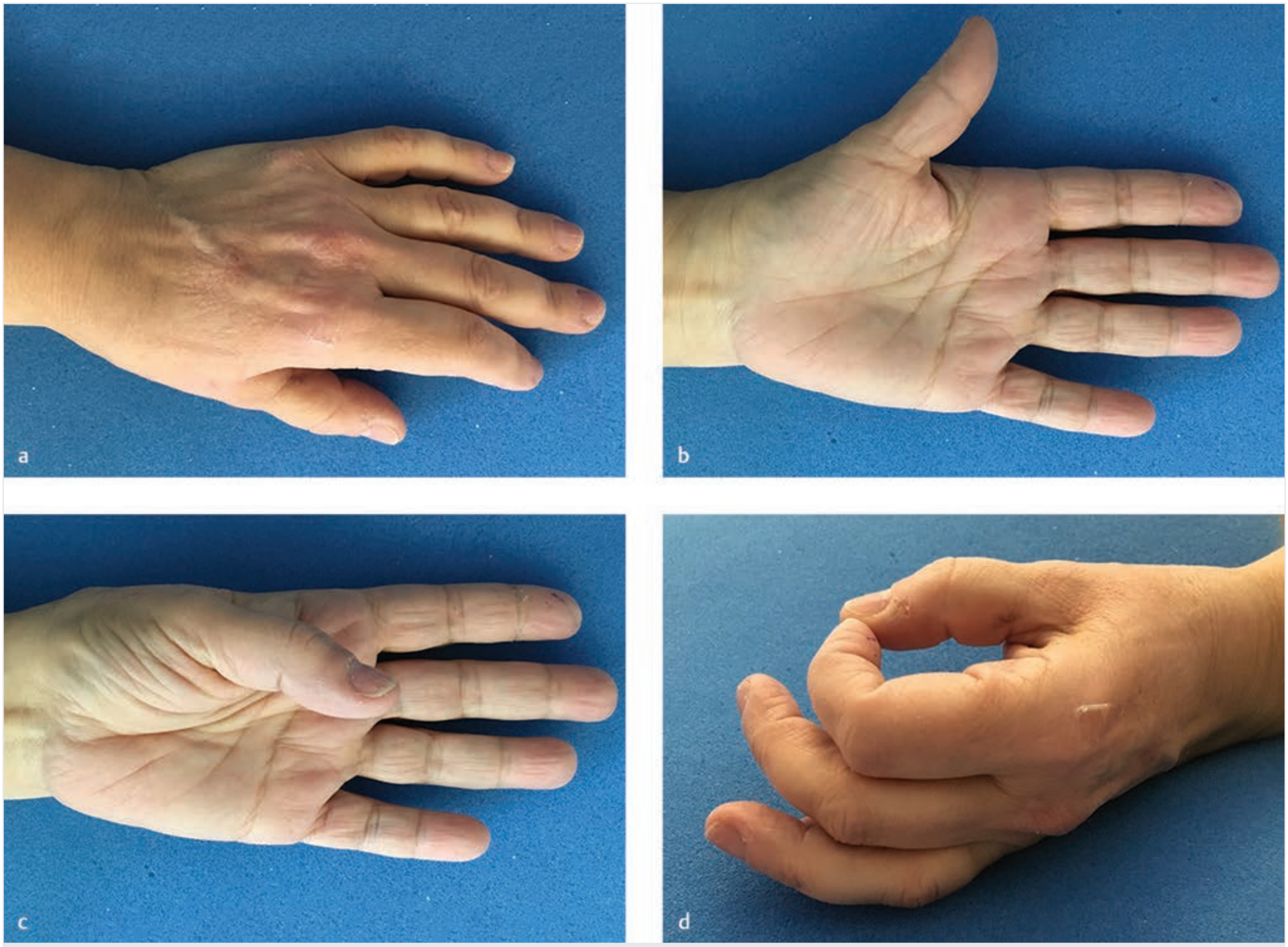

Fig. 47.7 Four-month postoperative photographs after carpometacarpal (CMC) arthroplasty and MCP volar plate arthroplasty. **(a)** Dorsal hand view. **(b)** Volar hand view. **(c)** Thumb opposition. **(d)** Tip pinch.

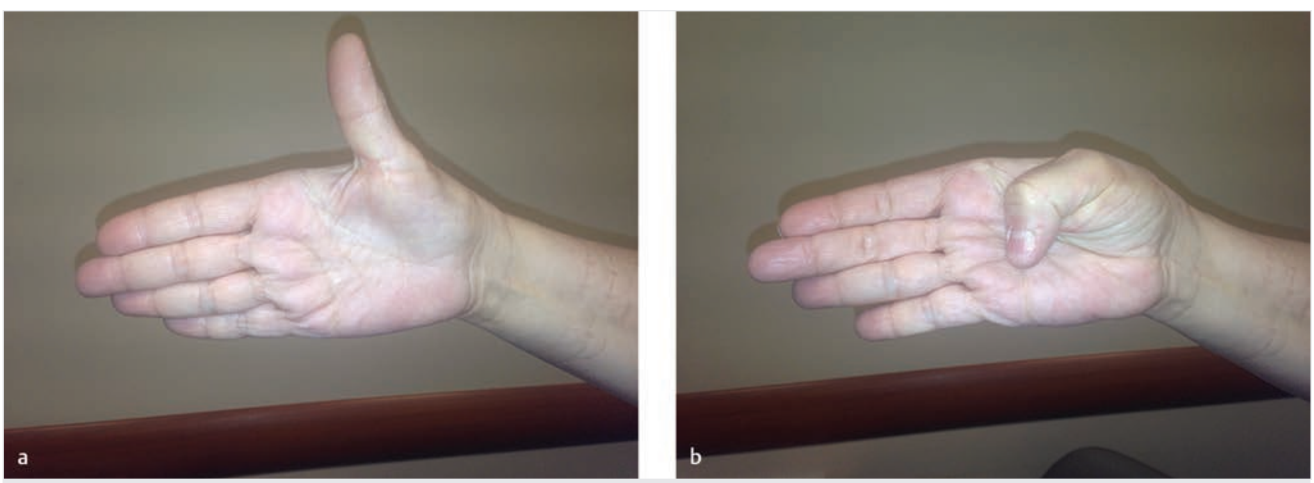

Fig. 47.8 One-year follow-up of the contralateral carpometacarpal arthroplasty with MCP volar plate arthroplasty. **(a)** Thumb extension. **(b)** Thumb flexion.

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Part XVI

Problems with Metacarpal Phalangeal Osteoarthritis after Implant Arthroplasty

48 Intraoperative Instability During Metacarpophalangeal Joint Arthroplasty for Osteoarthritis *220*

49 Revision of Subsided Pyrocarbon Implants *226*

XVI

48 Intraoperative Instability During Metacarpophalangeal Joint Arthroplasty for Osteoarthritis

Chelsea Harris, Yuki Fujihara, and Kevin C. Chung

48.1 Patient History Leading to the Specific Problem

A 63-year-old, right-hand-dominant man presents to a tertiary hand center complaining of poor grip strength, decreased arc of motion, and persistent pain at his right long and ring finger metacarpophalangeal (MCP) joints. The patient sustained a crush injury 3 months prior to presentation for which he underwent amputation of the right index finger, just distal to the MCP joint. His original surgical team did not attempt any operative interventions at his other joints. Given his ongoing pain and minimal deformity, we offered him staged pyrocarbon implant arthroplasty, beginning with the long finger MCP joint. Intraoperatively, his MCP joint was contracted and dislocated, with the proximal phalanx base positioned volar to the head of the metacarpal. After resecting the head of the metacarpal, the joint became unstable.

48.2 Anatomic Description of the Patient's Current Status

Anticipating intraoperative instability begins with identifying the appropriate inclusion and exclusion criteria for pyrocarbon arthroplasty. Owing to their nonconstrained design, pyrocarbon implants rely on good press fit into medullary bone and robust ligamentous support for stability. Before performing pyrocarbon arthroplasty, the surgeon must ensure that the patient has adequate cortical bone stock to support the implant. The surgeon must also confirm that the extensor mechanism, collateral ligaments, and capsular components of the joint are intact, or at least amenable to operative repair. Preoperative evaluation should always include three-view radiographs to delineate the degree of joint congruity and assess the cortical bone stock.

On physical examination, this patient demonstrated loss of active and passive range of motion at both the long and ring finger MCP joints, likely secondary to dense adhesions of the extensor apparatus (▶Fig. 48.1). When stressed in the radial and ulnar directions, neither joint proved unstable, suggesting the collateral ligaments were intact. Preoperative radiographs demonstrated loss of MCP joint congruity, destruction of the joint surface, and subluxation of the proximal phalanx base below the long metacarpal head (▶Fig. 48.2). Given his irreducible joint incongruity and proximal phalanx dislocation, we planned to perform radical bone resection and joint mobilization at the time of arthroplasty. Finally, owing to poor extensor tendon excursion, we planned extensor tenolysis to improve joint mobility.

48.3 Recommended Solution to the Problem

Intraoperative instability can occur even with meticulous technique, so it is important to understand the salvage maneuvers to remedy an unfavorable situation. Upsizing the distal and/or proximal implant can be an effective initial measure, as larger implants bridge tissue gaps to achieve better contact between implant components. In instances of ligamentous laxity or collateral ligament damage, repairing the ligament primarily or reconstructing the ligament with a tendon graft can restore soft-tissue stability.

In cases of intraoperative fracture, poor bone or soft-tissue support, or multifactorial instability, immobilization with external fixation provides the most structural integrity. External fixation not only keeps joints aligned, but immobilization allows repaired soft tissues to heal. Finally, if these techniques fail, surgeons may exchange pyrocarbon for constrained silicone prostheses. Here, external fixation was most appropriate.

48.3.1 Recommended Solution to the Problem

- In joints with large tissue gaps, upsizing implants can bridge space to improve implant apposition and stability.
- Collateral ligaments may be repaired primarily or with tendon reconstruction to further improve soft-tissue support.
- If the joint is unstable intraoperatively, an external fixator with pins placed proximal and distal to the implant immobilizes the joint for 6 to 8 weeks.
- If all other salvage maneuvers fail, the pyrocarbon implant may be exchanged for a constrained silicone implant.

48.4 Technique

48.4.1 Intraoperative Instability

As with preoperative examination, mitigating intraoperative instability starts with precise operative technique: fastidious attention to implant placement is key. We gain access to the joint through the sagittal band, which spares the extensor mechanism and preserves overall joint stability (▶Fig. 48.3). To select an appropriate place to ream the metacarpal, we identify the collateral ligament insertion on the dorsolateral depression of the metacarpal head and choose an entry point a safe distance away. On the cross-sectional axis, we advance the starter awl at a point one-third the distance to

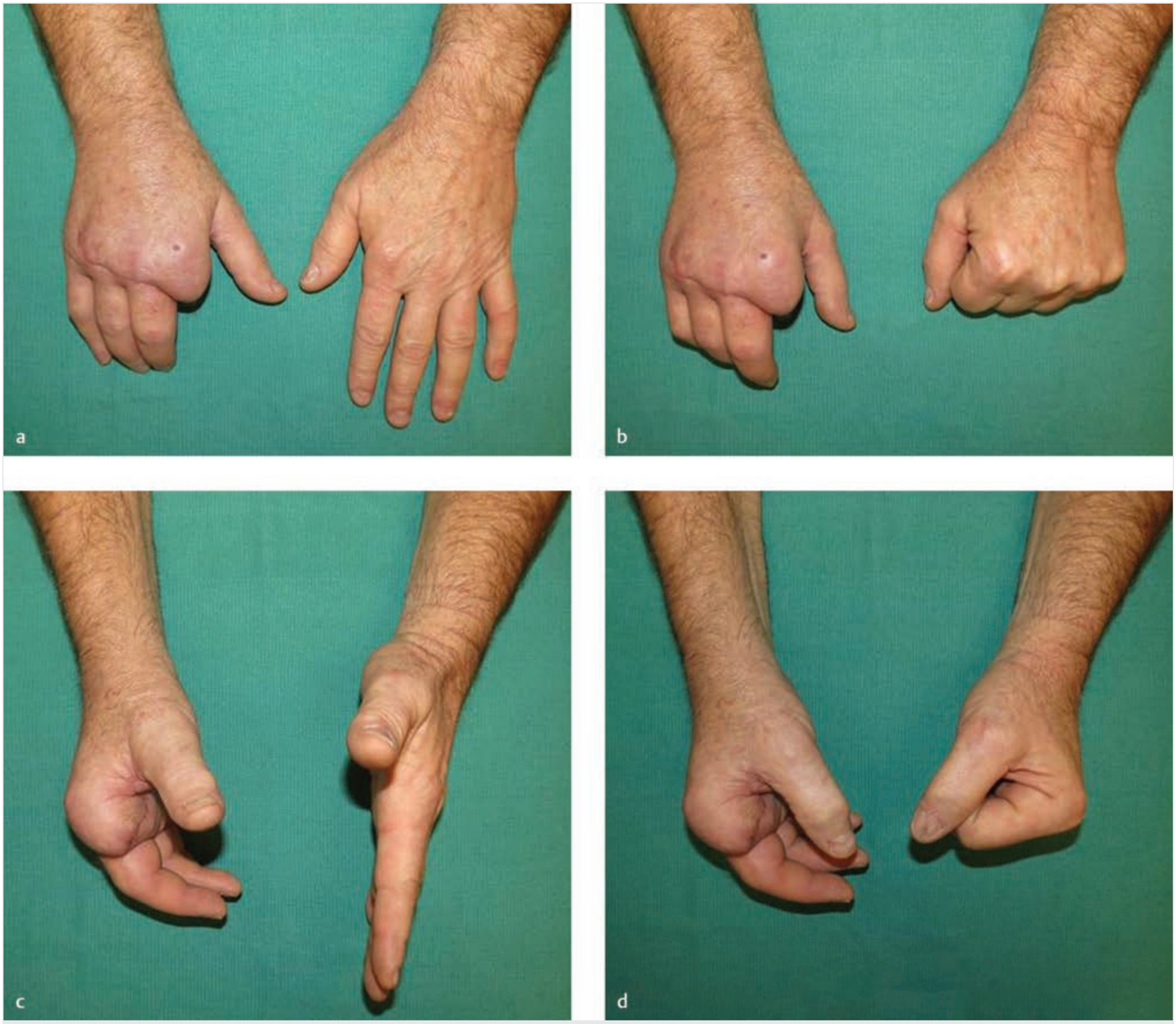

Fig. 48.1 (a–d) The patient demonstrated loss of active and passive range of motion at both the long and ring finger MCP joints, likely secondary to dense adhesions of the extensor apparatus.

Fig. 48.2 (a–c) The radiographs demonstrated loss of MCP joint congruity, destruction of the joint surface, and subluxation of the proximal phalanx base below the long metacarpal head (*arrows*).

the dorsal cortex and ulnar to midline. We use fluoroscopy to confirm we have not seated implant stems in a radial position, as this will place the joint at risk for ulnar drift and subsequent instability. We ream the proximal phalanx in a similar fashion.

For this patient, after we gained access to the joint, we clearly appreciated subluxation of the proximal phalanx base below the metacarpal head (▶Fig. 48.4a). We used an oscillating saw to remove the metacarpal head and reduce the joint, which removed the collateral ligaments as well. We distracted the proximal phalanx and removed the fibrinous material between the metacarpal and proximal phalanx with a rongeur. We seated a no. 30 in the metacarpal, but could not maintain joint congruity. Even after upsizing the proximal phalanx implant to a no. 40, the joint remained unstable (▶Fig. 48.4b).

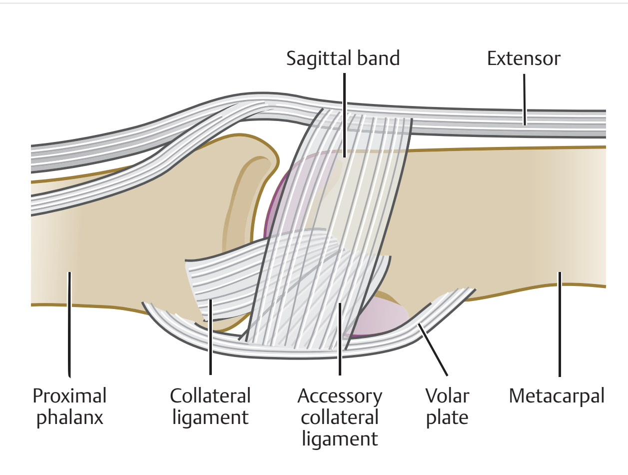

Fig. 48.3 We gain access to the joint through the sagittal band, which spares the extensor mechanism and preserves overall joint stability.

48.4.2 External Fixation

If instability occurs at the time of surgery, surgeons must make every effort to reduce and stabilize the joint. To begin external fixation, we made a 1-cm mid-axial incision over the distal head of the proximal phalanx. We dissected to an entry point between the Cleland ligament and the lateral band, which avoids the volar digital neurovascular bundle (▶Fig. 48.5). We then confirmed implant stem position with fluoroscopy. Starting with the distal pin, we inserted two offset 2.0-mm pins at 90 degrees, 5 mm distal to the end of the implant.

We made a second incision on the dorsal aspect of the hand over the proximal metacarpal base to the mid-shaft. We took care to retract the terminal branches of the radial sensory nerve. We moved the dorsal interosseous muscle anteriorly to make space for the pins. After identifying the extensor complex dorsally, we used fluoroscopy to identify the implant and inserted pins proximal and distal to the implant (▶Fig. 48.6).

We reduced the MCP joint to 10 degrees of flexion and placed a bar to secure the pins. We confirmed appropriate implant alignment with direct visualization and fluoroscopy (▶Fig. 48.7). We repaired the collateral ligament primarily using 4–0 braided horizontal interrupted sutures. Finally, we directed our attention to improving extensor mobility: using a no. 15 blade, we sharply excised interposing scar tissue between the extensor tendon at the MCP joint and the underlying bone. We repaired the sagittal band with 3–0 horizontal mattress braided permanent suture, and closed the skin. We left pins in place for 7 weeks.

48.4.3 Steps for the Procedure

1. Make additional incisions over the metacarpal base and proximal phalanx head.
2. Identify the implant stems under fluoroscopy, select insertion points for pins 5 mm distal from the implant stem.
3. Flex the MCP to 10 degrees to reduce the joint and lock the external fixator into place.

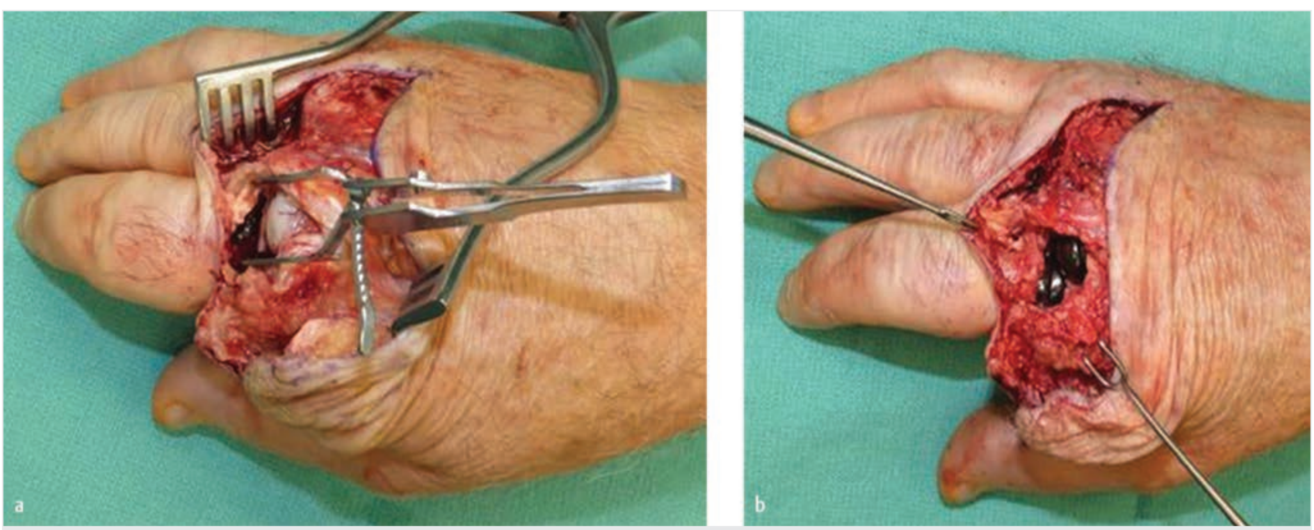

Fig. 48.4 **(a)** Subluxation of the proximal phalanx base below the metacarpal head. **(b)** An unstable joint continues despite increasing the size of the implant.

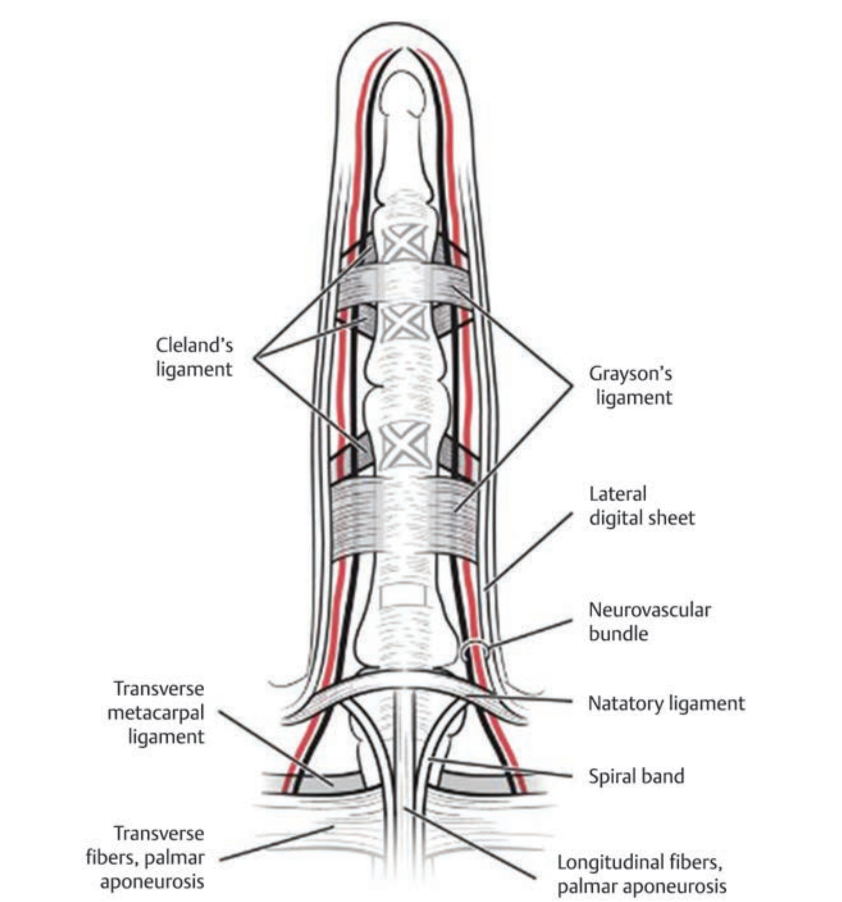

Fig. 48.5 The surgical entry point on the finger is between Cleland's ligament and the lateral band, which avoids the volar digital neurovascular bundle.

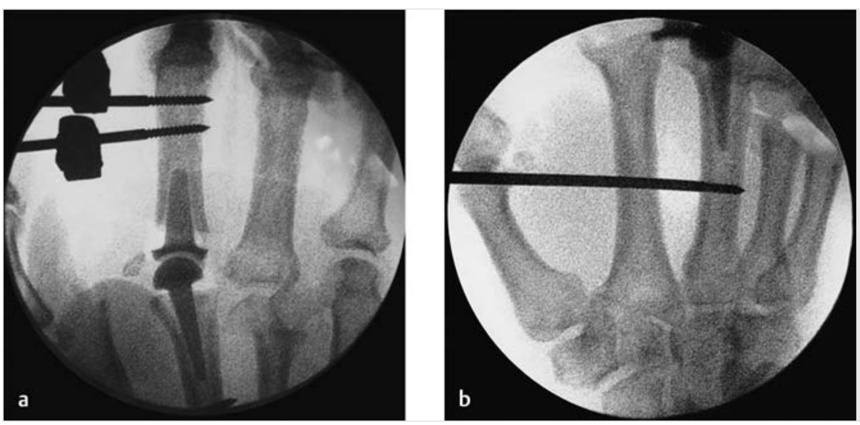

Fig. 48.6 (a, b) Fluoroscopy is used to identify the implant and inserted pins proximal and distal to the implant.

4. In cases of dense adhesions, free the extensor mechanism sharply with a no. 15 blade.
5. If the collateral ligament is damaged, repair with a 4–0 braided permanent horizontal mattress suture.
6. Leave pins in place for 6 to 8 weeks for adequate stabilization.

48.5 Postoperative Photographs and Critical Evaluation of Results

Initial studies indicate that unlike the high complication rate encountered at the proximal interphalangeal joint, pyrocarbon implants at the MCP joint are durable and provide good motion; however, much of the data on which these conclusions are based come from small retrospective cohorts with limited follow-up times. Thus, meticulous follow-up is imperative. We removed this patient's pins at 7 weeks, at which point the joint was reduced and stable. An additional operation was performed for his right ring finger MCP with an extensor indicis proprius (EIP) tendon transfer, proximal interphalangeal dorsal capsulotomy, and tenolysis at the level of the A1 pulley. He obtained sufficient arc of motion and he reported good satisfaction with his surgery (▶Fig. 48.8). Postoperative radiographs demonstrated good joint alignment (▶Fig. 48.9).

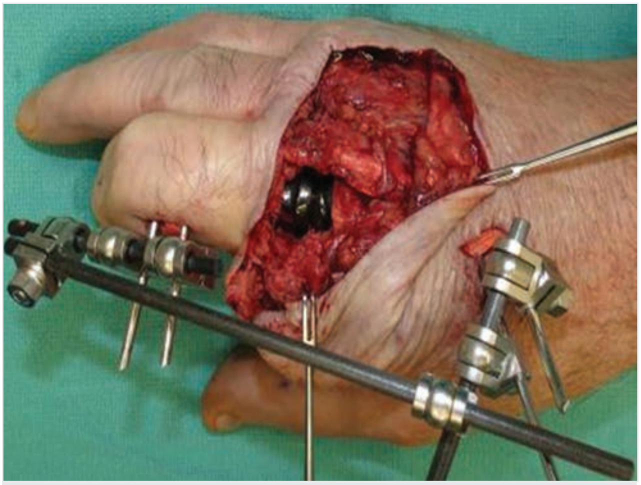

Fig. 48.7 Confirmed appropriate implant alignment with direct visualization and fluoroscopy.

48.6 Teaching Points

- Pyrocarbon implants rely on periarticular soft tissue and cortical bone for support; they are at risk for instability when these supports are inadequate.
- Preoperative physical examination should assess the extensor mechanism with active and passive range of motion testing, and evaluate the collateral ligament integrity with ulnar and radial stressing.
- Three-view radiographs are obtained to ensure adequate cortical bone stock.
- Intraoperative fracture, poor soft-tissue support, or trauma necessitating bone resection can all cause instability necessitating additional operative intervention.
- Upsizing implants, repairing collateral ligaments, external fixation, or replacing the pyrocarbon implant with a constrained one are all appropriate interventions upon encountering intraoperative joint instability.
- When performing external fixation, pins should be placed 5 mm from ends of implant stems.

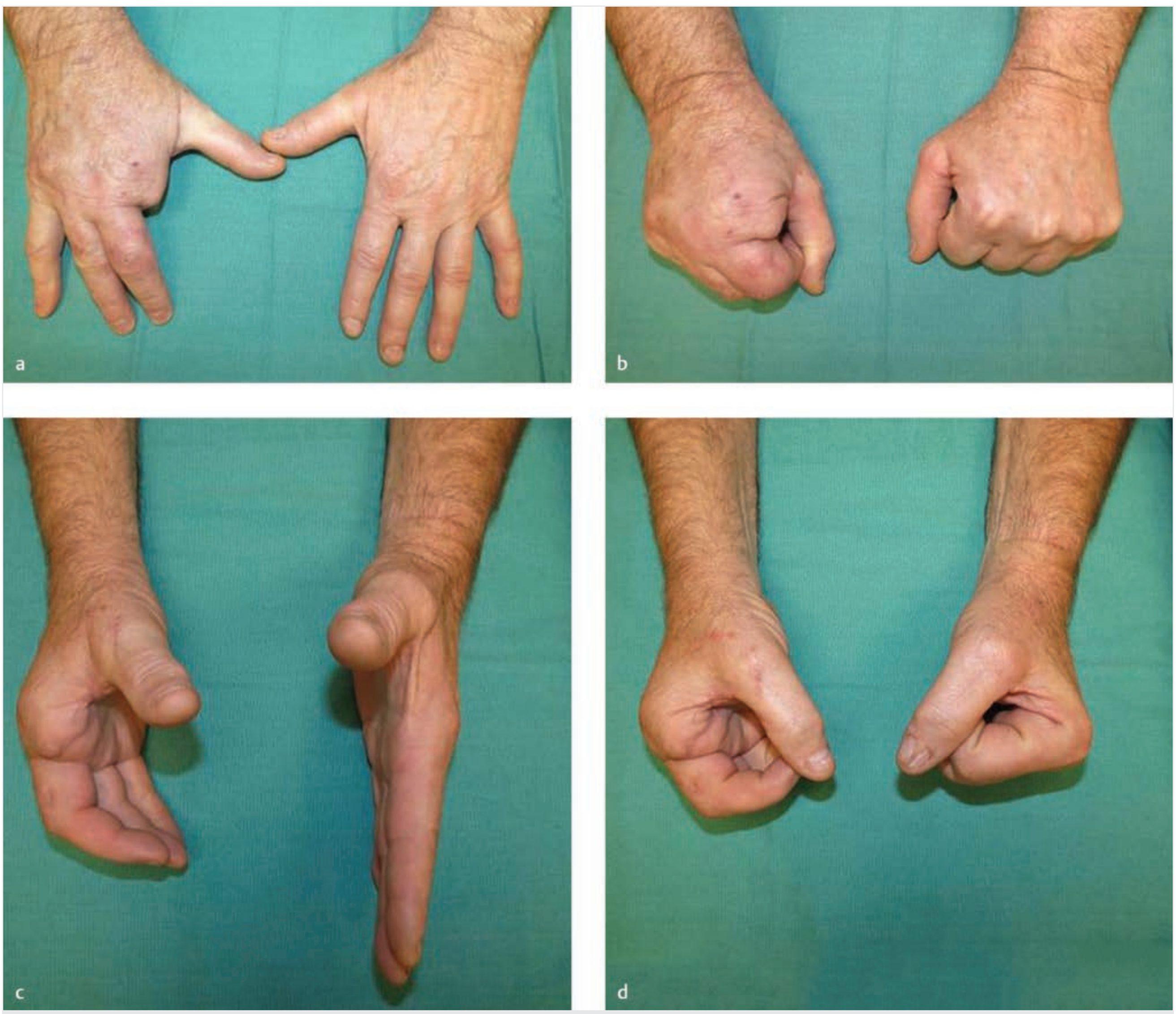

Fig. 48.8 (a–d) Satisfactory painless range of motion is observed. The joint is stable.

Fig. 48.9 (a–c) Radiographs confirm long-term maintenance of alignment.

Acknowledgments

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49 Revision of Subsided Pyrocarbon Implants

Steven C. Haase

49.1 Patient History Leading to the Specific Problem

A 55-year-old woman presents with a painful right middle finger metacarpophalangeal (MCP) joint. She has a history of osteoarthritis and underwent arthroplasty of this joint 6 years ago; one revision procedure was required 5 years ago for subsidence. Cement was used to secure the implant at the time of revision. Although she initially enjoyed pain-free motion, she has noticed increasing pain, limitation in motion, and shortening of the digit over time (▶Fig. 49.1).

Fig. 49.1 **(a–c)** Radiographs demonstrating pyrocarbon metacarpophalangeal joint arthroplasty with subsidence. **(d)** The patient's right middle finger is shortened and deviated ulnarly.

49.2 Anatomic Description of the Patient's Current Status

▶Fig. 49.1 shows the characteristic silhouette of a pyrolytic carbon (pyrocarbon) implant arthroplasty at the middle finger MCP joint. Although most authors have reported a large proportion of good and excellent results with this implant in this location, occasional problems do occur.

Currently, both components of the implant have subsided dramatically, such that there is now an encasement of bone around the implant, and impingement of the metacarpal bone against the proximal phalanx bone with hand use. Furthermore, there is subluxation of the joint such that the two components of this surface replacement arthroplasty are no longer properly articulating with each other. This has led to a reduction in possible range of motion and overall shortening of the digit, in addition to an increase in pain from the bony impingement.

While this degree of subsidence is relatively uncommon, a similar situation can arise if an undersized implant is utilized, leading to bony impingement with ulnar and/or radial deviation (▶Fig. 49.2).

Fig. 49.2 Radiograph showing an undersized pyrocarbon implant, with bony impingement on the ulnar side of the metacarpophalangeal joint.

49.3 Recommended Solution to the Problem

- Bony resection should be minimized, although some bone resection may be required to extract the existing implant.
- Implants cemented in place may present unique removal challenges. Extraction can be sometimes be facilitated by creation of a dorsal longitudinal osteotomy and use of a bone tamp to dislodge the implant. Residual cement can be removed with an appropriate high-speed burr if needed.
- Given the failure of two previous attempts at surface replacement arthroplasty, conversion to a hinged silicone arthroplasty is appropriate.
- Using a larger silicone implant can help partially correct the bone deficit and restore some length to the digit.

49.4 Technique

The surgery is performed in the operating room with the patient in the supine position. Although multiple types of anesthesia would suffice, we prefer light sedation plus a regional block (supraclavicular technique), due to the extended period of comfort provided for many hours after surgery. Bier block or WALANT (wide-awake local anesthesia and no tourniquet) are two other good options; general anesthesia is probably not indicated for most patients. The hand is prepped and draped in sterile fashion. Use of a tourniquet makes visualization easier, although the need for a tourniquet could be reduced with use of a local anesthetic containing epinephrine.

A dorsal longitudinal incision provides excellent visualization of the involved structures; in this case, the previous scar was utilized (▶Fig. 49.3a). The extensor tendon is split longitudinally, and the joint capsule is opened. In this case, the capsule was very thin dorsally, and the metacarpal component of the implant was readily identified, surrounded by chronic synovitis (▶Fig. 49.3b). The implants were easily removed, as the cement was not adherent to the surrounding bone (▶Fig. 49.3c).

Minimal bone resection was performed to remove cortical prominences around the medullary openings, which were then carefully broached up to the maximum size silicone implant that could be inserted without compromising the already atrophic bone (▶Fig. 49.4a). Only minimal broaching was required due to the bony resorption and remodeling resulting from the previous implant. Residual collateral ligaments on the radial and ulnar sides of the joint were carefully preserved. After installing the silicone implant, intraoperative fluoroscopy revealed a well-seated implant without any residual bony impingement (▶Fig. 49.4b).

Capsular closure was performed, followed by repair of the split extensor tendon with nonresorbable sutures. Routine skin closure was performed. The patient was immobilized in a volar resting splint with the fingers in position of function. Occupational therapy was initiated on postoperative day 5, beginning with active flexion and active-assisted extension using a dynamic orthosis.

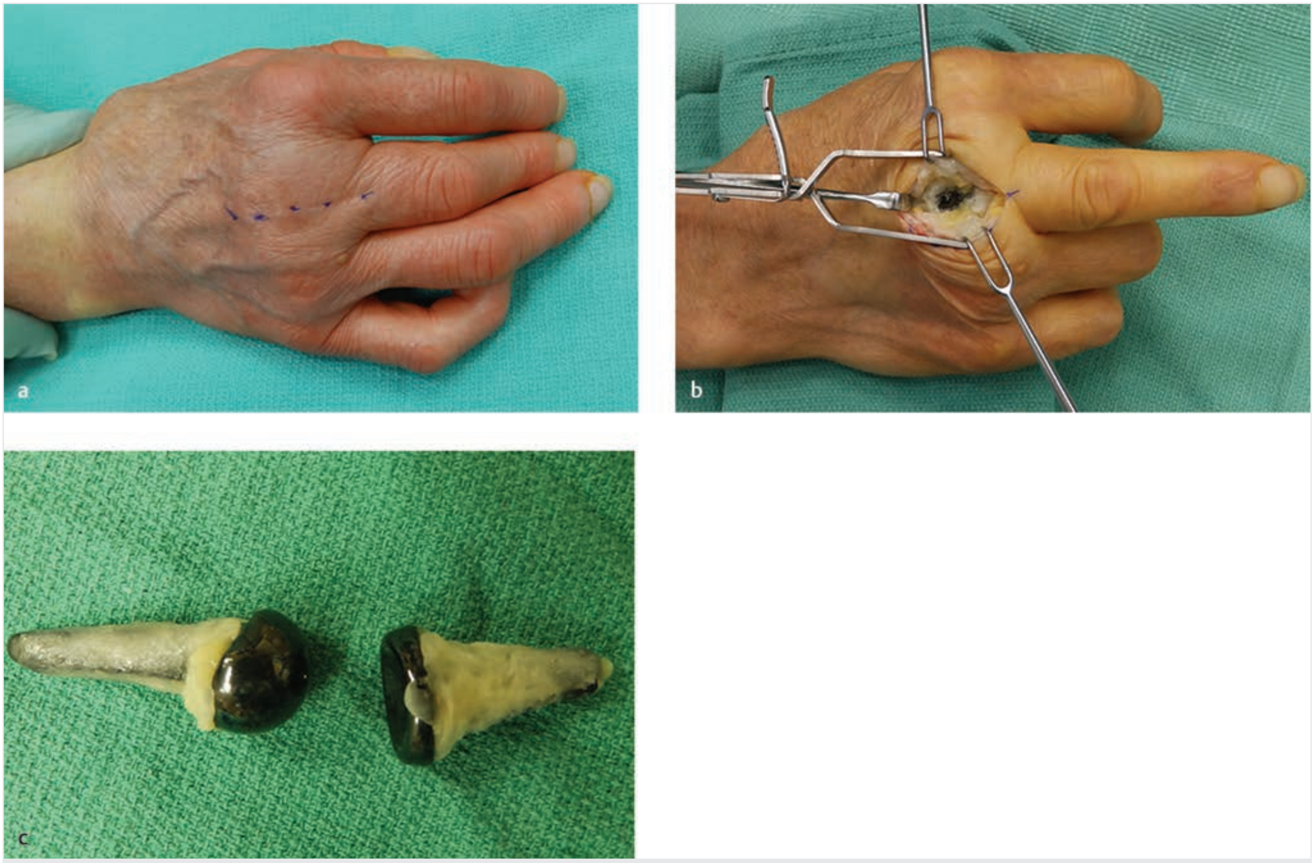

Fig. 49.3 **(a)** Revision surgery is performed from the dorsal approach, utilizing previous scar. **(b)** The implant is exposed by splitting the extensor tendon. **(c)** In this case, the cement was not adherent to the bone, and removal was easily accomplished.

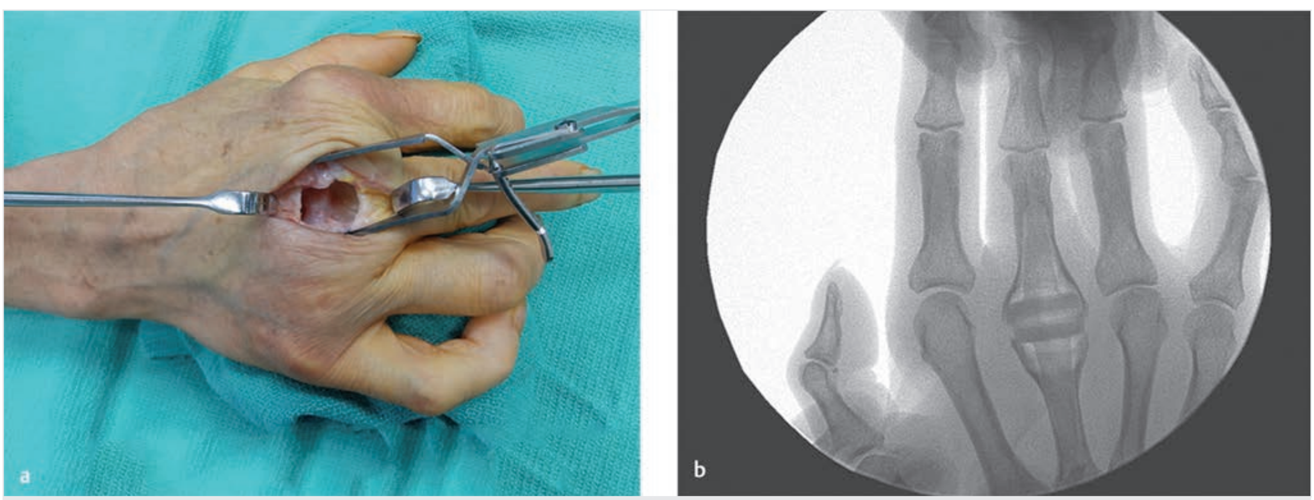

Fig. 49.4 **(a)** The arthroplasty space was created by minimal bone resection and careful broaching. **(b)** Intraoperative fluoroscopy shows the silicone implant in position.

49.5 Postoperative Photographs and Critical Evaluation of Results

Careful review of postoperative radiographs (▶Fig. 49.5) revealed the distal implant stem had become folded on itself. It is not clear how this occurred, since the patient reported no interval trauma, and the implant appeared seated properly at the time of placement. It is theorized this was due to the overly capacious medullary space resulting from previous bone resorption. After thorough discussion with the patient, a joint decision was made to observe this over time.

One year after surgery, the patient reports improved hand function, with reduction in pain and increased strength. She was very satisfied with her ultimate result, although her finger remains short relative to the adjacent digits (▶Fig. 49.6a–d). Radiographs reveal the implant position to be stable, although the distal stem remains folded (▶Fig. 49.6e–g). There is

Fig. 49.5 (a–c) Postoperative films in the outpatient clinic show that the distal stem of the implant is folded over on itself.

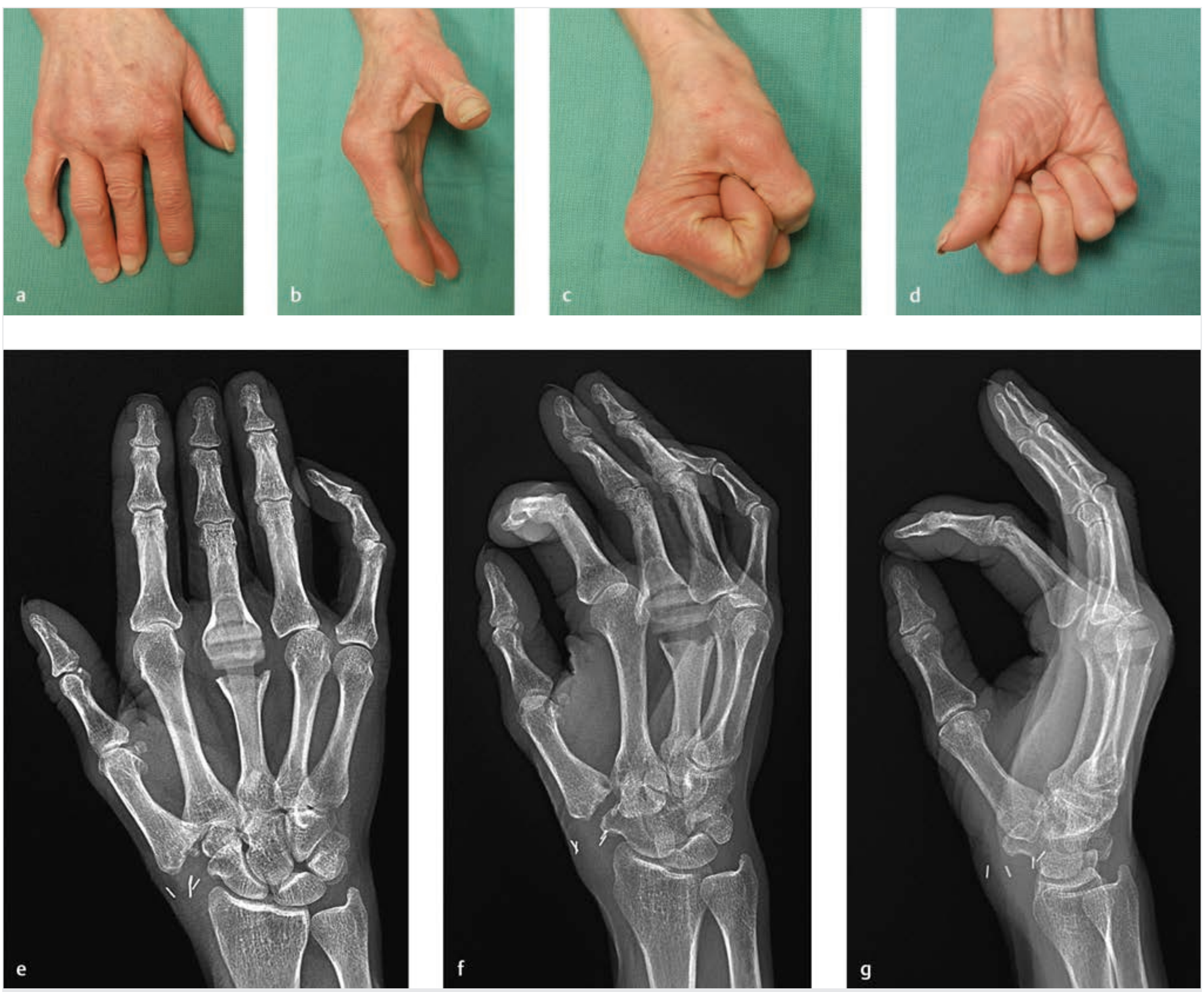

Fig. 49.6 (a–d) Clinical and **(e–g)** radiographic images of the patient at one-year follow-up, showing improved function and stable implant arthroplasty on radiographs.

evidence of some bone growth/consolidation around the stems of implant, reducing some of the medullary void that had been present.

49.6 Teaching Points

- Subsidence of pyrocarbon implants, or use of undersized implants, can lead to painful bony impingement and synovitis.
- In cases of failed surface replacement arthroplasty, consider salvage with a hinged silicone implant.
- Minimize bone resection at the time of revision and preserve collateral ligaments, if present.
- Implant the largest silicone implant that the medullary canal and/or soft tissues can accommodate. With a trial implant in place, confirm that full passive motion is possible before making a final choice on the implant size.
- These patients can follow routine occupational therapy for MCP silicone arthroplasty in most cases.

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Part XVII

Problems with Interphalangeal Osteoarthritis

50 Failed Silicone Proximal Interphalangeal Joint Arthroplasty *232*

51 Stiffness in Interphalangeal Osteoarthritis *238*

52 Contracture in Interphalangeal Osteoarthritis *241*

53 Proximal Interphalangeal Posttraumatic Osteoarthritis *244*

XVII

50 Failed Silicone Proximal Interphalangeal Joint Arthroplasty

Elvira Bodmer and Stephan Schindele

50.1 Patient History Leading to the Specific Problem

We report a case of a 67-year-old woman who had suffered from known severe osteoarthritis in the finger joints, long-standing complaints, and pain of several proximal interphalangeal (PIP) joints with resultant loss of mobility. Prior to our consultation, an implantation of a PIP silicone arthroplasty to the PIP joint of the middle finger using volar approach was performed at another hospital due to severe pain.

After the surgery, the patient was satisfied initially and showed a significant pain relief. However, fixated ulnar longitudinal axis deviation, active range of motion (ROM), and pain aggravated over the following years. At the time of our first consultation of the patient, which took place 3 years after primarily performed surgery, the treated finger showed an ulnar axis deviation of 20 degrees and a ROM of 55 degrees; full extension was possible. Increased functional restriction in combination with pain due to disturbing ulnar axis deviation with instability of the radial collateral ligament and loss of mobility provided the indication for further treatments (▶Fig. 50.1).

50.2 Anatomic Description of the Patient's Current Status

Arthroplasty is a well-established proven treatment option for destructed PIP joints caused by degenerative or posttraumatic osteoarthritis. Compared to arthrodesis, arthroplasty shows increased patient acceptance and significant improvement of function as a result of preserved mobility especially of the ulnar rays. Our own experience in accordance to literature show promising outcome and low complication rate in the long term; an average of 50- to 60-degree ROM can be expected.

Disadvantages of silicone arthroplasty are low implant stiffness and necessary partial resection of collateral ligaments, which often causes a postoperative axis deviation, especially to the ulnar side. In particular, preoperative axis deviation with insufficiency of the collateral ligaments plays a key role for a renewed axis deviation in the long term. This phenomenon is accentuated by implant breakages, which are usually not clinically symptomatic and do not require treatment or revision arthroplasty, as this occurrence is not necessarily painful. The rate of implant breakage occurrence varies from 10 to 30% according to the literature.

Finger joints treated with silicone arthroplasty do not show a physiological rolling motion such as anatomically healthy joints or joints with surface replacement. In such interposition arthroplasties as represented by silicone arthroplasty, volar bony impingement occurs frequently due to deformation of material. Therefore, it is particularly important that the bone be resected sufficiently volar on the proximal and distal side.

In our presented case, pain could not be significantly alleviated by the priorly performed silicone arthroplasty in the long term. Active flexion postoperatively was similar to the possible flexion preoperatively. However, there was a temporary flexion contracture of 30 degrees. Three years after the primary surgery, the patient suffered from pain again, showed an increased ulnar deviation of 20 degrees, a restriction of ROM with a flexion of 55 degrees, and full extension. Fingertip to palmar distance was 2 cm at the affected finger (▶Fig. 50.2a). Implant breakage was suspected radiologically (▶Fig. 50.2b).

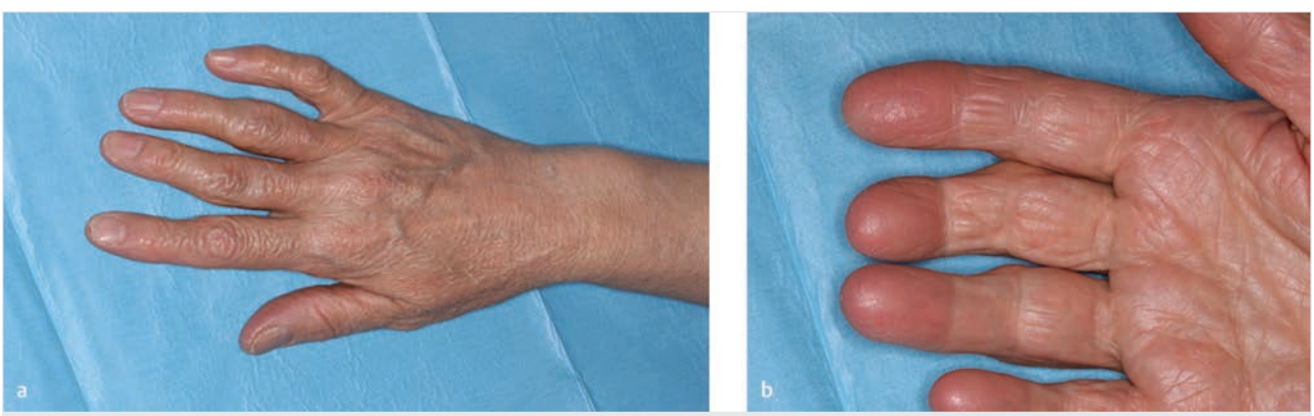

Fig. 50.1 **(a, b)** Photographs show the patient 3 years after primary silicone replacement of the middle finger. Patient with limited ROM, persistent pain, and increasingly ulnar angulation.

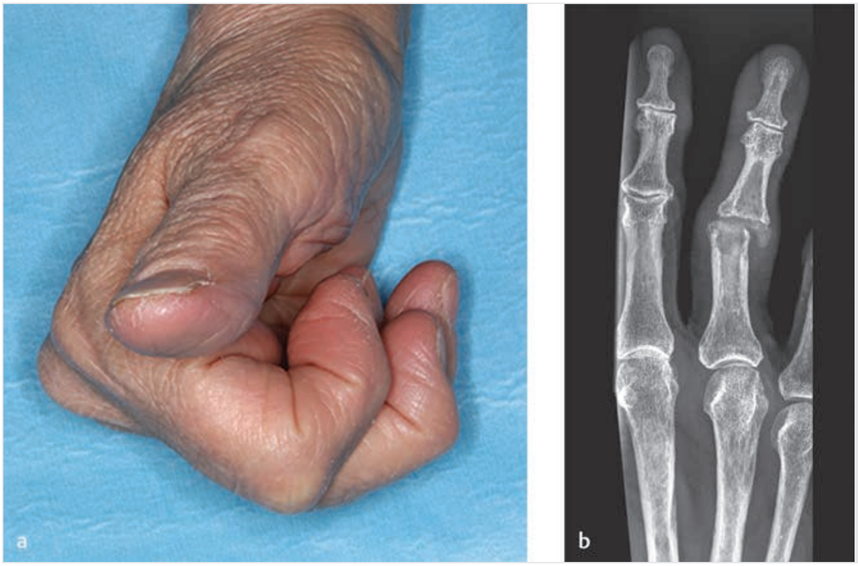

Fig. 50.2 **(a)** Restricted active flexion with fingertip to palm distance of 2 cm at the middle finger. **(b)** X-ray shows a broken silicone implant between the proximal stem and the hinge.

50.3 Recommended Solution to the Problem

Persistent pain after primary silicone arthroplasty is rare. Not every breakage of a silicone implant necessitates revision, because the silicone implant still serves as a spacer with the result that no increased pain is expected and good function can be preserved. Additionally, Swanson described in the early 60s a soft-tissue reaction due to the silicone material, which he called "encapsulation." This soft-tissue capsule should provide in the long term stability and pain-free mobility even in broken silicone implants. However, revision is recommended and promising, if pain and active restricting mobility are dominant. The correction of an axis deviation after silicone arthroplasty is not always satisfying due to flexibility of the material. Nevertheless, soft-tissue reconstruction with the reconstruction of the radial collateral ligament should be carried out during the revision surgery together with replacement of the silicone implant. Arthrodesis as revision surgery is recommended for strong deformity with unstable collateral ligaments.

50.3.1 Recommended Solution to the Problem

- Not every implant failure needs revision.
- Pain and restriction of ROM can often be well addressed by revision surgery.
- Massive ulnar deviation is difficult to correct in the long term. In these cases, arthrodesis is recommended.
- Collateral ligament reconstruction should be performed together with the revision surgery involving a change of the silicone implant.
- Silicone arthroplasty of the PIP joint can be done using a dorsal or a volar approach depending on the previous operation and clinical findings.

50.4 Technique

Revision procedure takes place in the operation theater under local, regional, or general anesthesia with tourniquet to the upper arm or forearm level. As the primary procedure was carried out from the volar side, a Bruner incision in the area of the scar with the base of the flap on the radial side was performed. Visualization of both vascular and nerve bundles and preparation leading to the flexor tendons are shown in ▶Fig. 50.3a–c. A flexor tendon sleeve between A2 and C1 pulleys under entrainment of the volar plate and checkrein ligaments are formed (▶Fig. 50.3d,e). After release of the ulnar-sided collateral ligament, the complete visualization succeeds with hyperextension of the joint dorsally like a shotgun approach (▶Fig. 50.3f–h). Then the broken silicone implant is completely removed. The volar cortical bone lip at the base of the middle phalangeal is smoothened. Both marrow spaces are prepared for any possible placement of the implant using the corresponding rasps. The next step is positioning of the definitive silicone implant and clinical and radiological control. Overstuffing must be avoided, because this often leads to strong impairment of ROM. Thereafter, the radial collateral ligament is reconstructed with nonabsorbable suture (▶Fig. 50.3i) in an anatomical position. The flexor tendon sheath is refixed with a 4–0 or 5–0 absorbable sutures (▶Fig. 50.3j). The next steps are skin closure (▶Fig. 50.3k), sterile hand bandage, and volar splint in slightly flexed position of the fingers. The first change of dressing is done after 3 to 5 days with application of a thermoplastic splint in intrinsic plus position immobilizing the PIP joints for 3 to 4 weeks.

50.4.1 Steps for the Procedure

1. Volar approach as described by Simmen and Schneider.
2. Resection of the volar cortical bone lip at the base of the middle phalanx.

3. Reconstruction of the collateral ligaments with nonabsorbable 3–0 suture.
4. Postoperative immobilization for 3 to 4 weeks after collateral ligament reconstruction.

50.5 Postoperative Photographs and Critical Evaluation of Results

In our case report, pain could be positively influenced by the performed revision arthroplasty. The active ROM improved significantly to a flexion of 75 degrees and an extension lag of 15 degrees active and 0 degrees passive. The ulnar axis deviation was corrected from 20 to 10 degrees (▶Fig. 50.4a,b). In contrast to the primary PIP arthroplasty with early immobilization, we recommend an additional postoperative immobilization of 3 to 4 weeks after PIP revision surgery in case of preoperative axis deviation (▶Fig. 50.5). This immobilization relieves the reconstructed collateral ligament and additionally corrects the most contract and fixed soft tissues of the entire finger. The approach in the case of revision is dependent on the primary approach. However, there is a prevailing problem on the volar side after a dorsal approach (osseous impingement); we recommend relocating the approach to volar. The postoperative radiograph shows the resection of the volar cortical bone lip at the base of the middle phalanx as recommended (▶Fig. 50.6).

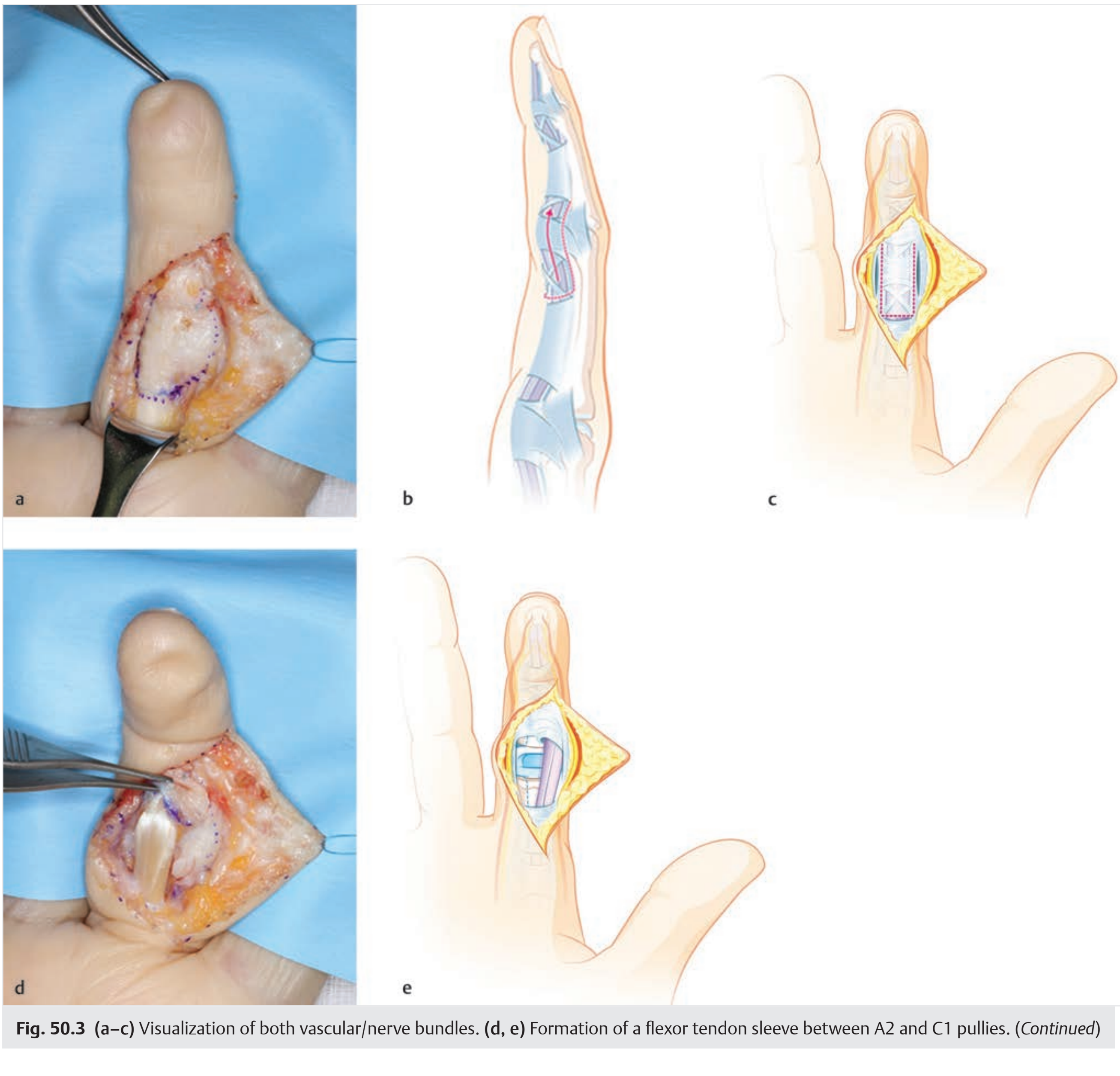

Fig. 50.3 (a–c) Visualization of both vascular/nerve bundles. **(d, e)** Formation of a flexor tendon sleeve between A2 and C1 pullies. (*Continued*)

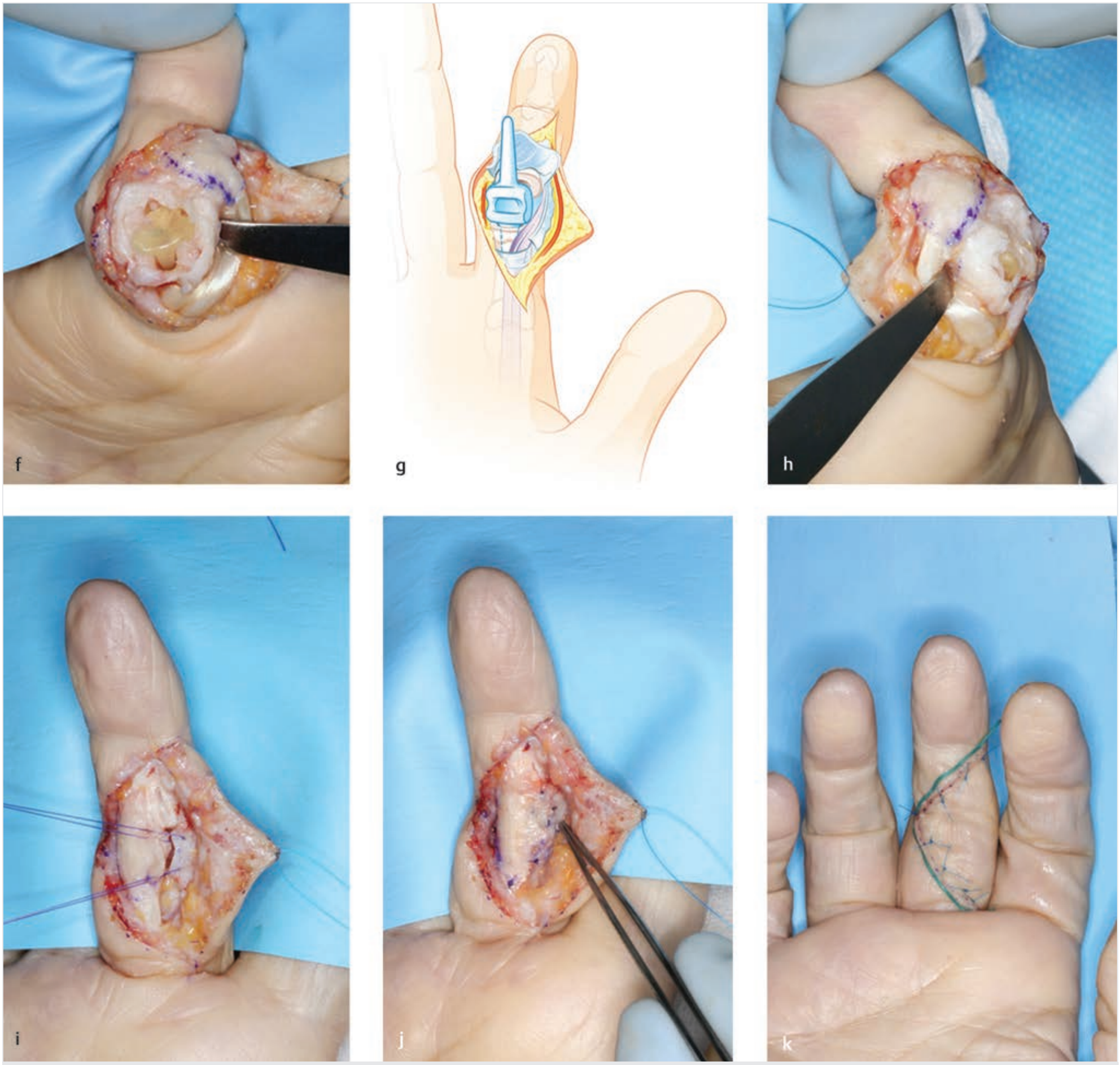

Fig. 50.3 (*continued*) **(f–h)** Visualization succeeds with hyperextension of the joint dorsally. **(i)** Reconstruction of the radial collateral ligament with nonabsorbable suture. **(j)** Refixation of the flexor tendon canal with absorbable sutures. **(k)** Skin closure with nonabsorbable suture.

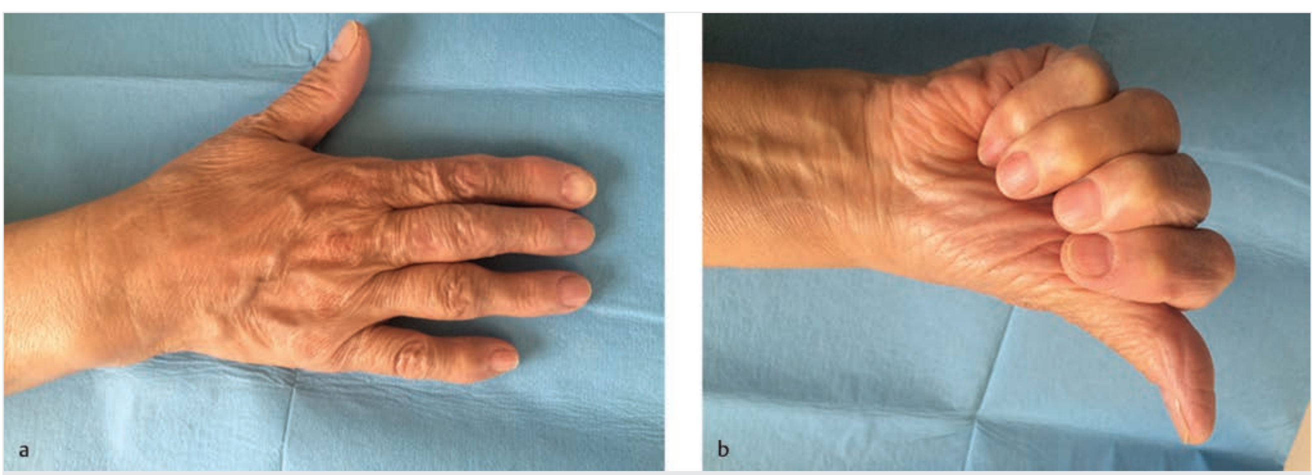

Fig. 50.4 **(a, b)** Six months after revision surgery, the middle finger presents sufficient correction of ulnar deformity and better active range of motion.

Fig. 50.5 Postoperative immobilization of the affected finger in a thermoplastic splint for 3 to 4 weeks in revision surgery.

50.6 Teaching Points

- Pain and restriction of active ROM can be well addressed by revision arthroplasty.
- In our clinic, the most commonly used size of the original Swanson PIP joint silicone implant is size 1 for the index, middle, and ring fingers, and size 0 for the little finger.
- A larger implant is often necessary in revision surgery.
- For the volar approach, it is important that both vessel and nerve bundles are visualized.
- After soft-tissue reconstruction, immobilization of 3 to 4 weeks postoperatively is recommended to allow sufficient and stable scar formation and new encapsulation.
- Arthrodesis as revision procedure is preferred in very unstable soft-tissue situations with an axis deviation of more than 30 degrees.

Fig. 50.6 **(a, b)** Postoperative radiographic control shows correct angulation in the posteroanterior view and well-resected bony lip at the volar proximal phalangeal with no subsidence of the silicone implant.

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51 Stiffness in Interphalangeal Osteoarthritis

Peter M. Murray, Kimberly H. McVeigh, and Ammar Humayun

51.1 Patient History Leading to the Specific Problem

A 66-year-old, right-hand-dominant, retired female teacher presents with a progressive history of right hand stiffness and pain. These symptoms have progressed to the point that she finds it difficult to manipulate fine objects and to tend to such activities as buttoning shirts and typing on a computer. These symptoms have developed over a 5-year period. She has been diagnosed with index, long, and small finger degenerative osteoarthritis of the proximal interphalangeal (PIP) joints (▶Fig. 51.1). Her symptoms were refractory to nonoperative management including nonsteroidal anti-inflammatory drugs, hand therapy, and resulting orthosis. At the time of presentation, the patient's range of motion at the PIP joints was as follows: index finger 20 to 45 degrees; long finger 25 to 50 degrees; and small finger 20 to 60 degrees.

She had full and unrestricted range of motion of the metacarpophalangeal joints (MCP) of the right hand. Ultimately, the patient underwent surface replacement arthroplasty of the index, long, and small finger PIP joints (▶Fig. 51.2).

Rehabilitation was started at 5 days postoperative and consisted of a volar-based splint, which allowed for progressive, controlled PIP flexion as follows: 0 to 30 degrees of flexion from week 0 to 2; 0 to 60 degrees of flexion from week 2 to 4; and unrestricted PIP joint flexion thereafter. The patient's postoperative course was slow and although she was compliant with orthosis wear, she was reluctant to flex her fingers at the PIP joints due to fear of "rupturing the implants."

51.2 Anatomic Description of the Patient's Current Status

At 3 months postoperative, she complained of ongoing stiffness and swelling of the right hand. The patient's PIP joint range of motion improved from the preoperative range of motion: index finger 20 to 65 degrees; long finger 15 to 80 degrees; and small finger 20 to 80 degrees. Her MCP motion, however, was restricted and measured 0 to 60 degrees for the index, long, ring, and small fingers. With hyperextension of the MCP joints of the index, long, and small fingers, the PIP joint flexion was only 40 degrees of each digit. With maximum flexion of each of the MCP joints, the PIP flexion could be restored to the following: index finger 65 degrees; long finger 80 degrees; and small finger 80 degrees. This finding was indicative of intrinsic tightness or stiffness of the right hand. This test is known as the Bunnell intrinsic tightness test (▶Fig. 51.3).

51.3 Recommended Solution to the Problem

The patient should start with hand therapy, to include intrinsic stretching of each of the affected digits, MCP extension block

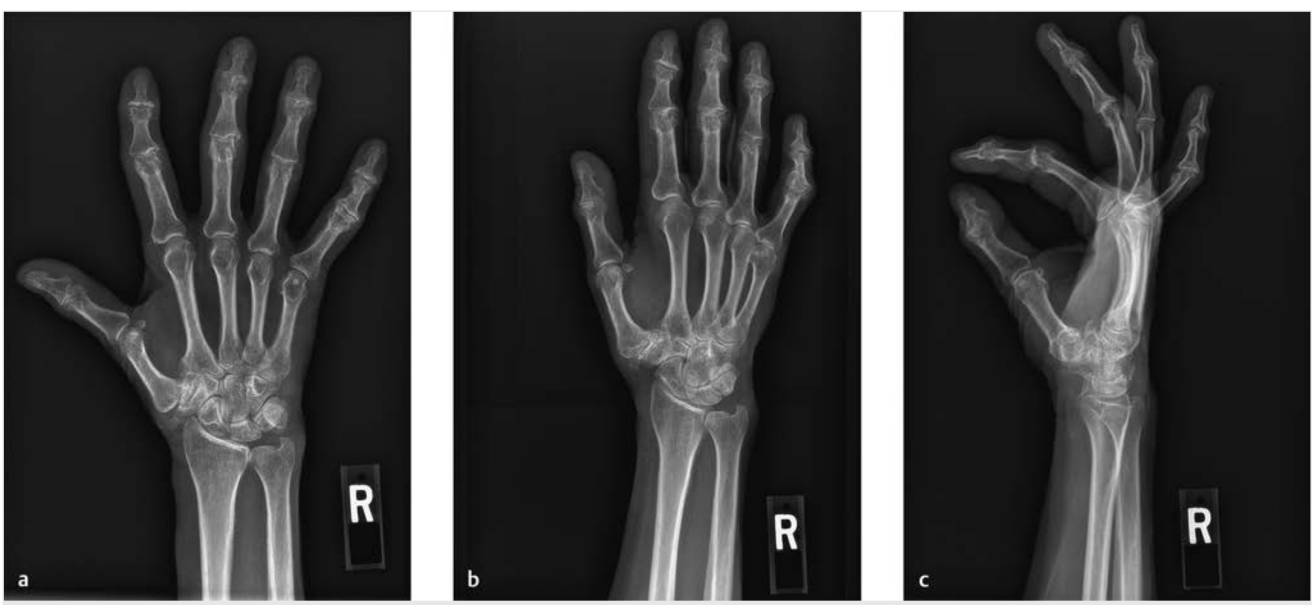

Fig. 51.1 (a–c) Preoperative posteroanterior, lateral, and oblique radiographs of the right hand demonstrating advanced proximal interphalangeal joint degenerative osteoarthritis of the index, long, and small fingers.

Fig. 51.2 (a–c) Postoperative posteroanterior, lateral, and oblique radiographs of the right hand demonstrating nonconstrained surface replacement arthroplasties of the index, long, and small fingers.

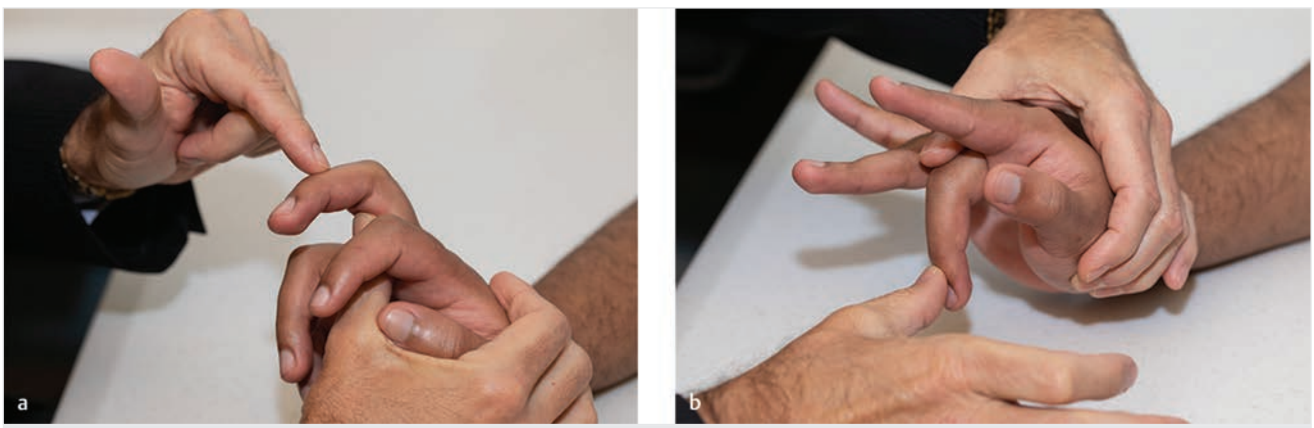

Fig. 51.3 (a, b) Performance of the Bunnell intrinsic tightness test.

orthosis to provide active intrinsic stretching during activities of daily living (▶Fig. 51.4), anti-edema exercise to include overhead fisting maneuverers of the right hand as feasible by the patient, and an anti-edema glove for the right hand to be worn 8 hours per day. The patient should also be given a Medrol dose pack (Solu-Medrol 8 mg, 6 mg, 4 mg, and 2 mg given over a 4-day period).

If there is no response from nonoperative management by 6 months, intrinsic release of the index, long, and small digits is necessary.

51.4 Technique

A longitudinal incision is made over the MCP joints of the index, long, and small fingers (▶Fig. 51.5). The ulnar and radial intrinsic tendons are identified deep in the wound. The intrinsic tendons are delivered into the surgical field with a small retractor. A 1-cm portion of each digital radial and ulnar intrinsic tendon is resected. The Bunnell test is repeated to insure improvement of PIP joint flexion with the MCP joint in the hyperextended position.

51.5 Postoperative Photographs and Critical Evaluation of Results

Following intrinsic release, PIP motion in all MCP positions can be expected to improve and be maintained, relieving the patient of the sensation of digital stiffness. Swelling of the digits can be expected to improve with the use of a Medrol dose pack and anti-edema garments.

Fig. 51.4 Metacarpophalangeal extension block orthosis to provide active intrinsic stretching during activities of daily living.

51.6 Teaching Points

- Prolonged orthosis wear with limited active and passive PIP joint range of motion following PIP joint surface replacement arthroplasty can lead to intrinsic tightness of the hand.
- The Bunnell test is an accurate way of determining the presence of intrinsic tightness.
- In the absence of improvement in digital stiffness following an integrated and therapy program, intrinsic release may be necessary to restore PIP joint range of motion following PIP surface replacement arthroplasty complicated intrinsic tightness.

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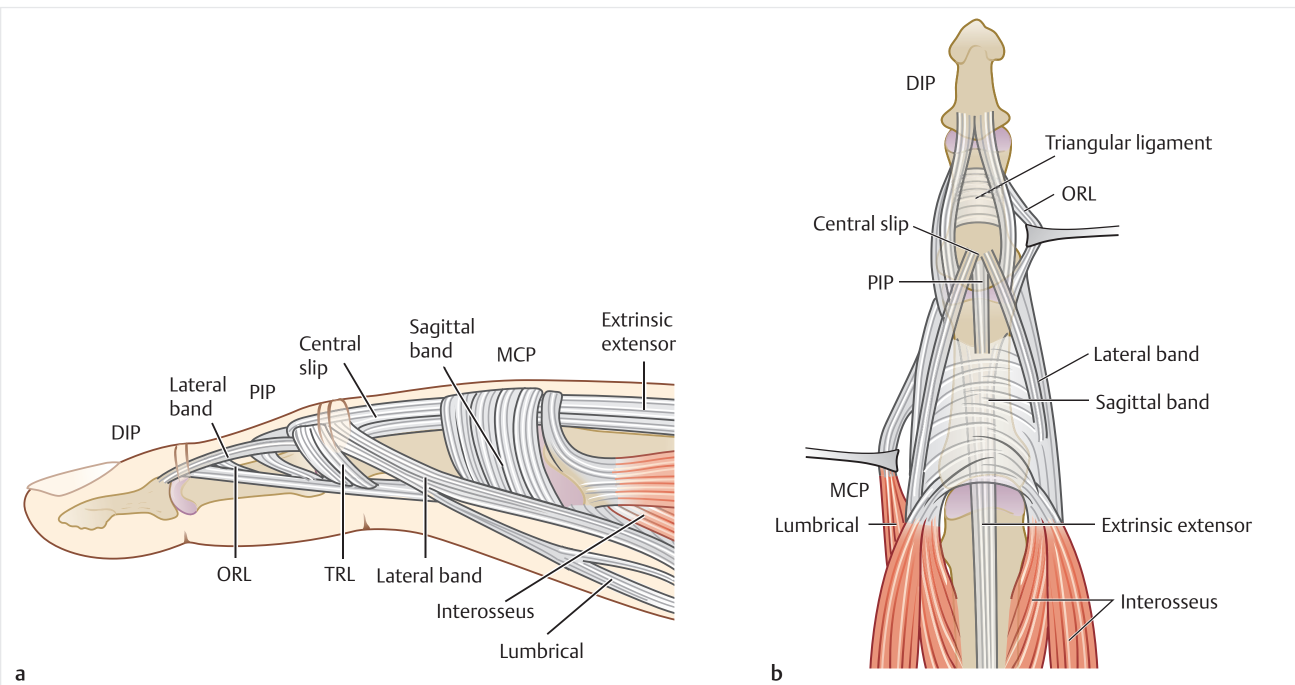

Fig. 51.5 **(a, b)** Dorsal view of the extensor mechanism of the finger. Extrinsic and intrinsic contributions of the dorsal aponeurosis.

52 Contracture in Interphalangeal Osteoarthritis

Peter M. Murray, Kimberly H. McVeigh, and Ammar Humayun

52.1 Patient History Leading to the Specific Problem

A 78-year-old woman presents with difficulty moving her right hand. She has a several year history of right hand digital pain of the index and long fingers. She has noticed a progressive loss of digital range of motion of the right hand, particularly involving the index and long fingers. She is now 6 months postoperative following proximal interphalangeal (PIP) joint surface replacement arthroplasty for advanced, symptomatic degenerative osteoarthritis of the index and long PIP joints. Prior to surgery, she was treated with a variety of nonoperative measures including nonsteroidal anti-inflammatory drugs, outpatient hand therapy, a resting orthosis, and activity modifications. Her preoperative ranges of motion for the index and long finger PIP joints were 20 to 47 degrees of flexion and 20 to 60 degrees of flexion, respectively.

The modified Chamay dorsal approach was used for both the index and long finger PIP joint surface replacement arthroplasties whereby a 3-cm longitudinal incision was first made over the proximal phalanx. A distally based flap of the extensor mechanism was then made to expose the PIP joint and the collateral ligaments were maintained (▶Fig. 52.1). The proximal phalanx and middle phalanx components were inserted in a press fit fashion and cement was deemed not necessary.

Rehabilitation was started at 5 days postoperative and consisted of a volar-based digital short arc motion orthosis, which allowed for progressive, controlled PIP flexion as follows: 0 to 30 degrees of flexion from week 0 to 2, 0 to 60 degrees of flexion from week 2 to 4, and unrestricted PIP joint flexion thereafter (▶Fig. 52.2).

52.2 Anatomic Description of the Patient's Current Status

At 3 months postoperative, the long finger PIP joint motion was 20 to 80 degrees of flexion and was considered functional. The index finger PIP joint, however, was contracted in 0 degrees of extension with no demonstrative digital flexion (▶Fig. 52.3). Due to failure of progression of index finger digital motion, aggressive hand therapy was instituted including active-assisted and passive range of motion of the isolated index finger PIP joint as well as a dynamic flexion orthosis for the PIP joint (▶Fig. 52.4). Despite continued hand therapy, no progress was made in the index finger PIP joint contracture by 6 months postoperative. It was determined at that time that surgical intervention was necessary.

52.3 Recommended Solution to the Problem

The recommended solution to the problem is extensor tenolysis, supraclavicular regional anesthesia with indwelling catheter placement for 3 days, and immediate, postoperative aggressive, supervised hand therapy to include active-assisted and passive range of motion as well as a dynamic flexion orthosis.

Fig. 52.1 Chamay's approach to the proximal interphalangeal joint through a distally based flap of the extensor mechanism.

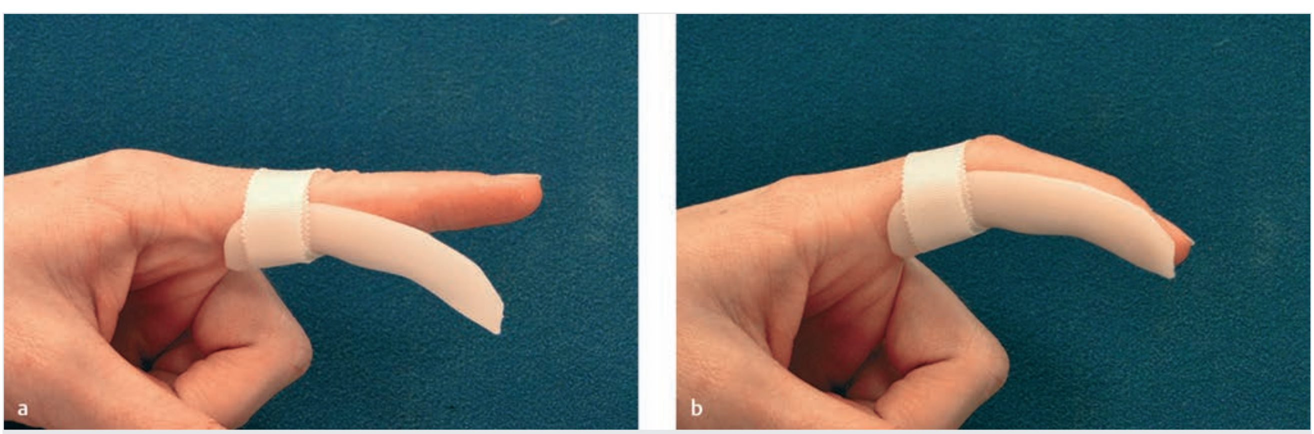

Fig. 52.2 (a, b) An example of a digital short arc motion orthosis.

Fig. 52.3 (a–c) Postoperative radiographs following nonconstrained surface replacement arthroplasty of the left index and long finger PIP joints.

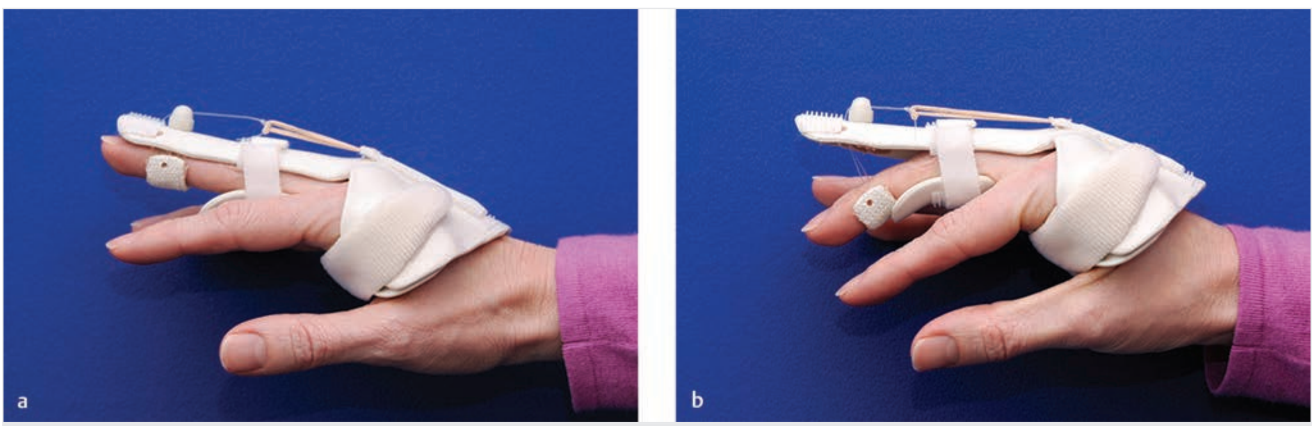

Fig. 52.4 (a, b) An example of a dynamic digital flexion orthosis.

52.4 Technique

Through a dorsal approach (using the same incision used for the index procedure), the extensor mechanism is fully exposed. The radial and ulnar margins of the extensor mechanisms are identified throughout the extent of the proximal phalanx.

A freer elevator is used to gently separate the extensor mechanism from the dorsal cortical surface of the proximal phalanx, which had become adherent due to adhesion formation. This is carried out throughout the full length of the proximal phalanx. During the freeing of extensor mechanism adhesions, great care is exercised to protect the insertion of the extensor tendon at the base of the middle phalanx.

In a firm but controlled fashion, the PIP joint is then manipulated into flexion, being careful to not disrupt the insertion of the extensor tendon at the base of the middle phalanx (▶Fig. 52.5).

52.5 Postoperative Photographs and Critical Evaluation of Results

At the time of surgery, it can be anticipated that up to 90 degrees of flexion of the PIP joint can be obtained. It is common that the ultimate postoperative PIP joint flexion result following tenolysis will be less than that obtained at the time of surgery. This reality must be stressed to the patient in order that realistic expectations are established preoperatively. Attenuation or even failure of the extensor mechanism, particularly at the extensor tendon insertion at the base of the middle phalanx is a very real potential postoperative complication of extensor tenolysis and PIP arthroplasty manipulation. This can lead to extensor tendon incompetence postoperatively and ultimately can result in a boutonniere deformity.

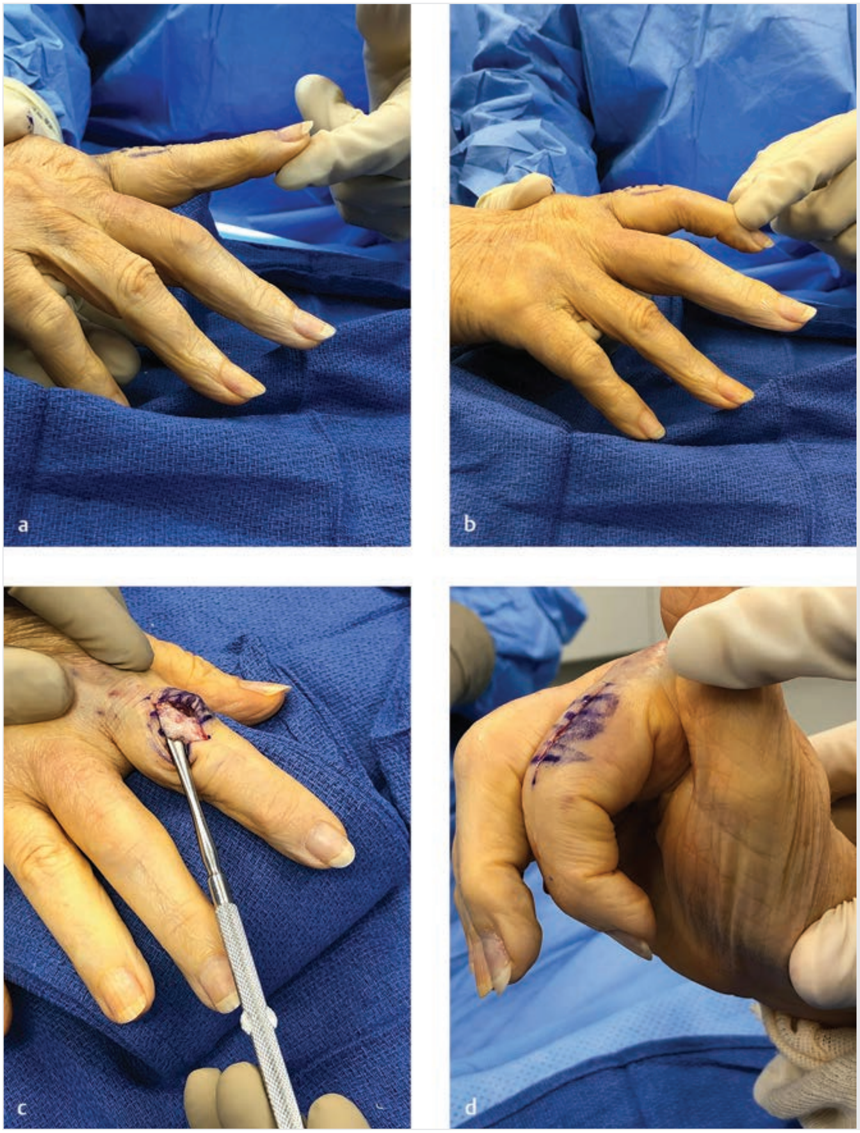

Fig. 52.5 (a, b) Pre-op range of motion of the index proximal interphalangeal (PIP) joint. **(c)** Intraoperative tenolysis of the extensor mechanism using a Freer elevator. **(d)** Resulting index finger PIP joint motion immediately following tenolysis.

52.6 Teaching Points

- The dorsal Chamay approach to the PIP joint can result in an extension contracture of the PIP joint despite the early initiation of hand therapy to restore digital flexion.
- The first line of treatment is an aggressive hand therapy regime to include active-assisted range of motion and a dynamic digital flexion orthosis.
- Operative treatment includes extensor tenolysis under regional anesthesia with an indwelling catheter, which permits complete limb anesthesia for 3 days and facilitated early, aggressive postoperative hand therapy.
- Postoperative hand therapy should include active-assisted range of motion and a dynamic digital flexion orthosis.
- Ultimate postoperative flexion range of motion is seldom maintained at the same level as that obtained at the time of tenolysis.
- Extensor tendon attenuation or even failure resulting in a boutonniere deformity can occur following an extensor tenolysis and PIP joint manipulation.
- Realistic expectations regarding the extent of flexion recovery should be set with the patient preoperatively.

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53 Proximal Interphalangeal Posttraumatic Osteoarthritis

Sergio Daroda and Fernando Menvielle

53.1 Patient History Leading to the Specific Problem

A 35-year-old woman sustained a fracture dislocation of the proximal interphalangeal (PIP) joint. She presents years later with persistent pain at the PIP joint and gross deformity of her ring finger of her left nondominant hand. The discomfort impairs her to deal with her work at the green grocery and the activities of daily living. The patient is an active manual worker who requires almost complete mobility with grip and pinch strength without pain.

53.2 Anatomic Description of the Patient's Current Status

The inspection of the patient's left hand shows a rotational and ulnar deviation of the ring finger at the PIP joint. The passive PIP joint motion results in 40 degrees of flexion and −30 degrees of extension, with normal metacarpophalangeal and distal interphalangeal joints. Simple radiographs show the PIP joint with a dorsal dislocation with severe damage to the articular surfaces, not only the base of the middle phalanx but also the condyles of the proximal one (▶Fig. 53.1).

53.3 Recommended Solution to the Problem

We should keep in mind that the best solution to this particular problem would have been to have dealt with it immediately. In spite of the easy diagnosis, these old injuries are very frequent, and the delayed diagnosis does not allow us to give them a better solution. The patient has severe arthritis at the PIP joint with deformity and joint discontinuity.

53.3.1 Recommended Solution to the Problem

- With the two articular surfaces damaged, the PIP joint cannot be reconstructed so we need to think of an arthroplasty or an arthrodesis.
- Our first option is an arthroplasty with a second-toe vascularized articular transfer (SVAT).

Fig. 53.1 (a, b) The anteroposterior and lateral radiographs show ulnar deviation and dorsal dislocation of the PIP joint with a mirror articular damage.

- We do not recommend the use of PIP prosthesis in young patients with high strength demands.
- The PIP joint arthrodesis is an option, but our patients were dissatisfied with the lack of flexion and the aesthetic appearance.

53.4 Technique

At the recipient site, we make a curved dorsal incision centered at the PIP joint. The extensor apparatus is released and prepared for the tendon suture. The proximal and distal osteotomies are performed, and the damaged joint is elevated with the volar plate and kept on the operating table. Extreme care should be taken not to injure the flexor tendons, the digital nerves, and the digital vessels. The next step is the preparation of the recipient vessels. Depending on the length of the pedicle, we localize a proper digital artery close to the operative site or we make an extra incision at the distal palmar crease for a larger common digital artery. We identify a vein proximal to the dorsal incision.

The donor site is then addressed. With the patient in the supine position, the tourniquet is applied without exsanguination for an easy identification of the vascular tree. A dorsal approach is made on the ipsilateral foot over the first interosseous space and we proceed to identify the venous return of the flap. We continue the incision up to the first web space. If the dominant vessels are dorsal, we perform the dissection up to the digital artery, taking a long pedicle. But if the dominant pedicle is plantar, we go directly to the digital artery skipping the complex dissection of the plantar vessels. Venous interposition graft will likely be needed to acquire appropriate length to reach the recipient vessels. We always elevate the flap with a monitor skin paddle centered on the dorsomedial cutaneous vessels, which will not compromise the articular vessels. The tendon extensor is harvested and the transverse osteotomies are performed. We keep the flap vascularized for about 20 minutes to assure a correct perfusion before cutting the pedicle.

After adjusting the measurements of the transfer, the osteosynthesis is performed with one transarticular longitudinal nail and two extra-articular transversal ones to prevent rotation. Then the extensor tendon is reconstructed and the vessels are sutured either directly or with a bypass. Finally, the skin is closed keeping the monitor island to evaluate the correct flap perfusion. We use the excised articular block as a nonvascularized graft for the reconstruction of the donor site to minimize morbidity (▶Fig. 53.2).

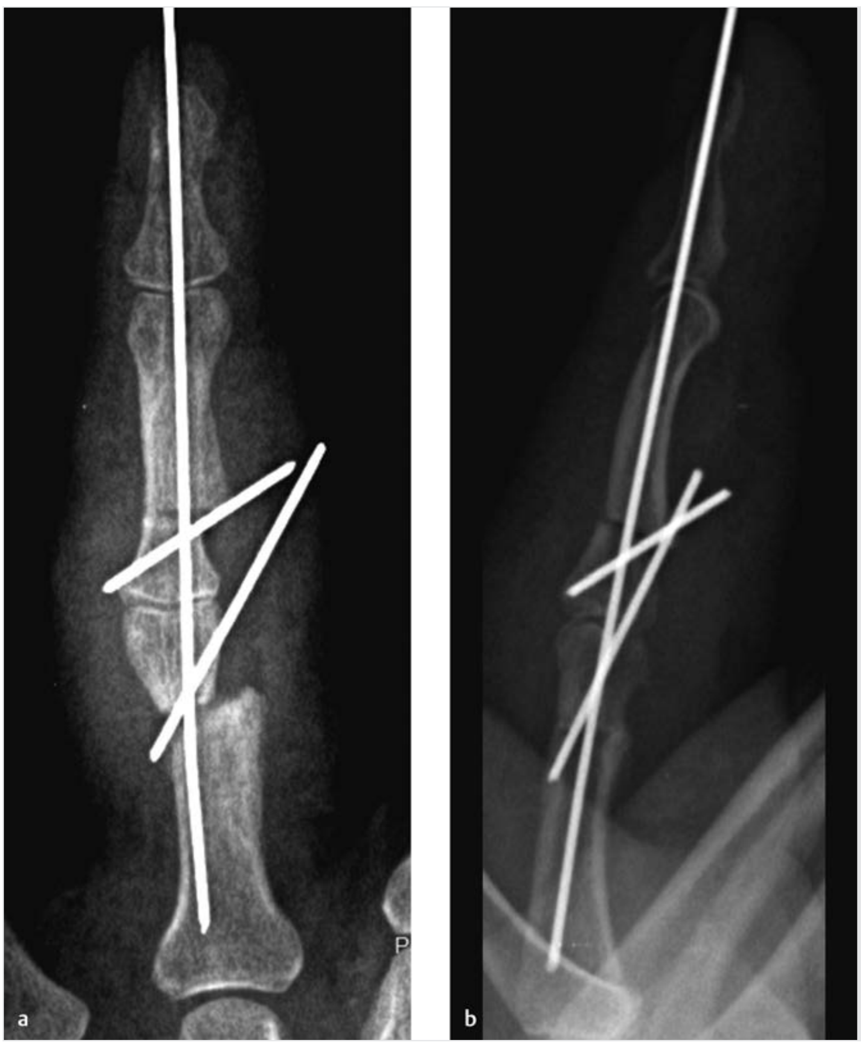

Fig. 53.2 (a, b) Immediate postoperative radiographs with minimum osteosynthesis.

53.4.1 Steps for the Procedure

See ▶Video 53.1.

1. Address the recipient site:
   - Dorsal approach.
   - Transversal osteotomies.
   - Isolation of dorsal veins and volar arteries.
2. Address the donor site:
   - Tourniquet without exsanguination.
   - Identification of the vascular pattern of the first web, either dorsal or plantar.
   - Retrograde arterial dissection.
   - Preservation of a monitor skin island.
   - Twenty minutes of compound flap vascularization before cutting the vessels.
3. Assemble:
   - Adjustment of the flap length.
   - Osteosynthesis with one longitudinal and two transversal Kirschner's wires.
   - Direct microanastomosis or interposition if needed.
   - Second toe reconstruction with the excised ring finger PIP joint.

53.5 Postoperative Photographs and Critical Evaluation of Results

The patient has a 1-year follow-up with a pain-free PIP motion of 60 degrees in flexion and 0 degrees in extension (▶Fig. 53.3). She has a mild shortening and radial rotation that corrects with the closing fist. She is very satisfied with the final result and was able to return to her previous job. She does not have any pain or impairment for the ambulation. The PIP arthroplasty with a SVAT offered this patient a good result with absence of pain and an acceptable motion and final grip.

Because of its biological homologous nature, once the osteotomies are healed, the SVAT will maintain the same structure without changes in the future. The SVAT is a surgical technique that has passed the proof of time, but it is highly demanding and takes a long curve of learning. The donor site offers low morbidity, minimizing the second-toe shortening with the interposition of the excised block from the PIP ring finger.

Fig. 53.3 **(a, b)** One-year follow-up with consolidation of both osteotomies with a good axis. **(c–e)** Final appearance and motion.

53.6 Teaching Points

- The best solution for this patient is to diagnose and treat her at the initial time of the injury.
- We must evaluate the two articular PIP surfaces to offer the right treatment.
- The extensor tendon should be elevated with the vascularized joint.
- A monitor skin pad is used to evaluate the perfusion of the compound flap.
- A simple osteosynthesis should always be used.

Acknowledgments

The authors are grateful to Gilda Ines Pinciroli for her help in translation of this chapter.

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Part XVIII

Problems with Infection in the Thumbs, Fingers, and Wrist

54 Inadequate Drainage of Infection in the Thumbs, Fingers, and Wrist *250*

55 Salvage of Osteomyelitis of the Distal Radius after Internal Fixation of an Open Fracture *253*

56 Infectious Destruction of the Wrist *259*

XVIII

54 Inadequate Drainage of Infection in the Thumbs, Fingers, and Wrist

Nikhil Agrawal and William C. Pederson

54.1 Patient History Leading to the Specific Problem

A 38-year-old diabetic man presents with worsening pain and swelling of his left ring finger (▶Fig. 54.1). About 5 days ago, he sustained a small laceration on the volar surface when he was working with a screwdriver in his garage. Two days ago, he was seen in a minor emergency center and had drainage of a small "superficial" abscess on the volar surface of this finger by the ER physician. He was started on oral cephalosporins and he was told to soak this.

54.2 Anatomic Description of the Patient's Current Status

The patient presents with a serious infection of the hand after an inadequate incision and drainage. He appears to have flexor tenosynovitis as well as an abscess on the dorsal hand, the so-called collar button abscess. Inadequate treatment of the infection in the face of his diabetes has led to marked progression of the infection.

Early on with flexor tenosynovitis, there may not be obvious purulent drainage but on minimal palpation, purulence can sometimes be expressed. The septations that form separate abscess pockets can fool the surgeon into thinking that all the infection has been drained when it is actually just lurking nearby.

The most important anatomical consideration in this case is the presence of bursae and potential spaces in the hand that must be taken into account. The ulnar and radial bursae have an important connection in the forearm, which is called Parona's space. This potential space lies between pronator quadratus and flexor digitorum profundus and can result in a "horseshoe abscess" that tracts from the small finger tendon sheath connecting to the thumb flexor tendon sheath. The deep thenar space and the mid-palmar space also should be taken into account. This patient appears to have extension of the abscess to the dorsal hand in the loose tissues of the web space and was found at surgery to have extension of the abscess into the distal forearm in the region of Parona's space.

When bacteria inoculate the tendon sheath, the pressure can rise above 30 mm Hg. High pressures then obstruct the arterial flow to the tendon sheath. The effects of poor blood flow are twofold. One, inflammatory cells and antibiotics are unable to get to the infection and fight it adequately. Second tendon ischemia and necrosis result in long-term damage. Dead tissue mixed with synovial fluid that is devoid of white blood cells is an ideal breeding ground for bacteria and further long-term damage. If the patient and extremity survive the infection, then the hand surgeon will be left with a nonviable tendon and muscle that must be debrided. Eventually the surgeon must come up with a plan to make that extremity as functional as possible.

54.3 Recommended Solution to the Problem

The problems that need to be fixed include adequate drainage of the infection (through debridement of nonviable tissue), skin coverage, and function of the hand. All of those will be addressed operatively.

54.3.1 Recommended Solution to the Problem

- Debridement of nonvital tissues.
- Reconstruction of the complex soft-tissue defect.
- Rehabilitation.

54.4 Technique

The patient is taken to the operating theater and put under general anesthesia. A tourniquet is applied and a povidone–iodine prep is done. The arm should be elevated for exsanguination instead of an elastic bandage to prevent spreading of the infection more proximally. The tourniquet is inflated.

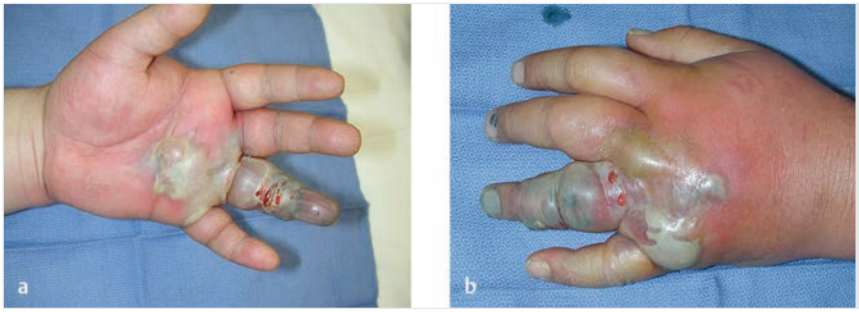

Fig. 54.1 (a, b) A serious infection of the hand after an inadequate incision and drainage. He appears to have flexor tenosynovitis as well as an abscess on the dorsal hand, which is the so-called collar button abscess.

The first step is drainage. Usually, the previous incision must be incorporated, but the finger must be opened enough to allow complete drainage and debridement (▶Fig. 54.2). Multiple cultures should be taken and tissue sent for pathology and culture. All necrotic tissue is then debrided to healthy bleeding tissue, with the possible exception of neurovascular structures. Fasciotomies must be considered or extended if there is any question of increased compartment pressures. The wound should then be heavily irrigated. The understanding that the wound should be packed and dressings should be kept loose and allow for drainage was understood and originally developed by Hippocrates.

Subsequent washout procedures follow the same steps and are repeated until the patient is recovered systemically from infection and debridement is deemed to be adequate. Adequate debridement may require amputation as in this patient who required a ray resection to adequately get rid of the necrotic, infected tissue (▶Fig. 54.3).

First and foremost, the infection must be adequately drained. After the relief of pressure that comes with removal of all purulent fluid, the patient should feel that their pain has improved, not worsened. In a case of necrotizing fasciitis, multiple washouts should be planned to allow the infected and necrotic tissue to fully demarcate. Healthy tissue is most clearly and simply identified by seeing it bleed when incised sharply.

Skin should never be closed if there is any question of remaining infection or tension of the skin closure. It is never wrong to perform dressing changes and allow a wound to granulate and heal by secondary intention. In most situations with a larger wound, partial wound closure with a skin graft may be feasible, but in the case of a complex wound, a flap may be required. If there are exposed vital structures, they may be covered by fascia, muscle, dermal matrix, or partial closure of the wound. This patient required a radial forearm flap to reconstruct the soft-tissue defect (▶Fig. 54.4).

The most important consideration is future functionality of the hand. In the short term, there may be missing tendon or muscle that was debrided. In the long term, adhesions from scarring are certain to limit tendon excursion despite aggressive occupational therapy and splinting. The tendons will require either two-stage tendon repair or tendon transfer. Tendon repair should occur only once the wound is totally clean and infection free.

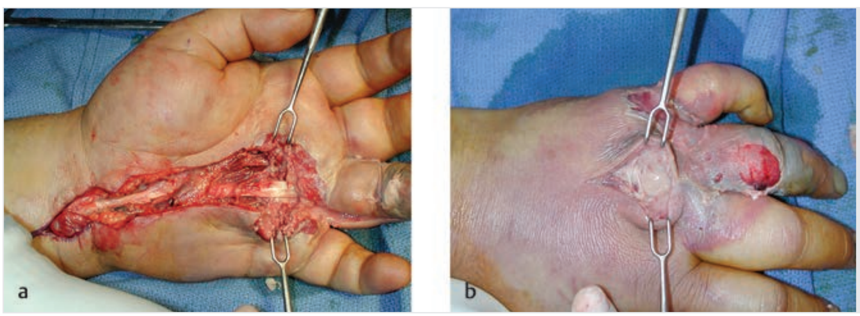

Fig. 54.2 (a, b) The finger must be opened enough to allow complete drainage and debridement. All devitalized tissue is excised. New cultures are taken.

Fig. 54.3 (a) Extended necrosis due to the initial limited drainage. **(b, c)** Adequate debridement may require ray amputation.

Fig. 54.4 (a–c) Soft-tissue closure obtained with a radial forearm flap.

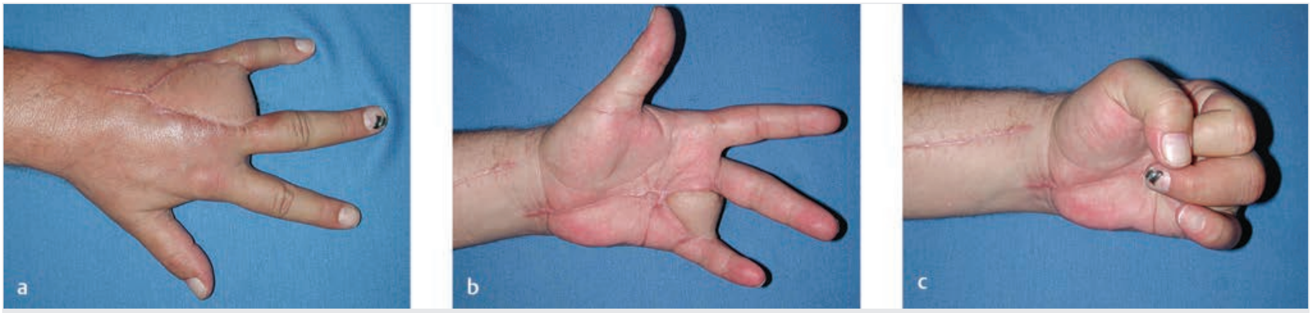

Fig. 54.5 (a–c) Final outcome following infection control, debridement, definitive closure, and therapy.

54.4.1 Steps for the Procedure

1. Complete the drainage of the infection and obtain cultures.
2. Wash wound out and debride unhealthy tissue.
3. Repeat trips to the operating room for washouts and debridements.
4. Soft-tissue reconstruction as necessary.

54.5 Postoperative Photographs and Critical Evaluation of Results

The patient was started on range of motion (ROM) exercises prior to leaving the hospital. He had no further problems with infection and his wounds healed without difficulty. Adding well vascularized tissue to this wound bed facilitates this great result. While it might be possible to close this ray amputation primarily, in a patient with diabetes this would have very likely led to more difficulties. His final hand function was very good with good return of motion. His hand would be better if the gap in the hand were to be closed at some point, but he refused further surgery. Considering the severity of his infection on presentation, we would consider this a very good final result (▶Fig. 54.5).

54.6 Teaching Points

- Large incisions are required to adequately drain an infection.
- It is important to understand the spaces of the fingers, hand, and wrist so that you know where to track an infection.
- Multiple washouts are required for a deep or necrotizing infection.
- It must cover all vital structures; importation of vascularized tissue aids in healing.
- Aggressive ROM exercises are paramount and must be started as soon as possible.

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55 Salvage of Osteomyelitis of the Distal Radius after Internal Fixation of an Open Fracture

Florian Neubrech and Michael Sauerbier

55.1 Patient History Leading to the Specific Problem

A 57-year-old man presented initially with an open fracture of the distal forearm (▶Fig. 55.1a, b). Initial treatment in an orthopaedic and traumatology-oriented department included external fixation with additional palmar locking plate fixation of the radius and k-wire osteosynthesis of the distal ulna in the interval of several days. At the second operation, cancellous bone from the anterosuperior iliac crest was used to fill the osseous defect (▶Fig. 55.1c, d). Wounds did not heal primarily; a puncture with smeary secretion persisted. The patient was sent to the department of septic surgery. In the revision surgery, 2 weeks after definitive osteosynthesis, a sequestrum was found in the distal radius. Dead bone and necrotic soft tissue on the palmar side were removed. The bony cavity was filled with artificial bone and with a vancomycin carrier. Smear tests revealed *Staphylococcus epidermidis* as the pathogenic germ. Soft-tissue defect was covered another 14 days later with a free lateral arm flap from the contralateral arm by the department of plastic, hand, and reconstructive surgery of the hospital (▶Fig. 55.2). Flap was hooked up to radial artery (end to side) and vein (end to end). Despite all efforts, the infection could not be controlled during the next 6 weeks. Recurrent abscesses were found at a deep level, whereas soft-tissue coverage was sufficient.

55.2 Anatomic Description of the Patient's Current Status

In the presented case, an open fracture led to acute osteomyelitis with concomitant bone and soft-tissue loss because of accompanying necrosis. Acute and chronic soft-tissue infection is thrombogenic and does often compromise local perfusion by occlusion of small and mid-size vessels. Despite specific local and systemic antibiotic therapy and radical debridement, the infection could not be treated satisfactorily. In addition, bone was not sufficiently stabilized despite the retained implants and despite the use of autologous and artificial replacement materials. Remarkable is the fact that soft-tissue coverage was sufficient and bony infection could at least be contained for 6 weeks through free tissue transplantation with the related advanced local perfusion. After the next revision surgery with excision of all necrotic bone and removal of all implants, it was necessary to address the challenge of a large bone defect with instability of the forearm (▶Fig. 55.3).

55.3 Recommended Solution to the Problem

Hardware in an infected site is coated by a biofilm within a short time. A biofilm consists of locally resistant bacterial colonies that are organized into coordinated functional communities through a slimy extracellular matrix composed of extracellular polymeric substances. The biofilm bacteria are able to share nutrients and are sheltered from harmful factors such as antibiotics and the immune system. Therefore, de novo radical debridement with removal of any hardware is strongly recommended. Temporary external fixation without the use of pins in direct trauma or infection zone should be considered. It should also be ensured that tissue is decontaminated from bacteria before definitive reconstruction of the bone may be achieved. In the literature, 6 weeks of local and/or systemic antibiotic therapy is typically recommended. One should realize that even after correct treatment there is still the risk of rest colonization with a single surviving bacteria.

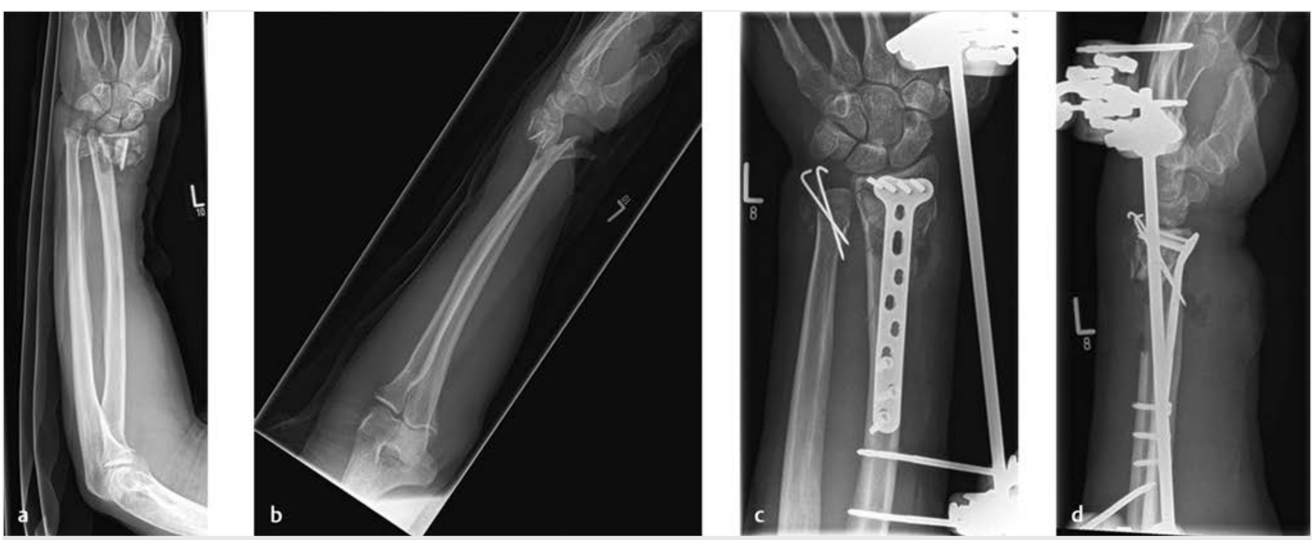

Fig. 55.1 (a–d) X-ray images of the initial (open) fracture with related initial operative treatment.

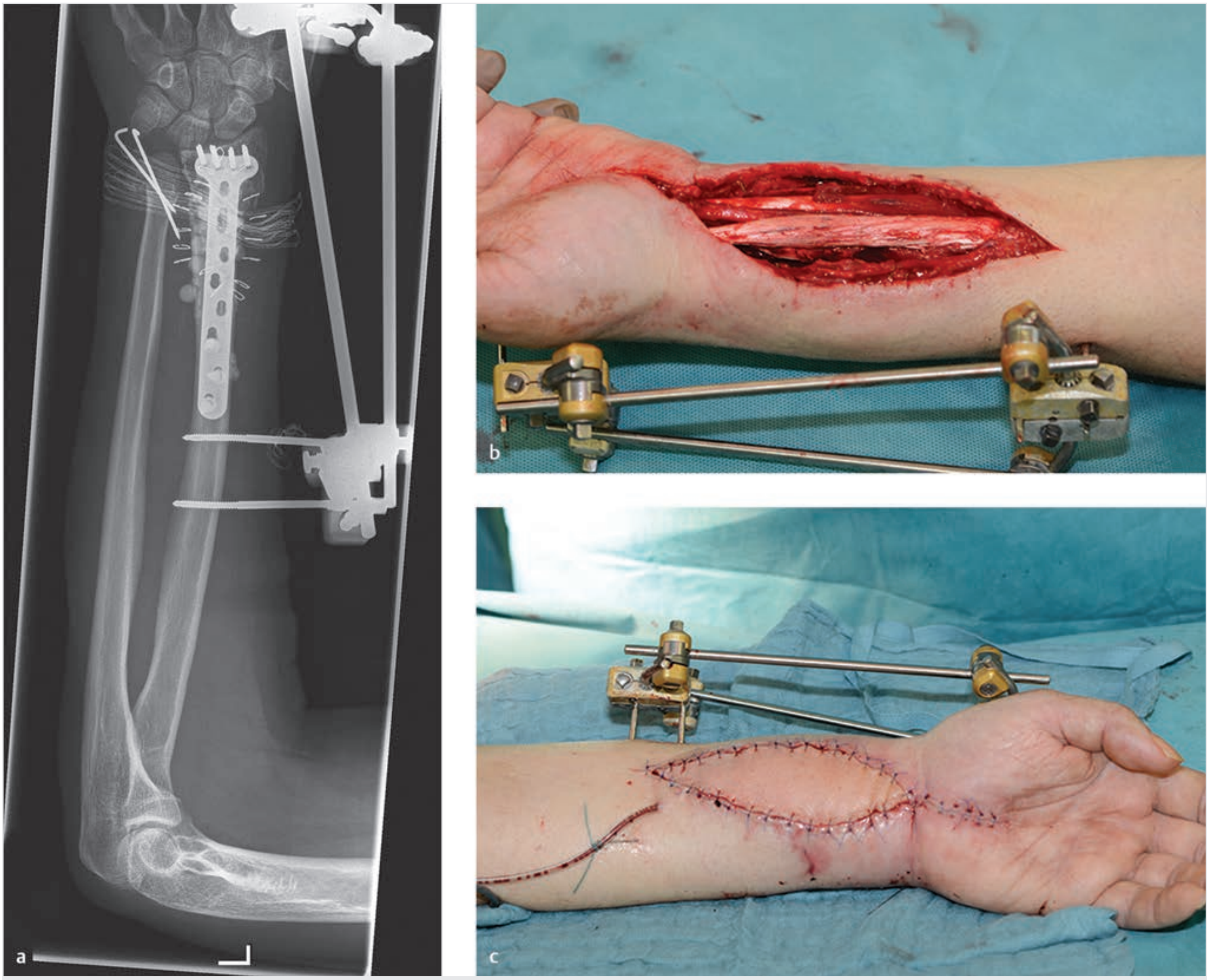

Fig. 55.2 (a–c) Situation after removal of a sequestrum with corresponding soft-tissue defect after debridement, tenolysis, and anterior neurolysis. Defect coverage was performed by a free lateral arm flap. Note retained hardware.

The resulting bone defect is challenging. This holds especially true in a site with limited perfusion and contamination. The aim of the reconstruction was to preserve the distal part of the bone with the nearly sustained radiocarpal joint surface to maintain a residual mobility. Therefore, in the presented case a vascularized fibular autograft was used. It was inserted into the medullary cavity of the distal radius in combination with cancellous bone. Initially, a common end-to-end osteosynthesis with a long and exceptionally stable locking plate was performed.

55.3.1 Recommended Solution to the Problem

- Radical debridement with hardware removal.
- Meanwhile, external fixation provides stability and bridges the injured part of the bone.
- Wait for the antibiotic effect after all necrotic substrate for bacteria has been removed.
- Reconstruct the distal radius including preservation of the radiocarpal joint surface in an interval of approximately 6 weeks.
- We recommend free microvascular bone grafts for the reconstruction of bone defects that exceed 4 cm in length.
- An intercalated vascularized fibular autograft in combination with cancellous bone graft from iliac crest was suitable in the presented case.

55.4 Technique

Operation is performed under general anesthesia with use of tourniquets in two bloodless fields, separate for the arm and the leg. The use of loupes is highly recommended.

The recipient site is debrided; the remaining bone is checked for vitality. Hemorrhage spots are required to be identified; if unsure, check again after opening the tourniquet. The defect size is measured. The recipient vessels are exposed. Usually, the radial artery with its concomitant veins is used. In this case, because of the preceding flap, ulnar vessels were used. The angiography (conventional digital subtraction angiography) revealed two uninterrupted vessel axes beforehand.

The patient is placed in the supine position with the ipsilateral hip slightly elevated. The axis of the fibula is drawn.

Fig. 55.3 (a, b) X-ray images after radical redebridement and implant removal. Osteomyelitis of the radius with nonunion.

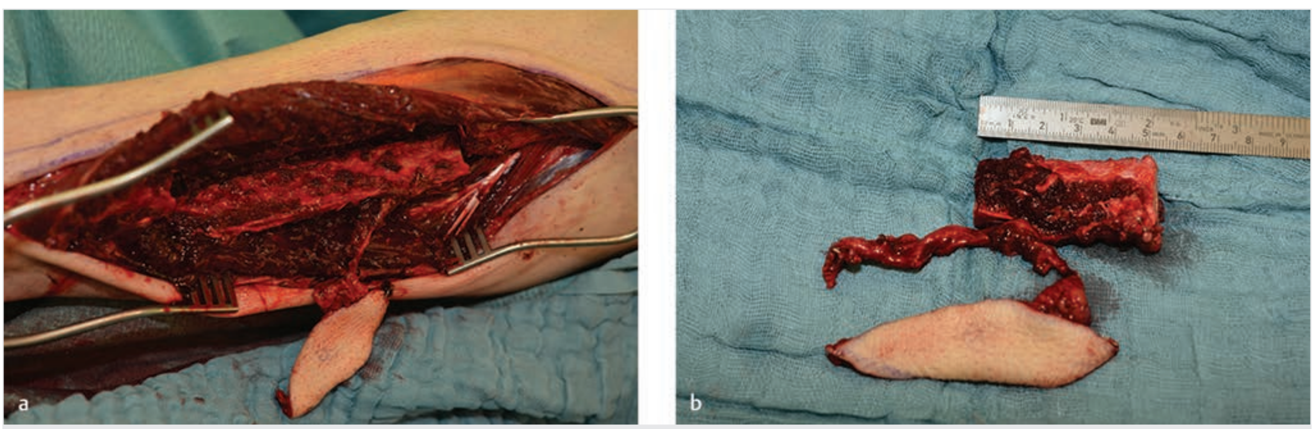

Fig. 55.4 (a, b) Raising the fibula bone flap with monitor skin island based on the peroneal vessels. The fibula is already shaped for the inset in the distal radius.

The axis of the skin paddle follows the posterior border of the fibula and incorporates a septal perforator near the midpoint of the fibula. The cutaneous flap is elevated just above the muscle and deep to the muscular fascia from anterior to posterior. A small cuff of muscle is left attached to the bone. Osteotomy is made with an oscillating saw. It is important to preserve the distal 6 to 7 cm of the bone to ensure the integrity of the upper ankle joint. The interosseous membrane is divided exposing the peroneal vessels just behind the membrane. The flap can then be raised with its vascular pedicle (▶Fig. 55.4).

The fibular is first inserted into the medullary cavity of the distal radius. For this step, the pre-stress of an external fixation that has been left until this moment can be useful. The cavity is filled with cancellous bone from the iliac crest that is harvested in a common manner. Osteosynthesis is performed using a long and especially stable palmar locking plate (Medartis AG, Basel, Switzerland) that bridges the bony defect and also holds the graft (▶Fig. 55.5). After supply of the hard tissue, the fibular graft (peroneal artery and concomitant vein) is hooked up to the recipient vessels (ulnar artery and vein) in the end-to-side technique using the microscope.

Fig. 55.5 (a, b) Fibula bone flap in situ with palmar locking plate fixation. The distal ulnar fracture was left untreated.

Integration and healing of bony free flaps is mostly successful but could take a longer time than one would expect; it could take up to several months. Periodic X-ray controls are recommended. The monitor island can be resected after 14 days.

55.4.1 Steps for the Procedure

1. Recipient site is debrided until vital bone can be seen; recipient vessels are exposed.
2. Fibular graft is elevated as mentioned earlier.
3. Graft is inserted in the distal cavity of the radius together with some cancellous bone and trimmed fitting end to end to the proximal part of the radius.
4. An especially stable locking plate fixation is necessary.
5. Graft is connected to ulnar vessels.
6. Process of bony healing may take some time.
7. Immobilization in a thermoplastic palmar splint is necessary for 12 weeks, followed by free-of-strain physiotherapy under X-ray controls.

55.5 Postoperative Photographs and Critical Evaluation of Results

Despite the challenging starting situation with an extended bone defect, chronic infection, and limited local perfusion, bony healing can be achieved in many cases with this technique.

It took 9 months until the bone flap was completely integrated in radiographs. ▶Fig. 55.6 shows the radiologic postoperative results 1 year after revision surgery. At that time, fist closure and forearm rotation were restricted and the wrist was nearly stiff (▶Fig. 55.7). Active range of motion of the wrist could be improved during the next 4 months, but consistent hand therapy was required to compensate the massive trauma and the long phase of immobilization. Final functional results were sufficient. Forearm rotation was complete. The active range of motion of the wrist for extension/flexion was 20–0-20 degrees and that for ulnar/radial deviation was 10–0-10 degrees. Fist closure was complete. Grip strength, measured with a Jamar dynamometer on level II, was 8 kg, while it was 36 kg on the right-dominant, contralateral hand. The patient was completely pain free. He could return to work as a craft artist in the automotive industry after 24 months of intense treatment since the accident. The complexity and the duration of the conservative procedures were possible through workers' compensation. The accompanying video (▶Video 55.1). shows the functional result 14 months after revision surgery.

55.6 Teaching Points

- Open fractured bone is highly under risk for developing an osteomyelitis. Infection, in turn, conditions (bony) necrosis.
- Management of the osteomyelitis of the forearm and wrist consists of a combined surgical and antibiotic approach. Necrotic tissue must be radically excised, and infected hardware should be removed whenever possible. Temporary external fixation is often a standard treatment option. Detection of the pathogenic germ should always be enforced.
- Debridement in the condition of an infection must be radical. To be gallant enough to face large bone and soft-tissue defects, knowledge of microsurgical reconstruction techniques is essential.
- Pathogenic germs in osteomyelitis often have a slow turnover rate and the minimum inhibitory concentration of antibiotics in bone is less than in other tissues. Therefore, specific antibiotic therapy is necessary for at least 6 weeks.

Fig. 55.6 (a, b) Complete bony healing with full inclusion of the fibular graft 1 year after microvascular transplantation.

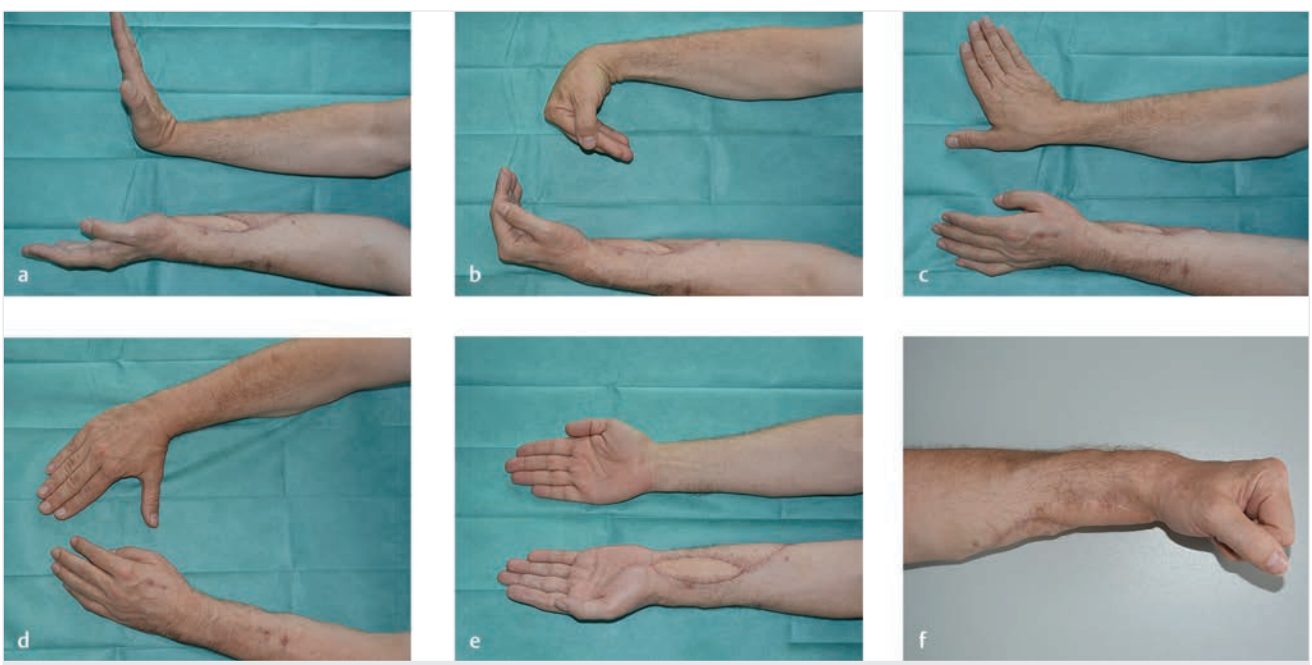

Fig. 55.7 (a–f) Clinical results 1 year after revision surgery.

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56 Infectious Destruction of the Wrist

Florian Neubrech, Michael Sauerbier, and Berthold Bickert

56.1 Patient History Leading to the Specific Problem

A 68-year-old man suffered from pain in his left thumb for years because of advanced osteoarthritis of the first carpometacarpal (CMC I) joint. Diabetes mellitus, peripheral arterial occlusive disease, and heavy smoking were preexisting conditions. Therefore, in a private practice, an operative procedure such as a resection arthroplasty was avoided and a steroid injection in the painful CMC joint was performed. One month later, the patient presented in another department for general surgery with wrist pain and with a general but unspecific feeling of sickness. There was no fever. Laboratory diagnostics revealed a mild increase in CRP (C-reactive protein) and no leukocytosis. X-rays did not show any bony disorders beside the preexisting osteoarthritis of the CMC joint (▶Fig. 56.1). The patient was discharged with the advice for a symptomatic treatment. Five months later, the patient presented in the hospital and workplace of the authors with increasing pain and extensive swelling of the wrist (▶Fig. 56.2).

Fig. 56.1 Initial X-ray image of the left wrist captured 1 month after steroid injection in the first carpometacarpal joint.

56.2 Anatomic Description of the Patient's Current Status

In the presented case, a steroid injection led to a chronic infection of the bone with a slow but relentless destruction of the wrist and of the distal radioulnar joint.

Generally, a deep injection in a joint is difficult to treat. A sterile setting is strongly recommended if the operative procedure is indispensable. Otherwise, germs will find the synovial fluid and only few intra-articular immune cells as the perfect breeding ground. Potentially, immunosuppression caused from steroids and a general condition of reduced resistance due to diabetes facilitated the unfaithful course in addition in this case.

A sufficient treatment of the infection and the bacterial colonization is now required. It is necessary to address the challenge of extensive bone loss after radical debridement. Thereby, total wrist arthrodesis is difficult due to loss of bone stock. Furthermore, the destructed distal radioulnar joint also has to be treated.

Fig. 56.2 **(a, b)** X-ray images of the left wrist 5 months after steroid injection in the first carpometacarpal joint. A severe destruction of all wrist joint surfaces with advanced osteolysis was detected.

56.3 Recommended Solution to the Problem

First, radical debridement with removal of infectious tissue, necrotic bone, and destructed articular surfaces is necessary. Subsequently, local and systemic antibiotic therapy for 6 weeks is demanded. Meanwhile external fixation of the wrist is applied. A huge bony defect remains, and total wrist fusion with interposition of a huge bone graft is required.

In wrist fusion, the carpal height has to be reconstructed to maintain the force transmission of the forearm. Therefore, the resulting bone defect has to be reconstructed. A postinfectious site always comes along with necrosis due to limited micro-perfusion and has the risk of a rest contamination. Hence, we recommend free microvascular bone flaps in bone defects of more than 4 cm instead of nonvascularized bone grafts. A vascularized fibular autograft is not adequate because of the narrow contact surfaces of the metacarpal bases that have to be included into the wrist arthrodesis in this case. Therefore, a deep circumflex iliac artery (DCIA) bone flap is used for total wrist fusion in combination with a conventional AO wrist fusion plate that bridges the former CMC III joint.

The distal radioulnar joint is treated by resection arthroplasty. In this case, a Darrach procedure is suitable because of the extended destruction of the ulnar head.

56.3.1 Recommended Solution to the Problem

- Radical debridement with removal of necrotic bone and destructed joint surfaces.
- External fixation of the wrist is applied, and local and systemic antibiotic therapy is demanded.
- Wrist arthrodesis with replacement of the lost bone and restoration of carpal height in an interval of approximately 6 weeks.
- A post infectious bone defect of more than 4 cm is reconstructed by a free microvascular bone graft.
- In the presented case, a DCIA bone flap is adequate.
- Darrach's procedure is used for the distal radioulnar joint.
- We recommend implant removal after ensured radiological consolidation.

56.4 Technique

The wrist is debrided. In advanced cases, a resection of the whole carpus is often unavoidable. Mostly, bony infection of the wrist is caused by the *Staphylococcus* species. The defected is filled with an antibiotic carrier; typically, gentamicin chains are used. An interval of local and systematic antibiotic therapy of 6 weeks is frequently recommended in the literature. Meanwhile, external fixation is used (▶Fig. 56.3), and the ulnar head is resected.

Wrist arthrodesis in the interval is realized by a DCIA bone flap. Therefore, the patient is placed in the supine position with the ipsilateral hip slightly elevated. The inguinal ligament and the femoral vessels are marked for orientation. Incision is made just above and parallel to the inguinal ligament. Superficial circumflex iliac artery (SCIA) and DCIA are identified at their origin. DCIA is traced in the level of fascia transversalis toward the anterosuperior iliac spine. Dissection should proceed laterally, the lateral cutaneous nerve should be preserved. The iliac crest is encountered; superficial muscles are divided from their iliac crest insertion, exposing the iliacus muscle with the overlaying vessels. Now osteotomy can be performed. In this case, a full-thickness graft is required. Closure is performed in layers over suction drains (▶Fig. 56.4).

After de novo debridement, graft is inserted in the resection cavity and the carpal height is restored. Wrist fusion and osteosynthesis are performed using a standard AO wrist fusion plate (Synthes, West Chester, PA, United States). The CMC III joint has to be incorporated in the arthrodesis in this case. After supply of the hard tissue, the graft is hooked up to the recipient

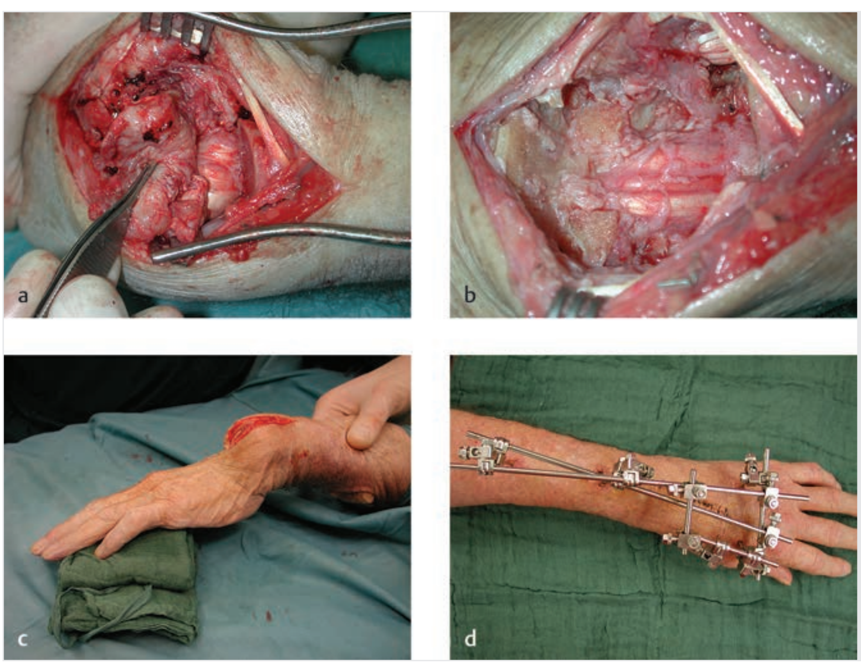

Fig. 56.3 (a–d) Radical debridement of the wrist with joint resection and external fixation.

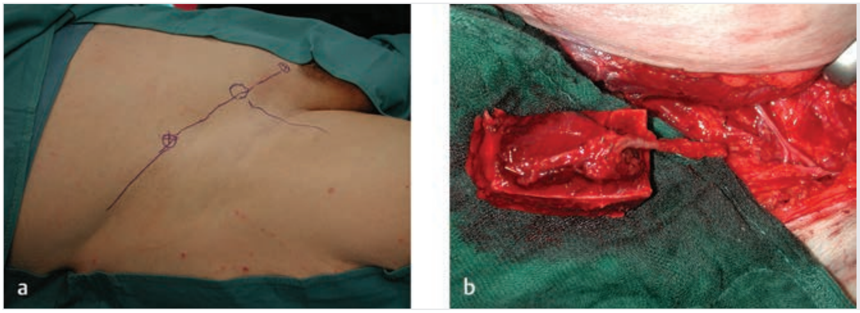

Fig. 56.4 (a, b) Raising the deep circumflex iliac artery bone flap from the right, contralateral side. Preoperative drawing and completely raised flap.

Fig. 56.5 (a, b) Complete bony healing with full integration of the deep circumflex iliac artery bone flap at the left wrist.

vessels (ramus carpalis dorsalis, a side branch of radial artery and vein) in end-to-end technique using the microscope.

The implant is removed after a radiologically verified consolidation to prevent material breakage and recurrence of infection originating from a biofilm.

56.4.1 Steps for the Procedure

1. Resection of the wrist with insert of antibiotic chains and use of external fixation.
2. Wait for 6 weeks of local and systemic antibiotic therapy.
3. DCIA bone flap is elevated as mentioned earlier.
4. The flap is connected to radial vessels.
5. Wrist arthrodesis is performed by AO wrist fusion plate.
6. Immobilization in a thermoplastic palmar splint was necessary for 12 weeks.

56.5 Postoperative Photographs and Critical Evaluation of Results

A follow-up examination of the patient after 3 years was feasible. Radiographs (▶Fig. 56.5) showed complete integration of the bone graft with mild bony atrophy in the area of the graft that was bridged by the plate. An implant removal was declined by the patient, but there were no signs of recurrence of infection or implant failure.

Fist closure and forearm rotation were complete (▶Fig. 56.6). Grip strength, measured with a Jamar dynamometer on level II, was 26 kg on the left, whereas it was 36 kg on the right and dominant contralateral side. The Disabilities of the Arm, Shoulder, and Hand (DASH) score was 1.7. The patient was nearly pain free.

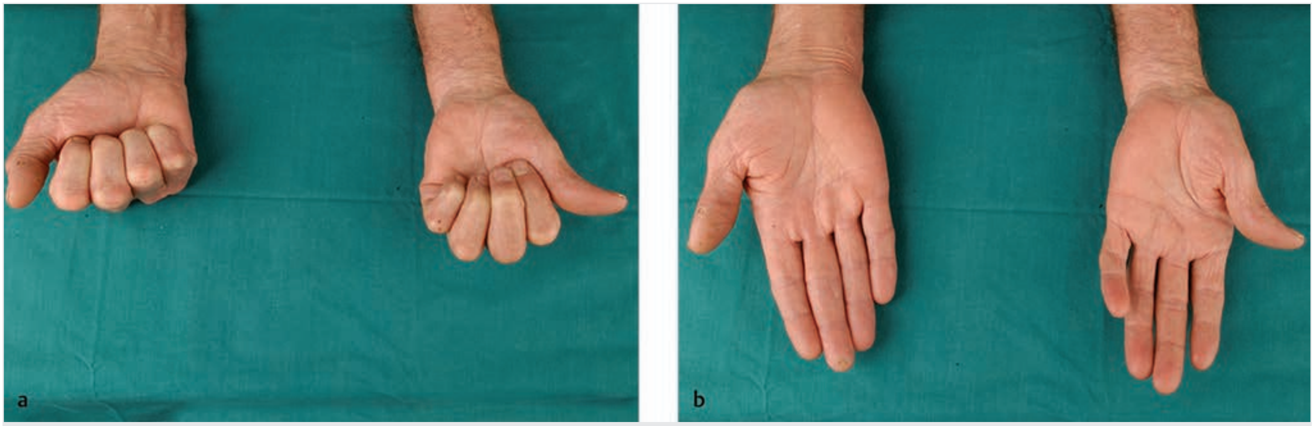

Fig. 56.6 (a, b) Clinical results 3 years after surgery.

56.6 Teaching Points

- Articular injections of steroids into the wrist may lead to significant complications. A serious articular and bone infection can result.
- Laboratory results can occur clinically unspecific even in cases of severe wrist infection. In doubt, a primary surgical exploration, at least by minimal invasive wrist arthroscopy, should be enforced.
- Standard treatment for manifest osteitis of the wrist consists of radical debridement, followed by 6 weeks of local and systemic antibiotic therapy. Under most circumstances, external fixation is required.
- The restoration of the carpal height should be a therapeutic aim in total wrist fusion.
- We recommend the use of microvascular bone grafts in bone defects that extend up to 4 cm.

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Part XIX

Problems with Replantation

57 Stiffness After Replantation *264*

58 Failed Replant: Ray Amputation *270*

59 Failed Digit Replant: Toe-to-Hand Transfer *273*

60 Failed Thumb Replant: Great Toe-to-Thumb Transfer *277*

61 Failed Replant: Failed Degloving Revascularization *281*

62 Attempted Replantation *284*

63 Nonunion following Digital Replant *289*

64 Nonunion following Major Replant *293*

65 Painful Finger after Bony Nonunion *296*

66 Stiff Fingers and Elbow after Replantation *302*

67 Poor Grip or Weak Motion after Replantation *305*

XIX

57 Stiffness after Replantation

Walter Lin, Bauback Safa, and Gregory M. Buncke

57.1 Patient History Leading to the Specific Problem

In this example, a 38-year-old construction worker sustained an accidental table saw injury to the volar hand with near-complete amputations of the dominant thumb, index, middle, and ring fingers (▶Fig. 57.1a–c). He underwent successful revascularization with repair of the bone, tendon, nerves, and vessels within zones 2 and 3 (▶Fig. 57.1d, e). A volar splint provided protection throughout the healing period. After inpatient hospitalization, hand therapy was initiated at 2 weeks for the wrist and the small finger. The Kirschner's wires were removed at 6 weeks postoperatively, and range of motion was initiated for the remaining affected joints.

Over the following months, the patient had persistent stiffness with finger flexion and extension, in addition to a first web-space contracture (▶Fig. 57.1f, g). A staged approach was planned to regain passive and active range of motion, beginning with dorsal joint capsulotomy and extensor tenolysis, followed by volar plate release and flexor tenolysis.

57.2 Anatomic Description of the Patient's Current Status

Replantation and revascularization commonly result in joint stiffness due to the required immobilization in the immediate perioperative period, but stiffness is particularly problematic with injuries within zone 2. The length of immobilization required to achieve stable bony union consequently results in scarring around the metacarpophalangeal (MCP) and interphalangeal joints, as well as along the flexor and extensor tendons. Early hand therapy is initiated around 2 weeks postoperatively, and is transitioned to aggressive therapy around 4 to 6 weeks postrepair with goals of breaking existing scar adhesions. Patient compliance with hand therapy is paramount to functional improvement and is the ultimate factor determining overall outcome. However, despite appropriate patient compliance, joint and tendon adhesions may persist and require secondary revision surgeries in order to achieve maximal improvement.

In this example, the patient has undergone successful fracture fixation, flexor tendon repair, and digital artery and nerve repairs in multiple digits. He primarily has joint stiffness around the MCP joints of the injured digits that limit passive flexion. Active flexion is hampered by adhesions along the flexor tendon repairs.

57.3 Recommended Solution to the Problem

Staged revision procedures are performed in a specific strategic sequence to restore motion. Prerequisites include skeletal stability and stable soft-tissue coverage; these must be

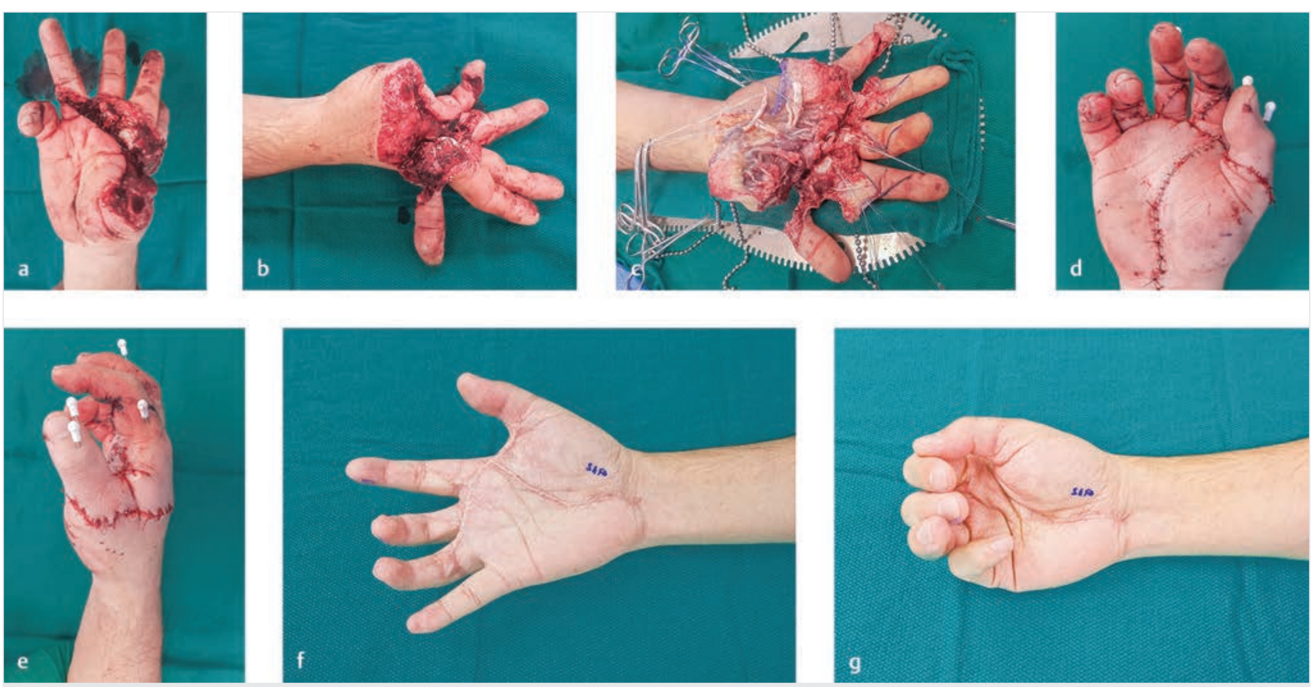

Fig. 57.1 **(a, b)** Table saw injury to the volar thumb, index, middle, and ring fingers with near amputation of the digits. **(c)** Exposure of traumatically transected structures within zones 2 and 3. **(d, e)** Appearance immediately postoperatively. Note that the traumatic laceration across volar metacarpophalangeal flexion creases and first webspace ended up forming a flexion contracture. **(f)** Stiffness with flexion and extension prior to revision surgery. Flexion contractures of the middle and ring fingers, and a first web-space contracture. **(g)** Limited active and passive flexion.

addressed before tenolysis and capsulotomy, as nonunion and soft-tissue coverage typically require immobilization and result in stiffness.

In most cases, aggressive hand therapy is performed for a minimum of 4 to 6 months, allowing time for the soft-tissue envelop to regain suppleness and reach soft-tissue equilibrium. Revision surgery may be scheduled once progress with hand therapy plateaus. The first stage consists of open dorsal capsulotomies of the MCP and/or proximal interphalangeal (PIP) joints along with extensor tenolysis, thus providing full passive flexion and improving active extension.

After another 6 to 8 weeks, with soft-tissue equilibrium and plateau of progress with hand therapy, the second stage consists of flexor tenolysis. If flexion contractures are present, volar plate release is performed at this stage as well. In some cases, staged flexor tendon reconstruction may be required using Hunter rods, which should be placed at this stage. A third stage would be required for tendon graft exchange, followed by a fourth stage for repeat flexor tenolysis.

Throughout the rehabilitation period, aggressive hand therapy should be maintained, and therapy should be restarted for the day immediately following each revision surgery.

57.3.1 Recommended Solution to the Problem

- Confirm skeletal stability and stable soft-tissue coverage. Await supple soft-tissue equilibrium and plateau with hand therapy.
- Perform extensor tenolysis and open dorsal joint capsulotomy.
- Perform flexor tenolysis and volar plate release.
- Continue aggressive hand therapy throughout the rehabilitation period, including the day following surgery.

57.4 Technique

Extensor tenolysis is performed as an outpatient procedure with regional or general anesthesia. Under tourniquet control, longitudinal midline incisions are made over the MCP and/or the PIP joints. Curvilinear extensions around the joints help redistribute the points of maximal tension away from the joint (▶Fig. 57.2a). Skin flaps are sharply elevated off of the extensor mechanism, exposing the radial and ulnar aspects (▶Fig. 57.2b). The superficial surface of the extensor is freed proximally along the dorsal hand from this exposure. While taking care to preserve the central slip insertion, the deep surface of the extensor is then elevated from the underlying periosteum using tenotomy scissors, a freer elevator, or scalpel (▶Fig. 57.2c).

At this point, the joint space is identified by palpation. The extensor is retracted, and the dorsal joint capsule is carefully incised with the scalpel. The joint passive flexion is tested using firm steady pressure, taking care to avoid iatrogenic fracture (▶Fig. 57.2d). The accessory and proper collateral ligaments are serially divided from dorsal to volar, taking care to avoid injury to the neurovascular bundles. The ligaments are progressively divided until the joint achieves full passive flexion without excessive elasticity.

The tourniquet is then deflated and hemostasis is obtained, as hematoma formation likely contributes to reformation of adhesions, and bleeding is discouraging to patients during hand therapy. The tourniquet may be reinflated once again. The skin is closed using a 4–0 nylon suture. Soft dressings are applied, and aggressive hand therapy should be resumed on the day following surgery.

Extensor tenolysis key points:
- Longitudinal midline incisions with curvilinear extensions are made overlying the joints.
- The superficial and deep surfaces of the extensor are freed sharply.
- Care is taken to protect the central slip insertion.
- The dorsal joint is incised, and the collateral ligaments are divided until full passive flexion is achieved.
- Careful hemostasis decreases postoperative edema and adhesion recurrence.
- Aggressive hand therapy is resumed within several days of surgery.

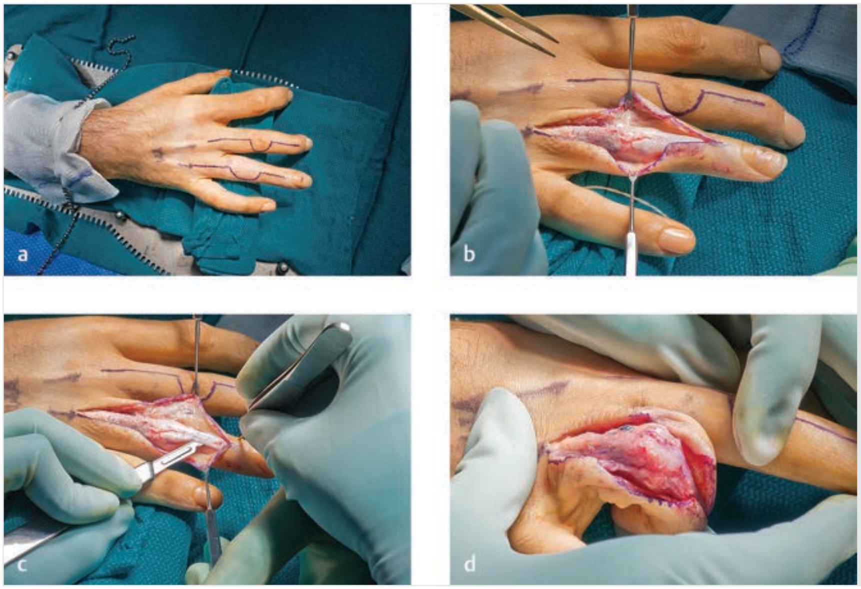

Fig. 57.2 **(a)** Extensor tenolysis incision markings. A curvilinear extension around the joints prevents tension directly over the joint. **(b)** Extensor tenolysis. Skin flaps are elevated from the extensor mechanism. **(c)** Extensor tenolysis. A freer elevator and a no. 15 blade are used to free tendon adhesions. The central slip is carefully preserved. The dorsal joint capsule is incised with the scalpel. **(d)** Dorsal capsulotomy. Steady pressure is applied to achieve passive flexion. The accessory and proper collateral ligaments are progressively divided from dorsal to volar until full passive flexion is achieved.

Aggressive hand therapy continues while awaiting flexor tenolysis, which is performed in 6 to 8 weeks months when soft-tissue equilibrium is once again attained, with soft supple tissue and resolution of edema (▶Fig. 57.3). When progress reaches a plateau once again, flexor tenolysis is performed.

Flexor tenolysis is similarly performed as an outpatient procedure using general or regional anesthesia. In some cases, it is helpful to perform surgery awake with regional anesthesia, allowing the patient to test active motion intraoperatively. Under tourniquet control, Brunner's incisions are made along the volar digits and are extended to the palm (▶Fig. 57.4a). To minimize skin flap tip loss, the flaps should be kept volar to the mid-axial line.

Incisions are carefully made and skin flaps are elevated. The flaps should be full thickness over the tendon sheath and shallower at the corners to protect the neurovascular bundles. The neurovascular bundles are identified and protected, and do not need to be skeletonized. Longitudinal windows are made within the flexor sheath using a scalpel overlying the A1 and A3 pulleys; A2 and A4 pulleys are preserved to prevent bowstringing. Flexor digitorum superficialis (FDS) and profundus tendons are identified and separated. Tenotomy scissors are used to free adhesions within the flexor sheath circumferentially (▶Fig. 57.4b). Of note, the FDS tendon is not routinely repaired at the time of replantation because of the dense scarring and difficulty during separation from flexor digitorum profundus. If FDS is still present, it is excised at the time of tenolysis. Traction along the tendon confirms freedom of movement distally.

If volar plate release is required, the flexor tendons are retracted, and the volar plate is exposed. A rectangular section of the volar plate is excised sharply using a beaver blade scalpel, taking care to protect the neurovascular bundles (▶Fig. 57.4c).

Fig. 57.3 After extensor tenolysis, active flexion of the index, middle, and ring fingers is limited **(a)**, but the patient has full passive flexion **(b)**.

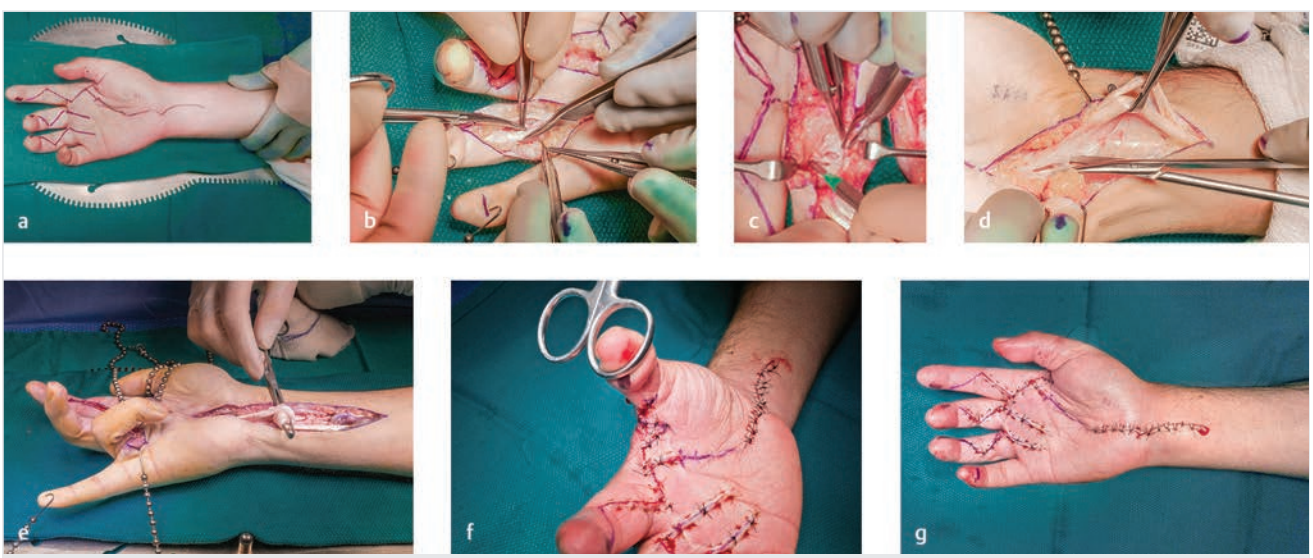

Fig. 57.4 **(a)** Flexor tenolysis. Brunner's incisions are designed along the digits to the palm. Access to the flexor tendons at the level of the wrist should be planned as well. **(b)** Flexor tenolysis is performed, freeing the tendon from the surrounding pulleys using tenotomy scissors. The digital nerve has been retracted and protected. **(c)** Volar plate release using a beaver blade. A block section of the volar plate is excised. **(d)** Flexor tenolysis within the volar wrist is performed as well. **(e)** Traction on the tendon within the wrist ensures complete freedom within the palm and digits. **(f)** Z-plasty of a contracture within the first web space. **(g)** Immediate postoperative appearance after flexor tenolysis and first webspace z-plasty.

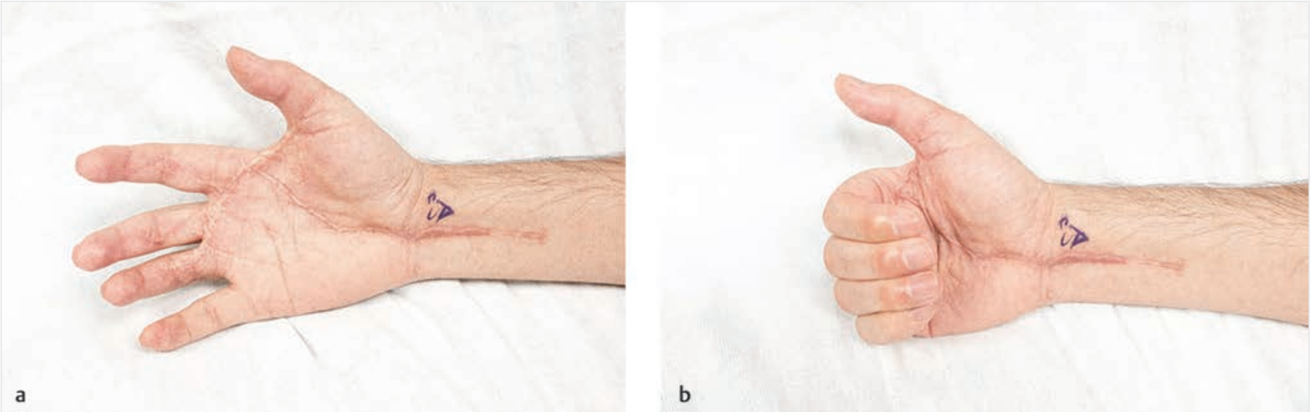

Fig. 57.5 (a, b) Near-full active flexion after completion of flexor tenolysis.

If adhesions are suspected proximally with tendon traction, flexor tenolysis should be performed within the distal forearm as well. A chevron incision or previous scars provide adequate access. The flexor tendons are identified and freed using tenotomy scissors as well (▶Fig. 57.4d). Tendon excursion is tested once again to confirm complete tenolysis within the palm and digits (▶Fig. 57.4e).

At this point, sedation may be lightened and the patient is allowed to test active range of motion. Adjunct procedures, such as contracture Z-plasties, may be performed as well (▶Fig. 57.4f). The tourniquet is deflated to obtain hemostasis and confirm perfusion to the fingertips. The tourniquet is reinflated and the wounds are closed using a 4–0 nylon suture (▶Fig. 57.4g). Soft dressings are applied. If volar plate release is performed, the patient is kept in an extension splint when not exercising. Hand therapy resumes on the day following surgery.

Flexor tenolysis key points:

- Brunner's incisions are designed along the digits and palm, and a chevron incision is made over the wrist.
- The A1 and A3 pulleys are divided to provide access to the flexor tendons. The A2 and A4 pulleys are preserved.
- Flexion contractures are released by excising a block of volar plate.
- FDS is not routinely repaired at the time of replantation, and remnants are excised at this stage.
- Tenolysis may be performed within the wrist, and traction confirms complete release of adhesions.
- Careful hemostasis decreases postoperative edema and adhesion recurrence.
- Aggressive hand therapy is resumed within several days of surgery.

57.5 Postoperative Photographs and Critical Evaluation of Results

With aggressive hand therapy, the patient continued to make functional gains. Nine months after flexor tenolysis, the middle and ring fingers achieved reasonable composite active flexion; however, the index finger had limited active flexion. A second flexor tenolysis was performed to further improve hand function, again with resumption of aggressive hand therapy. Considering the extent of his initial injury with the thumb, index, middle, and ring fingers involved, the patient was pleased with his functional result (▶Fig. 57.5).

Long-term results are highly variable and are largely dependent on patient participation. The example discussed in this chapter shows good results and was chosen due to the availability of photos at each stage of surgery. ▶Video 57.1 shows return of full range of motion in another patient requiring multi-digit zone 2 replantations of the index, middle, and ring fingers, after completion of secondary revision surgeries. In other instances, without proper encouragement or motivation, patients are burdened with stiff digits after maximal medical improvement.

At the extreme end of motivation and compliance, some patients achieve full active extension and flexion without requiring any revision surgery after complete zone 2 replantation. In this second example, a teenaged patient suffered a traumatic amputation through zone 2 (▶Fig. 57.6) and underwent replantation (▶Fig. 57.7). The patient was highly motivated, and within 4 months postoperatively they regained full active flexion and extension without the need for revision surgery (▶Fig. 57.8).

57.6 Teaching Points

- With the anticipated secondary revision surgeries, digit replantation can result in good functional outcome, even in zone 2.
- Skeletal stability, stable soft-tissue coverage, and soft-tissue equilibrium are required prior to functional improvement surgeries.
- Hand therapy is paramount to successful functional improvement and must be resumed immediately after revision surgery.
- In the rare individual, revision surgery may not be required given enough patient motivation and compliance with hand therapy.

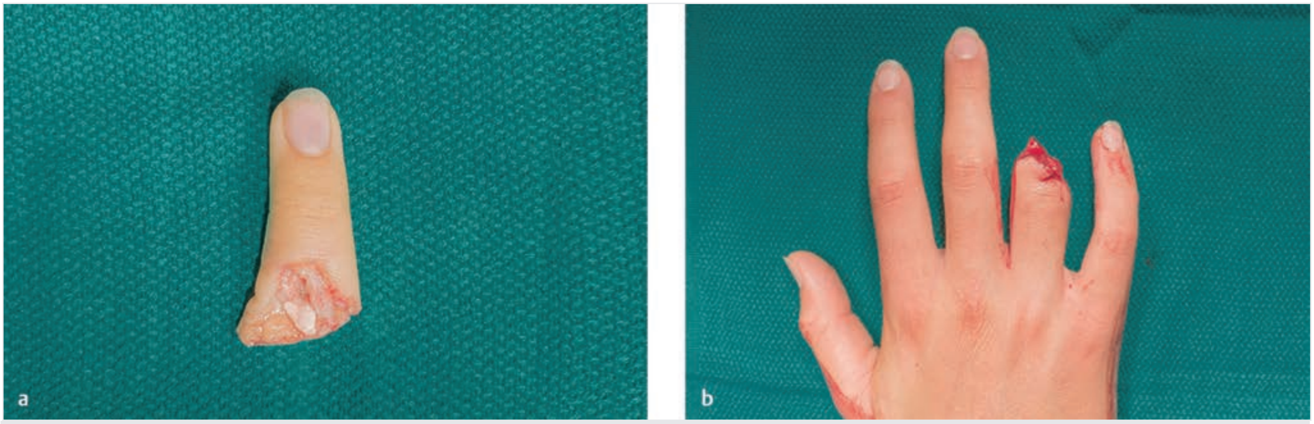

Fig. 57.6 (a, b) Complete traumatic amputation through zone 2 in a teenage patient.

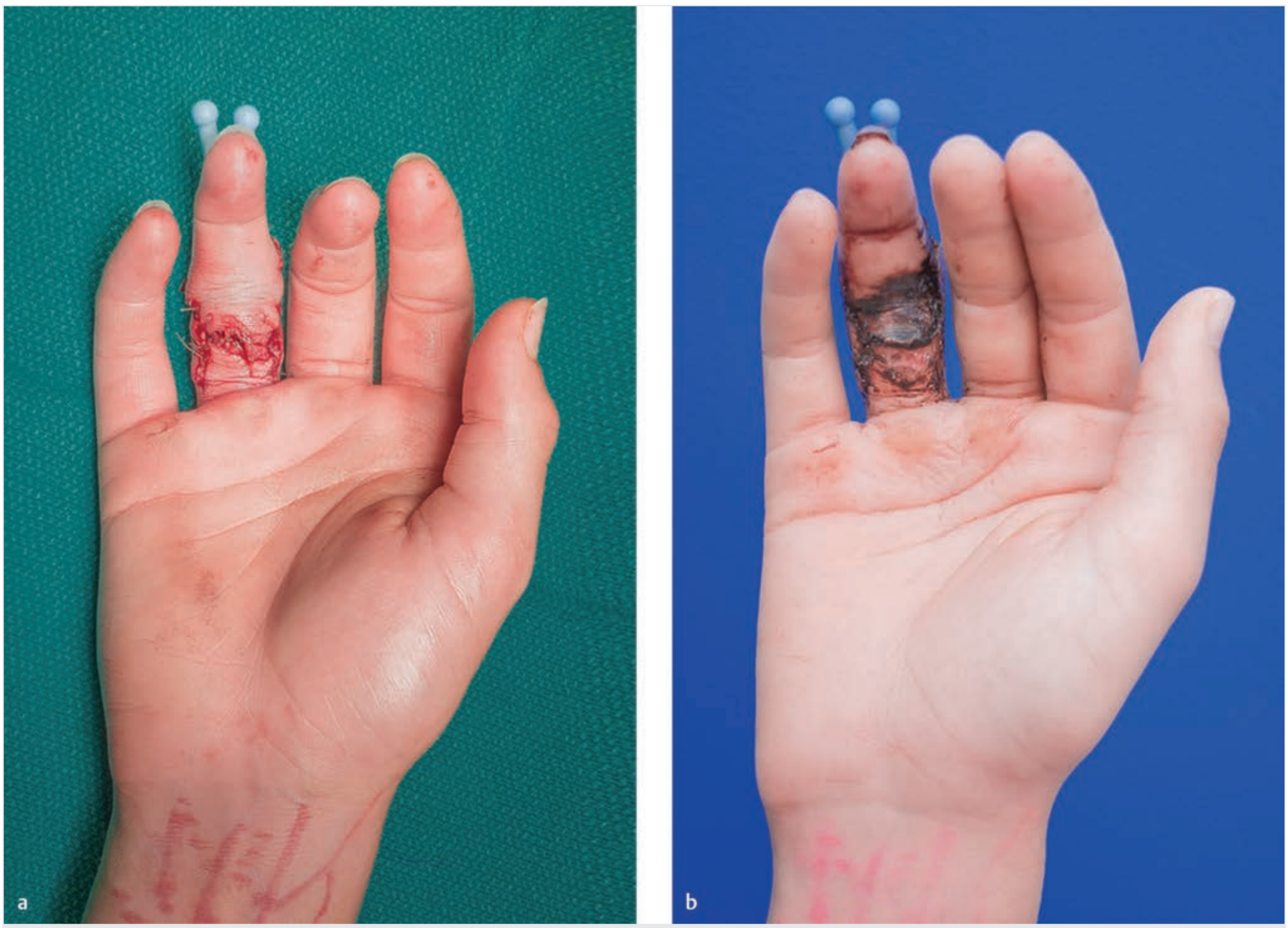

Fig. 57.7 (a) Appearance after replantation immediately postoperatively. **(b)** Appearance 17 days postoperatively.

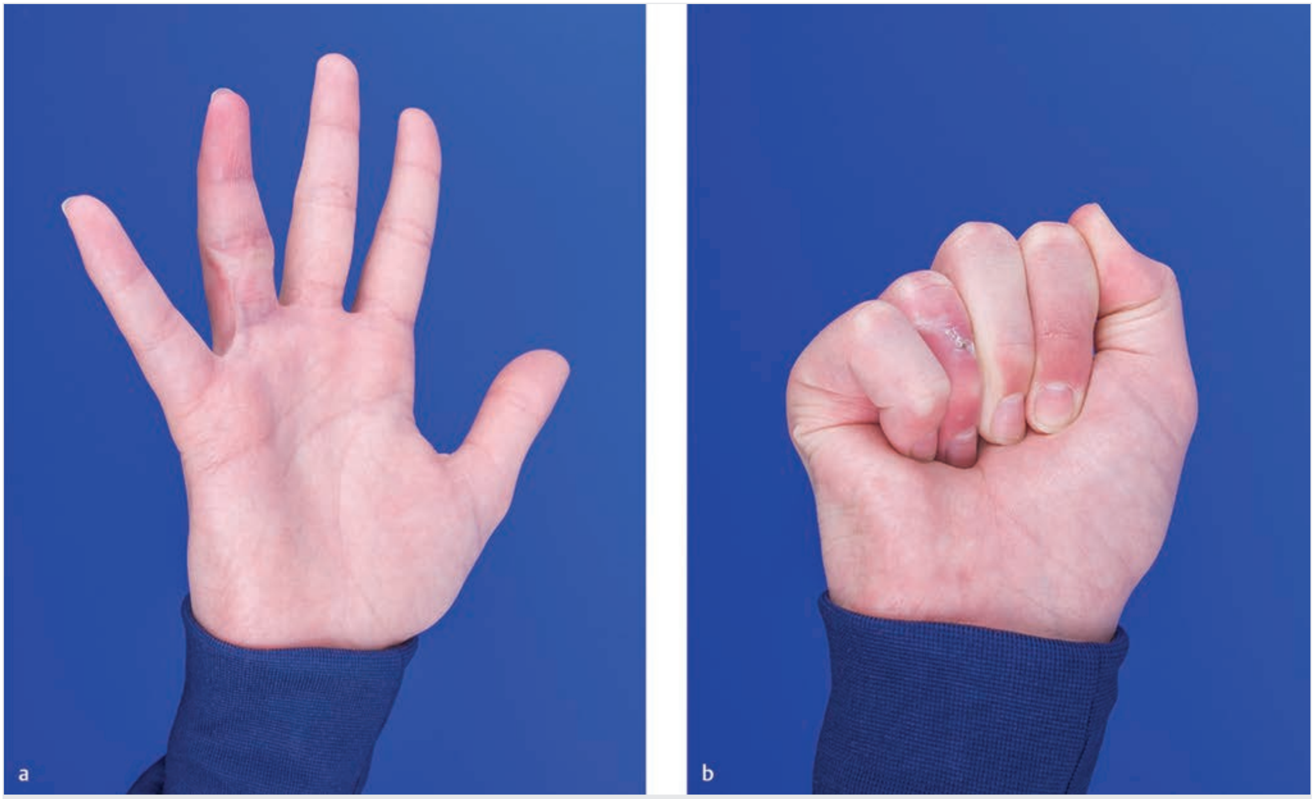

Fig. 57.8 (a, b) By 4 months postoperatively, this highly motivated patient has achieved full active extension and flexion without revision surgery for this zone 2 replantation.

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58 Failed Replant: Ray Amputation

Sang Hyun Woo

58.1 Patient History Leading to the Specific Problem

A 36-year-old woman sustained a complete amputation of the left index finger through the proximal phalangeal bone. The patient was taken to the operating room emergently. An attempt at replantation failed (▶Fig. 58.1).

58.2 Anatomic Description of the Patient's Current Status

The patient had an amputation of the index finger at the level of the mid-proximal phalanx. There was no movement of the phalanx, which was too short to be functional.

58.3 Recommended Solution to the Problem

- Revision amputation at the just proximal part of replantation is performed by denuding articular cartilage, shaping the condyles of the proximal phalanx, and employing tension-free skin closure.
- Primary ray amputation shortens lost work time, eliminates the cost of a second procedure, and improves cosmetic appearance.
- Second toe-to-hand transfer for the digits recovers a normal appearance and also maintains the original digit length, but consideration of donor site morbidity and risk of operation failure must be taken.

58.4 Technique

Through a **Y**-shaped incision on the dorsal surface of the metacarpophalangeal joint area, the extensor tendons and the first dorsal interossei muscle are divided at the level of the second metacarpal base. After striping of the dorsal periosteum, the second metacarpal is transected in a bevel design at the metacarpal base (▶Fig. 58.2).

At least 1 cm of the metacarpal bone should be left to preserve the insertion of the extensor carpi radialis longus tendon. On the palmar aspect, the digital artery to the radial side of the index finger is ligated and the digital nerves dissected distally into the proximal phalangeal segment and divided. When the ulnar digital nerve of the index finger is resected, the radial digital nerve and accompanying digital artery of the long finger should be protected. The digital nerves should be transected as far proximally as possible to prevent painful neuroma formation. The flexor tendons of the index fingers are pulled distally and transected. The first palmar interosseous tendon, volar plate, transverse intermetacarpal ligament, and proximal portion of the flexor tendon sheath are sharply resected. The rough edge of the distal end

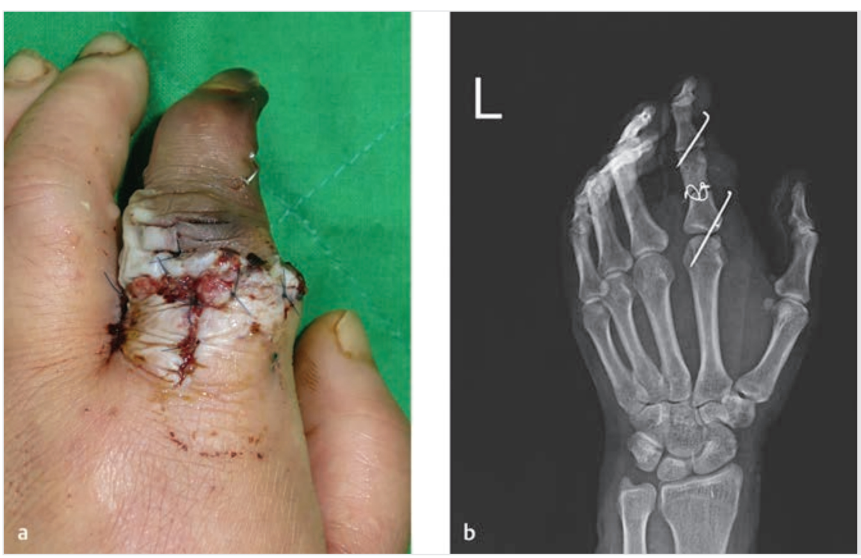

Fig. 58.1 (a, b) Left index finger failed an attempt at replantation. The finger is nonviable, leaving the patient with a stump of the proximal phalanx.

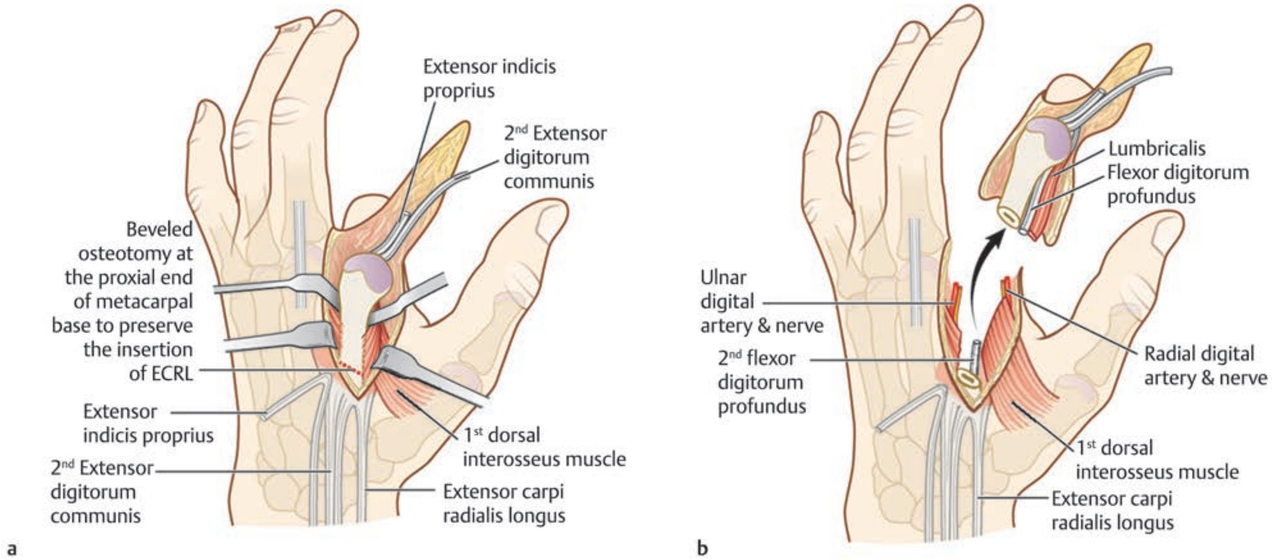

Fig. 58.2 (a–c) The metacarpal bone is isolated and removed with excess tendon and soft tissue. The neurovascular bundles are resected proximally and buried in the intrinsic muscles of the hand.

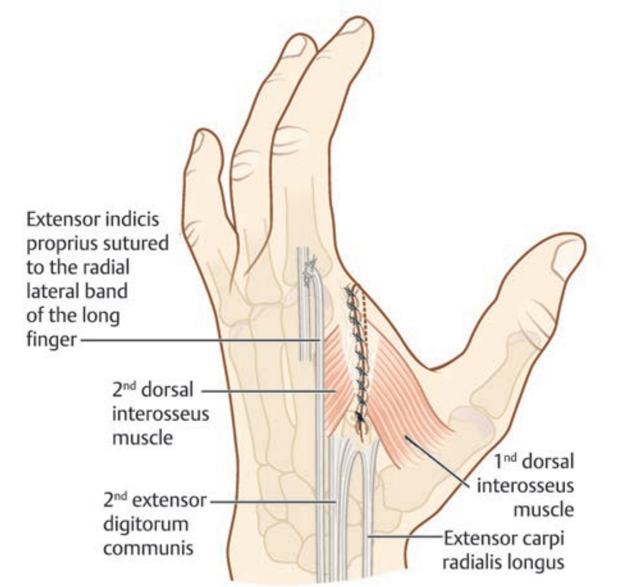

Fig. 58.3 The first dorsal interosseous muscle is sutured to the soft tissue around the long finger metacarpophalangeal joint. The extensor indicis proprius tendon is transferred to the extensor hood of the long finger to make a new primary pincher and manipulator for more independent extension.

of the metacarpal bone should be smoothened by a rasp. The tendon of the first dorsal interosseous muscle is transferred to the radial lateral band of the long finger for good abduction of the long finger for pinching and for a smooth, contoured first web space between the thumb and long finger. The extensor indicis proprius tendon is transferred to the extensor hood of the long finger to make a new primary pincher and manipulator for more independent extension (▶Fig. 58.3).

Closure of the skin is done by tailoring and adjustment of the skin over the dorsum of the hand. The smooth web space gives a more normal hand appearance.

58.5 Postoperative Photographs and Critical Evaluation of Results

Index ray finger amputation does not cause any severe functional deficits in performing activities of daily living. Compared with amputation through the middle or proximal phalanx, there is no significant loss of strength regarding tip pinch, key pinch, and grip pinch, and cosmetic appearance is much better. However, loss of a ray finger results in a narrowed span of the palm and decreased strength of pronation and supination.

Single ray amputation is a viable immediate salvage procedure to improve hand use after irretrievable central or border digit amputation. When possible, primary ray amputation is

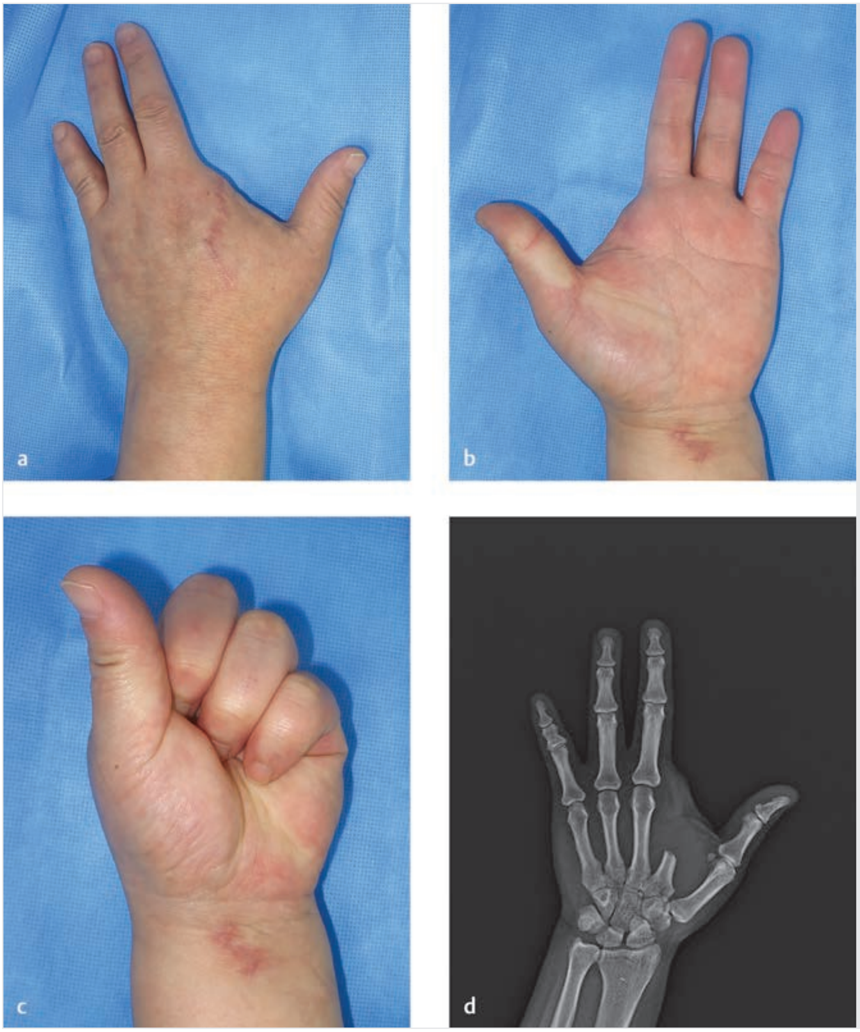

Fig. 58.4 (a–d) A ray amputation offers good function and wide first web space.

preferable in shortening the period of disability and improving ultimate function of the hand. It allows the patients to return to work earlier than other procedures.

At 2 years out, the patient had excellent function and was able to return to full work duties (▶Fig. 58.4).

58.6 Teaching Points

- Revision amputation is a sound viable choice for failed replants of the index finger.
- The second metacarpal resection should be at least 1 cm of length to preserve the insertion of the extensor carpi radialis longus tendon.
- Insertion of the first dorsal interosseous tendon to the radial sagittal band of the long finger to provide adduction.
- The extensor indicis proprius transfer to the extensor hood of the long finger helps support independent motion of the long finger.

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59 Failed Digit Replant: Toe-to-Hand Transfer

Sang Hyun Woo

59.1 Patient History Leading to the Specific Problem

A 34-year-old male patient sustained a complete amputation of the right index, long, and ring fingers by a press machine (▶Fig. 59.1).

After replantation failed, the index finger was closed primarily at the middle phalanx. The long finger was disarticulated at the distal interphalangeal (DIP) joint and soft tissue was lost distal to the proximal interphalangeal (PIP) joint. The radial pulp of the ring finger was defected. The patient was eager to recover the original length and shape of the index and long fingers. First, the open wound of the long and ring fingers was covered with distant groin flap to maintain proximal phalangeal bone for the next stage of toe transfer procedure (▶Fig. 59.2).

After division of the groin flap, secondary division between the long and ring fingers was performed (▶Fig. 59.3).

59.2 Anatomic Description of the Patient's Current Status

The patient now has soft tissue covering the foreshortened right index and long fingers. The ring finger had a minor soft-tissue defect closed but did not require any bone shortening. There is motion at the PIP joints of each finger. The index is amputated just distal to the PIP joint, whereas the long finger is amputated at the DIP joint. The foreshortened fingers inhibit key pinch and render the fingers dysfunctional.

Fig. 59.1 Amputation of the distal aspect of the index, long, and ring fingers.

Fig. 59.3 Division and inset of the groin flap provided early coverage of the exposed bone of the long and ring fingers.

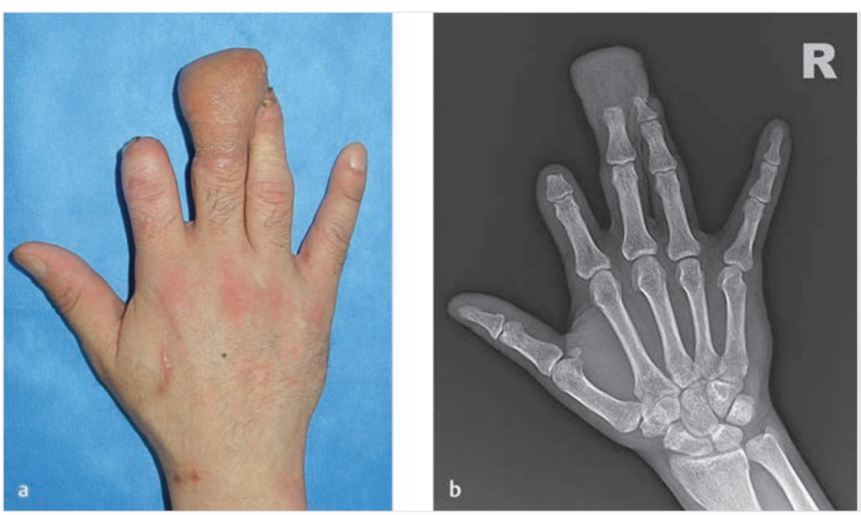

Fig. 59.2 (a, b) A groin flap was used to cover the exposed bone at the end of the long and ring fingers.

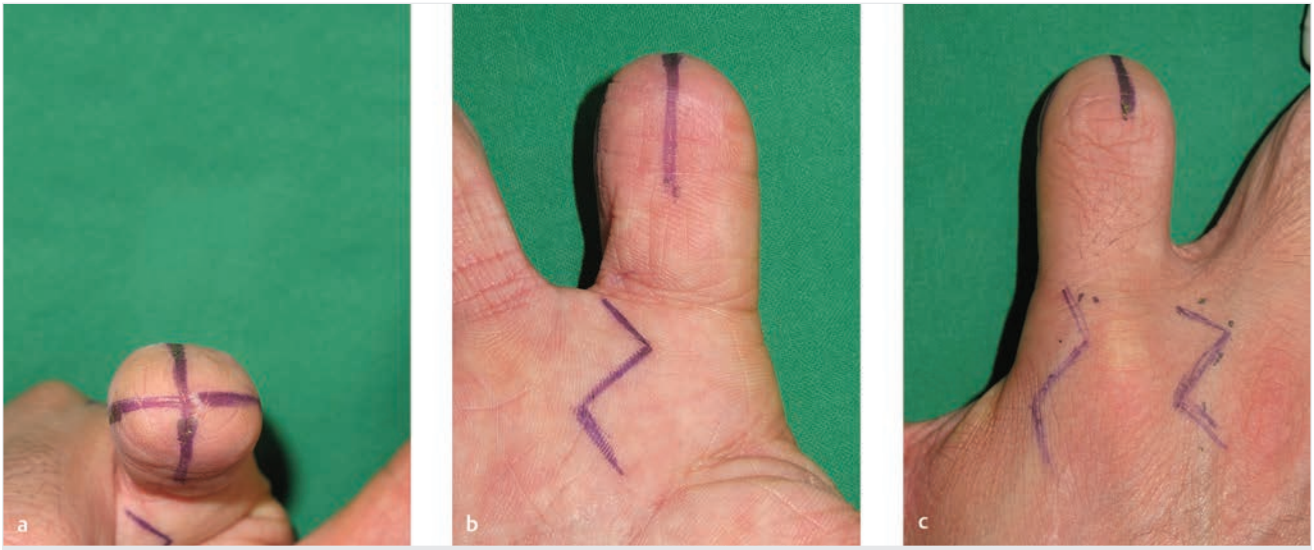

Fig. 59.4 (a–c) Cruciform incision markings on the recipient site.

59.3 Recommended Solution to the Problem

Second toe transfer is the recommended reconstruction of the index and long fingers. The toe size matches appropriately and the neurovascular pedicles are of similar sizes for each of the donor and recipients. The soft tissue on the fingers should be allowed to mature for a number of months to limit inflammation and edema. A great toe would be too large for the fingers. Lengthening procedures such as distraction osteogenesis would create longer fingers but would not restore sensation and would not be as aesthetic.

Six months later, bilateral second toe-to-hand transfer was carried out to reconstruct the index and long fingers.

59.4 Technique

For the toe transfer, dissection of the recipient site begins under upper arm tourniquet control. A cruciform incision was made on the distal end of the finger stump (▶Fig. 59.4).

Four skin flaps were developed away from the phalangeal bone and tendons were defatted. The digital nerves were isolated, trimmed sparingly down to the level of normal-looking fascicles, and tagged with 6–0 black silk sutures. The flexor digitorum profundus and the extensor digitorum communis tendons were also isolated. The distal end of the middle phalangeal bone remnant was freshened with an electric saw at the desired level. To carry out the arterial anastomosis at the proximal site where the common digital artery divides distally into two digital arteries, a longitudinal incision of about 2 cm was made at the proximal volar web space. Directly opposite this at the dorsum of the hand, another 2-cm longitudinal incision was made for the dissection of one or two subcutaneous veins. To avoid an unsightly scar made by a long incision or by a skin graft on the reconstructed fingers, a subcutaneous tunnel was created by bluntly passing a silicone drain or Nelaton catheter between two incisions of the digit and the web space. Through this tunnel, the neurovascular pedicle of the toe flap gains access to the web space of the hand.

Fig. 59.5 Preoperative design on the foot for harvesting the second toe.

Regarding the dissection of the donor site along the circumference of the second toe, a zigzag incision was made at the desired level (▶Fig. 59.5).

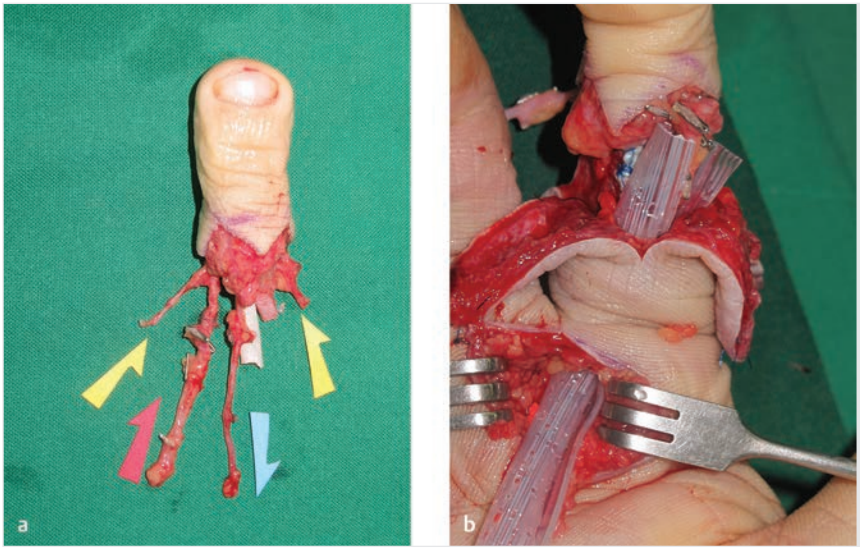

Fig. 59.6 (a, b) Harvested partial second toe flap with relatively long and slender neurovascular pedicle. After defatting of skin flap, bone preparation, and tagging of the neurovascular bundles, a silastic drain is inserted between incisions to create a subcutaneous tunnel for passage of the neurovascular pedicle.

Through the incision at the dorsum of the distal foot, the required length of the subcutaneous veins was dissected. Then, the first dorsal metatarsal artery was identified in the first interdigital web space of the foot and dissected in a retrograde fashion. All the communicating branches of the first dorsal metatarsal artery supplying the great toe were ligated from the plantar side of the foot. Both plantar digital nerves were preserved and tagged with 6–0 black silk sutures. The flexors and extensors were likewise isolated. The toe was disarticulated at the PIP joint or at the metatarsophalangeal joint depending on the length of bone required. After all dissection was completed, the tourniquet was deflated to verify toe viability and to allow toe perfusion for at least 20 minutes. The donor site was closed primarily.

The preferred technique of bone union between the finger and the toe is two perpendicular interosseous 90–90 loop wiring (▶Fig. 59.6).

To reinforce this fixation and to prevent a claw finger deformity, a temporary longitudinal Kirschner's wire is used. Subsequent to bone fixation, repair of the extensor and flexor tendons followed. The vascular pedicle was then carefully passed through the subcutaneous tunnel to reach the web space. At the web space, the artery and both digital nerves of the toe were microanastomosed to their counterparts in the finger using a 10–0 nylon suture. After digital nerve repair, microanastomosis of the subcutaneous veins at the dorsum of the web space followed. Skin incisions were sutured loosely. A well-padded short arm splint was applied.

Postoperatively, the intensive monitoring of toe perfusion commenced. Immediate re-exploration was carried out for any suspicion of vascular compromise. Anticoagulation therapy using heparin, aspirin, and prostaglandin E1 was instituted for 5 days. On the 14th day, the intramedullary Kirschner's wire was pulled out, allowing passive motion of the finger. By the fourth week following operation, gentle active range of motion exercises commenced. Coban (3M, United States) taping was applied to minimize edema of the transferred toe during rehabilitation. Secondary procedures such as pulp plasty were performed on the third month. Tenolysis or scar revision was performed 6 months after operation.

When revision amputation is distal to the flexor digitorum superficialis insertion, the remaining middle phalanx can participate effectively in grasping activities, although PIP joint function is a little limited. If amputation has occurred proximal to the insertion of flexor digitorum superficialis insertion, there will be no active flexion control of the remaining portion of the middle phalanx. In this case, revision amputation at the PIP joint is recommended. However, in children or young women or in multiple digit amputation, preservation of the middle phalangeal bone is necessary for cosmetic reasons more than functional ones. Later, secondary reconstruction with toe-to-hand transfer may be requested in the next stage. At this level of amputation, at least 1 cm of the middle phalangeal bone is required for toe transfer to achieve an acceptable range of proximal phalangeal joint motion. If this amount is not available, finger reconstruction options are limited.

59.5 Postoperative Photographs and Critical Evaluation of Results

The postoperative appearance and range of motion following the toe-to-hand transfer are shown in ▶Fig. 59.7.

59.6 Teaching Points

- Revision amputation at the just proximal part of replantation is performed by denuding articular cartilage, taping the condyles of the proximal phalanx, and employing tension-free skin closure.
- Primary ray amputation shortens lost work time, eliminates the cost of a second procedure, and improves cosmetic appearance.
- Second toe-to-hand transfer for the digits recovers a normal appearance and also maintains the original digit length, but consideration of donor site morbidity and risk of operation failure must be taken.

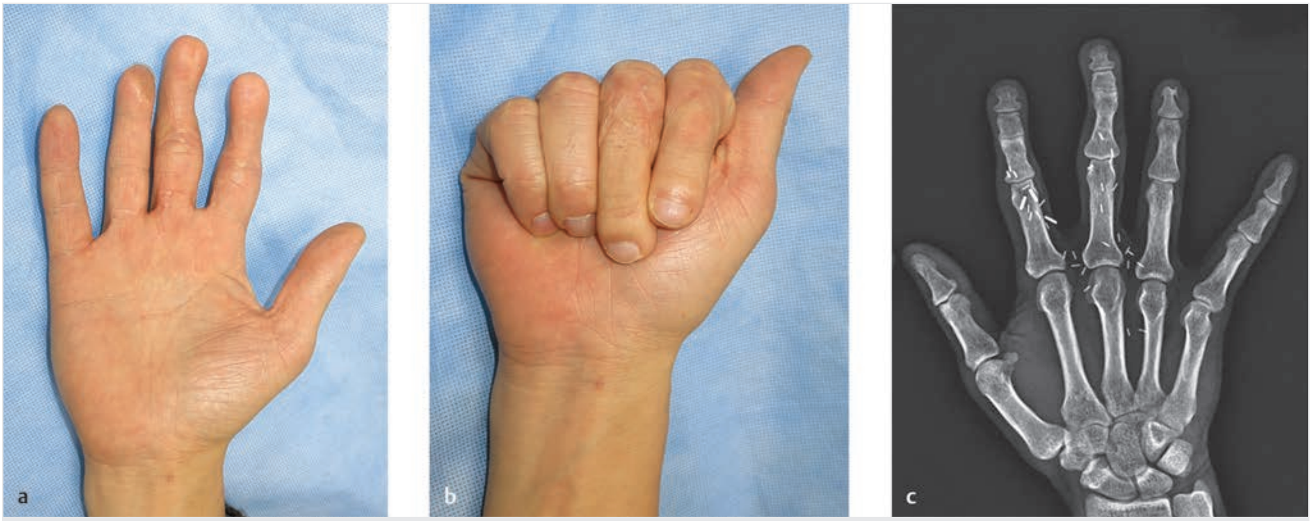

Fig. 59.7 (a–c) The postoperative appearance, 38 months later.

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60 Failed Thumb Replant: Great Toe-to-Thumb Transfer

Sang Hyun Woo

60.1 Patient History Leading to the Specific Problem

A 47-year-old male patient sustained a crushing amputation of the left thumb by agricultural machine. The distal phalangeal bone was segmentally fractured and two attempts of reanastomosis of the ulnar digital artery were not successful. On the seventh postoperative day, the necrotic thumb was debrided (▶Fig. 60.1).

60.2 Anatomic Description of the Patient's Current Status

The patient has a distal thumb amputation through the base of the distal phalanx. The thumb requires soft tissue coverage for exposed phalangeal bone as well as length for restoration of key pinch and grip.

60.3 Recommended Solution to the Problem

There are a number of options for this patient. The goals are to provide sensate stable coverage and added length to restore optimal function and form. The wounds could be dressed with a Vaseline dressing and allowed to heal by secondary intent. This would take a number of weeks and still not address the short thumb problem A revision amputation would shorten the bone even more, but would offer glabrous skin coverage with sensation and have the least amount of down time for the patient. Thoracoepigastric flaps do not offer sensation. Local flaps from perforators from the digital arteries can be propelled from the proximal thumb to the distal thumb and offer stable coverage, but again thumb length has not been addressed and the distal end remains insensate. The first dorsal metacarpal artery flap can also provide stable, sensate coverage but does not address thumb lengthening.

An optimal solution to this problem would be to use the great toe as a toe-to-hand transfer offer restoration of sensation and thumb length.

60.4 Technique

The great toe flap is designed first by measuring the contralateral thumb to be accurate with the required length of toe needed to restore normal anatomy (▶Fig. 60.2).

Using a retrograde approach on the first web space of the foot, the dominant artery should be dissected from the first web space to the proximal direction. In this case, the first plantar metatarsal artery is dominant and extension incision on the plantar area is necessary. The artery is skeletonized by a

Fig. 60.1 (a–c) A failed distal thumb replantation resulted in a revision amputation with soft-tissue loss to the volar skin and a bone loss at the level of the base of the distal phalanx.

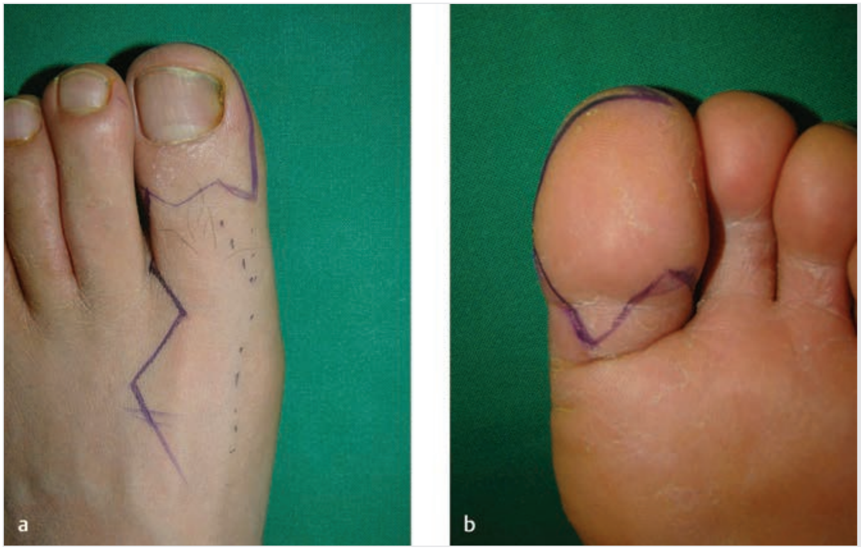

Fig. 60.2 (a, b) The great toe flap is designed to equal the length of the contralateral thumb.

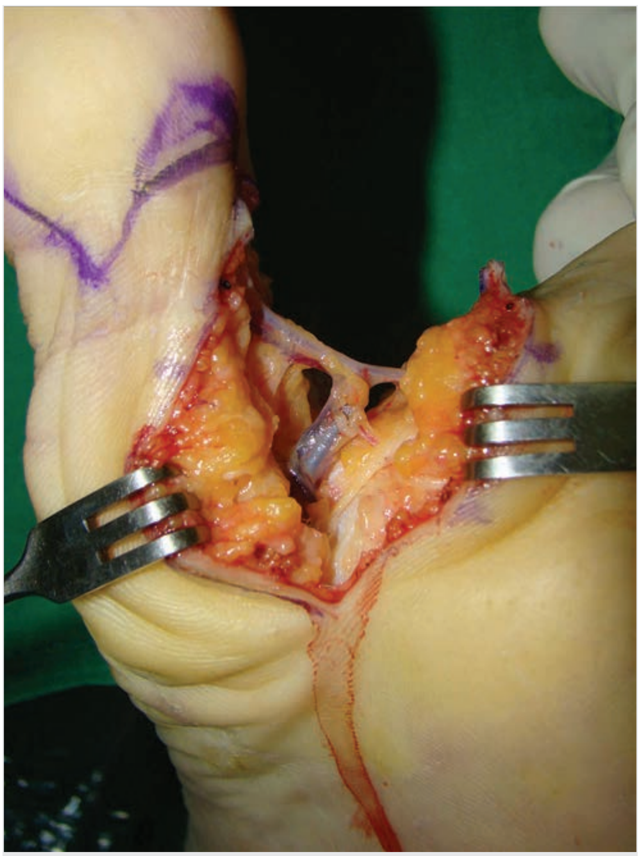

Fig. 60.3 The dissection is initiated in the first web space to identify the dominant artery system being either dorsal or plantar.

radical resection of adventitia and the vein is dissected with the perivenous tissues (▶Fig. 60.3).

Digital nerves of the great toe are also harvested to coapt with the corresponding structures of the thumb. The venous network on the medial aspect of the great toe is more reliable than the first web space. There are always prominent branches of the great saphenous vein proximal to the medial nail fold on the tibial aspect of the great toe. This vein should be included in the flap to prevent necrosis of the remnant skin flap. On the dorsum side of the great toe, the subdermal venous plexus should be preserved to close the donor site (▶Fig. 60.4).

Partial great toe from the left foot was transferred after disarticulation at the interphalangeal joint (▶Fig. 60.5).

After arthrodesis of the interphalangeal joint of the thumb with two or three Kirschner's wires, arterial anastomosis was performed between the first palmar metatarsal artery and the princeps pollicis artery at the first web space of the dorsum. When the arterial anastomosis is performed at the anatomical snuffbox, a subcutaneous tunnel is made by intraoperative expansion with a Nelaton catheter or silastic drain between two incisions for passage of the vascular pedicle. This helps avoid the scarring caused by a long incision and the necessity to perform a skin graft on the reconstructed thumb. Venous anastomosis is performed with a superficial vein at the dorsal aspect of the thumb.

In management of the donor site, primary closure without tension is preferred. If needed, a cross-toe flap or skin graft from the plantar aspect is performed to resurface the donor defect.

Intensive postoperative monitoring of the perfusion of the transferred toe is performed for 5 to 7 days. From the third week after the operation, rehabilitation therapy is begun for restoration of sensation and Coban taping is applied to decrease edema of the transferred toe. In the seventh to eighth week after the operation, the Kirschner wires are removed. Secondary procedures such as pulp plasty, nail fold plasty, or scar revision can be carried out 3 to 6 months after surgery.

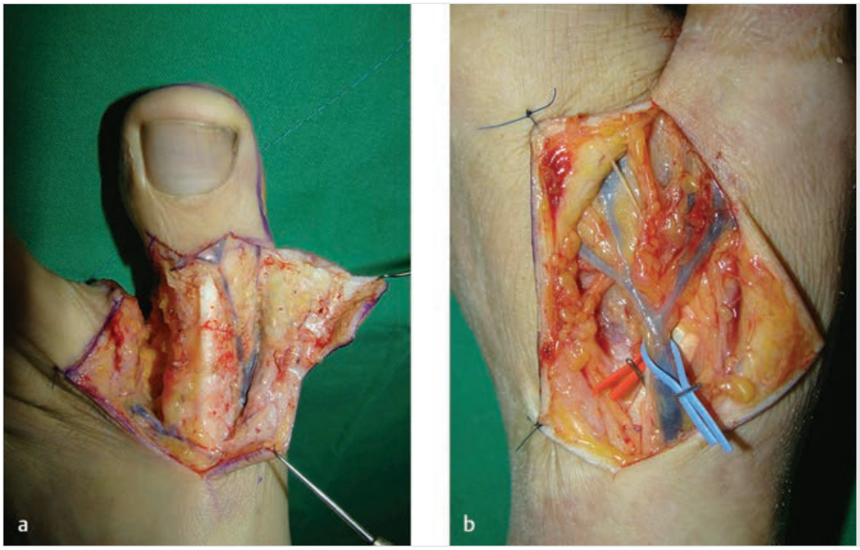

Fig. 60.4 **(a, b)** The superficial veins are maintained with the distal toe to provide adequate venous drainage.

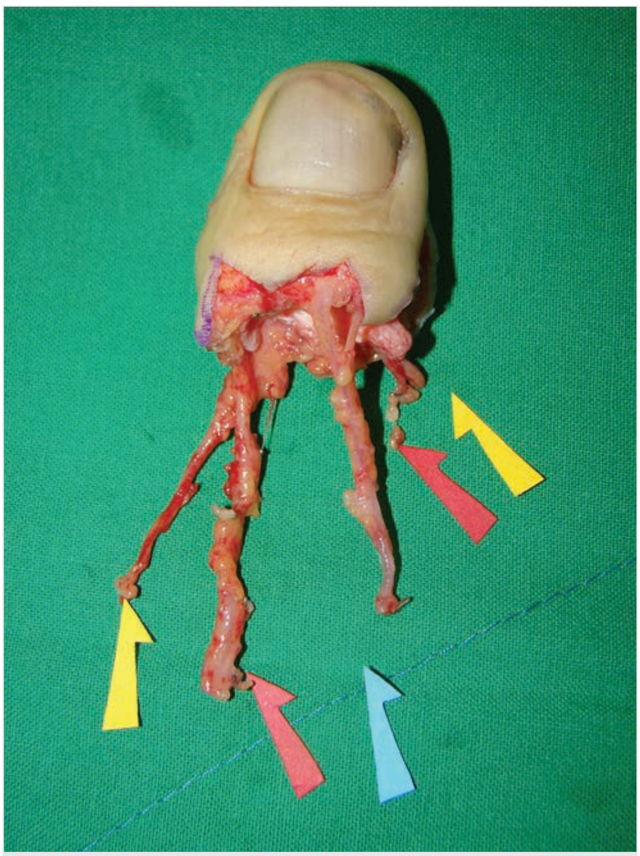

Fig. 60.5 The great toe is disarticulated at the level of the interphalangeal joint. Each vein, artery, and nerve are dissected in preparation for anastomosis or coaptation on the thumb.

60.5 Postoperative Photographs and Critical Evaluation of Results

The patient regained key pinch function and protective sensation to the reconstructed thumb. All aspects of the patient's activities of daily living resumed without impairment. The patient was able to ambulate normally without pain. The donor site healed without event (▶Fig. 60.6).

Sometimes, toe transfer may be performed immediately after revision amputation of the failed replant. The concept of emergency or immediate toe-to-hand transfer is based on early microsurgical reconstruction to cover the open wound with toe flap. It provides both new digit and wound coverage with skin flap of the toe. Compared with the elective or staged operation, it avoids shortening exposed phalangeal bone and prevents the formation of tendon adhesions or atrophy, thus preserving the length of the finger and providing smooth gliding of the tendons to achieve greater total active range of motion. From a socioeconomic viewpoint, it reduces the convalescent period by using single-stage reconstruction. The duration of insurance coverage for the patients is significantly shorter and return to work is earlier. However, there are also significant disadvantages of emergency toe transfer. Patients should understand the entire process of the operation based on strong rapport between the patient and the surgeon. Subjective satisfaction of the patients with postoperative function and appearance might have diminished because there is no period of mourning following digital loss. Furthermore, all soft tissues needed for wound closure must be harvested from one donor site, which may increase donor site morbidity.

There are various methods of great toe-to-hand transfer to restore the interphalangeal joint that play a critical role in key

Fig. 60.6 (a–d) Final outcome of the toe-to-thumb transfer 1 year later. The sensation is protective and the function is excellent. The donor site is healed and the patient ambulates without dysfunction.

pinch and vice grip for larger objects. The mini wraparound flap can be harvested from the great toe with arthrodesis of the interphalangeal joint. Using a similar technique, key pinch and power grip of approximately 60 to 66% and 57%, respectively, of the contralateral side can be achieved. With activities of daily living, the patients' complaint is not serious. Therefore, for the reconstruction of distal thumb defects at the interphalangeal joint with the intact metacarpophalangeal joint and carpometacarpal joint of the thumb, a simple procedure of arthrodesis at the interphalangeal joint is recommended over a complex design or difficult dissection involving both the great toe and the second toe. Primary closure of the great toe with a medial skin flap from the remnant great toe is more acceptable after disarticulation at the interphalangeal joint to minimize the morbidity of the donor site.

60.6 Teaching Points

- Failed replantation of the thumb should be reconstructed irrespective of amputation level. Great toe transfer for thumb reconstruction is the most promising method regarding the functional restoration as well as cosmetic result.
- In reconstruction of distal thumb defects with great toe transfer at the interphalangeal joint, arthrodesis of the interphalangeal joint is recommended.
- In reconstruction of proximal thumb defect, 1 cm of proximal phalangeal bone should be preserved to allow normal gait. Primary closure of the great toe with a medial skin flap from the remnant great toe is more acceptable.

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61 Failed Replant: Failed Degloving Revascularization

Sang Hyun Woo

61.1 Patient History Leading to the Specific Problem

A 27-year-old male patient sustained a degloving amputation of the right hand by a roller machine. All soft tissues of the index, long, ring, and small fingers were completely detached from the phalangeal bones and tendons distal to the digitopalmar crease. Even though there was vessel anastomosis between artery and vein, all replanted soft tissues were necrosed (▶Fig. 61.1).

The distal phalanx was disarticulated at the distal interphalangeal joint of all fingers (▶Fig. 61.2).

61.2 Recommended Solution to the Problem

The degloved digits require coverage with a flap. Free tissue coverage is an option, but that would require vein grafts into the forearm. A staged reconstruction can be achieved while keeping the hand elevated using the thoracoepigastric flaps and the medial arm flaps. These are random flaps that will be used to create a surgical syndactyly with subsequent separation of the digits after neovascularization of the flaps from surrounding tissue. This often takes 2 to 3 weeks. The syndactylized digits will remain in that disposition for 2 to 3 months and then debulked and separated. Skin grafts may be needed to obtain full closure.

61.3 Technique

The soft-tissue defect of the palmar area was covered with anterior chest flap and the dorsal area covered with medial upper inner arm flap (▶Fig. 61.3).

Before resurfacing the degloved fingers, two steps are mandatory to achieve successful postoperative results. Revision amputation of the distal phalangeal bone should be carried out. If not, the distal phalangeal bone inside the flap becomes necrosed due to insufficient perfusion through the flap. Transverse fixation on the adjacent proximal phalangeal bones is also necessary to avoid narrowing of the interdigital

Fig. 61.1 Devascularized skin of all fingers.

Fig. 61.2 (a, b) The skin was removed and the distal phalanx will be removed to permit better function without contractures.

Fig. 61.3 (a) The palmar defects were closed with a thoracoepigastric flap. **(b)** The dorsal defects were closed with a medial arm flap. All fingers were syndactylized but will be separated at a later procedure. **(c)** The flaps will remain in place for 3 weeks and then divided.

spaces as the flap shrinks. Temporary longitudinal Kirschner's wire fixation prevents flexion contracture of the finger inside the flap. In some cases, disarticulation at the proximal interphalangeal joint is also required. The importance of preservation of the first web space and interdigital web space cannot be overemphasized.

For more comfortable inset of the distant flap, a cross-chest position is recommended. One flap is harvested from upper inner arm proximal to elbow joint to cover the dorsum part of whole digits. The other flap is elevated from the anterolateral chest area below the nipple.

To resurface both palmar and dorsal aspects of whole digits, pedicled flaps can be used as two separate flaps. After 2 weeks of pedicled flaps, delayed procedure is performed with incision at the base of the flap. A further 1 week later, flaps are divided. After 3 months, division of the interdigital space is commenced on the third web space. On the next step, the second and fourth web spaces are divided. After division of the flap, defatting of each digit is carried out.

Compared with the complexity of free flaps, the pedicled flaps are simple and easy to handle in emergencies. Donor sites of pedicled flaps are the groin, upper inner arm, and chest. Besides chest flap and upper inner arm flap, a bilobed flap, which is composed of groin flap and hypogastric flap, can be used to resurface the whole defect of the hand. The hypogastric flap is used to cover the palm, and the groin flap to cover the dorsum of the hand. Pedicled flaps can be used in the cases where general anesthesia is not suitable due to the patient's health, prolonged operation time, or preservation of the vessels for secondary reconstruction such as toe transfer. The disadvantages of pedicled flaps are multiple procedures and long hospital stays, immobilization of the hand and upper extremity with potential stiffness of the multiple joints, and requirement of an additional procedure like defatting and division.

There are further options for microsurgical reconstruction with fascial free flaps and perforator flaps to cover extensive soft-tissue defects of the hand. For large volar surface defects, the plantar surface is the only appropriate option for resurfacing with glabrous skin. The plantar skin has similar tissue characteristics to the palmar skin of the hand. The medial plantar flap is harvested from the non-weight-bearing area of the plantar foot based on the medial plantar artery. Very thin and large anterolateral thigh perforator flaps can be used to wrap both the dorsum and the palmar surface of whole digits.

After covering the whole digits and hand, serial defatting and division of surgical syndactyly are needed to achieve an acceptable volume and thickness of the hand and digits. When the flap is divided and defatted, the remnant skin should be preserved to use as a donor of skin graft for coverage of the defects. When planning division and defatting of the flap, grafted skin or incision scar should not occur on the skin of the contact area of digits to avoid pain from pinching and grasping.

61.4 Postoperative Photographs and Critical Evaluation of Results

One year after the division and inset of the flaps between the fingers, the patient has a useful assist hand (▶Fig. 61.4).

If secondary reconstruction is possible, glabrous sensate flap can be used to replace the nonsensate flap of the thumb and index pulp. Donor sites of pulp reconstruction are the fibular side pulp of the great toe and the tibial side flap of the second toe. Meticulous nerve anastomosis is required under the microscope between digital nerves of the thumb and the index and proper digital nerves of the deep peroneal nerve of the foot.

61.5 Teaching Points

- Pedicled flap is still a very useful procedure in covering large defects of multiple digit amputation especially in the cases where general anesthesia is unsuitable for microsurgical reconstruction.
- Before resurfacing with flaps, disarticulation at the distal interphalangeal joint is done. Narrowing of the interdigital web space can be prevented with transverse Kirschner's wire fixation on the adjacent proximal phalangeal bones. Temporary longitudinal Kirschner's wire fixation prevents flexion contracture of the finger inside the flap.
- Flap division and serial defatting of the flap are necessary to reconstruct appropriate length and circumference of the digits.

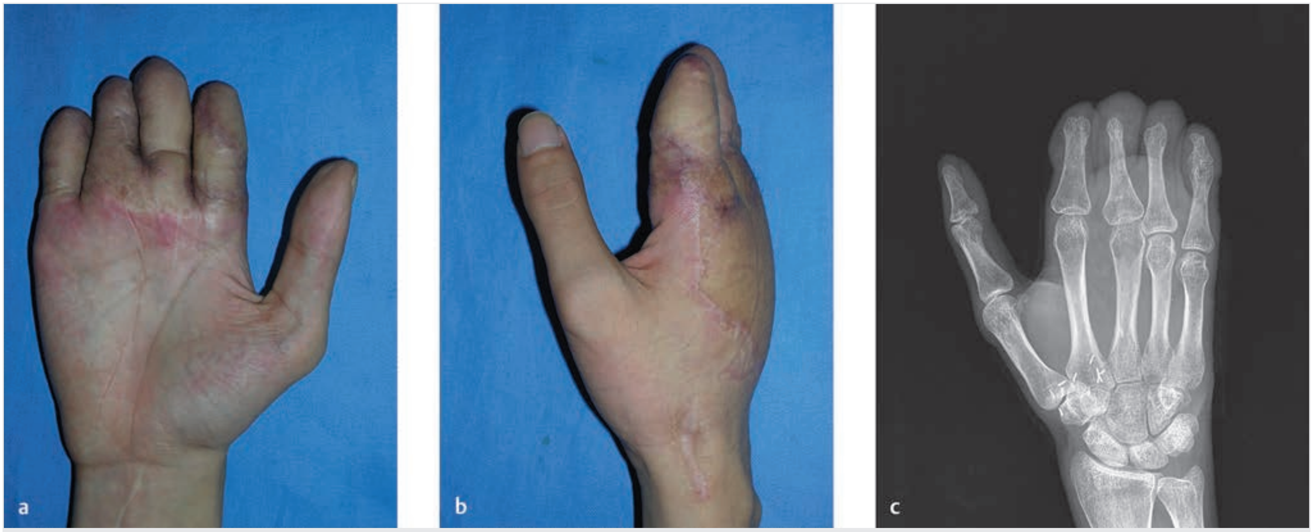

Fig. 61.4 (a–c) The final outcome after definitive debulking and separation of the digits.

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62 Attempted Replantation

Alexandru Valentin Georgescu and Ileana Rodica Matei

62.1 Patient History Leading to the Specific Problem

A 22-year-old woman presented 4 hours after suffering a zone 3 amputation of all fingers at the distal metacarpal level of the right hand. The little finger was severely crushed (▶Fig. 62.1). The mechanism of injury was by crush and torsion. Although it was a relative indication for revision amputation, due to the age of the patient and her very good health status, replantation was attempted.

62.2 Anatomic Description of the Patient's Current Status

The patient presented a zone 3 metacarpal amputation with deglovement of the dorsal aspect of the hand. The little finger was completely mangled. The remaining metacarpals were comminuted fractures with a 2-cm defect.

After a careful irrigation and debridement and metacarpal shortening, it was decided to try the replantation. In the second postoperative day, signs of arterial sufferance appeared: pallor and loss of capillary refill. The patient was readmitted in the operating room and the arterial anastomoses were checked. All three sutured arteries were found with thrombosis. After resection of the thrombosed segments, the arteries were reconstructed with 3-cm-long venous grafts. A good revascularization was obtained. Unfortunately on the fourth postoperative day, the thrombosis reappeared, which determined the reamputation (▶Fig. 62.2). The stump remained opened and, after obtaining a good granular bed 7 days later, the reconstruction was planned (▶Fig. 62.3).

62.3 Recommended Solution to the Problem

Taking into account the mechanism of injury and the aspect of the lesion, maybe it would have been better not to try the replantation. However, the indication was a little forced by the age of the patient and because she was right handed. Sometimes it would be better to start the reconstruction immediately.

Being the dominant hand, the functional reconstruction is mandatory in such a case. The reconstruction should be done as soon as possible to allow the rehabilitation program to start very early.

Multistage or single-stage reconstructions can be considered the possible solutions.

62.3.1 Multiple-Stage Reconstruction

- Skin defect coverage by using split-thickness skin graft or a flap.
- Secondary reconstruction of the prehensile function by using toe(s) transfer.

Fig. 62.1 (a, b) Zone 3 midcarpal amputation of the right hand.

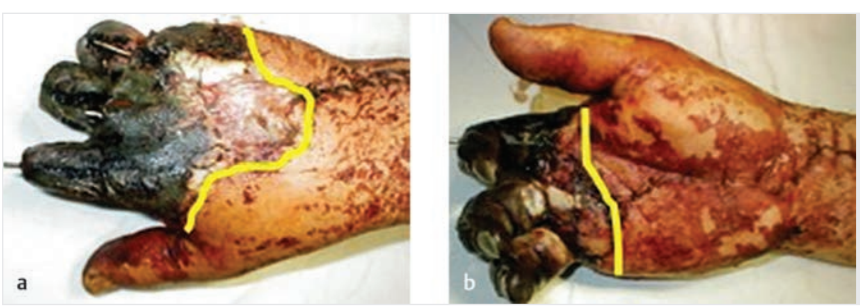

Fig. 62.2 (a, b) Vascular compromise of the replanted digits demonstrates dry gangrene.

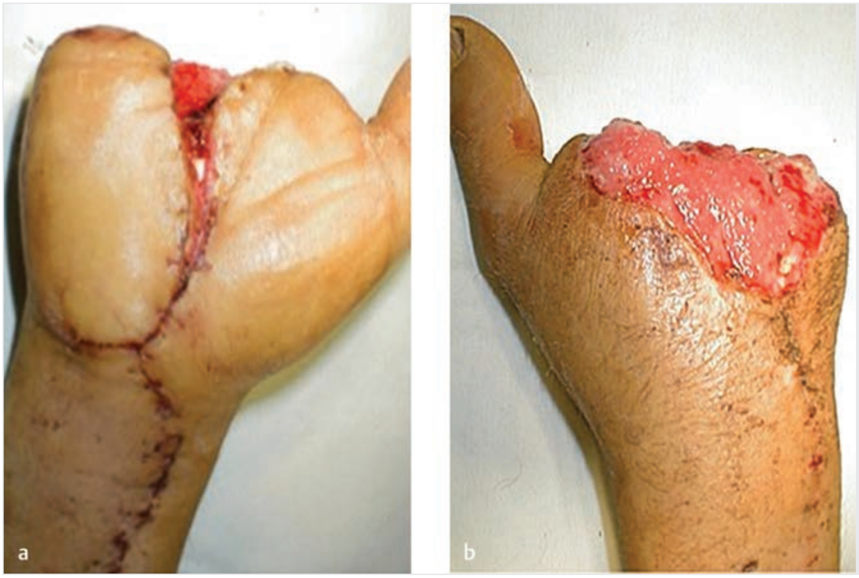

Fig. 62.3 **(a, b)** The gangrenous digits were removed and the stump of the hand allowed to granulate.

62.3.2 Single-Stage Reconstruction

- Using combined toe(s) transfer and dorsalis pedis flap.
- Using a free flap and toe(s) transfer separately vascularized.
- Using toe(s) transfer revascularized through a free flow-through flap.
- Regarding the toe transfer, it is possible to use a single toe, two toes (one from each foot), or a digital block of two toes from the same foot.

Considering the large dimensions of the skin defect and the amputation level proximal to the metacarpal head, our option was to use a free anterolateral thigh (ALT) flow-through perforator flap and a toe transfer of the second and third toes from the right foot.

62.4 Technique

The patient is placed in the supine position. The surgery is done under general anesthesia and a two-team approach.

62.4.1 Steps for the Procedure

1. Hand.
2. Right thigh.
3. Right foot.
4. Hand.

Hand

The hand is prepared with disinfecting solutions and an arm tourniquet is applied. The wound is debrided and the tendon and nerve stumps are identified and isolated. The dorsal branch of the radial artery (RA) in the anatomical snuffbox and the cephalic vein (CV) are identified and isolated.

Right Thigh

The right lower limb is prepared with disinfecting solutions. Using a handheld Doppler, the perforators' location on the anterolateral aspect of the thigh is determined. An ALT flap of 15 × 10 cm is designed, centered on the most powerful perforator, located at 15 cm below the anterior iliac crest. An incision following the anterior edge of the flap is performed, and the skin is undermined until the identification of the perforator, which is a septocutaneous one. The perforator is dissected until its origin from the descending branch of the lateral circumflex femoral (DBLCF) artery. Then, the DBLCF is dissected for a 15-cm length. The complete incision and dissection of the entire flap is performed and, after cutting the vascular pedicle proximally and distally, the flap is harvested (▶Fig. 62.4). The donor site of the flap is closed partially by direct suture and the remaining 6 × 4 cm defect is skin grafted.

Right Foot

A second surgical team starts the harvesting of the composite second and third toes. A tourniquet is placed on the thigh above the knee. A transversal incision is performed 1 cm proximal to the second and third metatarsophalangeal (MP) joints continued longitudinally over the first intermetatarsal space. The skin over the second and third metatarsals is carefully dissected with identification and isolation of three veins draining in a main branch of the dorsal arch (▶Fig. 62.5). The first intermetatarsal artery (IMA) is identified and dissected until the origin from the dorsalis pedis artery. The branch for the big toe and the deep plantar artery are ligated and cut. The transversal incision is prolonged transversally over the plantar aspect of the foot 1 cm proximally to the second and third MP joints. A careful dissection is performed, with the identification of the digital nerves and flexor and extensor tendons, which are cut. Then, the second

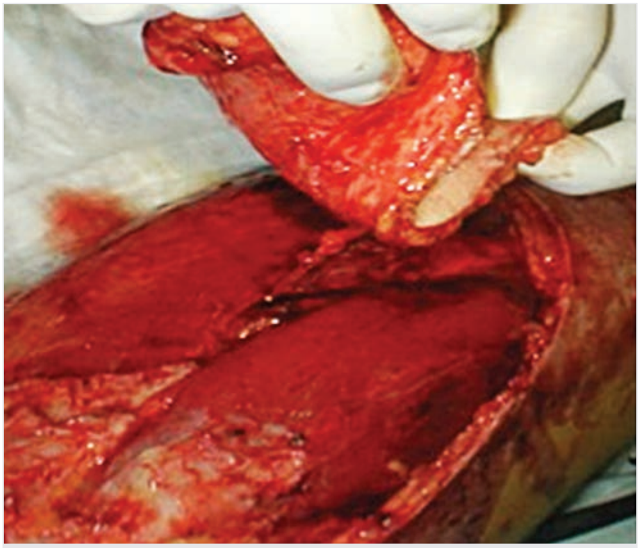

Fig. 62.4 The anterolateral perforator thigh flap elevated on the pedicle.

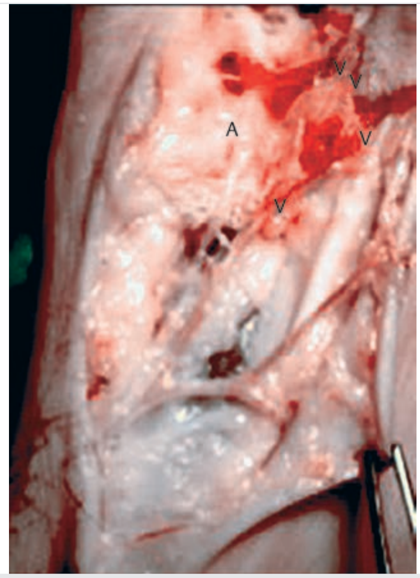

Fig. 62.5 The dorsal incision for the composite toe harvest demonstrates the three veins that need to be included in the dissection and the dorsal arterial arch.

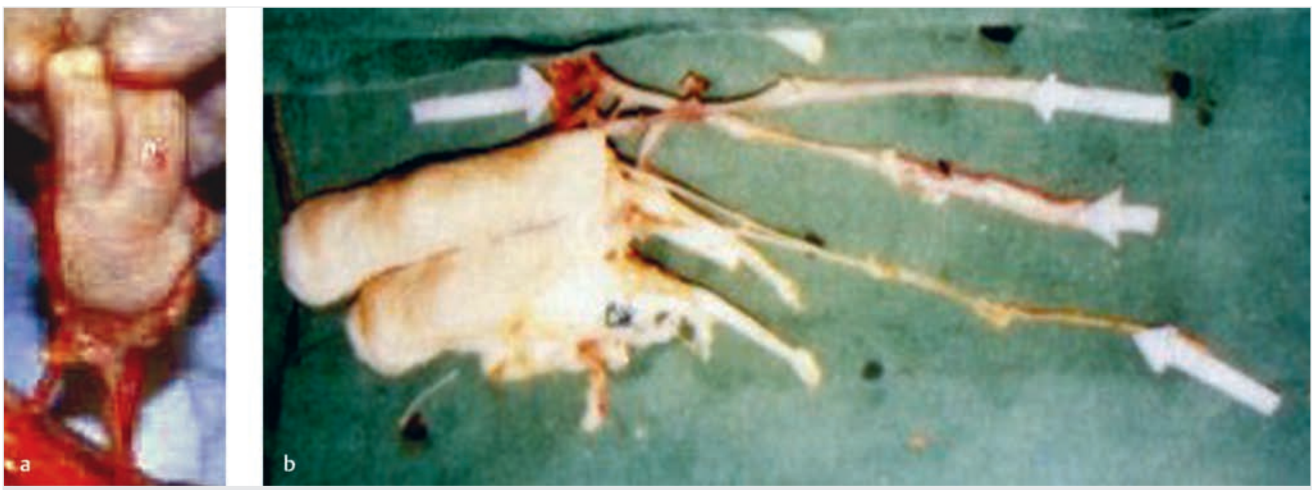

Fig. 62.6 **(a, b)** The composite second and third toe with dissected vessels, nerves, tendons, and bone.

and third metatarsals are prepared and cut 3 cm proximal to the MP joints. The tourniquet is released and the revascularization of the toes is checked. The first signs of revascularization appear after 20 minutes (▶Fig. 62.6a). The artery and vein are cut (▶Fig. 62.6b) and the donor site is directly closed.

Hand

While the second surgical team is working on the foot, the first surgical team starts the work on the hand. The ALT flap is placed over the defect and secured with few sutures. The vascular pedicle is passed through the previously prepared tunnel to reach the RA and CV. Under a microscope with 10× magnification, the vessels are prepared and sutured terminoterminal with 9–0 stitches, first, one concomitant vein to the CV and then the DBLCF to the dorsal branch of the RA. The wounds over the sutured vessels and of the dorsal edge of the flap are sutured. Now, the digital block is transferred to the third and fourth metacarpals and fixed Kirschner's wires are introduced through the metatarsal heads and metacarpals. The flexor digitorum profundus and long extensor tendons are sutured. Under microscope with 20× magnification, the digital nerves and the vessels are prepared and sutured with 9–0 stitches, first the nerves, then the vein of the toes to the distal end of a concomitant vein of the DBLCF, and finally the dorsalis pedis artery to the DBLC. A very good revascularization of the toes is observed (▶Fig. 62.7). Finally, all the remaining wounds are sutured and the hand is dressed and immobilized.

62.5 Postoperative Photographs and Critical Evaluation of Results

Such a case should be very well monitored to be able to intervene immediately if a sign of vascular sufferance appears. Immobilization and elevation are essential, but beginning of the rehabilitation program early is equally important. The chosen type of osteosynthesis, which leaves free the interphalangeal joints, allows the early beginning of passive and controlled active mobilization. Kirschner's wires and the immobilization are maintained for 3 weeks, and then a long and sustained program of physical therapy is continued.

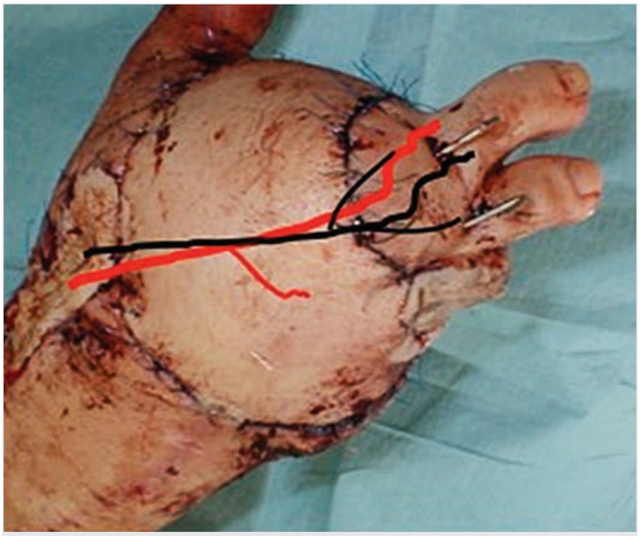

Fig. 62.7 Intraoperative photographs of the vascularized anterolateral thigh flap and composite second and third toe transfer.

Long-term result is very good from the functional point of view, with S4 sensitive recovery and M3 motor recovery 1 year later (▶Fig. 62.8, ▶video 62.1, ▶video 62.2, and ▶video 62.3). The hand demonstrated enough strength and mobility for performing activities of daily living.

62.6 Teaching Points

- In a young and healthy patient with such a complex injury, attempt at replantation can be done, but maybe it is better to consider another reconstructive procedure from the beginning.
- From psychological point of view, in case of a failed replantation like in this case, it is better to do an all-in-one reconstruction, in an attempt to achieve functional rehabilitation as soon as possible.
- The use of a flow-through flap helps in using a single recipient artery, but it can have as disadvantage the possible compromise of both flaps in case of thrombosis. That is why the indication for such a procedure should be closely watched; it should be performed by experienced surgical teams and it should be very clearly explained to the patient and the relatives.

Fig. 62.8 (a–e) Long-term follow-up of the reconstructed hand demonstrating return of good function.

Fig. 62.9 The donor site of the toe harvest.

- The use of a digital block of two toes is possible only if the amputation is proximal to the metacarpal heads. It has the advantages of having a single foot affected and fewer vascular anastomoses. There is no functional deficit on the foot, but the morphological implications should be discussed with the patient (▶Fig. 62.9).
- The osteosynthesis should leave the interphalangeal joints free, in an attempt to start the physical therapy very early after surgery.

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63 Nonunion following Digital Replant

S. Raja Sabapathy

63.1 Patient History Leading to the Specific Problem

A 25-year-old man presented to the emergency room having sustained a machinery crush injury that resulted in total amputation of all the fingers in his dominant right hand (▶Fig. 63.1). Only the amputated part of the middle finger was found replantable and it was heterotopically replanted over the index finger stump. Bone fixation was by a K-wire. The wound healed well and the K-wire was removed at 6 weeks. The index replant survived, but despite adequate immobilization, he developed a nonunion at the replant site. He has a normal thumb. The nonunion in the only available finger in his dominant right hand was very painful and disabling.

63.2 Anatomic Description of the Patient's Current Status

Six months after an index finger replantation, the patient presents with instability at the replant site. The instability prevented him from using the finger for any pinch or grip activities (▶Fig. 63.2). All the interphalangeal (IP) joints are stiff in straight position, and 40 degrees of active flexion is possible at the metacarpophalangeal (MCP) joint. The thumb is unable to meet the index finger tip. On attempting thumb–index side pinch, due to the instability at the nonunion site, he is not able to generate any pinch or grip strength.

In the type of injury sustained by the patient, the aim is for the salvage of maximum functional units. Only one digit

Fig. 63.1 (a–c) Crush avulsion amputation of the right index, long, ring, and little fingers.

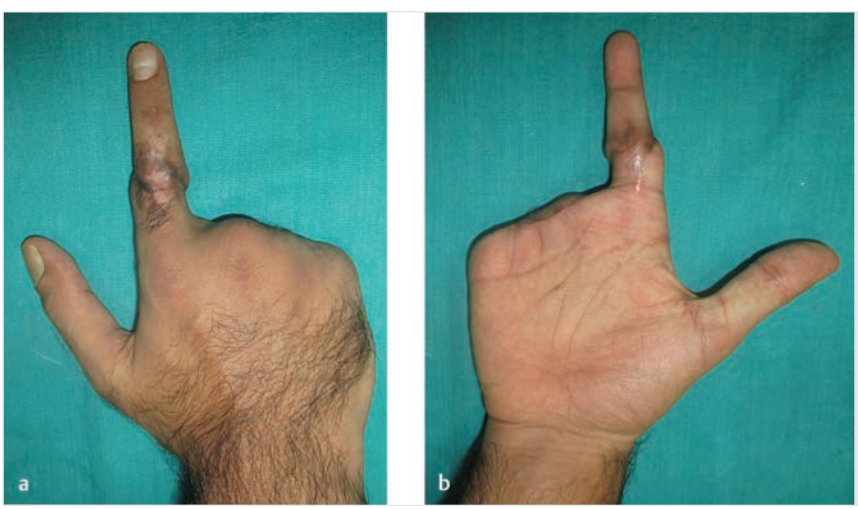

Fig. 63.2 (a, b) The successfully replanted index finger is dysfunctional because of the nonunion of the middle phalanx.

was replantable. Since the MCP joint was intact and skin cover was adequate, it was decided to replant it over the index finger stump. The rest of the finger stumps had raw areas that needed flap cover to salvage the base of the proximal phalanges of the middle and little fingers, which would enhance function if toe transfers were done at a future date. The patient was not willing for the option of toe transfers at all and so replantation over the stump of the index and closure of the amputation stumps of other fingers was done. When only one finger is replanted, we prefer to do it in the index position since it is more comfortable for pinch activities and the strength generated. A little finger placement will provide a wider span of the grip, but our patients have found more satisfaction with index placement. In replantation surgery, primary bone union is a determinant for successful functional outcome.

63.3 Recommended Solution to the Problem

Secondary procedures following replantation are complex procedures. There is a potential risk of losing the replant due to inadvertent injury to the vessels, since most replants are dependent on the repaired blood supply for a long time. So prevention of nonunion is important. This is achieved by adequate bone shortening to ensure viable bone ends, good soft-tissue cover, adequate fixation, and primary wound healing. In this patient, on viewing the X-ray it is possible that the articular surface of the middle phalanx was not adequately nibbled to present a good cancellous bone stock. Single K-wires do not provide rigid fixation adequate enough for bone union. In this situation, we need to gain access to the nonunion site without damaging the repaired vessels, freshen up the nonunion site to viable bone ends, and achieve bone union. An angulation of 30-degree flexion at the site was planned, so that the thumb–index tip pinch is possible.

63.4 Recommended Solution to the Problem.

- Access to the nonunion site has to be achieved without injuring the vessels repaired during replantation.
- The nonunion ends have to be freshened up to reveal viable cancellous bone ends.
- While fixing up the bone, it has to be fixed in an angle to obtain good functional outcome, in this instance, a good thumb–index pinch.
- Fixation techniques that do not require too much dissection are to be used to prevent inadvertent injury to the vessels and achieve primary wound healing.

63.5 Technique

The notes and the intraoperative photographs taken are studied to have an idea of the course of the repaired vessels (▶Fig. 63.3). Post replant, the vessels do not always lie in their anatomical pathway. A handheld Doppler was used to mark the signals of the digital arteries. In this patient, we could get continuous signals only from the ulnar-side digital artery. The area to be protected from injury was determined. The surgery was done under brachial block with upper arm tourniquet. A 2.5-cm longitudinal incision was made in the midline on the dorsum centered at the level of the replant. The incision was deepened to beneath the tendon, dissection was made just over the bone, and the two bone ends were freed. The surface of the proximal bone end was transversely freshened. We planned for a 30-degree flexion at the replant site and a little radial tilt so that the index finger tip should easily meet the thumb tip. We find it easy to do all the adjustment needed to achieve this position by appropriate shaping of the bony surface at one end. We chose to do this at the distal surface since it presented a broader surface. A single K-wire was obliquely driven distally and then keeping the replanted part in 30-degree flexion and about 10-degree

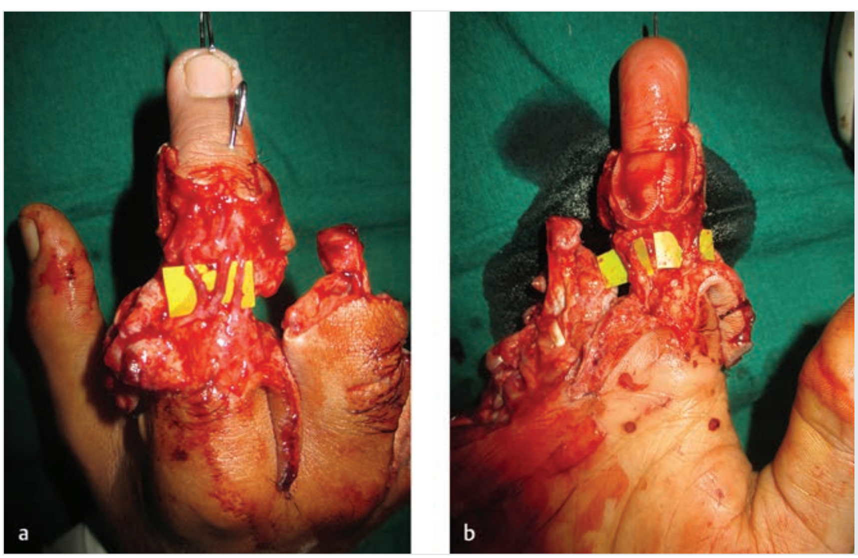

Fig. 63.3 (a, b) Initial position of the repaired vessels at the time of replantation. Taking photographs at the initial surgery may help in planning secondary procedures.

radial deviation, the K-wire was driven in a retrograde manner into the proximal phalanx to achieve fixation. It was done in a single attempt and the fixation was stable. Adequate contact of good bone surface was confirmed. Tourniquet was released and the finger viability was confirmed. Hemostasis was achieved and skin closed with 6–0 nylon sutures.

The finger was immobilized in a plaster for 4 weeks. Gentle movement of the MCP joint was started within the dressing from day 2. Sutures were removed at 2 weeks and K-wires were removed at 4 weeks. The MCP joint was actively mobilized and he achieved 60 degrees of flexion. The bone ends achieved good union at the replant site, resulting in a stable and useful finger. He became comfortable with all the activities of daily living.

63.5.1 Steps for the Procedure

1. An idea of the location of the crucial vessel anastomosis is gained from the operation notes, intraoperative pictures, and by using a handheld Doppler to prevent inadvertent injury during the secondary procedure in replantation.
2. A dorsal longitudinal skin incision is used over the nonunion site and deepened directly to bone. Avoid raising flaps to prevent injury to the veins.
3. Freshen up the bone ends well.
4. Choose the angle of the arthrodesis to achieve good function. We chose 30 degrees of flexion and a 10 degrees of radial tilt to help the index finger meet the thumb tip comfortably in view of movement present only at the MCP joint.
5. Satisfy yourself of good bone contact. If inadequate, some cancellous bone graft taken from the base of the metacarpals or the distal end of radius may be used. Here, it was not needed.
6. Single K-wire was used. The surgery was planned well and the bone was fixed by a K-wire in a single attempt. That is important for success. Multiple passes during K-wire fixation result in loose fixation and additional fixation techniques may be needed.

63.6 Postoperative Photographs and Critical Evaluation of Results

The procedure resulted in successful bone union and the patient developed a good pinch strength. The angle of fixation was perfectly suited for day-to-day activities like writing, buttoning the shirt, and gripping large objects (▶Fig. 63.4). Due to the severity of the injury, the quality of tendons available for repair was poor at the time of replantation. Since all the fingers were amputated, successful replantation of at least one finger greatly adds to the functional status of the hand. The flexor repair, though not adequate for distal interphalangeal joint movement, nevertheless provided flexion power at the MCP joint. He achieved a sensory recovery of 7 mm of two-point discrimination, which was sufficient for useful function. Stability, sensation at the fingertip, and appropriate positioning of the replanted part are the key to success.

63.7 Teaching Points

- Primary bone union at the replant site is an important determinant for successful rehabilitation.
- Secondary surgery in replant has the risk of endangering the viability of the replant. Replants may depend upon the repaired blood supply for a long time and care to prevent injury to the repaired vessels must be taken at all times.
- Choose access incisions directly leading to the nonunion site and avoid raising flaps to prevent injury to the veins.

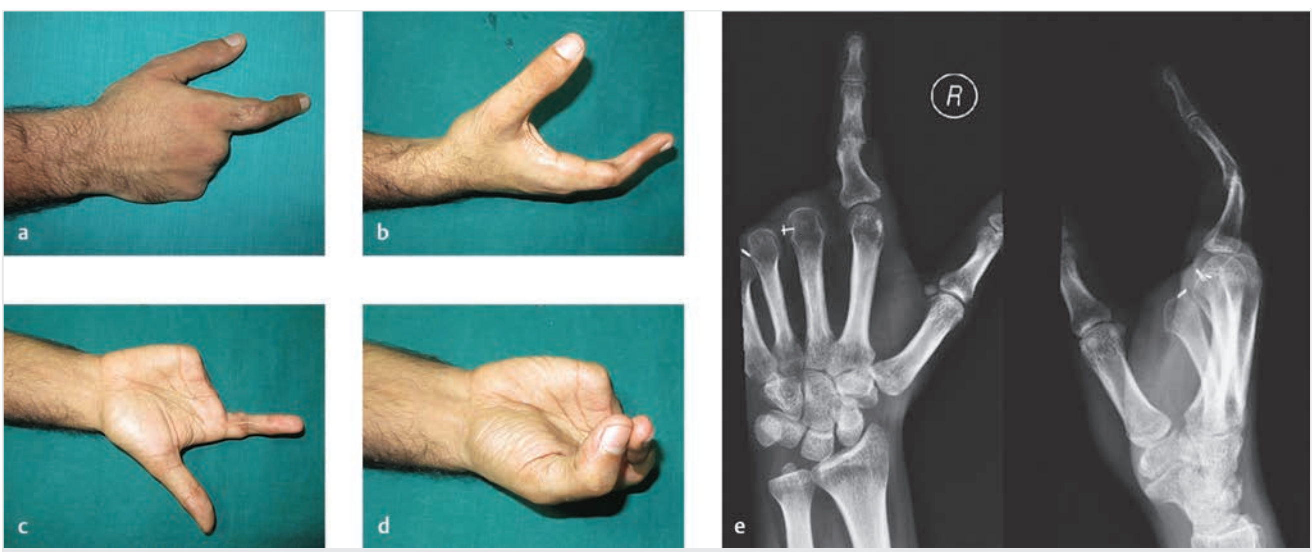

Fig. 63.4 (a–e) The final outcome of the correction of the nonunion with a bone graft. The patient enjoys a pain-free functional hand.

- Use the opportunity of nonunion surgery to achieve appropriate positioning of bones to achieve good function.
- Use simple techniques for bone fixation. If K-wires are used, fixation must be achieved in a single attempt. Avoid techniques that need wide dissection.
- If bone contact is inadequate, add a little of cancellous bone graft around the bone coaptation site.
- Concentrate on achieving full function at all the nearby uninjured joints to maximize the functional potential.

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64 Nonunion following Major Replant

S. Raja Sabapathy and Hari Venkatramani

64.1 Patient History Leading to the Specific Problem

A 32-year-old woman sustained total crush avulsion amputation of the left forearm when a car overturned and she was thrown out of the vehicle (▶Fig. 64.1a, b). The hand was caught in the door edge and was ripped off. In addition she had injuries in the face, trunk, and legs and thigh, with some injuries needing skin cover. The forearm was successfully replanted. In the immediate postoperative period, she developed skin necrosis at the replant site, which was debrided and skin grafted. There was an area of major necrosis where skin graft was lost, resulting in exposure of the plates used for bone fixation (▶Fig. 64.1c). A pedicled flap was done, to cover the raw area, which settled (▶Fig. 64.1d), but the fracture site got infected resulting in loosening of the implant and nonunion (▶Fig. 64.1e). She presented for the management of nonunion 6 months after the primary surgery.

64.2 Anatomic Description of the Patient's Current Status

When she presented at 6 months following primary surgery, the wounds had all healed but for a sinus at the edge of the flap. Radiographs revealed implant loosening and nonunion. This is a significant complication following a major replant. The following discussion can help understand the causation and the factors to be considered while providing the solution. The injury was of crush avulsion in nature, with degloving of the skin for about 5 cm on either side of the injury with friction burns in patches. The muscles were crushed and partly avulsed and debridement was probably inadequate. Bone fixation was done by plates and screws with 3.5 cm of bone shortening. The radial artery was found avulsed and the proximal end was not available. Only the ulnar artery was present. Ulnar artery and three veins were repaired, resulting in successful revascularization. Both the median and the ulnar nerves were repaired. The problem started with skin necrosis at the replant site. With delayed flap coverage, infection and nonunion are inevitable. The infective nonunion site needs radial debridement and plan for bridging the resultant long-segment bone gap.

64.3 Recommended Solution to the Problem

Infected nonunion with skin necrosis is a serious complication that could result in disasters like rupture of anastomosis and loss of the replant. This could be prevented by adhering to the principles of major replantation. The main aim is to achieve primary wound healing. If that is not achieved, we cannot expect any underlying tissue to heal primarily. In this case, there has been significant injury to the wound edges, with degloving of skin and friction burns. Debridement has been inadequate. The need for soft-tissue flap cover must have been anticipated in the beginning itself. In case of doubtful viability of skin flaps at the earliest possible time, a good flap cover must have been provided.

We have found that one of the best ways to address the problem is to shorten the bone. Up to 10 cm of shortening is tolerated with acceptable functional outcome. This often obviates the need for complex soft-tissue cover, vein, and nerve grafts, and makes available good and healthy bone ends for fixation, In this case, the problem started with inadequate debridement,

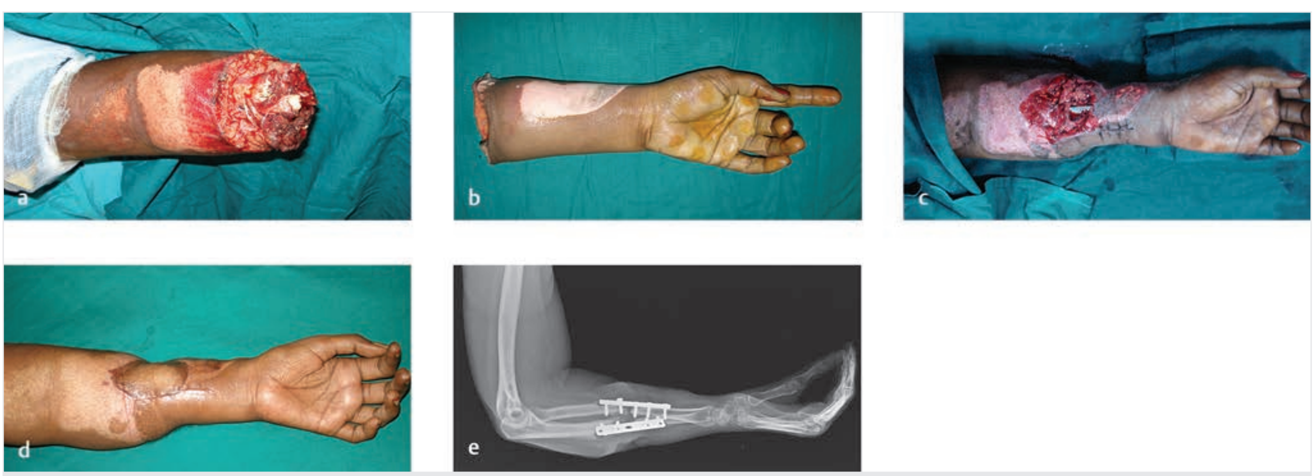

Fig. 64.1 **(a)** Presentation of the forearm at the time of injury. **(b)** Presentation of the hand at the time of injury. **(c)** Development of skin necrosis in the immediate postoperative period; this was debrided and skin grafted. **(d)** There was an area of major necrosis where skin graft was lost, resulting in exposure of the plates used for bone fixation. **(d)** A pedicled flap was used to cover the raw area. **(e)** The fracture site got infected, resulting in loosening of the implant and nonunion.

failure to address the skin necrosis with early flap cover, and inadequate bone shortening.

At the present state, she needed removal of the implants, radial debridement of the bone and soft tissues, and good bone ends for fixation or use vascularized bone graft for filling the gap. Access has to be made in such a way that there is no damage to the repaired vessels. Major replants continue to survive on the repaired arteries for a long time and any injury will end in disaster. Since in this instance it is dependent upon the ulnar artery, the line of the vessel is mapped by a handheld Doppler and care is taken to avoid injury. The bone gap will usually be longer than what would have been in the primary setting because in addition to the injured segment there is loss of viability due to exposure and infection. Two options for bone fixation were thought of. One was to create a one-bone forearm with fixation of the proximal ulna to the distal radius. The other was to use free vascularized fibula transfer. Of the two options, the one-bone forearm creation was chosen since it was the simpler option with lesser amount of dissection needed in the scarred recipient bed and because of the unavailability of the proximal radial artery.

64.3.1 Recommended Solution to the Problem

- Radical debridement of bone ends and surrounding tissue is the key to success.
- Access has to be far away from the line of the repaired ulnar artery since it is a single vessel limb.
- Since we are addressing a complication, we cannot afford to take further chances, so definitive bone fixation has to be done only when one is sure of the quality of debridement.
- In view of the infected area, the loss of proximal radial artery, to keep the dissection lesser the one-bone forearm creation was preferred. The option of vascularized fibular graft was kept as the second option, which could be done with vein grafts.
- The one-bone forearm option could also preserve the proximal vessels if they were needed for subsequent free-functioning muscle transfer.
- Secure bone fixation is needed for success.

64.4 Technique

Surgery is done under brachial plexus block and upper arm tourniquet. There is no contraindication for using tourniquet during secondary procedures following replantation. By a dorsal approach and an incision along the line of the flap on the volar side, the plates were removed. The infected granulomatous material was removed and the fibrous tissue lining the area was excised. Since the area was heavily infected, it was decided to perform the definitive procedure after a few dressings.

Postimplant removal radiographs were studied (▶Fig. 64.2a) and it was felt that it would be a simpler option to create an one-bone forearm by joining the proximal ulna to the distal radius. Seven days later, the patient was again taken up for surgery. Posterior forearm incision was made and debridement of

Fig. 64.2 **(a)** Postimplant radiographs. **(b, c)** Postoperative radiographs taken to confirm union.

the ends of the radius and ulna was done. Proximal end of the ulna and the distal radius were plated together with a narrow 10-hole dynamic compression plate. Part of the distal ulna and the cancellous bone graft from the left iliac crest were taken, and the fixation site was packed with bone grafts. The wound was closed with a drain. Healing was uneventful and bone union occurred (▶Fig. 64.2c,d). The patient then underwent aggressive physical therapy. She is developing power in intrinsics and would need long flexor reconstruction by a free-functioning muscle transfer.

64.4.1 Steps for the Procedure

1. The first step in the management of nonunion following major replant is to remove the implant and perform radical debridement of the wound and the bone ends.
2. The course of the repaired arteries has to be mapped by a handheld Doppler to prevent inadvertent injury to the arteries during secondary surgery.
3. After removal of the implant, it is wiser to give a gap of a week for the wound to settle and have an opportunity for a second look before the next definitive fixation.
4. Due to the configuration of bone loss and the available bone ends, one-bone forearm creation was considered a simple and effective solution to the complex problem.
5. At the second look, further debridement is done. Good rigid fixation is chosen

64.5 Postoperative Photographs and Critical Evaluation of Results

An infected nonunion in a major replant is an avoidable functional disaster. It sets the rehabilitation behind clock by 6 to 9 months. In the unfortunate event of its occurrence, it can be managed by radical debridement, followed by secure fixation. Bone union was successful in the patient. She has a grade M4 recovery of intrinsics, which allow adduction pinch power in the hand. Sensory recovery is S3. Long flexors and extensors had mass repair and though power transmission is found, isolated finger movements are not possible. Functional assessment is Chen grade 3. She uses her hand as a good supportive hand to the other hand for bimanual activities and is satisfied with the aesthetic outcome.

64.6 Teaching Points

- Primary wound healing and bone union must be obtained in major replants.
- Bone shortening is one of the key steps of the procedure.
- In instances of doubtful viability of skin or soft tissue at the site of replant, one has to be proactive in providing a flap cover before infection sets in.
- In the event of established nonunion, if there is an infective component, radical debridement must be done first.
- The definitive fixation can be done when one is confident of the wound status.
- The one-bone forearm creation is a quick and easy solution to the complex problem.
- Secondary surgeries following replantation are always fraught with danger of losing the replant and care has to be taken to avoid injury to the repaired arteries.
- Since no reconstructive option is available following a proximal amputation, replantation must be attempted if it is technically possible.
- Attention to detail at the initial surgery is essential to obtaining a good functional outcome.

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65 Painful Finger after Bony Nonunion

Florian Neubrech and Ulrich Kneser

65.1 Patient History Leading to the Specific Problem

A 25-year-old man presents with painful bony nonunion of the middle phalanx of his right middle finger. He incurred amputation of the finger 10 weeks before by trauma with electric-powered scissors. Original surgery included replantation via suture of the deep flexor tendon, extensor tendon, and primary end-to-end suture of both neurovascular bundles and of two dorsal veins. Osteosynthesis was performed by diagonal Kirschner's wires (K-wires) with additive intraosseous suture. The distal interphalangeal joint was transfixed because of ligament instability. ▶Fig. 65.1 shows initial findings and results of the original surgery. Absence of bony healing was diagnosed in plain radiological follow-up controls. ▶Fig. 65.2 shows radiological findings 10 weeks after replantation.

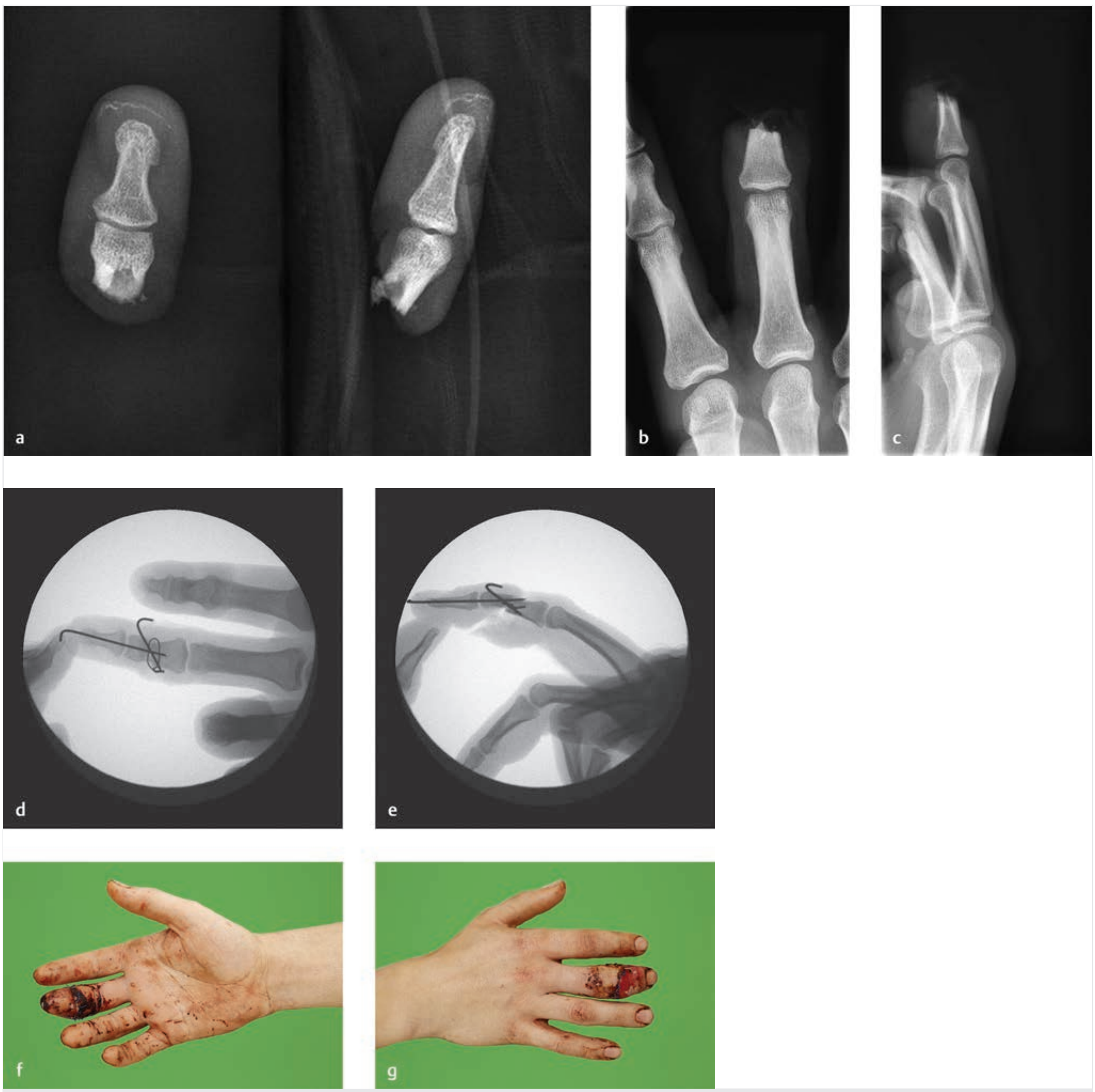

Fig. 65.1 Exemplary case of a single-finger replantation. **(a–c)** Preoperative findings. **(d, e)** Intraoperative findings. **(f, g)** Early postoperative clinical result.

Fig. 65.2 (a, b) Missed bony healing 10 weeks after replantation.

65.2 Anatomic Description of the Patient's Current Status

In the presented case, replantation surgery was performed without significant intraoperative complications. Postoperative blood supply of the finger was regular; wound healing was primary. However, the lateral X-ray raises suspicion that the axial K-wire did not sufficiently stabilize the proximal fragment. In further course, consolidation of the phalanx was not adequate. Nevertheless, active physical therapy was started after 6 weeks of immobilization with only guided and passive exercises to prevent further stiffening of the fingers. Active tendon function was present upon careful examination. Yet, the patient felt pain and had the feeling of instability of the affected finger. Further course of rehabilitation was ineffective in the face of the radiologically confirmed bony nonunion. Therefore, the indication for surgical revision was confirmed.

65.3 Recommended Solution to the Problem

Localized pain was caused by bony nonunion; thus, the clinical problem could be solved by bony revision in this case. In digital replantation, the 6-month period is not always a prerequisite for establishing the diagnosis of nonunion and for the decision in favor of a revision surgery. This holds especially true if biomechanical factors such as inadequate stabilization and biological factors such as suboptimal perfusion and excessive soft-tissue trauma prohibit bony healing. In the presented case, the early date of revision was chosen because painful instability of the finger disturbed physical therapy and postoperative recovery. Due to the significant risk for joint or even finger stiffness as a consequence of prolonged immobilization, mobility of the unaffected fingers has to be preserved at all costs. Effective physical therapy and early mobilization are essential for this purpose.

One should realize that especially a replantation with limited postoperative perfusion needs a stable fixation to prevent nonunion. Suitable methods are after primary shortening of the bone, shortened arthrodesis, osteosynthesis using K-wires, tension band wiring, or internal plate fixation. Of course, replantation is an individual situation every time, and not all these principles can be always implemented in favor of primary finger rescue. Therefore, the hand surgeon should be prepared for nonunion revision.

In the presented case, revision was performed by stable plate fixation and a cancellous bone graft from distal radius with moderate shortening of the bone and resection of avital bone and scar tissue. Because of preservation of venous perfusion and because of the mostly sclerotic soft tissue, length of the finger cannot always be restored. Corticocancellous bone grafting from iliac crest is only indicated if a larger gap results after removal of all fibrous tissue and resection of the affected bone. We recommend a dorsal approach. It must be emphasized that replanted tissue in finger replantation does not always randomize steadily after a certain time, so not only the palmar arteries but also the dorsal veins should be identified and preserved.

65.3.1 Recommended Solution to the Problem

- Replantation demands stable osteosynthesis. Often, a primary shortening of the bone is suitable. This may prevent nonunion.

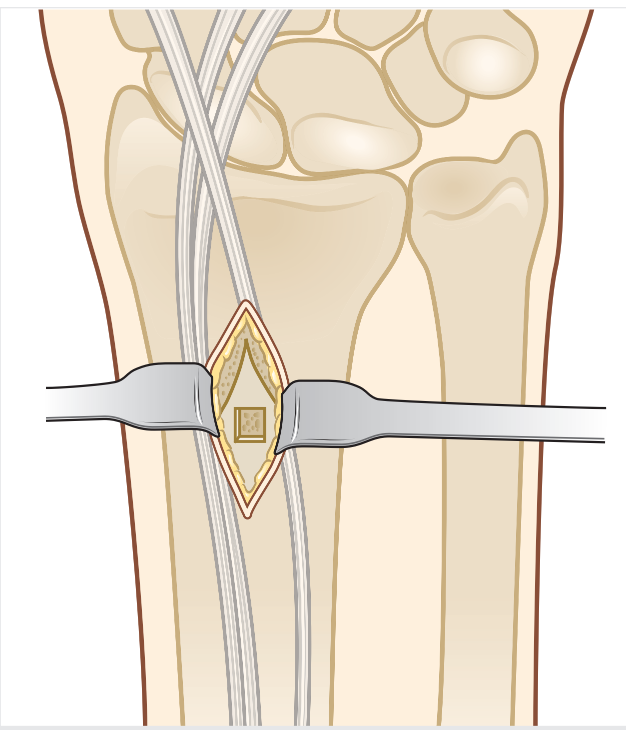

Fig. 65.3 Illustration demonstrating harvest of cancellous bone graft from distal radius.

- If a revision of bony nonunion is indicated, we recommend a dorsal approach.
- The dorsal veins should be identified and conserved during the procedure.
- Bone should be carefully debrided by moderate shortening and by removal of all fibrous tissue. Bone grafting from the distal radius is mostly adequate. Osteosynthesis should be performed by mechanically stable methods like internal locking plate fixation if the quality of skin and soft tissues is adequate. In selected cases, local flaps might be required for stabile defect coverage.

65.4 Technique

Operation is performed under general or regional anesthesia with use of a tourniquet in a bloodless field. The use of magnifying loupes is recommended mandatory.

As long as a low-grade infection as the cause of bony nonunion cannot be excluded, it is recommended to start the operation with harvesting of cancellous bone from distal radius. Therefore, a small longitudinal incision is made just proximal of the dorsal tubercle. The third compartment is opened in its proximal portion, a small flake of cortical bone is removed using a chisel, and cancellous bone can be harvested with a curette (▶ Fig. 65.3). Simple closure of skin is sufficient for donor site; drainage is mostly not necessary.

The bone is exposed via the longitudinal dorsal approach (▶ Fig. 65.4). The veins are identified and preserved within the overlaying skin. We recommend a median split of extensor tendon with subsequent repair of it by using a thin absorbable running suture. Fibrous tissue is removed. Bone is carefully debrided using a luer or a small chisel. We recommend a microbiological and histological analysis of the removed material. A suitable plate is chosen. The reduction of the fragments is easier if the plate is first fixed on the proximal fragment by a single cortical screw. The proximal fragment and

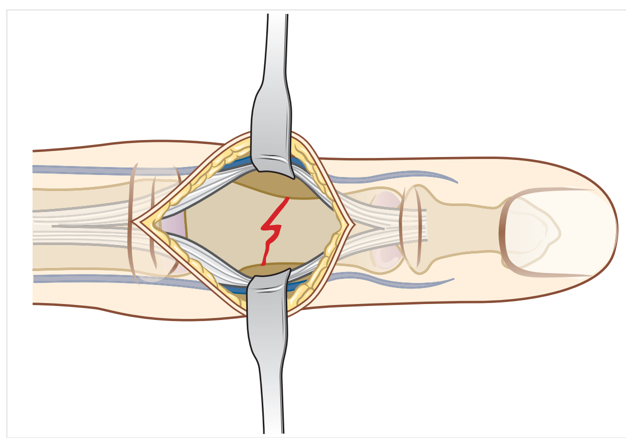

Fig. 65.4 Illustration demonstrating dorsal approach with split of the extensor tendons. The dorsal veins have to be treated with care.

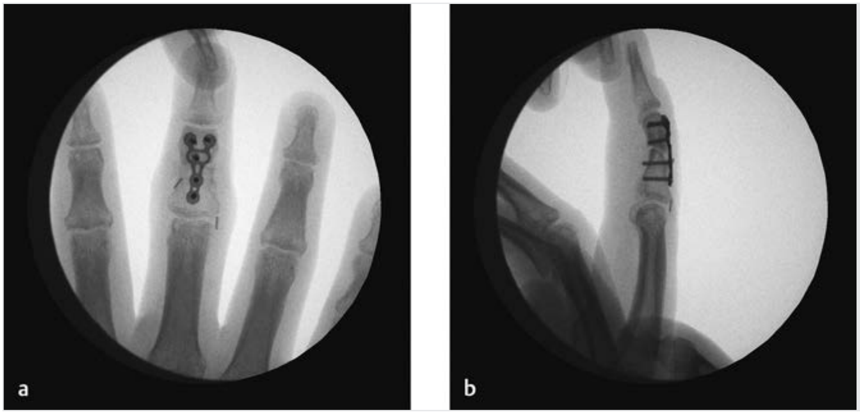

Fig. 65.5 (a, b) Intraoperative findings after reosteosynthesis.

the plate can now serve as fixed point for anatomic reposition of the distal fragment. The reduction is saved by another single cortical screw in the distal position, and interfragmentary compression is applied. Now the correct rotation of all fingers has to be checked carefully. All fingers have to be parallel and oriented toward the thenar when the fist is closed passively by extension of the wrist. After this has been done properly, gaps are filled with the harvested cancellous bone and the other positions of the plate are occupied by locking screws. We usually use locking plates with 1.5-mm screws (▶Fig. 65.5).

65.4.1 Steps for the Procedure

1. Cancellous bone is harvested from the distal radius.
2. Bone is exposed from dorsal with preservation of the veins.
3. Fibrous tissue is removed. Bone is carefully debrided.
4. Reposition is done with attention to finger rotation. It could be easier to fix the proximal fragment first on the plate.

65.5 Postoperative Photographs and Critical Evaluation of Results

Despite the necessity of surgical revision and limited local perfusion, bony healing can be achieved in most cases (▶Fig. 65.6). Functional results were finally also excellent (▶Fig. 65.7), but 4 additional months of consistent hand therapy were required. An extension deficit in the DIP joint remained, probably because of adhesions of extensor tendon with the osteosynthesis plate. However, due to the insignificant functional impairment and the considerable risk of a consecutive tenolysis, the patient does not wish for a revision surgery at the moment. The patient clearly stated that the pain during active or passive motion disappeared after surgery.

At a closer look on the postoperative results, mild atrophy of the distal phalanx can be seen. This typical finding after digital replantation is frequently accompanied by cold intolerance.

It has to be emphasized at this point that a painful course after replantation is not common. In contrast, a successful replantation that comprised repair of both digital nerves can be seen as a prevention measure for painful neuroma that can be seen frequently after amputation. This fact should especially be kept in mind when making a decision for very distal amputation injuries. Neuropathic pain, for instance through scar formation surrounding nerve sutures, is rare. Interestingly, according to our experience, complex regional pain syndrome can result from any kind of trivial hand injury, but we almost never see it after replantation. However, cold intolerance and atrophy of the replanted finger, as an expression of chronic compromised perfusion in spite of artery repair, are common. Cold intolerance is the most frequent “painful” complication after replantation of fingers and is unfortunately therapy resistant all too often. We recommend our patients to use protection against cold irritation, which could mean wearing gloves even in summer time. A therapy with prostacyclin derivates is described in the literature, but records and our own experiences are limited. An unpleasant stiffness of adjacent joints is also a well-known problem. Localized pain or a feeling of instability of the finger should lead the examiner to look for bony nonunion. Blood supply after replantation is mostly not comparable to a normal state, so it should be noted that bony healing is often primarily defective.

65.6 Teaching Points

- Pain and neuropathic pain, in particular, are no specific complications of finger replantation. Painful findings could be found more often after amputation.
- Persistent and therapy refractory cold intolerance is typically for replantation.
- A primary stable osteosynthesis with shortening of the bone could prevent bony nonunion in replantation.
- Revision surgery in replanted fingers comes along with the risk of finger loss. Therefore, revision surgery is only indicated if a functional gain could be anticipated.
- For revision of bony nonunion, we recommend a dorsal approach. The dorsal veins should be preserved. Bone should be moderately shortened and refreshed. We recommend internal plate fixation and adsorption of the cancellous bone from the distal radius. Physical therapy should start immediately. Therefore, an exercise-stable osteosynthesis method is required.

Fig. 65.6 (a, b) Bony healing 8 weeks after revision surgery.

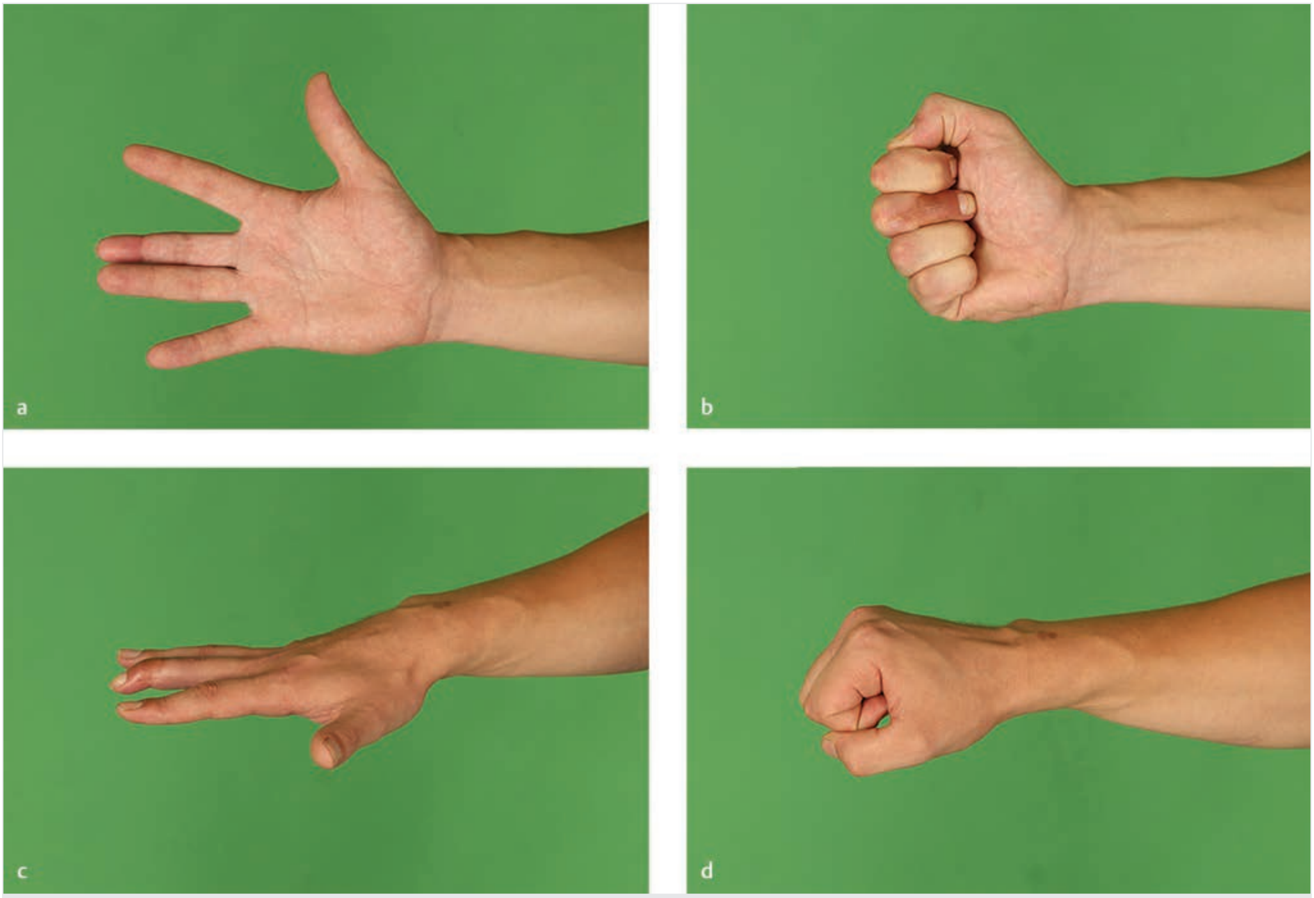

Fig. 65.7 (a–d) Clinical results 4 months after revision surgery.

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66 Stiff Fingers and Elbow after Replantation

Chih-Hung Lin

66.1 Patient History Leading to the Specific Problem

A 21-year-old, right-handed woman was a victim of motorcycle accident 1 year ago. She underwent a free groin flap for her left volar wrist soft-tissue defect and a transposition flap and skin graft for dorsal hand skin defect. In addition, she suffered from left elbow intra-articular fracture. She received a split-thickness skin graft (STSG) for her left elbow skin defect within the first month after trauma in the first hospital visit. She sustained left wrist and carpal bones posttraumatic fusion with functional impaired left hand, so she went to another hospital for a left wrist Suave–Kapandji procedure.

She presented to us with left hand extrinsic and intrinsic tightness. The left thumb ray was stiff and unopposable (▶Fig. 66.1).

66.2 Anatomical Description of the Patient's Current Status

This patient demonstrated left hand stiffness with limited pronation and supination because of tissue fibrosis after trauma and repeated surgeries. She had little active flexion on the thumb, index, and middle fingers, and inadequate ring and little finger proximal interphalangeal joint (PIPJ) flexion. The examination also revealed both extrinsic and intrinsic tightness (▶Fig. 66.2). There was no visible or palpable thenar muscle contraction. Thus, she could not oppose or circumduct the thumb ray. She had a contractured first web space with the first and second metacarpal angle of less than 15 degrees. She was supposed to have left hand flexor and extensor tendon extensive adhesion requiring tenolysis.

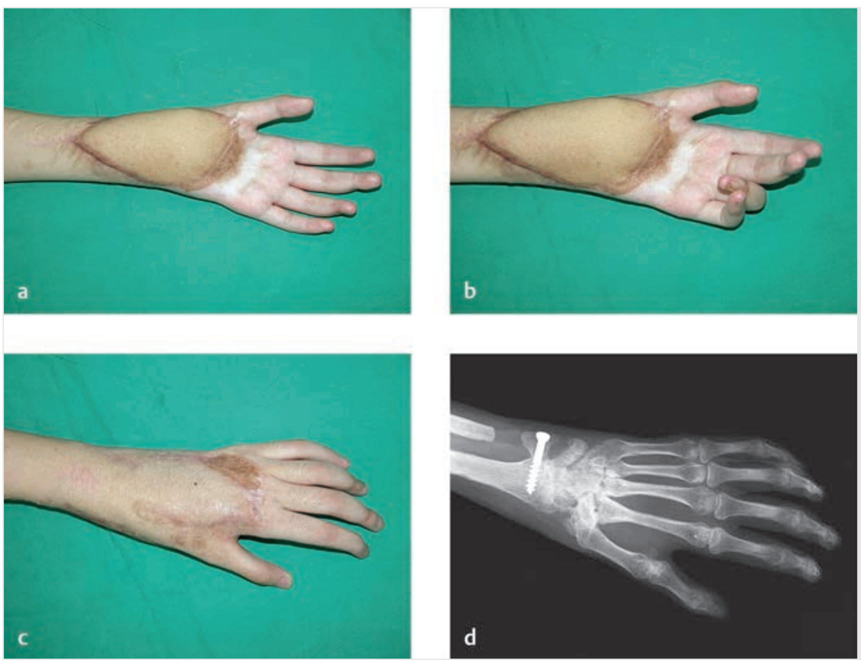

Fig. 66.1 **(a)** Left hand extension. **(b)** Left hand flexion failing in opposition. **(c)** Dorsal hand skin grafted and fibrotic. **(d)** Posttraumatic fused basal joint and carpal bones, after the Suave–Kapandji procedure.

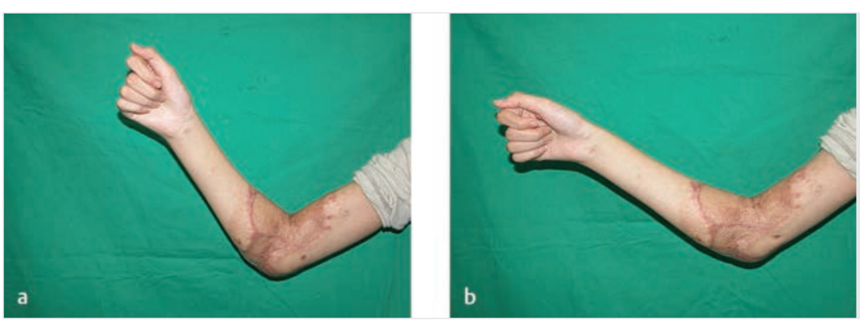

Fig. 66.2 **(a)** Fingers exhibiting intrinsic tightness at metacarpophalangeal joint (MCPJ) extension. **(b)** Extrinsic tightness at MCPJ flexion.

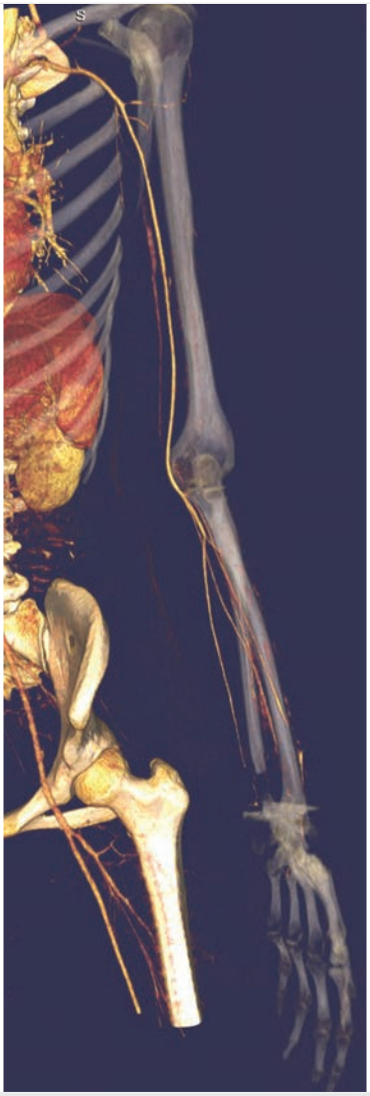

Fig. 66.3 Both left radial and ulnar arteries occluded at the distal forearm.

The left forearm CT angiography showed both radial and ulnar arteries occluded at the distal forearm level with collateral circulation to the hand (▶Fig. 66.3).

66.3 Recommended Solution to the Problem

Opposable hand should be the essential goal for hand functional restoration. Opposable hand requires the integration of the functional thumb ray and the capability of the flexible fingers. The thumb ray should possess adequate first web space, circumduction on the basal joint, and acceptable flexion on two of the three other thumb joints (basal joint, metacarpophalangeal [MCPJ], and IPJ).

66.3.1 Recommended Solution to the Problem

- The first ray contracture has to be released. She underwent a transposition flap and STSG for dorsal hand soft-tissue defect, which deprived the feasibility of local flap for interposition after first web-space release. Either a free flap or distant groin flap will be indicated. The hand requires flexor and extensor tenolysis, followed by early rehabilitation. Thus, a thin skin flap will be preferred as a soft tissue for web-space maintenance.
- Either forearm flap or lateral arm flap can be one of the options for the web space. Considering the radial and ulnar arteries were occluded at the distal third of the left forearm, an anterolateral thigh flap carries a sizable caliber and long pedicle will be justified.
- Left thumb basal joint and MCPJ were fused. In order to provide a mobile basal joint, a resection osteotomy on the basal joint and a suspension interpositional arthroplasty are some of the options to afford a mobile and stable basal joint. The commonly used donor tendons can be extensor carpi radialis longus (ECRL) or flexor carpi radialis. Since the wrist was fused and the resection osteotomy and free lateral arm flap would be on the dorsal hand, ECRL was recommended.
- Her thenar muscles were traumatized; an opponensplasty was indicated to provide the circumduction of the thumb ray. The donor tendon would be dependent on the surgical exploration for flexor tendon during tenolysis of the flexor tendons.

66.4 Technique

The first web space on her left hand was released, including the scar contractured intrinsic fascia. An opening of 60 degrees was obtained. The ECRL and extensor carpi radialis brevis (ECRB) were explored at the distal dorsal forearm, and a resection osteotomy was performed on the fused first carpometacarpal joint. A drill hole was created at the first metacarpal base and a split ECRL was used to suspend the first metacarpal to the second metacarpal base. The excess ECRL and ECRB were used as an interposition arthroplasty. The extrinsic extensor tenolysis was done to allow full passive PIP and distal interphalangeal (DIP) flexion during MCPJ flexion. A subperiosteal dissection of the intrinsic muscle was done to have PIP and DIP full passive flexion at MCPJ extension. The thumb ray was kept at abduction and circumduction position of 60 degrees with cross K-wires to both the first and the second metacarpal bones (▶Fig. 66.4).

The left radial artery and cephalic vein were harvested as recipient vessels at the distal forearm. The left anterolateral thigh flap was elevated and trimmed thin to fill the first web defect, followed by revascularization.

Four months later, she underwent left hand and forearm flexor tenolysis and ring finger flexor digitorum superficialis tendon transfer for opponensplasty through its pivot point at the flexor carpi ulnar loop. She received another subsequent flexor lysis.

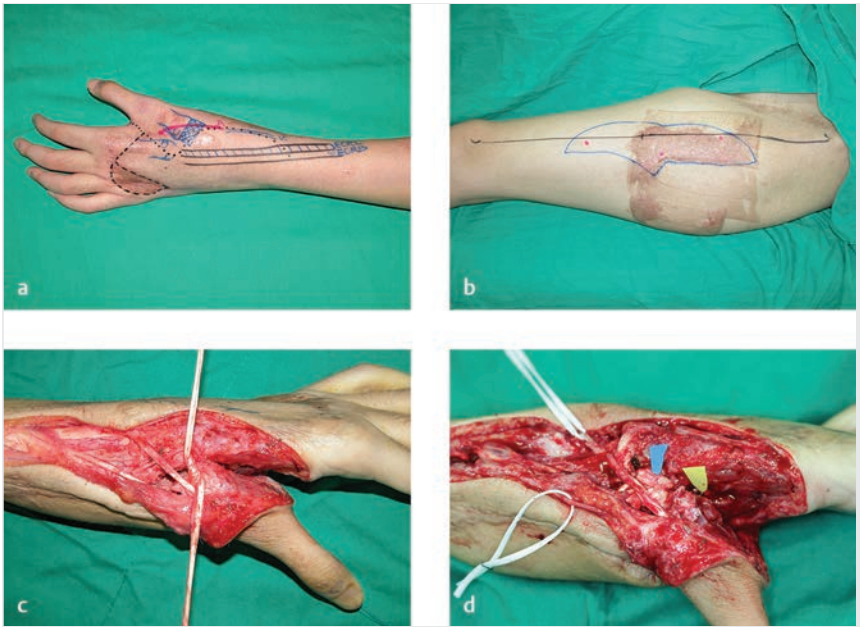

Fig. 66.4 (a) Planning for resection of fused basal joint, extensor carpi radialis for arthroplasty. **(b)** Left anterolateral thigh donor site. **(c)** Suspension arthroplasty using extensor carpi radialis longus. **(d)** Interposition arthroplasty with partial facial for radial collateral ligament.

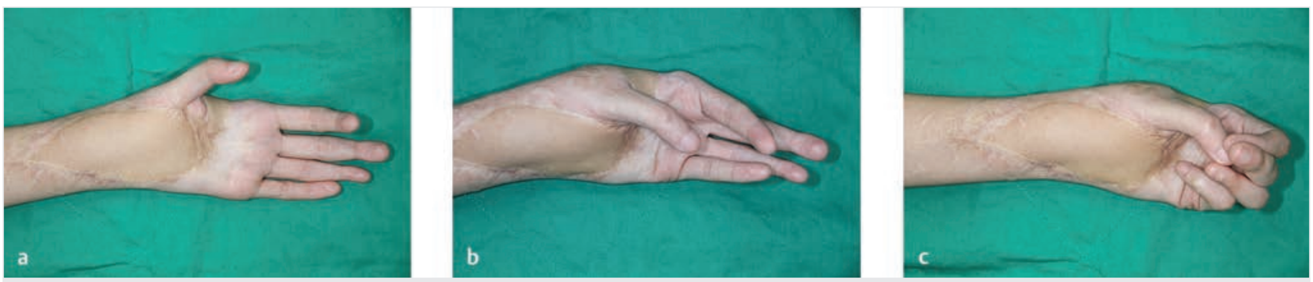

Fig. 66.5 (a) Improved left hand and finger extension. **(b)** Improved thumb ray circumduction after opponensplasty. **(c)** Improved opposition.

66.5 Postoperative Photographs and Critical Evaluation of Results

Over 1 year later, she can demonstrate good thumb opposition to ring finger, and thumb ray abduction (▶Fig. 66.5).

66.6 Teaching Points

- Physical examination of hand function assessing each joint and tendon function individually.
- Hand extrinsic and intrinsic tightness assessment.
- Hand first web-space contracture release must be performed to restore grasp function.
- Thumb basal joint suspension and interposition arthroplasty is needed if the distal thumb joints are fused.
- Bunnel's opponensplasty provides a reproducible opposition of the thumb.
- Sequence the hand reconstruction. The scar release may need staged and sequential or repeat releases.

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67 Poor Grip or Weak Motion after Replantation

S. Raja Sabapathy

67.1 Patient History Leading to the Specific Problem

A 23-year-old man sustained amputation of both hands in a paper cutting machine. On the right side, it was a total amputation through the base of the distal carpal row (▶Fig. 67.1a). On the left side, amputation was at the thumb tip and through the head of the metacarpals of the index, middle, ring and little fingers (▶Fig. 67.1b). The fingers were attached by a 2-cm skin tag, which did not have any identifiable vessels. The patient reached the hospital 12 hours after the accident and the part was fairly well preserved. Intrinsic muscles of the right hand had suffered ischemic damage as evidenced by a stiff thumb. Both hands were simultaneously replanted.

Due to the long ischemia period, speed was considered important and mass repair of flexor digitorum superficialis (FDS) and flexor digitorum profundus (FDP) was done on the right side. Median and ulnar nerves and radial and ulnar arteries and four veins were repaired. On the left side, three common digital arteries, three veins, and all digital nerves were repaired. Both flexor tendons were individually repaired. The thumb tip had a triangular flap done. The total ischemia time was 16 hours. Both replants survived, except for the left little finger, which was shortened. The patient underwent a rehabilitation program and resumed duty in the same printing press. He presented to us 1.5 years later with complaints of weak grip and poor motion on the right side.

67.2 Anatomic Description of the Patient's Current Status

The finger flexion range was limited with the tip-to-palm distance of 6 cm and poor grip (▶Fig. 67.2). The grip strength on the right side was 0.5 kg compared to 12 kg on the left side. He had full passive range of flexion of the interphalangeal (IP) joints. In addition, there was no active movement at the thumb IP joint. There was also a mild intrinsic tightness in the middle and the ring fingers as evidenced by the tendency to swan neck deformity on extension of the middle and ring fingers.

On the left side, he had full range of motion (ROM) in the metacarpophalangeal (MCP) and IP joints and was functionally happy (▶Fig. 67.3). He had a two-point discrimination of 8 mm on both sides.

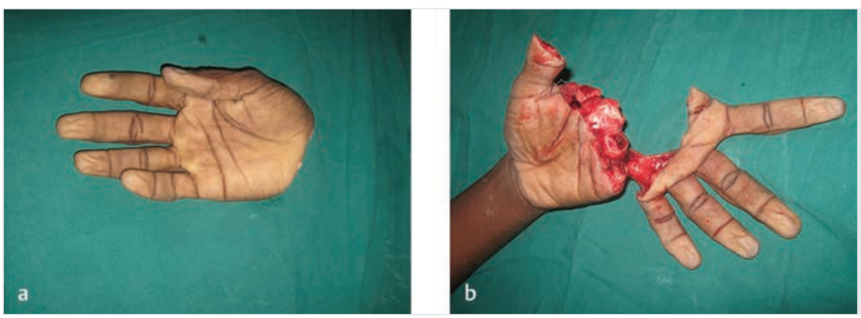

Fig. 67.1 **(a)** Total amputation of the right hand at the level of the distal carpal row. **(b)** Amputation of the left hand.

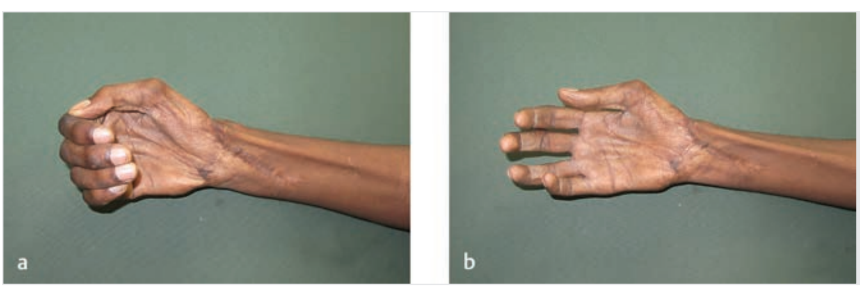

Fig. 67.2 **(a)** Right hand at 18 months. Attempt to make a fist results in a tip-to-palm distance of 6 cm. There is no flexion at the interphalangeal joint of the thumb. **(b)** Position of the hand in full extension. There is increased extension at the proximal interphalangeal joint with flexion at the distal proximal interphalangeal joint.

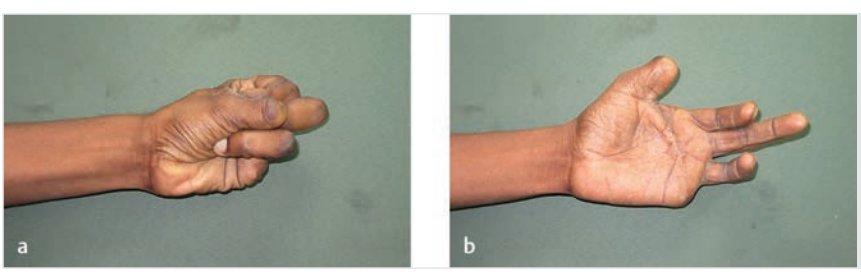

Fig. 67.3 **(a, b)** Left hand at 18 months: adequate function with full range of motion.

67.3 Recommended Solution to the Problem

Poor motion with weak grip is a complication that leads to a poor functional outcome after a “successful” replant. This complication has occurred in the right hand probably due to the following causes.

Poor motion/weak grip with tendons in continuity could be a result of adhesions at the repair site or due to the stretching at the site of repair. In the presence of full passive ROM of the joints, adhesions and tendon lengthening cause reduced active ROM. This was considered the problem of long flexor tendons. Rupture of the repaired tendons results in no movement at the joint. There was no flexion or movement of the IP joint of the thumb and we presumed that this probably could be due to the rupture of the repaired flexor pollicis longus (FPL) tendon.

This patient also had another uncommon problem of a tendency of the fingers to go for a swan neck deformity on attempted extension of the fingers. This is due to tightness of the intrinsics due to ischemic contracture. This was also reducing his capacity to grip objects. He arrived with an ischemia time of 12 hours and on arrival the thumb was stiff, indicating ischemic damage to the thenar muscles. Total ischemia time was 16 hours. Ischemia causes contracture of the lumbricals and the interossei and they cause intrinsic plus deformity. This is confirmed by Bunnel’s test, which is performed by keeping the MCP joints extended and actively or passively flexing the IP joints. There is increased resistance to flexion of the IP joints, which is not there with the MCP joints flexed. The intrinsic tightness also has to be released to gain full ROM in the fingers.

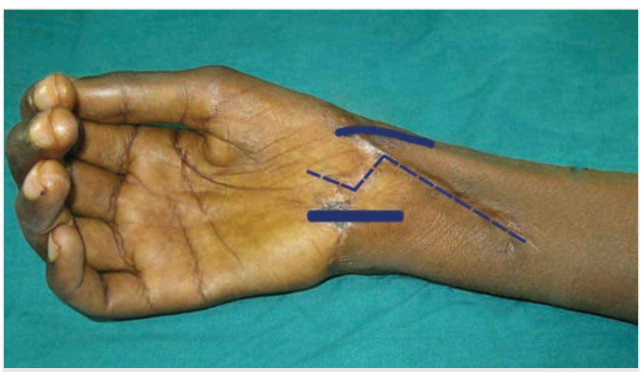

Fig. 67.4 The solid line shows the line of the radial and ulnar arteries as mapped by Doppler. The dotted line is the proposed line of incision.

67.3.1 Recommended Solution to the Problem

- In the presence of continuity of tendons, poor ROM could be due to adhesions or stretching at the site or repair. Most of the time, both coexist. Correction is by adhesiolysis and plication of the repair site or re-repair.
- In case of rupture of the tendon, it will not be possible to approximate the tendon ends. It will usually need an interposition tendon graft.
- Intrinsic tightness could be corrected by excision of a strip of the lateral band.

67.4 Technique

The tendon repair site has to be exposed without damaging the repaired arteries. Replanted limbs depend upon the repaired vessels for a long time or even on a permanent basis and so injury to the vessels has to be avoided. The course of the repaired vessels was marked by Doppler and the line of incision was made avoiding them (▶Fig. 67.4). Tendons and nerves were first isolated well proximal and distal to the replant site and dissected to the region of repair. Median and ulnar nerves were identified and isolated to safety. The adhesions at the tendon repair site were excised. The repair site was in continuity, but stretched due to a combination of stretch and partial rupture. FPL was identified, but the repair was found to be ruptured.

Since mass repair of the finger flexors had been done, there was no way to revise the repair. Adhesions were released and tendon repair isolated (▶Fig. 67.5a). In order to gain increased ROM, a stretched segment at the repair site was excised and the proximal FDS was repaired to the distal FDP. A four-strand strong repair with 3–0 Prolene was used for the repair. Reconstruction of the ruptured FPL tendon required a tendon graft. It is good to keep the graft suture sites in the forearm and in the thenar eminence proximal to the A1 pulley for ease of gliding. By an incision over the MCP joint of the thumb, the distal end of the FPL was identified and 2 cm of tendon was

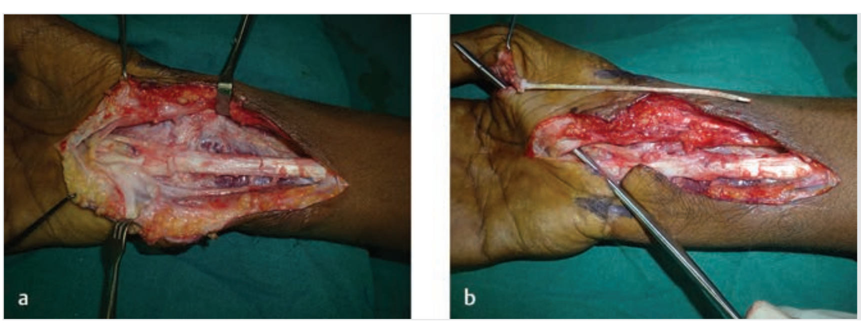

Fig. 67.5 **(a)** Isolation of the repaired tendon after release of adhesions. **(b)** Long flexors reconstructed with flexor digitorum superficialis and flexor digitorum profundus repair. Flexor pollicis longus being reconstructed with palmaris longus tendon graft. The tendon tunneler shows the pathway of the tendon graft.

dissected out proximally and prepared for repair. The proximal end of the FPL in the distal forearm was prepared and the gap was 10 cm. A 14-cm palmaris longus tendon graft was taken from the same forearm and the FPL was reconstructed by using Pulvertaft sutures (▶Fig. 67.5b).

The intrinsic tightness was released by excising 1 cm of the lateral band of the extensor expansion over the shaft of the proximal phalanx (▶Fig. 67.6). The adequacy of release is checked on the table by the ease of flexion of the IP joints with the MCP joint in extension. The patient was on supervised physical therapy with immediate mobilization.

67.4.1 Steps for the Procedure

1. Access to the repair site of the tendons is obtained by planning incisions well away from the course of the repaired vessels.
2. The repair site is reached by identifying structures well away from the site of replant both proximally and distally. Median and ulnar nerves are first identified, traced, and isolated to safety.
3. The cause of the poor ROM is identified. Adhesions are released and the simplest method of proximal FDS to distal FDP repair was chosen. FDS is more powerful than FDP and this motor will provide powerful grip.
4. Strong tendon repair techniques like Pulvertaft weave and placement of repair ends in sites of unhindered excursion facilitate early movement after tendon graft.
5. Excision of a strip of the lateral band of extensor tendons reduces the tightness of the intrinsics caused by the ischemic contracture of the intrinsic muscles due to long ischemia time.

Fig. 67.6 The lateral band of the extensor expansion has been isolated. Segment between the marks (*arrows*) excised to release the intrinsic tightness.

67.5 Postoperative Photographs and Critical Evaluation of Results

With 3 months of therapy, the patient regained full ROM with the tips of fingers touching the palm and the grip strength improving to 16 kg from 0.5 kg (▶Fig. 67.7). On assessment, he has Chen grade 1 status. He is able to do heavy manual activities in the printing press. A replant can be considered a success only if a good functional outcome is achieved. A guillotine amputation at the level of the wrist is one of the levels where good functional outcomes can be achieved. In instances of long ischemia time or with multiple associated injuries, primary repair can be compromised. In such situations, careful assessment of the cause and correction can yield good outcomes. Poor grip and weak movement can be corrected by secondary repair of tendons. The secondary surgery can be timed when the improvement reaches a plateau, and the overlying skin becomes soft and supple.

67.6 Teaching Points

- "Poor grip and weak movement" are a cause of poor functional outcome following replantation.
- Adhesions at the site of tendon repair, tendon rupture, or lengthening at the repair site are the common causes of poor grip and weak movement. Treatment involves addressing the cause.
- Secondary surgery is done when there is a plateau in improvement, and the skin at the site of access is soft and supple.
- Incisions are planned to avoid injury to the repaired vessels since major replants are dependent on the source vessel for a long time or even permanently.
- Structures are isolated well away from the repair site proximally and distally and then dissected to the level of the replant.

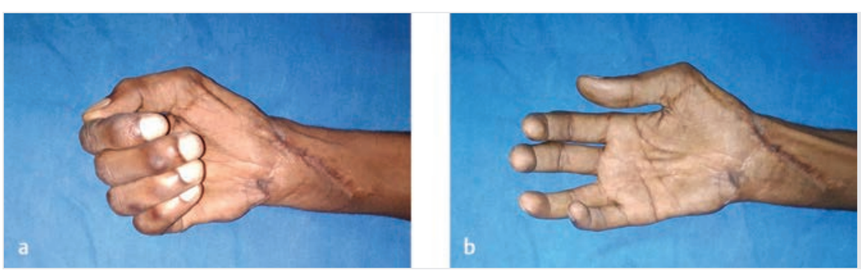

Fig. 67.7 (a, b) Postoperative result of flexion and extension after secondary surgery. The tips reach the palm and the thumb tip has pinch power due to flexion at the interphalangeal joint. Tendency toward swan neck deformity on extension is no longer present.

- Strong tendon repair is essential to start active movement in the immediate postoperative period.
- In instances where there is a long ischemia period, ischemic contracture of the intrinsic muscles can occur and they could be a cause of poor grip and weak movement. This is corrected by excision of a segment of the lateral band of the extensor tendon.

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Part XX

Problems with Complex Regional Pain Syndromes

68 Complex Regional Pain Syndrome *310*

XX

68 Complex Regional Pain Syndrome

Erik Hansen and Jonathan Isaacs

68.1 Patient History Leading to the Specific Problem

A 53-year-old otherwise healthy Caucasian woman presented with a history of chronic left wrist pain due to late-stage scaphoid nonunion advanced collapse wrist arthritis (▶Fig. 68.1). Having failed nonoperative treatment, she agreed to undergo triquetrum and scaphoid excision with lunocapitate and hamate fusion as well as carpal tunnel release (▶Fig. 68.2). She was discharged home following the operation and noted worsening pain and swelling on postoperative day 1. She was evaluated and sent to the emergency room where she was found to have significant swelling and erythema diffusely involving the back of her wrist and hand. Her sutures were removed and a hematoma evacuated. Cultures were sent and she was empirically started on antibiotics.

Fig. 68.1 (a–c) Late-stage scaphoid nonunion advanced collapse of the left wrist.

Fig. 68.2 (a, b) The treatment offered was a triquetrum and scaphoid excision with lunocapitate and hamate fusion as well as carpal tunnel release.

Fig. 68.3 (a–c) The postoperative course was complicated as the patient developed hyperhidrosis, “shiny and tight” appearing skin, hypersensitivity to non-noxious stimuli, and disproportionate edema and discoloration over her fingers.

Despite negative cultures, she returned 3 days later with continued severe pain and swelling and was given an oral steroid taper and referred to hand therapy for edema control. Over the ensuing weeks, she was followed closely and noted to have worsening swelling with erythema and intermittent sensations of temperature sensitivity. Additionally, physical examination revealed hyperhidrosis, “shiny and tight” appearing skin, hypersensitivity to non-noxious stimuli, and disproportionate edema and discoloration over her fingers (▶Fig. 68.3). Reduced range of motion was most notable in her digits. She did not demonstrate further physical findings or serological markers indicative of infection. Despite aggressive therapy and evolving successful arthrodesis, gains in pain control and mobility were modest.

68.2 Anatomic Description of the Patients Current Status

The patient presented with disproportionate postoperative pain and hyperesthesia extending beyond the surgical field. Classical signs of complex regional pain syndrome (CRPS) including diffuse erythema, swelling, and soft-tissue changes were noted shortly after surgery and did not abate with routine interventions such as elevation, therapy, and even oral steroids. CRPS is a pain syndrome that affects the upper and lower extremities and is of unknown etiology and often presents after seemingly minor trauma, fracture, surgery, or rarely may develop spontaneously. There is an estimated incidence rate of 26.2 per 100,000 person-years. The syndrome most commonly affects Caucasian females with a 2 to 4:1 female-to-male ratio. There may be a genetic component with recent genomic data showing a possible predisposition in association with HLA-DQ1 and HLA-DR3. Severe, intense pain within a week of the injury/intervention, as seen in our patient due to the postoperative hematoma formation, may also be a risk factor or indicator for the development of CRPS.

The syndrome is evident by abnormalities of the sensory and motor function of the extremity as well as with autonomic disruption. The diagnosis is one of exclusion in addition to noting specific signs and symptoms in conjunction with a published criterion (Budapest diagnostic criteria [Box. 68.1]). Imaging is generally of minimal use in assisting with diagnosis due to the difficulty in differentiating posttraumatic, disuse, or age-related changes with that of changes from CRPS, though radiographic imaging may show severe osteopenia with patchy demineralization and subperiosteal resorption of the bones in the affected extremity. Magnetic resonance imagery and triple-phase bone scintigraphy have been used and may show changes in bony edema or local blood flow patterns. Bone scan in particular is a commonly obtained imaging modality, as periarticular tracer signal uptake in multiple joints of the affected extremity in phase 3 of the test had been considered pathognomonic. A meta-analysis comparing MRI, bone scan, and plain radiographs showed bone scans had a high sensitivity and negative predictive value, indicating the study is best used to rule out CRPS in patients with a low suspicion of having the condition.

Box 68.1 Budapest Diagnostic Criteria

1. Continuing pain that is disproportionate to an inciting event.
2. Patient must report one symptom in three of the four following categories:
   – Sensory: hyperesthesia and/or allodynia.
   – Vasomotor: temperature asymmetry and/or skin color changes and/or skin color asymmetry.
   – Sudomotor/edema: edema and/or sweating changes and/or sweating asymmetry.
   – Motor/trophic: decreased range of motion and/or motor dysfunction (weakness, tremor dystonia) and/or trophic changes (hair, nail, and/or skin).
3. Patient must have one sign at the time of evaluation in two or more of the following categories:
   – Sensory: evidence of hyperalgesia to pin prick and/or allodynia to light touch and/or deep somatic pressure and/or joint movement.
   – Vasomotor: evidence of temperature asymmetry and/or skin color changes and/or asymmetry.
   – Sudomotor/edema: evidence of edema and/or sweating changes and/or sweating asymmetry.
   – Motor/trophic: evidence of decreased range of motion and/or motor dysfunction (weakness, tremor, dystonia) and/or trophic changes.
4. There is no other diagnosis that explains the signs and symptoms.

Source: Harden RN, Bruehl S, Stanton-Hicks M, Wilson PR. Proposed new diagnostic criteria for complex regional pain syndrome. Pain Med 2007;8(4):326–331.

68.2.1 Classification and Pathogenesis

CRPS is divided into three types: CRPS type I (formerly known as reflex sympathetic dystrophy), CRPS type II (also known as causalgia), and CRPS NOS (not otherwise specified). CRPS type II is characterized by injury to a peripheral nerve with associated abnormalities noted on nerve testing (including anatomic distribution sensory loss, focal percussion sign, electromyography, and nerve conduction studies). CRPS NOS includes patients who only partially meet the above-listed diagnostic criteria but whose condition is not otherwise better explained by another pathologic process. Our patient in question had trophic and autonomic changes such as hypersensitivity, cutaneous discoloration, cold sensations, hyperhidrosis, and edema with shiny-appearing skin. Based on her signs and symptoms, she was diagnosed with CRPS type I. The specific pathogenesis of this condition is unknown, but there is evidence of an elevated inflammatory state with central and peripheral sensitization leading to increased activity of afferent nociceptors and alterations in sympathetic activity.

68.3 Recommended Solution to the Problem

CRPS is a complicated problem without a straightforward solution or treatment. The management of this condition requires a multidisciplinary and multimodal approach. Additionally, early diagnosis with early treatment initiation may reduce the severity and longevity of the syndrome. The main goal of treatment is restoration of the functional use of the extremity. Other endpoints include pain control, return to work, and improved quality of life. There are ample data indicating the importance of physical and occupational therapy as a vital early and first-line intervention. These modalities improve range of motion, function, edema control, and pain when utilized in the acute setting. A recent Cochrane review showed some supporting evidence for graded motor imagery and mirror therapy in providing improved pain and function in this patient population. These modalities should be used in all patients with findings consistent with CRPS.

Vitamin C is a supplement that has been given prophylactically in high doses after several studies have shown its effectiveness in lowering a patient's risk of developing CRPS after injury, surgery, or other mechanisms that may increase the possibility of the patient to develop the syndrome. It should be noted that Ekrol et al published a double-blind randomized controlled trial of 336 patients in which vitamin C or a placebo was given prophylactically following distal radius fractures. They found no difference in outcomes or incidence of CRPS between the groups. This was supported by a meta-analysis by Evaniew et al. However, given the low cost and risk of this intervention, it is often still given and recommended for prophylaxis.

Pharmacological therapy is an additional important treatment modality for established CRPS. An extensive list of medications have been used and studied in the treatment of this condition (Box 68.2).

Box 68.2 Medications for Use in Treatment of CRPS

Nonsteroidal anti-inflammatory drugs (NSAIDs) and corticosteroids: These are used to treat the inflammatory component of the syndrome. Oral steroids are most often given in short-term tapers in the acute setting since only limited benefit has been found in patients with long-standing CRPS.

Dimethyl sulfoxide: Free radical scavenger given topically as a 50% cream has shown some benefit in certain populations of patients with CRPS. Side effects include a garliclike taste or odor after administration, hypersensitivity reactions, and local pain.

Antiepileptic medications: Gabapentin (maximum 1,800 mg daily) and pregabalin (300–600 mg daily) are most often prescribed and a Cochrane review noted that these medications might provide relief in some patients with neuropathic pain. The study noted insufficient data to recommend the use of other antiepileptic medications.

Antidepressant mediations: Often used in the treatment of neuropathic pain, with tricyclic antidepressants (TCAs) being the most common. Amitriptyline is the most studied and the most commonly used medication. It has the most anticholinergic effect of the TCAs, which causes sedating effects. The serotonin–norepinephrine reuptake inhibitors venlafaxine and duloxetine have also been used.

Opioids: Commonly used in the acute treatment of all pain.

Bisphosphonates: It is most commonly used in early CRPS in patients with changes seen on bone scan. Its mechanism of action for pain relief has not been fully determined. It may function by modulating inflammatory response early in the disease process or through its antiosteoclastic properties by reducing bone turnover.

Muscle relaxants (cyclobenzaprine, baclofen, methocarbamol): Beneficial in patients with concomitant muscle spasms.

Topical medications: EMLA and capsaicin creams, and Lidoderm patches.

Ketamine: An anesthetic N-methyl-D-aspartate receptor blocker has been shown to be effective in reducing pain in some patients with CRPS.

68.3.1 Interventional or Surgical Treatments May Be Beneficial in Certain Patients

Sympathetic blockades, involving the injection of local anesthetic around the stellate ganglion, are utilized in patients with primarily sympathetic nervous system–related abnormalities. These injections are often repeated multiple times due to their relatively short-lived effectiveness but may be given prior to physical therapy, allowing increased range of motion, improved pain, and better functional outcomes. However, a Cochrane review of the available data was unable to recommend the use of sympathetic blockade injections independent of other treatment options. More invasive interventions, such as spinal cord stimulator implantation, have shown benefit, and surgical amputation of the affected extremity has been documented in

Fig. 68.4 Resolved signs of complex regional pain syndrome. The patient had almost full function.

the literature as an option for intractable disease after all other options had failed. Recent comparative study showed improved functional outcome in patients undergoing amputation but with the risk of recurrent CRPS at the amputation stump and phantom limb pain. CRPS type II is related to an injury to a peripheral nerve. Operative interventions in patients with CRPS have been historically avoided; however, in patients with evidence of a compressive neuropathy or a neuropathic pain generator amendable to surgical intervention, this treatment should be pursued with strict adherence to aggressive perioperative pain control. We often approach these situations with inpatient admission and continued postoperative extremity regional anesthesia for 5 to 7 days.

These medications and interventions may be used alone or in combination to treat the myriad of symptoms that may be present in this syndrome. The amount of quality evidence for each of these interventions is severely limited, so each is best used on a patient-specific basis.

Our patient developed CRPS shortly after an operative intervention. She was initially treated with short-term oral methylprednisolone and opiate pain medication, followed by physical therapy for edema control and range of motion. Additionally, she was started on NSAIDs and Gabapentin with localized corticosteroid injections into the small joints of her hand. Despite these efforts, persistent pain and swelling promoted a referral to a pain specialist who performed intermittent stellate ganglion blockade injections. Six months after symptom onset, the patient regained functional use of her extremity but with persistent limited range of motion of her wrist and fingers. She continued to have intermittent symptom flares that were controlled with either oral steroids or repeat sympathetic blockade. She eventually returned to work and almost full function but has permanent trophic changes, stiffness, and intermittent bouts of pain (▶Fig. 68.4).

68.4 Teaching Points

- Early diagnosis with early intervention is important to improve outcomes.
- Diagnosis is made clinically and is a diagnosis of exclusion.
- Treatment should be patient specific with the use of a multimodal and multidisciplinary approach.
- Pharmacologic, interventional, behavioral, and physical therapy modalities should all be utilized in the management of this condition.

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Part XXI

Problems with Scaphoid Fractures

69 Nonunion of the Proximal Pole *316*

70 Scaphoid Nonunion with Avascular Necrosis *320*

71 Scaphoid Revision Nonunion *325*

72 Scaphoid Nonunion *329*

73 Scaphoid Implant Malplacement *336*

XXI

69 Nonunion of the Proximal Pole

Hermann Krimmer

69.1 Introduction

Most common scaphoid nonunions occur in the middle third caused by fractures through the waist. Proximal pole fractures, which are often missed due to less clinical symptoms, lead to the pattern of proximal pole nonunion. These patterns represent significant differences. Nonunions through the waist have an increased risk for unstable situations leading to humpback deformity with a collapsed and shortened scaphoid; however, blood supply and bony architecture are preserved. In contrast, nonunions at the proximal pole usually do not lead to humpback deformity, but have a higher risk of avascularity due to the pattern of blood supply demonstrating incoming vessels in the distal and middle of the scaphoid. In progressive cases, even complete loss of bony architecture is seen.

69.2 Patient History Leading to the Specific Problem

A young machine fitter when 19 years old got open dorsal screw fixation due to a proximal pole fracture of the scaphoid of his left wrist. After 6 weeks of immobilization, the patient returned to work without further clinical examination and X-ray control. Two years later, he was referred to our institution with complaints at his wrist under load.

69.3 Anatomic Description of the Patient's Current Status

Clinical examination showed reduced motion by 40–0-60 degrees of extension/flexion and grip strength by 80% compared to the uninjured hand. Plain radiographs revealed nonunion of the scaphoid at the proximal pole and loosening around the cannulated mini-screw (▶Fig. 69.1a). An MRI of the wrist performed elsewhere was not really helpful due to the interference caused by the screw. Additionally, a CT scan was performed and the resorption areas around the screw were confirmed as well as additional complete loss of bone stock and architecture of the proximal pole (▶Fig. 69.1b). Based on this information, we did not believe bony union could be achieved by conventional techniques or by local vascularized bone graft.

69.4 Recommended Solution to the Problem

We decided to replace the proximal pole completely by free vascularized osteochondral graft transplantation from the femoral condyle (▶Fig. 69.2).

With respect to the morphology, in his original 1984 classification, Herbert differentiated five types of nonunion, which were later modified and reduced to four types, where the occurrence on plane radiographs and CT is typical for each type. D1 represents a fibrous nonunion where the shape of the scaphoid bone is maintained by fibrous connecting tissue. D2 means complete nonunion with mobile fragments and significant resorption area. In D3, sclerosis is seen at the nonunion side with increased defect and in D4 necrotic bone with loss of bony architecture is observed (**see** ▶Fig. 69.1b).

The situation has to be clearly defined when comparing different treatment strategies for nonunion of the proximal pole. Assessment of blood supply by MRI and bone morphology by CT scan, and duration of the nonunion represent major prognostic factors.

Since vascularized bone grafts have gained popularity, assessment of avascularity of the proximal fragment based on preoperative MRI findings is frequently performed. It must be remembered that a precise assessment of vascularity with MRI can only be obtained if an intravenous contrast agent, gadopentetate, is used. With this technique, assessment of vascularity preoperatively may be useful. But there is a concern that avascular necrosis (AVN) is often diagnosed by the presence of a simple signal loss on plain

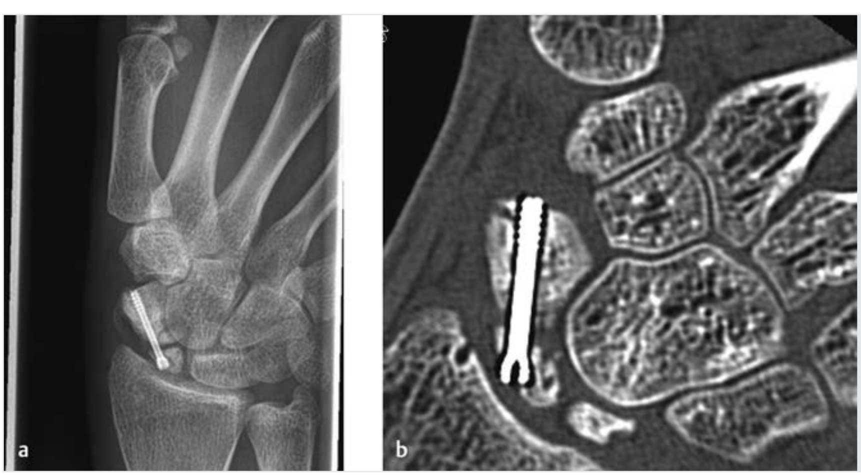

Fig. 69.1 **(a)** Nonunion following 2 years after screw fixation of an acute fracture of the proximal pole of the scaphoid. **(b)** CT scan demonstrating loss of bone stock and architecture of the proximal pole.

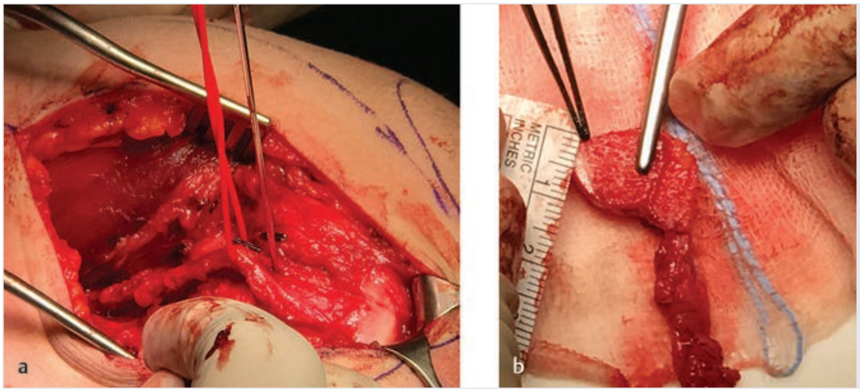

Fig. 69.2 **(a)** Intraoperative view of the mobilized pedicle to the dorsal area of the knee joint. **(b)** Harvested osteochondral graft with pedicle.

Fig. 69.3 Example for preserved bony architecture on CT scan.

T1-weighted images. The term AVN should be only used when there is loss of bone stock or even fragmentation due to long-standing avascularity. Signal loss in contrast MRI and loss of punctuate bleeding intraoperatively should be used to indicate an avascular or ischemic fragment. Recent studies, however, have given more importance to the morphological structure of the proximal pole defined by a CT scan. As long as the structure according to D1 to D3 (▶Fig. 69.3) is preserved, bony healing even with nonvascularized graft can be expected. In the case of destroyed bony architecture according to D4 (AVN), bony union with traditional techniques is no more possible. In these situations, transplantation of free vascularized osteochondral grafts from the femoral condyle with complete replacement of the proximal pole has proven to be a real reconstructive solution, avoiding salvage procedures such as resection and replacement by a pyrocarbon implant or partial wrist fusion.

69.4.1 Recommended Solution to the Problem

- For preoperative diagnostics, plain radiographs (posteroanterior, lateral, and Stecher's views) and CT scan longitudinally to the axis of the scaphoid are mandatory; MRI is optional.
- In D1, use local bone graft even by arthroscopy and screw fixation.
- In D2, use bone graft from the iliac crest with mini-Herbert screw.
- In D3, complete removal of the sclerotic bone, vascularized local bone graft is the primary treatment; in case of failure, osteochondral bone graft from the femoral condyle can be used.
- D4 requires complete replacement of the destroyed proximal pole by free vascularized osteochondral bone graft from the femoral condyle.

69.5 Technique

Fixation was done with two Kirschner's wires (▶Fig. 69.4). After immobilization for 8 weeks, the Kirschner wires were removed when union was present by CT scan (▶Fig. 69.5).

69.6 Postoperative Photographs and Critical Evaluation of Results

Six months later, the patient returned to his previous work still complaining of slight pain at his right knee joint. One year after the surgery on follow-up, he felt pain free at his wrist and knee, range of motion had improved to 50–0-70 degrees of extension/flexion, and grip strength was the same level as his uninjured right wrist (▶Fig. 69.6).

69.7 Teaching Points

- CT scan is mandatory for decision-making.
- Preserved bony architecture is a prerequisite for healing by conventional techniques.
- The term AVN should be limited to loss of bony structure and requires complete replacement of the proximal pole.

Fig. 69.4 Radiographs showing **(a)** posteroanterior and **(b)** lateral views after reconstruction.

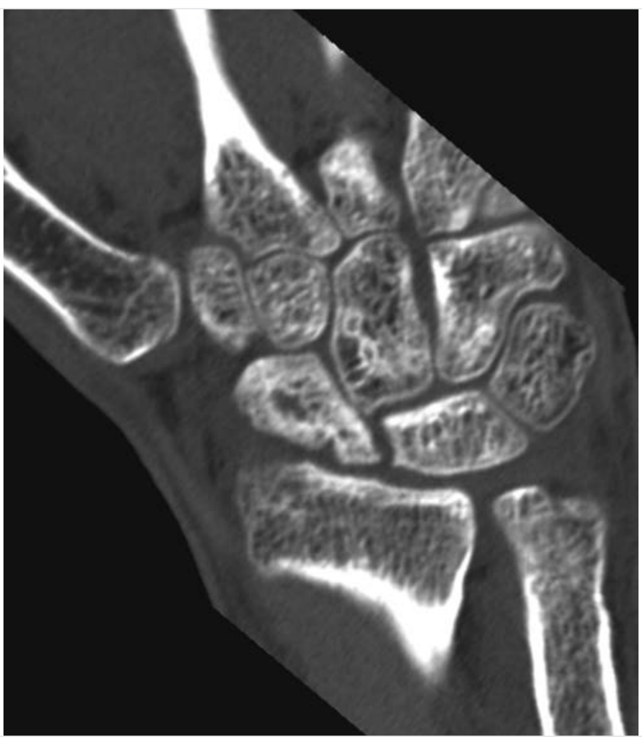

Fig. 69.5 Bony union on CT scan 11 months postoperative.

Fig. 69.6 These images were taken 1.5 years postop. **(a)** Posteroanterior radiograph. **(b)** Lateral radiograph with neutral position of the lunate. **(c)** Stecher's view with closed scapholunate gap.

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70 Scaphoid Nonunion with Avascular Necrosis

Nikolas H. Kazmers, Stephanie Thibaudeau, Zvi Steinberger, and L. Scott Levin

70.1 Patient History Leading to the Specific Problem

A 31-year-old woman presents with left radial-sided wrist pain. The patient is an avid motorcyclist and fell off her dirt bike 1 year prior to presentation. At the time of her accident, she was diagnosed with a displaced left scaphoid waist fracture (▶Fig. 70.1a–c) for which she was treated with an open reduction and internal fixation (ORIF) surgery with a compression screw placed through a volar approach (▶Fig. 70.1d–f). Six months after surgery, radiographs and a CT scan failed to show signs of bridging across the fracture sight (▶Fig. 70.2). In addition, sclerosis of the proximal pole of the scaphoid was then evident on CT scan, suggestive of proximal fragment avascular necrosis (AVN).

70.2 Anatomic Description of the Patient's Current Status

The patient suffered a scaphoid waist nonunion with suspected AVN of the proximal fragment with hardware in place. Fractures of the scaphoid waist often occur through a fall onto an outstretched hand, resulting in injury from a combination of hyperdorsiflexion and loading of the radial side of the wrist. The proximal fragment blood supply is tenuous and susceptible to AVN. The proximal pole is encompassed in the articular cartilage and receives inflow solely from the dorsal carpal branches of the radial artery entering its dorsal ridge to travel proximally in a retrograde fashion. Placement of a cannulated screw through a volar approach typically does not compromise the blood supply, and it is probable that AVN resulted from proximal fragment vascular disruption secondary to the displaced fracture rather than the initial failed surgical treatment. Although this patient does not currently display signs of radiographic arthrosis, the natural history of scaphoid nonunion is well described with a predictable progressive pattern of arthritic changes. Although treatment is recommended for symptomatic and asymptomatic nonunions, it is unclear whether the progression to arthritis is influenced.

70.3 Recommended Solution to the Problem

Scaphoid nonunion with AVN of the proximal fragment can be challenging for the hand surgeon, especially in the setting of a previous failed surgery. Treatment options differ based upon the absence or presence of arthritic changes. For patients with arthritic changes, several salvage options exist including scaphoidectomy with limited intercarpal arthrodesis, proximal row carpectomy, total wrist arthrodesis, and total wrist arthroplasty. In the absence of arthritic changes, the mainstay treatment comprises nonunion repair with vascularized bone grafting, as this is thought to afford higher rates of treatment success as compared to nonvascularized grafting (union rates of 88 vs. 47%, respectively). Although both pedicled bone grafts and microvascular bone transfers have been described, recent evidence suggests that treatment with the medial femoral condyle (MFC) flap may provide the highest rate of union. A retrospective cohort study demonstrated a greater union rate and decreased time to union with the MFC flap relative to a pedicled distal radial vascularized bone graft. To assess union rates for MFC and iliac crest free flaps, a systematic review was performed demonstrating superiority of the MFC flap (union rates of 100 vs. 88%). Other treatments include excision and replacement of the proximal pole with an osteochondral MFC or rib flap; however, partial or complete scapholunate ligament excision may lead to carpal collapse and compromised wrist kinematics. Proximal pole replacement with an implant arthroplasty has been described with good mid-term results, although long-term follow-up is required to determine the durability of this procedure.

Based on aforementioned considerations and recent evidence suggesting minimal donor site morbidity results from MFC harvest, a treatment solution utilizing an MFC corticoperiosteal free flap was proposed with the following points of surgical technique as previously detailed.

70.4 Technique

Remove the prior compression screw through the previous volar approach. Expose the nonunion site (▶Fig. 70.3a) and curettage of the proximal fragment necrotic bone, leaving behind a subchondral shell of approximately 2 mm. Verify integrity of the proximal pole cartilage cap and absence of arthritic changes. Deflate the tourniquet to confirm lack of punctate bleeding from the proximal pole (preoperative MRI does not reliably predict proximal fragment AVN). Dissect free the descending genicular artery (DGA) and elevate a small corticoperiosteal bone block based upon the DGA. While doing so, identify cutaneous perforators based upon the saphenous artery or a DGA communicating branch at the level of the femoral condyle (▶Fig. 70.3b), and elevate a chimeric flap (▶video 70.1). Administer 2,500 U of intravenous heparin prior to pedicle sectioning (▶Fig. 70.3c).

Curettage a small cavity in the distal fragment to accommodate the bone block. Trim then inset the bone block into the volar scaphoid while distracting the volar aspect of the scaphoid to restore its normal length. Ensure that the cortical portion of the bone block resides within the scaphoid, similar to the Russe technique. Pin the scaphoid to secure the bone block (▶Fig. 70.4). Expose the radial artery and venae comitantes in the distal forearm, and preserve any sizable superficial veins encountered during the exposure as potential outflow options. Perform microvascular anastomosis (end-to-end radial artery following normal intraoperative Allen testing; end-to-end to venae comitantes and/or cephalic vein branches).

Fig. 70.1 (a–c) Displaced left scaphoid waist fracture. **(d–f)** Open reduction and internal fixation (ORIF) with a compression screw placed through a volar approach.

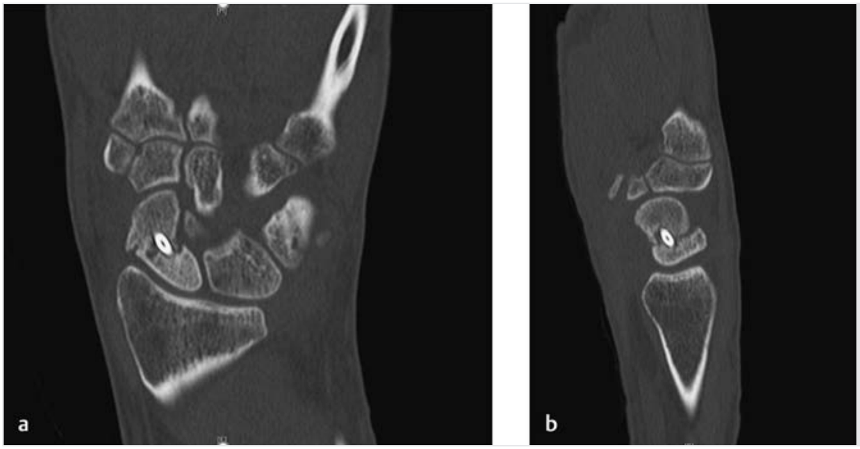

Fig. 70.2 (a, b) Radiographs and a CT scan failed to show signs of bridging across the fracture sight.

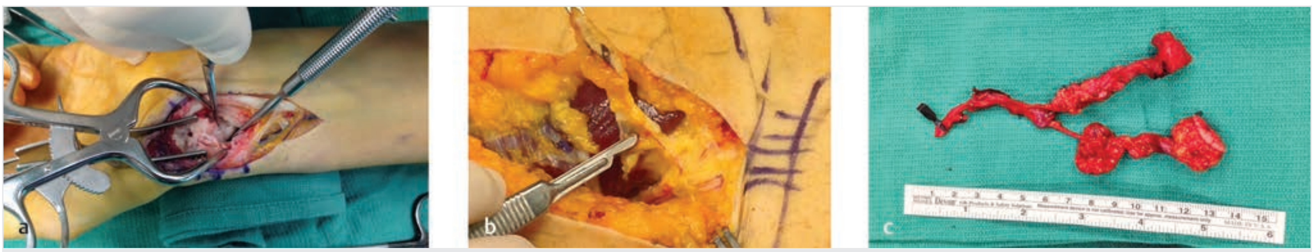

Fig. 70.3 (a) Exposure of the nonunion site of the scaphoid fracture. The curette was used to remove necrotic bone from the proximal pole. **(b)** Cutaneous perforators based upon the saphenous artery or a descending genicular artery communicating branch at the level of the femoral condyle. **(c)** Harvesting the cutaneous paddle on a communicating branch results in a chimeric flap of bone and skin.

Fig. 70.4 (a, b) The scaphoid and vascularized bone flap are fixated with a K-wire.

70.5 Postoperative Photographs and Critical Evaluation of Results

The postoperative regimen for the upper extremity involves thumb spica splinting in the OR, then casting for a total of 8 weeks, followed by a removable splint to be worn at all times for an additional 4 weeks. For the donor knee, an immobilizer was used for comfort for 3 days, followed by progressive weight bearing and physical therapy for range of motion (ROM) exercises. Hospital stay typically ranges from 3 to 5 days. Radiographs of the donor knee taken 2 weeks postoperatively were unremarkable (▶Fig. 70.5), and the patient resumed jogging 6 weeks after surgery. The K-wire was removed in the OR 8.5 weeks postoperatively. At 3 months postoperatively, the patient was completely asymptomatic and a CT scan was obtained, revealing partial bridging along the dorsal and volar aspects of the scaphoid with intervening ununited fracture lines (▶Fig. 70.6a). Based upon these results, continued splinting during high-risk activities and progressive ROM exercises with hand therapist were recommended. A CT scan was repeated (▶Fig. 70.6b) and radiographs (▶Fig. 70.7) were obtained 5.5 months postoperatively, demonstrating progressive healing and a

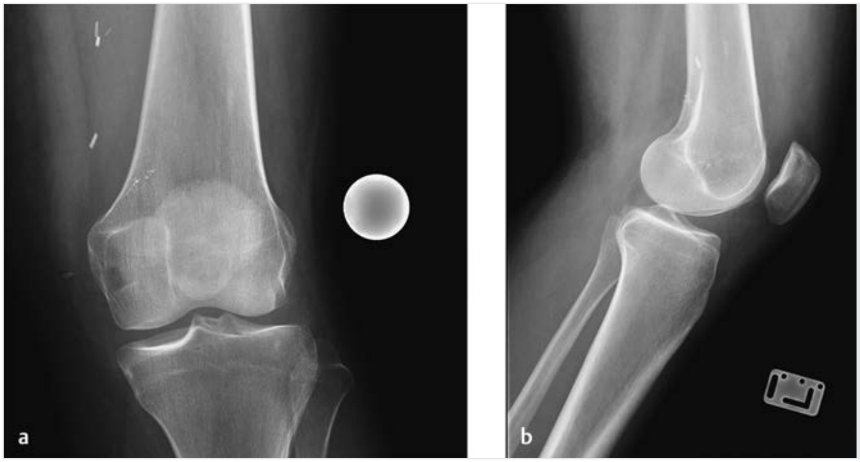

Fig. 70.5 (a, b) Radiographs of the donor knee taken 2 weeks postoperatively were unremarkable.

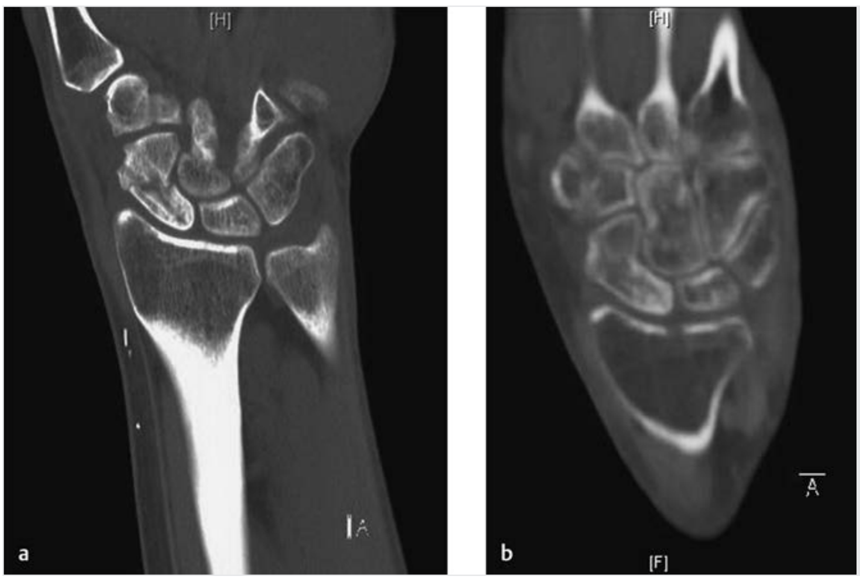

Fig. 70.6 CT scan was obtained, revealing partial bridging along the dorsal and volar aspects of the scaphoid. **(a)** Three months post-op. **(b)** Eighteen months post-op.

Fig. 70.7 (a–c) Radiographs were obtained 5.5 months postoperatively, demonstrating progressive healing and a completely united scaphoid.

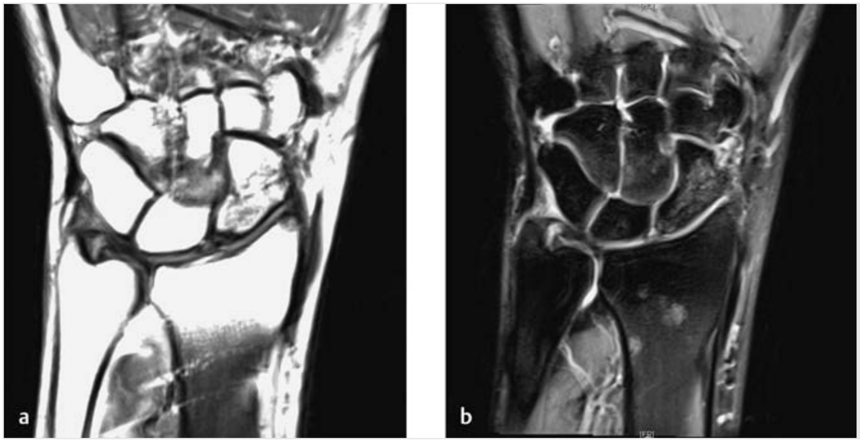

Fig. 70.8 (a, b) Twenty-two-month postoperative MRI suggested that the proximal pole blood supply had been restored with no evidence of avascular necrosis, and preservation of the articular cartilage.

completely united scaphoid. At this point, the patient was cleared to resume all activities, including high-intensity sports and motorcycling. Results from a 22-month postoperative MRI suggested that the proximal pole blood supply had been restored with no evidence of AVN, and preservation of the articular cartilage (▶Fig. 70.8).

70.6 Teaching Points

- The MFC flap is well suited for the treatment of scaphoid waist or proximal pole nonunion with AVN, particularly in the setting of bone loss or humpback deformity.
- Although a preoperative MRI may be obtained to evaluate for proximal fragment AVN, the gold standard remains intraoperative assessment of the proximal pole for punctate bleeding.
- A skin paddle can be elevated to facilitate flap monitoring as well as tension-free wound closure.
- Encourage early weight-bearing and ROM exercises to minimize donor site complications.
- Postoperatively, evaluate for bony bridging across the fracture site with serial radiographs and a CT scan.

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71 Scaphoid Revision Nonunion

Heinz Bürger

71.1 Patient History Leading to the Specific Problem

This man was hit by a soccer ball at the age of 18 years. X-rays were taken 1 week later with no signs of fracture. Because of persistent pain, new X-rays were done 1 year later, showing proximal pole pseudarthrosis of the right scaphoid. Colleges in Austria then performed a nonvascularized cancellous bone transplantation from the iliac crest and fixed the scaphoid using a scaphoid screw by a dorsal approach. After the surgery, he was put in a cast for 8 weeks.

Due to persistent nonunion, 1 year later a shock wave therapy, followed by another 8 weeks of immobilization, was performed in another hospital in Vienna. The patient was sent to the author 5 years after the accident in a situation as described in the following section.

71.2 Anatomic Description of the Patient's Current Status

The patient has no signs of osteoarthritis in the radiocarpal and midcarpal joint (▶Fig. 71.1). The alignment of the carpal bones is normal. He still has a good range of motion. Grip strength is less than on the opposite side.

71.3 Recommended Solution to the Problem

In the author's experience, saving the proximal pole by use of an osteoperiosteal free flap or avascular graft from iliac crest gives only unsecure healing prognosis. So a complete replacement of the proximal pole of the scaphoid by use of a medial free vascularized osteochondral graft from the medial femoral condyle (MFC) is the author's recommended treatment to avoid a salvage procedure like a proximal row carpectomy or a midcarpal fusion.

In January 2006, the author performed his first osteochondral free flap from the MFC for the reconstruction of the proximal scaphoid pole. Now, 12 years later, he has replaced nearly all local pedicled bone flaps as well as free microvascular iliac crest grafts for carpal indications by free microvascular grafts from the medial and the lateral region of the knee. Since January 2006, the author has performed more than 280 of these grafts, 179 from the medial trochlea (MFC-[C]) and 101 from the lateral trochlea (LFC-[C]).

In the author's practice, the healing rate of these grafts is superior compared to all the different free and pedicled flaps that he used before. The use of supramicrosurgical techniques is trainable; the insertion and stabilization of the graft remains challenging.

In scaphoid nonunion both, the MFC-(C) and the LFC-(C) can be successfully applied. Depending on the indication, the proximal or distal pole can be completely replaced or the flap can be applied as an inlay graft without cartilage.

71.4 Technique

The patient is placed in a supine position with pneumatic arm and leg tourniquet. The donor vessels are prepared first (▶Fig. 71.2). When available, the author mainly uses the palmar branches of the radial artery in an end-to-end fashion with a USP 10–0 or 11–0 suture. Alternatively, the radial artery can be used for an end-to-side anastomosis. For venous drainage, the deep accompanying veins or superficial skin veins can be used either in an end-to-end or in an end-to-side fashion. To avoid kinking, the author prefers a short pedicle. The

Fig. 71.1 (a, b) X-rays presenting persistent scaphoid nonunion. **(c)** Corresponding CT scan of the same patient.

further preparation is radial to the flexor carpi radialis tendon. The nonunion is exposed and it is decided whether to keep the proximal pole and use a medial femur graft without cartilage as an interposition graft or to replace the proximal pole. If the proximal scaphoid is avital, it is resected “on bloc” or gradually and an osteochondral flap is performed. The scaphoid fossa is inspected and as far as valuable the corresponding lunate and hamate.

Then a template out of bone cement is formed to reduce the donor morbidity and to keep the graft as small as is necessary, especially in the cartilage-bearing area of the knee joint (▶Fig. 71.3). The author uses bone wax or bone cement in a silicon sheet to form the template. On the template, the author marks the planes (distal scaphoid, capitate, lunate, and cartilage).

Now, the flap can be harvested. The flap (medial condyle osteochondral flaps; MFC-C) is based on either the descending genicular or the medial superior genicular artery. The descending genicular artery is described to be present in 89% of the cases. The descending genicular artery arises from the superficial femoral artery and vein proximal to the adductor hiatus at a mean of 13.7 cm proximal to the joint line. Should it be absent or too small, the medial superior genicular artery is larger and should be selected instead. The surgical approach is through a longitudinal skin incision overlying the adductor magnus in the distal medial thigh. By retracting the vastus medialis anteriorly, the descending genicular vessels are found on the adductor magnus tendon and the superomedial genicular vessels are between the proximal medial condyle and the adductor tendon. These vessels form an arching arcade on the surface of the MFC.

Loop magnification (×2.5–4.5) is strongly recommended. In a bloodless field, the incision starts at the level of the knee joint and runs mid-sided proximally.

The fascia is opened in a longitudinal direction (▶Fig. 71.4). The vastus muscle is mobilized anteriorly. The ligated perforator leads you to a superficial and then deep periosteal network of vessels. A longitudinal branch supplies the periosteum and the distal femur and a transverse ascending branch supplies the proximal anterior articular cartilage. The arteria and the veins can now be dissected epiperiosteal in direction to the popliteal vessels. For complete pole replacement, the ascending osteochondral branch is selected, the proximal end of the cartilage is palpated, and the knee joint is carefully opened. Closed to the graft, the epiperiosteal dissection is changed into a subperiosteal one. According to the template, the graft is cut with an oscillating saw. There is no need to make a cut in the cartilage surface opposite to the patella (hard to be reached) of the knee; it can be carefully broken out if the other cuts have the same deepness. (The author measures or makes a mark on the saw.)

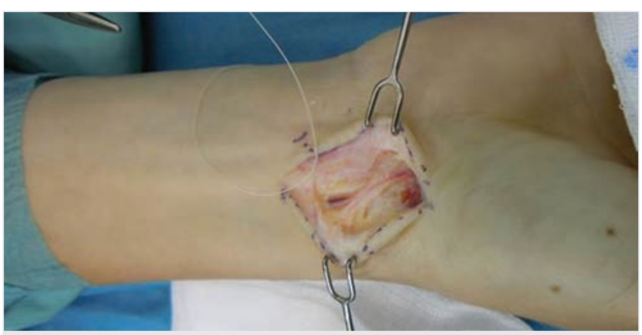

Fig. 71.2 The palmar branch of the radial artery is prepared for later anastomosis.

Depending on the required diameter and length of the pedicle, the dissection proceeds proximally. The tourniquet is opened and the perfusion of the transplant is ensured before the pedicle is clipped (▶Fig. 71.5). The author recommends an intra-articular and a subfascial Redon Drainage. The joint capsule is closed with three to four resorbable sutures, followed by closure of the fascia lata and subcutaneous and skin sutures.

The graft is now tailored according to the template, introduced “under reduction” into the defect, and fixed with the prepared K-wire (▶Fig. 71.6). This K-wire can be replaced by a cannulated screw or another parallel K-wire can be added to prevent rotation. A static and dynamic check and documentation is performed under fluoroscopy. The anastomosis to the prepared vessels is done now under the microscope. If possible, the author tries to connect one deep and one superficial vein in an end-to-end or end-to-side fashion. Kinking of the pedicle must be avoided during the single-layer skin closure. For later Doppler or duplex check, the pedicle area is marked.

A dorsal forearm splint including the thumb is applied until the sutures are removed, followed by a circular plaster cast for 12 weeks after surgery. Physical therapy for regaining wrist motion begins after confirmation of healing in CT scan after 12 to 16 weeks. The donor side should be immobilized in a splint for about 10 days. No further therapy for the knee is needed.

71.5 Postoperative Photographs and Critical Evaluation of Results

Seven years after proximal pole replacement by using the free microvascular medial femur osteochondral graft, the patient’s wrist and knee are completely pain free (▶Fig. 71.7). He is working in an Austrian hospital in the OR (▶Fig. 71.8).

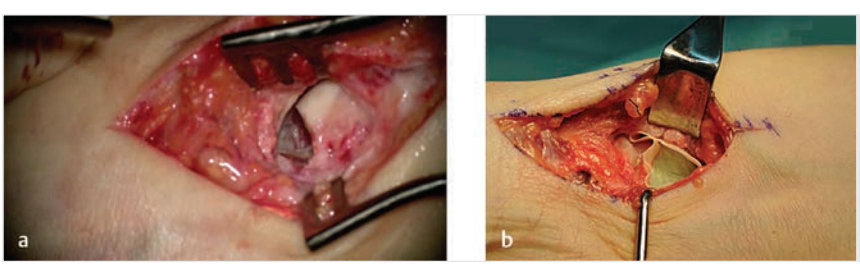

Fig. 71.3 (a) The proximal scaphoid pole is completely removed. **(b)** A template of bone cement or bone wax is formed after resection of the proximal scaphoid pole.

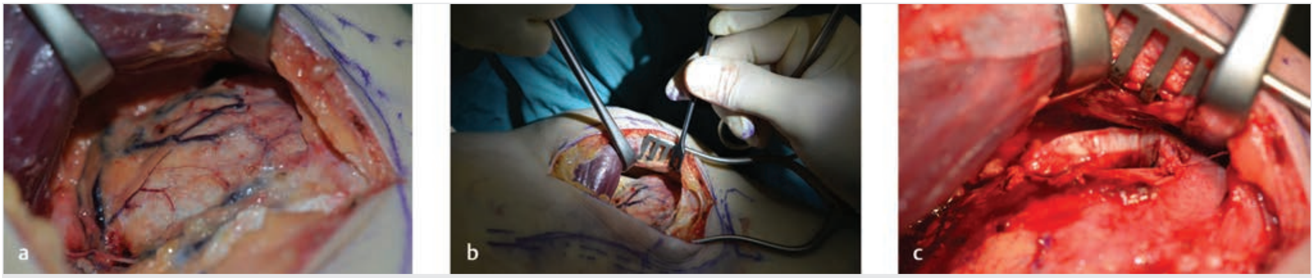

Fig. 71.4 **(a)** The vessels are found at the distal border of the vastus medialis. **(b)** From the vascular network, the best vessels are chosen. **(c)** From the most cranial anterior knee region, the graft is harvested corresponding to the template—please take care of the planes and the depth of your cuts. Then the cartilage, you see in front, breaks nicely without an extra cut on the patella side

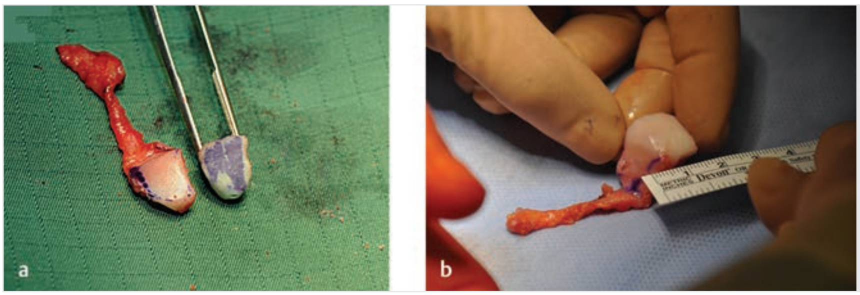

Fig. 71.5 **(a)** The planes of the graft must be carefully corrected if needed .Otherwise, gaps will result after insertion. **(b)** The graft is adapted exactly the same size as the template.

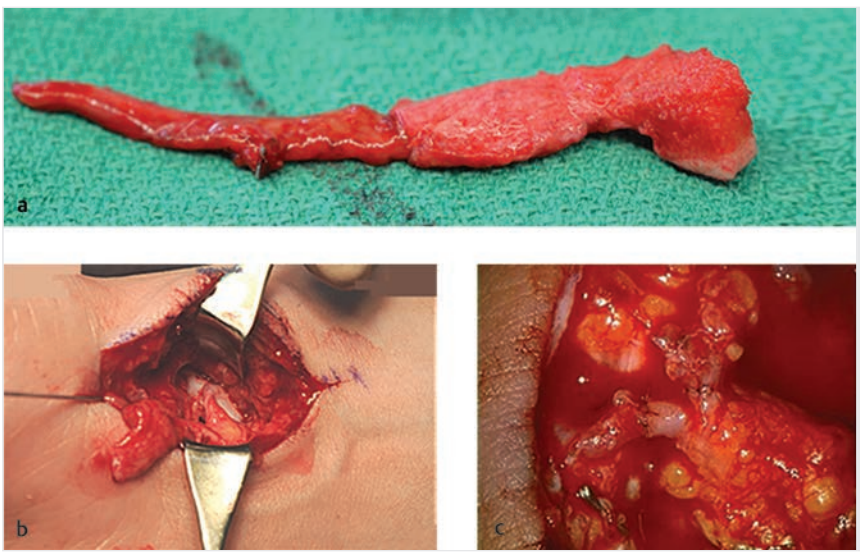

Fig. 71.6 **(a)** Close to the bone, the periosteum is included only as much as needed. Too much could cause additional bone growing in the soft tissue and reduce wrist flexion later. **(b)** The graft is inserted; here one K-wire was prepared before. **(c)** End-to-end anastomosis of the flap artery to the palmar branch of the radial artery and end-to-end anastomosis of the flap vein to a superficial vein.

71.6 Teaching Points

- Prepare the palmar branch of the radial artery and one superficial vein during the palmar approach.
- Decide to keep or remove the proximal scaphoid pole intraoperatively.
- Make a template from bone wax or cement in a silicon sheet.
- Open the knee joint and take the graft only as big as is needed.
- Take care to cut the right planes and angles in comparison to the template.
- Ask for perfect relaxation during dissection of the graft and pedicle.

Fig. 71.7 (a,b) X-rays 6 months after surgery. **(c)** CT 6 months after surgery showing complete healing.

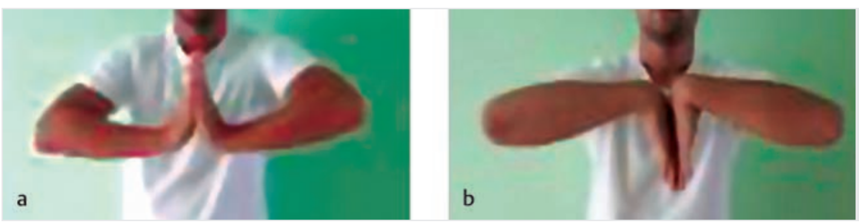

Fig. 71.8 (a, b) Clinical result 6 and a half years after surgery.

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72 Scaphoid Nonunion

Mohamed Morsy, Assaf Kadar, and Steven L. Moran

72.1 Patient History Leading to the Specific Problem

A 17-year-old adolescent boy presents with complaints of wrist pain and limited wrist function. He has had mild wrist pain ever since he fell on his outstretched hand 3 months ago while playing football, for which he did not seek medical care. The pain was aggravated after falling on the same wrist, while flexed, a month ago. The pain is generalized and increases with wrist movement, especially extension.

72.2 Anatomic Description of the Patient's Current Status

On examination, the patient was nontender around the wrist, but he had a limited range of motion especially in extension with a maximum of 10 degrees. Plain radiographs revealed a scaphoid waist fracture with displacement and bone resorption around the fracture site, and a sclerotic proximal pole in the anteroposterior (AP) view (▶Fig. 72.1a). In the lateral view, the scaphoid showed a humpback deformity and the lunate was in a mildly extended position, a condition known as dorsal intercalated segment instability (DISI) deformity (▶Fig. 72.1b). CT of the wrist demonstrated an ununited scaphoid waist fracture with marked resorption and cystic changes at the fracture site and a humpback deformity (▶Fig. 72.1c–e). There were no signs of wrist or carpal arthritis. MRI demonstrated changes suggesting early avascular necrosis (AVN) of the proximal pole of the scaphoid (▶Fig. 72.1f).

72.2.1 Anatomic Etiology of Complication

Blood supply to the scaphoid is critical and is predominantly retrograde. Seventy to 80% of the blood supply to the scaphoid including the proximal pole is from branches of the radial artery entering distally through the dorsal ridge (▶Fig. 72.2). A fracture may disrupt this pattern of blood supply and eventually lead to AVN of the proximal pole and could contribute to the development of fracture nonunion. Other factors that have been related to the development of a scaphoid nonunion are fracture displacement more than 1 mm, delay in treatment more than 4 weeks, and tobacco use.

72.3 Recommended Solution to the Problem

Early diagnosis and treatment of a scaphoid fractures is the primary means of preventing the development of a scaphoid nonunion. Many scaphoid fractures can be minimally symptomatic, as in our patient's case. Minimal discomfort may delay the diagnosis of an acute fracture. Additionally, many scaphoid fractures may not be seen on the initial AP and lateral radiograph, leading to an inappropriate diagnosis of a wrist sprain. While the diagnosis of acute scaphoid fractures is beyond the scope of this chapter, it should be emphasized that acute radial-sided wrist pain, and specifically snuff box tenderness following trauma, warrants close monitoring to rule out the presence of an occult scaphoid fracture.

Primary treatment of scaphoid fractures includes casting and open reduction and internal fixation. Open reduction and fixation is usually reserved for cases where the fracture is displaced or involves the proximal pole. Casting is most appropriate for nondisplaced fractures. Various options exist to manage a scaphoid fracture that proceeds to nonunion including fixation and bone grafting techniques; however, if the nonunion is associated with AVN, collapse, and carpal instability (as evident by a humpback deformity or DISI), it is more difficult to treat. In the case of our patient, structural support is needed to restore scaphoid height and correct midcarpal instability, and a bone graft with a vascular supply is needed to overcome the difficult healing environment associated with AVN. Without adequate treatment, the scaphoid will fail to unite and carpal collapse will progress, leading to a predictable pattern of arthritis know as scaphoid nonunion advanced collapse (SNAC) arthritis.

Vascularized bone grafts are a good treatment choice for scaphoid nonunions where the proximal pole's vascularity is compromised and have a well-established track record within the literature. Vascularized bone grafts allow for primary and accelerated bone healing. Vascularized grafts can be pedicled grafts harvested locally from nearby bones such as the distal radius, the first metacarpal, or free flaps that require microsurgical anastomosis at the recipient site. The free vascularized medial femoral condyle (MFC) graft has been shown to be effective in providing structural support in the setting of carpal instability and is capable of restoring scaphoid geometry and carpal alignment. It is associated with minimal donor site morbidity and possesses bone density that is similar to that of the scaphoid. The MFC has shown reliable results of achieving scaphoid union and has a shorter average healing time than other forms of bone grafting.

72.3.1 Recommended Solution to the Problem

- The MRI and CT suggest evidence of nonunion with probably AVN of the proximal pole. In addition, there is scaphoid collapse and midcarpal instability. All these risk factors support the use of a free vascularized bone graft. Our preference is to use the MFC graft due to its ease of harvest, minimal donor site morbidity, and length of vascular pedicle.
- To restore scaphoid anatomy, a vascularized volar wedge graft is required to correct the humpback deformity.

Fig. 72.1 **(a)** Anteroposterior view of the wrist showing a scaphoid nonunion, with cyst formation and bony resorption. **(b)** Lateral radiograph of the wrist showing a humpback deformity and loss of intrascaphoid angle. **(c)** CT image of the wrist showing cystic osteolysis at the fracture site and increased density of the proximal pole. This can be suggestive of avascular necrosis. **(d)** Lateral image from CT showing dorsal osteophyte on distal portion of scaphoid with collapse of scaphoid. **(e)** Lateral image from CT showing lunate in extended posture, suggesting dorsal intercalated segment instability. **(f)** MRI of the wrist. MRI shows clear line of demarcation between proximal and distal poles. This finding may be suggestive of avascular necrosis of the proximal pole.

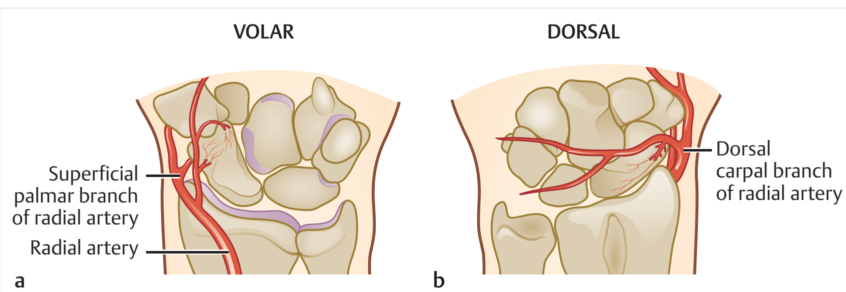

Fig. 72.2 **(a, b)** Blood supply entering the scaphoid. The majority of the blood supply enters the bone distal to the waist. Thus, proximal pole fractures may produce a proximal scaphoid fragment with no blood supply predisposing it to the development of avascular necrosis.

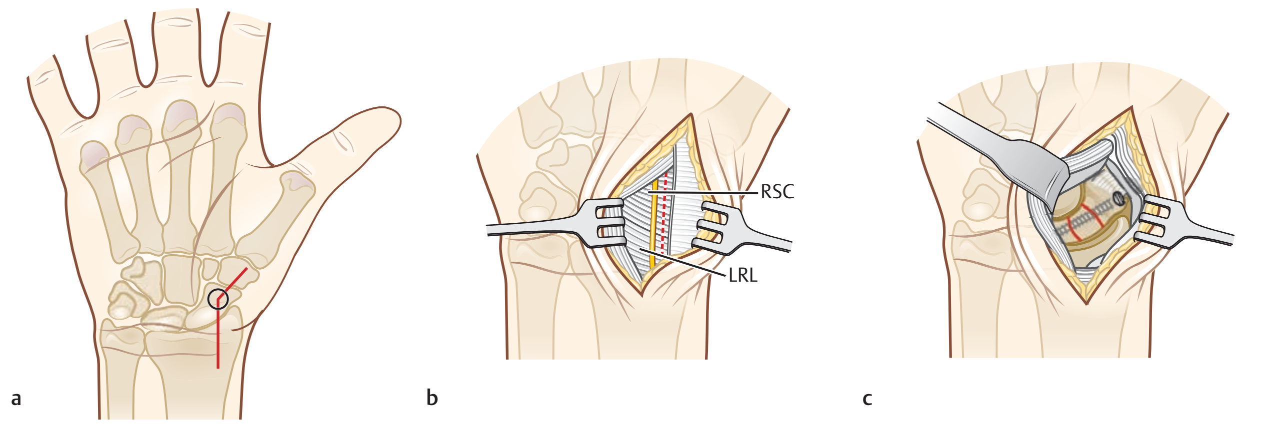

Fig. 72.3 **(a)** A volar approach to the scaphoid is used to correct the humpback deformity. **(b)** The scaphoid is identified by mobilizing the FCR and going through the FCR subsheath. The capsule is best mobilized by dividing a portion of the radioscaphocapitate ligament off of the distal radius and radial styloid. **(c)** Once the capsule is mobilized, the fracture can be opened and a vascularized wedge graft is placed and secured with a retrograde screw.

- Correction of the scaphoid humpback deformity is crucial to realigning the carpus, correcting the DISI deformity, and restoring the normal carpal kinematics.
- If this is left untreated, carpal collapse and instability will eventually lead to arthritis.
- This problem could be prevented by early diagnosis and immediate surgical treatment of a displaced scaphoid fracture with a compression screw or other means of internal fixation.
- Due to the patient's young age, we elected to try to save the scaphoid bone; however other options for this problem include scaphoidectomy and four-corner fusion, distal scaphoid resection, and proximal row carpectomy.

72.4 Technique

The patient is placed in the supine position on the operating table with the arm abducted and rested on an arm board. A two-team approach can be used with one team preparing the scaphoid nonunion site and the other team harvesting the MFC flap. If such manpower is not available, preparation of the nonunion site is performed first.

The scaphoid is approached through a standard volar approach exposing the nonunion site, which is further extended proximally for access to the radial vessels and superficial veins required for graft anastomosis. The skin is first incised overlying the flexor carpi radialis tendon (▶Fig. 72.3a), and its sheath divided, followed by retraction of the tendon ulnarly (▶Fig. 72.3b). The floor of the sheath is then divided to expose the underlying scaphoid, and is extended distally as far as the trapezium (▶Fig. 72.3c). The nonunion site is then examined and debrided.

The vascularity of the proximal pole can be judged according to the presence or absence of punctate bleeding after deflating the tourniquet. The DISI deformity can be corrected using a Kirschner wire passed dorsally through the radiolunate articulation after correction of the dorsal lunate angulation by flexing the wrist. This holds the lunate in a neutral position.

Extending the wrist with the lunate fixed opens up the cleared nonunion site, correcting the humpback deformity and restoring the original scaphoid length and carpal alignment (▶Fig. 72.4). This step should be performed under fluoroscopy guidance. With the wrist in extension, debridement of the nonunion site is completed. A saw blade can be used to flatten the edges of the bone, creating a straight surface to accept the MFC bone graft for better contact between the bony ends. Precise measurement of the defect is done to determine the size and shape of graft to be harvested. A wedge-shaped graft is usually required to maintain the corrected position. Provisional wires can be placed in the distal pole of the scaphoid in preparation for screw placement. The tourniquet is now released and a sponge is placed over the incision.

Now that preparation of the recipient site is completed, harvest of the MFC graft is performed. With the patient still in the supine position, the ipsilateral knee is flexed and a longitudinal incision is performed over the distal medial thigh centered close to the posterior border of the vastus medialis muscle. The incision starts at the joint line and extending proximally as required to expose the pedicle (▶Fig. 72.5). The fascia over the vastus medialis is incised and the muscle is retracted medially with a Chandler retractor to expose the MFC and its blood supply.

Examination of the main supplying vessel to the medial condyle is now performed. In the majority of cases, the main supplying vessels are the osteoarticular branch and its venae comitantes from the descending genicular vessels, which in turn originate from the superficial femoral vessels before traversing the adductor hiatus. If this is the case, the descending genicular vessels are followed retrograde along their course between the vastus medialis and the adductor muscles, ligating smaller branches supplying surrounding muscles and structures until the point of origin is reached. In 10 to 15% of cases, the superior medial genicular vessels will be the main blood supply, and these will be selected for the pedicle and dissected to their origin directly from the popliteal artery (▶Fig. 72.6).

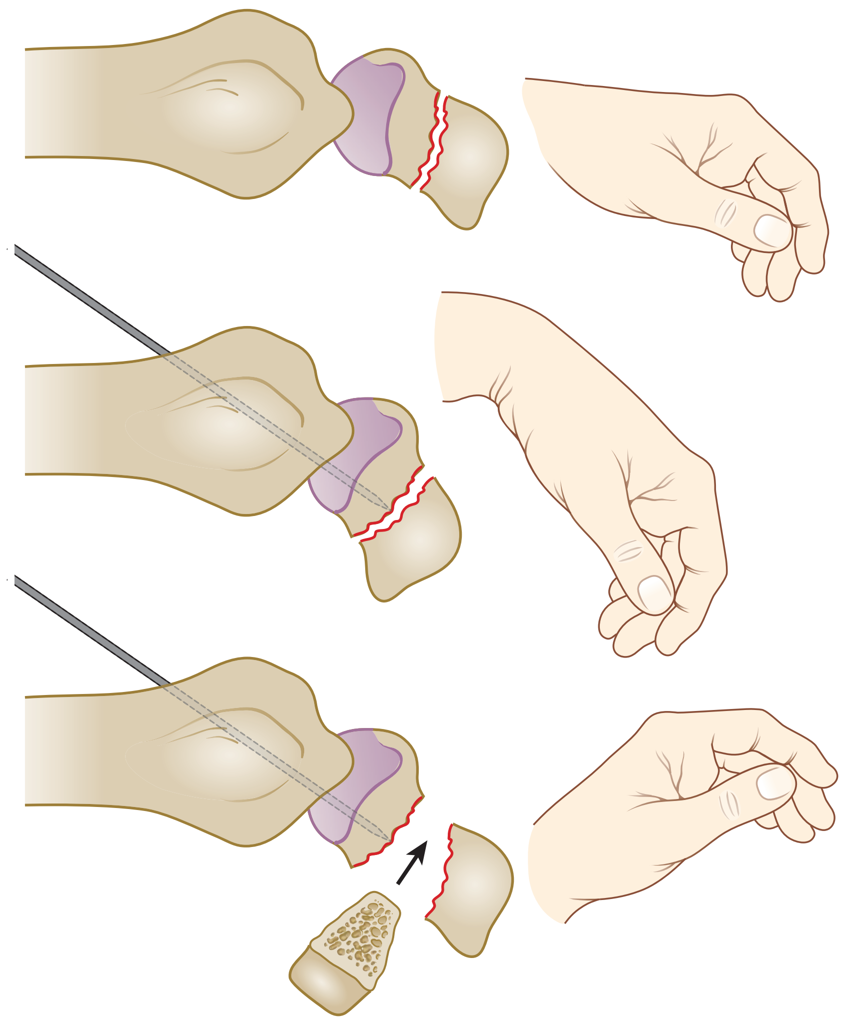

Fig. 72.4 Correction of the lunate position and proximal pole position can be performed prior to graft placement by placing a Kirschner wire into the lunate with the wrist flexed. With the lunate pinned, the wrist can be brought into extension, which opens up the nonunion site and allows for correction of the intrascaphoid angle.

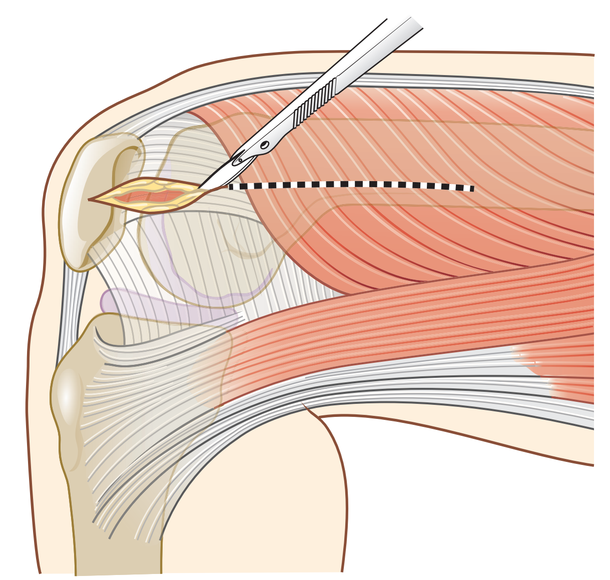

Fig. 72.5 The medial femoral condylar graft is harvested through an incision in line with the medial femoral condyle and the adductor tendon.

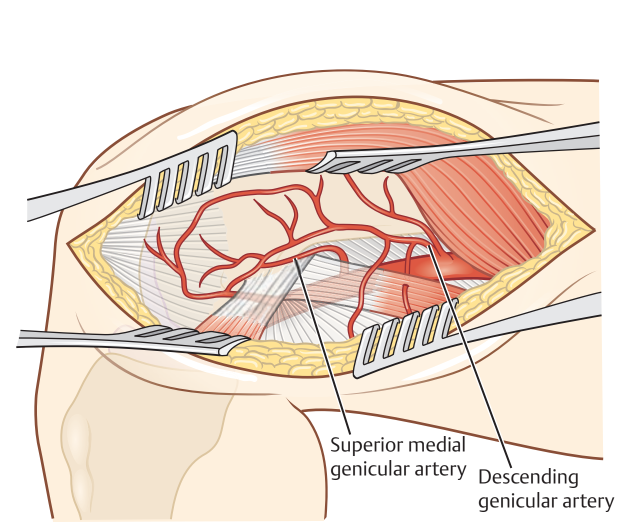

Fig. 72.6 The descending geniculate pedicle is exposed by mobilizing the vastus medialis muscle anteriorly and placing retractors behind the femur.

An appropriately sized and shaped graft is carefully harvested according to the previously determined measurements using an osteotome or saw (▶Fig. 72.7). This is ideally chosen from the distal posterior quadrant of the exposed condyle as this area possesses the highest density of bony perforators. Before division of the pedicle, a final check on the vascularity of the graft is done after deflation of the tourniquet; this is demonstrated by bleeding from the graft substance. If needed, a small skin paddle may also be harvested with the flap based on the descending geniculate artery (▶Fig. 72.8). The pedicle is then divided completing harvest of the graft, followed by anatomical closure of the wound in layers.

The graft is then inset in the scaphoid defect such that the cortical surface faces forward to provide the structural support required to correct the humpback deformity, and also to protect the pedicle from any twist or compression. The scaphoid is then fixed using a cannulated screw and its position is checked using fluoroscopy. The incision is now extended proximally exposing the radial vessels and the cephalic vein if needed. The artery is anastomosed in an "end-to-side" fashion to the radial artery and the vein is anastomosed either to one of the radial artery's venae comitantes or to the cephalic vein in an "end-to-end" fashion (▶Fig. 72.9). After confirming the patency of the anastomosis, the wound is closed in layers making sure that there

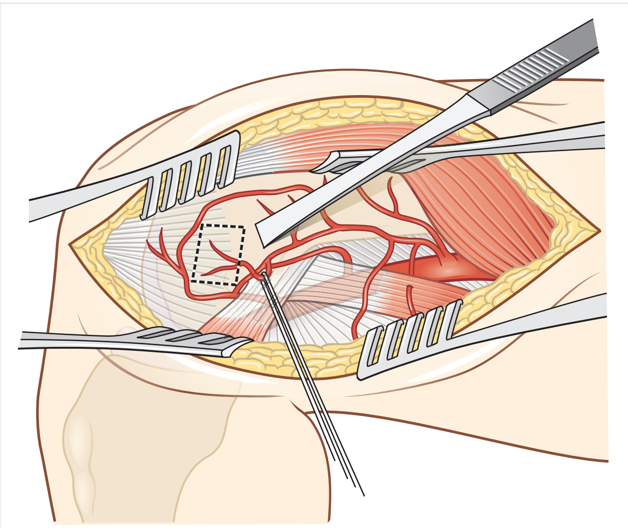

Fig. 72.7 The bone graft is designed on a perforating branch of the artery. A small osteotome or sagittal saw can be used to harvest the graft, which for most cases is less than 1 cm × 1 cm.

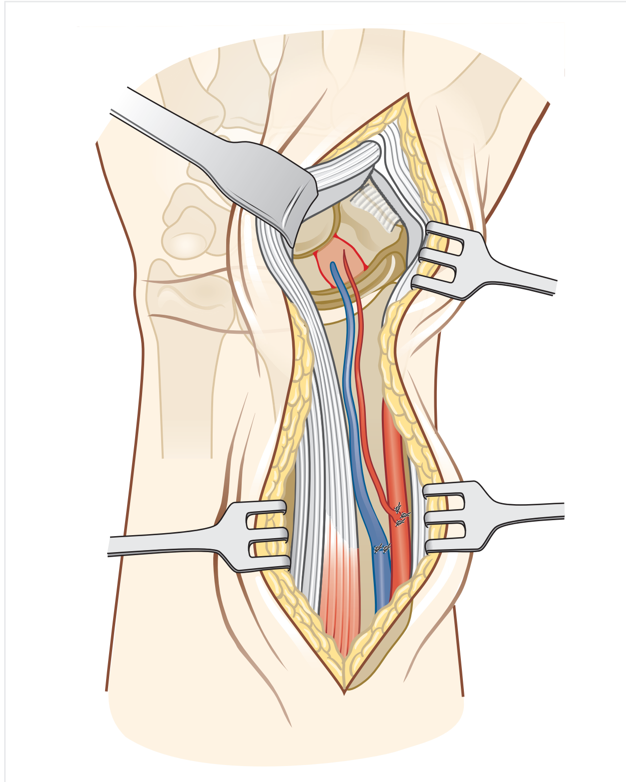

Fig. 72.9 The medial femoral condyle graft is anastomosed to the radial artery in an end-to-side fashion. The vein can be sewn end to end to one of the radial artery's venae comitantes or the cephalic vein.

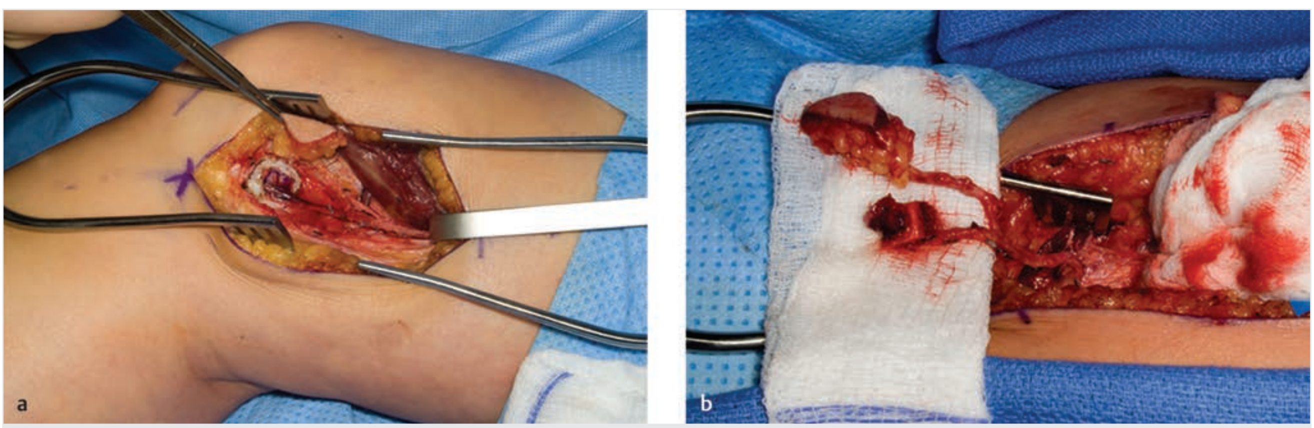

Fig. 72.8 **(a)** Intraoperative image of bone graft exposed prior to harvesting with osteotome. A skin paddle has been dissected superiorly. **(b)** Intraoperative image of the bone graft harvested (inferiorly) with a skin paddle taken on the same pedicle to allow for monitoring of the flap (superiorly).

Fig. 72.10 **(a)** Anteroposterior (AP) postoperative radiograph at 2 weeks. The implantable Doppler probe can be seen at the proximal margin of the forearm. **(b)** AP radiograph showing incorporation of the bone graft across the distal and proximal osteotomy site. **(c)** CT scan showing bridging bone across nonunion site with evidence of healed scaphoid and restoration of normal carpal alignment.

is no undue tension on the pedicle. We often employ a small skin paddle with the MFC graft to act as a monitor of flap perfusion or we use and implantable Doppler probe to verify vessel patency. A bulky dressing together with a long-arm thumb spica splint is applied with the wrist in neutral position for 2 weeks until the stitches are removed. A long-arm thumb spica cast is applied for another 3 weeks, which is exchanged for a short arm thumb spica cast until radiological signs of union are evident.

72.4.1 Steps for the Procedure

1. The nonunion is debrided thoroughly checking for vascularity of the proximal pole.
2. The MFC graft is harvested on the appropriate pedicle that is custom sized and shaped to correct and maintain the scaphoid length and geometry.
3. The graft is inset in the defect and the scaphoid is fixed with a cannulated screw.
4. The pedicle is anastomosed to the radial artery and one of its venae comitantes or the cephalic vein.
5. Undue tension is avoided on the pedicle during closure by utilizing a small skin island or a skin graft.

72.5 Postoperative Photographs and Critical Evaluation of Results

The MFC graft has been used successfully to restore vascularity to the scaphoid proximal pole and achieving healing together with correcting carpal deformity and instability (▶Fig. 72.10a). Average time to union was reported to be 13 weeks, with minimal donor site morbidity. The patient is followed up with radiographs (▶Fig. 72.10b) and the final union is confirmed with CT as shown in ▶Fig. 72.10c.

72.6 Teaching Points

- Early diagnosis and appropriate treatment of scaphoid fractures can help avoid complications.
- Fracture displacement of greater than 1 mm requires open reduction and surgical fixation.
- The presence of AVN, humpback deformity, and carpal instability necessitates more complicated procedures to avoid the irreversible wrist arthritis.
- AVN requires vascularized bone grafts to assist in revascularizing the necrotic area and fracture healing.
- Humpback deformity and carpal instability in the form of DISI require structural support to restore scaphoid length and geometry, and carpal stability.
- The MFC graft can provide a solution to these problematic situations.
- The MFC graft has to be precisely shaped and sized to match the debrided nonunion site in the corrected position, with the cortical surface anteriorly to ensure the needed structural support.
- Undue pressure on the pedicle is to be avoided during closure.
- Final healing of the fracture and integration of the graft is confirmed using CT.

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73 Scaphoid Implant Malplacement

Wesley N. Sivak and Joseph E. Imbriglia

73.1 Patient History Leading to the Specific Problem

A 29-year-old right-hand-dominant woman presented 6 months after a fall on an outstretched right arm from which she sustained a scaphoid fracture. Her referring physician initially treated her with immobilization in a thumb spica cast for 12 weeks, but the fracture did not heal. An MRI demonstrated a scaphoid waist fracture and a nonunion. She had developed a mild humpback deformity across her nonunion (▶ Fig. 73.1a, b). Of note, she was an active smoker and was chronically disabled secondary to bipolar disorder. She then underwent repair of her right scaphoid waist fracture nonunion by means of open reduction and internal fixation (ORIF) augmented with distal radius cancellous bone autograft. Her surgery was uneventful. Fixation of her fracture (by report) was obtained with a 20-mm Acutrak mini-screw with bone graft across the nonunion site. Intraoperative fluoroscopy was utilized to confirm hardware placement across the fracture site (▶ Fig. 73.1c, d). She presented to us with point tenderness in the right anatomic snuffbox. No crepitus was appreciated with active or passive ranging of the wrist, although motion was both painful and limited secondary to her prolonged period of immobilization.

73.2 Anatomic Description of the Patient's Current Status

The scaphoid receives its blood supply from the radial artery via the superficial palmar arch and the dorsal carpal branch. The dorsal carpal branch enters the scaphoid through foramina along its nonarticulating dorsal ridge and supplies the vast majority of the bone; branches from the superficial palmar arch supply only the distal third (or pole) after entering through the distal tubercle. While these branches provide ample blood supply to middle and distal thirds, the proximal pole receives no direct branches and relies solely on retrograde flow through the bone. Thus, when fractures occur across the middle third of the scaphoid, blood supply to the proximal pole is limited.

Fractures across the scaphoid become increasingly more difficult to heal as the fracture line moves proximal, resulting in

Fig. 73.1 (a, b) MRI demonstrated a scaphoid waist fracture and a nonunion. She had developed a mild humpback deformity across her nonunion. **(c, d)** Intraoperative fluoroscopy was utilized to confirm hardware placement across the fracture site. A 20-mm Acutrak mini-screw with bone graft across the nonunion site.

Fig. 73.2 (a, b) X-rays from her first follow-up visit at 2 weeks confirm the problems. **(c, d)** CT scan of the right wrist at 3 months post-op. Nonunion is observed.

greater degrees of disrupted blood supply to the bony fragment. Indications for ORIF of scaphoid fractures include unstable fractures, proximal pole fractures, displacement greater than 1 mm, greater than 15 degrees of scaphoid humpback deformity, radiolunate angle greater than 15 degrees (dorsal intercalated segment instability [DISI]), scaphoid fractures associated with perilunate dislocation, comminuted fractures, unstable vertical, or oblique fractures. Our patient met the criteria for ORIF at the time of presentation given her humpback and DISI deformities and degree of displacement. Unfortunately, the mini-screw was placed too volar in the scaphoid. X-rays from her first follow-up visit at 2 weeks confirm the problems, which can also be seen on the intraoperative fluoroscopy (▶Fig. 73.2a, b). Further complicating things, the mini-screw appeared too long and rested within the scaphoid facet of the distal radius. The patient continued to have persistent wrist pain, prompting a CT scan of the right wrist at 3 months post-op (▶Fig. 73.2c, d). CT scan confirmed a chronic nonunion of the scaphoid with a significant degree of comminution and demonstrated volar malplacement of the hardware.

73.3 Recommended Solution to the Problem

One should first realize that this problem could have been be prevented by obtaining adequate reduction and fixation of the fracture at the time of surgery. On the postoperative CT scan at 3 months, the proximal pole has a significant degree of comminution that cannot be appreciated on the original X-rays. This stresses the importance of obtaining and thoroughly reviewing additional imaging studies such as CT or MRI prior to surgical intervention. Our patient may have benefited from a vascularized bone graft at her original surgery given the severity and degree of comminution of her fracture in the proximal pole.

The goals of surgery have now changed. A pain-free wrist is now the goal. However, this comes at a great expense, as salvage procedures must be utilized. Salvage procedures, such as scaphoid excision/four-corner fusion and proximal row carpectomy (PRC), are employed when normal wrist function can no longer be achieved because the original injury has deteriorated beyond repair. The four-corner fusion is preferred to PRC in younger, higher demand patients, as they are prone to developing arthritis in the newly formed capito-radial articulation following PRC.

73.3.1 Recommended Solution to the Problem

- Scaphoid nonunions can be treated with ORIF and bone grafting, provided adequate reduction can be obtained.
- Nonvascularized bone grafts can be utilized for simple fractures, whereas vascularized bone grafts are indicated for comminuted and more proximal fractures.

- Inadequate reduction and hardware malplacement can be avoided with meticulous assessment on intraoperative fluoroscopy.
- Wrist salvage procedures (i.e., four-corner fusion and PRC) can be utilized to obtain pain-free albeit limited wrist motion in patients.

73.4 Technique

Under tourniquet control, a longitudinal incision is made along the line of the third metacarpal over the radiocarpal and midcarpal joints. Skin flaps are elevated and sensory nerves protected. The third extensor compartment is opened and the extensor pollicis longus is retracted radially. Division of the septum between the third/fourth and fourth/fifth extensor compartments creates an ulnarly based flap of retinaculum. The extensor tendons are retracted and posterior interosseous neurectomy is performed. Ligament-sparing capsulotomy is made by making an incision along the radioscaphoid, dorsal radiocarpal, and intercarpal ligaments. The radially based capsule flap is then elevated to expose the radiocarpal and midcarpal joints. The articular surfaces of the radiocarpal joints are carefully examined; if the radiolunate articulation is without degenerative changes, one can proceed with scaphoid excision and four-corner fusion.

Soft-tissue attachments are systematically elevated from the scaphoid until it is removed. Care must be taken not to damage the radioscaphocapitate or long radiolunate volar ligaments. Once the scaphoid is removed, the fusion sites are prepared with meticulous decortication of cartilage of the capitolunate and triquetrohamate joints. Correction of the DISI deformity is imperative to prevent dorsal radiocarpal impingement.

Neutral capitolunate alignment and reduction is obtained under fluoroscopic image, and a guidewire is then placed from the capitate to the lunate. The depth of the reaming should be such that it sinks just below the edge of the cortices. Compression screws are then placed and copious amount of bone graft is packed. X-rays then confirm proper positioning of the screws. The ligament-sparing capsulotomy is closed and the retinacular flap is repaired with the extensor pollicis longus dorsally transposed. The skin is closed and a plaster splint is applied.

73.4.1 Steps for the Procedure

1. Dorsal, ligament-sparing approach is made to the wrist. If the radiolunate articulation is without degenerative changes, proceed with scaphoid excision.
2. Take care not to damage the radioscaphocapitate ligament when removing the scaphoid.
3. Decortication of cartilage of the capitolunate and triquetrohamate joints is performed.
4. Downward pressure on the capitate will correct the DISI deformity.
5. Neutral capitolunate alignment is obtained, and a guidewire is then placed from the capitate to the lunate to maintain the alignment.
6. Compression screws are placed across the capitolunate and triquetrohamate joints.
7. The capsulotomy is closed and the retinacular flap is repaired with the extensor pollicis longus dorsally transposed. The skin is closed and a plaster splint is applied.

73.5 Postoperative Photographs and Critical Evaluation of Results

Performing scaphoid excision and four-corner fusion mandates that the patient have better function than the preoperative state. When done properly and the bones fuse as intended, the patient can have a pain-free albeit limited wrist motion with good strength and overall function for performing activities of daily living (▶Fig. 73.3). Our patient's problem could have been avoided with anatomic reduction of the fracture, use of bone graft, and appropriately positioned hardware at the time of her initial surgery.

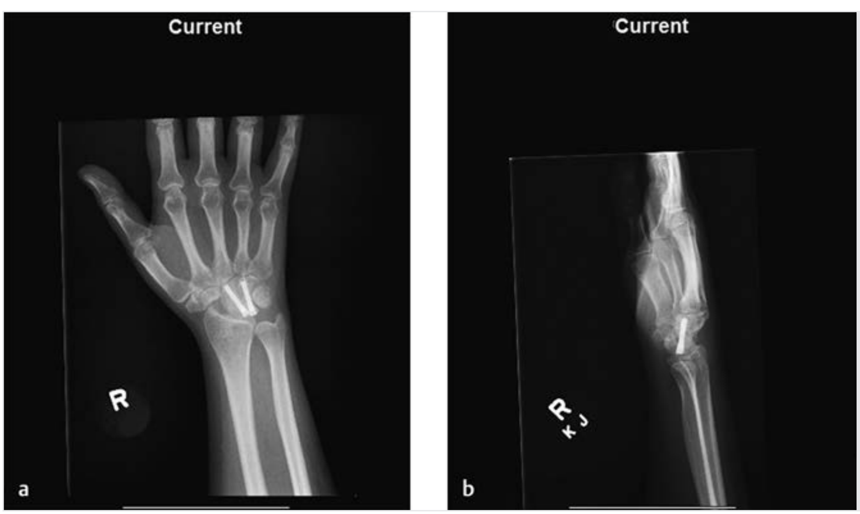

Fig. 73.3 (a, b) Scaphoid excision and four-corner fusion.

73.6 Teaching Points

- Indications for operative management of scaphoid fractures include unstable fractures, proximal pole fractures, displacement greater than 1 mm, greater than 15 degrees of humpback deformity, radiolunate angle greater than 15 degrees (DISI), and scaphoid fractures associated with perilunate dislocation.
- Nonvascularized bone grafts can be utilized for simple fractures, whereas vascularized bone grafts are indicated for comminuted and more proximal fractures.
- Four-corner fusion is reserved for younger, higher demand patients with debilitating wrist injuries.
- Care must be taken not to disrupt the radioscaphocapitate or long radiolunate volar ligaments when performing four-corner fusion.
- DISI deformity should be corrected when performing a midcarpal fusion.
- Meticulous attention must be paid to anatomic alignment and hardware placement.

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Part XXII

Problems with Scapholunate Instability

74 Failed Scapholunate Ligament Repair: Acute *342*

75 Failed Reconstruction with Tenodesis: Chronic *346*

XXII

74 Failed Scapholunate Ligament Repair: Acute

Dirck Añaños Flores, Alex Lluch Bergadà, and Marc Garcia-Elias

74.1 Patient History Leading to the Specific Problem

On August 1989, a 19-year-old male patient fell from a horse (high-energy incident) with minimal pain initially. He did not seek medical attention and therefore no X-rays were taken. Four months later, he presented to us complaining of minimal loss of motion, but intense pain and severe loss of strength, particularly when the wrist had what he described as "something that was suddenly out of its correct position."

X-rays at that time, December 1989, demonstrated carpal misalignment with an increased scapholunate (SL) gap (Terry Thomas sign) and flexion of the scaphoid with a "ring sign" present. These signs were said to disappear under slight traction of the wrist; hence, the case was interpreted as a dynamic SL ligament injury.

The patient was taken to the operating theater and a closed reduction was performed obtaining what was thought to be a good anatomical reduction. A single 1.2-mm K-wire was used to hold the scaphoid and lunate in position. This fixation was deemed adequate at the time of surgery.

Follow-up X-rays at 6 days demonstrated an ongoing adequate reduction (▶Fig. 74.1). The arrow points at the expected area of contact between the remnants of the SL ligament. The SL gap is minimal and there is no pathological flexion of the scaphoid.

K-wires were removed at the 3-month mark. Unfortunately, a follow-up X-ray at 4 months was rather disappointing as it demonstrated recurrence of the misalignment.

74.2 Anatomic Description of the Patient's Current Status

When last seen, on February 1994, the patient was troubled by established SL dissociation. Clinical symptoms included pain, weakness, and inability to weight bear, making this an unstable wrist.

X-rays (see ▶Fig. 74.1) demonstrated a disruption of the linkage system between the scaphoid and the lunate, which means that the lunate no longer followed the scaphoid when it went into flexion. Given that the lunotriquetral (LTq) ligaments were competent, the lunate had a tendency to follow the triquetrum into extension instead (▶Fig. 74.2), the so-called dorsal intercalated segment instability (DISI) deformity.

With disruption of this linkage system, the carpal bones no longer followed their usual anatomical displacements when submitted to an axial force, and a painful dysfunction ensued.

It became evident that to establish the correct subsequent treatment we should have been aware of the difference between misalignment (improper positioning of the carpal bones in the three-dimensional space) and instability (the inability to resist a physiological load without yielding). Unfortunately, he could not be followed up any longer; the final long-term outcome remains unknown. Yet, the evolution of many such cases towards the so-called SL advanced collapse is so well described in the literature that we have little doubt that this was probably the fate of that wrist. This, however, does not mean that the wrist had to be necessarily painful or greatly dysfunctional.

74.3 Recommended Solution to the Problem

When the SL ligament is not repairable, the surgeon needs to choose between reconstructing the ligament (ligamentoplasties)

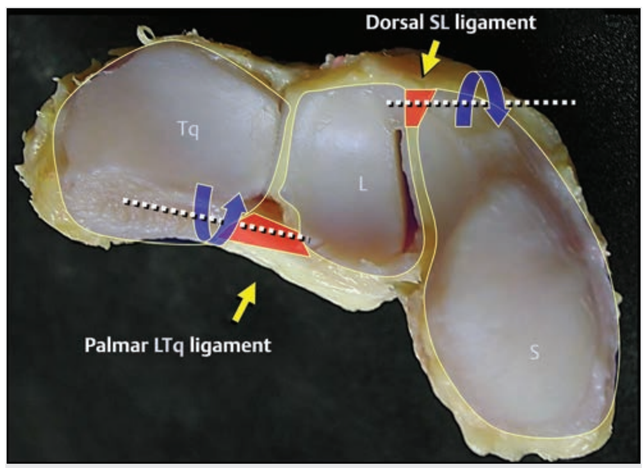

Fig. 74.2 Axial view of the proximal carpal row and main ligaments of the linkage system.

Fig. 74.1 **(a)** Closed reduction. **(b)** Six days post-fixation. **(c)** Four months post-fixation.

and performing a salvage procedure (proximal row carpectomy vs. partial wrist fusion, depending on the status of the capitate head cartilage).

In order to make this important decision, the surgeon should assess the following:

- The reducibility of the carpal malalignment.
- The stability of the lunate relative to the radius.
- The status of the scaphoid, capitate, and distal radius cartilages (▶Table 74.1).

Reducibility can be determined via a dynamic assessment with image intensifier. Lunate instability can be evaluated forcing the bone in an ulnoradial direction, and finally the status of the surrounding cartilages is to be documented with an arthro-CT scan, MRI, or ideally by arthroscopy prior to committing to a definitive procedure in the operating theater.

If the joint surfaces are intact and the carpus is easily reducible, the surgeon should proceed with an SL ligament reconstruction (extensor carpi radialis longus [ECRL] tenodesis).

The procedure was developed following on the concept of helical antipronation ligaments (HAPL). This group of ligaments—namely, the radioscaphocapitate (RSC), the volar radiolunotriquetral, the dorsal intercarpal, and the palmar scaphocapitate (SC) ligamentous complexes—are set forming a helical system of passive restraints against the tendency of the distal row of rotating into pronation when the wrist is axially loaded. Indeed, the HAPL prevents excessive pronation of the distal carpal row. When the SL ligament and HAPL secondary stabilizers are injured, the scaphoid flexes and pronates out of its fossa. The ECRL tenodesis realigns the scaphoid back to its anatomical position by restoring this group of ligaments instead of solely addressing the dorsal SL ligament.

74.4 Technique

Two versions of the procedure exist: three-ligament tenodesis ECRL (3LT–ECRL) and ECRL spiral tenodesis. The first is indicated only if the lunate is stable enough as to resist all forces coming from the distal row under physiologic loads. If the lunate were found to be either excessively lax or fully unstable, the second procedure would be indicated.

The wrist is approached via a dorsal incision. Sensory branches of the ulnar and radial nerves are protected. The third extensor compartment is opened and extensor retinacular flaps are raised from the second to the fifth compartment. If the posterior interosseous nerve is identified with normal features, a nerve sparing proximally based capsulotomy is performed and the diagnosis of SL instability confirmed (▶Fig. 74.3).

It is essential to determine if the scaphoid and lunate are easily reducible. Any tenodesis will fail if they are not. Traction to the index and middle fingers should reduce the proximal carpal row without excessive force. In addition, the wrist should be visually explored. The presence of damaged cartilage is also a contraindication to perform a tenodesis.

A 2-cm transverse incision is made on the dorsoradial surface of the forearm, just proximal to the oblique contour of the abductor pollicis longus (APL) muscle belly and a distally based strip of ECRL tendon (3-mm diameter) is harvested. The ECRL tendon has a better control over the tendency of the scaphoid to flex and pronate than a volar wrist tendon (flexor carpi radialis [FCR]). This is because of its anatomical location and vector of pull.

A blunt mosquito is used to tent the volar wrist skin from dorsal to volar. A small skin incision is made onto the tented skin and a tendon passer is used to transfer the ECRL graft from dorsal to volar. The harvested tendon is passed through the so-called inside passage, the triangular space formed by the inner aspect of the scaphotrapeziotrapezoidal ligament, the radial surface of the distal scaphoid, and the proximolateral corner of the trapezium.

A tunnel is made through the scaphoid with a K-wire and a 2.7-mm cannulated drill, connecting the distal/radial corner of the scaphoid tuberosity and a point on the dorsal/ulnar surface

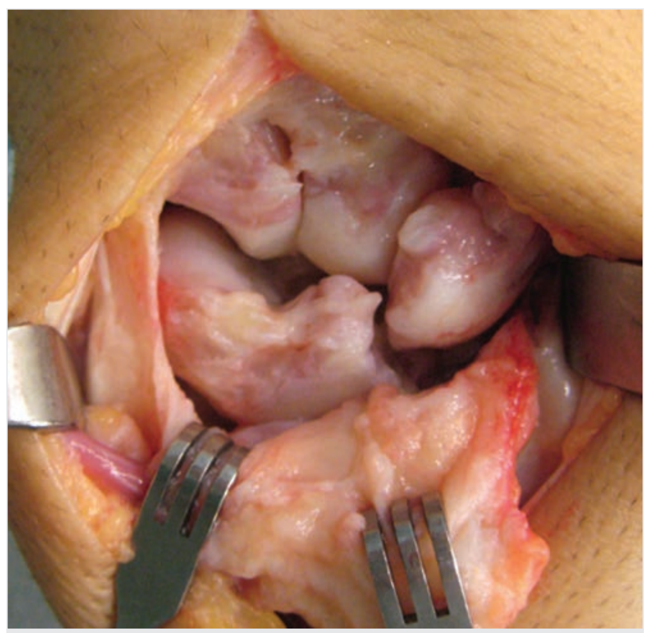

Fig. 74.3 Dorsal wrist approach. Note evident scapholunate dissociation

Table 74.1 Case presenting failed scapholunate (SL) ligament repair (acute)

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7
Is the dorsal SL ligament intact?	Yes	No	No	No	No	No	No
If repaired, has it good chances of healing?	Yes	Yes	No	No	No	No	No
Is the radioscaphoid angle normal?	Yes	Yes	Yes	No	No	No	No
Is the lunate uncovering index normal?	Yes	Yes	Yes	Yes	No	No	No
Is the misalignment easily reducible?	Yes	Yes	Yes	Yes	Yes	No	No
Are the joint cartilages normal?	Yes	Yes	Yes	Yes	Yes	Yes	No

Source: Garcia-Elias M. Classification of scapholunate injuries. In Shin AY, Day CS, eds. Advances in Scapholunate Ligament Treatment. Chicago, IL: American Society for Surgery of the Hand; 2014:52–62 of the scaphoid where the dorsal SL ligament had originally inserted. The ECRL tendon graft is then passed through this tunnel from volar to dorsal.

Pulling the tendon as it passes through the tunnel will reduce the scaphoid onto extension and supination (▶Fig. 74.4). An interference screw is used to secure the tendon onto the scaphoid. Alternatively, a 2 × 8 mm cortical graft taken from Lister's tubercle may be nailed in the empty space between the tendon and the tunnel. The goal is to normalize and secure adequate SC alignment. When properly done, transarticular K-wires should not be necessary.

The dorsal surface of the lunate is decorticated down to bleeding cancellous bone. An anchor is placed onto this surface and sutures are used to tie down the tendon graft onto the lunate to reconstruct the SL linkage. Should any local remnant of the original dorsal SL ligament stumps be viable, they need to be carefully preserved, for they may still recover their proprioception capability, its stability being reinforced by the ECRL tendon graft.

If there is no ulnar displacement of the lunate, the procedure ends by securing the end of the tendon onto the triquetrum with an interference screw. This procedure receives the name of 3LT–ECRL.

However, if the LTq unit is found far too mobile (congenitally hyperlax or posttraumatically unstable), the 3LT–ECRL method may not be sufficient to stabilize such multidirectional radiocarpal and SL instability. In such instances, the so-called ECRL antipronation spiral tenodesis, as described below, may be utilized.

Surgery now continues on the volar aspect of the wrist and the carpal tunnel opened through an extended approach. The pisotriquetral joint is identified via palpation and a K-wire is placed through the triquetrum while avoiding this joint. A tunnel is created around the wire with a 2.7-mm cannulated drill from palmar to dorsal. The tendon is passed through the triquetrum from dorsal to palmar. By pulling the graft palmarly through the volar incision, a dorsally placed interference screw will secure both the proximal row transverse stability and the normal LTq alignment.

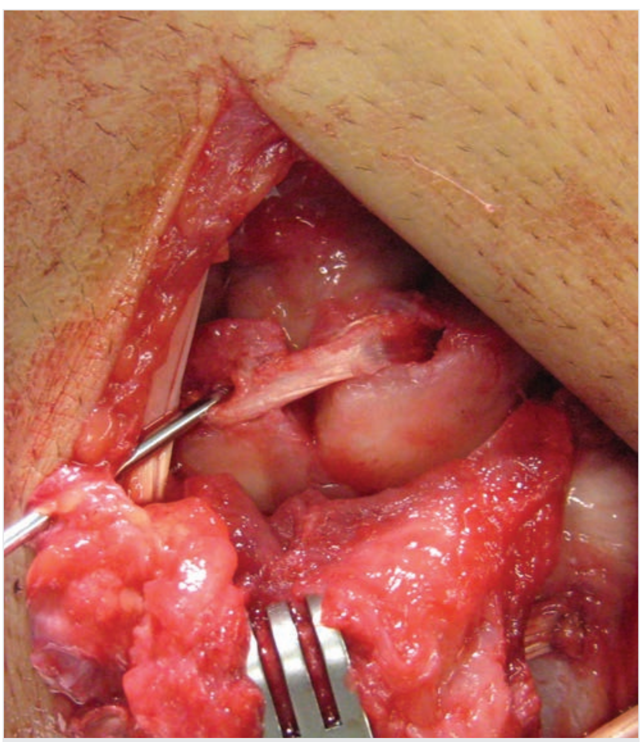

Fig. 74.4 Reduced scaphoid with traction on extensor carpi radialis longus.

Once in the front, the tendon graft is to be passed from ulnar to radial, toward the palmar insertion site of the radial styloid, the triangular palmar surface that usually gives insertion to both the RSC and the long RL extrinsic ligaments. This deep passage of the tendon graft along the floor of the carpal tunnel, deep to its soft-tissue contents (flexor tendons, median nerve, and radial artery), is an important step in this operation that should be done with exquisite care. To facilitate this, a small 20–mm-long, vertical incision, palmar to the first extensor compartment, is created, and the distal insertion of the pronator quadratus (PQ) muscle is exposed. Through gentle blunt dissection using a small (5-inch) curved mosquito hemostat, the two palmar incisions are communicated, using the distal edge of the PQ muscle as a reference. If the volar component of the SL joint remains unstable, the tendon can be secured onto the volar surface of the lunate and scaphoid with anchors to reconstruct the volar SL ligament. The tendon graft end is finally tightly secured onto the radial styloid either with a transosseous suture or via a suture anchor. Excess graft is trimmed and the wound is closed in layers.

The wrist is placed in a plaster cast for 2 weeks. Immobilization is continued with a removable orthosis until removal of K-wires at 8 to 10 weeks, if they had to be used, or 6 weeks if they were not needed. Physical therapy should emphasize on strengthening ECRL, APL, and FCR (scaphoid supinators) while minimizing extensor carpi ulnaris activation (scaphoid pronator).

74.5 Postoperative Photographs and Critical Evaluation of Results

As mentioned earlier, this patient was lost to follow-up. We can only speculate that his symptoms were not troublesome enough in the long run for him to seek further treatment.

His latest examination revealed a limited but functional range of motion and a relatively symmetrical grip and pinch strength, which reminds us to always treat a patient and their symptoms rather than their X-rays alone.

SL ligament reconstruction with an ECRL tendon is a relatively new technique with good initial results. ▶Fig. 74.5 illustrates the wrist range of motion at 4 months post-left ECRL tenodesis on a different patient with similar pathology who underwent the procedure. Any patient booked for a ligamentoplasty needs to be made aware of their diminished chances of recovering a full range of motion. The aim of the operation is instead to restore pain-free movement and to prevent osteoarticular degeneration of the wrist.

Wrist surgery is a relatively new specialty and as such it is continually evolving. Far too many patients have undergone incorrect surgery for the incorrect diagnosis based on outdated concepts. It is extremely important for the surgeon to be familiar with the definitions of instability and misalignment and to fully understand their differences:

Fig. 74.5 (a, b) Postoperative range of motion.

- Instability refers to the inability of the wrist to resist normal loads without yielding. If a force induces a carpus to collapse, that wrist is by definition unstable, despite being well aligned.
- Misalignment refers to an improper position of the wrist elements in the three-dimensional space. A misaligned wrist may become evident on imaging by the presence of a wide SL gap or by an increased SL angle. However, it is important to understand that "instability" and "misalignment" are not synonyms. Instability is a dynamic concept that cannot be measured in static terms (millimeters of a gap or degrees of an SL angle). Only carpal misalignment may be quantified this way. Therefore, a wrist with an SL injury may be both misaligned and unstable, either or neither.

74.6 Teaching Points

- A stepwise approach is the key to achieve the diagnosis and hence the correct treatment. ▶Table 74.1 illustrates the clinical findings that need to be assessed to determine the correct procedure for the patient:
  – Stages 1 and 2: attempt primary repair.
  – Stages 3 to 5: suitable for ligamentoplasties.
  – Stages 6 and 7: not suitable for ligamentoplasties anymore and a salvage procedure is indicated.
- Having said that, it is extremely important (however obvious it may sound) that the surgeon does not fall into the trap of treating an X-ray rather than the symptomatic patient.
- Each case needs to be assessed individually and treated accordingly. Pain, weakness, and giving way need to be addressed. A wide SL gap without any of these may be better off left alone.

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75 Failed Reconstruction with Tenodesis: Chronic

Dirck Añaños Flores, Alex Lluch Bergadà, and Marc Garcia-Elias

75.1 Patient History Leading to the Specific Problem

A 36-year-old man presented to us complaining of pain and weakness in his left wrist. The patient had a fall on his outstretched hand 6 months prior to the consultation. He is a right-handed taxi driver with no other history of previous trauma. At the time of clinical examination, the patient had pain on the radial side of the wrist. Active range of motion (ROM) was almost symmetric to the contralateral side. Palpation was especially painful at the level of the scapholunate (SL) interval and scaphoid tubercle. Scaphoid shift test (Watson's maneuver) and other specific test for SL instability were negative.

Radiological examination showed a flexed and pronated scaphoid and an increased SL joint space in the anteroposterior view, as well as an increased SL angle in the lateral view. No degenerative changes were seen. CT and Magnetic Resonance Imaging (MRI) confirmed these findings. Stress dynamic fluoroscopic examination showed a wider SL interval compared to the opposite side, especially in supination and ulnar inclination against resistance (▶Fig. 75.1).

Arthroscopic examination confirmed a complete rupture of SL primary stabilizers and insufficiency of secondary, with an easily reducible malalignment and with no cartilage wear, so a ligament reconstruction following the principles of the "three-ligament tenodesis (3LT) technique" was performed. A slip obtained from flexor carpi radialis (FCR) tendon is passed obliquely through the scaphoid from palmar to dorsal, emerging at the point of insertion of the dorsal SL ligament. The slip is then fitted in a trough created in the dorsum of the lunate, passed through a split made in the dorsal radiotriquetral ligament, and looped around. The scaphoid, lunate, and capitate are reduced and stabilized with two 1.5-mm Kirschner's wires (K-wires) prior to tensioning and suturing the tendon graft onto itself. One wire is placed across the SL joint and one across the scaphocapitate joint (▶Fig. 75.2). Routine postoperative protocol, with immobilization for 6 weeks with a cast and K-wire removal 8 weeks after surgery, was followed.

75.2 Anatomic Description of the Patient's Current Status

Eight months after surgery, the patient still had a painful wrist, with limited active ROM (80-degree extension/25-degree flexion) and weakness (10-kg grip strength in the operated side vs. 35-kg contralateral). Although intra- and postoperative carpal alignment was satisfactory, after removal of the K-wires, a progressive flexion deformity of the proximal row developed (▶Fig. 75.3). Functional views and dynamic fluoroscopic

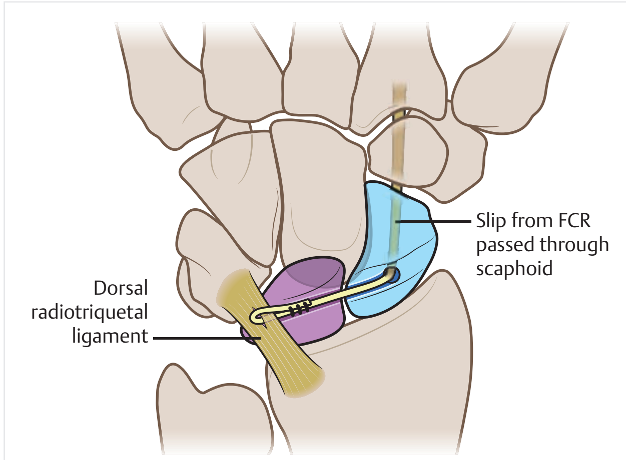

Fig. 75.2 The "three-ligament tenodesis reconstruction" used for chronic scapholunate instability without ulnar translocation of the lunate.

Fig. 75.1 (a, b) Wrist anteroposterior view showing increased scapholunate joint space, and scaphoid flexion and pronation. Increased scapholunate angle and dorsal displacement of the proximal scaphoid in the lateral view. These findings support the diagnosis of a static scapholunate dysfunction.

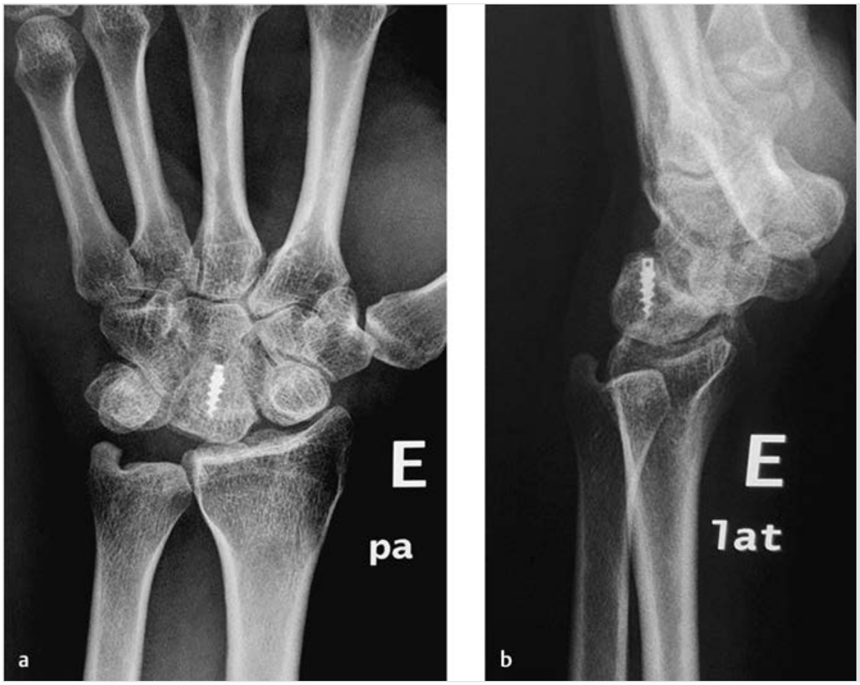

Fig. 75.3 (a, b) Symptomatic flexion malalignment of the proximal row 6 months after the "three-ligament tenodesis" procedure.

evaluation showed that it was a fixed malalignment. No images of arthrosis were seen in X-rays, CT scan, or MRI.

Several reasons may explain a flexion deformity of the lunate. Unrecognized lunotriquetral instability (e.g., as part of a perilunate instability) in which the surgical solution is focused just to solve an SL problem may end with a static palmar intercalated segmental instability deformity. Alternatively, flexion of the whole proximal row is associated with a dysfunction of the radiocarpal extrinsic ligaments, especially the dorsal radiocarpal ligament, as it happens in palmar midcarpal instabilities or in some operated distal radius fractures even with proper fracture reduction.

75.3 Recommended Solution to the Problem

Given that soft-tissue procedures are prone to fail when applied to a fixed carpal deformity, in those cases where some joint surfaces are still preserved and some degree of motion is desired, the treatment of choice is a partial carpal fusion.

75.4 Technique

Due to the abundant dorsal scar tissue and the fixed deformity, exploration of joint surface status was performed through an open dorsal approach. If possible, arthroscopic evaluation is preferred. The extensor retinaculum was divided again along the third compartment. This allows easy repositioning of extensor pollicis longus in its compartment after any intracapsular procedure is performed. The retinacular septa between the second and fourth compartments are sectioned and the two retinacular flaps so created are retracted. Dorsal fiber-splitting capsulotomy, as described by Berger and Bishop, was performed for the second time, with a wider extension toward the ulnar side in order to expose the triquetrum and triquetrohamate joint.

When exposed, the radiolunate joint was seen to be preserved, whereas chondral lesions were seen in the dorsum of both radioscaphoid and lunocapitate joints. Therefore, scaphoidectomy and midcarpal arthrodesis was performed.

To make scaphoidectomy easier, a small palmar approach can be done to release the scapho-trapezio-trapezoid and scaphocapitate ligaments, and the entry point of the FCR slip in the scaphoid. Reduction of lunate and triquetrum flexion deformity (volar intercalated segment instability) is the next step, in order to achieve a proper postoperative ROM (▶Fig. 75.4). Care has to be taken not to overcorrect the lunocapitate fusion, as too much ulnar translation of the distal row may create radial inclination of the wrist (▶Fig. 75.5). Finally, a midcarpal arthrodesis using three anterograde cannulated screws was performed. As in this case the lunocapitate joint was wide enough, two screws were placed between the lunate and the capitate, and one between the triquetrum and the hamate.

75.5 Postoperative Photographs and Critical Evaluation of Results

Ten years after the partial fusion, the patient is pain free, with mild discomfort when doing heavy work with the operated hand, and still working as a taxi driver. His active ROM is 50/50 degrees. Control X-rays at 10 years show no degenerative changes (▶Fig. 75.6).

75.6 Teaching Points

- The treatment of SL dissociations is stage dependent.
- A normally aligned wrist can be unstable.

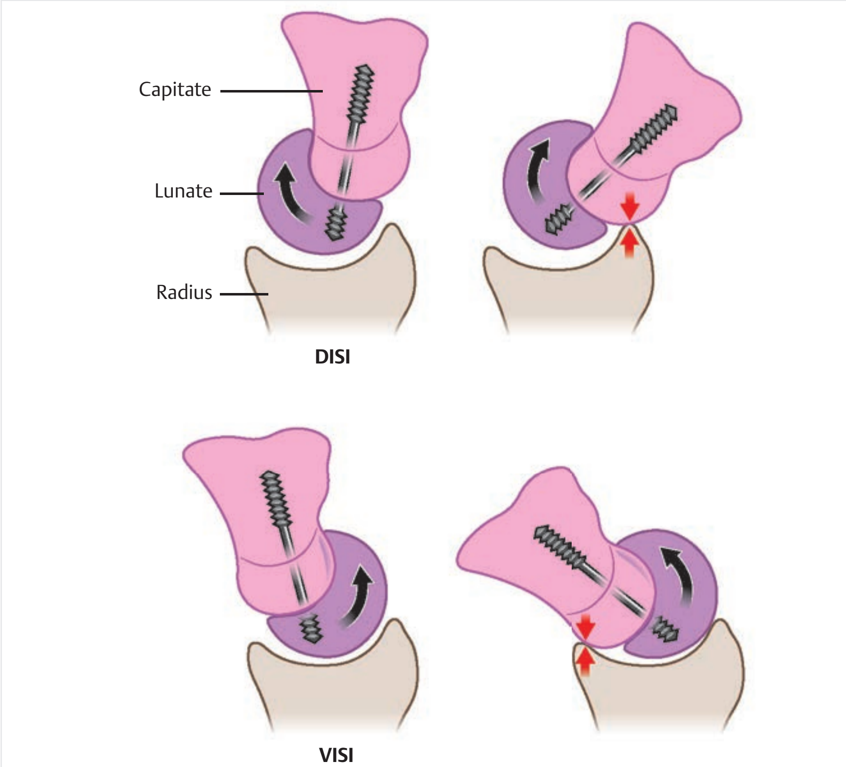

Fig. 75.4 Correction of lunotriquetral malalignment is mandatory in order to get a proper range of motion when doing a "four-corner fusion." Undercorrection of lunate extension would limit wrist extension, whereas keeping lunate in flexion (as in this case) would limit wrist flexion.

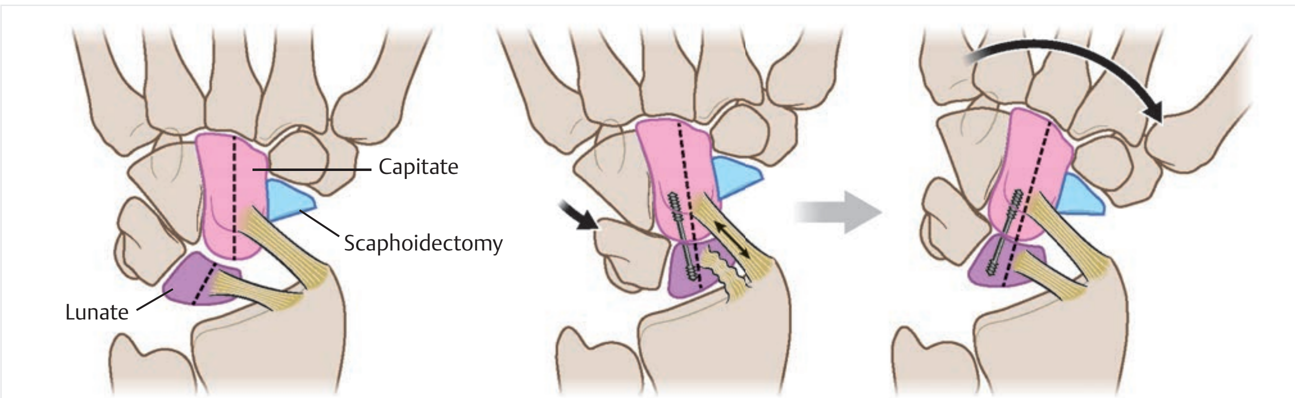

Fig. 75.5 Overcorrection of the lunocapitate joint creates triquetrohamate incongruency and, due to the secondary different tension of the radiocarpal ligaments, induces wrist radial inclination during rest.

- A malaligned wrist is not always unstable.
- When the carpal misalignment, due to deterioration of the secondary stabilizers, is easily reduced, tendon reconstruction may help in controlling the underlying SL instability.
- Normally aligned but unstable SL wrists (previously known as dynamic instabilities) are the best indication for tendon reconstruction.
- There is no standard measurement method in order to consider an SL instability to be easily reducible.
- A stiff malaligned wrist (static instability) treated with tendon reconstruction may lead to a disappointing end result. This situation is closer to a collapsed but stable wrist rather than an unstable wrist.
- Heavy manual workers and noticeably hyperlax individuals are not good candidates for tendon reconstruction procedures.
- Wrist stiffness and loss of reduction, which sometimes can remain asymptomatic or is well tolerated by the patient, are the most common problems after failure of a tendon reconstruction for SL instability.
- Fractures or vascular complications have also been described when passing tendons through holes drilled in proximal carpal bones.
- Partial fusion and proximal row carpectomy are more reliable for failures than a new ligament reconstruction. Preserved cartilage and proper position of the fused bones are mandatory in order to have good results.

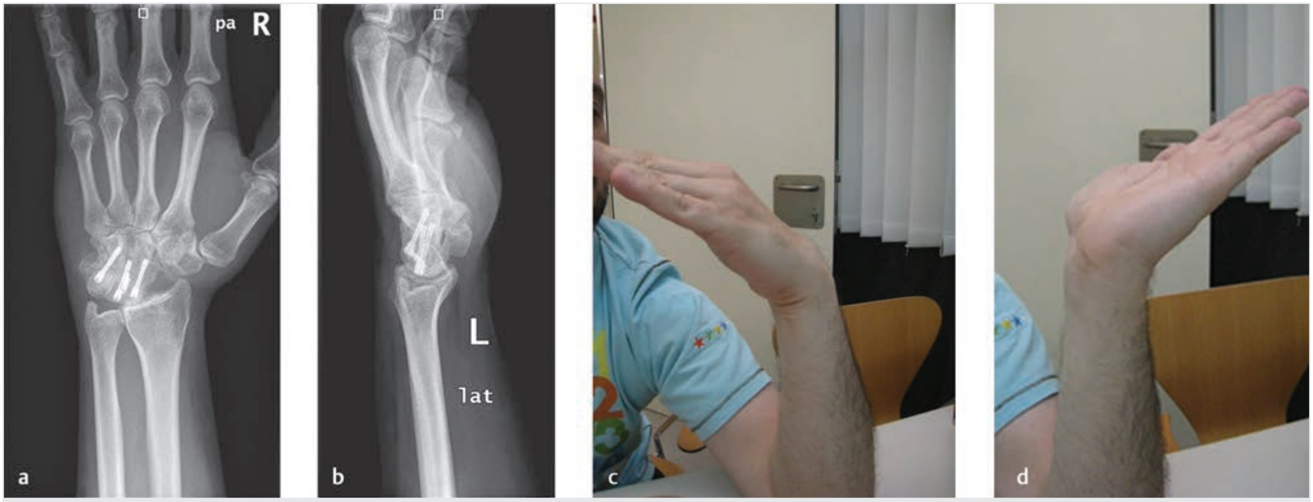

Fig. 75.6 (a–d) Radiologic and clinical results 10 years after scaphoidectomy and four-corner fusion in case 1.

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Part XXIII

Problems with the Lunotriquetral Joint

76 Problems with the Lunotriquetral Joint after Ligament Repair *352*

77 Problems with Lunotriquetral Fusion *355*

XXIII

76 Problems with the Lunotriquetral Joint after Ligament Repair

William R. Aibinder and Alexander Y. Shin

76.1 Patient History Leading to the Specific Problem

A 30-year-old right-hand dominant man presented 2 weeks after punching a machine with the radial aspect of his arm and hand.

76.2 Anatomic Description of the Patient's Current Status

On examination, he was noted to have significant bruising, tenderness over the lunotriquetral (LT) interval, and a positive shear, shuck, and compression test. MRI demonstrated disruption of the dorsal capitohamate (CH) and the dorsal LT ligaments (▶Fig. 76.1a). Radiographs did not reveal a fixed volar intercalated segment instability (VISI) deformity (▶Fig. 76.1b). The patient was initially treated with 4 weeks of cast immobilization, which was not successful. Subsequently, he underwent a midcarpal diagnostic injection with local anesthetic and steroid, which provided good pain relief.

76.3 Recommended Solution to the Problem

The patient presented with acute traumatic axial midcarpal instability without evidence of fixed VISI deformity or carpal collapse. Initial treatment should include a period of conservative management with immobilization. If failed, operative procedures to reestablish the lunocapitate axis and stabilize the proximal carpal row should be attempted, if there is no evidence of carpal collapse or fixed deformity. Wrist arthroscopy should be performed to inspect the LT stability, as well as the stability of all other intercarpal joints. The LT joint can be stabilized with a reconstruction or a direct repair. The senior author's preferred technique is a reconstruction using a strip of the extensor carpi ulnar (ECU) tendon when both the volar and the dorsal ligaments are disrupted.

76.3.1 Recommended Solution to the Problem

- Wrist arthroscopy should be performed to thoroughly assess the stability of all intercarpal joints and articular surfaces.
- The LT joint can be stabilized with a reconstruction (if both volar and dorsal ligaments are incompetent) or a direct dorsal repair (if volar ligament is competent, and the tissue quality of the dorsal ligament is adequate).
- Reconstruction with a strip of the ECU tendon provides uniformly good outcomes.

76.4 Technique

The patient was taken to the operating room for a diagnostic wrist arthroscopy, CH fusion with iliac crest bone autograft, and an LT reconstruction. The patient was placed in the supine position with an arm board. General endotracheal anesthesia was administered and the operative extremity was prepped and draped in the usual sterile fashion. A tourniquet was applied and a standard wrist arthroscopy was performed using the 3–4, 4–5, radial midcarpal, ulnar midcarpal, and 6U portals. The scapholunate (SL), LT, and midcarpal joints are inspected. Geissler stage II instability was noted in the SL interval, stage III in the LT interval, and stage IV in the CH interval.

A mid-axial longitudinal dorsal wrist incision was made and an ulnarly based extensor retinacular flap was created. A posterior interosseous nerve neurectomy is performed. A radially based dorsal capsular flap is then created, with care to avoid damage to the underlying carpal cartilage. The intercarpal joints are then inspected under direct visualization to confirm disruption of the dorsal ligaments. Attention was first directed to the CH interval and the articular surfaces of the capitate and the hamate were prepared with a small burr. Iliac crest autograft was inset and the interval was fixed with two staples.

Attention is then directed toward the LT interval. The joint should be inspected for any remnants of the dorsal ligaments. The ECU tendon is identified in the forearm and a no. 15 blade scalpel is used to make a transverse incision over the proximal

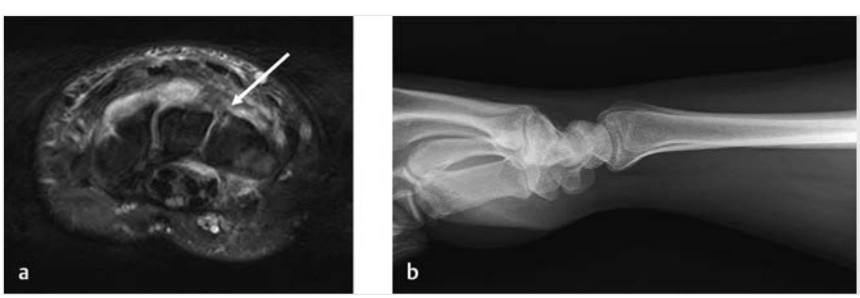

Fig. 76.1 **(a)** MRI showing disruption of the dorsal capitohamate (*arrow*) and the dorsal LT ligaments. **(b)** X-rays did not show a fixed volar intercalated segment instability.

aspect of the tendon. One-third of the ECU tendon is isolated and brought into the wound distally (▶Fig. 76.2a). Bone tunnels are drilled in the lunate and the triquetrum. The lunate tunnel is drilled in a radial dorsal to volar ulnar direction, while the triquetral tunnel is drilled in an ulnar dorsal to radial volar direction. A 28-G wire is then sutured into the free end of the ECU tendon. It is then passed through the drill holes in the triquetrum and then the lunate (▶Fig. 76.2b). The tendon is then folded back on itself, passed underneath its distal insertion, and pulled tight to reduce the LT interval (▶Fig. 76.2c).

Two 0.045-inch K-wires are placed across the LT interval to secure the joint (▶Fig. 76.3). Once stabilized, multiple figure-of-eight 2–0 nonabsorbable sutures are used to fasten the reconstruction. When remnants of the native ligament are present, anchors may be placed in the lunate and the triquetrum to sew down the ligament under the reconstruction prior to the suturing of the ligament reconstruction.

The wound is then thoroughly irrigated. The capsular and retinacular flaps are repaired with absorbable sutures with the extensor pollicis longus tendon dorsally transposed, and the wound is closed in a standard layered fashion. The patient is placed in a postoperative splint.

76.4.1 Steps for the Procedure

1. A longitudinal dorsal incision is made with a standard radially based capsular flap.
2. Inspect the LT joint and assess for any remnants of the native ligament.
3. Identify the ECU tendon proximally and harvest a distally based graft one-third of the tendon width without disruption of the ECU sheath.
4. Prepare bone tunnels in the lunate and triquetrum.
5. Pass the graft using a 28-G wire.
6. Reduce the LT interval and stabilize the joint with two 0.045-inch K-wires.
7. Secure the ECU tendon back onto itself.
8. Close the wound in a standard layered fashion.

76.5 Postoperative Photographs and Critical Evaluation of Results

The pins are removed at 10 weeks and the patient is placed in a protective splint for an additional 4 weeks (▶Fig. 76.4). The

Fig. 76.2 **(a)** One-third of the extensor carpi ulnar (ECU) tendon is brought into the wound distally. **(b)** The ECU tendon is then passed through the drill holes in the triquetrum and the lunate. **(c)** The tendon is folded and passed under its distal insertion and pulled tight.

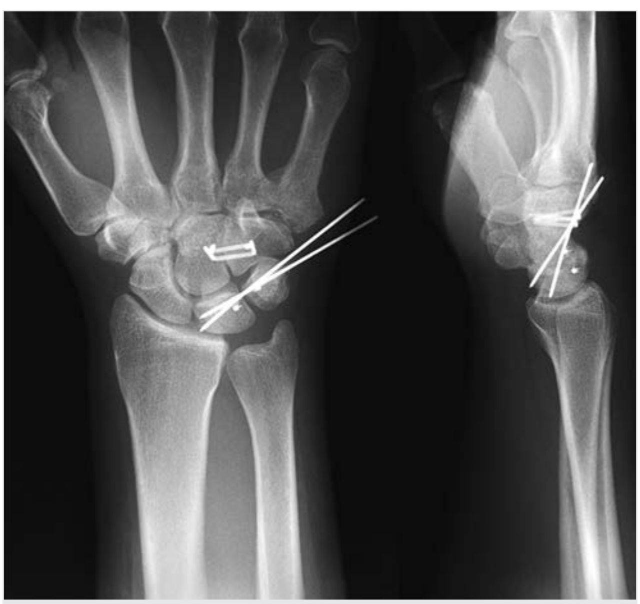

Fig. 76.3 K-wires are used to secure the joint.

Fig. 76.4 X-rays after pin removal, 10 weeks postoperative.

patient then begins therapy to work on range of motion and strengthening.

Ligament reconstruction and repair provide satisfactory results in patients with LT instability. Both procedures preserve motion between the lunate and the triquetrum, thus maintaining normal carpal kinematics. Reconstruction provides a more durable result in high-demand patients as a direct repair likely results in attenuation over time of an already weakened tissue, causing late failures and a higher rate of reoperation with repeat repair and subsequent arthrodesis.

It is not uncommon for patients to have pain initially, during the first 3 to 6 months of recovery. With appropriate patient expectations and a good hand therapist, LT reconstruction is likely to result in good outcomes with regard to pain relief, strength, and range of motion.

Many problems associated with LT ligament reconstruction or repair can be addressed with careful patient selection. Patients with midcarpal arthrosis, carpal collapse, or fixed VISI deformities are unlikely to benefit from a soft-tissue procedure and often require a salvage procedure such as a four-corner fusion. Isolated LT arthrodesis has been shown to have a high rate of nonunion and unsatisfactory outcomes given the resultant altered carpal kinematics. Finally, individuals with collagen disorders are likely to have late failures of their reconstruction or repair due to incompetent soft tissues.

76.6 Teaching Points

- Contraindications to repair or reconstruction for LT joint instability include any fixed VISI deformity, midcarpal joint arthrosis, and collagen disorders such as Ehlers–Danlos syndrome.
- Fixed or nonreducible deformities should be treated with a salvage procedure, such as a scaphoidectomy and a four-corner fusion.
- It is common for patients to have pain for 3 to 6 months following surgery, but most will improve. Preoperative counseling is crucial to guide patient expectation and outcomes.
- Ensure all significant components of carpal instability are addressed.

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77 Problems with Lunotriquetral Fusion

Rocco Barbieri

77.1 Patient History Leading to the Specific Problem

A 23-year-old man presents with persistent dorsal ulnar pain on his dominant right wrist following a surgical procedure to fuse the lunate and triquetral bones 1 year earlier. According to the patient, the procedure was performed to relieve pain that was the result of the joint between his two bones being abnormally formed from birth. The patient had been a collegiate basketball player and during the last 2 years of his career, he had developed persistent ulnar-sided wrist pain. Since the procedure, he has also had limited motion as well as severe hypersensitivity and diminished sensation along the dorsal ulnar border of the hand. He was referred to the office by an outside orthopaedist with a diagnosis of a failed lunotriquetral arthrodesis.

77.2 Anatomic Description of the Patient's Current Status

77.2.1 General Appearance

The patient has a well-healed longitudinal 4-cm incision on the dorsal aspect of the wrist in the axis of the ring digit. The wrist is moderately swollen and is exquisitely tender along the lunotriquetral joint. He has very minimal tenderness in the region of the ulnar fovea and has no tenderness along the distal radioulnar joint, the scapholunate interval, or the anatomic snuff-box. He has severe pain with lunotriquetral ballottement and compression tests. The patient also has hyperesthesia and diminished sensation to light touch along the dorsal ulnar border of the hand. He has Tinel's sign 1 cm lateral to the incision along the path of the dorsal sensory ulnar nerve. There are no tropic changes along the skin and the patient has full range of motion of the digits. His wrist range of motion is limited to 25 degrees of flexion and 30 degrees of extension with 5 degrees of radial deviation and 10 degrees of ulnar deviation. He exhibits pain at the end range of wrist motion. Pronation and supination are normal and nonpainful. He has pain with ulnar impaction maneuvers.

77.2.2 Radiographs

The patient presented with a disk that contains his prearthrodesis radiographic studies. These include plain films (▶Fig. 77.1a) that demonstrate an irregularity along the lunotriquetral joint. A three-phase bone scan confirms the presence of increased uptake in the lunotriquetral region of the wrist (▶Fig. 77.1b). An MRI of the wrist reveals the presence of a Minnaar type I lunotriquetral coalition (▶Fig. 77.1c). Review of the patient's operative report explains that the arthrodesis was done using artificial bone graft and K-wire fixation through a dorsal approach. X-rays from the first postoperative visit demonstrate two 1.1 mm guide wires transfixing the lunotriquetral joint (▶Fig. 77.2a). New X-rays taken at the time of this visit reveal the presence of a failed arthrodesis of the lunotriquetral joint (▶Fig. 77.2b).

77.3 Recommended Solution to the Problem

A complete review of the patient's complaints and presurgical studies confirms the fact that the patient underwent a lunotriquetral arthrodesis in order to treat a symptomatic partial carpal coalition. The indications and the decision to proceed with an isolated lunotriquetral fusion were correct. The primary problem is likely due to the surgical technique. K-wire stabilization across an intercarpal fusion provides no compression and little stability compared to compression screw fixation. In addition, the use of synthetic bone graft may have made the likelihood of failure higher than if autograft had been utilized. Finally, it seems that the surgical approach, including the placement of the K-wires, either damaged or scarred the

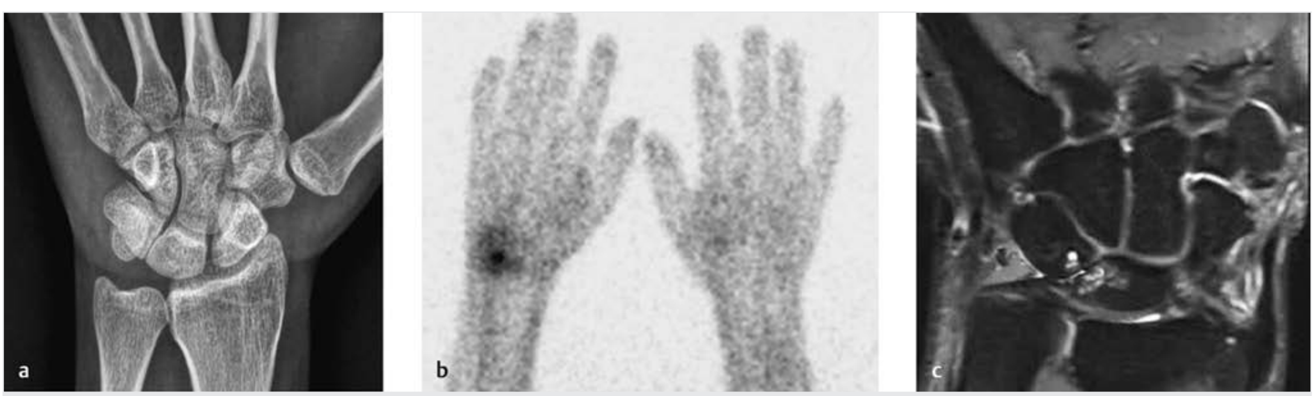

Fig. 77.1 (a) Radiographs of the wrist demonstrate an irregularity along the LT joint. **(b)** A three-phase bone scan confirms the presence of increased uptake in the LT region of the wrist. **(c)** An MRI of the wrist reveals the presence of a Minnaar type I LT coalition.

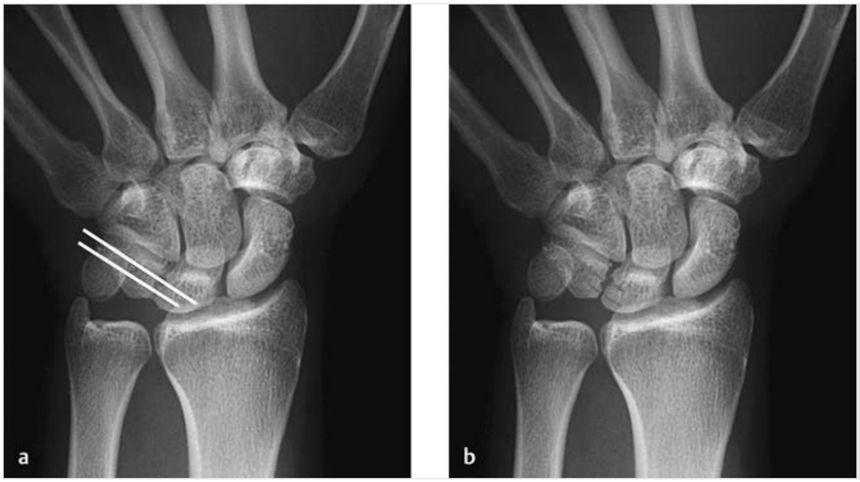

Fig. 77.2 **(a)** X-rays from the first postoperative visit demonstrate two 0.045-mm K-wires transfixing the LT joint. **(b)** New X-rays taken on today's visit reveal the presence of a failed arthrodesis of the LT joint.

dorsal sensory branch of the ulnar nerve. The nerve typically crosses dorsally to innervate the dorsal ulnar portion of the wrist emerging from the dorsomedial border of the flexor carpi ulnaris at a mean distance of 5 cm from the proximal edge of the pisiform. Great care should be taken not to injure the nerve when performing surgical approaches in this region. Revision of the failed lunotriquetral arthrodesis should address all of the shortcomings of the original procedure. A careful surgical approach with exploration of the dorsal sensory branch of the ulnar nerve should be carried out, followed by a dorsal approach to the lunotriquetral joint. Clearing out of the fibrous tissue on the nonunion site with exposure down to bleeding bone surfaces on the lunotriquetral joint needs to be accomplished. Cancellous bone graft should be harvested from the patient and placed in the arthrodesis site, followed by headless compression screw fixation from the triquetrum to the lunate. The wrist should be immobilized for 8 weeks, followed by splinting and protected range of motion for an additional 4 weeks.

77.3.1 Recommended Solution to the Problem

- The dorsal sensory branch of the ulnar nerve needs to be explored during the repeat surgical approach to the lunotriquetral joint.
- The nonunion site needs to be debrided down to healthy, bleeding cancellous bone.
- Cancellous autograft should be placed in the arthrodesis site.
- Compression screw fixation is used to stabilize the fusion.
- Immobilization for 8 weeks, followed by protected range of motion in a splint for an additional 4 weeks is recommended.

77.4 Technique

The patient is taken to the operating room and placed in the supine position with the arm abducted 90 degrees on a radiolucent arm board. General anesthetic supplemented by a regional block is optimal for postoperative pain control. A well-padded tourniquet is applied above the elbow and the limb is prepped and draped in the usual sterile manner. The limb is exsanguinated using an Esmarch tourniquet and the tourniquet is elevated to 250 mm Hg. The previously utilized dorsal incision is employed extending it proximally for 1 to 2 cm into an unscarred area. Radial and ulnar flaps are elevated and the proximal portion of the dorsal sensory ulnar nerve is identified proximally. Using meticulous dissection under loupe magnification, the dorsal sensory branch of the ulnar nerve is carefully released from the surrounding scar tissue and in this case it was found to be in continuity but trapped within the scar at the site of the previous K-wire insertion sites. After freeing up the nerve, the interval between the fourth and the fifth dorsal compartments is determined and the extensor tendons are lifted up away from the underlying dorsal capsule of the wrist. The extensor retinaculum does not need to be released for this maneuver. Next, a Weitlaner retractor is used to spread the extensor tendons away from the dorsal wrist capsule. The dorsal radiotriquetral and scaphotriquetral ligaments are identified and a capsulotomy is made as described by Berger and Bishop (▶Fig. 77.3). In this manner, the lunotriquetral joint is exposed and the radiocarpal and midcarpal joints are examined for the presence of any arthritic changes other than the lunotriquetral joint. C-arm fluoroscopy can be utilized to help localize landmarks during the dorsal approach.

At this point, two 1.5-mm K-wires are drilled in a dorsal-to-palmar direction in the lunate and triquetral bones in order to rotate and distract them. A combination of a curette and a rongeur is used to remove all fibrous tissues and denude any remaining cartilage down to bleeding subchondral bone on both sides of the lunotriquetral joint. Usually, the volar 15% of the joint is not removed in order to maintain the proper anatomic relationship between the lunate and the triquetrum.

Next, a guidewire for a headless screw is placed across the joint starting from the ulnar border of the triquetrum to the center portion of the lunate perpendicular to the lunotriquetral joint. Using the previously placed 1.5-mm wire, the lunate is rotated to a neutral position in its relationship to the distal radius when placing this wire. A second wire is passed to help control rotation when the headless screw is inserted.

At this time, the length of the screw is measure based on the guidewire depth and usually 4 mm is subtracted from this number to allow for appropriate countersinking of the headless screw. Before inserting the compression screw, cancellous bone graft is harvested to fill the lunotriquetral joint. Typically, olecranon bone graft from the ipsilateral arm is harvested by making

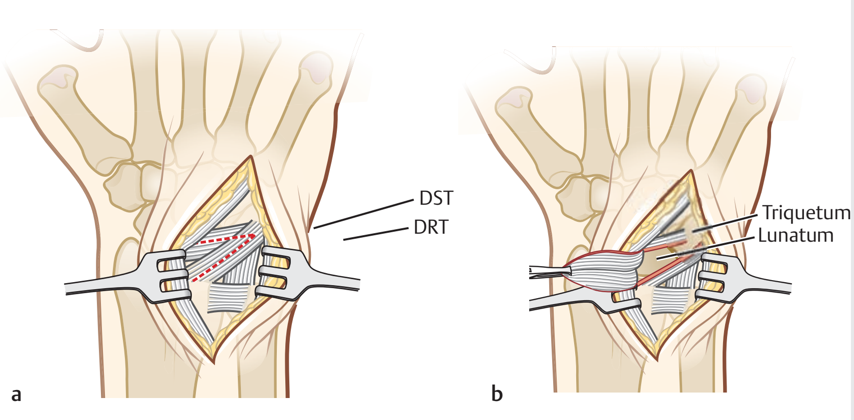

Fig. 77.3 (a, b) The dorsal radiotriquetral and scaphotriquetral ligaments are identified and a capsulotomy is made.

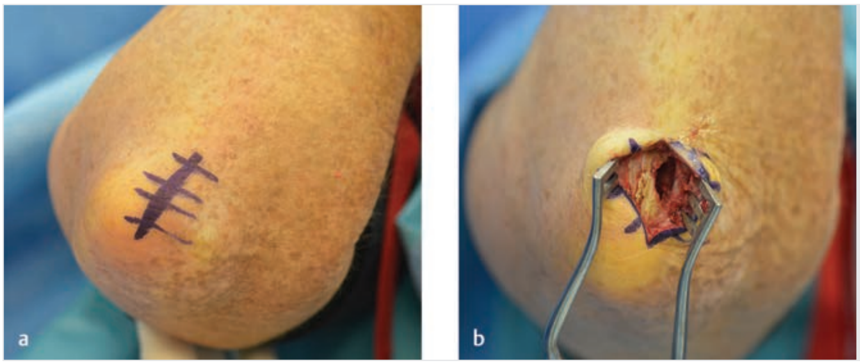

Fig. 77.4 (a, b) Olecranon bone graft from the ipsilateral arm is harvested by making a 2-cm incision along the radial crest of the olecranon and with electrocautery elevating the periosteum off the bone.

a 2-cm incision along the radial crest of the olecranon and with electrocautery elevating the periosteum off the bone (▶Fig. 77.4). Handheld techniques can be used to make a cortical window in the olecranon and harvest cancellous bone. It is more efficient to use the Acumed bone graft harvesting drill to accomplish this task (▶Fig. 77.5). Usually 2.5 to 3 cm of cancellous bone can be harvested from the olecranon. Alternatively, a similar quantity of cancellous bone can be obtained from the distal radius through either a volar or a dorsal approach.

The cancellous bone is then densely packed into a 10-mL syringe where it is compressed and removed with an 18-G spinal needle. A compressed pellet of graph typically is created for interposition (▶Fig. 77.6). The wrist is irrigated thoroughly with normal saline before the graft is inserted and then the graft is placed in the lunotriquetral joint and packed in using a freer elevator. Finally, the appropriately sized headless screw is inserted across the joint, thereby compressing the lunate, the bone graft, and the triquetrum together.

At this time, all wires are removed and final C-arm fluoroscopic views are taken to ensure adequate placement of the screw and good compression with grafting across the nonunion site (▶Fig. 77.7). The dorsal capsular incision is closed and the tourniquet is deflated, and meticulous hemostasis is obtained. Both skin incisions are closed and the patient is placed in a well-padded short arm splint. At 10 to 14 days, the sutures are removed, followed by placement in a waterproof short-arm cast to be worn until 8 weeks post-op. A removal splint can be worn for the next 4 weeks to allow for early protected wrist motion and no lifting greater than 2 lb.

77.4.1 Steps for the Procedure

1. A dorsal approach to the lunotriquetral joint between the fourth and the fifth extensor tendon compartments is utilized.
2. In this case, because of the paresthesias along the dorsal sensor ulnar nerve, the nerve is explored. Typically, one does not expose that nerve nor want to take the dissection ulnar to the fifth dorsal compartment in order to avoid injuring the nerve.
3. The dorsal wrist capsule is elevated as a radially based flap based on the fibers of the dorsal scaphotriquetral and radiotriquetral ligaments.
4. The radial and midcarpal joints are carefully examined for any arthritic changes seen outside of the lunotriquetral joint.
5. All fibrous tissue and bone across the joint is removed to healthy subchondral bone.
6. A guidewire for a headless screw is placed perpendicular to the joint from the triquetrum to the lunate.
7. Cancellous bone is packed in the arthrodesis site and the headless compression screw is inserted.
8. The wrist is protected for 3 months.

77.5 Postoperative Photographs and Critical Evaluation of Results

Lunotriquetral coalitions are the most common carpal coalition and when incomplete can lead to arthritic symptoms

Fig. 77.5 Acumed bone graft harvesting drill.

Fig. 77.6 Cancellous bone is packed into a 10-mL syringe where it is compressed and the removed with an 18-G spinal needle.

Fig. 77.7 Radiograph views are taken to ensure adequate placement of the screw and good compression with grafting across the nonunion site.

across the joint. Lunotriquetral arthrodesis is one of the more successful limited intercarpal fusions and patients often maintain a good range of motion postoperatively. In one series of lunotriquetral fusions, flexion–extension averaged 77 to 90% and radioulnar deviation 91 to 95% compared with the unaffected side. In contrast, fusions that cross the midcarpal joint typically limit range of motion by at least 50%.

A universal surgical tenet in all joint fusions is to utilize a surgical approach that is the least traumatic to normal anatomy and to debride the joint surfaces to be fused down to healthy bleeding subchondral bone. By employing these principles, injury to the dorsal sensory branch of the ulnar nerve might have been avoided. Such an injury has been shown to occur in 7% of lunotriquetral fusions. Additionally, most studies demonstrate higher rates of fusion when utilizing fixation methods, which provide greater initial stability. For lunotriquetral arthrodesis, it has been shown that using compression screw versus K-wires or staples leads to higher successful fusion (85 vs. 60%). However, regardless of which fixation method is chosen, one often needs to use bone graft to fill any gaps between the articular surfaces to be fused (▶Fig. 77.8).

77.6 Teaching Points

- Adhere to proper principles universal for all fusions.
- Follow a safe and minimally traumatic surgical approach. In lunotriquetral fusions, the safe zone is a dorsal approach between the fourth and the fifth extensor compartments. The dorsal capsule is elevated as a radially based flap in line with the dorsal ligaments.
- Remove all fibrous tissues or cortical bone down to bleeding subchondral bone.
- Bone graft is used to fill any gaps between the surfaces to be fused. Autograft is preferred to synthetic bone. Graft is usually harvested from the ipsilateral extremity (i.e., the radius or olecranon).
- Use stable fixation. In lunotriquetral fusions, compression screw fixation has high rates of success compared to K-wires or staples.
- Immobilize the joint for an adequate period of time to allow for healing. For lunotriquetral fusions, a cast is typically worn for 8 weeks, followed by protective splinting an additional 4 weeks.

Fig. 77.8 Healed lunotriquetral fusion in adequate position.

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Part XXIV

Problems after Partial Wrist Fusions

78 Complications of Partial Wrist Fusion *362*

79 Dislocated Lunar Facet Fragments and Radioscapholunate Arthrodesis *367*

XXIV

78 Complications of Partial Wrist Fusion

James Higgins, Kenneth R. Means, Jr., and Kenneth L. Fan

78.1 Patient History Leading to the Specific Problem

A 55-year-old salesman presented to the office with right-dominant wrist pain. He suffers from osteoarthritic pain in multiple additional joints, including his knees, left hip, and bilateral shoulders. He is morbidly obese and ambulates with the assistance of a cane in his right symptomatic hand.

78.2 Anatomic Description of the Patient's Current Status

His examination reveals dorsoradial wrist synovitis with motion limited to 40 degrees of flexion and 30 degrees of extension. Radiographs demonstrated stage II scapholunate advance collapse (SLAC) arthritis (▶Fig. 78.1).

After initial treatment with splinting and radiocarpal cortisone injections, the patient agreed to surgical intervention. Due to the diffuse arthritic changes on X-ray, the patient was consented for partial or total wrist fusion depending on the intraoperative findings of arthritis.

Intraoperative exploration revealed severe arthritic changes at the radioscaphoid and scaphocapitate articulations. Early cartilage changes were observed at the radiolunate joint. In an effort to preserve motion, a scaphoid and triquetrum excision and capitolunate (CL) fusion were performed.

Postoperative X-rays demonstrated healing of the capitolunate fusion, but incomplete correction of the extended posture of the lunate (▶Fig. 78.2). Rapid progressive arthritic changes were witnessed at the remaining radiolunate articulation. This became increasingly symptomatic as the patient depended on this wrist for cane-assisted ambulation. After failure of improvement, a total wrist arthrodesis was performed with success (▶Fig. 78.3).

78.3 Recommended Solution to the Problem

Operative exploration of the SLAC wrist requires surgical decision-making based on the quality of the various cartilage surfaces. The goal should be reliable pain relief while preserving motion if possible. Surgeons may select proximal row carpectomy (PRC) if the lunate fossa and capitate surfaces are well preserved. Alternatively, deficient proximal capitate cartilage in the setting of

Fig. 78.1 Anteroposterior radiograph of the wrist demonstrating stage II scapholunate advanced collapse arthritis. Note widening of scapholunate interval and joint space narrowing of radioscaphoid articulation.

Fig. 78.2 **(a)** Anteroposterior and **(b)** lateral postoperative X-ray of the wrist after operative excision of scaphoid and triquetrum and capitolunate fusion. Note that the extended posture of the lunate is not corrected on lateral radiograph. The lunate remains in extended posture relative to the capitate.

Fig. 78.3 Anteroposterior radiograph of total wrist arthrodesis after failed midcarpal arthrodesis.

well-preserved radiolunate articulation is an indication for midcarpal wrist arthrodesis.

In this patient, all of these joint surfaces were suboptimal, but the radiolunate articulation was deemed least diseased and midcarpal fusion was selected. This patient had significant risk factors for failure: morbid obesity and reliance on cane-assisted ambulation. After observing cartilage wear on the native radiolunate joint, an immediate total wrist arthrodesis would have been more likely to provide durable long-term pain relief appropriate for his functional requirements.

78.3.1 Background

Total wrist arthrodesis is a reliable method of producing pain relief in patients suffering from diffuse wrist arthritis. However, range of motion is sacrificed and can limit activities of daily living. Total wrist arthroplasty (TWA) has had less widespread success as arthroplasty has experienced in other joints due to the demands specific to the wrist and associated bone and soft-tissue anatomic constraints. Variable rates of aseptic loosening and 5-year survival have led to TWA being employed primarily in elderly and other low-demand patients.

Younger, active patients with arthritic wrists often pursue a durable pain-relief procedure with preservation of range of motion. Limited wrist arthrodesis eliminates painful motion at arthritic joints, while preserving motion at uninvolved articulations. SLAC wrist often demonstrates preservation of cartilage in the radiolunate joint, enabling motion to be preserved after scaphoid excision and midcarpal fusion. Thirty to 50% of sagittal motion occurs in the midcarpal joint, with the remainder through the radiocarpal joint. Compensatory increases in range of motion at the unfused joints have been demonstrated within 1 year postoperatively.

78.3.2 Scapholunate Advance Collapse

SLAC wrist is the most common observed arthritic wrist pattern, a sequence of degenerative change based on and caused by articular alignment problems between the scaphoid, lunate, and radius. However, to date, there is no scientific evidence that scapholunate (SL) injury visualized arthroscopically without static radiographic changes inevitably leads to SLAC wrist. Although cadaver models indicate progressive rotatory subluxation of the scaphoid leads to altered contact, implying a nidus for arthritis, limited evidence indicates that reconstruction or repair of acute SL tears delays or prevents arthritis.

SLAC pattern begins at the radial styloid and scaphoid junction (stage I), progressing to include the radioscaphoid articular surface (stage II). The radioscaphoid joint is more susceptible due to its elliptical shape. As the SL interval widens, the head of the capitate migrates proximally into the widened interval, resulting in midcarpal capitate–lunate joint arthritis (stage III), with the radiolunate joint spared. The radiolunate joint is generally spared due to its uniformly spherical nature allowing cartilage loading in all positions despite changes in lunate orientation.

Midcarpal Arthrodesis with Scaphoidectomy versus Proximal Row Carpectomy

Midcarpal arthrodesis (MA) and PRC offer motion-preserving alternatives to total wrist arthrodesis. PRC is a less demanding technique with a shorter immobilization time. Good preservation of cartilage on the proximal capitate (i.e., SLAC wrist stages I and II) is considered a prerequisite for PRC, although surgeons have also employed capitate resurfacing techniques in conjunction with PRC and reported reasonable outcomes.

Treatment of stage III SLAC/SNAC wrist with MA is feasible as it does not require a preserved capitate. The procedure is technically more demanding than PRC, necessitates longer immobilization, and requires achievement of radiographic/clinical union. Range of motion is felt to be particularly limited if care is not taken to reduce the lunate into neutral posture or slight flexion when performing the arthrodesis. If the lunate is arthrodesed in extension, the fusion mass may impinge on the dorsal lip of the radius, limit extension, and cause pain. Despite these requirements, advocates cite advantages of preservation of carpal height and radiolunate congruity. With appropriate surgical technique and bone graft placement, reported failure rates and conversion to total wrist arthrodesis can be 2 to 4% at 15-year follow-up.

In the short term, outcomes are generally equal; differences in degrees of range of motion or grip strength have questionable clinical relevance. Mulford et al, in a systematic review of 52 studies, found pain relief can be achieved in 85% of patients, grip strength reaches approximately 80% of the opposite side, and conversion to total wrist arthrodesis is seen in 5% for both procedures, although the flexion–extension arc may be slightly less in MA.

Other considerations should be made when selecting the right procedure. It has been suggested that MA may be more durable in the young active laborer. DiDonna et al studied a series of PRCs and found all failures occurred in patients younger than 35 years of age. In this subset of patients, MA has been advocated. PRC has been found to have a significant increase in developing subsequent osteoarthritis on systematic review. The proximal capitate has a smaller radius of curvature than the lunate and does not demonstrate ideal congruity in the lunate fossa of the radius. MA has the advantage of preserving the native spherical radiolunate articulation. However, many authors have found minimal clinical correlation with eventual radiocapitate degeneration after PRC.

78.3.3 Alternative Midcarpal Fusions

The goal of midcarpal fusion is creating a stable arthrodesis via the CL joint and enabling wrist articulation load bearing to be assumed by the radiolunate joint. Initial reports of CL arthrodesis with K-wire fixation were unsuccessful, with nonunion rates as high as 33 to 50%. In 1984, Watson described including the hamate and triquetrum to the CL fusion mass to improve bony fusion rates. This procedure is often referenced as a four-corner fusion (4CF).

Authors began revisiting techniques when compression screw technology improved fusion rates. Goubier and Teboul had a high fusion rate in their CL arthrodesis series (12 of 13) all with improved pain. Calandruccio et al, in their series of 14 patients, had 2 patients with nonunions and 1 with persistent pain. Most recently, Gaston et al compared 16 CL arthrodesis to 18 patients who received 4CF. They found the CL arthrodesis group had similar grip strength, range of motion, and pain outcome to the 4CF group. There was decreased need for bone graft (50 vs. 100%) and the lunate was easier to reduce following triquetral excision, particularly in a type II lunate where the CL joint is not collinear. Impressively, there were no nonunions with use of the compressive screws with CL arthrodesis compared to 11% in the 4CF. Two patients in each group required conversion to total wrist arthrodesis.

As an alternative, there has also been increased interest in 3CF (fusion of the capitate, lunate, and hamate and excision of the scaphoid and triquetrum) as a means to increase range of motion but mitigate incidence of nonunion seen in CL arthrodesis. Cadaver studies show subsequent excision of the triquetrum improved wrist range of motion when converting arthrodesis from 4CF to 3CF. A small case series has demonstrated success with 3CF in 12 patients, with 1 nonunion and 2 revisions.

Persistent/Recurrent Pain after Partial Arthrodesis and Conversion to Total Wrist Arthrodesis

When limited wrist arthrodesis patients have incomplete relief or worsening pain, total wrist arthrodesis is considered the next step in the surgical algorithm. Neubrech et al examined long-term results (14.7 years) of 594 4CF with K-wire and bone graft with a 6.7% conversion rate to total wrist arthrodesis primarily due to persistent pain and nonunion, and an 11.1% complication rate requiring revision surgery. Other authors report failure of 4CF due to persistent pain occurring in up to 30% of patients.

78.4 Technique

A dorsal longitudinal wrist incision is made to expose the extensor retinaculum. The dorsal retinaculum is opened in the third compartment, releasing the extensor pollicis longus. The fourth compartment is elevated ulnar-ward and the second compartment retracted radially. The dorsal capsule is reflected generously to expose the radiocarpal and midcarpal joints. The joints are inspected, primarily with the goal of assessing the quality of the cartilage surfaces of the proximal lunate and lunate fossa of the radius. If these surfaces are free of arthritic changes, a midcarpal fusion may be pursued.

The scaphoid and triquetrum are resected completely. The intact volar wrist ligaments will be visible after complete resection of the scaphoid and should be preserved.

A rongeur is used to remove the cartilage and dense subchondral bone of the opposing surfaces of the distal concave lunate and the proximal convex capitate. After meticulous preparation of these surfaces, they are coapted in a cup/cone relationship with great care taken to reduce the lunate into neutral posture or slight volar flexion. The longitudinal axis of the capitate and lunate should be collinear in both lateral and posteroanterior projections. With the wrist flexed, a guidewire is inserted antegrade through the proximal lunate cartilage surface into the capitate (▶Fig. 78.4). Care is taken not to violate the capitohamate or carpometacarpal joints. Cancellous bone autograft may be harvested from the triquetrum and inserted into the arthrodesis site prior to screw placement. Cannulated headless compression screws are inserted and generously buried beneath the cartilage surface (▶Fig. 78.5).

With the guidewires removed, the wrist may be brought into extension. Fluoroscopy confirms position, placement, and depth of hardware as well as the lunate position and coaptation of the fusion surface (▶Fig. 78.6).

78.5 Postoperative Photographs and Critical Evaluation of Results

In the first case presented, patient selection and operative technique led to overall failure in achieving pain relief. Postoperative radiographs demonstrated inadequate reduction of the midcarpal joint prior to fixation, with a persistent extended posture of the lunate relative to the capitate (see ▶Fig. 78.2b). In a separate patient, appropriate reduction of the lunate resulted in neutral posture of the lunate relative to the capitate (▶Fig. 78.7).

Fig. 78.4 Intraoperative fluoroscopic anteroposterior image of the wrist after scaphoid and triquetrum excision and instrumentation for capitolunate arthrodesis. Guidewire for cannulated screw is introduced antegrade from lunate to capitate. Various “joystick” Kirschner wires can be seen in the image holding lunate reduction.

78.6 Teaching Points

- SLAC wrist stage II can be treated with PRC or midcarpal fusion.
- MA may be performed with a variety of techniques, with CL fusion being the common goal of the described procedures.
- The most common symptom of clinical failure necessitating reoperation is persistent or recurrent pain.

Fig. 78.6 Intraoperative fluoroscopic lateral image of the wrist after scaphoid and triquetrum excision and instrumentation for capitolunate arthrodesis. Note the neutral position of the lunate.

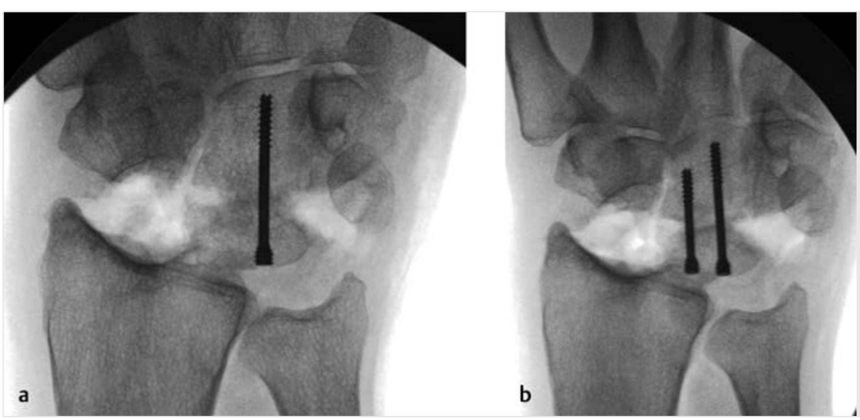

Fig. 78.5 Sequential intraoperative fluoroscopic anteroposterior images of the wrist after scaphoid and triquetrum excision and instrumentation for capitolunate arthrodesis. **(a)** First cannulated screw placement. **(b)** Successful placement of the second screw across the capitolunate arthrodesis.

Fig. 78.7 (a, b) Postoperative anteroposterior and lateral radiographs of an appropriately performed scaphoid and triquetral excision and midcarpal capitolunate arthrodesis. Note the neutral position of the lunate relative to the capitate on the lateral radiograph.

- Risk factors for clinical failure of midcarpal fusion include early arthritic change of the radiolunate cartilage surfaces at the time of midcarpal fusion, inadequate correction of lunate dorsiflexion when aligning the fusion, high-demand wrist, and young patient age.
- Conversion to a total wrist arthrodesis is the most common salvage operation of failed midcarpal fusion.

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79 Dislocated Lunar Facet Fragments and Radioscapholunate Arthrodesis

Christoph Pezzei

79.1 Patient History Leading to the Specific Problem

A 49-year-old man fell on his hand in November 2006. It resulted in a complex intra-articular distal radius fracture. The ulnar facet was displaced and the carpus was subluxated volarly (▶Fig. 79.1). Open reduction and internal fixation with a fixed-angle plate was performed on the next day. Focused on the small ulnar fragment, the plate was placed very distally and ulnar. The postoperative X-ray showed a good result (▶Fig. 79.2). A short arm cast was applied for 5 weeks. Although the plate was placed very carefully, the small ulnar fragment could not be addressed sufficiently. The X-ray 3 weeks after the operation showed a re-dislocation of the ulnar fragment and a palmar shift of the carpus (▶Fig. 79.3). The patient rejected the urgent recommended reoperation. This situation persisted for 6 months.

79.2 Anatomic Description of the Patient's Current Status

The fracture healed in malunion. As a result of the volar subluxation of the carpus and hardware irritation, the cartilage of the lunate was completely destroyed (▶Fig. 79.4). The patient had constant swelling at the left wrist; pain occurred only during heavy working. The range of motion (ROM) in extension/flexion was 30–0-40 degrees. The forearm rotation was not affected.

79.3 Recommended Solution to the Problem

Anatomical reconstruction of the radiocarpal articular surface is not possible; the cartilage is destroyed and shows progressive osteoarthritis.

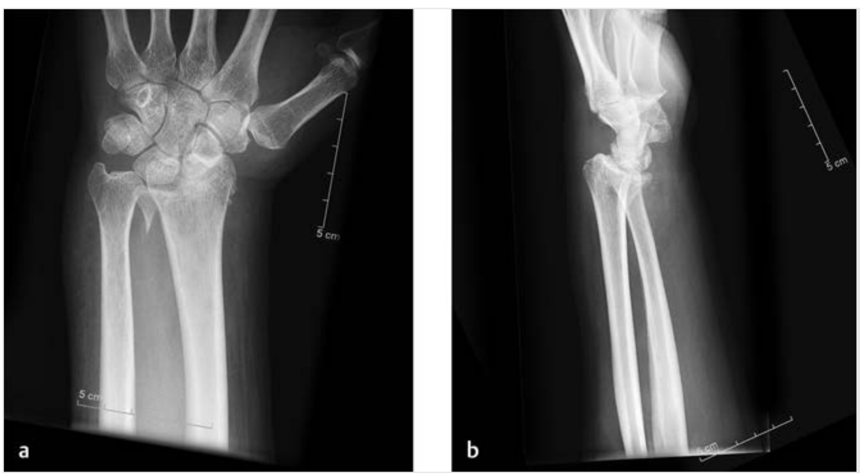

Fig. 79.1 (a, b) Complex intra-articular distal radius fracture. The ulnar facet was displaced and the carpus was subluxated volarly.

Fig. 79.2 (a, b) Open reduction and internal fixation with a fixed-angle plate was performed. The postoperative X-ray showed a good result.

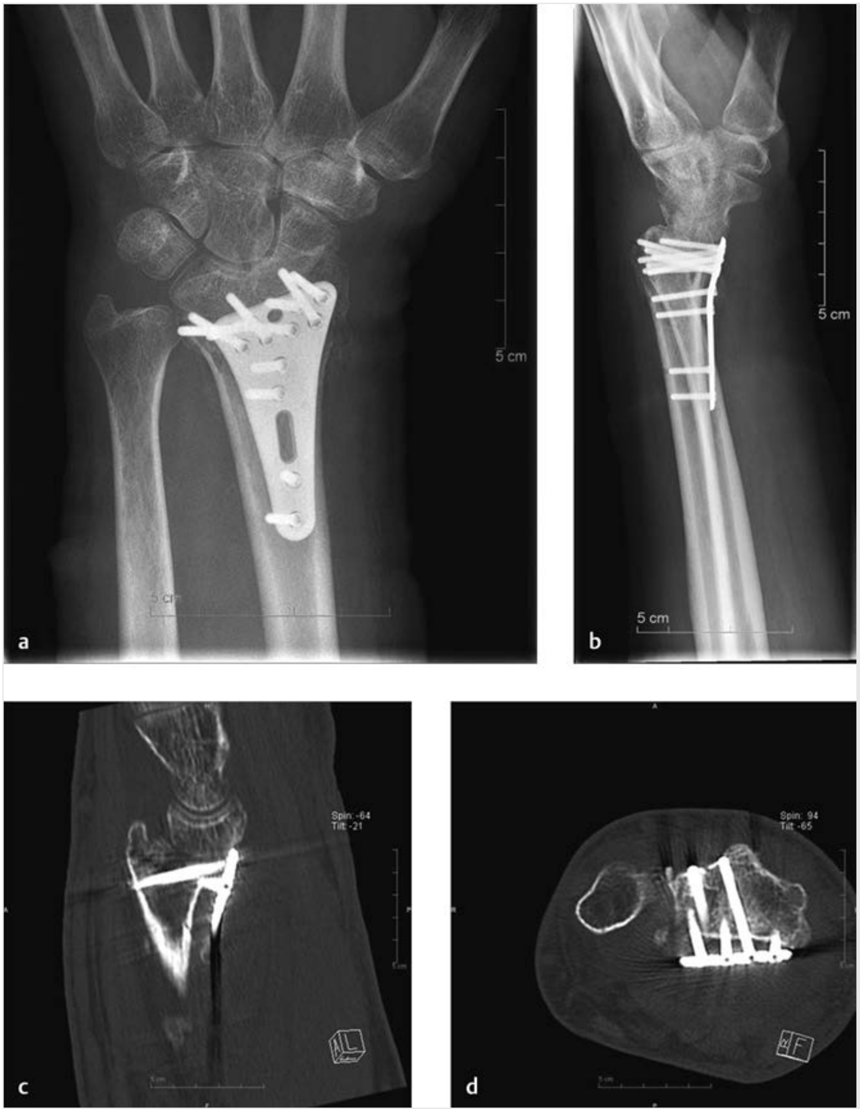

Fig. 79.3 (a–d) The radiographs taken 3 weeks after the operation showed a re-dislocation of the ulnar fragment and a palmar shift of the carpus.

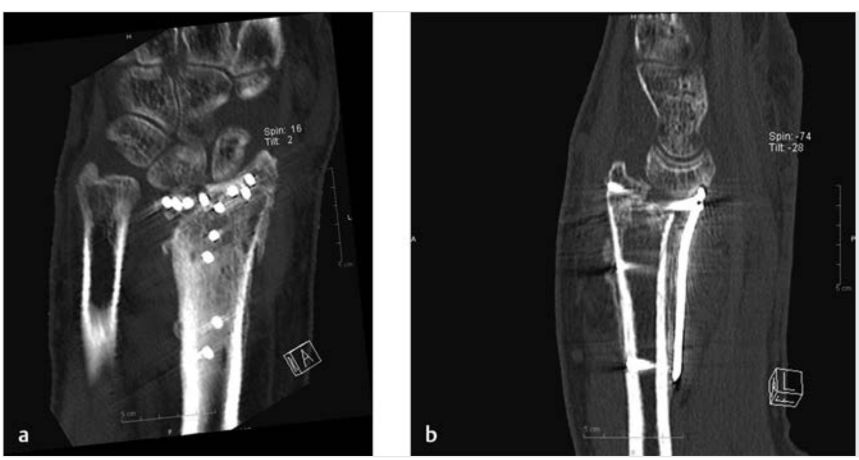

Fig. 79.4 (a, b) The fracture healed in malunion. As a result of volar subluxation of the carpus and hardware irritation, the cartilage of the lunate was completely destroyed.

Wrist denervation is a successful treatment of pain in the wrist with some useful remaining ROM, but contraindicated with obvious inflammation or edema.

Wrist arthroplasty could be one option in severe arthritis. The primary reasons for wrist replacement surgery are to relieve pain and to maintain function in the wrist without heavy demands in daily use.

Total wrist fusion is an option for treating such cases. High fusion rates are reported, and good pain relief can be achieved, but especially in young people the loss of wrist motion causes limitations in performing their daily activities.

As the midcarpal joint was unaffected, a radioscapholunate (RSL) fusion as salvage procedures was our preferred method. Typically, RSL arthrodesis is carried out from a dorsal approach.

The advantage of the volar approach is that previously placed hardware can be removed without an additional dorsal incision. Distal scaphoidectomy in RSL arthrodesis increases the ROM in flexion and radial deviation and decreases the level of pain.

79.3.1 Recommended Solution to the Problem

- Wrist denervation for pain management.
- Wrist arthroplasty in severe arthritis.
- Total wrist fusion for pain relief, but it has limitations.
- Our preferred method to increase ROM is RSL fusion.

79.4 Technique

The volar approach was used for hardware removal and RSL arthrodesis. The incision was extended distally to the radial side to expose the scaphoid sufficiently. Previous hardware was removed. The complete palmar rim of the radius was cut off using a chisel to ensure there was no tendon irritation from the incoming plate.

The distal quarter of the scaphoid is resected. This unlocks the midcarpal joint, decreases the rate of nonunion, and increases the postoperative ROM. The articular surfaces of the scaphoid, lunate, and distal radius were exposed under maximal extension. The cartilage surface was denuded until cancellous bone was exposed. During this procedure, particular care must be taken to avoid damage to the midcarpal joint. The scapholunate ligaments were intact and left untouched.

The extracted part of the scaphoid and palmar rim of the radius were used for the cancellous bone graft, and no additional bone harvesting was necessary. K-wires in the scaphoid and lunate are used as joysticks to control the position of the carpus. Then under image intensification, temporary fixation of the lunate and scaphoid to the radius was achieved with two 1.2-mm K-wires. It is very important to avoid any dorsal intercalated segment instability (DISI) or volar intercalated segment instability (VISI) position of the lunate.

For the final fixation, we use a straight polyaxial locking frame plate (▶Fig. 79.5). It is important that the plate is not placed too distally to avoid intra-articular placement of the screws. Two screws were placed in the lunate and scaphoid under image intensification. The variable angle locking system allows exact screw placement in the carpal bones. The K-wires are removed, and the cancellous bone graft is compacted (▶Fig. 79.6). The patient was put under postoperative immobilization using a short arm cast for 5 weeks.

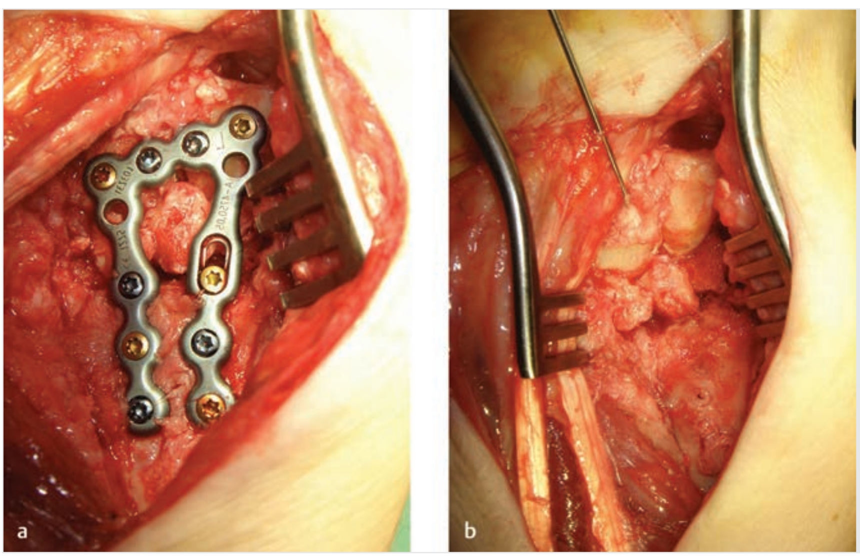

Fig. 79.5 (a, b) For the final corrective surgery fixation, we use a straight polyaxial locking frame plate.

Fig. 79.6 (a, b) Radiographs demonstrating that the cancellous bone graft is compacted within the fixation.

79.5 Postoperative Photographs and Critical Evaluation of Results

Two months later, the patient complained of constant swelling and pain at the wrist.

The CT scan showed that the lunate was fixed in a DISI position. Within this short period of time, painful midcarpal osteoarthritic changes occurred with subchondral cysts. The head of the capitate is subluxated dorsally (▶Fig. 79.7). ROM was 40 degrees of extension and 15 degrees of flexion. The forearm rotation was not affected (▶Fig. 79.8).

The next step and final solution would be a total wrist fusion from a dorsal approach. It is not necessary to remove the previous volarly located hardware. Unfortunately, the patient died in July 2016.

79.6 Teaching Points

There are some essential operative technical steps to observe:

- Hardware removal and RSL arthrodesis form a single volar approach.
- Distal scaphoidectomy reduces pain and increases ROM.

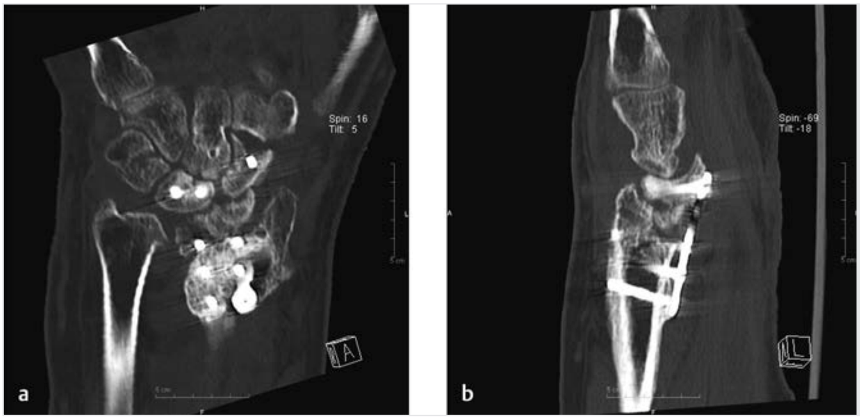

Fig. 79.7 (a, b) The CT scan showed that the lunate was fixed in a dorsal intercalated segment instability position. Within this short period of time, painful midcarpal osteoarthritic changes occurred with subchondral cysts. The head of the capitate is subluxated dorsally.

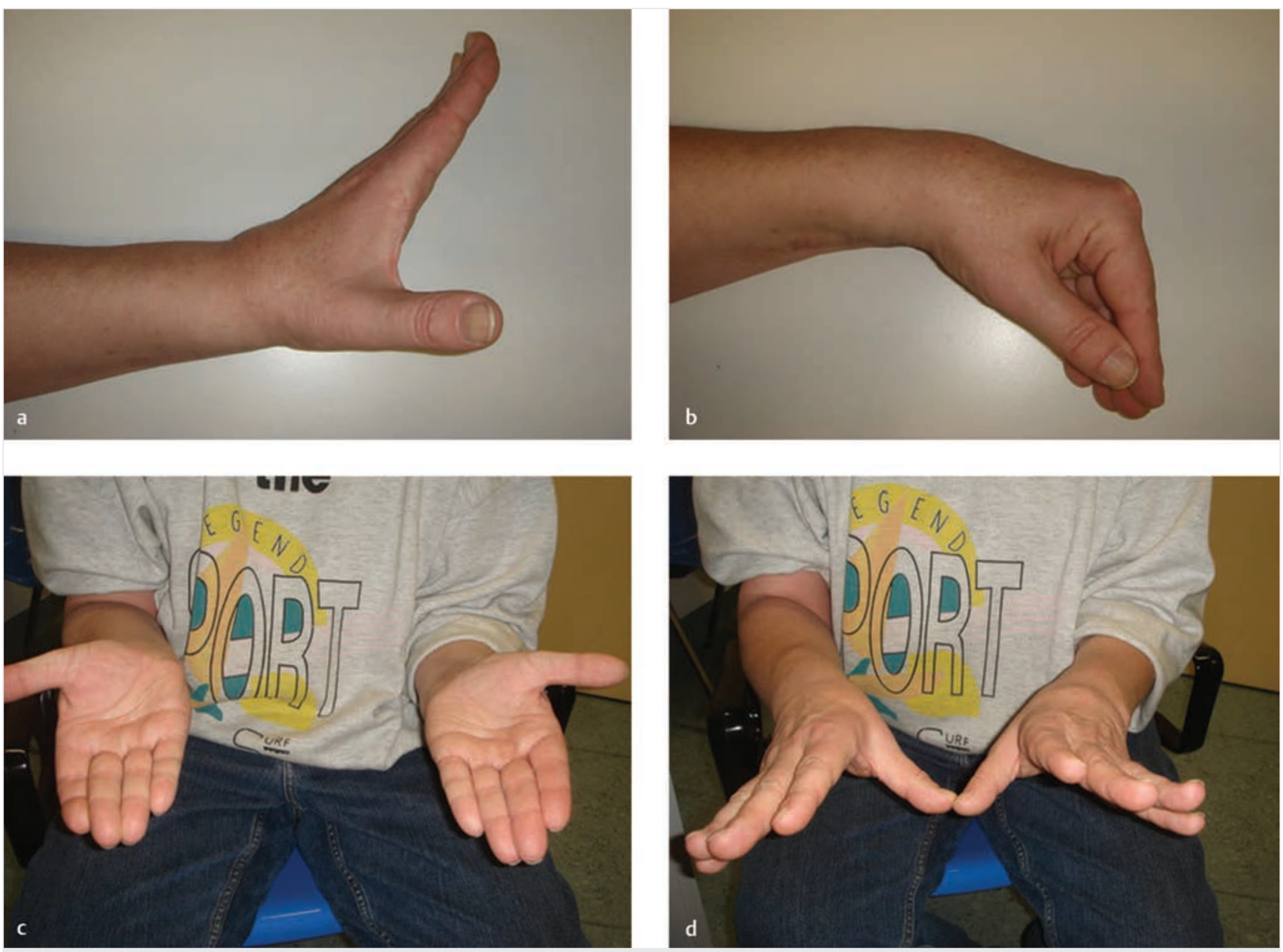

Fig. 79.8 (a–d) Postoperative range of motion.

- Exact positioning of the carpal bones is necessary to avoid DISI or VISI positioning of the carpus.
- The lunate and scaphoid were temporarily fixed to the radius with K-wires before plate fixation.
- Fixation with a fixed-angle plate reduces the nonunion rates as reported in the literature.
- During this procedure, particular care must be taken to avoid damage to the midcarpal joint.
- If the scapholunate ligament is intact and stable, a decortication of this area is not necessary. If the scapholunate ligament is unstable or missing, the scapholunate area must be denuded and filled with a cancellous bone graft.
- To avoid tendon irritation by volar access, the palmar rim of the radius has to be removed.
- No additional bone graft harvesting is necessary.

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Part XXV

Total Wrist Arthroplasty

80 Implant Migration after Total Wrist Arthroplasty *374*

XXV

80 Implant Migration after Total Wrist Arthroplasty

Brian D. Adams

80.1 Patient History Leading to the Specific Problem

A 67-year-old woman presents with a 2-month history of gradually increasing right wrist pain and swelling. She has long-standing rheumatoid arthritis that caused bilateral severe wrist arthritis for which she had a right total wrist arthroplasty 9 years ago, with an excellent result and returned to using her hand without wrist pain.

Approximately, 1 year ago she had right hip and left knee replacements and used walking aides routinely during her recoveries and continues to use aides occasionally. Subsequently, the right wrist began to hurt and intermittently swell, which has gradually worsened. Her rheumatoid arthritis and hand function have remained stable since beginning disease-modifying antirheumatic drugs (DMARDs) 5 years ago. She has no local or systemic signs of infection.

80.2 Anatomic Description of the Patient's Current Status

Examination shows mild diffuse dorsal wrist swelling, no erythema, satisfactory alignment and motion, and minimal tenderness. All digital flexor and extensor tendons are intact. She has no neurologic deficits.

Radiographs of the wrist show severe migration of the distal component of the total wrist implant, with surrounding carpal osteolysis. The proximal component appears stable with minimal osteolysis of the radius (▶Fig. 80.1).

80.3 Recommended Solution to the Problem

Treatment options for a failed arthroplasty include revision of the implant(s), resection arthroplasty, and conversion to an arthrodesis. Revision wrist arthroplasty is often not possible when there is substantial bone loss associated with implant loosening, particularly in the carpus. Resection arthroplasty can result in an unstable joint, wrist deformity, and reduced hand strength. Conversion to a complete wrist arthrodesis will produce a stable wrist and maintain hand strength, but there are several potential technical challenges, including restoration of proper wrist height, obtaining stable fixation, and achieving bony fusion.

80.3.1 Recommended Solution to the Problem

- Although infection is unlikely, appropriate laboratory studies and possible joint aspiration should be done to assess for infection.
- Progression of loosening is likely and therefore proceeding with operative treatment is recommended but not urgent.
- Conversion to a total wrist fusion is the best option due to the amount of carpal bone loss and the physical demands on the wrist from her use of walking aides.

80.4 Technique

DMARDs and methotrexate are discontinued for one cycle before and one cycle after surgery; however, any prednisone therapy is not altered. A dedicated wrist arthrodesis dorsal plate and a contoured cancellous femoral head structural allograft are used.

The previous skin incision over the dorsum of the hand and wrist is used. The extensor retinaculum is opened through the fourth extensor compartment and raised in continuity with the overlying skin to help preserve skin vascularity and reduce wound-healing problems. The joint capsule is opened and the implants are removed with care to preserve bone stock. Typically, the carpal component can be removed with minimal

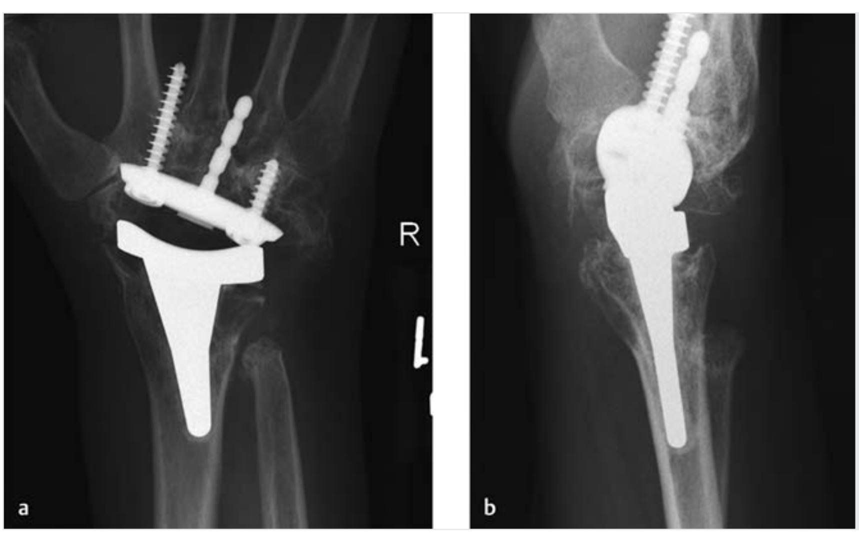

Fig. 80.1 (a, b) Radiographs of the wrist show severe migration of the distal component of the total wrist implant with surrounding carpal osteolysis.

force if it is loose. To remove a well-fixed radial component, a radius osteotomy is usually required to disrupt the osteointegration of an uncemented component or to break the cement mantle of a cemented component.

An osteotomy is made along the radial aspect of the radius using a thin osteotome, followed by gently prying open the cortex. As much cement as possible is removed without substantially weakening the bone. By making the osteotomy at this site, the radius is better preserved for subsequent plate fixation, and the screws fixing the plate will close and secure the osteotomy.

A femoral head structural allograft is prepared using only its cancellous core. It is contoured using an oscillating saw and rongeur to create a size and shape that will fill the defects in the distal radius metaphysis, carpus, and possibly the metacarpals, as well as fill the void left by the implant articulation. The allograft is typically V-shaped proximally, trapezoidal in its midportion, and irregular distally to match the carpal defects (▶Fig. 80.2). The goal of the allograft is to fill the bony defects, provide a stable construct, and maintain or improve wrist height.

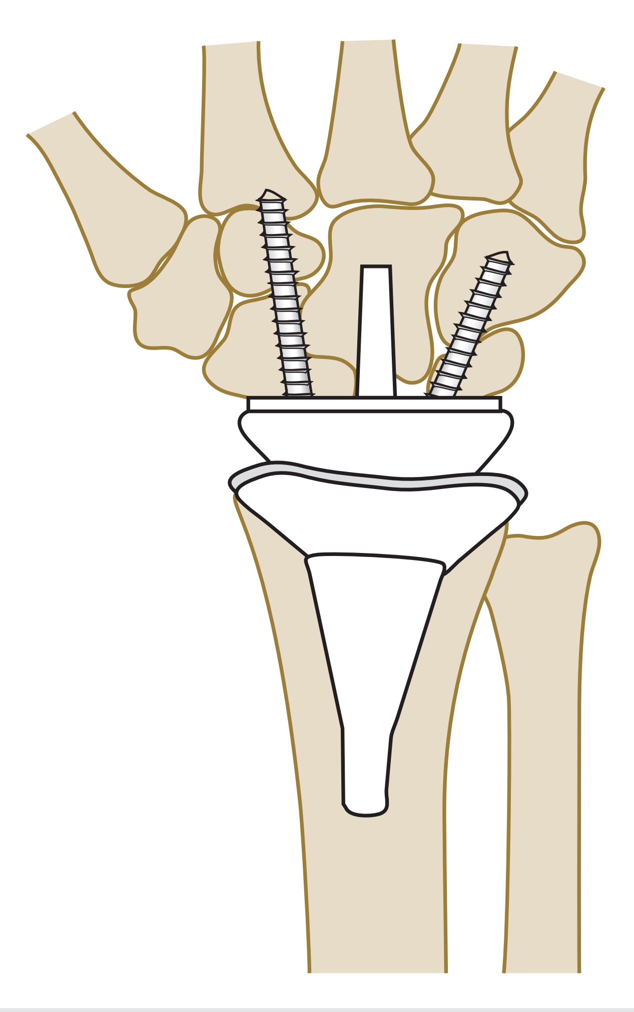

Fig. 80.2 The allograft is typically V-shaped proximally, trapezoidal in its midportion, and irregular distally to match the carpal defects.

Manual intraoperative distraction of the wrist is done to determine optimum wrist height to achieve proper tension in the extensor and flexor tendons. To insert the allograft, flex the wrist and gently impact the graft into the radius, and then with a combination of wrist distraction and extension reduce the carpus onto the distal aspect of the graft.

A stainless steel or titanium wrist arthrodesis plate or wrist spanning plate is applied to the radial shaft and third metacarpal using standard technique. The plate is applied to the second metacarpal if the third metacarpal is severely eroded. Screws are not inserted through the central portion of the plate to avoid graft fracture and displacement. Either a straight or a precontoured plate is used, depending on the fit. When a straight plate is used, it can be bent to create approximately 15 degrees of wrist extension if this will provide better function, for example, in a patient with an opposite wrist fused in flexion. A plate with locking screw technology is considered in patients with poor bone quality due to the prolonged time that may be required to achieve fusion.

Fill voids caused cystic erosions and gaps between the allograft and native bone interfaces using allograft cancellous chips. Consider also using a commercial bone substitute product with osteoinductive and osteoconductive properties to help speed healing.

A short arm splint is applied initially, followed by a cast for at least 2 months. A custom, removable splint is used until there is radiographic evidence of union.

80.4.1 Steps for the Procedure

1. The previous skin incision over the dorsum of the hand and wrist is used.
2. The extensor retinaculum is opened and raised in continuity with the overlying skin.
3. The joint capsule is opened and the implants are removed.
4. An osteotomy is made along the radial aspect of the radius, then gently pry open the cortex.
5. Remove cement.
6. Determine optimum wrist height to achieve proper tension in the extensor and flexor tendons.
7. A femoral head structural cancellous allograft is contoured for proper fit.
8. Insert the allograft proximally.
9. Reduce the carpus onto the distal aspect of the graft.
10. Apply a stainless steel or titanium wrist arthrodesis plate or wrist spanning plate to the radial shaft and third metacarpal using standard technique.
11. Fill voids using allograft cancellous chips.

80.5 Postoperative Photographs and Critical Evaluation of Results

Although she had a good outcome following total wrist arthroplasty that persisted for 9 years, the recent use of walking aides for extended durations in combination with altered bone quality by rheumatoid disease and medical treatment caused excessive wrist stress and eventual carpal component loosening. The initial fusion resulted in a painless stable wrist (▶Fig. 80.3)

Fig. 80.3 (a, b) A stainless steel or titanium wrist arthrodesis plate or wrist spanning plate is applied to the radial shaft and the third metacarpal using standard technique. The plate is applied to the second metacarpal if the third metacarpal is severely eroded. Screws are not inserted through the central portion of the plate to avoid graft fracture and displacement.

Revision arthroplasty is usually only considered when remaining bone stock, particularly in the carpus, will support a new component after only minimal contouring and bone grafting. Conversion to a total wrist fusion is more complex than a resection arthroplasty, but the functional outcome is better and the risks are not substantially greater.

80.6 Teaching Points

- Conversion to a complete wrist arthrodesis is not urgent for a failing total wrist arthroplasty, but should be considered before there is severe bone loss and possible tendon damage.
- Careful extraction of the implants is necessary to maintain maximum bone stock for plate fixation and healing.
- Use of a femoral head cancellous bone structural allograft avoids the morbidity associated with the use of a large autograft.
- A dedicated wrist arthrodesis or spanning plate provides durable long-term fixation for the extended time that is often necessary to achieve fusion.

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Part XXVI

Problems with Triangular Fibrocartilage Complex Tears

81 Pain after Triangular Fibrocartilage Complex Tears *378*

82 Persistent Instability after Triangular Fibrocartilage Complex Tears *382*

XXVI

81 Pain after Triangular Fibrocartilage Complex Tears

Alejandro Badia

81.1 Patient History Leading to the Specific Problem

A 34-year-old right-hand-dominant warehouse manager for the county elections department was referred for persisting ulnar-sided wrist pain of his nondominant hand. Some months prior, he had undergone wrist arthroscopy by a general orthopaedist due to presumed triangular fibrocartilage complex (TFCC) pathology. At the time of initial injury, he noted immediate pain after a hyperextension injury where he then presented to an occupational health center and he was automatically referred for therapy. After seven sessions with no improvement, he was referred to the general orthopaedist who performed arthroscopy of the wrist, apparently the radiocarpal joint only, and he reported performing simple debridement of the TFCC. There was no specification as to whether this was a peripheral or central lesion. Postoperatively, he was placed in a short arm splint for only 1 week, allowing protosupination, and then he began therapy again. The patient quickly noted that he had no improvement and requested consultation with a hand specialist via workers' compensation.

The patient presents with persistent ulnar-sided wrist pain that is aggravated even by simple daily activity including driving. His job is not very manual and he had continued to work for the most part in a supervisory capacity. At physical examination, there was no visible swelling or deformity, but there was pain with extreme ulnar deviation and some discomfort with passive translation of the distal radioulnar joint although there was no clunking. There was also minimal pain with hypersupination of the wrist and there was a negative lunotriquetral (LT) shuck test and no tenderness over the extensor carpi ulnaris (ECU). Grip strength on the left was diminished to 95 lb compared to 125 lb on the right dominant side. Plain X-rays demonstrated no osseous abnormalities and no carpal stability patterns. He demonstrated ulnar neutral variance. Due to persistent pain after wrist arthroscopy, an MRI was performed that showed peripheral fraying of the TFCC articular disk but no complete detachment of the structure, and a normal LT ligament was specifically mentioned. There were no other relevant findings in this 1.5-T closed MRI read by an experienced MSK (musculoskeletal) radiologist.

81.2 Anatomic Description of the Patient's Current Status

This patient is suffering from persistent pain in the ulnar-sided wrist, often termed the "low back of the wrist," after a relatively minor hyperextension injury of the wrist. It is important to understand the vast differential diagnosis that is present here with careful clinical assessment, but often requiring detailed wrist arthroscopic assessment to confirm, elucidate, and provide definitive treatment during this vital procedure.

This patient already underwent wrist arthroscopy, but by a less experienced clinician who practices general orthopaedics. It is important to read the op note and then confirm by that review and visual assessment of the wrist dorsum that a midcarpal arthroscopy was not performed. Persistent ulnar wrist pain after arthroscopic debridement can have many causes. For starters, one must determine if a simple debridement sufficed, and many times this friable tissue can quickly degenerate, leading to recurrent secondary synovitis. Furthermore, a peripheral repair may actually be needed and this would require an ample period of immobilization, usually in supination. Conversely, a central degenerative-type tear (Palmer type IIa) needs to be stabilized and this is best done with radiofrequency shrinkage. This assumes that the TFCC pathology is the primary cause for the ulnar-sided wrist pain. Other causes of pain need to be ruled out.

Much of the ulnar wrist pain differential can be ruled out by clinical examination, starting by simple palpation. Starting by range of motion assessment, the fact that full supination was possible with minimal discomfort often rules out a significant peripheral TFCC tear. Pain with radial and ulnar deviation can be less specific. Palpating particular structures with a clear understanding of anatomy is vital. This patient had no tenderness along the course of the ECU and there were no signs of subluxation, as might be seen with a sixth compartment subsheath tear. These issues can largely be ruled out by ultrasound assessment, something the author now routinely performs in the office environment. Short-axis ultrasound assessment of the ECU will show if significant fluid around the tendon is present and dynamic examination will show if there is tendon subluxation out of the dorsoulnar groove.

Palpation around the carpus tends to be less specific, but certainly a significant intercarpal ligament tear will usually demonstrate point-specific tenderness to firm palpation. Provocative maneuvers, such as the LT shuck test and Watson's test, are typically positive if carpal instability is present. However, smaller tears can cause pain with little biomechanical consequence other than weakness in grip and pain with extremes of motion. These truly require arthroscopic assessment, and via the midcarpal portals, to elucidate symptomatic grade II and III tears (Geissler's criteria). A negative MRI in this clinical instance is neither surprising nor particularly helpful in the overall assessment of this patient with persistent ulnar-sided wrist pain.

81.3 Recommended Solution to the Problem

This patient requires a stepwise, detailed arthroscopic assessment of the wrist. Further diagnostic studies might only serve to confuse and certainly do not address the patient's clinical problem, which is clearly persistent pain.

Arthroscopy of the wrist must almost always include both radiocarpal and midcarpal joint assessment from dorsal portals. Distal radioulnar joint assessment has more limited indications but certainly may prove valuable if the radiocarpal view of the ulnar compartment sheds no light on the etiology of pain, for example, an Atzei class 3 lesion of type IB TFCC tear of the articular disk insertion. Volar portals are occasionally used for more in-depth assessment of the dorsal extrinsic ligaments or when a more difficult arthroscopic arthrolysis is performed.

Midcarpal arthroscopy will be crucial to assess for intercarpal ligament tears, namely, lesions causing dynamic carpal instability. A high index of suspicion for LT tear in this patient must be maintained as he already had a failed simple wrist arthroscopy. Although his examination appeared more focal and ulnar directed, we must ensure that a floating lunate lesion (or Herzberg type 0 perilunate injuries, not dislocated (PLIND) lesion) is not present, where scapholunate disruption is concomitantly present with the LT pathology. This can be easily determined and generally requires aggressive ligament debridement, coupled with pin fixation, as will be discussed.

81.3.1 Recommended Solution to the Problem

- Extrinsic causes of ulnar wrist pain ruled out.
- Radiocarpal arthroscopy assesses previous procedure/current pathology.
- Midcarpal arthroscopy determines if carpal instability present.
- Post-op immobilization (type + time period) depends on procedure performed.
- Wrist rehabilitation critical to regain motion, followed by strength.

81.4 Technique

The patient was placed in the supine position with the upper arm held down with a Velcro strap over the upper arm tourniquet. Simple wrist block anesthesia was placed once slight intravenous (IV) sedation was induced. The wrist was distracted via the Chinese finger traps on the index and middle fingers, which we used to provide 10 lb of traction with an arm holder that would allow easy introduction of fluoroscopy into the operating room field. A traditional wrist tower is never utilized.

With the wrist in pronation and the surgeon sitting at the head of bed, the joint is insufflated just distal to Lister's tubercle using an 18-G needle and several milliliters of a local anesthetic mixture of lidocaine/Marcaine. The 2.7-mm 30-degree arthroscope is introduced into the 3–4 working portal created via a small transverse incision. Cursory, but systematic examination, of the radiocarpal joint is made by beginning on the radial side and progressing ulnarward. The 2.9-mm full radius shaver is inserted in the 6R portal, which allows for immediate synovectomy (▶Fig. 81.1a), necessary to identify the anatomy and assess for any abnormalities and the primary pathology. This thorough synovectomy is also vital for post-op pain relief, but the offending injury causing this process must now be identified (▶Fig. 81.1b). Looking toward the ulnocarpal compartment, minor adhesions and subtle changes in the coloration of the peripheral TFCC are noted once the proliferative synovium is cleared (▶Fig. 81.1c). This represents scar from prior debridement but appears to have little clinical relevance as no detachment is noted, there is no loss of trampoline effect, and the lift-off test is negative, all of which are determined by palpation with a small hook probe. To stabilize some of the frayed dorsal capsule and articular disk capsular insertion, a 2.5-mm bipolar radiofrequency shrinkage probe is then inserted via 6R and is utilized with a "striping technique." Essentially the relevant soft tissues are touched with the probe in horizontal, parallel, but spaced stripes so that the intervening tissue perfusion is unaltered. This allows for capsular healing and minimizing redundancy and recurrent synovitis. The SL ligament had been clearly visualized and unremarkable, but the LT ligament is poorly seen via the radiocarpal portals. Regardless, the volar component is biomechanically more critical, and this would be assessed from the midcarpal joint.

The syringe/needle is also utilized to help dilate the midcarpal joint via the radial midcarpal portal, just distal and slightly more ulnar than the 3–4 portal. After opening the portal with a straight, small mosquito clamp, the arthroscope is introduced. Similar systematic assessment is performed in the midcarpal joint where the SL ligament, articular surfaces of scaphoid, lunate, and capitate are all examined. Almost immediately, it was noted that there is a step off and even mild diastasis of the LT interval (▶Fig. 81.2a). The ulnar midcarpal portal is created by localization with an 18-G needle, and the full radius shaver is now inserted. Thorough synovectomy is performed, so this interval and the dorsoulnar midcarpal capsule can be better visualized. The hook probe is soon inserted and the

Fig. 81.1 **(a)** Scope and shaver placement for ulnar compartment assessment. **(b)** Synovitis ulnar radiocarpal joint. **(c)** Post-debride scar and intact triangular fibrocartilage complex demonstrated after synovectomy.

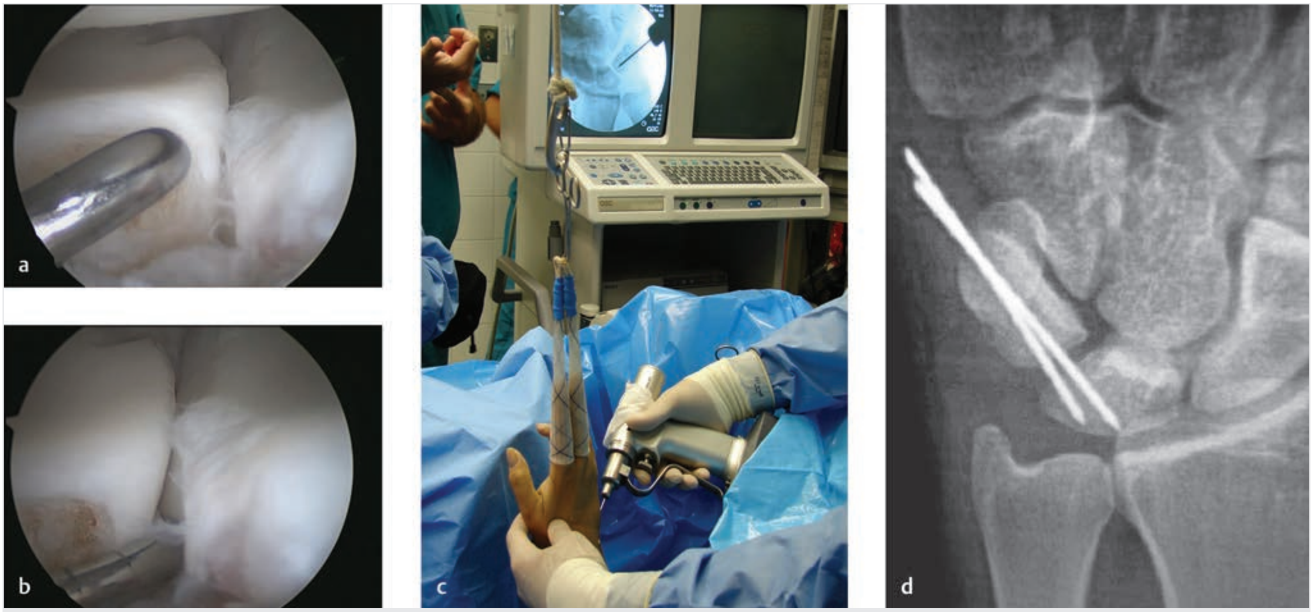

Fig. 81.2 **(a)** Lunotriquetral (LT) instability noted via midcarpal arthroscopy. **(b)** A Geissler grade 3 LT tear demonstrated with hook probe. **(c)** Pinning of LT interval (external view). **(d)** Radiograph of LT pin placement.

gross motion, much more than normally deemed acceptable, confirms the presence of an LT ligament tear with dynamic instability. The probe is easily inserted in the interval and can be rotated 90 degrees, constituting a grade III tear as per the Geissler staging of intercarpal ligament tears (▶Fig. 81.2b). In order to stabilize and reverse this motion, we will create scar by aggressively debriding the intercarpal LT interval with particular attention to the volar aspect where the most critical portion of LT stability is found. Similar limited shrinkage is performed to the dorsal capsule and at this point the arthroscope is retired. To truly generate a new surrogate ligament, we must minimize motion at the interval. Fluoroscopy is now brought in via a sagittal plane so that we can visualize the LT interval, initially by the posteroanterior (PA) view. A wire driver is now used to pass a 0.045-inch Kirschner wire across the LT interval, near perpendicular to the axis of this intercarpal space, until the tip of the wire abuts the radial cortex of the lunate (▶Fig. 81.2c). Stable and precise placement of the single wire is assessed via both PA and lateral views of pulsed fluoroscopy as well as wiggling the wire externally, confirming concomitant motion of both the triquetrum and the lunate (▶Fig. 81.2d). The lateral is simply assessed by supinating the forearm passively. When wire placement is deemed acceptable, it is cut just under the skin and the remnant is similarly loaded onto the driver. This wire is similarly passed, near parallel to the first wire and cut under the skin once deemed secure.

Now that the LT interval has been stabilized, and pins cut after fluoro-confirmation, the four transverse portals are closed by simple Mastisol/Steri-Strip placement. Sutures are not necessary since there is minimal tension and this avoids punctate scarring. Xeroform Gauze, 4 × 4 dressings, and sterile cast pad are rolled, followed by application of a small, volar short arm plaster splint, secured with Kerlix circumferential gauze application.

81.4.1 Steps for the Procedure

1. Assess radiocarpal joint and debride/shrink capsule judiciously.
2. Evaluate midcarpal joint and aggressively debride LT interval.
3. Pin to stabilize LT interval.
4. Short arm splint/cast for approximately 8 total weeks.

81.5 Postoperative Photographs and Critical Evaluation of Results

Within days to a week, a short arm waterproof fiberglass cast is applied once post-op X-rays confirm good pin position. Those pins are removed at approximately 8 weeks, in either the office or surgery center environment, depending on whether the position requests IV sedation. Portal scars are barely visible even before discharge since transverse scars are in Langer's lines, and no sutures were used (▶Fig. 81.3a). Gentle manipulation under anesthesia can be done to initiate the rehab process of recovering range of motion, followed by progressive strengthening initiated by the therapist but can be later completed via home exercises. Incorporation to work and sports activities is done in a progressive but gradual manner with the vast majority of motion regained by the time of discharge (▶Fig. 81.3b). Recovery of strength is gradual and much more prolonged but usually occurs during the process of return to full activities of daily living.

Post-op recovery is simply determined by recovery of wrist functional range of motion, followed by strength. Long-term radiographs are not very helpful in assessment since the LT interval is generally not appreciably altered in the pre-op phase and the clinical issue is strictly of dynamic instability leading

Fig. 81.3 **(a)** Wrist view demonstrating portal scars. **(b)** Wrist extension without pain at the time of discharge.

to synovitis and subsequent pain. Post-op pain is generally modest, but it can take months to recover painless wrist flexion in particular. Recovery of measured grip strength typically lags behind the arc of motion and perceived patient pain levels. Specific and demanding maneuvers of the wrist, such as doing full pushups, can take upward of a year to reach full recovery.

Persistent pain in ulnar-sided wrist pain can be avoided by making a thorough radiocarpal and midcarpal assessment of pathology via a systemic wrist arthroscopy. Once pathology is addressed, soft-tissue healing and restitution require adequate time of immobilization.

81.6 Teaching Points

- Ulnar-sided wrist pain has a wide differential diagnoses.
- Persistent symptoms after wrist arthroscopy often mean the offending pathology was not elucidated fully.
- Imaging studies are often not helpful when assessing for painful, dynamic carpal instability.
- Thorough arthroscopic assessment and intraoperative management of pathology are critical to healing of injury.
- Adequate immobilization to allow tissue healing, followed by rehabilitation should yield good functional results.

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82 Persistent Instability after Triangular Fibrocartilage Complex Tears

Brian D. Adams

82.1 Patient History Leading to the Specific Problem

A healthy 26-year-old woman was referred for recurrent left ulnar-side wrist pain and distal radioulnar joint (DRUJ) instability. She had a left distal radius fracture 2 years ago while alpine skiing for which she was treated in a cast. Because of persistent wrist symptoms, she had an arthroscopic triangular fibrocartilage complex (TFCC) repair 6 months ago. The TFCC was sutured to the dorsal ulnar wrist capsule beneath the extensor carpi ulnaris (ECU) tendon. She claims the preoperative symptoms returned during rehabilitation while trying to recover motion and strength. She now has pain and weakness when lifting in supination and while performing tasks requiring torque using forearm rotation. She occasionally has painful clicking and rarely a clunk in the wrist when attempting power grip. These symptoms are consistent with DRUJ instability, which was likely caused by the combination of a TFCC tear and an ulnar styloid fracture in association with the distal radius fracture.

82.2 Anatomic Description of the Patient's Current Status

There is slight prominence of the ulnar head, with overlying mild swelling surrounding the head. She has full wrist and forearm motion; however, she has obvious pain when at full supination, especially if done against resistance. Manipulation of the DRUJ shows increased translation (piano key sign), causes pain, and reproduces her usual symptoms (▶Fig. 82.1). The modified press test produces a typical dimple sign consistent with increased volar translation of the ulnar head (▶Fig. 82.2).

Radiographs show evidence of an old distal radius fracture, with mild loss of volar tilt (reduced to neutral tilt); however, there is no substantial shortening (~1 mm negative ulnar variance; ▶Fig. 82.3). There is also a moderately displaced ulnar styloid fracture and widening of the DRUJ space. The DRUJ is not subluxated on the lateral view. CT scan shows a flattened sigmoid notch, with substantial deficiency of its volar rim (▶Fig. 82.4). MRI shows a thick TFCC in its horizontal components (disk and radioulnar ligaments), a chronic avulsion of the TFCC from the fovea, and a moderately displaced ulnar styloid fracture (▶Fig. 82.5).

82.3 Recommended Solution to the Problem

The history, physical examination, and imaging studies are consistent with an avulsion of the TFCC from the fovea that resulted in DRUJ instability. Although an arthroscopic repair was performed, a repair to the wrist capsule does not reestablish the important site of attachment of the TFCC to the fovea. In

Fig. 82.2 The modified press test produces a typical dimple sign consistent with increased volar translation of the ulnar head.

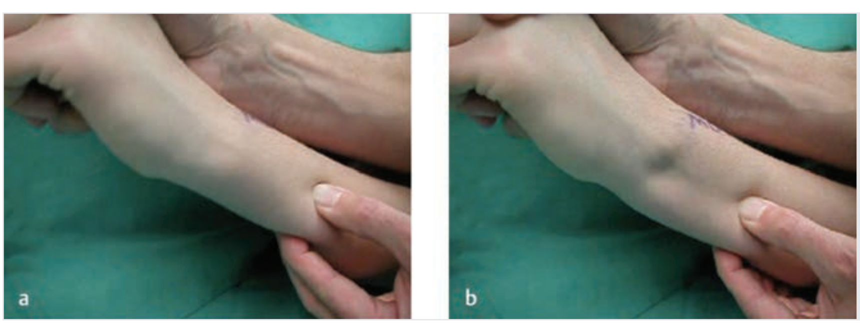

Fig. 82.1 **(a, b)** Manipulation of the distal radioulnar joint shows increased translation (piano key sign), causes pain, and reproduces her usual symptoms.

Fig. 82.3 (a, b) Radiographs show evidence of an old distal radius fracture, with mild loss of volar tilt (reduced to neutral tilt); however, there is no substantial shortening (~1 mm negative ulnar variance). There is also a moderately displaced ulnar styloid fracture and widening of the distal radioulnar joint (DRUJ) space. The lateral view does not show subluxation of the DRUJ.

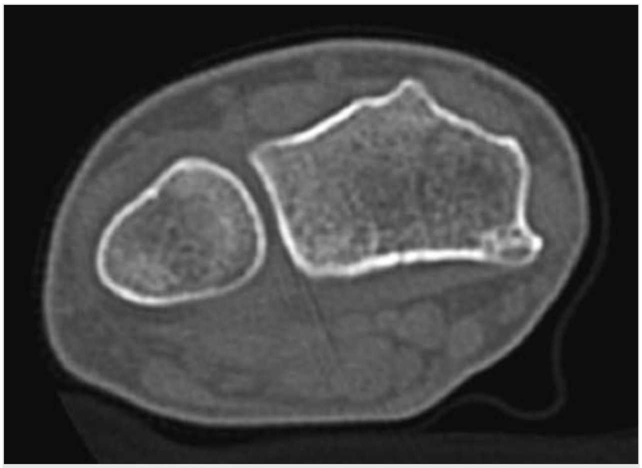

Fig. 82.4 CT scan shows a flattened sigmoid notch, with substantial deficiency of its volar rim.

Fig. 82.5 MRI shows a thick triangular fibrocartilage complex (TFCC) regarding its horizontal components (disk and radioulnar ligaments), a chronic avulsion of the TFCC from the fovea of the ulnar head, and confirms a moderately displaced ulnar styloid fracture.

addition, a flat sigmoid notch substantially reduces the inherent stability of the DRUJ and likely increases the risk of failure of an isolated soft-tissue repair.

The options of treatment for persistent DRUJ instability after a failed arthroscopic, peripheral TFCC repair include open TFCC repair, reconstruction of the distal radioulnar ligaments using a tendon graft, or a DRUJ salvage procedure. As shown in biomechanical and clinical studies, the DRUJ stability is dependent upon a combination of soft-tissue restraints and a competent sigmoid notch.

82.3.1 Recommended Solution to the Problem

- Repeat arthroscopic repair to the peripheral capsule is unlikely to establish durable DRUJ stability.
- A salvage DRUJ procedure is not indicated in a young patient without arthritis.
- A ligament reconstruction can be used but may not be required if the TFCC is found at surgery to have sufficient substance for repair.

- TFCC repair to the fovea of the ulnar head is an appropriate option when the MRI shows a thick TFCC that is avulsed from the fovea, as seen in this case.
- A sigmoid notch osteoplasty to augment the soft-tissue repair will likely improve the long-term success since the sigmoid notch is shallow.

82.4 Technique

82.4.1 Open Peripheral Repair of the TFCC

A 4-cm incision is made between the fifth and the sixth extensor compartments, extending proximally from the level of the ulnar styloid. The fifth compartment is opened, except for its distal portion, and the extensor digiti minimi tendon is retracted. A rectangular capsulotomy is made, beginning proximally at the ulnar neck and extending to the dorsal radioulnar ligament, with care not to cut the dorsal radioulnar ligament. The distal transverse limb is made parallel and proximal to the dorsal radioulnar ligament, extending to but not into the ECU sheath. The ECU sheath should not be opened or dissected from the ulnar groove, as preserving the sheath will maintain its important wrist-stabilizing functions. The proximal transverse limb extends across the ulnar neck. The DRUJ articular surfaces are inspected for arthritis and the TFCC assessed for its potential for repair. If it is inadequate, then proceed to reconstruct the radioulnar ligaments using a tendon graft. Debride granulation tissue from the fovea and any central TFCC tear, but retain the radioulnar ligaments. If an ulnar styloid nonunion is present, resect the styloid by subperiosteal sharp dissection volar to the ECU sheath. A transverse ulnocarpal capsulotomy is made parallel and distal to the dorsal radioulnar ligament.

The ulnar confluence of the radioulnar ligaments (peripheral TFCC) is reattached to the fovea with transosseous sutures. Use a 0.062-inch Kirschner wire to create two or three tunnels that extend from the dorsal aspect of the neck to the fovea (▶Fig. 82.6a). Double-armed sutures of 2–0 absorbable monofilament, or other preference, are used. Create two horizontal mattress sutures through the ulnar periphery of the TFCC by passing the needles through the ulnocarpal capsulotomy and across the TFCC next to the fovea. Each of the two suture limbs is passed through different bone tunnels (▶Fig. 82.6b). While pulling on the limbs of one suture to hold the TFCC firmly against the fovea, the other suture is tied over the bony bridge between the tunnels. The other suture is then tied (▶Fig. 82.6c). Tie the sutures with the joint reduced and the forearm in neutral rotation. The dorsal DRUJ capsule and retinaculum are closed together as a single layer with only slight imbrication to avoid loss of motion. The extensor digiti minimi is left subcutaneous.

82.4.2 Osteoplasty for a Deficient Sigmoid Notch

A preoperative CT is recommended to evaluate the rims of the notch and the shape of the ulnar head if there is a history of fracture involving the sigmoid notch or an apparent shallow notch on plain radiographs. Although a sigmoid notch osteoplasty can be done as an isolated procedure, it is more commonly done in conjunction with a TFCC open repair or distal radioulnar ligament reconstruction. An osteoplasty increases the buttress effect of rim, and increases the tension in the ligaments. Use a very narrow osteotome to reduce bone loss when making the cuts. Begin by making parallel cuts approximately 7-mm deep, with one cut 3 to 4 mm proximal to the lunate fossa and the other just proximal to the sigmoid notch (▶Fig. 82.7). A longitudinal osteotomy

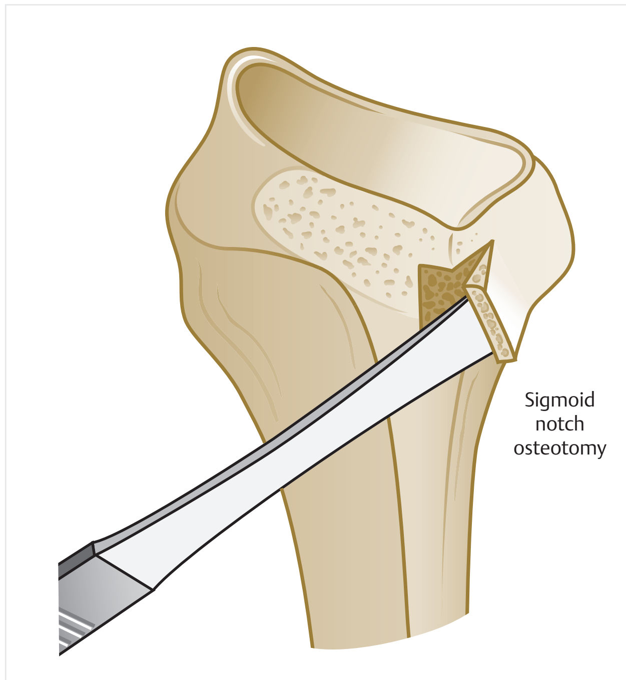

Fig. 82.7 Illustration demonstrating sigmoid notch osteoplasty.

Fig. 82.6 (a) Horizontal mattress sutures are placed through two or three bone tunnels extending from the fovea to the ulnar neck. **(b)** Horizontal mattress sutures (*blue color*) shown passing through the periphery of the triangular fibrocartilage complex (TFCC) and bone tunnels from the fovea to the ulnar neck. **(c)** Horizontal mattress transosseous sutures are shown fixing the periphery of the TFCC tightly to the fovea.

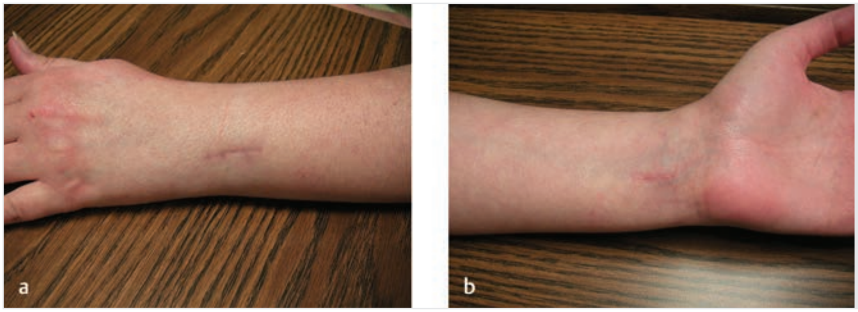

Fig. 82.8 (a, b) Postoperative dorsal and volar healed incisions are shown following combined open triangular fibrocartilage complex repair and volar sigmoid notch osteoplasty.

extends between these two cuts and 5 mm from the notch surface and approximately 7-mm deep. If the osteoplasty is being performed in conjunction with a radioulnar ligament reconstruction, create the radius tunnel for the graft before making the osteoplasty, and make the longitudinal osteotomy through the opening of the tunnel. Advance the osteotome carefully, and incrementally lever it to produce a thin, slightly curved osteocartilaginous flap. The wedge-shaped bony defect left behind the flap is filled with a bone graft harvested from the distal radius or ulna (only a small bone graft is necessary). Wallwork and Bain described fixing the construct with Kirschner's wires; however, sufficient stability can also be achieved by placing sutures through the soft tissues overlying the osteoplasty. When an osteoplasty is used in conjunction with a ligament reconstruction, bone graft stability is achieved by passing the tendon graft over the bone graft and osteoplasty flap.

82.5 Postoperative Photographs and Critical Evaluation of Results

A long arm splint is applied with the forearm typically rotated 20 degrees toward supination. The splint is converted to a long arm cast at 2 weeks with the forearm in similar rotation, followed by a short arm cast for an additional 2 to 4 weeks (▶Fig. 82.8). A removable splint is then used for 4 weeks while motion is regained. Strengthening and resumption of activities is typically delayed until pain is minimal and motion is nearly recovered. The results of open TFCC repair are generally good; DRUJ stability is achieved and motion and strength are recovered in most cases.

82.6 Teaching Points

- Gross DRUJ instability due to severe injury involving multiple soft-tissue restraints may not respond to soft-tissue reconstruction.
- Substantial skeletal deformity must be corrected prior to or simultaneously with soft-tissue reconstruction.
- Positive ulnar variance must be corrected to optimize DRUJ congruency and soft-tissue tension.
- Sigmoid notch should be assessed for shape and rim competency, and a sigmoid notch osteoplasty performed if necessary.

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Part XXVII

Problems with Ulnar Impaction

83 Arthroscopic Treatment of Ulnar Impaction *388*

84 Nonunion after Ulnar Shortening *391*

XXVII

83 Arthroscopic Treatment of Ulnar Impaction

William Dzwierzynski

83.1 Patient History Leading to the Specific Problem

A 53-year-old woman presented with a 1-year history of right ulnar wrist pain. At times, she gets a very painful click. Torqueing with a key or other object increases the pain; opening a door is very painful. If she attempts to push off from a seated position, she gets severe pain. There is no history of trauma. She had been previously treated with a steroid injection into the wrist, which gave her 2 months of relief, but now the pain has returned to its previous level. Physical examination showed tenderness over the distal ulna. Lunotriquetral (LT) ballottement produces pain; compression of the distal radioulnar joint is painful.

83.2 Anatomic Description of the Patient's Current Status

The carpus is separated and cushioned from the distal ulna by the triangular fibrocartilage complex (TFCC). The TFCC extends from the distal radius to the ulnar fovea and the styloid. The TFCC is the primary stabilizer of the distal radial ulnar joint. In the ulnar neutral wrist, the ulnar carpal joint bears 18% of the load of the wrist. Increasing the length of the ulna has been shown to increase the load on the ulnar carpal joint. Increasing the length of the ulnar by 2.5 mm can increase the load to 42% of the total load on the wrist. Forearm pronation and grip both result in increased ulnar length. Resection of the wafer of distal ulna has been shown to decrease the ulnar carpal load transmission. Ulnar impaction syndrome is a common source of ulnar-sided wrist pain secondary to excessive load across the ulnar carpal joint (▶Fig. 83.1). It is usually associated with a positive ulnar wrist, although it can occur in any ulnar variation. Ulnar impaction is commonly associated with a tear of the TFCC (▶Fig. 83.2).

83.3 Recommended Solution to the Problem

- Treatment of ulnar impaction syndrome is initially nonoperative with rest, splinting, NSAIDs (nonsteroidal anti-inflammatory drugs), and steroid injection.
- If conservative treatment options fail, surgery is recommended.
- Ulnar shortening osteotomy is considered the standard for surgical treatment.
- Complications of ulnar shortening osteotomy include nonunion, malunion, stiffness from prolonged immobilization, and long scars.
- Distal ulnar wafer resection is a less invasive procedure that has been shown to effectively reduce the load on the ulnar carpal joint.
- Distal ulnar wafer resections can be performed through an open or arthroscopic approach.
- Systematic reviews have shown that the arthroscopic procedure is a viable option to ulnar-shortening osteotomy.

83.4 Technique

Surgery is performed under general or regional anesthesia, using an upper arm tourniquet (▶Fig. 83.3). Standard 3–4 and

Fig. 83.1 (a–c) Radiographs showed positive ulnar variance. Pronated wrist views show increased positive ulnar variance.

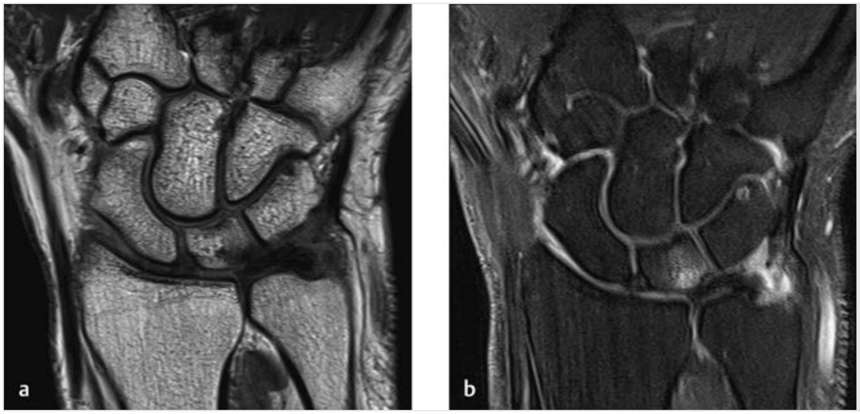

Fig. 83.2 (a, b) An MRI of the wrist delineatesthe triangular fibrocartilage complex (TFCC). MRI is suggestive of a TFCC tear and ulnar impaction syndrome with lucency in the lunate.

Fig. 83.3 An upper arm tourniquet is used, and the arm is placed in 10 to 15 lb of traction utilizing sterile finger traps.

4–5 (or 6U) portals are utilized. A 2.7- to 2.9-mm arthroscope is used to visualize the radial carpal joint (▶Fig. 83.4, ▶Video 83.1); a complete arthroscopic examination including evaluation of the midcarpal joint is important to evaluate the integrity of the scapholunate (SL) and LT ligaments. A defect is found in the TFCC in the cases of ulnar impaction syndrome. The arthroscopic shaver and radiofrequency debrider is used to debride the frayed edges of the TFCC. Once the TFCC is debrided, the ulnar head can be visualized through the defect. A 3.0-mm burr is used to remove the distal ulna. The diameter of the burr is used to assess proper bone excision. Pronation and supination of the wrist in the traction tower ensure uniform circumferential bone excision. Interoperative C-arm fluoroscopy is utilized to ensure complete bone removal. The incisions are closed with fast-absorbing gut sutures and the wrist is immobilized in a splint.

83.5 Postoperative Photographs and Critical Evaluation of Results

The patient was seen in the hand therapy clinic 3 days after surgery. Motion was initiated within the first postoperative week. She used a removable orthotic for wrist support and protection for 8 weeks. She noted that her pain was significantly improved. Her grip strength returned to the level of her contralateral extremity.

83.6 Teaching Points

- Positive ulnar variance of 2 to 3 mm can be safely removed arthroscopically.
- The central defect of the TFCC should not be excessively debrided.
- Pronation and supination of the wrist in the arthroscopic traction tower allow complete circumferential resection of the distal ulna.
- Mini C-arm fluoroscopy should be utilized in conjunction with arthroscopic visualization.
- Complications of arthroscopic wafer procedures are rare but include portal scar sensitivity and dorsal sensory nerve neuropraxia.

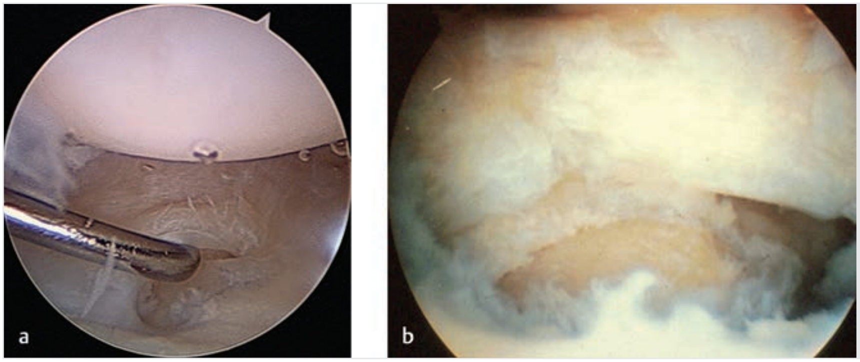

Fig. 83.4 **(a)** Probe in radiocarpal portal demonstrates central triangular fibrocartilage complex (TFCC) tear. **(b)** The distal ulna is visualized through the TFCC tear.

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84 Nonunion after Ulnar Shortening

Ladislav Nagy

84.1 Patient History Leading to the Specific Problem

A 54-year-old truck driver presented to us 3 months after an operative treatment of his dominant left wrist elsewhere. According to his medical records, he had been suffering from ulnar-sided wrist pain for about 6 months following a wrist sprain and received the diagnosis of ulnocarpal impaction syndrome. Ultimately, following failed conservative treatment, the patient had undergone an ulnar-shortening osteotomy with plate fixation. The intra- and postoperative course had been uneventful, and wound healing was prompt, but the patient already began to feel a persistent pain in his distal ulna only some days postoperatively. This failed to improve with forearm cast immobilization and increased with loading. Subsequent imaging explained the symptoms as the plate showed loosening with delayed or absent bone healing of the osteotomy. Therefore, the patient presented for a second opinion at our institution.

84.2 Anatomic Description of the Patent's Current Status

The patient is a 54-year-old man in excellent general health condition. He is a nonsmoker, with no coexisting disease, medication, or allergies. The dominant left wrist is slightly swollen, the ulnar-sided longitudinal scar shows no sign of inflammation, and the implant underneath is prominent and painful upon palpation. The range of motion of the wrist is diminished in all directions compared to the healthy side and painful, especially with forearm rotation and ulnar deviation of the wrist.

The preoperative X-rays taken at another facility show a normal wrist with an ulnar zero variant (▶Fig. 84.1). The intraoperative fluoroscopy images could not be found. The postoperative X-rays at 3 weeks show the ulnar osteotomy fixation with a five-hole dynamic compression (DCP) plate; the X-rays also show insufficient contact of the plate to the

Fig. 84.1 (a, b) Preoperative X-rays from a different facility, 6 months before ulnar-shortening osteotomy for ulnocarpal impaction.

Fig. 84.2 X-rays taken **(a, b)** 3 weeks and **(c, d)** 3 months postoperative.

proximal fragment (▶Fig. 84.2a) and progressive loosening of the plate, screws, and the whole construct during the following 3 months (▶Fig. 84.2b,c) with some signs of callus formation.

84.3 Recommended Solution to the Problem

Among the different methods of ulnar-shortening, osteotomy of the ulnar shaft with plate fixation is an established method for treatment of ulnocarpal impaction. Complications include loosening, loss of reduction, delayed healing or nonunion as in this case, and ultimately the need for removal of a painful implant. According to the literature, nonunions after ulnar-shortening osteotomy occur in 0 to 12.7% of cases. Risk factors are smoking, possibly the site and orientation of osteotomy, the heat generated by the saw blade, and others. Union rates have been higher when using longer and more rigid implants and external compression devices. Thus, this complication might have been avoided if a more rigid fixation were used. It has to be kept in mind that conventional plates (as used here) unconditionally need to adhere snugly on the bone surface as the fixation strength is generated by the friction between the plate and the bone surfaces. Thus, gap in between the plate and the bone surface is evidence of an unstable construct, which in an ulnar osteotomy is unlikely to result in bony union, even with prolonged immobilization in an above-elbow cast. In contrast, modern implants with angular stable screws act as internal fixators and do not need to be pressed onto the bone surface without compromise of the strength of the fixation and even allowing for better vascularity of the bone.

Thus, as revision surgery obviously is inevitable, a more rigid construct is necessary. This can be achieved with compression of the two bone surfaces on another and use of a longer (more screws) implant using locked screws and avoiding the preexisting holes.

84.3.1 Recommended Solution to the Problem

- Use a stronger construct (= ideal fixation of a conventional plate), preferably an angular stable fixation/plate.
- Compression upon the osteotomy enhances rigidity.
- Avoid old screw holes/change orientation of the plate.

84.4 Technique

The surgical approach was done using the previous longitudinal incision at the ulnar border of the distal forearm with exposure of the ulnarly located plate and the palmar shaft of the ulna. The new plate, an eight-hole locking compression plate is positioned on the palmar bone surface, oriented 90 degrees to the previous implant, aligned and contoured with the bone, and fastened with locking screws to the distal fragment.

The previous implant is loosened by removing the proximal screws and the nonunion site is inspected. As there was callus formation, decortication of the bone ends or bone graft was not needed. As most locking plates allow generating only a limited amount of compression with excentric drilling and DCP hole design, compression between the fragments was generated using a compression device fastened to the proximal end of the plate and the bone. The old plate, loosely fixed to the proximal fragment with a cerclage wire, was used to control reduction (▶Fig. 84.3).

Once the desired amount of compression was reached, the proximal part of the plate was also fixed to the bone (▶Fig. 84.4). All plate holes were filled with screws.

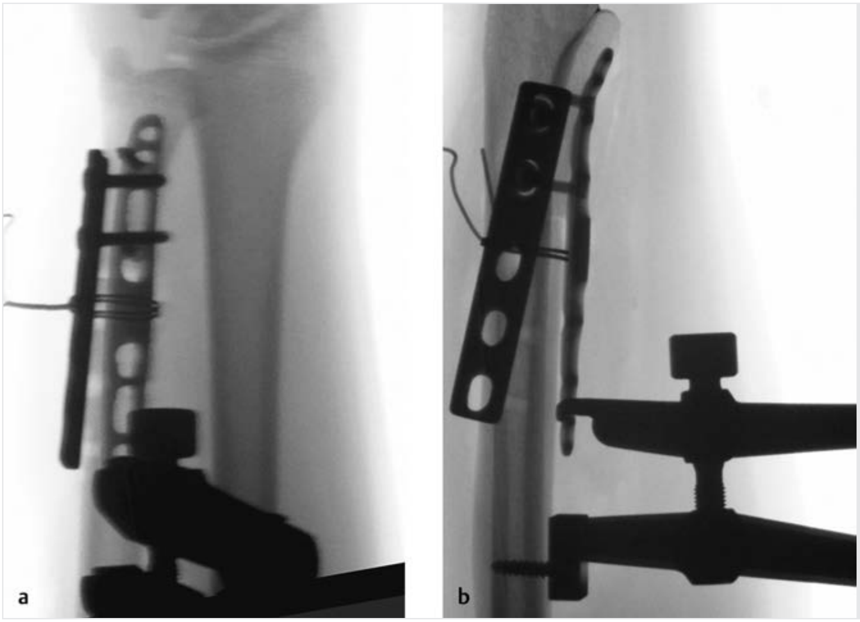

Fig. 84.3 (a, b) Intraoperative X-rays showing the previous implant still in place and the new plate already fixed to the distal fragment. A compression device pulls the new plate proximally compressing the nonunion site while reduction is supported by a cerclage wire around the proximal stump of the ulna and both plates.

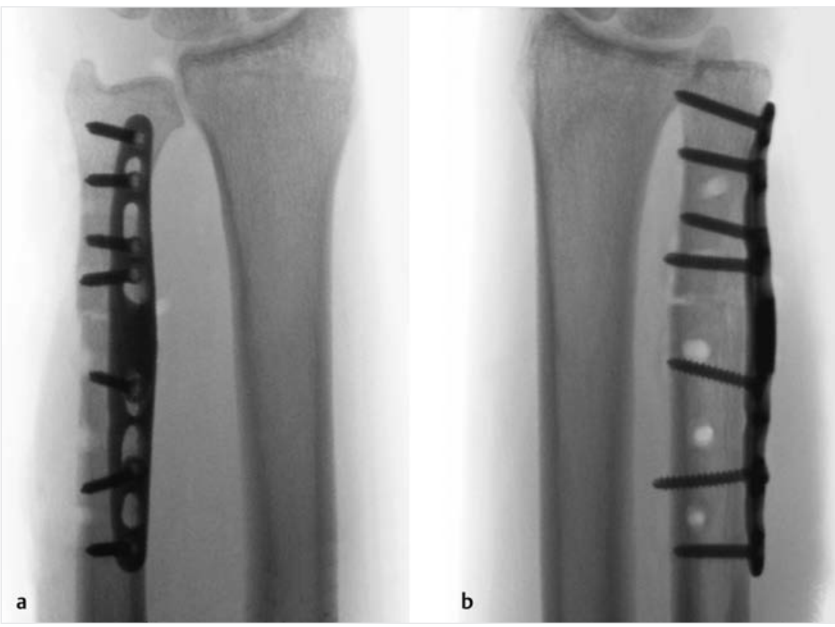

Fig. 84.4 (a, b) Postoperative presentation of the nonunion after new plate fixation.

Postoperatively, the wrist was immobilized in a forearm splint only until wound healing, but immediate light pronation/supination exercise was allowed. After this, the patient was allowed to use the hand for light functional demands, but still needed the splint for exposed activities. Increasing weight bearing was allowed at 8 weeks after radiographic evidence of bone healing.

84.4.1 Steps for the Procedure

- Expose previous implant and nonunion site using old incision/approach.
- Inspect nonunion site: with callus present (= hypertrophic nonunion), sole compression and rigid fixation is sufficient. (In the case of a hypotrophic nonunion, the avascular bone has to be debrided and the defect filled with bone graft.)
- Align the new plate with the shaft oriented 90 degrees to the old implant and fix it to the distal fragment. In soft bones, use of locking screws is preferable.
- Install the compression device proximally, then loosen or completely remove the previous implant before progressively tightening the compression device.
- Control the position of the proximal stump while still allowing further compression. The previous plate and cerclage wire(s) can be useful.
- After reaching the desired compression and correct alignment, the plate is fixed proximally as well. Additional screws can be added in order to increase the strength of the construct.

Fig. 84.5 (a, b) Radiologic presentation with complete union at 15 months postoperative.

84.5 Postoperative Photographs and Critical Evaluation of Results

At 18 months postoperatively, the wrist has returned to normal range of motion, but still lacks about 40% of strength compared with the healthy side (▶Fig. 84.5). There is an exquisite pain upon palpation over the fourth distal screw tip. Thus, implant removal is scheduled.

84.6 Teaching Points

- Strive for maximal stability in primary operation to avoid delayed healing/nonunion.
- Nonunion with callus needs stable compression reosteosynthesis (in atrophic nonunions, the bone ends should be decorticated and bone graft added).
- Locking plates provide maximal strength of fixation but not the amount of compression needed. Therefore, the use of a compression device is recommended.

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Part XXVIII

Problems with Distal Radial Ulnar Joint

85 Failed Bowers' Arthroplasty: Ulnar Head Prosthesis *396*

86 Dislocated Ulnar Head Prosthesis *401*

XXVIII

85 Failed Bowers' Arthroplasty: Ulnar Head Prosthesis

Florian Neubrech and Michael Sauerbier

85.1 Patient History Leading to the Specific Problem

A 46-year-old man presents with persisting ulnocarpal pain, reduced forearm rotation, and the feeling of instability of the distal ulnar stump after a partial ulnar head resection was performed 3 months before in an orthopaedic-oriented outside department at the right hand.

Three years ago, the patient suffered from a distal radius fracture with an additional scaphoid fracture. Despite several operations, the scaphoid fracture did not heal properly and a painful osteoarthritis of the wrist developed. Therefore, total wrist fusion was performed elsewhere. Radiocarpal pain could be improved, but ulnocarpal complaints persisted through a severe osteoarthritis of the distal radioulnar joint (DRUJ). A Bowers hemiresection arthroplasty was performed with ancillary decompression of distal ulnar nerve in loge de Guyon. ▶Fig. 85.1 shows X-rays of the affected right wrist after the last operative intervention including a partial ulnar head resection.

85.2 Anatomic Description of the Patient's Current Status

For the stability of the DRUJ, the contact between the ulnar head and the sigmoid notch is essential. Without that condition, the force transmission of the wrist, especially in transversal direction, is dysfunctional. A painful impingement of the ulnar stump against the radius is typical sequelae (▶Fig. 85.2). In the presented case, hoisting of objects in orthogonal direction to the axis of the forearm was extraordinarily painful. For example, simple grip strength testing using a Jamar dynamometer (Saehan Corporation, Changwon, South Korea) was not possible preoperatively because of pain when holding the device. Without osteochondral support, the triangular fibrocartilage complex (TFCC), the capsuloretinacular flap, or other surgical options cannot stabilize the forearm properly. Hence, the feeling of instability of the former DRUJ is a frequent problem after ulnar head resection. In the presented case, forearm rotation was also restricted to 45–0–55 degrees for supination/pronation. Of course, this was an especially remarkable handicap after total wrist fusion (▶Fig. 85.3).

85.3 Recommended Solution to the Problem

The replacement of the ulnar head by prosthesis is a well-established procedure for failed partial or complete ulnar head resection arthroplasty. The therapeutic goal is to restore the anatomic conditions of the DRUJ, stabilize the parallel movement of radius and ulna, and facilitate pain-free forearm rotation. The implant (Herbert prosthesis, KLS Martin,

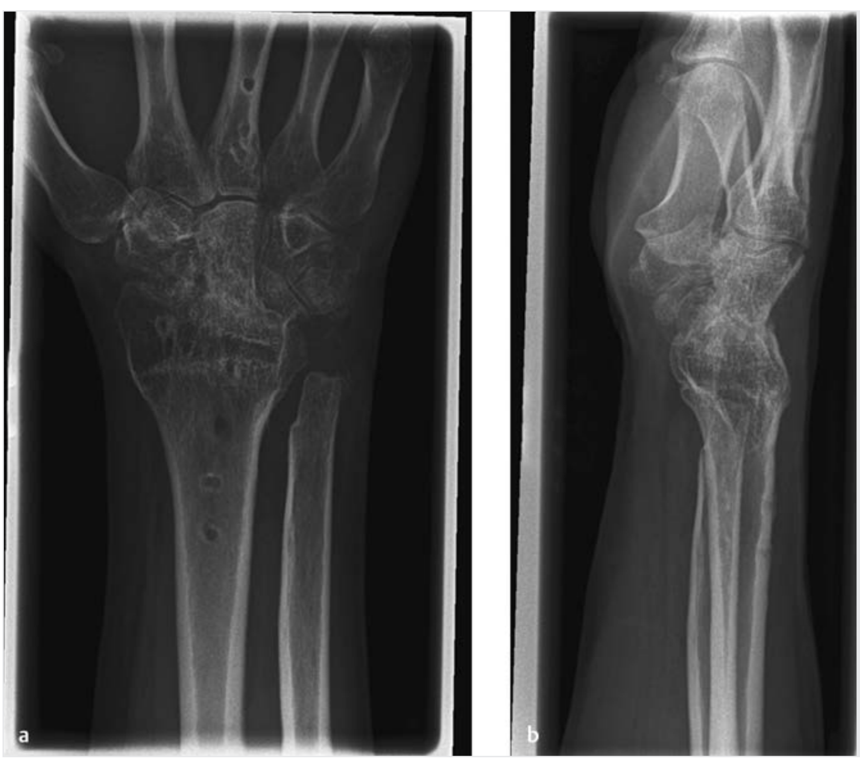

Fig. 85.1 (a, b) X-ray images of the right wrist after total wrist fusion and partial ulnar head resection. At rest, the ulnar stump is in correct position.

Tuttlingen, Germany) is a modular system with porous titanium shafts, collars of different lengths, and ceramic heads, available in three sizes each. The shaft osteo-integrates without the use of bone cement. Hemireplacement of the joint is sufficient, as it was shown that sigmoid notch remodels by itself over time in most cases (▶Fig. 85.4). Of course, a nonhinged prosthesis needs external soft-tissue stabilization. That is realized by an ulnar-based, capsuloretinacular flap. Longitudinal instability of the forearm, for example, following an Essex-Lopresti injury or resection of the radial head, and soft-tissue or ligamentous insufficiencies are contraindications for the use of this kind of prosthesis.

85.3.1 Recommended Solution to the Problem

- Replacement of the ulnar head with a distal ulnar (Herbert) prosthesis.

Fig. 85.2 X-ray under load (Lees–Scheker view).

- Stabilization of the prosthesis and the reconstructed v by an ulnar-based, capsuloretinacular flap.
- The sigmoid notch does remodel in most cases so that no surface replacement is necessary despite osteoarthritic changes.

85.4 Technique

Operation is performed under regional or general anesthesia with use of a tourniquet (300 mm HG) in a bloodless field.

The DRUJ is exposed dorsally from the bottom of the fifth extensor compartment by raising an ulnar-based, capsuloretinacular flap including the articular capsule, the retinacular tissue, and left dorsal parts of the TFCC. Special care must be taken in patients with an already resected ulnar head due to the loss of anatomic landmarks. The osteotomy of the distal ulna and removal of the ulnar head and neck is performed corresponding to the preoperatively planned size of the prosthesis. A trial prosthesis is inserted into the ulnar medullary canal. The trial prosthesis must fit accurately into the shaft. An ulnar minus situation of 1 to 2 mm at the former radius level should result. Now the sizer is replaced by the definitive shaft, collar, and head. The capsuloretinacular flap is reattached by transosseous sutures (Ethibond Excel USP 0, Ethicon, Somerville, MA, United States) to the dorsal rim of the sigmoid notch. The main steps of the procedure are shown in ▶Fig. 85.5.

Postoperatively, a long forearm splint that includes the elbow joint and the wrist and therefore prohibits supination and pronation (Muenster type Sugar Tong orthosis) is applied for 3 weeks. Subsequently, an ulnar encompassing forearm splint (Bowers' splint) is adjusted for another 3 weeks. Full load is not allowed for 12 weeks postoperatively.

85.4.1 Steps for the Procedure

1. Dorsal exposure of the DRUJ with raising of an ulnar-based, capsuloretinacular flap.
2. Osteotomy of the distal ulna and removal of the ulnar head and neck or the remnants of the distal ulna after prior resection.
3. Insertion of a trial prosthesis and verification of an ulna minus situation of 1 to 2 mm.
4. Assembly of the definitive modular prosthesis.
5. Stabilization of the prosthesis with the capsuloretinacular flap.

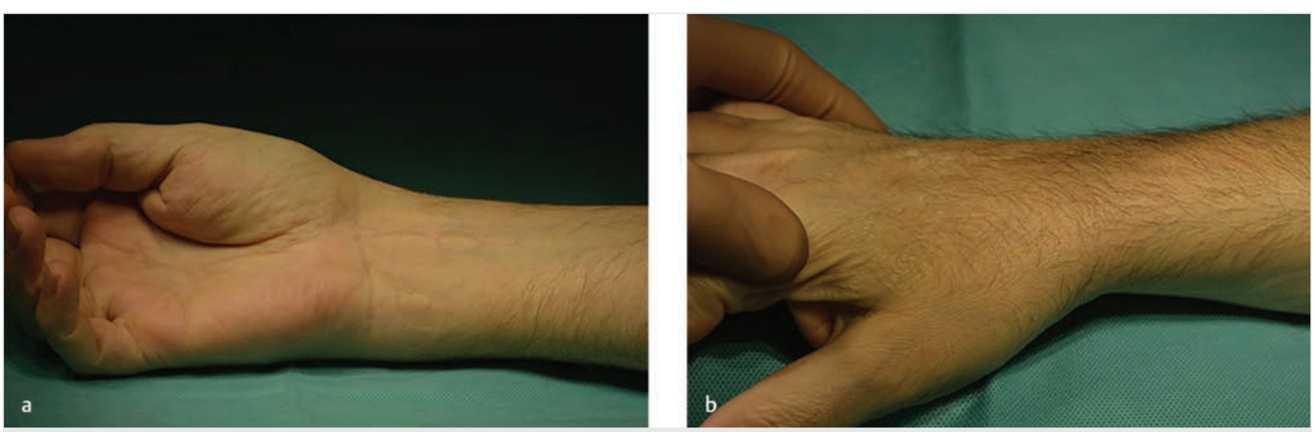

Fig. 85.3 (a, b) Limited painful forearm rotation (especially supination) before ulnar head replacement.

Fig. 85.4 X-ray images of the right wrist **(a, b)** immediately and **(c, d)** 3 months after ulna head replacement with a Herbert prosthesis (size 2).

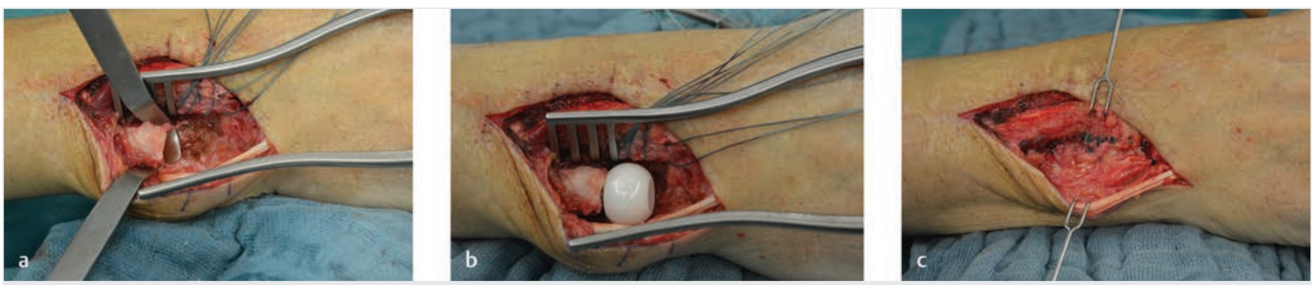

Fig. 85.5 Implantation of an ulnar head (Herbert) prosthesis. **(a)** Ulnar head and neck are resected and transosseous sutures are placed. **(b)** Definitive prosthesis is inserted. **(c)** The operation field is closed with the capsuloretinacular flap due to an anatomic reconstruction of the soft-tissue surroundings of the distal radioulnar joint.

85.5 Postoperative Photographs and Critical Evaluation of Results

Three months after implantation of ulnar head (Herbert) prosthesis, there were no radiological signs of prosthetic loosening or displacement. One year later, an accurate fit of the implant could also be found (▶Fig. 85.6).

A clinical follow-up after 15 months was also feasible. Functional parameters did improve. Active range of wrist motion for supination/pronation was 50–0–80 degrees and grip strength was 15 kg (▶Fig. 85.7). Pain under load did improve from 9/10 on visual analog scale preoperatively to 5/10 postoperatively, also when lifting objects in orthogonal direction to the forearm. Further on, there were remarkable handicaps in the activities of daily living due to total wrist fusion.

85.6 Teaching Points

- A stable DRUJ is mandatory for the function and load transmission of the wrist and forearm.
- Resection procedures, such as the Bowers operation, include significantly the risk of developing radioulnar instability and dynamic radioulnar impingement, which can lead to persisting pain and reduction of forearm rotation.
- In these situations, soft-tissue stabilization techniques for the ulnar stump are mostly of limited success.
- An ulnar head prosthesis, on the contrary, is a good option for secondary treatment of failed ulnar head resection.
- Contraindications are longitudinal instability of the forearm and inadequate soft-tissue coverage for the stabilization of the prosthesis.

Fig. 85.6 (a, b) X-ray images of the right wrist 15 months after ulna head replacement with a Herbert prosthesis.

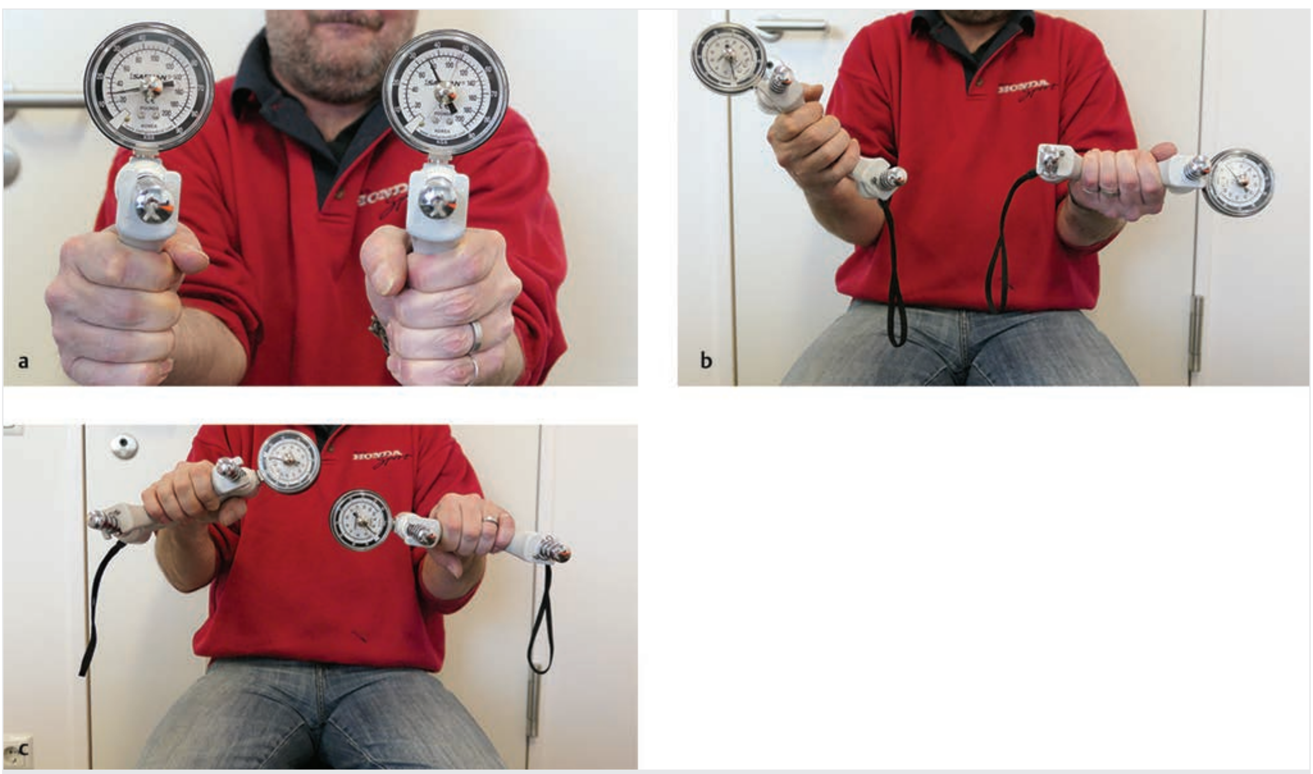

Fig. 85.7 (a–c) Functional results 15 months after implantation of an ulnar head (Herbert) prosthesis.

- The long-term results of these implants are so promising that a primary use for treatment of osteoarthritis of the DRUJ is also discussed frequently.
- To be brief: “It is good to have an ulnar head.”

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86 Dislocated Ulnar Head Prosthesis

Luis R. Scheker and Mark T. Shima

86.1 Patient History Leading to the Specific Problem

This 78-year-old patient presented with pain on his left wrist, localized to the ulnar side with limited pronation/supination and inability to lift weight. He retired from his job 13 years ago, but he was an avid wood worker, to which he devoted at least 8 hours of the day. Since his last surgery, he was unable to do any work with his left hand.

He was initially seen somewhere else because of severe pain in the left wrist. Weight bearing was most painful while holding the shoulder abducted, the elbow flexed at 90 degrees, and the forearm in neutral position.

Physical examination found no piano key sign, but pain with compression of the radius and ulna in the distal forearm, which had a grinding sensation while pronating and supinating the forearm.

Radiography found arthritis of the distal radioulnar joint (DRUJ), and after conservative therapy was exhausted, the patient opted for surgical intervention.

The ulnar head was excised, and a bipolar no constraint prosthesis was placed, including resurfacing of the sigmoid notch. In short period of time, the prosthesis was unstable, and three attempts were made to stabilize the implant, including brachioradialis wrap.

After the third procedure, the patient sought a second opinion. He consulted us because of his inability to use the hand, with feeling of instability, pain, and limitation on pronation and supination.

86.2 Anatomic Description of the Patient's Current Status

The patient was in obvious discomfort during our examination. Clinically, the ulnar part of the implant was prominent and the patient had pain with the most minimal contact in the area of the ulnar head.

Supination was more restricted than pronation, and both were painful. His pronation was measured at 30 degrees and supination at 5 degrees. The range of motion was limited mechanically as well as by pain, and he was unable to lift weight.

Initial radiographs in our clinic showed dislocation of the prosthesis (▶Fig. 86.1). The ulnar head component was dorsal, and the radial part was palmarly displaced. The sigmoid notch part of the implant was in good position. The reason of the radius being palmarly displaced is because there is no support for the radius as the triangular fibrocartilage (TFC) cannot be sutured to the metal head of the implant.

86.3 Recommended Solution to the Problem

The DRUJ is an intrinsically unstable joint due to the difference in arcs of the sigmoid notch and the seat of the ulnar head. Stabilization of this joint depends on the dynamic and static stabilizers. The radioulnar ligaments are responsible for the static stability of the DRUJ. The pronator is the main dynamic stabilizer of the DRUJ. The deep head of the pronator is particularly important in compressing the DRUJ through the radius's arc of motion about the ulna. The static stabilizers have been excised or defunctionalized during the course of the prosthesis placement, similar to a Darrach procedure. Some implants have holes distally for reinsertion of the TFC; it is unlikely that the TFC ligaments can be connected to metal, ceramic, or any other material and stay there.

The DRUJ can be saved when there is instability, but cartilage is present. Ligament reconstruction of the TFC can solve the problem by creating a new dorsal, palmar, or both ligaments following the direction of the damaged ligament(s). With this technique, the origin and insertion of the ligament is maintained and allows the original ligament to adhere to the grafted tendon that are placed on top of the TFC, restoring the function

Fig. 86.1 **(a, b)** Radiograph of the first visit to our office showing a subluxated nonconstraint implant of the left forearm in this 78-year-old man.

of the mechanoreceptors. This technique does not require wide opening of the DRUJ and only a 3-mm capsulotomy is required to find the fovea and the most distal part of the sigmoid notch, either dorsal, palmar, or both (▶Fig. 86.2). With this technique, the tendon inside the joint is nourished by the synovial fluid and the interosseous part is in cancellous bone from where the tendon gets its nourishment. When there is instability of the DRUJ, treatment should not be delayed.

If there is limited area of arthritis, as in the cases of post-traumatic arthritis, an ulnar shortening can change the contact between the radius and the ulna (▶Fig. 86.3). It makes the joint more congruent and distributes the forces evenly. Where the most proximal border of the seat of the ulna was pressing on limited area of the sigmoid notch, with the ulna shortening as shown in the picture, there is more evenly applied pressure and the pain settles. This technique has helped 57% of patients to achieve excellent to good results. An added benefit of ulnar shortening is that it helps tighten the TFC as well as decompressing the ulnar side of the carpus. If there is instability after ulnar shortening, ligament reconstruction could be added to the shortening. But when the cartilage is totally gone, the only solution is a joint replacement.

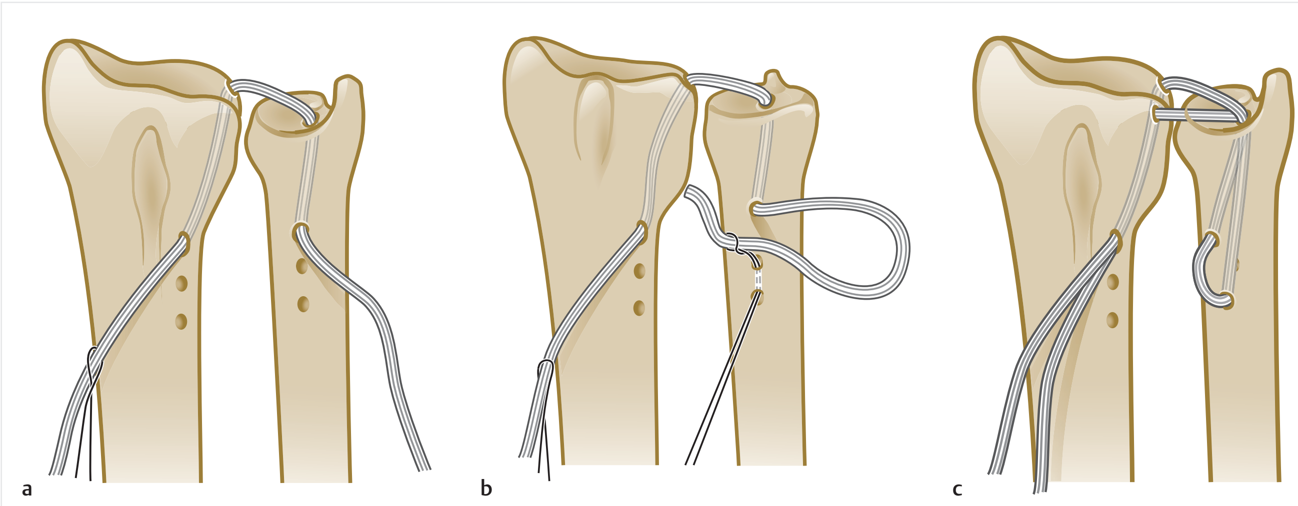

Fig. 86.2 The reconstruction of the triangular fibrocartilage (TFC) ligaments in chronic cases can be achieved with a tendon graft. Depending on the ligament that has been torn, the reconstruction can be done for the palmar ligament as shown in **(a)**. The dorsal ligament as shown in **(b)** or both ligaments as shown in **(c)**. With this type of intra-articular reconstruction of the ligaments of the TFC with a tendon graft, the origin and insertion are the same as the original ligaments.

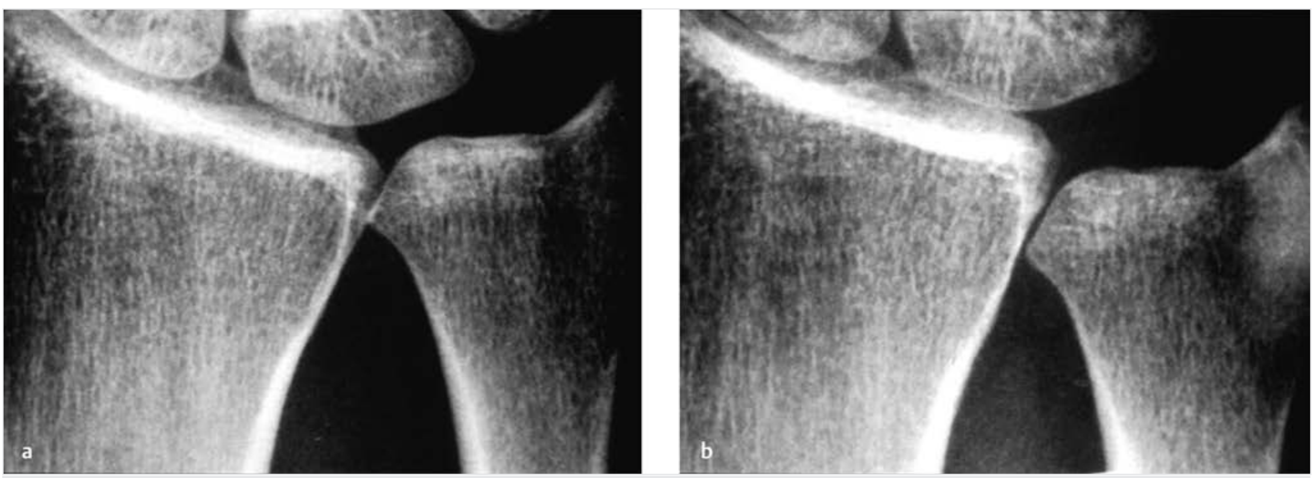

Fig. 86.3 (a, b) Ulnar shortening makes these two articular surfaces more congruent, extending the life of the distal radioulnar joint that had limited area of arthrosis.

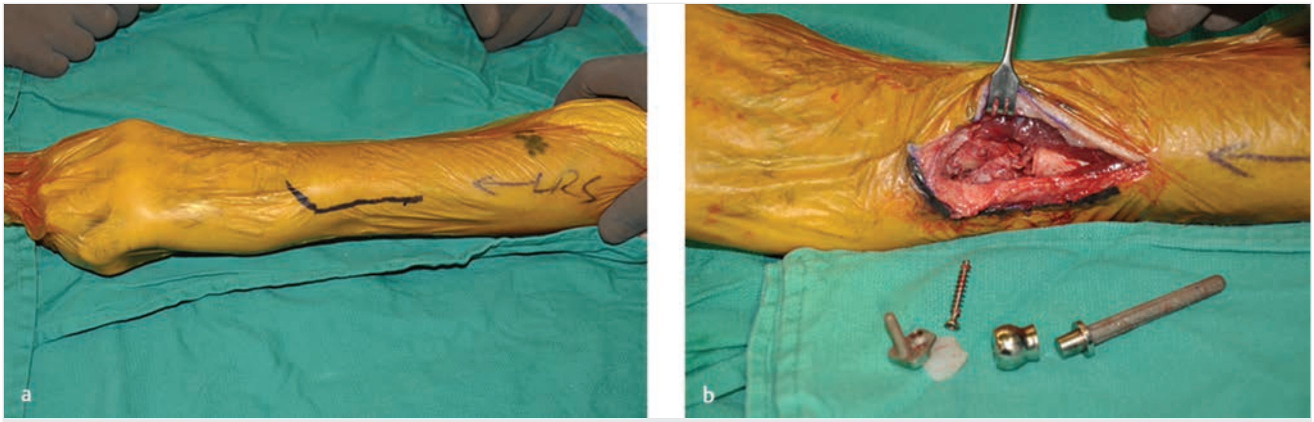

Fig. 86.4 **(a)** The previous incision is used to approach the distal radioulnar joint. **(b)** The nonconstraint implant is removed, and the area prepared for the semiconstraint implant.

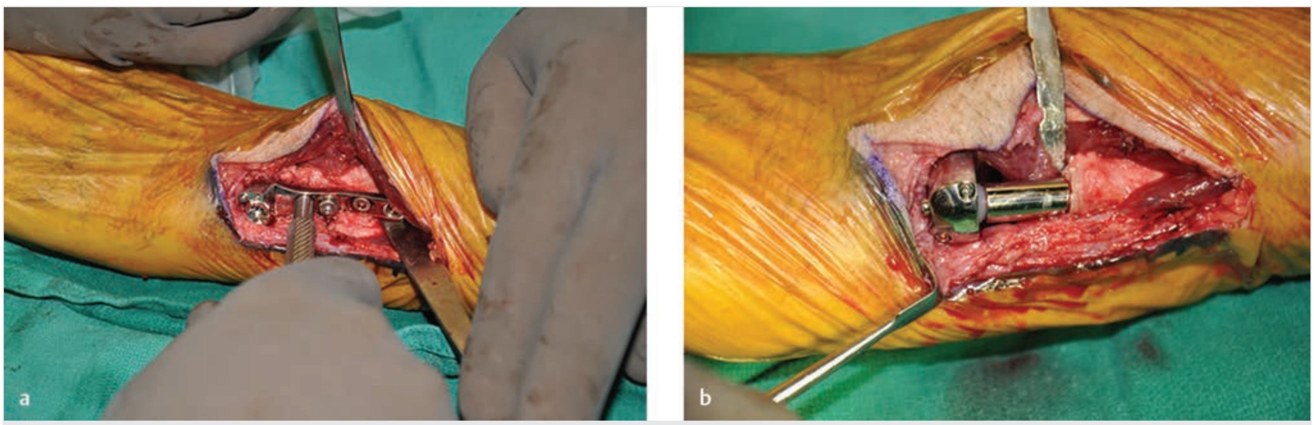

Fig. 86.5 **(a)** The radial plate being secured in alignment with the shaft of the radius. **(b)** A 2-cm extended ulnar stem was utilized to correct the missing distal ulna.

If the joint is totally arthritic but stable, a resurfacing of the ulnar head could be a solution if the sigmoid is maintained and not too deformed. But with severe arthritis, it is difficult to match a distorted sigmoid notch and the resurfacing implant. In these cases, a semiconstraint implant is a better solution because there is no need for ligament to be present, nor is there the need for the sigmoid notch to be present as the semiconstraint implant replaces all three elements of the DRUJ. In the case of the patient in ▶Fig. 86.4, the patient had subluxation of the nonconstraint implant; he was a 78-year-old very active man and an excellent woodworker. Because of his age, some authors have recommended a less invasive approach, as described later.

Our recommendation, regardless of the age, is a semiconstraint prosthesis that does not need ligaments for stability, restores the ability to lift weight, and allows the patient to use the operated extremity as soon as the axillary block has worn off.

86.3.1 Recommended Solution to the Problem

- Take the prosthesis out and leave it as a Darrach procedure. But this leads to dynamic impingement as shown by Lees and Scheker.
- Use of interposition arthroplasty with an Achilles tendon allograft. This tends to fail as the patient starts to lift weights.
- Make a one-bone forearm. This is extremely limiting to the patient's activities of daily living.

86.4 Technique

The previously implanted device was removed through the original scar, and all the tissue used for stabilization was removed and a new implant was inserted (▶Fig. 86.5). The important part of the surgery is to align the radial plate of the implant with the shaft of the radius. To achieve this, it is necessary to use an image intensifier during the procedure. Once the radial plate is secured in the right position, the missing bone of the ulna is measured and the defect corrected with an extended ulnar stem up to 4 cm. The diameter of the stem varies from 4 to 6 mm.

86.4.1 Overview of the Technique

The technique for implantation of the semiconstraint device includes the following:

- The interosseous membrane is detached from the interosseous crest of the radius for approximately 6 cm.

Fig. 86.6 This is an X-ray taken 6 weeks after surgery. At this stage, the patient was lifting heavy objects and returning to his hobby as a wood worker.

- Preparation of the distal radius at the level of the DRUJ by removing the volar lip of the sigmoid notch. This allows the implant to be in the same direction of the shaft of the radius and avoid dorsal angulation.
- The trial plate is positioned in the desired location and alignment and confirmed with X-rays. The screw hole and radial peg hole are created in such a way that the permanent plate will be able to be positioned correctly. It is secured with three to five screws, depending on the size of the radial plate.
- The ulna is prepared by measuring the ulna defect and placing to the most proximal centimeter of the reference guide. If the defect is 1.5 cm, then it is cut at the 2-cm level.
- A guidewire is placed in the ulna medullary canal and a drill bit of the required diameter is used to create the canal for the ulna stem. Then the reamer provides the shape of the ulna stem.
- After the ulnar stem is press fit in the medullary cavity of the ulna, the plastic ball is inserted at the end of the stem and the cover secured with a screw. The patient is able to use the extremity as soon as the anesthesia wears off.

86.5 Postoperative Photographs and Critical Evaluation of Results

The postoperative X-rays demonstrated stable fixation and good prosthetic position (▶Fig. 86.6). The patient recovered excellent range of motion and strength with minimal residual pain at the 1-year follow-up (▶Fig. 86.7). The new implant remained stable. The patient was able to resume all activities of daily living.

86.6 Teaching Points

- The DRUJ is the most important joint for the function of the forearm. It is possible to do everyday activities with a fused radiocarpal joint, but not with a radioulnar fusion.
- The ulna supports the radius actively and passively.
- Excision of the ulnar head leads to impingement.
- When there is instability of the DRUJ, it should be treated early. After 6 months, the ulnar head cartilage is permanently damage.
- Ulnar shortening is a great procedure to extend the life of the DRUJ.

Fig. 86.7 Just 6 weeks after replacement of the dislocated distal radioulnar joint for a semiconstraint implant, the patient recovered **(a)** flexion and **(b)** extension of the wrist, **(c)** full pronation and **(d)** supination, but more importantly, he can **(f, g)** lift heavy objects as the forearm feels stable.

- When seeing a patient with DRUJ instability within 4 weeks of injury, placing an above-elbow cast in the neutral position could solve the problem for that patient.
- Examination of the DRUJ instability is mainly clinical.

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Part XXIX

Problems with Distal Radius Fractures

87 Distal Radius Fracture Malunion *408*

88 Distal Radius Fracture Nonunion *412*

89 Troublesome Lunate Facet *415*

90 Troublesome Lunate Facet: Treatment with Microvascular Techniques *419*

XXIX

87 Distal Radius Fracture Malunion

Karl-Josef Prommersberger

87.1 Patient History Leading to the Specific Problem

A 75-year-old man presents with a malunited, dorsally tilted distal radius fracture (▶Fig. 87.1a, b). He complained of decreased wrist motion and forearm rotation, and pain on the ulnar side of the wrist. He fractured the distal radius a year ago slipping in his garden (▶Fig. 87.1c, d). The fracture was treated conservatively with immobilization in a cast for 4 weeks. After removal of the cast, the wrist appeared deform. Physical therapy did not result in a satisfied wrist and forearm function.

87.2 Anatomic Description of the Patient's Current Status

The patient had a malunited extra-articular distal radius fracture with dorsal tilt of the articular surface of the radius of 30 degrees, and an ulna-plus of 6 mm. There was no severe osteoarthritis of the radiocarpal and the distal radioulnar joint (DRUJ) as shown by MRI (▶Fig. 87.2). There was an osteoarthritis of the first carpometacarpal (CMC 1) joint grade 2 according to the Eaton and Littler classification, and a sclerosis of the radial artery. It is true that not all nonanatomically aligned distal radius fractures, especially in elderly, low-demand patients, result in a poor functioning outcome. In this patient, the malunion of the distal radius resulted in a limited wrist motion with an extension/flexion arc of motion of 60/20 degrees (uninjured side 60/60 degrees) and an ulnar/radial deviation of 20/10 degrees (uninjured side 40/20 degrees). Forearm supination/pronation was decreased to 60/60 degrees compared to the uninjured side with 90/90 degrees. In addition, the patient complained of pain on the ulnar side of the wrist with activity of 5/10 on the visual analog scale.

Normal wrist biomechanics depend upon maintenance of the anatomical position of the distal end of the radius in relation to the carpus and the distal end of the ulna. The

Fig. 87.1 (a, b) Malunited extra-articular distal radius fracture of the right wrist with dorsal tilt of the articular surface of the radius of 30 degrees, and an ulna-plus of 6 mm. In addition, there is an osteoarthritis of the first carpometacarpal (CMC 1) joint grade 2 according to the Eaton and Littler classification, and a sclerosis of the radial artery. **(c, d)** Radiographs of the original fracture showing a much less dislocation as seen 1 year later after conservative treatment of the fracture.

Fig. 87.2 (a, b) MRI shows no severe osteoarthritis of the radiocarpal and the distal radioulnar joint.

osseous deformity of the distal radius influences the normal mechanics of the radiocarpal joint producing a limitation of the extension–flexion arc of motion. Tilting and shortening of the distal radius cause incongruity of the DRUJ and reduction of radioulnar contact area. Radial shortening in relation to the ulna increases the strain in the triangular fibrocartilage complex and may result in a disruption of the deep portion of the dorsal radioulnar ligament. These factors limit the arc of forearm rotation.

Furthermore, the malalignment affects the normal load transmission not only through the radiocarpal joint but also across the whole wrist joint. Dorsal tilting of radial surface reduces the joint contact area by shifting axial loading through the wrist dorsally and ulnarly. So the pressure distribution on the radial articular surfaces becomes more concentrated and may represent a prearthritic condition of the wrist joint. The force borne by the ulna increases with shortening of the radius and dorsal tilting of the articular surface. As the angulation of the distal radius fragment increases from 10 degrees of palmar tilt to 45 degrees of dorsal tilt, the load through the ulna increases from 21 to 67% of the total load. Lengthening of the ulna relative to the radius by 2.5 mm increases the force borne by the ulna from 18.4 to 41.9% of the total axial load.

87.3 Recommended Solution to the Problem

One should first realize that this problem could be prevented by a careful initial treatment. Because there was only a minor dislocation at the time of injury, the chosen conservative treatment was justified. However, because the risk of a secondary dislocation is greater in elderly patients, there was a need for a close follow-up. This was missed. A close follow-up with radiographs of the wrist, that is, after 4, 7, 11, 21, and 28 days before removing the cast, will show the secondary dislocation. It will give the chance for a surgical intervention before the bone heals. At least it gives the opportunity to talk to the patient over the potential risk of a malunion leading to discomfort with limitation of wrist and forearm motion, reduced grip strength, and pain.

Now, however, to restore the anatomical relationship between the distal radius and the carpus and the distal ulna, the distal radius needs to be corrected. Due to the huge loss of length of the radius with respect to the distal ulna, there is a need for a complete osteotomy and lengthening of the radius. The osteotomy gap can be handled in different ways. However, because of the patient's age and the need for lengthening of the radius, a corticocancellous bone graft from the iliac crest might be the most secure option. For the osteotomy, the radius can be approached from dorsal, radial, or palmar. While in former times most authors prefer to correct a dorsally tilted malunion of the distal radius from dorsally, now a palmar approach is used more and more, what we have done since the middle of the 70 s of the last century.

87.3.1 Recommended Solution to the Problem

- The radius needs to be completely osteotomized.
- The osteotomy gap can be filled with a corticocancellous bone graft, harvested from the iliac crest.
- The radius can be fixed with a locking plate.
- This problem could be prevented by a closed follow-up after the initial fracture and a surgical intervention after secondary dislocation.

87.4 Technique

See ▶Video 87.1.

A **Y**-shaped incision with the long leg of the Y overlying the radial artery is carried out over the distal radiopalmar aspect of the wrist. The oblique leg of the Y on the palmar side extends to the middle crease of the wrist where it crosses the flexor carpi radialis. The dorsal leg of the Y ends at the radial border of both radial wrist extensors. Throughout the whole procedure, care is taken to protect the superficial branch of the radial nerve, which remains attached to the subcutaneous flap. The first extensor compartment and any additional subcompartment are released. The third dorsal compartment is opened and the extensor pollicis longus tendon is transposed subcutaneously. The tendon of the brachioradialis muscle is partially or, if necessary, totally detached from the radius. The pronator quadratus, together with the flexor pollicis longus muscle and the radial artery, is retracted from the radius to the ulnar side.

The used special radius correction plate is positioned as far distally as possible and fixed by a locking screw through the middle of the three distal holes. The plate must be positioned according to the angle of correction of the ulnar inclination. Therefore, the plate is pivoted around the middle of the three distal holes until the angle between the radial border of the radius and the radial border of the proximal part of the plate corresponds to the angle of correction of the ulnar inclination. After positioning of the plate, the radial and ulnar distal screw holes are drilled and locking screws are inserted. After distal fixation of the plate, the stem of the plate sticks out from the radius. The angle between the shaft of the radius and the stem of the plate corresponds to the necessary correction of the radius in the sagittal plane.

With the plate in place, the site of the osteotomy is marked with an osteotome. It should be as close to the original fracture site as possible and lie just proximal to the distal three screws. The osteotomy is carried out with use of an oscillating saw. The angle of osteotomy in both planes in relation to the long axis of the radial shaft should be half the planned angle of correction. This has proved to be advantageous; while opening up the osteotomy a double-trapezoid gap is created, which eases the fitting and wedging in of the bone graft. If a smaller angle is chosen, the distal fragment needs to be tilted more with the result that the long axis of the carpus lies palmar to the axis of the forearm. Therefore, load transmission through the radiocarpal joint is still affected. If one chooses a greater angle for the osteotomy, the distal fragment becomes longer. This, in turn, results in a posterior humpback when the fragments are spread.

The osteotomy gap is opened up with a spreader inserted between the posterior cortices of the fragments. This brings the stem of the plate in contact with the shaft of the radius as soon as the distal fragment has reached its proper position of correction. With two plate-holding forceps, the plate is fixed temporarily to the radial shaft. A double-trapezoid, bicortical bone graft harvested from the iliac crest is now inserted into the widened gap. However, the use of cancellous bone graft will be enough. The plate is then fixed definitively to the radius. A lag screw is inserted through the plate into the bone graft. The extensor retinaculum will not be sutured and the tendon of the extensor pollicis longus remains subcutaneously. The pronator quadratus muscle is loosely sutured to the tendon of the brachioradialis muscle. After a careful hemostasis, the wound is closed. The wrist is immobilized in a palmar plaster splint until the wound has healed properly.

87.4.1 Steps for the Procedure

1. A radiopalmar approach can be used.
2. Opening of the first extensor compartment and (partial) detachment of the brachioradialis tendon will facilitate the procedure.
3. The pronator quadratus, together with the flexor pollicis longus and the radial artery, is retracted from the radius to the ulnar side.
4. The plate is positioned as far distally as possible and fixed by a screw in the middle of the three distal holes.
5. The plate must be positioned according to the angle of correction of the radial inclination.
6. After positioning the two other distal screws are inserted.
7. After distal fixation of the plate, the stem of the plate forms an angle with the shaft of the radius that corresponds to the necessary correction in the dorsopalmar plane.
8. The osteotomy should be as close to the original fracture site as possible.
9. The osteotomy is performed by an oscillating saw.
10. The angle of the osteotomy in both planes in relation to the long axis of the radius should be half the planned angle of correction.
11. The osteotomy gap is opened with a spreader inserted between the posterior cortices of the fragments.
12. This brings the stem of the plate in contact with the shaft of the radius as soon as the distal fragment has reached its proper position of correction.
13. After control of the length of the radius by fluoroscopy, the plate is definitively fixed.
14. A bicortical bone graft from the iliac crest is inserted into the osteotomy gap and fixed with a lag screw.
15. The wrist is immobilized in a palmar plaster splint until the wound has healed properly.

87.5 Postoperative Photographs and Critical Evaluation of Results

Performing the procedure to correct the distal radius results in a more anatomical position of the distal radius with respect to the carpus and the distal ulna. In fact, done appropriately, this improves wrist and forearm motion, reduces pain, improves grip strength, and leads to a better appearance of the wrist joint.

Two years after the corrective osteotomy of the distal radius, the patient wished to have the plate to be removed, what is common in European countries (▶Fig. 87.3). At this time, extension/flexion arc of motion measured 60/60 degrees, ulnar/radial deviation measured 25/20 degrees, and forearm supination/pronation was 80/70 degrees. The patient was pain free, and grip strength increased to 90% of the uninjured side. Radiographs after plate removal showed the radius healed with an ulna-plus of 1 mm, a slightly overcorrected ulnar inclination, and a neutral dorsopalmar tilt of the radius.

87.6 Teaching Points

- Dorsally tilted malunion of the distal radius can be corrected from the palmar site.
- To lengthen the radius, a complete osteotomy is required.
- Dealing with the osteotomy gap depends on several factors, for example, bone quality and quality of bone fixation. Even in huge gaps, a bicortical bone graft from the iliac crest is still a good option.
- Even elderly patients benefit from a corrective osteotomy of a distal radial malunion.

Fig. 87.3 (a, b) Radiographs after plate removal shows the radius has healed with an ulna-plus of 1 mm, a slightly overcorrected ulnar inclination, and a neutral dorsopalmar tilt of the radius.

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88 Distal Radius Fracture Nonunion

Richard J. Tosti and Jesse B. Jupiter

88.1 Patient History Leading to the Specific Problem

A 78-year-old woman suffered a left distal radius fracture 25 months ago. She was initially treated with cast immobilization. She has noticed progressive deformity in the left wrist, which is now flexed and radially deviated (▶Fig. 88.1a). She had pain and crepitus over the distal radius, 5% grip strength compared to the right hand, and limited ability to rotate, flex, or extend the wrist. Radiographs showed an atrophic, ununited, extra-articular fracture of the distal radius with volar and radial angulation (▶Fig. 88.1b).

88.2 Anatomic Description of the Patient's Current Status

This patient has distal radius fracture nonunion and a deformity consistent with posttraumatic radial club hand. Historically, nonunion of the distal fracture is quite rare comprising 0.0003 to 0.2% of distal radius fractures. Injury factors associated with nonunion of long bones are open fracture, high-energy fracture, soft-tissue interposition, infection, and pathologic fracture. Concomitant ulna fracture may also increase the risk of nonunion in the radius due to a more global injury associated with greater forearm instability. Patient comorbidities, tobacco use, and alcoholism may additionally affect healing. Potential iatrogenic causes for nonunion include inadequate immobilization, over-distraction with external fixation, devascularization of bone fragments during surgery, inadequate reduction or fixation, and failure to bone graft large comminuted defects.

Most individuals achieve bone union by 3 months. A surgeon should suspect distal radius nonunion if continued pain and progressive deformity in the wrist are observed. Failure of the bone to achieve union by 4 months is considered a delayed union, while failure at 6 months is considered a nonunion. Stable, fibrous nonunions may be asymptomatic but have persistent fracture lines on radiography. Unstable, synovial nonunions are often painful, unstable, and associated with soft-tissue contracture, weakness, and deformity; radiographs show bone loss and atrophy. Unstable or symptomatic nonunions may be considered for surgical correction.

88.3 Recommended Solution to the Problem

Given the significant limitation of function, nonoperative management is only reserved for ill or elderly patients. Some surgeons have recommended wrist arthrodesis, especially if less than 5 mm of subchondral bone is supporting the lunate facet in the distal fragment. However, Prommersberger et al reported encouraging outcomes irrespective of size. While a smaller distal fragment certainly increases the technical difficulty of the surgery, the radial column often has sufficient mass, and purchase can be enhanced by angular stable implants and orthogonal plates. As the radiocarpal and midcarpal joints are often undisturbed, wrist motion can be preserved by restoring the radius; we therefore recommend reserving wrist arthrodesis for lower demand patients or failed nonunion surgery.

Presurgical planning should include orthogonal radiographs at minimum. Stress views in flexion and extension may show motion of the fragments at the fracture site. Additionally, a CT scan can be helpful for diagnosis and presurgical planning. The size and quality of the bone fragments should also be noted. The surgeon should note the disturbance in normal radiographic parameters of radial height, inclination, volar tilt, and ulnar variance, and plan realignment by templating from normal radiographs of the contralateral wrist. An extensile approach with soft-tissue releases should be anticipated. A small skeletal distractor may be required for excessive shortening. Lengthening of the radius may be performed as a one- or two-staged procedure. Bone loss should also be anticipated and may be replaced with graft using iliac crest or the resected distal ulna. Surgeons may decide to use a variety of fixation strategies, which include external fixation, volar plating, dorsal plating, orthogonal plating, or bridge plating. Currently, our preferred fixation method is orthogonal plating

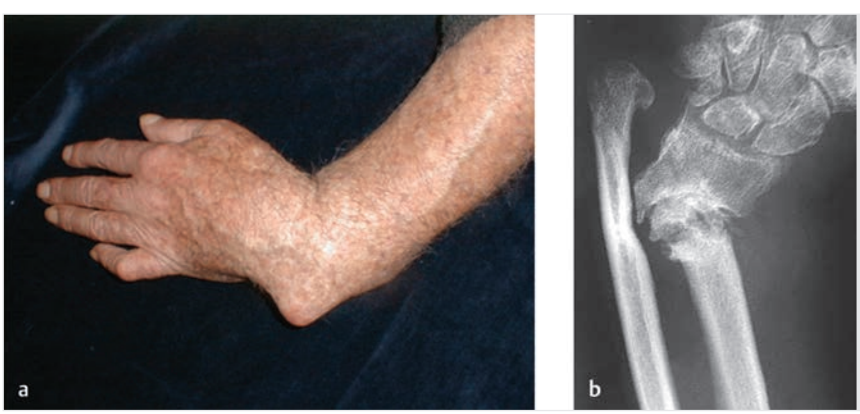

Fig. 88.1 **(a)** Preoperative photograph showing the "radial club" hand deformity. **(b)** Anteroposterior and lateral radiographs showing an atrophic nonunion with radial and volar angulation.

with fixed angle implants. After fixation, attention should be turned to the ulna and distal radioulnar joint (DRUJ). Stability from lengthening and aligning the radius is possible but often difficult. Options for addressing the ulna most commonly include ulnar-shortening osteotomy, hemiresection/interposition (Bowers' arthroplasty), and resection arthroplasty (Darrach's procedure).

88.3.1 Recommended Solution to the Problem

- Total wrist arthrodesis is an option for lower demand patients.
- Modern implants and reduction/fixation techniques can achieve union while sparing wrist motion and should be attempted in a functional patient.
- The ulna can be addressed at the time of index surgery or in a subsequent operation if symptomatic.

88.4 Technique

Approach the radius through a volar Henry exposure. The fracture fragments are exposed and debrided with a rongeur, curette, or a burr. The intramedullary canals should also be recannulated to facilitate ingress of osteogenic factors. The brachioradialis and the flexor carpi radialis can be Z-lengthened if soft-tissue release is required to obtain length. The dorsal soft-tissue, DRUJ capsule, and wrist capsule may also require release. Provisional alignment can be gained with pins or a skeletal distractor. A small skeletal distractor (Synthes, Paoli, PA) may be used to facilitate reduction and gain length if excessive shortening (generally >12 mm) is present. We apply 2.5-mm Schanz pins on the radial side of the proximal and distal fragments (▶Fig. 88.2a). The radius is then secured using fixed-angle orthogonal plates. One plate is secured to the radial column where the bone is most generous. The second plate is usually placed volarly but may be secured dorsally depending on the fracture pattern and bone stock. Although some authors have reported success in restoring the DRUJ, we usually resect the distal ulna. Often, the amount of lengthening needed to restore the DRUJ will create a large bone gap. Additionally, malreduction of the joint or degenerative changes produce pain and arthrosis, which may require additional procedures. An osteotomy just proximal to the sigmoid notch is created, and the head of the ulna is resected subperiosteally, preserving the triangular fibrocartilage complex. The resected distal ulna can be used as autograft by packing it into the fracture site (▶Fig. 88.2b). A layered closure is performed, and a postoperative volar splint is worn for 2 weeks. Thereafter, a plastic splint is molded and worn for an additional 4 weeks except for hygiene and daily active motion exercises. At 6 weeks, the splint is discontinued and assisted motion is begun. Strengthening begins when radiographic union is achieved.

88.4.1 Steps for the Procedure

1. Approach the radius through a volar Henry exposure.
2. Debride fracture fragments.
3. Recannulate intramedullary canals.
4. Provisional alignment can be gained with pins or a skeletal distractor.
5. Apply pins on the radial side of the proximal and distal fragments.
6. Secure the radius using fixed-angle orthogonal plates.
7. Create an osteotomy just proximal to the sigmoid notch; head of the ulna is resected subperiosteally.
8. Layered closure.

88.5 Postoperative Photographs and Critical Evaluation of Results

This patient initially had limited range of motion and grip strength preoperatively. Her fracture united, and she recovered 80 degrees of flexion/extension arc, 120 degrees of pronosupination, and 20 degrees of ulnar/radial deviation; full motion was regained in the hand (▶Fig. 88.3), and grip

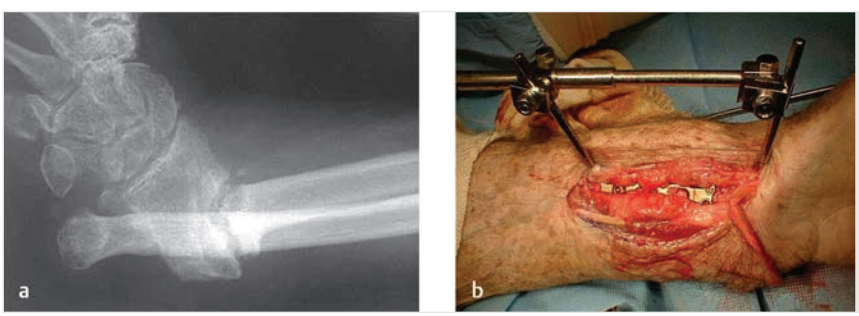

Fig. 88.2 (a) A small skeletal distractor can be a useful reduction tool. **(b)** Restoration of carpal alignment with orthogonal plating and distal ulna resection.

Fig. 88.3 (a, b) Postoperative alignment and motion.

strength was measured at approximately 70% of the contralateral side at 38 months. The optimal treatment for distal radius nonunion is still debated, as case series reporting outcomes for corrective osteotomies are few. Segalman and Clark reported their experience with 12 ununited fractures of the distal radius concluding that the technical difficulty of securing a distal fragment shorter than 5 mm might influence the surgeon to opt for a total wrist arthrodesis. However, with modern implants and surgical technique, secure fixation and union can be achieved, which spares wrist motion for the more functional patient. Prommersberger et al compared 13 nonunions with greater than 5 mm of subchondral bone to 10 nonunions with less than 5 mm of subchondral bone and found no significant radiographic or functional differences; the authors concluded that 22/23 nonunions healed. A few studies have confirmed similar findings: a reasonable rate of union with preservation of wrist motion is achievable—recommending total wrist arthrodesis be reserved for failed nonunion surgery.

88.6 Teaching Points

- Approach the radius with a volar radial Henry approach.
- Anticipate soft-tissue contracture release.
- Consider using a small skeletal distractor for significant radial shortening.
- Debride the nonunion and secure with fixed-angle orthogonal plates.
- Assess the DRUJ and consider an ulnar-sided procedure (often a Darrach).
- Bone graft the nonunion site using autograft from the resected ulna or iliac crest.

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89 Troublesome Lunate Facet

Hermann Krimmer

89.1 Introduction

In recent years, the treatment of distal radius fracture has seen a significant change in trend, moving away from conservative treatment toward surgical treatment. With the introduction of fixed-angle plates, and ultimately also multidirectional fixed-angle plates, it was possible to solve many of the problems related to osteoporosis and severely comminuted fractures. Palmar fixed-angle plate fixation now represents the preferred method of osteosynthesis and allows long-term anatomical retention of the articular surface, especially in the cases of intra-articular involvement.

However, we still see anatomically reduced and fixed fractures, where during follow-up severe displacement occurs. Especially the lunate facet is of special importance as it represents the area where the strong radiocarpal ligaments insert, which stabilize the carpus. Fractures in this area can be diagnosed as ligament avulsion leading to instability of the proximal carpal row due to lack of bony and ligamentous support. If these fragments are not properly fixed, a high risk for secondary dislocation with carpal subluxation may lead to significant problems. Depending on the size of these fractures, lunate facet and palmar rim fractures are classified.

To detect and adequately treat these fracture patterns, CT scans are mandatory as these fractures are often underestimated and options for conservative treatment are lacking. Standard palmar plates are unable to safely capture and support these fragments. Special devices have been developed for the lunate facet by the watershed plate design and flexor pollicis longus (FPL) plate design (see ▶ Fig. 89.6), where the special shape allows mounting the plate far distally avoiding the risk for flexor tendon irritation. Palmar rim fractures, however, cannot be stabilized by single plates and need additional fragment-specific fixation by small screws or hook plates.

In the case of secondary dislocation with carpal subluxation, decision-making for treatment may be difficult. Early revision with anatomical restoration is indicated, however, as it is challenging. Alternatively, early salvage procedures by partial radiocarpal fusion may be performed.

89.2 Patient History Leading to the Specific Problem

A 42-year-old man sustained an intra-articular distal radius fracture with involvement of the lunate facet (▶ Fig. 89.1).

89.3 Anatomic Description of the Patient's Current Status

Following reduction and cast immobilization, a CT scan was performed, which confirmed the intra-articular involvement and the fractured lunate fossa, however, without severe palmar displacement (▶ Fig. 89.2a, b). Fracture fixation was done through the typical palmar approach using a conventional T-plate with one row distally where the postoperative CT scan demonstrated anatomical reduction (▶ Fig. 89.2c, d).

Due to increasing pain during mobilization, radiograph control was performed, which surprisingly demonstrated secondary dislocation with palmar subluxation of the whole carpus and the palmar rim (▶ Fig. 89.3). Additionally, the situation was checked by CT scan demonstrating subluxation of the carpus over the distal part of the plate with significant intra-articular step-off (▶ Fig. 89.4).

Fig. 89.1 Preoperative radiographs. **(a)** Posteroanterior view. **(b)** Lateral view.

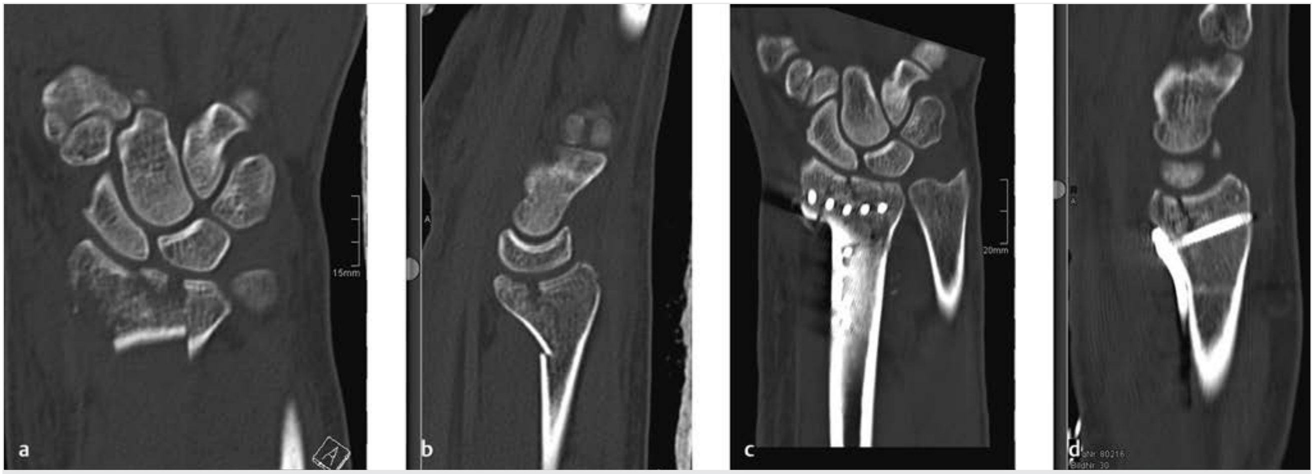

Fig. 89.2 Preoperative CT scans show **(a, b)** involvement and dislocation of the lunate facet and **(c, d)** anatomical restoration by a conventional fixed-angle T-plate.

Fig. 89.3 Postoperative radiographs show palmar dislocation of the lunate facet of the radius. **(a)** Posteroanterior view. **(b)** Lateral view.

89.4 Recommended Solution to the Problem

Eight weeks posttrauma, the patient was referred to our unit. Clinically, the patient complained of pain and loss of motion (20–0-10 degrees of range of motion [ROM]). In order to avoid partial wrist fusion with the need of an appropriate bone graft for restoration length and reduction of the carpus, it was decided to undergo early revision with the aim of anatomical restoration at least to realign the carpus to the radius.

89.5 Technique

The palmar approach was used again and after removal of the plate, the palmar rim was osteotomized, realigned with the carpus, and fixed with four 1.5-mm screws. Additionally for further support of the lunate facet, a so-called FPL plate (Medartis AG, Basel, Switzerland) was used, which allows a far distal position due to the sparing gap for the FPL tendon (▶Fig. 89.5). Keeping in mind that revision cases have an inherent risk for secondary dislocation, an additional two temporary Kirschner's wires from the radius to the scaphoid and lunate for fixation of the entire carpus have been inserted (▶Fig. 89.6). The wrist was immobilized in a thermoplastic splint for 6 weeks. After removal of the Kirschner wires, mobilization was started. Radiographic control 3 months later showed a realigned carpus in a stable position with no signs of intra-articular step-off. However, slight ulnar plus situation, but at that time with no complaints, was detected. Clinically, the patient was pain free with ROM of 50–0-40 degrees (extension/flexion) and 80–0-70 degrees for pronation/supination and grip of 80% of the opposite site. He already had started to work in his profession as a blue-collar worker in a metal company.

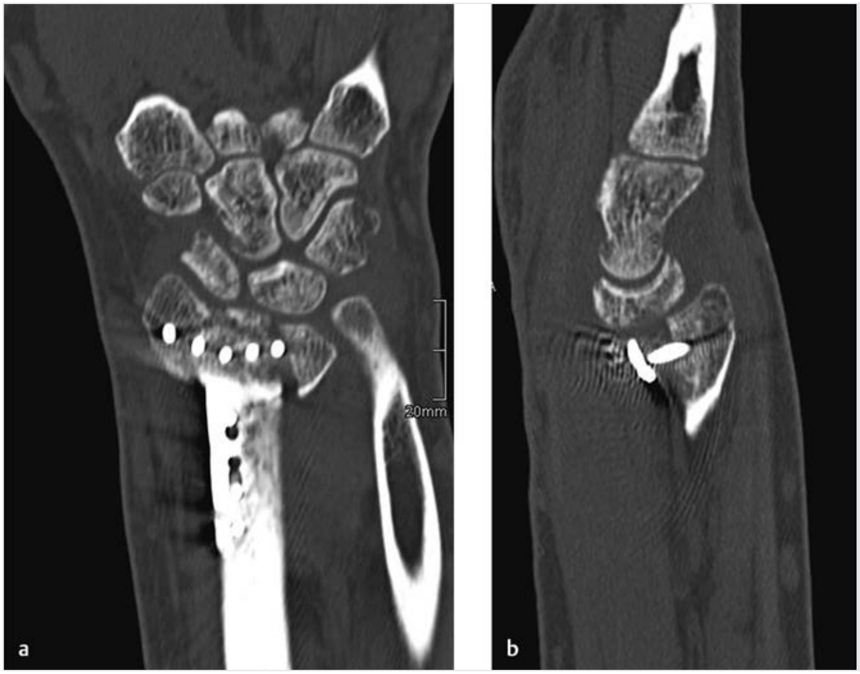

Fig. 89.4 (a, b) CT scan with significant step-off.

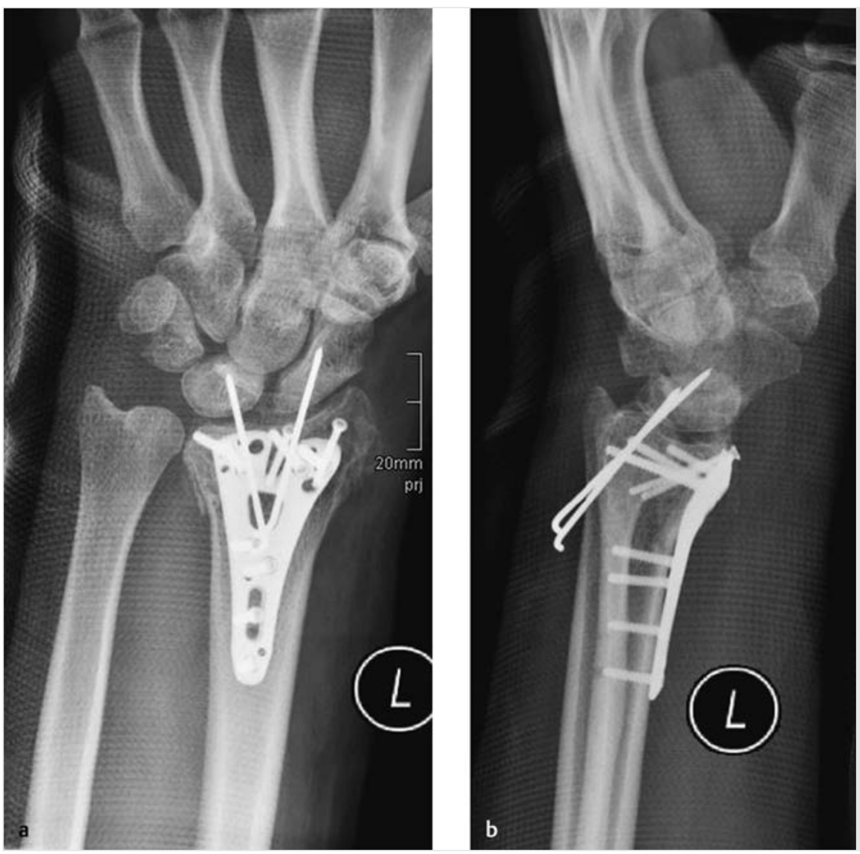

Fig. 89.5 (a, b) Posteroanterior and lateral X-rays after revision with fixation of the palmar rim by four 1.5-mm screws and additional support of the lunate facet by the flexor pollicis longus plate and temporary fixation of the carpus with two Kirschner's wires.

89.6 Teaching Points

- CT scan is mandatory to evaluate precisely the intra-articular fracture patterns.
- In the case of lunate facet involvement or palmar rim fractures, there is no way for conservative treatment.
- Rigid support can be done by special plates or, in the case of rim fractures, by fragment-specific fixation with small screws or hook plates.
- If secondary dislocation occurs after failed treatment, early revision should be performed to avoid salvage procedures.
- Always check radiocarpal stability; when in doubt, go for temporary radiocarpal fixation by Kirschner's wires.

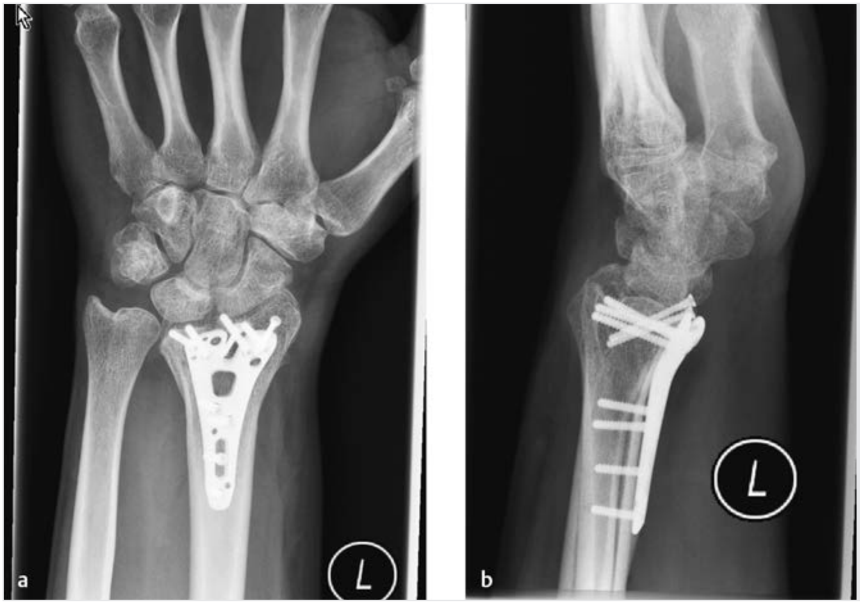

Fig. 89.6 (a, b) Final result with realignment of the articular surface of the radius and the carpus, slight radial shortening.

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90 Troublesome Lunate Facet: Treatment with Microvascular Techniques

Francisco del Piñal

90.1 Patient History Leading to the Specific Problem

This 26-year-old man was seen 4 months after sustaining a distal radius fracture in a bike accident. The fracture had been operated and a volar plate plus an external fixator was applied. An ulnar approach was also carried out in order to tackle the ulnar styloid fracture. Nevertheless, he complained of pain, diminished grip strength (59%), no extension (0 degrees), and no supination (20 degrees; ▶Fig. 90.1).

Preoperative imaging was taken (▶Fig. 90.2). Notice that there is no evidence of subchondral bone in the sunken area

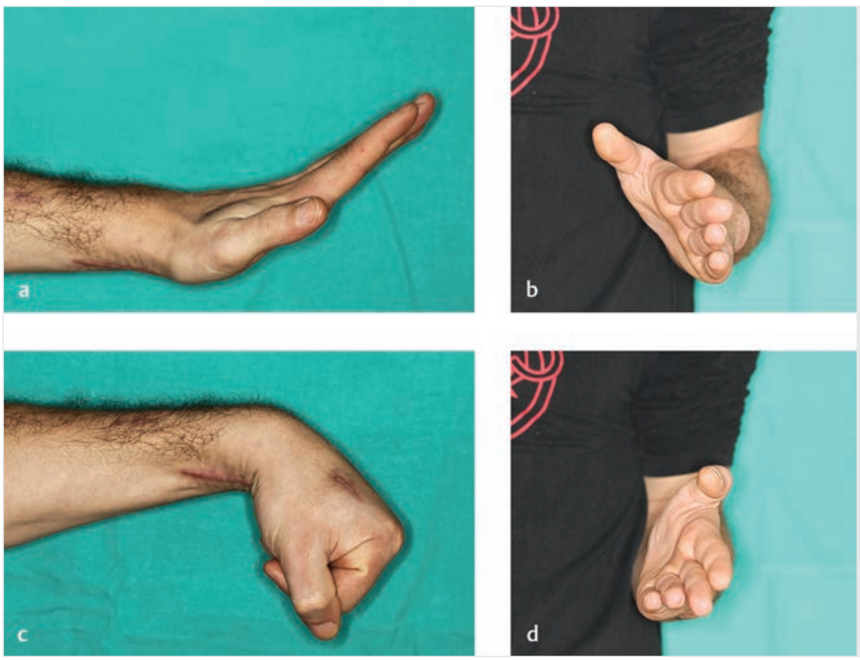

Fig. 90.1 (a–d) Preoperative range of motion.

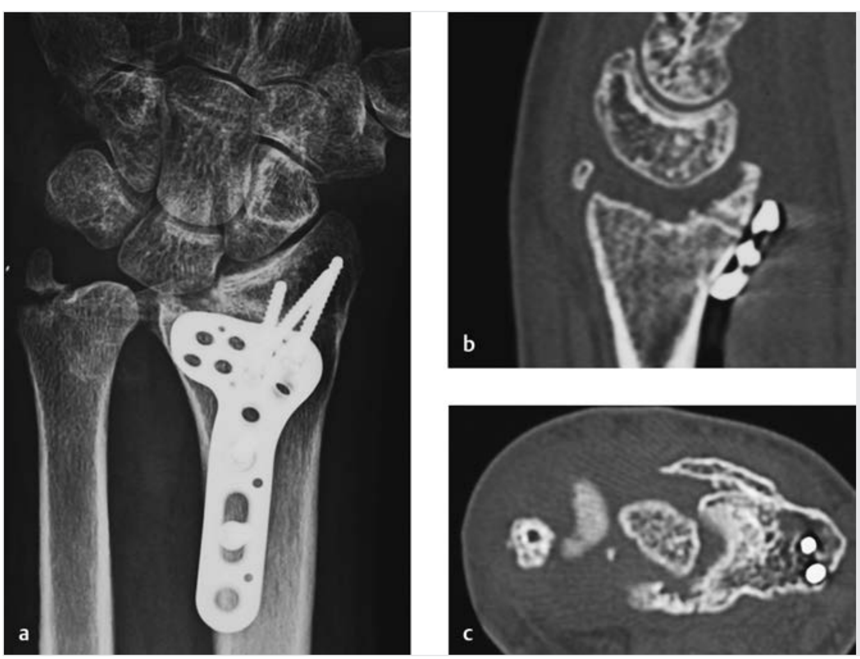

Fig. 90.2 (a–c) Preoperative X-rays and CT scan.

that could make one consider repositioning a malunited fragment. Whether those fragments were removed at the initial surgery is unknown. There is also a radially displaced fracture of the ulnar styloid including the fovea, with pain at that level.

90.2 Anatomic Description of the Patient's Current Status

The information gathered from the radiological workup was very valuable. Virtually, all the lunate facet was destroyed and through the different slices on the CT scan neither the lunate nor the sigmoid notch was recognizable. On the other hand, although the pictures of the lunate hanging in the void looked frightening, they were encouraging as far as the possibility of reconstruction was concerned: when the cartilage does not rub against bony irregularities, it will remain in pristine condition for months. Another positive finding was that the scaphoid fossa and scaphoid bone were not damaged.

90.3 Recommended Solution to the Problem

For several years, we have been using the base of the third metatarsal as a vascularized osteochondral graft to replace major articular defects on the radial articular surface. The base of the third metatarsal has a principal facet that we use for reconstructing the radial articular surface, and an accessory facet to the fourth metatarsal, which is invaluable to reconstruct the sigmoid notch provided the contralateral side is harvested (▶Fig. 90.3). The operation requires microsurgical expertise, but allows patients to maintain a painless range of motion.

It should be stressed that when dealing with malunions of the radius, the decision-making process is complicated and multiple issues should be considered (▶Fig. 90.4). In most cases the author treats, the author first carries out a diagnostic arthroscopy, and then—in the same operation—select the procedure to perform. Depending on whether the cartilage is healthy in radius and carpals or not, one of the following procedures is opted: an intra-articular osteotomy, a osteochondral graft, a resection arthroplasty, or a partial fusion. As shown in the algorithm, the vascularized osteochondral graft is reserved for the scenarios in which the damage is limited to the radius and the cartilage of the carpals is preserved. Some allowances on the cartilage quality can be accepted, but bare bone or major cartilage damage on the opposing carpal will lead to failure.

In this case, the unfeasibility of osteotomy was clear as the lunate fossa was "gone," and the option of replacing the area by the graft was the best one. Only a major cartilage loss would have contraindicated the operation and that was very unlikely due to the fact that the lunate was "hanging in the void."

90.4 Technique

At the time of planning, one has to take into account that if the sigmoid notch needs to be reconstructed, the contralateral third metatarsal should be used. Otherwise, the smaller facet to the second metatarsal will face the ulna offering a poor match (▶Fig. 90.5).

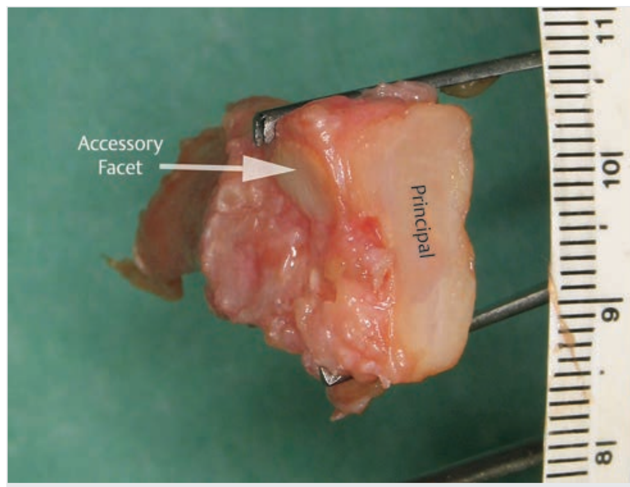

Fig. 90.3 Proximal to distal view of the base of a left base of the third metatarsal.

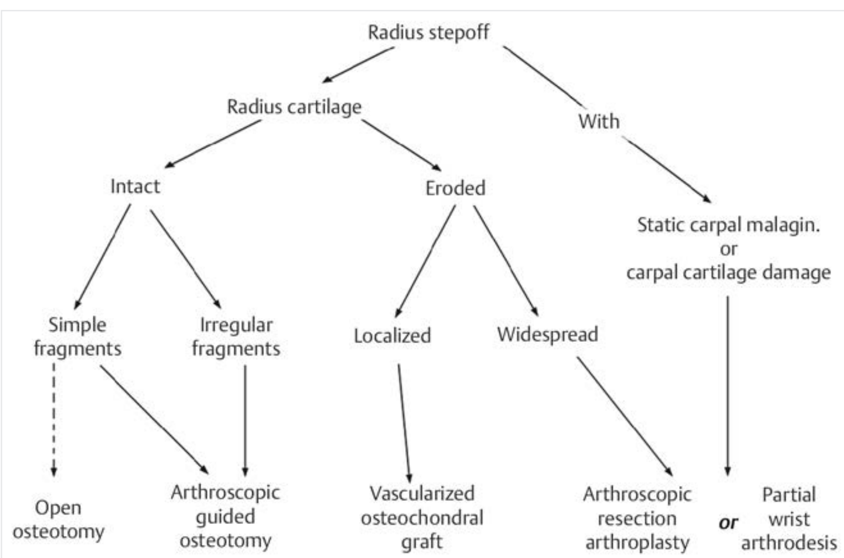

Fig. 90.4 Algorithm showing the decision-making process for dealing with malunion of the radius.

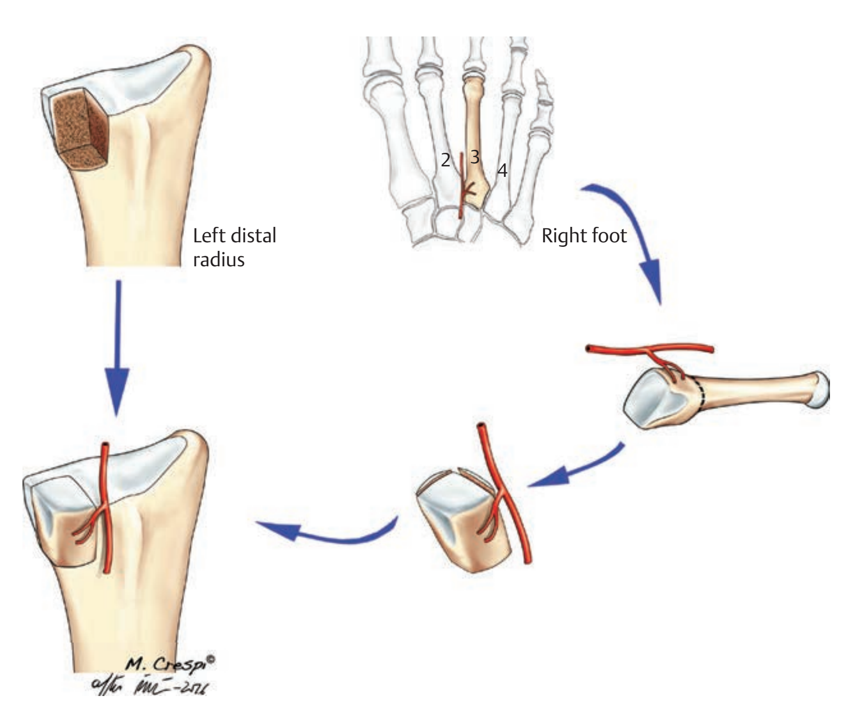

Fig. 90.5 Notice how in a left-side defect the right side is the one that matches the defect.

The operation is usually performed under regional anesthesia and the recipient site is prepared first. The lunate facet was approached through a longitudinal dorsal midline incision. The extensor pollicis longus was released from the third extensor compartment, and the second and fourth extensor compartments were dissected from the radius subperiosteally. The posterior interosseous nerve was identified and divided. The affected area of the distal radius was removed with an osteotome, sagittal saw, or rongeur as needed. This excision included the metaphyseal bone in order to create a three-dimensional defect to allow for placement of the flap. At this point, corrective osteotomies are usually performed for any salvageable malpositioned fragment (usually the anterior fragments), although in this case this was not needed. Notice at the completion of this part of the operation that the cartilage of the lunate is of good condition and that the head of the ulna is exposed (▶Fig. 90.6). The skin was closed temporarily with staples, a soft bandage applied, and the tourniquet released.

Attention is directed to the foot. Again it is important to stress that the flap is to be raised from the contralateral foot. In our anatomic study, we noticed that the vascular supply is variable. There is a competitive situation to supply the periosteum of the third metatarsal between the distal lateral tarsal artery (DLTA) and the arcuate artery (AA), both branches of the dorsalis pedis artery (DPA). Depending on the actual size at surgery, only one or both arteries (the DLTA and AA) pedicled on the dorsalis pedis are harvested (▶Fig. 90.7).

The foot was approached though a zigzag incision in the cleft between the extensor hallucis longus and the extensor digitorum longus. The extensor hallucis brevis (EHB) was cut and retracted laterally together with the extensor digitorum longus. This maneuver exposed the blood supply to the dorsum of the foot (▶Fig. 90.8). In this case, a periosteal arcade was formed between a well-developed arcuate and distal lateral tarsal arteries that crossed the base of the third metatarsal. During this dissection, a perforator to the skin was located and a skin flap was raised on it as a skin monitor.

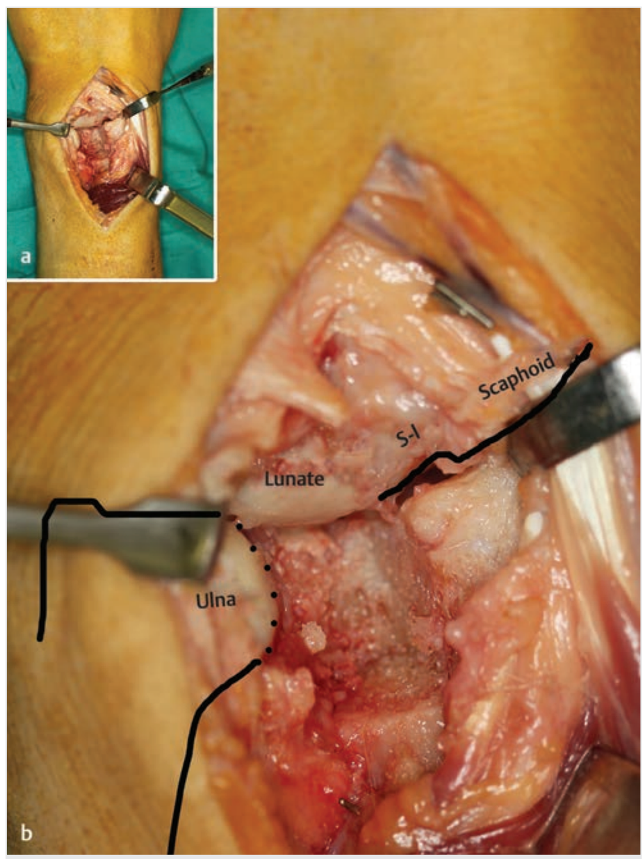

Fig. 90.6 (a, b) Intraoperative view of the defect created by the radius. Inset: external view.

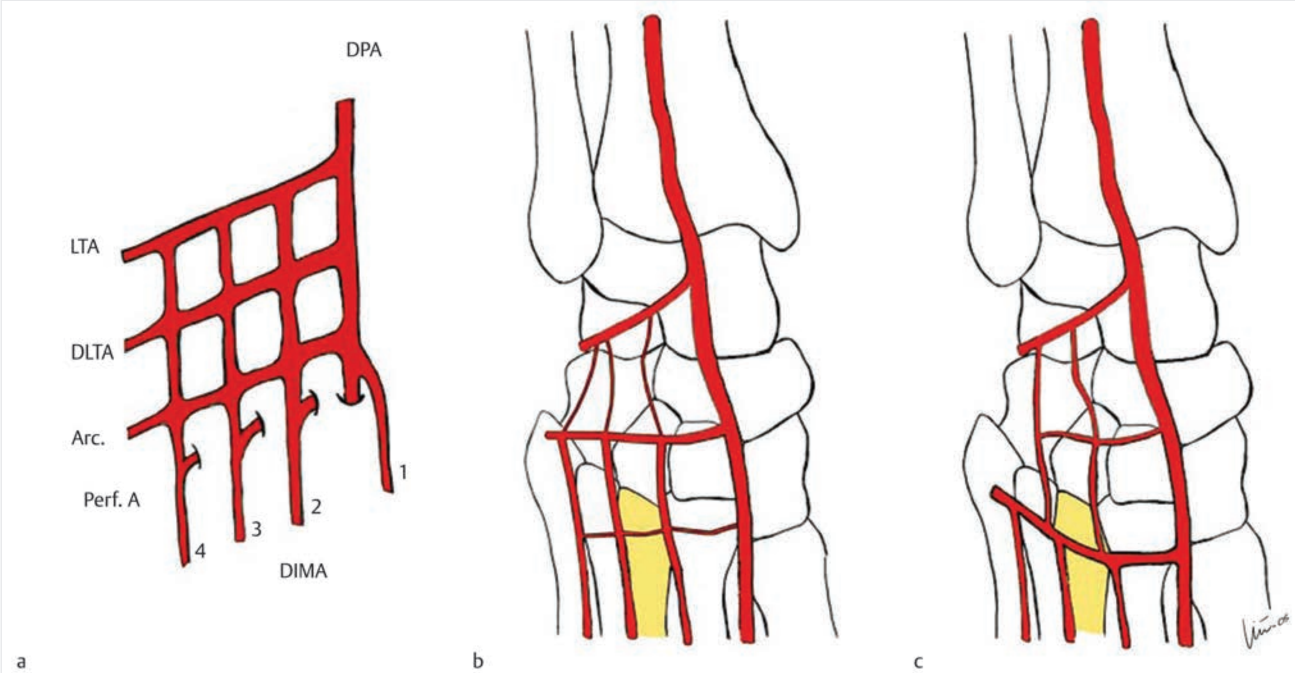

Fig. 90.7 **(a)** Schematic representation of the blood supply of the dorsum of the foot. **(b)** In this illustration, the dominant vessels run longitudinally to the base of the third metatarsal. **(c)** In this illustration, the dominant vessels run transversely. (Arc, arcuate artery; DIMA, dorsal intermetatarsal arteries; DLTA, distal lateral tarsal artery; DPA, dorsalis pedis artery; LTA, lateral tarsal artery; Perf. A, perforated artery.)

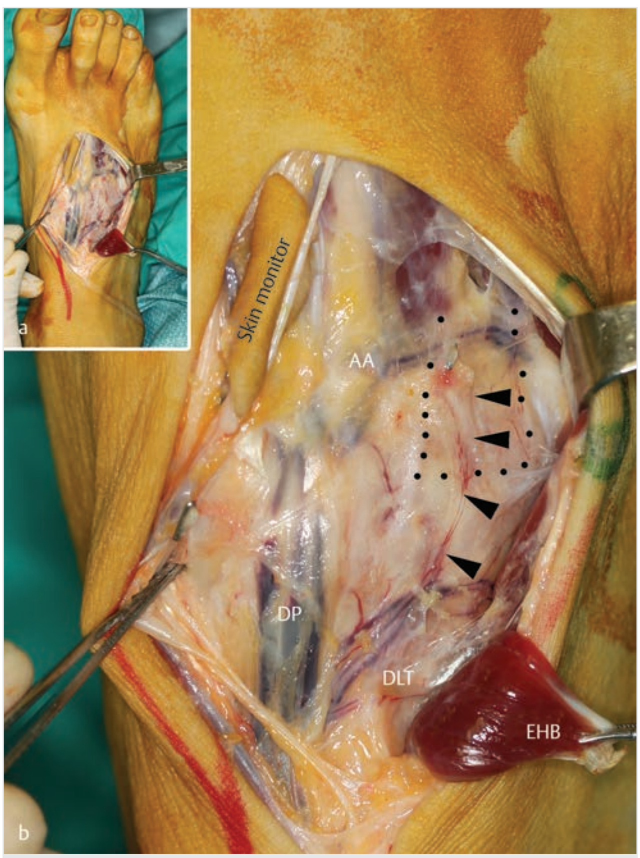

Fig. 90.8 **(a, b)** In this case, a periosteal arcade (*arrowheads*) was formed between a well-developed arcuate artery (AA) and distal lateral tarsal artery (DLT) that crossed the base of the third metatarsal (*black dots*). (DP, dorsalis pedis; EHB, extensor hallucis brevis.)

Once the anatomy was clear, the feeding vessels (DLTA and AA) were dissected from the periosteum, maintaining intact the tiny periosteal rete of vessels over the base of the metatarsal. The third metatarsal was cut distal to the AA at about 1.5 cm distal to the base, and dissected from its ligamentous attachments. The intermetatarsal space is very tight and the intermetatarsal ligaments are very deep. Rough maneuvers may put the nutrient vessels at risk: a lamina spreader was invaluable in this part of the surgery to separate the metatarsals. The first dorsal metatarsal artery was ligated distal to the takeoff of the AA. The graft was the isolated on the dorsalis pedis vessels.

The tourniquet was released to assure that bone and skin monitor had good perfusion. Topical verapamil, warm sponges, and a few minutes may be needed for the small periosteal vessels to “open up” and before profuse bleeding is seen. The pedicle was then severed (▶Fig. 90.9). The incision in the foot was closed in layers over a suction drain. No attempt was made to reconstruct the metatarsal base.

The flap was taken to the hand and then tailored to fit the distal radial defect. The corresponding medial cortex of the metatarsal (the facet to the second metatarsal) was removed to appose cancellous bone of the flap to the cancellous bone of the radius. Several attempts were needed before the articular cartilage surface was restored and the flap was temporarily fixed with K-wires (▶Fig. 90.10).

Definitive fixation with two lag screws, avoiding the periosteal vessels, was then carried out. The vessels were passed under a skin bridge to reach the anatomical snuff-box. The DPA was anastomosed to the radial artery in an end-to-side fashion and the vena concomitants to a radial vena concomitants end to end. A subcutaneous vein was sutured end to end to a local subcutaneous vein. All sutures were performed with a 9–0 nylon suture on a 140-μm needle in a running fashion. The wrist was closed in a layered fashion and included the skin island as a monitor.

Attention was then directed to the ulnar side of the joint. Not only did the patient have a painful ulnar styloid nonunion, but also the radioulnar ligaments lacked appropriate tension as the foveal attachment had moved radially. Using the same incision as the original surgeons, the ulnar styloid nonunion was debrided and repositioned more ulnarly, thus retightening the radioulnar ligaments. A headless cannulated 2.0-mm screw was used for fixation. The tourniquet was released and immediate pinking-up of the skin island occurred (▶Fig. 90.11). The patient was kept immobilized with a volar splint.

As is customary in our free flap postoperative protocol, the skin island was monitored for color and Doppler signal hourly for the first 48 hours, then every 2 hours for another 48 hours, and on a shift basis until discharge, usually 4 to 5 days after the surgery. In addition to this, a perfusion of 500-U heparin hourly for 48 hours was prescribed and progressively changed to one of the available low-molecular-weight heparins until normal ambulation was reestablished. Broad spectrum antibiotics were prescribed for 5 days.

90.5 Postoperative Photographs and Critical Evaluation of Results

Finger motion was encouraged. Active and active-assisted exercises began after 5 weeks, with continued splint use for comfort between exercises for 2 to 4 more weeks. Passive exercises were added at 8 weeks. After 10 to 12 weeks, strengthening exercises were added. The latest radiographs at 2 years are shown in ▶Fig. 90.12.

The clinical results are shown at 3 years (▶Fig. 90.13). At 7 years, when contacted by phone, he denied any limitation. He resumed all his activities including working as a mason and mountain biking.

To control postoperative foot swelling, elevation and a compression stocking were recommended. Ambulation in a cast shoe was permitted starting on the first postoperative day, and the shoe was weaned after 4 to 6 weeks. On the long term, the only noticeable sequelae on the donor site is the scar and minimal shortening of the third toe (▶Fig. 90.14). We have not had any long-term problems in any of our patients.

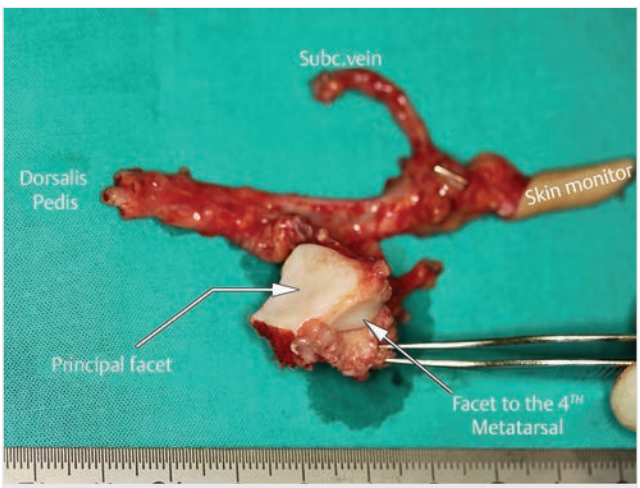

Fig. 90.9 The harvested flap.

Fig. 90.11 Pinking of the skin after release of the tourniquet.

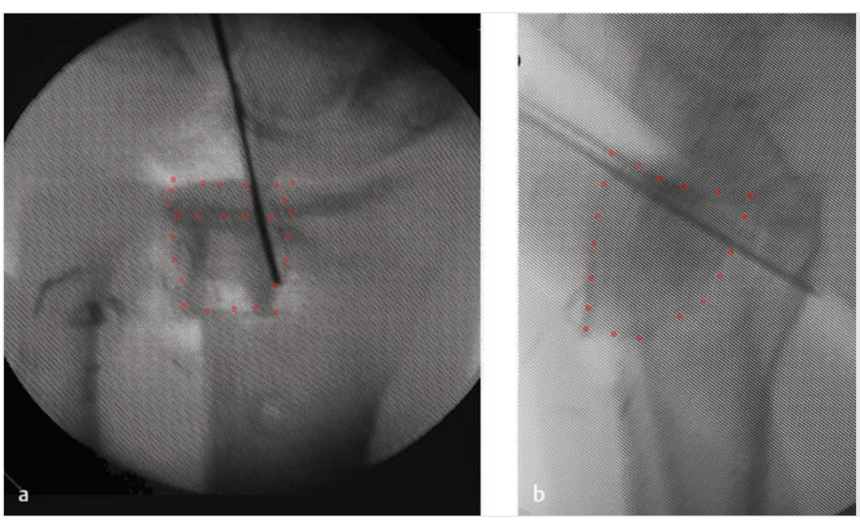

Fig. 90.10 **(a, b)** Fluoroscopic view of the flap in place before the definitive fixation.

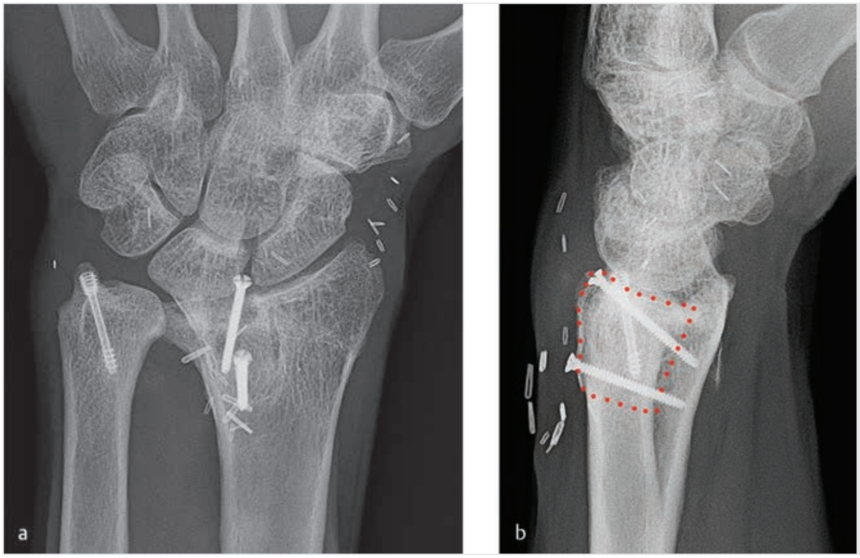

Fig. 90.12 (a, b) Radiographs 2 years postoperative. The graft is shown (*dots*).

Fig. 90.13 (a–d) Range of motion 3 years postoperative.

The main advantage of this operation is that in one stage the lunate facet and sigmoid notch are reconstructed. The main limitation is that we do not know the long-term outcome. So far, we have patients with more than 10-year follow-up, and all are doing well. On the other hand, the fate of osteochondral grafts are long lasting provided they are vascularized. This has been proved in full joint transfers and also in vascularized epiphyseal transfers. Nonvascularized grafts, not only in our experience but also when critically assessing the literature, look perfect in the short term, but after a year, major changes and collapse of the joint occur (▶Fig. 90.15).

At the time of planning, one should take into account the graft size limitations: the base of the third metatarsal permits one to reconstruct the lunate or the scaphoid fossa, not both.

Having put forward these limitations, it should be added that the alternatives for major osteochondral defects available in the literature are basically partial arthrodesis (radioscapholunate or, at best, radiolunate arthrodesis), which have been shown to have midterm problems. Even more worrying is the fact that with these operations, the sigmoid notch problem is not addressed and would need some form of Darrach's procedure, Sauvé–Kapandji procedure, or prosthesis, all very limiting.

Fig. 90.14 Donor site at 3 years. Note minor shortening of the third toe (*arrow*).

Finally, it should be stressed that it is unwise to push the indication of this flap: if the cartilage is severely damaged or bare bone exposed, the surgeon should choose another reconstructive alternative. Our only failure was in a patient where the carpal cartilage was completely worn.

90.6 Teaching Points

- Fluoroscopy is unreliable when assessing step-offs. Use the arthroscope when dealing with articular distal radius fractures.
- Step-offs located in the middle of the scaphoid or in the middle of the lunate facets of the radius are much worse tolerated than interfacetary.
- The base of the contralateral third metatarsal permits reconstructing in one stage the lunate facet and the dorsal part of the sigmoid notch.
- This flap is a mere part of the future well-being of the patient with a malunited distal radius fracture. Most patients have multiple issues to address. Full understanding of radiocarpal and distal radioulnar joints is needed.
- The flap elevation and fitting can be demanding, but nothing in comparison to the decision-making process.

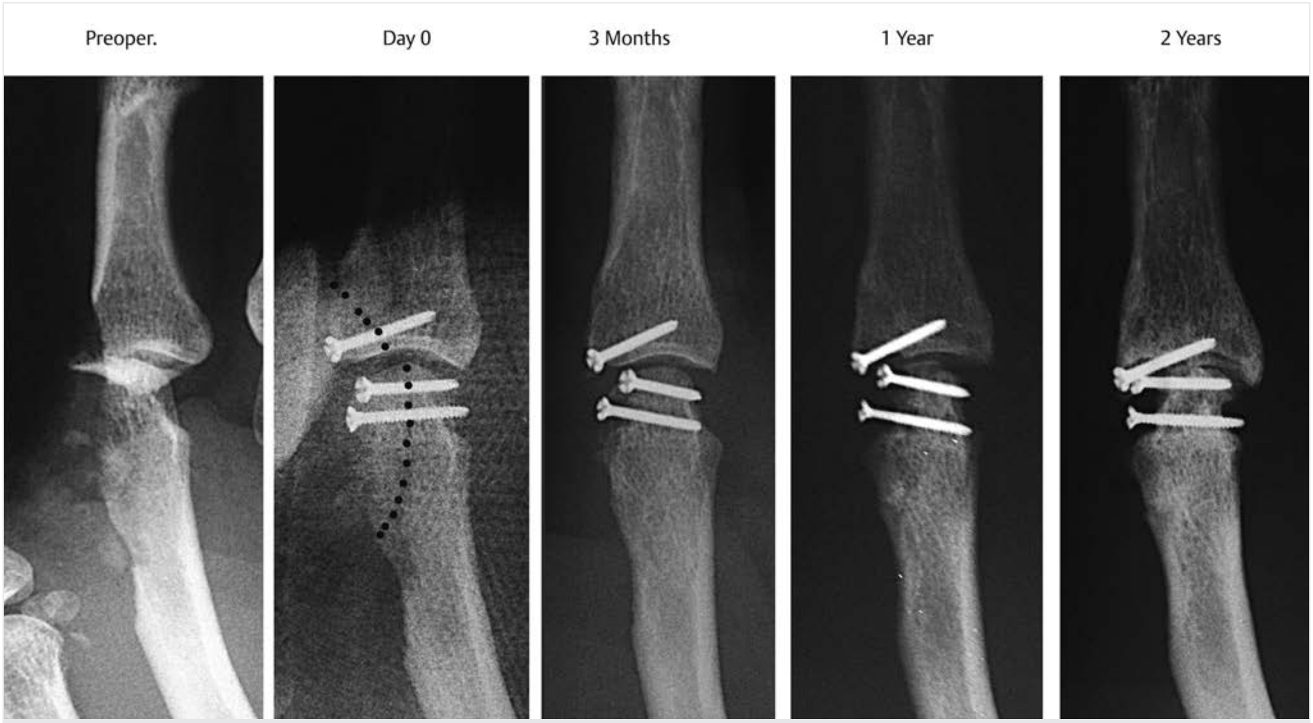

Fig. 90.15 In a different patient, this osteochondral defect in the head of the metacarpal and the base of the proximal phalanx was reconstructed acutely with a nonvascularized graft harvested from the second metatarsal and base of the proximal phalanx. Note nearly perfect match at 3 months and the complete resorption at 2 years.

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Index

Note: Page numbers set in **bold** indicate headings or figures, respectively.

A

acute split graft 8
acute split grafting 8
acute trauma surgery of blast burn **141**
acute vascular compromise after Dupuytren's fasciectomy **23**
anconeus epitrochlearis 91
annular pulleys 45
antecedent grafting 185
anterior interosseous nerve (AIN) 100
arcade of Frohse 105
arcuate ligament 91
arsupialization 10
Arthrodesis of interphalangeal joint 51
arthroscopic treatment of ulnar impaction **388**
articular phalanx fractures **168**, **172**, **178**
– angulation in 168
– contractures in 178
– posttraumatic bone loss in 172

B

bailed lacerations 8
basalar joint osteoarthritis, recurrent pain in **202**
begin physical therapy 22
Bier block 28
bowstringing **16**
bowstringing of flexor tendon **45**
brachial plexus block 28
brachioradialis-splitting approach 104
Bruner-type incision 51
Bruner zigzag incision 28
Brunner incision 17
bulky flap **136**
Bunnell test 70

C

cable grafting 115
calcium channel blockers 76
canal of Guyon 80
cancellous bone graft 156
carpal tunnel release 80
carpal tunnel release (CTR) 83
carpal tunnel syndrome (CTS) 87
chronic boutonniere deformity 63
chronic boutonniere deformity, relative motion treatment of **62**
chronic nonadherence 2
chronic opioid therapy 112
chronic paronychia 10
chronic sagittal band rupture, management of **64**
chronic tendon rupture 52
circumferential decompression 97
circumferential neurolysis 93
Cleland's ligament 23
clostridium histolyticum (CCH) injection 27
coaptation 110, 117
complex regional pain syndrome **310**
complex regional pain syndrome (CRPS) 115
contracted scars 159
contracture recurrence 31
conventional one-stage tendon grafting 47
crooked finger 152
crow's foot 147
cubital tunnel release at elbow **91**
cubital tunnel syndrome 91

D

deep inferior epigastric artery perforator (DIEP) flap 137
delayed primary bone grafting 173
dermofasciectomy 20
desensitization 115
digital flexor tendon 38
digital sympathectomy 76
digit tourniquet 7
diligent dissection 115
dislocated lunar facet fragments **367**
dislocated ulnar head prosthesis **401**
distal compression points 115
distal intermuscular septum (DIMS) 97
distal interphalangeal (DIP) joints 26
distal nonadherence 2
distal radius fracture **408**, **412**
– malunion 408
– nonunion 412
donor site problem 136
dorsal eponychial fold 3
dorsal hand defect **145**
dorsal roof of nail 2
Doublecrush syndrome 88
Dupuytren's contracture treatment, complications of **33**
Dupuytren's disease 20
Dupuytren's fasciectomy **23**
dysfunctional local sympathetic nervous system 76

E

electrodiagnostic testing 91
end neuroma **110**
endoscopic carpal tunnel release (ECTR) 87
eponym Dupuytren's contracture 23
exostoses 58
exposed tendons **20**
extended periarterial sympathectomy 76
extensor carpi radialis brevis (ECRB) 104
extensor carpi radialis longus (ECRL) 104
extensor digitorum communis (EDC) 69
extensor hood rupture 63
extensor lag **54**
extensor mechanism 69, 70
extensor retinaculum 16
extensor tendon, stiffness in **58**
extra-articular osteotomy 169
extrinsic tightness 70

F

failed bowers' arthroplasty **396**
failed carpal tunnel release **87**
failed reconstruction with tenodesis: chronic **346**
failed scapholunate ligament repair: acute **342**
fasciocutaneous free flap 137
finger arthrodesis 173
finger contractures **122**
finger tourniquet 3
fixed contracture 62
flexor carpi radialis (FCR) 87
flexor carpi ulnaris (FCU) 91
flexor digitorum profundus (FDP) 16, 45, 33, 91
flexor digitorum superficialis 136
flexor digitorum superficialis (FDS) 16
flexor pollicis longus (FPL) 87
flexor pollicis longus tendon 50
flexor tendon **45**, **38**
– bowstringing of 45
– rupture 38
flexor tenosynovectomy 85
force transmission of flexor tendons 51
fracture healing 185
free tendon grafts 16
Froment's sign 96
full-thickness flaps of skin and 28
full-thickness skin grafting (FTSG) 3

G

Garrod's pad 26
gentian violet treatment 11, 12
gentian violet treatment of severe chronic paronychia **10**
germinal matrix 2
gradient parakeratosis 2
Grayson's ligament 23

H

high above-elbow sterile tourniquet 97
Hunter rod 46
hypertrophic nonunions 157
hyponychium 8
hypothenar fat pad flap **84**

I

iatrogenic nerve injury 92
incomplete resection of sarcoma at hand **126**
initial flexor tendon 38
intercalating corticocancellous bone graft 156
intra-articular osteotomy 169
intrinsic extensor mechanism 69

K

keratinization 2
Kirschner's wire fixation **174**

L

lacertus syndrome **87**
lateral antebrachial (LABC) cutaneous nerve 114
lateral digital sheet 23
left upper extremity **115**
lidocaine 43
local neurotrophic factors 110
loop technique 17
lunotriquetral fusion, problems with **355**
lunotriquetral joint after ligament repair **352**
lunula 2

M

McCash's technique 20
mechanical blocks 58
medial antebrachial cutaneous (MABC) nerve 92
medial antebrachial cutaneous nerve (MABC) 97
medial antebrachial (MABC) 114
medial epicondylectomy 92
metacarpal fractures **184**, **190**, **194**
– angulation in 194
– malunion in 190
– nonunion in 184
metacarpal phalangeal hyperextension **212**
metacarpophalangeal (MCP) joint 16, 23, 26
meticulous nerve repair 118
meticulous suture alignment 8
multiple cable grafts 116
multiple intraoperative techniques 24

N

nail plate, nonadherence of **2**
nail remnants 4
natatory ligaments 23
nerve grafting **116**
neuropathic pain medications 115
neurotmesis 110
neurovascular bundles 23, 24
nonadherence of nail plate **2**
nonadherent tie-over bolster dressings 20
nonarticular phalanx fractures **155**, **158**, **164**
– angulation in 164
– nonunion in 155
– stiffness and hardware problems in 158
nonarticular phalanx fractures, malrotation in **152**
noncompressive dressing 24
nonsterile tourniquet 28
nonsteroidal anti-inflammatory drugs (NSAIDs) 91, 104
nonunion of proximal pole **316**
nonvascularized bone grafting 320

O

oblique retinacular ligament (ORL) reconstruction 70
occult fracture 62
one-stage tendon grafting 46
onycholysis 2
open fasciectomy 27
open palm technique 20, 22
Osborne's ligament 91

P

pain following nerve repair **114**
painful proximalization of first metacarpal after trapeziectomy **207**
palmar aponeurosis 23
palmar cutting injury 50
palmar fasciectomy 23
palmaris longus tendon 47
partial wrist fusion, complications of **362**
pediatric fractures 165
perfusion problems **132**
phalangeal extra-articular malunions 169
Phalen's signs 83
posterior antebrachial cutaneous nerve (PACN) 105
posterior interosseous nerve (PIN) 104
postoperative rehabilitation 48
postoperative stellate ganglion block 118
posttraumatic bone loss, in articular phalanx fractures **172**
posttraumatic nail deformity 2
posttraumatic split nails **6**
posttraumatic swan neck deformity **68**
preoperative antibiotics 28
progressive ischemia 76
proximal counterpart (PMIS) 97
proximal incision 84
proximal interphalangeal (PIP) joint 16, 23, 20, 26
proximal nail bed injuries 5
proximal phalanx 69
pulley reconstruction techniques 16
Pulvertaft technique 51

R

radial nerve bifurcates 104
radial tunnel release in forearm **104**
radial tunnel syndrome 107
radioscapholunate arthrodesis **367**
Raynaud's syndrome 10
recalcitrant cubital tunnel syndrome 94
recurrent carpal tunnel syndrome **80**
– practical approach to 80
recurrent carpal tunnel syndrome **83**
recurrent cubital tunnel **96**
recurrent cubital tunnel syndrome 100
recurrent ulnar neuropathy **101**
reformed transverse carpal ligament 80
refractory Raynaud's phenomenon **76**
regenerative peripheral nerve interface (RPNI) 110
regional flaps 148
relative motion treatment of chronic boutonniere deformity **62**
reversed dorsal metacarpal artery 126
rigid fixation 155
rotational malunion 152
ruptured flexor pollicis longus tendon **50**

S

sagittal band ruptures 66
scaphoid implant malplacement **336**
scaphoid nonunion **329**
scaphoid nonunion, with avascular necrosis **320**
scaphoid revision nonunion **325**
scleroderma 10
scratch-collapse test 90
scratch collapse test (SCT) 87
secondary contractures **26**
secondary flexor tendon reconstruction 51
secondary tendon grafting 38
self-retaining retractor 105
Semmes-Weinstein testing 102
serratus anterior fascia 148
severe chronic paronychia, gentian violet treatment of **10**
shotgun approach 169
shunt restriction 132
single-stage tendon graft 46
single-stage tendon grafting 46
skin-grafted nail bed 4
spare parts graft 115
split-thickness skin graft 3
split-thickness skin grafting 3, 136
stellate (sympathetic) ganglion blocks 115
sterile matrix 2
structural bone grafting 172
sublimis sling 70
subtle malunion 152
supercharged end to side (SETS) 100
super glue 6
sural nerve harvest **115**
swan neck deformity (SND) 68
symptomatic neuromas 112
synechial scarring 7

T

targeted xmuscle reinnervation (TMR) 110
temporary needle fixation 40
tendon stripper 17
tenolysis 55, 155
thermoplastic splint 30
thick extraneural scar 80
Tinel's signs 83
total wrist arthroplasty, implant migration after **374**
tourniquet control 80
traction Tinel sign 83
transient devascularization of ulnar nerve 92
transverse carpal ligament 80
transverse retinacular ligaments 69
transverse sheathotomies 43
trapeziectomy, painful proximalization of first metacarpal after **207**
traumatic transfemoral amputation 110
triangular fibrocartilage complex tears **378**, **382**
– pain after 378
– persistent instability after 382
troublesome lunate facet **419**
– microvascular techniques, treatment with 419
troublesome lunate facet **415**
tug test 97
two-stage reconstruction 33

U

ulnar head prosthesis **396**
ulnar impaction, arthroscopic treatment of **388**
ulnar shortening, nonunion after **391**
unresponsive to hand therapy 62
upper extremity nerve repair **115**
– left upper extremity 115

V

vascularized bone grafting 320
vasoconstriction 59
venous flaps 133
visual analog scale (VAS) 96
volar carpal ligament 84
volar plate injury 62
volar transverse incision 122

W

WALANT 59, 71
warm saline-soaked gauze 24
Wartenberg's sign 96
web-space coalescence 23
web-space syndactyly 141

Y

Yasargil clamps 24
Y-V advancement techniques 141

Z

Z-plasty flaps 141