Fractures and Dislocations of the Talus and Calcaneus

A Case-Based Approach

Mark R. Adams
Stephen K. Benirschke
Editors

Springer

Fractures and Dislocations of the Talus and Calcaneus

Mark R. Adams • Stephen K. Benirschke
Editors

Fractures and Dislocations of the Talus and Calcaneus

A Case-Based Approach

Springer

Editors
Mark R. Adams
Associate Professor, Department of Orthopedics, Trauma Division
Rutgers – New Jersey Medical School
Newark, NJ
USA

Stephen K. Benirschke
Foot and Ankle Center at Harborview
University of Washington
Seattle, WA
USA

ISBN 978-3-030-37362-7 ISBN 978-3-030-37363-4 (eBook)
https://doi.org/10.1007/978-3-030-37363-4

© Springer Nature Switzerland AG 2020
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

This book is intended to serve the reader as an in-depth resource for study of fractures of the talus and calcaneus. As this is a narrow topic, the purpose of each chapter is to be comprehensive. This is achieved in two approaches: through an overall literature review that provided a broad understanding of the subject and case examples which provided an opportunity to delve into the nuance of these injuries. This dual approach will ideally provide the reader with a fuller understanding of these challenging injuries.

Newark, NJ, USA Mark R. Adams
Seattle, WA, USA Stephen K. Benirschke

Contents

Part I General Principles of Care of the Traumatized Foot

1 **Foot Injuries Outcomes Analysis** 3
Michael Sirkin, Michael Jung, and Joseph Ippolito

2 **Foot Injury: The Initial Evaluation** 17
Wayne S. Berberian and John Hwang

Part II Fractures of the Talus

3 **General Principles of Talus Fractures** 29
David Hubbard and James Richman

4 **Talar Neck Fractures** 37
Bo He and Michael Krosin

5 **Talar Body Fractures** 57
Mai P. Nguyen and Heather A. Vallier

6 **Fractures of the Talar Head** 71
James Richman, Adam Gitlin, and Mark R. Adams

7 **Posterior Talar Process Fractures** 83
M. Kareem Shaath and Mark R. Adams

8 **Fractures of the Lateral Process of the Talus** 97
Matthew P. Sullivan and Reza Firoozabadi

9 **Osteochondral Defects of the Talar Dome** 107
Daniel Thuillier and David Shearer

Part III Tarsal Dislocations

10 **Fractures and Dislocations of the Talus and Calcaneus: A Case-Based Approach** 127
Michael Jung, Joseph Galloway, and Jonathan Eastman

11 **Pantalar Dislocation** 141
Michael F. Githens and Jennifer Tangtiphaiboontana

12 Other Midfoot Dislocations 161
Erik A. Magnusson, Jeremy Hreha, and Lisa Taitsman

13 Hindfoot Sprains 175
Todd P. Pierce, Kimona Issa, and Jason Schneidkraut

Part IV Fractures of the Calcaneus

14 Intra-articular Calcaneal Fractures 181
Kenneth L. Koury

15 Lateral Extensile Approach for ORIF 197
Adam Cota and Timothy G. Weber

16 Minimally Invasive Treatment of Intra-articular Calcaneal Fractures 211
Thomas M. Large and Bruce Cohen

17 Open Calcaneus Fractures 239
Luke A. Lopas, Matthew M. Counihan, and Derek J. Donegan

18 Isolated Fractures of the Anterior Process 251
Brad J. Yoo

19 Posterior Calcaneal Tuberosity Fractures 263
Matthew C. Avery and Michael J. Gardner

20 Extraarticular Calcaneal Body Fractures 275
John W. Munz and Stephen J. Warner

21 Fractures of the Sustentaculum Tali 281
Jerad D. Allen and Michael F. Githens

22 Ipsilateral Talus and Calcaneus Fractures 291
Michael F. Githens and Reza Firoozabadi

Part V Post-traumatic Care and Reconstruction

23 Rehabilitation After Fractures and Dislocations of the Talus and Calcaneus 311
Janet M. Hobbs

24 General Principles of Reconstruction 333
James Meeker

25 Post Traumatic Arthrosis 339
James Meeker

Index 351

Contributors

Mark R. Adams, MD Associate Professor, Department of Orthopedics, Trauma Division, Rutgers – New Jersey Medical School, Newark, NJ, USA

Jerad D. Allen, MD Department of Orthopaedic Surgery and Sports Medicine, University of Washington/Harborview Medical Center, Seattle, WA, USA

Matthew C. Avery, MD Division of Orthopaedic Surgery and Sports Medicine, Memorial Healthcare System, Hollywood, FL, USA

Wayne S. Berberian, MD Hackensack Meridian School of Medicine at Seton Hall, Nutley, NJ, USA

Bruce Cohen, MD Atrium Musculoskeletal Institute, Foot and Ankle Division, OrthoCarolina, Charlotte, NC, USA

Adam Cota, MD Rocky Mountain Orthopaedic Associates, Grand Junction, CO, USA

Matthew M. Counihan, MD Department of Orthopaedic Surgery, University of Pennsylvania, Philadelphia, PA, USA

Derek J. Donegan, MD Department of Orthopaedic Surgery, University of Pennsylvania, Philadelphia, PA, USA

Jonathan Eastman, MD Orthopaedic Surgery, University of California, Sacramento, CA, USA

Reza Firoozabadi, MD, MA Department of Orthopaedics and Sports Medicine, Harborview Medical Center/University of Washington, Seattle, WA, USA

Joseph Galloway, MD Orthopaedic Surgery, Rutgers New Jersey Medical School, Newark, NJ, USA

Michael J. Gardner, MD Orthopaedic Trauma Service, Stanford University School of Medicine, Palo Alto, CA, USA

Michael F. Githens, MD Department of Orthopaedics and Sports Medicine, Harborview Medical Center/University of Washington, Seattle, WA, USA

Department of Orthopaedic Surgery and Sports Medicine, University of Washington/Harborview Medical Center, Seattle, WA, USA

Adam Gitlin, MD Crystal Run Healthcare, Middletown, NY, USA

Bo He, MD San Francisco Orthopaedic Residency Program, St Mary's Medical Center, San Francisco, CA, USA

Janet M. Hobbs, PT, RN Sigvard T. Hansen Jr. Foot and Ankle Institute, Harborview Medical Center/UW Medicine, Seattle, WA, USA

Jeremy Hreha, MD Department of Orthopaedics, Rutgers New Jersey Medical School, Newark, NJ, USA

David Hubbard, MD Orthopaedic Trauma Service, J.W. Ruby Memorial Hospital, West Virginia University, Morgantown, WV, USA

John Hwang, MD Orthopedic One, Columbus, OH, USA

Joseph Ippolito, MD Orthopaedic Surgery, Rutgers New Jersey Medical School, Newark, NJ, USA

Kimona Issa, MD Department of Orthopaedics, Seton Hall University, School of Health and Medical Sciences, South Orange, NJ, USA

Michael Jung, MD Orthopaedic Surgery, Rutgers New Jersey Medical School, Newark, NJ, USA

Kenneth L. Koury, MD Orthopaedic Trauma Surgery, Geisinger Wyoming Valley, Wilkes-Barre, PA, USA

Michael Krosin, MD Orthopaedic Surgery, Highland Hospital, Oakland, CA, USA

Thomas M. Large, MD Orthopaedic Trauma Services, Mission Hospital, Asheville, NC, USA

Luke A. Lopas, MD Department of Orthopaedic Surgery, University of Pennsylvania, Philadelphia, PA, USA

Erik A. Magnusson, MD Department of Orthopaedics and Sports Medicine, University of Washington, Harborview Medical Center, Seattle, WA, USA

James Meeker, MD Department of Orthopaedics and rehabilitation, Oregon Health and Sciences University, Portland, OR, USA

John W. Munz, MD Department of Orthopaedic Surgery, University of Texas Health Science Center, Houston, TX, USA

Mai P. Nguyen, MD Department of Orthopaedic Surgery, University of Minnesota, Minneapolis, MN, USA

Todd P. Pierce, MD Department of Orthopaedics, Seton Hall University, School of Health and Medical Sciences, South Orange, NJ, USA

James Richman, MD MultiCare Orthopedics & Sports Medicine, Tacoma, WA, USA

Jason Schneidkraut, MD Elite Orthopaedics and Sports Medicine, Wayne, NJ, USA

M. Kareem Shaath, MD University of Texas Health Science Center at Houston, Houston, TX, USA

David Shearer, MD UCSF – Department of Orthopaedic Surgery, San Francisco, CA, USA

Michael Sirkin, MD Orthopaedic Surgery, Rutgers New Jersey Medical School, Newark, NJ, USA

Matthew P. Sullivan, MD Orthopaedic Trauma Service, State University of New York, Upstate University Hospital, Oneida, NY, USA

Lisa Taitsman, MD, MPH Department of Orthopaedics and Sports Medicine, University of Washington, Harborview Medical Center, Seattle, WA, USA

Jennifer Tangtiphaiboontana, MD Department of Orthopaedic Surgery, Harborview Medical Center, Seattle, WA, USA

Daniel Thuillier, MD UCSF – Department of Orthopaedic Surgery, San Francisco, CA, USA

Heather A. Vallier, MD Department of Orthopaedic Surgery, Case Western Reserve University, Cleveland, OH, USA

Stephen J. Warner, MD, PhD Department of Orthopaedic Surgery, University of Texas Health Science Center, Houston, TX, USA

Timothy G. Weber, MD OrthoIndy, Indianapolis, IN, USA

Department of Orthopaedic Trauma, St. Vincent Hospital and OrthoIndy Hospital, Indianapolis, IN, USA

Brad J. Yoo, MD, FACS Department of Orthopaedics and Rehabilitation, Yale University, New Haven, CT, USA

Part I

General Principles of Care of the Traumatized Foot

1 Foot Injuries Outcomes Analysis

Michael Sirkin, Michael Jung, and Joseph Ippolito

In the initial assessment of orthopedic trauma patients, foot injuries are at risk for being overlooked. Particularly in patients with polytrauma, distracting injuries and requirement for urgent or emergent procedures at the thorax, abdomen, or long bones may delay recognition of these injuries. The need for the performance of secondary and tertiary surveys is highlighted by poor outcomes in multiply injured patients with missed foot injuries [1].

The ankle joint complex, and its articulation with the foot, is a fundamental kinetic linkage that allows the lower limb to interact with the ground to facilitate activities of daily living. The foot and ankle comprise 26 bones, forming 33 joints [2]. Spatial relationships between the tibiotalar (talocrural), talocalcaneal (subtalar), and transverse-tarsal (talocalcaneonavicular) joints play a vital role in kinematics of walking and weight-bearing [3]. Alterations in these relationships following foot and ankle trauma are tolerated poorly by patients and can contribute to significant alterations in quality of life in patients [3]. Following the management of foot and ankle trauma, poor vascularity of the foot (when compared to other regions of the body) increases morbidity and dysfunction for patients, particularly in injuries such as fractures of the talus [4]. Further, limitations in available soft tissue for wound coverage and as a buffer for force distribution can increase pain and dysfunction in these patients [5].

Fractures of the calcaneus and talus are associated with high-energy injuries and polytrauma, which may contribute to poorer outcomes [6–11]. Polytrauma patients with injuries at the foot and ankle frequently have a worse prognosis. Pain following lower extremity trauma has been correlated with increased depressive symptoms related to pain intensity [12]. Post-traumatic pain at the lower extremity has been found to contribute to limitations with participation in therapy and to depressive symptoms up to 8 months following injury [13, 14]. Additionally, patients with foot and ankle trauma have difficulty returning to work at their previous level of function [15].

To better understand analysis of outcomes following treatment for traumatic injuries to the foot, it is important to consider the variability in patient comorbidities, concurrent injuries, and treatment setting. In 2013, Hunt et al. reported that the most commonly used outcome measures in foot and ankle research papers included the American Orthopaedic Foot & Ankle Society Clinical Rating System (55.9%), visual analog scale (22.9%), Short Form-36 (SF-36) Health Survey (13.7%), Foot Function Index (FFI) (5.5%), and American Academy of Orthopaedic

---

M. Sirkin · M. Jung (✉) · J. Ippolito
Orthopaedic Surgery, Rutgers New Jersey Medical School, Newark, NJ, USA
e-mail: sirkinms@njms.rutgers.edu; jungmt@njms.rutgers.edu; ippolija@njms.rutgers.edu

© Springer Nature Switzerland AG 2020
M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_1

Surgeons (AAOS) Outcomes Instruments (3.3%) [16]. In this chapter, we review the AOFAS Clinical Rating System, SF-36, FFI, and AAOS Lower Limb Instruments and their utility in analysis of outcomes in trauma to the talus and/or calcaneus.

The American Orthopaedic Foot & Ankle Society (AOFAS) Clinical Rating System

The most popular region-specific rating scale for the foot and ankle is the subscales of the AOFAS [17]. The AOFAS Clinical Rating System has four sections: the Ankle-Hindfoot Scale, Midfoot Scale, Hallux-Metatarsophalangeal-Interphalangeal Scale, and the Lesser Toe Metatarsophalangeal-Interphalangeal Scale. It measures pain, alignment, and function on a scale of 0–100. A higher score indicates a better result [18]. This scoring system combines patient subjective parameters with objective physician measures such as gait, sagittal motion, hindfoot motion, and ankle-hindfoot stability [19] (Figs. 1.1a–d).

Although the AOFAS Clinical Rating System is one of the most commonly used scoring systems, its validity and reliability have been brought into question in several studies. Toolan et al. have reported that data from the AOFAS scale, collected retrospectively to assess preoperative pain and function, is a poor predictor of a patient's condition [20]. A study by SooHoo et al. examined the validity of the AOFAS scales compared to the SF-36 and found little association between the two, thus indicating poor construct validity of the AOFAS system when measured against the extensively validated SF-36 [21].

Still, others have reported the AOFAS Ankle-Hindfoot Scale to be valid and reliable. In a study of 118 patients with hindfoot fractures, De Boer et al. determined the AOFAS Ankle-Hindfoot Scale to have construct validity of 82.4% and adequate internal consistency. In the study group, the most common injuries were calcaneal and talus fractures at 72.6% and 31.9%, respectively [22]. They cautioned, however, there was inadequate longitudinal validity for assessing functional outcome in the long term.

Short Form-36 (SF-36) Health Survey

The SF-36 is a global rating scale (Fig. 1.2). It was not designed exclusively for the foot or ankle but instead measures the general health status of a patient and demonstrates the effect that a musculoskeletal condition, or other disease, has on that patient's overall well-being. Its main use is for community-based outcome studies [21].

The SF-36 is an extensively validated outcomes tool that has been used as a benchmark in examining the validity of outcomes instruments designed for the upper extremity, knee, shoulder, and general orthopedic conditions [21]. Although the SF-36 can be used to establish the effect that a foot problem may have on a patient's overall quality of life, it should not be used as a specific tool for the assessment of foot or ankle outcomes. It may lack the sensitivity required to detect small clinical change in a specific anatomic region like the foot and ankle [17].

Foot Function Index (FFI)

The Foot Function Index (FFI), initially developed for patients with rheumatoid arthritis (RA) to analyze patient function, consists of 23 items grouped into three subscales including foot pain, disability, and activity limitation [23]. All items are rated utilizing a visual analog scale, consisting of horizontal lines with verbal anchors representing opposite extremes at either ends of a line, rather than numbers or divisions. The pain subscale measures level of foot pain for nine items,

a

AOFAS Ankle-Hindfoot Scale (100 Points Total)

Pain (40 Points)	
None	40
Mild, Occasional	30
Moderate, daily	20
Severe, almost always present	0
Function (50 Points)	
Activity limitations, support requirement	
No limitations, no support	10
No limitation of daily activity, limitation of recreational activities, no support	7
Limited daily and recreational activities, canee	4
Severe limitations of daily and recreational activities, walker, crutches, wheelchair, brace	0
Maximum Walking Distance, Blocks	
Greater than 6	5
4-6	4
1-3	2
Less than 1	0
Walking Surfaces	
No difficulty on any surface	5
Some difficulty on uneven terrain, stairs, inclines, ladders	3
Severe difficulty on uneven terrain, stairs, inlines, ladders	0
Gait Abnormality	
None, slight	8
Obvious	4
Marked	0
Sagittal Motion (flexion plus extension)	
Normal or mild restriction (30° or more)	8
Moderate restriction (15°-29°)	4
Severe restriction (less than 15°)	0
Hindfoot Motion (inversion plus eversion)	
Normal or mild restriction (75%-100% normal)	6
Moderate restriction (25%-74% normall)	3
Marked restriction (less than 25% normall)	0
Ankle-Hindfoot Stability (Anteroposterior, varus-valgus)	
Stable	8
Definitely unstable	0
Alignment (10 points)	
Good, plantigrade foot, ankle-hindfoot well aligned	10
Fair, plantigrade foot, some degree of ankle-hindfoot malalignment observed, no symptoms	5
Poor, nonplantigrade foot, severe malalignment, symptoms	0

Fig. 1.1 (**a**) The American Orthopaedic Foot & Ankle Society (AOFAS) Ankle-Hindfoot Scale. (**b**) The American Orthopaedic Foot & Ankle Society (AOFAS) Midfoot Scale. (**c**) The American Orthopaedic Foot & Ankle Society (AOFAS) Hallux Metatarsophalangeal-Interphalangeal Scale. (**d**) The American Orthopaedic Foot & Ankle Society (AOFAS) Lesser Metatarsophalangeal-Interphalangeal Scale

b

AOFAS Midfoot Scale (100 Points Total)

Pain (40 Points)	
None	40
Mild, Occasional	30
Moderate, daily	20
Severe, almost always present	0
Function (45 Points)	
Activity limitations, support requirement	
No limitations, no support	10
No limitation of daily activity, limitation of recreational activities, no support	7
Limited daily and recreational activities, cane	4
Severe limitations of daily and recreational activities, walker, crutches, wheelchair, brace	0
Footwear requirements	
Fashionable, conventional shoes, no insert required	5
Comfort footwear, shoe insert	3
Modified shoes or brace	0
Maximum Walking Distance, Blocks	
Greater than 6	10
4-6	7
1-3	4
Less than 1	0
Walking Surfaces	
No difficulty on any surface	10
Some difficulty on uneven terrain, stairs, inclines, ladders	5
Severe difficulty on uneven terrain, stairs, inclines, ladders	0
Gait Abnormality	
None, slight	8
Obvious	4
Marked	0
Alignment (15 points)	
Good, plantigrade foot, midfoot well aligned	15
Fair, plantigrade foot, some degree of midfoot malalignment observed, no symptoms	5
Poor, nonplantigrade foot, severe malalignment, symptoms	0

Fig. 1.1 (continued)

c

AOFAS Hallux Metatarsophalangeal-Interphalangeal Scale (100 Points Total)

Pain (40 Points)	
None	40
Mild, Occasional	30
Moderate, daily	20
Severe, almost always present	0
Function (45 Points)	
Activity limitations, support requirement	
No limitations	10
No limitation of daily activities, such as employment responsibilities, limitation of recreational activities	7
Limited daily and recreational activities	4
Severe limitations of daily and recreational activities	0
Footwear requirement	
Fashionable, conventional shoes, no insert required	10
Comfort footwear, shoe insert	5
Modified shoes or brace	0
MTP joint motion (dorsiflexion plus plantarflexion)	
Normal or mild restriction (75° or more)	10
Moderate restriction (30°-74°)	5
Severe restriction (less than 30°)	0
IP Joint Motion (Plantarflexion)	
No restriction	5
Severe restriction (less than 10°)	0
MTP - IP stability (in all directions)	
Stable	5
Definitely unstable or able to dislocate	0
Callus related to hallux MTP-IP	
No callus or asymptomatic callus	5
Callus asymptomatic	0
Alignment (15 points)	
Good, hallux well aligned	15
Fair, some degree of hallux malalignment	8
Poor, obvious symptomatic malalignment	0

Fig. 1.1 (continued)

d

AOFAS Lesser Metatarsophalangeal-Interphalangeal Scale (100 Points Total)

Pain (40 Points)	
None	40
Mild, Occasional	30
Moderate, daily	20
Severe, almost always present	0
Function (45 Points)	
Activity limitations, support requirement	
No limitations	10
No limitation of daily activities, such as employment responsibilities, limitation of recreational activities	7
Limited daily and recreational activities	4
Severe limitations of daily and recreational activities	0
Footwear requirements	
Fashionable, conventional shoes, no insert required	10
Comfort footwear, shoe insert	5
Modified shoes or brace	0
MTP joint motion (dorsiflexion plus plantarflexion)	
Normal or mild restriction (75° or more)	10
Moderate restriction (30°-74°)	5
Severe restriction (less than 30°)	0
IP Joint Motion (Plantarflexion)	
No restriction	5
Severe restriction (less than 10°)	0
MTP- IP stability (in all directions)	
Stable	5
Definitely unstable or able to dislocate	0
Callus related to hallux MTP-IP	
No callus or asymptomatic callus	5
Callus asymptomatic	0
Alignment (15 points)	
Good, hallux well aligned	15
Fair, some degree of hallux malalignment	8
Poor, obvious symptomatic malalignment	0

Fig. 1.1 (continued)

the disability subscale describes difficulty in nine items, and the activity limitations subscale addresses extent of limitations in five items (Fig. 1.3). FFI scores are interpreted as 0–100% for each subscale and the overall score. Higher FFI scores indicate poor foot health-related quality of life. The FFI is easy to interpret and designed for an eighth-grade reading level for all patients. There is low administrative cost with no formal training required to score or interpret the test [24].

In a study by Budiman-Mak et al., 87 patients with RA were administered the FFI. They showed that the index had a test-retest reliability range from 0.87 to 0.69. They concluded that the FFI was a reasonable tool for evaluating outcomes in both clinical and research settings [23]. Agel et al. evaluated the utility of the FFI in a patient population without systemic disease. They found that 68.8% of respondents were consistent within one point in their responses, concluding again that the FFI was appropriate for evaluation of patients with foot disorders [25].

The FFI has been utilized extensively in the literature to analyze outcomes following fracture management at the calcaneus and talus [26, 27]. For example, Potter and Nunley reported [26] FFI scores were significantly worse in patients with calcaneal fractures following motor vehicle accidents versus fall. In a series of 191 intra-articular calcaneal fractures by Gaskill [28], FFI scores were significantly worse in patients younger than 50 compared with patients older than 50. Additionally, Vallier et al. [29] found that the presence of talar neck comminution was associated with significantly worse FFI scores in their series of 102 talar neck fractures. In an analysis of outcomes following fractures of the

1. In General, would you say your health is:

Excellent	**1**
Very Good	2
Good	3
Fair	4
Poor	5

2. Compared to one year ago,

Much better now than one year ago	**1**
Somewhat better now than one year ago	2
About the same	3
Somewhat worse now that one year ago	4
Much worse now than one year ago	5

3. The following items are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much?

	YES, LIMITED A LOT (1)	**YES, LIMITED A LITTLE (2)**	**NO, NOT LIMITED AT ALL (3)**
A. VIGOROUS ACTIVITIES,SUCH AS RUNNING, LIFTING HEAVY OBJECTS, PARTICIPATING IN STRENUOUS SPORTS	1	2	3
B. MODERATE ACTIVITIES,SUCH AS MOVING A TABLE, PUSHING A VACUUM CLEANER, BOWLING, OR PLAYING GOLF	1	2	3
C. LIFTING OR CARRYING GROCERIES	1	2	3
D. CLIMBING SEVERAL FLIGHTS OF STAIRS	1	2	3
E. CLIMBING ONE FLIGHT OF STAIRS	1	2	3
F. BENDING, KNEELING, OR STOOPING	1	2	3
G. WALKING MORE THAN A MILE	1	2	3
H. WALKING SEVERAL BLOCKS	1	2	3
I. WALKING ONE BLOCK	1	2	3
J. BATHING OR DRESSING YOURSELF	1	2	3

4. During the **past 4 weeks,** have you had any of the following problems with your work or other regular daily activities **as a result of your physical health? (Circle One Number on Each Line)**

	YES (1)	**NO (2)**
A. CUT DOWN THE AMOUNT OF TIME YOU SPENT ON WORK OR OTHER ACTIVITIES	1	2
B. ACCOMPLISHED LESS THAN YOU WOULD LIKE	1	2
C. WERE LIMITED IN THE KIND OF WORK OR OTHER ACTIVITIES	1	2
D. HAD DIFFICULTY PERFORMING THE WORK OR OTHER ACTIVITIES (FOR EXAMPLE, IT TOOK EXTRA EFFORT)	1	2

Fig. 1.2 Short Form-36 (SF-36) Health Survey Questionnaire

5. During the **past 4 weeks,** have you had any of the following problems with your work or other regular daily activities **as a result of any emotional problems** (such as feeling depressed or anxious)? **(Circle One Number on Each Line)**

	YES (1)	**NO (2)**
A. CUT DOWN THE AMOUNT OF TIME YOU SPENT ON WORK OR OTHER ACTIVITIES	1	2
B. ACCOMPLISHED LESS THAN YOU WOULD LIKE	1	2
C. DIDN'T DO WORK OR OTHER ACTIVITIES AS CAREFULLY AS USUAL	1	2

6. During the past 4 weeks, to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbors, or groups?

Not at all	1
Slightly	2
Moderately	3
Quite a bit	4
Extremely	5

7. How much bodily pain have you had during the past 4 weeks

None	1
Very mild	2
Mild	3
Moderate	4
Severe	5
Very severe	6

8. During the past 4 weeks, how much did pain interfere with your normal work (including both work outside the home and housework)?

Not at all	1
Slightly	2
Moderately	3
Quite a bit	4
Extremely	5

Fig. 1.2 (continued)

9. How much of the time during the past **4 weeks…**

	ALL OF THE TIME	MOST OF THE TIME	A GOOD BIT OF THE TIME	SOME OF THE TIME	A LITTLE OF THE TIME	NONE OF THE TIME
A. DID YOU FEEL FULL OF PEP?	1	2	3	4	5	6
B. HAVE YOU BEEN A VERY NERVOUS PERSON?	1	2	3	4	5	6
C. HAVE YOU FELT SO DOWN IN THE DUMPS THAT NOTHING COULD CHEER YOU UP?	1	2	3	4	5	6
D. HAVE YOU FELT CALM AND PEACEFUL?	1	2	3	4	5	6
E. DID YOU HAVE A LOT OF ENERGY?	1	2	3	4	5	6
F. HAVE YOU FELT DOWNHEARTED AND BLUE?	1	2	3	4	5	6
G. DID YOU FEEL WORN OUT?	1	2	3	4	5	6
H. HAVE YOU BEEN A HAPPY PERSON?	1	2	3	4	5	6
I. DID YOU FEEL TIRED?	1	2	3	4	5	6

10. During the past 4 weeks, how much of the time has your physical health or emotional problems interfered with your social activities (like visiting with friends, relatives, etc.)? (Circle One Number)

All of the time	1
Most of the time	2
Some of the time	3
A little of the time	4
None of the time	5

11. How TRUE or FALSE is each of the following statements for you. (Circle One Number on Each Line)

	DEFINITELY TRUE	MOSTLY TRUE	DON'T KNOW	MOSTLY FALSE	DEFINITELY FALSE
A. I SEEM TO GET SICK A LITTLE EASIER THAN OTHER PEOPLE	1	2	3	4	5
B. I AM AS HEALTHY AS ANYBODY I KNOW	1	2	3	4	5
C. I EXPECT MY HEALTH TO GET WORSE	1	2	3	4	5
D. MY HEALTH IS EXCELLENT	1	2	3	4	5

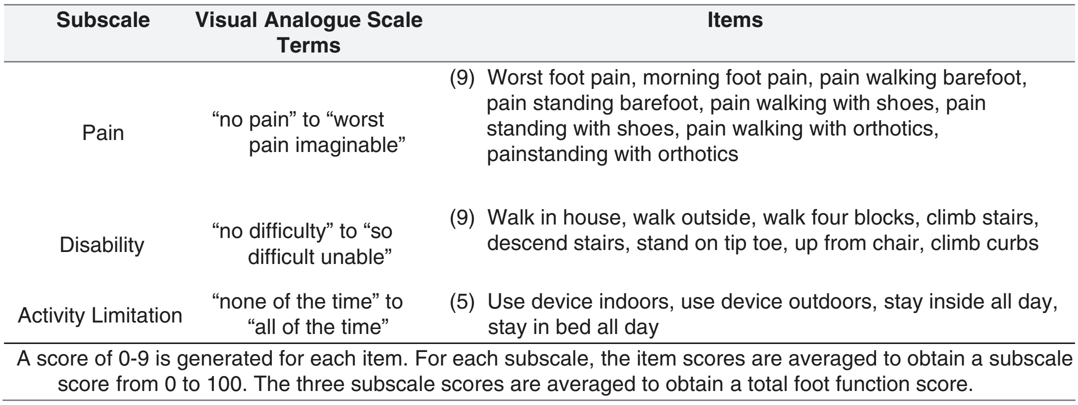
Fig. 1.2 (continued)

talus in young children versus adolescents, Eberl [30] found that young children had considerably lower FFI scores when stratified and compared by severity.

Despite its utilization, criticism of the FFI led to the development of a revised index (FFI-R), which added a psychosocial scale [31]. The FFI-R was developed from the 23 items originally described in the FFI with the addition of several more. In total, the FFI-R includes 68 items with a six-point response scale in its long form. A shorter form has only 34 questions, which assesses foot function only. Budiman-Mak et al. found that the FFI-R had person and item reliability of >0.93. However, because the FFI-R is a newer survey, there are fewer independent studies evaluating its utility [32].

American Academy of Orthopaedic Surgeons (AAOS) Lower Limb Instruments

The AAOS Lower Limb Outcome Assessment Instruments were published in 2004 to guide surgeons on objective ways in measuring patient



Subscale	Visual Analogue Scale Terms	Items
Pain	"no pain" to "worst pain imaginable"	(9) Worst foot pain, morning foot pain, pain walking barefoot, pain standing barefoot, pain walking with shoes, pain standing with shoes, pain walking with orthotics, painstanding with orthotics
Disability	"no difficulty" to "so difficult unable"	(9) Walk in house, walk outside, walk four blocks, climb stairs, descend stairs, stand on tip toe, up from chair, climb curbs
Activity Limitation	"none of the time" to "all of the time"	(5) Use device indoors, use device outdoors, stay inside all day, stay in bed all day

A score of 0-9 is generated for each item. For each subscale, the item scores are averaged to obtain a subscale score from 0 to 100. The three subscale scores are averaged to obtain a total foot function score.

Fig. 1.3 Foot Function Index (FFI)

pain and function. These instruments were developed after the distribution of questionnaires to 290 patients across the United States and Canada. Within this study, the Lower Limb Core Scale, the Hip and Knee Core Scale, and the Foot and Ankle Module were developed. For the purpose of this chapter, we will focus on the Foot and Ankle Module within the AAOS instruments.

The Foot and Ankle Module combines items from the Lower Limb Core Scale with additional items to assess pain and function related to foot or ankle problems (Fig. 1.4). The scale can be divided into subscales to assess pain (nine items), function (six items), stiffness and swelling (two items), and giving way (three items), with each subscale having good internal (alpha = 0.83 to 0.91) [33]. Overall, the AAOS Lower Limb Instruments had a retest reliability of 0.80 [33].

In an analysis of 122 polytrauma patients comparing outcomes between midfoot and hindfoot injuries, AAOS Foot and Ankle Scores (AAOS FAS) were found to be comparable between groups [34]. In a series of 114 patients sustaining hindfoot injuries related to combat, changes in AAOS scores were found to be most negatively impacted by a negative Böhler's angle, followed by coexisting talar and calcaneal fractures, and tibial plafond fractures in addition to hindfoot fractures [35]. In a series of 23 patients older than 60 who underwent treatment with the Ilizarov method for tibial nonunion, AAOS FAS consistently reflected pain and functional improvement, with 5.3 quality-adjusted life years added per patient [36]. Similarly, in a series of 38 patients with tibial nonunions treated with the Taylor Spatial Frame, AAOS FAS improved post-treatment comparatively with other outcome scores, including the SF-36.5 In an analysis of 25 patients treated nonoperatively with immobilization for a Jones fracture, AAOS FAS correlated well with patient satisfaction and radiographic assessment of union post-treatment [5].

AAOS Lower Limb Instruments : Foot and Ankle Questionnaire
Instructions

Please answer the following questions for the foot/ankle being treated or followed up. If it is BOTH feet/ankles, please answer the questions for your worse side. All questions are about how you have felt, on average, during the **past week**. If you are being treated for an injury that happened less than one week ago, please answer for the period since your injury.

1. During the **past week**, how **stiff** was your foot/ankle? (Circle one response.)
   1. Not at all 2. Mildly 3. Moderately 4. Very 5. Extremely

2. During the **past week**, how **swollen** was your foot/ankle? (Circle one response)
   1. Not at all 2. Mildly 3. Moderately 4. Very 5. Extremely

During the **past week**, please tell us about how painful your foot/ankle was during the following activities
(Circle ONE response on each line that best describes your average ability.)

	NOT PAINFUL	MILDLY PAINFUL	MODERATELY PAINFUL	VERY PAINFUL	EXTREMELY PAINFUL	COULD NOT DO BECAUSE OF FOOT OR ANKLE PAIN	COULD NOT DO FOR OTHER REASONS
3. WALKING ON **UNEVEN** SURFACES?	1	2	3	4	5	6	7
4. WALKING ON **FLAT**SURFACES?	1	2	3	4	5	6	7
5. GOING UP OR DOWN STAIRS?	1	2	3	4	5	6	7
6. LYING IN BED AT NIGHT?	1	2	3	4	5	6	7

During the **past week**, did your foot/ankle **give way**during the following activities.
(Circle ONE response on each line that best describes you for each activity level)

	DID NOT GIVE WAY AT ALL	PARTIALLY GAVE WAY, BUT DID NOT FAIL	COMPLETELY GAVE WAY, SO THAT I FELL	COULD NOT DO THE ACTIVITY BECAUSE OF FOOT/ANKLE GIVING WAY	COULD NOT DO FOR OTHER REASONS
7. **STRENUOUS ACTIVITY**, SUCH AS HEAVY PHYSICAL WORK, SKIING, TENNIS?	1	2	3	4	5
8. **MODERATE ACTIVITY**, SUCH AS MODERATE PHYSICAL WORK, JOGGING, RUNNING?	1	2	3	4	5
9. **LIGHT ACTIVITY**, SUCH AS WALKING, HOUSE WORK, YARD WORK?	1	2	3	4	5

Fig. 1.4 AAOS Lower Limb Instruments: Foot and Ankle Module

10. Which of the following statements **best** describes your ability to get around most of the time during the **past week**? (Circle one response.)
    1 I did not need support or assistance at all.
    2 I mostly walked without support or assistance
    3 I mostly used one cane or crutch to help me get around
    4 I mostly used two canes, two crutches or a walker to help me get around
    5 I used a wheelchair.
    6 I mostly used other supports or someone else had to help me get around
    7 I was unable to get around at all.

11. How much trouble have you had with balance during the **past week?** (Circle one response)
    1 No trouble at all
    2 A little bit of trouble
    3 A moderate amount of trouble
    4 Quite a bit of trouble
    5 A great amount of trouble
    6 I cannot balance on my feet at all

12. How difficult was it for you to put on or take off socks/stockings during the **past week?** (Circle one response)

1 Not at all difficult 2 A little bit difficult 3 Moderately difficult 4 Very difficult 5 Extremely difficult 6 Cannot do it at all

All questions are about how you have felt on average **during the past week**

During the **past week**, please tell us about how **painful** your **foot or ankle** was when you were performing the following activities. (Circle ONE response on each line that best describes your average ability)

	NO PAIN	MILD PAIN	MODERATE PAIN	SEVERE PAIN	EXTREME PAIN	COULD NOT DO BECAUSE OF FOOT OR ANKLE PAIN	COULD NOT DO FOR OTHER REASONS
13. **STRENUOUS ACTIVITY**, SUCH AS HEAVY PHYSICAL WORK, SKIING, TENNIS	1	2	3	4	5	6	7
14. **MODERATE ACTIVITY**, SUCH AS MODERATE PHYSICAL WORK, JOGGING, RUNNING	1	2	3	4	5	6	7
15. **LIGHT ACTIVITY,** SUCH AS WALKING, HOUSE WORK, YARD WORK	1	2	3	4	5	6	7
16. STANDING FOR AN HOUR	1	2	3	4	5	6	7
17. STANDING FOR A FEW MINUTES	1	2	3	4	5	6	7

Fig. 1.4 (continued)

18. How much difficulty do you have walking on uneven surfaces (eg., small stones, rocks, sloping ground)? (Circle one response.)
    1 No difficulty
    2 Mild difficulty
    3 Moderate difficulty
    4 Severe difficulty
    5 Extreme difficulty
    6 Cannot do because of foot/ankle
    7 Cannot do for other reasons

	YES	NO	NOT APPLICABLE
19. ANY WOMEN'S SHOE (INCLUDING HIGH HEELS) OR ANY MEN'S SHOE (INCLUDING FANCY DRESS SHOES)	1	2	3
20. MOST WOMEN'S DRESS SHOES (EXCEPT HIGH HEELS) OR MOST MEANS DRESS SHOES	1	2	3
21. SNEAKERS, WALKING ORCASUAL SHOES	1	2	3
22. ORTHOPAEDIC OR PRESCRIPTION SHOES	1	2	3
23. ALL SHOES	1	2	3

24. How much did your foot or ankle problem interfere with your normal work, including work both outside the home and house work? (Circle one response)

1 Not at all 2 A little bit 3 Moderately 4 Quite a bit 5 Extremely 6 Unable to work due to foot and ankle problems

25. How much did your foot or ankle problem interfere with your life and your ability to do what you want?

1 Not at all 2 A little bit 3 Moderately 4 Quite a bit 5 Extremely 6 It ruins everything

Fig. 1.4 (continued)

References

1. Turchin DC, Schemitsch EH, McKee MD, Waddell JP. Do foot injuries significantly affect the functional outcome of multiply injured patients? J Orthop Trauma. 1999;13(1):1–4.
2. Standring S, Gray H. Gray's anatomy : the anatomical basis of clinical practice. 40th ed. Edinburgh: Churchill Livingstone/Elsevier; 2008. p. xxiv, 1551 p.
3. Anderson RB, Coughlin MJ, Saltzman CL. Mann's surgery of the foot and ankle. 9th ed. Philadelphia: Saunders/Elsevier; 2014, online resource (xxii, 2186 pages) p.
4. Richter M, Kwon JY, Digiovanni CW. Foot injuries. Skeletal trauma. 9th ed. Philadelphia: Saunders; 2014. p. 2251–387.
5. Rozbruch SR, Pugsley JS, Fragomen AT, Ilizarov S. Repair of tibial nonunions and bone defects with the Taylor Spatial Frame. J Orthop Trauma. 2008;22(2):88–95.
6. Park IH, Song KW, Shin SI, Lee JY, Kim TG, Park RS. Displaced intra-articular calcaneal fracture treated surgically with limited posterior incision. Foot Ankle Int. 2000;21(3):195–205.
7. Aktuglu K, Aydogan U. The functional outcome of displaced intra-articular calcaneal fractures: a comparison between isolated cases and polytrauma patients. Foot Ankle Int. 2002;23(4):314–8.
8. Renovell-Ferrer P, Bertó-Martí X, Diranzo-García J, Barrera-Puigdorells L, Estrems-Díaz V, Silvestre-Muñoz A, et al. Functional outcome after calcaneus fractures: a comparison between polytrauma patients and isolated fractures. Injury. 2017;48(Suppl 6):S91–S5.
9. Elgafy H, Ebraheim NA, Tile M, Stephen D, Kase J. Fractures of the talus: experience of two level 1 trauma centers. Foot Ankle Int. 2000;21(12):1023–9.
10. Kou JX, Fortin PT. Commonly missed peritalar injuries. J Am Acad Orthop Surg. 2009;17(12):775–86.
11. Matuszak SA, Baker EA, Stewart CM, Fortin PT. Missed peritalar injuries: an analysis of factors in cases of known delayed diagnosis and methods for improving identification. Foot Ankle Spec. 2014;7(5):363–71. Epub 2014/07/17.
12. Archer KR, Abraham CM, Obremskey WT. Psychosocial factors predict pain and physical health after lower extremity trauma. Clin Orthop Relat Res. 2015;473(11):3519–26.

13. Vranceanu AM, Bachoura A, Weening A, Vrahas M, Smith RM, Ring D. Psychological factors predict disability and pain intensity after skeletal trauma. J Bone Joint Surg Am. 2014;96(3):e20.
14. Wegener ST, Castillo RC, Haythornthwaite J, Mackenzie EJ, Bosse MJ, Leap Study Group. Psychological distress mediates the effect of pain on function. Pain. 2011;152(6):1349–57. Epub 2011/03/10.
15. Balazs GC, Hanley MG, Pavey GJ, Rue JP. Military personnel sustaining Lisfranc injuries have high rates of disability separation. J R Army Med Corps. 2017;163(3):215–9. Epub 2016/12/09.
16. Hunt KJ, Hurwit D. Use of patient-reported outcome measures in foot and ankle research. J Bone Joint Surg Am. 2013;95(16):e118(1-9).
17. Button G, Pinney S. A meta-analysis of outcome rating scales in foot and ankle surgery: is there a valid, reliable, and responsive system? Foot Ankle Int. 2004;25(8):521–5.
18. Kitaoka HB, Alexander IJ, Adelaar RS, Nunley JA, Myerson MS, Sanders M. Clinical rating systems for the ankle-hindfoot, midfoot, hallux, and lesser toes. Foot Ankle Int. 1994;15(7):349–53.
19. de Boer AS, Tjioe RJC, Van der Sijde F, Meuffels DE, den Hoed PT, Van der Vlies CH, et al. The American Orthopaedic Foot and Ankle Society Ankle-Hindfoot Scale; translation and validation of the Dutch language version for ankle fractures. BMJ Open. 2017;7(8):e017040. Epub 2017/08/03.
20. Toolan BC, Wright Quinones VJ, Cunningham BJ, Brage ME. An evaluation of the use of retrospectively acquired preoperative AOFAS clinical rating scores to assess surgical outcome after elective foot and ankle surgery. Foot Ankle Int. 2001;22(10):775–8.
21. SooHoo NF, Shuler M, Fleming LL. Society AOFaA. Evaluation of the validity of the AOFAS Clinical Rating Systems by correlation to the SF-36. Foot Ankle Int. 2003;24(1):50–5.
22. De Boer AS, Meuffels DE, Van der Vlies CH, Den Hoed PT, Tuinebreijer WE, Verhofstad MHJ, et al. Validation of the American Orthopaedic Foot and Ankle Society Ankle-Hindfoot Scale Dutch language version in patients with hindfoot fractures. BMJ Open. 2017;7(11):e018314. Epub 2017/11/14.
23. Budiman-Mak E, Conrad KJ, Roach KE. The Foot Function Index: a measure of foot pain and disability. J Clin Epidemiol. 1991;44(6):561–70.
24. Budiman-Mak E, Conrad KJ, Mazza J, Stuck RM. A review of the foot function index and the foot function index – revised. J Foot Ankle Res. 2013;6(1):5. Epub 2013/02/01.
25. Agel J, Beskin JL, Brage M, Guyton GP, Kadel NJ, Saltzman CL, et al. Reliability of the foot function index: a report of the AOFAS outcomes committee. Foot Ankle Int. 2005;26(11):962–7.
26. Potter MQ, Nunley JA. Long-term functional outcomes after operative treatment for intra-articular fractures of the calcaneus. J Bone Joint Surg Am. 2009;91(8):1854–60.
27. Vallier HA, Nork SE, Barei DP, Benirschke SK, Sangeorzan BJ. Talar neck fractures: results and outcomes. J Bone Joint Surg Am. 2004;86-A(8):1616–24.
28. Gaskill T, Schweitzer K, Nunley J. Comparison of surgical outcomes of intra-articular calcaneal fractures by age. J Bone Joint Surg Am. 2010;92(18):2884–9.
29. Vallier HA, Nork SE, Benirschke SK, Sangeorzan BJ. Surgical treatment of talar body fractures. J Bone Joint Surg Am. 2004;86-A(Suppl 1 Pt 2):180–92.
30. Eberl R, Singer G, Schalamon J, Hausbrandt P, Hoellwarth ME. Fractures of the talus--differences between children and adolescents. J Trauma. 2010;68(1):126–30.
31. Budiman-Mak E, Conrad K, Stuck R, Matters M. Theoretical model and Rasch analysis to develop a revised Foot Function Index. Foot Ankle Int. 2006;27(7):519–27.
32. Riskowski JL, Hagedorn TJ, Hannan MT. Measures of foot function, foot health, and foot pain: American Academy of Orthopedic Surgeons Lower Limb Outcomes Assessment: Foot and Ankle Module (AAOS-FAM), Bristol Foot Score (BFS), Revised Foot Function Index (FFI-R), Foot Health Status Questionnaire (FHSQ), Manchester Foot Pain and Disability Index (MFPDI), Podiatric Health Questionnaire (PHQ), and Rowan Foot Pain Assessment (ROFPAQ). Arthritis Care Res (Hoboken). 2011;63(Suppl 11):S229–39.
33. Johanson NA, Liang MH, Daltroy L, Rudicel S, Richmond J. American Academy of Orthopaedic surgeons lower limb outcomes assessment instruments. Reliability, validity, and sensitivity to change. J Bone Joint Surg Am. 2004;86-A(5):902–9.
34. Diacon AL, Kimmel LA, Hau RC, Gabbe BJ, Edwards ER. Outcomes of midfoot and hindfoot fractures in multitrauma patients. Injury. 2018. Epub 2018/11/12.
35. Bennett PM, Stevenson T, Sargeant ID, Mountain A, Penn-Barwell JG. Outcomes following limb salvage after combat hindfoot injury are inferior to delayed amputation at five years. Bone Joint Res. 2018;7(2):131–8.
36. Brinker MR, O'Connor DP. Outcomes of tibial nonunion in older adults following treatment using the Ilizarov method. J Orthop Trauma. 2007;21(9):634–42.

Foot Injury: The Initial Evaluation

2

Wayne S. Berberian and John Hwang

Introduction

Hindfoot fractures and dislocations are among the most complex of all orthopedic injuries. Although talus and calcaneus fractures are the two most common tarsal bone injuries, they account for only 3% of all fractures seen [1, 2]. These injuries typically result from high-energy trauma, such as motor vehicle accidents or falls from heights. The initial evaluation and management of these fractures play a vital role in optimizing care and decreasing morbidity.

Initial Management

A high index of suspicion for foot injuries is needed during the initial assessment of all polytrauma patients. Numerous studies have demonstrated that foot injuries are among the most commonly missed extremity injuries in this population and that they account for 12–23% of all undetected extremity injuries [3–6].

Patient history is the cornerstone of diagnosis, and details about comorbidities, medications, and social habits may become instrumental in crafting a definitive treatment plan. For example, a calcaneus fracture in a 65-year-old neuropathic diabetic with peripheral vascular disease who smokes two packs of cigarettes per day may be treated differently from the same injury in a healthy 20-year-old with no medical problems.

Obtaining a thorough history from family members, police, and emergency medical transport personnel may provide information about mechanisms leading to potential hindfoot injuries. This data is especially crucial in the context of an unconscious, obtunded, or intoxicated patient.

After reviewing the history, a careful physical examination of all extremities, including a thorough examination of the feet, should be conducted. Gross deformity of the foot may be visible in the case of a subluxation, dislocation, or fracture. Examination of the skin may demonstrate abrasions, ecchymosis, lacerations, open wounds, or swelling. Talar body fractures are open in almost 20% of cases [7].

Comparing both feet may elucidate subtle swelling in unilateral injuries. Healed surgical incisions may help to differentiate acute injury from prior pathology. Careful attention must be devoted to the plantar surface of the foot and the web spaces as these sites are often overlooked.

Careful palpation of each area of the foot and ankle in a systematic manner may be the most crucial step in pinpointing acute fractures on

W. S. Berberian (✉)
Hackensack Meridian School of Medicine at Seton Hall, Nutley, NJ, USA
e-mail: wberberian@anklefootinstitute.com

J. Hwang
Orthopedic One, Columbus, OH, USA
e-mail: jhwang@orthopedicone.com

© Springer Nature Switzerland AG 2020

M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_2

exam. Obtunded or intubated patients are especially difficult to examine, and thus imaging takes on even greater importance in this population. Passive range of motion of the tibiotalar, subtalar, transverse tarsal, and metatarsophalangeal joints may be compared with an uninjured contralateral side, if applicable. Grading motor function in the ankle and toe dorsiflexors and plantarflexors, as well as the hindfoot invertors and evertors, may help to discern the presence of tendon ruptures or entrapment.

Finally, a thorough neurovascular exam should be performed, which should include a sensory exam, palpation of pulses in the dorsalis pedis and posterior tibial arteries, and the presence of capillary refill. Patients at the risk of lower extremity neuropathy due to comorbidities like diabetes or alcoholism should be screened carefully. The use of Semmes-Weinstein monofilament 5.07 on the plantar surface of the feet may identify patients with a dense loss of protective sensation that could lead to a change in treatment strategy.

Plain radiographs of the foot, ankle, and tibia should be taken when any clinical suspicion of fracture or dislocation is present. At a minimum, routine ankle views should consist of an AP, lateral, and mortise, while foot views should consist of an AP, lateral, and internal oblique. Special views for the talus and calcaneus will be discussed later.

Talus

Associated Injuries

Due to the high-energy component that is required for these types of fractures to occur, talus fracture and dislocations are highly associated with polytrauma patients who have multiple injuries, including those to the extremities and organs. A study by Sanders et al. found that in 70 patients with talus fractures, 59% had ipsilateral extremity injuries [8]. The most commonly associated orthopedic injuries were malleolar fractures, with rates reported as high as 28% [9–11]. Other less commonly associated fractures included calcaneus and navicular fractures [10, 12].

Signs and Symptoms

A standard neurovascular examination should be performed, including assessment of pulses, capillary refill, and sensation. The majority of talus fractures are not accompanied by neurovascular injury. Although posterior dislocation of the talus may compromise the posterior tibial nerve and vessels, the flexor hallucis longus (FHL) tendon has been shown to provide protection to these structures in most cases [13].

A high index of suspicion is critical for the detection of subtle fractures of the talus, as many of these patients may present with moderate pain as their only symptom. This is especially true with talar process fractures that often result from a low-energy mechanism. Patients with lateral process fractures may present with symptoms similar to those of ankle sprains, with pain localized near the distal aspect of the lateral malleolus [14]. Provocative testing for subluxation of the peroneal tendons should be undertaken for patients with lateral process fractures [15], and advanced imaging such as MRI should be considered in cases suspicious for such an injury.

Isolated talar head fractures typically present with pain and tenderness over the talonavicular joint. Foot deformity may not be present [16, 17]. Most talar head fractures are part of complex hindfoot injuries that occur following high-energy injuries. Patients with such injuries typically present with more obvious foot deformities, swelling, and ecchymosis.

Fracture-dislocation of the talar neck may result in deformity of the foot that is moderate to severe in appearance. In severely displaced cases with tibiotalar dislocation, bony prominences may be seen either medially or laterally, with the opposite side presenting with skin dimpling. Soft tissue must be closely examined to ensure that the injury is not open and that it does not compromise the skin. Fractures or dislocations with significant tenting of the skin must be relocated with urgency as prolonged circulatory impairment may cause skin necrosis and lead to wound infection [18].

Talar body fractures have similar findings to those of talar neck fractures. Pain, swelling, and tenderness are located diffusely over the ankle. Ecchymosis is variable and can be located anywhere in the hindfoot.

Peritalar dislocations in the absence of concomitant fracture are rare injuries and include dislocations of the subtalar, talonavicular, and/or tibiotalar joints. These injuries present with significant foot deformity. When these dislocations are closed, they cause significant skin compromise due to tension from the dislocated head or malleoli. Occult fractures or damage to the articular surface are frequently present [19]. A thorough neurovascular exam should always be performed as vascular compromise may be present. These injuries should be treated as surgical emergencies if they cannot be closed-reduced.

Imaging

Standard plain radiographs of the ankle and foot should be performed on all suspected talus fractures and dislocations. The anteroposterior (AP) view of the ankle allows for visualization of the lateral process and ankle mortise. The mortise view of the ankle is used to evaluate the congruency of the tibiotalar joint, while the lateral view allows for visualization of fractures along the body and neck of the talus.

AP and oblique views of the foot allow for visualization of the talar head, as well as the alignment of the talus to the forefoot. The lateral view of the foot allows for visualization of the talar neck, the subtalar joint, and alignment to midfoot and forefoot.

An additional view that can be taken during initial evaluation, but is typically used intraoperatively, is the Canale view, which is used to evaluate the talar neck. This view is taken by maximally plantarflexing the foot and 15 degrees of pronation of the foot with the X-ray beam directed 75 degrees cephalad from the horizontal [20]. If a lateral process fracture is suspected, an AP view that is taken with the ankle in neutral dorsiflexion and the leg in 20 degrees of internal fixation may assist in visualization [21].

If possible, computed tomographic (CT) imaging should be obtained as this type of imaging allows for better delineation of the fracture fragments in the coronal, sagittal, and axial planes and assists in surgical planning. During the acute management of these fractures, MRIs are uncommonly used and are not as useful as CT scans.

Initial Management

Following the history, physical exam, and imaging, the initial management of talus fractures varies according to the type of fracture and the severity of the injury. Simple fractures of the talar head, talar body, or talar process fractures that do not show signs of skin tenting, subluxation, or dislocation should be placed in a short-leg Stimson splint. Displaced fractures or dislocations may cause significant subcutaneous pressure and skin compromise if not addressed promptly. Under tension, the overlying skin begins to show extensive hemorrhagic infiltration and venous thrombosis, which may lead to skin necrosis over the affected areas [18]. A study by Bonnin found that 73% of 56 irreducible peritalar dislocations had slough of the skin [22]. Although in the past it was thought to be imperative that these fractures be reduced urgently in order to mitigate the risk of avascular necrosis [11], several recent studies have concluded that there appears to be no correlation between timing of surgery and incidence of avascular necrosis [23–25]. When closed reduction is performed in the emergency room, the patient should be adequately sedated to allow easy manipulation of the foot. Multiple attempts at closed reduction should not be performed following the first or second try. In the irreducible fracture, the patient should be expedited to the operating room for likely open reduction.

Approximately 50% of talar neck fractures with significant displacement of the talar body have been associated with open injuries [8, 25, 26]. Bedside irrigation during the initial evaluation may be performed for gross contamination prior to reduction of the fracture, especially if comorbidities or visceral injuries are expected to cause a delay in surgical treatment. The open wound should be covered with moist saline gauze and splinted in the reduced position until the patient can undergo formal irrigation and debridement, as well as stabilization of the fracture in the operating room. Though uncommon in open fractures, the talar body may extrude out of the open wound (Fig. 2.1a–e). Temporary reimplantation in the emergency department setting is usually not possible and is of questionable value. Instead, the extruded fragment should be wrapped in moist saline gauze prior to splinting and urgent operative treatment. Smith et al. retrospectively reviewed 19 patients with extruded tali. At the 1-year follow-up, two of the 19 patients had a postoperative infection. Irrigation and debridement of the wound were initially performed in the emergency room, followed by a formal debridement in the operating room. The extruded tali were soaked in bacitracin prior to reimplantation [27].

Subtalar dislocation can occur both in medial and lateral directions. Closed reduction in the emergency room should be attempted since the majority of these injuries can be closed reduced with adequate sedation. Regardless of the direction of dislocation, the initial reduction steps are the same. The hip and knee should be flexed to reduce the forceful pull of the gastrocnemius muscle. Manual longitudinal traction should be placed through the foot by pulling through the heel, and the deformity should initially be exaggerated to unlock the foot.

For medial dislocations, the foot must be then everted and dorsiflexed to achieve reduction. If closed reduction appears unachievable, it is often because the extensor retinaculum, talonavicular joint capsule, peroneal tendons, or the extensor digitorum brevis is blocking the reduction [28].

For lateral dislocations, pressure should be placed on the prominent talar head on the medial side as the foot is adducted into a reduced position. An irreducible lateral subtalar dislocation is typically the result of a block from the posterior tibialis tendon and less often caused by a block from the flexor digitorum longus [29].

Impaction and interlock of the talonavicular articular surfaces may cause a rigidly irreducible subtalar dislocation. As with irreducible dislocations blocked by soft tissue structures described above, this needs to be brought to the operating room for manual disimpaction through an open approach.

Total talus dislocation, or the dislocation of the subtalar and tibiotalar joints, requires urgent reduction. Closed reduction may be attempted in the emergency room with traction and gentle manipulation of the talus [30, 31]. A traction pin in the calcaneus can provide a point of fixation for manipulation and traction of the foot. These dislocations are often irreducible in an emergency setting and require urgent open reduction via either a lateral or medial approach [32, 33].

Calcaneus

Associated Injuries

Due to the high-energy mechanism that is needed in order for a calcaneus fracture to occur, 50% of these fractures have associated injuries. The majority of these associated injuries are lumbar spine injuries or lower extremity injuries. Up to 10% of calcaneus fractures are associated with lumbar spine injuries. The associated lower extremity injuries include tibial plateau, pilon, and talus fractures [34–38]. Bilateral calcaneus fractures have also been found in up to 10% of all patients [39]. In addition, the literature has demonstrated that open fractures account for 17% of these injuries [40–42].

Signs and Symptoms

The initial presentation of calcaneus fractures may vary greatly depending on the level of energy and degrees of fracture comminution and displacement. In a low-energy injury with a minimally displaced fracture, the skin may appear normal with minimal tenderness, swelling, and ecchymosis. Patients presenting with this type of injury often complain of difficulty with ankle plantarflexion due to the attachment of the gastrocnemius-soleus complex to the calcaneal tuberosity.

Fig. 2.1 (**a**) Lateral ankle radiograph of a 25-year-old male FedEx driver with an extruded talus after his truck collided with a car. The patient also sustained a fracture-dislocation of his lumbar spine that resulted in paraplegia. (**b**) Clinical photo of the extruded and grossly contaminated talus in the same patient. (**c**) Lateral ankle radiograph showing patient's ankle after debridement and provisional fixation. (**d**) Lateral ankle radiograph showing antibiotic cement spacer placement after he developed an infection and the talus had to be sacrificed. (**e**) Lateral ankle radiograph after surgery was performed for tibiocalcaneal arthrodesis. The patient later consolidated his arthrodesis site, recovered from his paraplegia, and returned to work

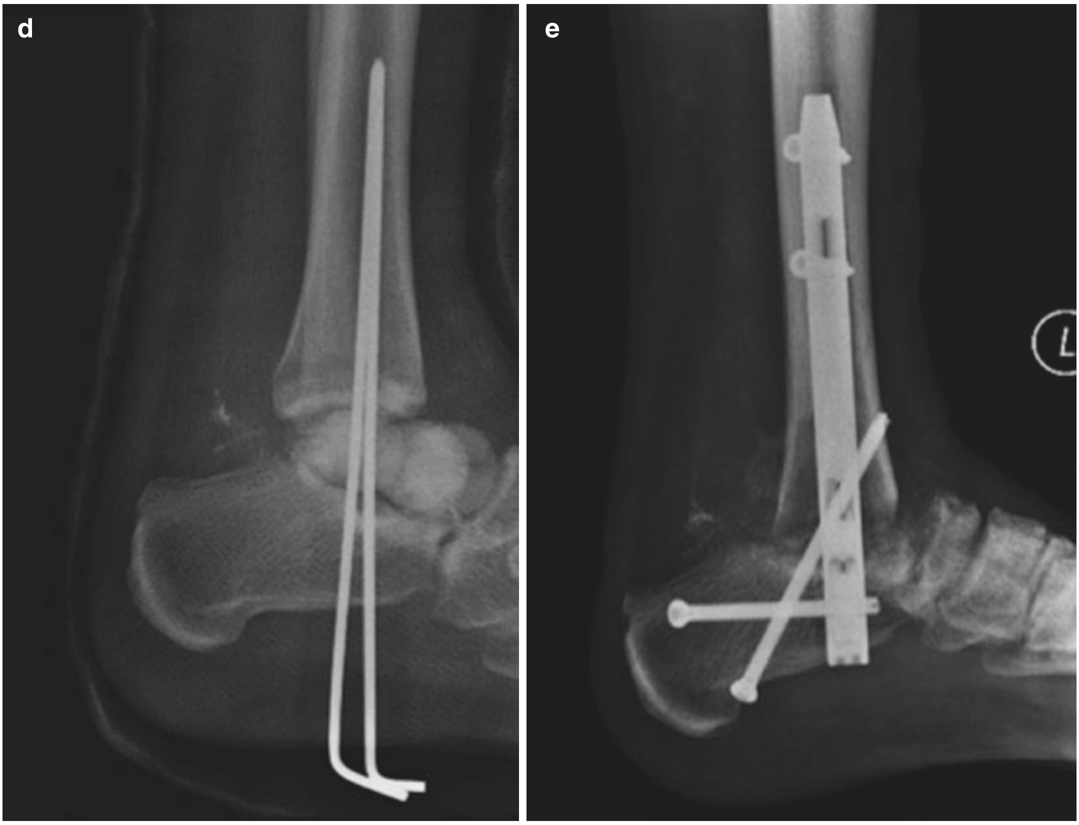


Fig. 2.1 (continued)

More often, patients with high-energy calcaneus fractures present with significant swelling and ecchymosis around the hindfoot. These patients present with significant pain in the heel that intensifies with movement of the ankle or foot. Patients with substantial swelling often lose the skin creases of the foot and may complain of decreased sensation in various areas of the foot. In these patients, a thorough neurovascular exam must be performed with continued monitoring due to the risk of associated foot compartment syndrome [43, 44]. Skin tenting may be apparent on the posterior aspect of the heel in patients with displaced tongue-type fractures.

Imaging

Initial imaging should consist of the standard three views of the foot and ankle. The foot views should include AP, lateral, and internal oblique views in order to appropriately evaluate the hindfoot, midfoot, and forefoot. The ankle views should include AP, lateral, and mortise views. In addition, a Harris heel view should be performed in all calcaneus fractures. The Harris heel view is performed by placing the cassette beneath the patient's dorsiflexed foot, with the angle of the beam aimed 30 to 40 degrees cephalad. This allows for an axial view of the calcaneus for evaluation of an axial plane deformity. This view is often difficult to obtain in the initial trauma setting due to the pain incurred by the patient while obtaining this view.

The lateral view of the ankle often demonstrates the fracture pattern as per the Essex-Lopresti classification: joint depression and tongue-type fracture [34]. The Gissane angle and Bohler's angle should be measured to help identify and quantify a collapse in the posterior facet. Double densities detected along the posterior facet typically signify split intraarticular fractures of the posterior facet [45].

A CT scan of the calcaneus should be performed as these images help better delineate fracture lines and displacement. The scan will assist in both surgical planning and identification of occult fractures. The CT should be performed with 2-mm cuts or less and in three planes of the calcaneus: axial, sagittal, and 30-degree semi-coronal. The semi-coronal view allows for evaluation of the posterior facet and is the basis of the Sanders classification [46]. In addition, this view can help visualize the peroneal tendons, FHL tendon, lateral wall blowout, and widening of the heel.

Initial Management

Initial management should begin with the patient's history and physical exam, as discussed previously in this chapter. For patients who have minimal displacement and meet nonoperative criteria, a short-leg Stimson splint should be placed with the heel appropriately padded in order to prevent skin irritation and provide compression. This can be converted to a short-leg cast once the initial swelling has subsided.

Calcaneus fractures that require surgery often cannot be operated on acutely due to the increased incidence of postoperative wound complications that result from the massive swelling and blistering caused by the initial injury [47–49]. A well-padded splint that provides compression to decrease swelling is vital in the management of calcaneus fractures. Depending on the type of fracture, the position of the foot in the splint will vary. Intra-articular depressed fractures should be placed in neutral dorsiflexion. Tongue-type fractures often require the ankle to be placed in plantarflexion in order to prevent skin compromise at the posterior heel.

Significantly displaced intra-articular tongue-type fractures, as well as extraarticular avulsion fractures of the calcaneal tuberosity, can cause skin compromise in the posterior heel. These fractures require urgent reduction in the operating room. As the strong gastrocnemius-soleus complex pulls the tuberosity into a plantarflexed and posterior position, skin tension at the heel causes impaired vascularity. This may be evident as a palpable deformity in the posterior heel with blanching of the skin in this location. While in the emergency room, these patients should be placed in plantarflexed splints in order to try to delay progressive necrosis of the soft tissue envelope.

Patients with severe swelling who do not require urgent reduction in the operating room should be closely monitored for risk of possible compartment syndrome. A thorough neurovascular exam should be performed with close monitoring during the initial 24-h period. The foot should be elevated in the bed to decrease swelling and increase venous blood return. Complaints of pain out of proportion to injury, severe pain with passive toe dorsiflexion, and abnormal values with intracompartmental pressure monitoring all support the diagnosis of compartment syndrome and mandate urgent fasciotomy of the hindfoot.

Open fractures of the calcaneus require initial antibiotics. Bedside irrigation may be performed with saline for grossly contaminated wounds in patients who are facing a delay in operative treatment. All wounds should be covered with saline gauze and splinted until the patient can be brought to the operating room.

References

1. O'Connell F, Mital MA, Rowe CR. Evaluation of modern management of fractures of the os calcis. Clin Orthop Relat Res. 1972;83:214–23.
2. Santavirta S, Seitsalo S, Kiviluoto O, Myllynen P. Fractures of the talus. J Trauma. 1984;24(11):986–9.
3. Guly HR. Diagnostic errors in an accident and emergency department. Emerg Med J. 2001;18(4):263–9.
4. Born CT, Ross SE, Iannacone WM, Schwab CW, DeLong WG. Delayed identification of skeletal injury in multisystem trauma: the 'missed' fracture. J Trauma. 1989;29(12):1643–6.
5. Houshian S, Larsen MS, Holm C. Missed injuries in a level I trauma center. J Trauma. 2002;52(4):715–9.
6. Juhl M, Moller-Madsen B, Jensen J. Missed injuries in an orthopaedic department. Injury. 1990;21(2):110–2.
7. Vallier HA, Nork SE, Benirschke SK, Sangeorzan BJ. Surgical treatment of talar body fractures. J Bone Joint Surg Am. 2003;85-A(9):1716–24.

8. Sanders DW, Busam M, Hattwick E, Edwards JR, McAndrew MP, Johnson KD. Functional outcomes following displaced talar neck fractures. J Orthop Trauma. 2004;18(5):265–70.
9. Canale ST. Fractures of the neck of the talus. Orthopedics. 1990;13(10):1105–15.
10. Lorentzen JE, Christensen SB, Krogsoe O, Sneppen O. Fractures of the neck of the talus. Acta Orthop Scand. 1977;48(1):115–20.
11. Hawkins LG. Fractures of the neck of the talus. J Bone Joint Surg Am. 1970;52(5):991–1002.
12. Coltart WD. Aviator's astragalus. J Bone Joint Surg Br. 1952;34-B(4):545–66.
13. Chapman MW. The use of immediate internal fixation in open fractures. Orthop Clin North Am. 1980;11(3):579–91.
14. von Knoch F, Reckord U, von Knoch M, Sommer C. Fracture of the lateral process of the talus in snowboarders. J Bone Joint Surg Br. 2007;89(6):772–7.
15. Klein SE, Varner KE, Marymont JV. Lateral talar process fracture and peroneal tendon dislocation: a previously unrecognized injury complex. Foot Ankle Int. 2008;29(10):1020–4.
16. Kenwright J, Taylor RG. Major injuries of the talus. J Bone Joint Surg Br. 1970;52(1):36–48.
17. Pennal GF. Fractures of the talus. Clin Orthop Relat Res. 1963;30:53–63.
18. McKeever FM. Fractures of tarsal and metatarsal bones. Surg Gynecol Obstet. 1950;90(6):735–45.
19. Bibbo C, Lin SS, Abidi N, Berberian W, Grossman M, Gebauer G, Behrens FF. Missed and associated injuries after subtalar dislocation: the role of CT. Foot Ankle Int. 2001;22(4):324–8.
20. Canale ST, Kelly FB Jr. Fractures of the neck of the talus. Long-term evaluation of seventy-one cases. J Bone Joint Surg Am. 1978;60(2):143–56.
21. Mukherjee SK, Young AB. Dome fracture of the talus. J Bone Joint Surg Br. 1973;55:319–26.
22. Bonnin JG. Dislocations and fracture-dislocations of the talus. Br J Surg. 1940;28(109):88–100.
23. Vallier HA, Nork SE, Barei DP, Benirschke SK, Sangeorzan BJ. Talar neck fractures: results and outcomes. J Bone Joint Surg Am. 2004;86-A(8):1616–24.
24. Vallier HA, Reichard SG, Boyd AJ, Moore TA. A new look at the Hawkins classification for talar neck fractures: which features of injury and treatment are predictive of osteonecrosis? J Bone Joint Surg Am. 2014;96(3):192–7.
25. Lindvall E, Haidukewych G, DiPasquale T, Herscovici D Jr, Sanders R. Open reduction and stable fixation of isolated, displaced talar neck and body fractures. J Bone Joint Surg Am. 2004;86-A(10):2229–34.
26. Vallier HA, Nork SE, Benirschke SK, Sangeorzan BJ. Surgical treatment of talar body fractures. J Bone Joint Surg Am. 2004;86-A(Suppl 1(Pt 2)):180–92.
27. Smith CS, Nork SE, Sangeorzan BJ. The extruded talus: results of reimplantation. J Bone Joint Surg Am. 2006;88(11):2418–24.
28. Bibbo C, Anderson RB, Davis WH. Injury characteristics and the clinical outcome of subtalar dislocations: a clinical and radiographic analysis of 25 cases. Foot Ankle Int. 2003;24(2):158–63.
29. Saltzman C, Marsh JL. Hindfoot dislocations: when are they not benign? J Am Acad Orthop Surg. 1997;5(4):192–8.
30. Newcomb WJ, Brav EA. Complete dislocation of the talus. J Bone Joint Surg Am. 1948;30A(4):872–4.
31. Rhanim A, Zanati RE, Younes O, Hassani ZA, Kharmaz M, Berrada MS. Nonoperative treatment of closed total talus dislocation without fracture: a case report and literature review. J Clin Orthop Trauma. 2014;5(3):172–5.
32. Heylen S, De Baets T, Verstraete P. Closed total talus dislocation: a case report. Acta Orthop Belg. 2011;77(6):838–42.
33. Sharifi SR, Ebrahimzadeh MH, Ahmadzadeh-Chabok H, Khajeh-Mozaffari J. Closed total talus dislocation without fracture: a case report. Cases J. 2009;2:9132.
34. Essex-Lopresti P. The mechanism, reduction technique, and results in fractures of the os calcis, 1951–52. Br J Surg. 1952;39(157):395–419.
35. Cave EF. Fracture of the os calcis--the problem in general. Clin Orthop Relat Res. 1963;30:64–6.
36. Essex-Lopresti P. The mechanism, reduction technique, and results in fractures of the os calcis, 1951–52. Clin Orthop Relat Res. 1993;290:3–16.
37. Rammelt S, Zwipp H. Calcaneus fractures: facts, controversies and recent developments. Injury. 2004;35(5):443–61.
38. Stiegelmar R, McKee MD, Waddell JP, Schemitsch EH. Outcome of foot injuries in multiply injured patients. Orthop Clin North Am. 2001;32(1):193–204, x.
39. Benirschke SK, Sangeorzan BJ. Extensive intraarticular fractures of the foot. Surgical management of calcaneal fractures. Clin Orthop Relat Res. 1993;292:128–34.
40. Benirschke SK, Kramer PA. Wound healing complications in closed and open calcaneal fractures. J Orthop Trauma. 2004;18(1):1–6.
41. Berry GK, Stevens DG, Kreder HJ, McKee M, Schemitsch E, Stephen DJ. Open fractures of the calcaneus: a review of treatment and outcome. J Orthop Trauma. 2004;18(4):202–6.
42. Gustilo RB, Anderson JT. Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: retrospective and prospective analyses. J Bone Joint Surg Am. 1976;58(4):453–8.
43. Fakhouri AJ, Manoli A 2nd. Acute foot compartment syndromes. J Orthop Trauma. 1992;6(2):223–8.
44. Manoli A 2nd, Fakhouri AJ, Weber TG. Concurrent compartment syndromes of the foot and leg. Foot Ankle. 1993;14(6):339.
45. Sanders R. Displaced intra-articular fractures of the calcaneus. J Bone Joint Surg Am. 2000;82(2):225–50.
46. Sanders R, Fortin P, DiPasquale T, Walling A. Operative treatment in 120 displaced intraarticular calcaneal fractures. Results using a prognostic computed tomography scan classification. Clin Orthop Relat Res. 1993;290:87–95.

47. Abidi NA, Dhawan S, Gruen GS, Vogt MT, Conti SF. Wound-healing risk factors after open reduction and internal fixation of calcaneal fractures. Foot Ankle Int. 1998;19(12):856–61.
48. Tennent TD, Calder PR, Salisbury RD, Allen PW, Eastwood DM. The operative management of displaced intra-articular fractures of the calcaneum: a two-Centre study using a defined protocol. Injury. 2001;32(6):491–6.
49. Koski A, Kuokkanen H, Tukiainen E. Postoperative wound complications after internal fixation of closed calcaneal fractures: a retrospective analysis of 126 consecutive patients with 148 fractures. Scand J Surg. 2005;94(3):243–5.

Part II

Fractures of the Talus

3

General Principles of Talus Fractures

David Hubbard and James Richman

Anatomy

The talus is divided into three parts, the head, neck, and body, and two processes, lateral and posterior. It has five articular surfaces, all of which have a weight-bearing function. The surfaces of the talus are illustrated in Fig. 3.1. Two-thirds of the talus is covered with articular cartilage, and no tendons insert or originate on it [2].

The head of the talus articulates with the navicular. The body includes the dome of the talus, which articulates with the ankle joint above. The inferior surface of the talar body is concave in the long axis and articulates with the posterior facet of the calcaneus. The neck of the talus does not articulate with the ankle or calcaneus, and it does not have articular cartilage. It sits atop the sinus tarsi laterally and the sustentaculum tali medially [1].

The talar neck is angled at a mean of 24 degrees plantarmedial with respect to the talar dome [2]. It is the weakest portion of the talus because it has both the smallest cross-sectional area and the most porosity due to its extensive vascular ingrowth. The medial border of the talar neck directly aligns with the medial border of the talar body, whereas the lateral cortex of the talar neck is concave and flares as one moves posterior to the lateral process. The talocalcaneal ligament, one of the main stabilizers of the subtalar joint, attaches on the inferior talar neck.

The talar body's superior surface is completely covered with articular cartilage. The talar body's shape is that of a large trapezoidal dome. The transverse diameter is greater anteriorly than posteriorly, meaning maximal congruence of the ankle joint occurs when the talus is dorsiflexed. The medial surface of the talar body articulates with the medial malleolus. The posterior inferior portion of this surface has a large oval area for insertion of the deep deltoid ligament.

The lateral surface of the talar body articulates with the distal fibula. The most lateral portion of this surface is the lateral process of the talus. The lateral process is the lower margin of the talar articular surface with the fibula. It also articulates with the anterolateral corner of the posterior facet of the calcaneus. Because of this boney architecture as well as its ligamentous attachments for the anterior and posterior talofibular ligaments, it is important in the stability of the ankle mortise and subtalar joint.

D. Hubbard
Orthopaedic Trauma Service, J.W. Ruby Memorial Hospital, West Virginia University,
Morgantown, WV, USA
e-mail: dhubbard@hsc.wvu.edu

J. Richman (✉)
MultiCare Orthopedics & Sports Medicine,
Tacoma, WA, USA
e-mail: jhrichman@multicare.org

© Springer Nature Switzerland AG 2020

M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_3

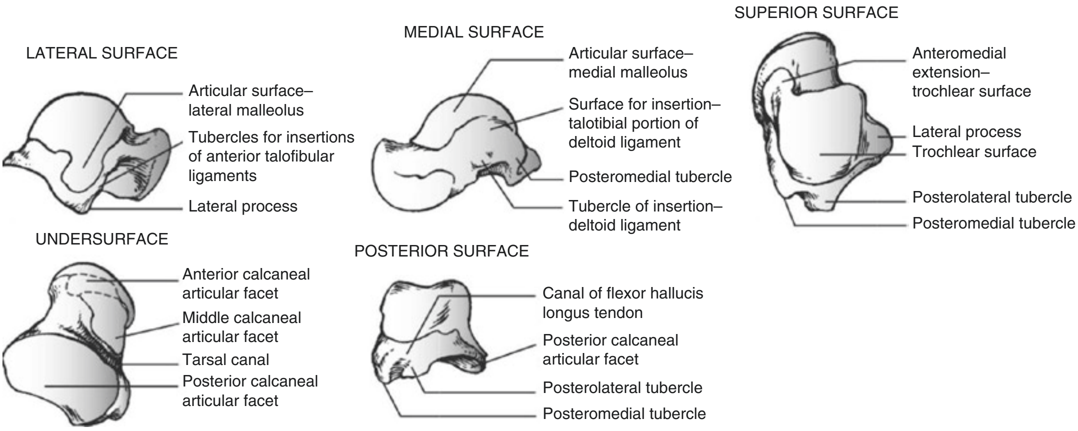


Fig. 3.1 Overview of the bony surfaces of the talus [1]

The posterior process of the talar body includes posterolateral and posteromedial tubercles that flank the sulcus for the flexor hallucis longus tendon. The posterolateral tubercle is larger and has an articular segment with the posterior facet of the calcaneus. The tubercle may either be oversized or appear as an accessory bone known as an os trigonum in up to 50% of the population. An os trigonum may be present unilaterally or bilaterally and may be fused to the talus or calcaneus [3]. The posteromedial tubercle also varies in size and is important for attachment of the talotibial component of the deltoid ligament.

The talar head is a convex round surface. It is rotated an average of 45 degrees laterally relative to the axis of the talar neck [4]. It too is covered by articular cartilage. The plantar spring ligament passes inferiorly to the talar head connecting the calcaneus to the navicular. The talar head forms its main articulation with the navicular in an area called the acetabulum pedis. Detailed by Sarrafian, it is composed of the anterior and middle calcaneal sections of the talus and linked to the navicular via the inferior and superomedial calcaneonavicular ligaments. The calcaneonavicular segment of the bifurcate ligament becomes the lateral hinge. The medial side is supported by the spring ligament and posterior tibial tendon.

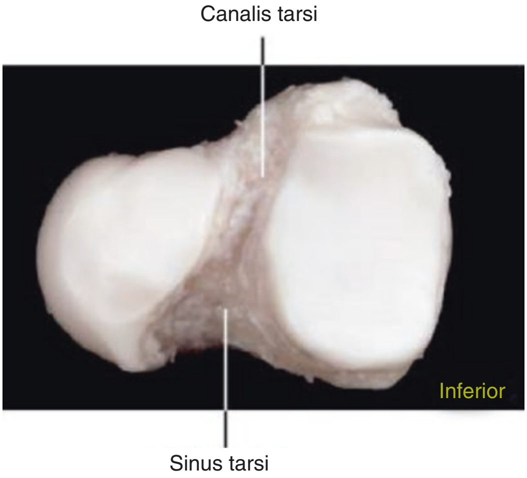


Fig. 3.2 Sulcus tali [5]

On the undersurface of the talus between the posterior and anterior/middle facets runs a deep groove called the sulcus tali (Fig. 3.2) It runs 40 degrees from anterolateral to posteromedial [2]. The sulcus is broader laterally and is thus referred to as the sinus tarsi, whereas medially it is more narrow and referred to as the tarsal canal. This sulcus gives rise to the strong talocalcaneal interosseous ligament as well as arteries of the tarsal canal and sinus tarsi, which provide the blood supply for two-thirds of the talar body.

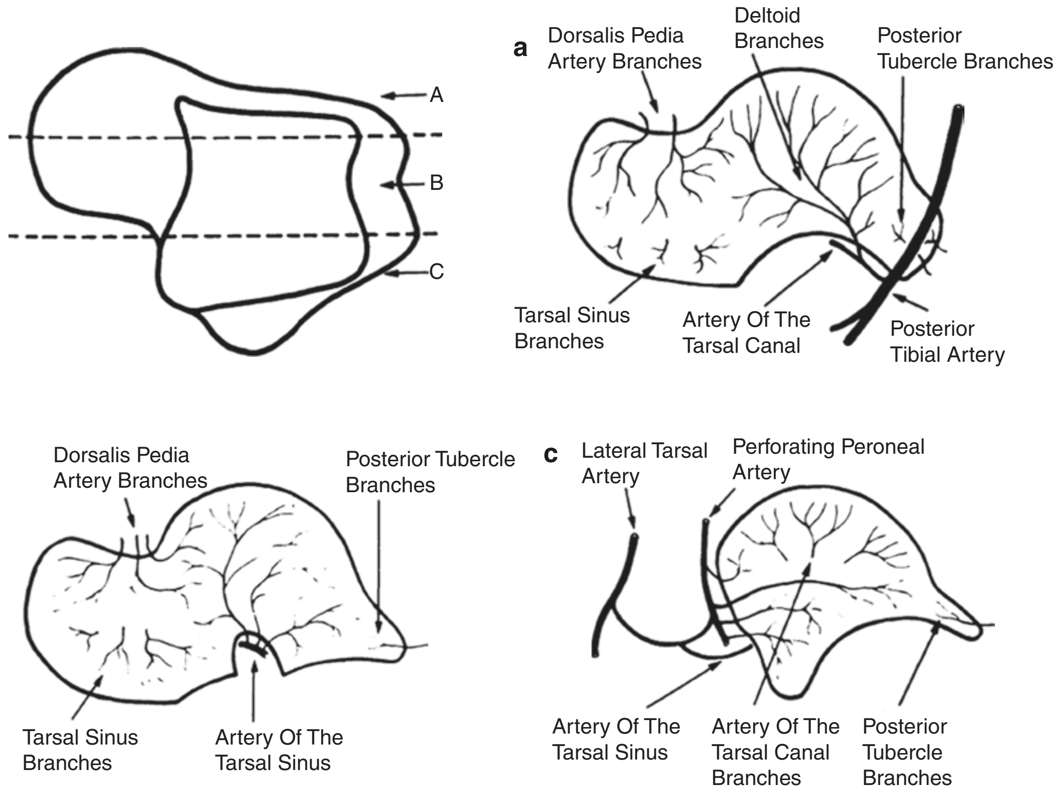


Fig. 3.3 The blood supply of the talus basedon anatomic location [6]. (**a**) The dorsal view of the blood supply to the medial one third of the talus. (**b**) The dorsal view of the blood supply to the middle one third of the talus. (**c**) The dorsal view of the blood supply to the lateral one third of the talus

Blood Supply

The blood supply to the talus is diffuse and arises from branches of the posterior tibial artery, the dorsalis pedis artery, and the peroneal artery (Fig. 3.3). The artery of the tarsal canal arises from the posterior tibial artery about 1 cm proximal to the origin of the medial and lateral plantar arteries. It passes between the sheaths of the flexor digitorum longus and flexor hallucis longus tendons to enter the tarsal canal. In the canal, the artery is dorsal. Branches into the body are given off in the canal with the largest branch entering the middle of the body. The artery of the tarsal canal anastomoses with the artery of the tarsal sinus in the tarsal canal. The deltoid branch of the artery of the tarsal canal arises about 5 mm from its origin. The deltoid branch runs between the talotibial and talocalcaneal parts of the deltoid ligament. It supplies the medial surface of the body and anastomoses with anterior tibial artery branches over the neck and talus [7].

The artery of the tarsal sinus generally originates from an anastomotic loop between the lateral tarsal branch of the dorsalis pedis artery and the perforating peroneal artery. It gives off a few branches to the talar head and then enters the tarsal canal. In the tarsal canal, it gives off branches to the talar body before anastomosing with the artery of the tarsal canal [8].

The peroneal artery gives off small branches that join the calcaneal branches of the posterior tibial artery to form a plexus over the posterior process of the talus. Of note, in some patients, the artery of the tarsal sinus is a branch of the peroneal artery rather than the dorsalis pedis artery.

The head of the talus is supplied directly from branches of the dorsalis pedis artery on its dorsal medial portion and from the artery of the tarsal sinus on its plantar lateral portion. The most important blood supply to the body of the talus comes from the anastomotic artery between the artery of the tarsal canal and the artery of the tarsal sinus. This artery gives about five main branches into the body that supply almost all of the middle and lateral thirds of the talar body. The blood supply to the medial third of the body come from the deltoid branches, which enter the body on its medial periosteal surface.

Injury Mechanism

Talar neck fractures are high-energy injuries that result from a dorsally directed force applied to the plantar surface of the foot distal to the talus (Fig. 3.4). The ankle is generally in neutral position. If the dorsally directed force is strong enough, it can disrupt the posterior and interosseous talocalcaneal ligaments and cause the calcaneus to dislocate anteriorly either laterally or medially. The talar head would be displaced dorsally with respect to the neck. Further dorsal force can lead to complete disruption of the posterior ankle capsule, resulting in the talar body extruding posterior medial between the Achilles tendon and the medial malleolus. The medial neurovascular bundle is infrequently injured as it is shielded by the flexor hallucis muscle belly [9]. Forced supination of the foot is another less frequent mechanism for talar neck fractures and is more often associated with combined talar neck/medial malleolus fractures [10]. The medial malleolus fracture is usually vertical, indicating a compression force is imparted onto the medial side of the talus. Accordingly, talar neck fractures from supination have comminution dorsomedially. Supination is thought to be caused by a contracted Achilles tendon, which imparts a supination stress on the foot and leads to compression on the medial side [11].

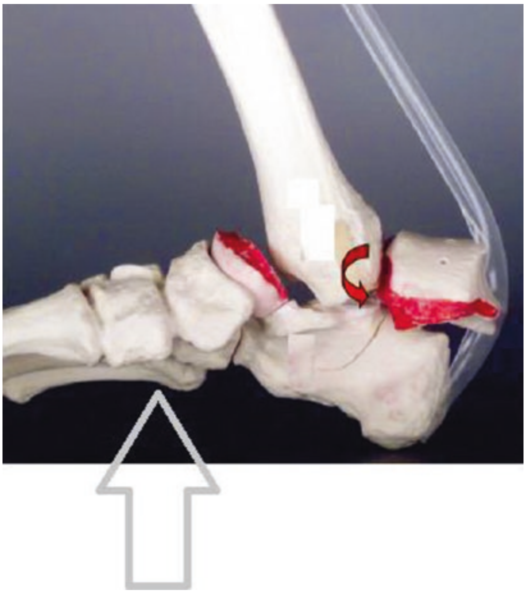


Fig. 3.4 Mechanism of injury for talar neck and body fractures. The talar body extrudes posteromedially

Talar body fractures are intra-articular injuries involving both the ankle and subtalar joints. The injury generally results from high-energy axial compression. They may also occur due to the shear mechanism described above for talar neck fractures (Fig. 3.4). The dorsally directed plantar force distal to the talus may lead to a more posterior fracture that involves the talar body rather than the neck [9].

Talar head fractures occur via other compression or shear forces. Compression injuries are the results of the talar head experiencing an axial load against a plantarflexed foot. This force causes the navicular to compress against the talar head and usually results in a medial-sided crush injury to the talar head [12]. In the other injury pattern, forced inversion of the midfoot causes the navicular to shear off a portion of the medial talar head, which generates two distinct fracture fragments [4].

The lateral tubercle of the posterior process may fracture by a direct mechanism from forced plantarflexion of the foot that causes compression of the posterior tibial plafond against the posterolateral process. This mechanism may result in fracture of the posterior process, separation of the fibrous attachment of the os trigonum from the talus, or fracture of the os trigonum. This first mechanism is most common and has been associated with soccer players and ballet dancers [13]. The other mechanism involves forced dorsiflexion on the ankle, which results in a tension-sided failure as the posterior talofibular ligament avulses off the posterolateral tubercle [14]. The medial tubercle of the posterior process is very rarely injured. The mechanism of injury involves avulsion of the posterior talotibial ligament when the ankle is dorsiflexed and pronated. Patients generally will have a tender firm mass behind the medial malleolus with an absence of the normal contour of the posteromedial ankle [15].

Finally, lateral process fractures are most commonly associated with snowboarding injuries. The injury mechanism is an axial load to a dorsiflexed ankle combined with forced external rotation or eversion of the hindfoot (Fig. 3.5) [17]. The foot is positioned in dorsiflexion during snowboarding with associated knee flexion, which further augments the degree of dorsiflexion achieved. During a fall forward, the leg positioned in front rotates toward the front of the board, which imparts an external rotation force or eversion force onto the ankle. Due to the relative frequency of this fracture among this sports group, lateral process fractures are generally termed "snowboarder's fracture" [18].

Fig. 3.5 The typical mechanism for lateral process fractures in snowboarders is shown here. An external rotation or eversion force is placed on the dorsiflexed ankle, which results in a lateral process fracture of the talus [16]

Imaging

Initial radiographic evaluation should begin with AP, lateral, and oblique radiographs of the foot and ankle. The oblique (mortise) view of the ankle will demonstrate the position of the talus beneath the tibial plafond. The lateral ankle radiograph is the best standard view to assess fractures of the talus. This view is best to assess dorsal-plantar displacement of a talus fracture as well. However, coronal displacement (varus-valgus) is difficult to ascertain from an AP view. Therefore, the Canale view is recommended as an additional view to discover talus fractures and understand coronal displacement, especially in talar neck fractures [19]. This view is taken with the x-ray beam directed cephalad and pointing 75 degrees with respect to the horizontal. The foot is held in maximal plantar flexion and 15 degrees of pronation (Fig. 3.6). For posterior process fractures, a lateral radiograph is best. It may be difficult to distinguish a posterior process fracture from an os trigonum; clues of a fracture on lateral radiograph include roughened and irregular surfaces of the two bone surfaces. Furthermore, fractures tend to be larger and extend into the talar body [20]. Lateral process fractures are best seen on the AP and lateral ankle radiographs. A Brodén view may also be helpful to show a lateral process fracture as well as to evaluate the subtalar joint for any irregularity or impaction fractures of the undersurface of the talus. Brodén views are taken with the x-ray beam aimed cephalad 10–40 degrees with respect to the vertical with the foot in neutral position and internally rotated at varying degrees from 20 to 60 degrees with respect to the vertical (Fig. 3.7) [22].

CT is helpful to diagnose nondisplaced talus fractures as well as to delineate the fracture pattern and degree of displacement. Multiplanar 1–2-mm cuts are especially helpful in identifying posterior process, lateral process, and avulsion fractures [23]. For process fractures in particular, a CT will help define the size of the fragment, the degree of displacement, the presence of comminution, and the involvement of the subtalar joint.

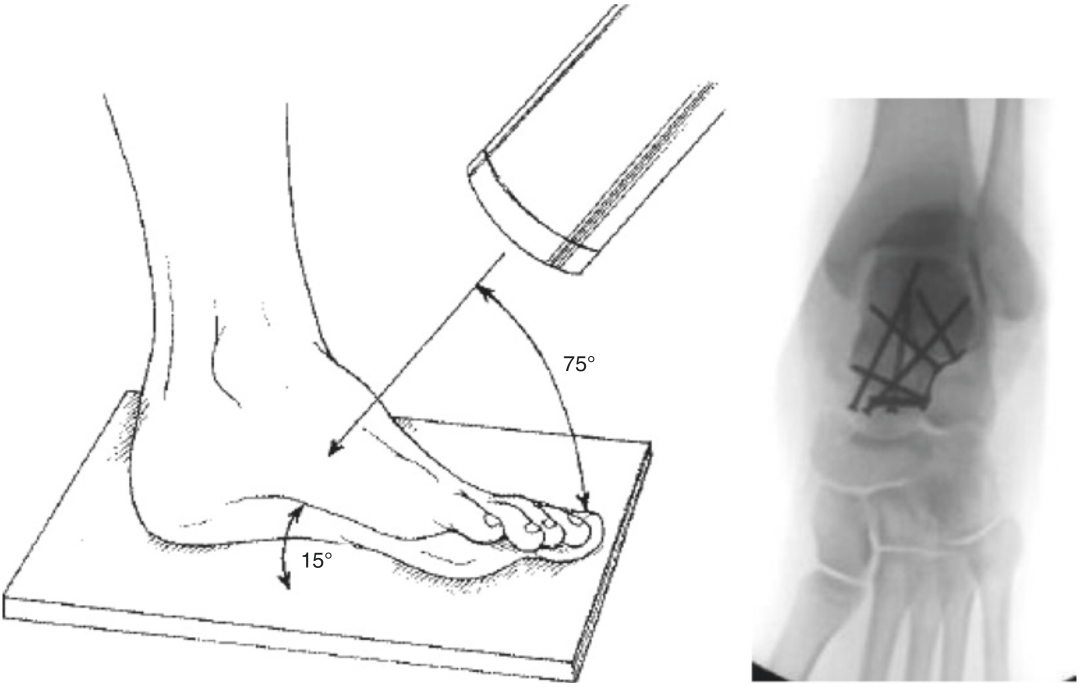
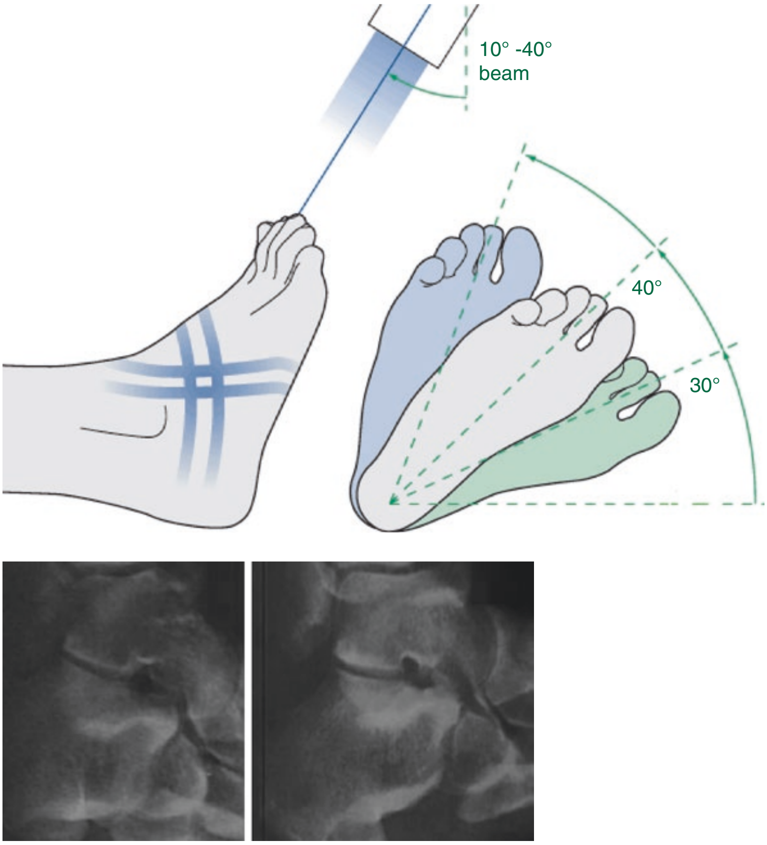


Fig. 3.6 Canale view [19]

Fig. 3.7 Brodén views [21]



References

1. Sanders R, et al. Fractures and fracture-dislocations of the talus. Mann's surgery of the foot and ankle. 9th ed. Philadelphia: Elsevier; 2014.
2. Sarrafian S. Anatomy of the foot and ankle. Philadelphia: Lippincott; 1983.
3. Grogan DP, Walling AK, Ogden JA. Anatomy of the os trigonum. J Pediatr Orthop. 1990;10:618–22.
4. Sangeorzan BJ, editor. Traumatized foot. Rosemont: Am Acad Orthop Surg; 2001.
5. Rammelt S, Zwipp H. Talar neck and body fractures. Injury. 2009;40:120–35.
6. Mulfinger GL, Trueta J. The blood supply of the talus. J Bone Joint Surg. 1970;52B:160–7.
7. Haliburton RA, Sullivan CR, Kelly PJ, Peterson LF. The extra-osseous and intra-osseous blood supply of the talus. J Bone Joint Surg Am. 1958;40-A:1115–20.
8. Schwarzenbach B, Dora C, Lang A, Kissling RO. Blood vessels of the sinus tarsi and the sinus tarsi syndrome. Clin Anat. 1997;10:173–82.
9. Daniels TR, Smith JW. Talar neck fractures. Foot Ankle. 1993;14:225–34.
10. Sneppen O, Buhl O. Fracture of the talus. A study of its genesis and morphology based upon cases with associated ankle fracture. Acta Orthop Scand. 1974;45:307–20.
11. Penny JN, Davis LA. Fractures and fracture-dislocations of the neck of the talus. J Trauma. 1980;20:1029–37.
12. Coltart WD. Aviator's astralagus. JBJS Br. 1952;34(4):545–66.
13. Hamilton WG. Stenosing tenosynovitis of the flexor hallucis longus tendon and posterior impingement upon the os trigonum in ballet dancers. Foot Ankle. 1982;3:74–80.
14. Yan YY, Mehta KV, Tan TJ. Fracture of the os trigonum: a report of two cases and review of the literature. Foot Ankle Surg. 2016;22(4):21–4.
15. Cedell CA. Rupture of the posterior talotibial ligament with the avulsion of a bone fragment from the talus. Acta Orthop Scand. 1974;45:454–61.
16. Funk J, Srinivasan S, Crandall J. Snowboarder's talus fractures experimentally produced by eversion and dorsiflexion. Am J Sports Med. 2003;31(6):921–8.
17. Boon AJ, Smith J, Zobitz ME, Amrami KM. Snowboarder's talus fracture. Mechanism of injury. Am J Sports Med. 2001;29:333–8.
18. Kirkpatrick DP, Hunter RE, Janes PC, et al. The snowboarder's foot and ankle. Am J Sports Med. 1998;26:271–7.
19. Canale ST, Kelly FB Jr. Fractures of the neck of the talus: long-term evaluation of seventy-one cases. J Bone Joint Surg Am. 1978;60:143–56.
20. Paulos LE, Johnson CL, Noyes FR. Posterior compartment fractures of the ankle. A commonly missed athletic injury. Am J Sports Med. 1983;11:439–43.
21. Schatzker J, Buckley R, Sands A. Calcaneus-simple undisplaced body fractures. AO Foundation. www.AOsurgery.org. 2010.
22. Gregory P, DiPasquale T, Herscovici D, Sanders R. Ipsilateral fractures of the talus and calcaneus. Foot Ankle Int. 1996;17:701–5.
23. Ebraheim NA, Skie MC, Podeszwa DA, Jackson WT. Evaluation of process fractures of the talus using computed tomography. J Orthop Trauma. 1994;8:332–7.

Talar Neck Fractures

4

Bo He and Michael Krosin

Introduction

The talus is a complex bone with unique anatomy. As it is very dense, it takes a significant amount of force to cause a fracture. These uncommon fractures account for 0.1–0.85% [1] of all fractures and typically result from high-energy trauma. When they do occur, they can lead to significant impairment of lower extremity function. Fractures of the talar neck comprise nearly 50% of all talus fractures [1]. These fractures are associated with injury and dissociation of the surrounding joints and warrant prompt management.

Anatomy

The talus is comprised of the head, neck, and body. Cartilage covers two thirds of its surface area, giving it numerous surfaces to articulate with adjacent bones. There are no muscular or tendinous attachments, so the bone is stabilized by the surrounding joint capsule and ligaments. The body of the talus resides in the ankle mortise and has five articular surfaces. The talar head sits in a deep socket, sometimes referred to as the *acetabulum pedis*, that is comprised of the navicular, anterior/middle calcaneal facets, and surrounding ligaments. The neck of the talus is a relative weak point of the bone. Instead of being covered in articular cartilage, it has multiple foramina for the extramedullary blood supply to enter the bone and is comprised primarily of cancellous bone.

This unique blood supply of the talus is comprised of branches from the posterior tibial, anterior tibial, and perforating peroneal arteries. This is covered in more depth in a previous chapter, but careful consideration of the blood supply is necessary during surgical treatment of talar neck fractures.

Fracture Patterns and Classifications

Talar neck fractures occur with axial loading and forced dorsiflexion of the foot. This drives the relatively weak cancellous bone of the talar neck into to the anterior tibial plafond. If the foot continues to dorsiflex, the fracture propagates though the talar neck into the subtalar joint, causing subluxation or dislocation of the talar body from the calcaneus. Continued foot dorsiflexion causes distraction of the posterior ankle, allowing for subluxation or dislocation of the talar body from the ankle mortise. Forced hindfoot supination drives the neck and body into the medial

B. He (✉)
San Francisco Orthopaedic Residency Program,
St Mary's Medical Center, San Francisco, CA, USA

M. Krosin
Orthopaedic Surgery, Highland Hospital,
Oakland, CA, USA

© Springer Nature Switzerland AG 2020

M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_4

malleolus, leading to dorsal medial failure in compression and lateral failure in tension. This typically results in medial comminution, medial shortening, and varus malposition.

The Hawkins classification of talar neck fractures is derived from the degree of involvement of the surrounding joints based on radiographic assessment (Fig. 4.1). This classification system is not only useful descriptively, it has been demonstrated to correlate with prognosis. Type I fractures are nondisplaced fractures of the talar neck with less than 1 mm of fracture displacement. The fracture line does not involve any articular surface and theoretically only disrupts the anterolateral blood supply. This is associated with a 0–13% risk of avascular necrosis (AVN). Type II fractures involve displacement of the subtalar joint. This disrupts the vasculature entering the neck anterolaterally and through the sinus tarsi while often sparing the medial body vessels and carries a 20–50% risk of AVN. Type III fractures have dislocation of the talar body from the subtalar and tibiotalar joints, effectively disrupting all three blood supplies to the body and carrying a 20–100% AVN risk. The body is often extruded posteromedially and can impinge on the posterior tibial neurovascular bundle. The type IV injury category, subsequently added by Canale and Kelly, involves subluxation or dislocation of the talonavicular joint and carries 70–100% AVN risk and the poorest outcomes [2, 3].

Vallier et al. subclassify type II fractures into type IIa, where the subtalar joint is subluxed, versus type IIb, where the subtalar joint is dislocated. They demonstrated via a retrospective review no AVN in type I and IIa fractures, 25% AVN in type IIb fractures. The rates of subtalar arthritis were similar (21% in type IIa, 25% in type IIb), but tibiotalar arthritis increased from 5.3% in type IIa to 13% in type IIb [3].

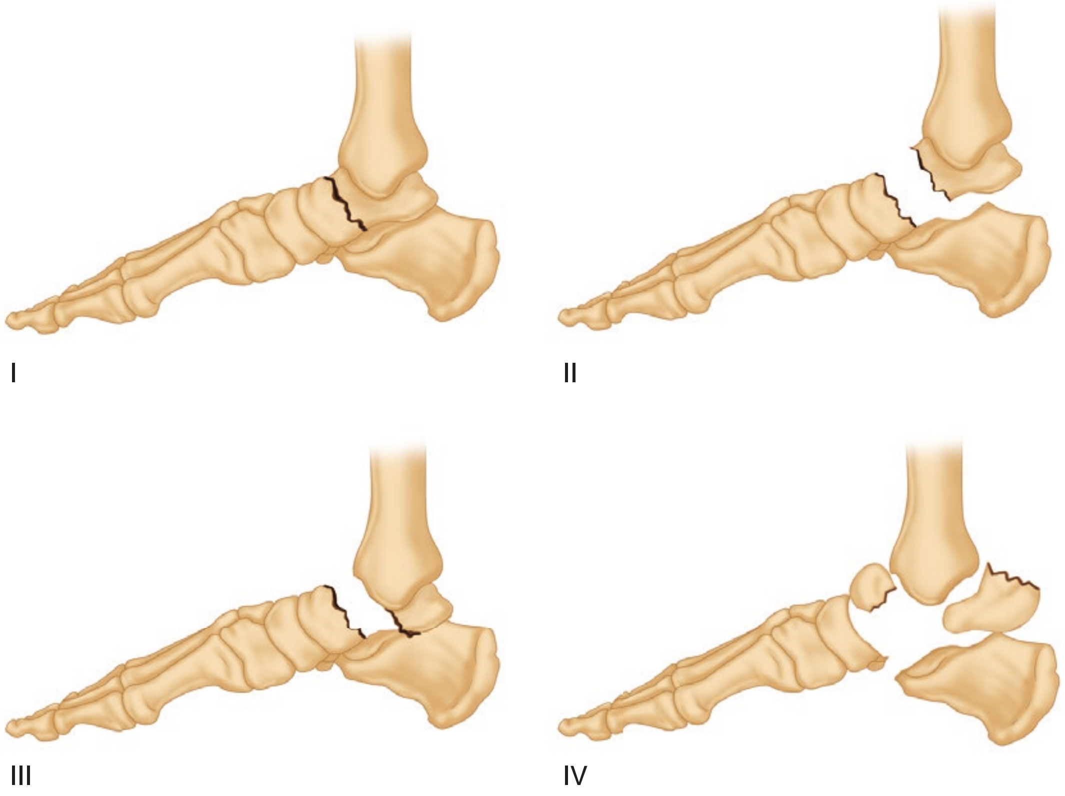


Fig. 4.1 The Hawkins Classification. Type I: nondisplaced talar neck fractures. Type II: with subtalar disruption. Type III: wtih subtalar and tibiotalar disruption. Type IV: with subtalar, tibiotalar, and talonavicular disruption

Evaluation and Treatment

Assessing the mechanism and energy of injury is important to determine the severity of the injury. High-energy axial load injuries are associated with increased comminution, articular cartilage damage, and ligamentous injuries that increase the risk of post-traumatic arthritis. Obtaining the patient's comorbidities can guide the treatment course. A thorough neurovascular exam is important to document given that type III and IV fractures are associated with posterior tibial nerve injury and possible skin tenting or compromise.

Radiographic evaluation should start with the standard anteroposterior (AP), lateral, and oblique views of the ankle and foot. The Canale view may be helpful to assess the talar neck and will show the amount of shortening and angulation. A computer tomography (CT) scan is important to obtain to understand the fracture pattern for surgical planning.

Temporary stabilization of the fracture with an adequately padded splint should be placed prior to definitive management. If there is peritalar dislocation or skin compromise, reduction should be expeditious to avoid neurovascular compromise or further skin necrosis. If closed reduction is not successful in the emergency department, the patient may require use of an external distractor or open reduction techniques in the operating room.

Open fractures account for 20–25% of all talus injuries and are associated with increased rates of AVN and post-traumatic arthrosis [4]. Initial management involves immediate antibiotic administration upon arrival to the hospital to decrease risk of infection. Urgent wound irrigation and debridement should be performed.

Previous teachings pertaining to definitive surgical management of talus fractures were to undergo immediate open reduction internal fixation to minimize the risk of AVN and subsequent joint arthrosis. However, recent literature has not supported this notion. Vallier et al. showed no difference in rates of osteonecrosis with immediate fixation versus delayed or staged fixation. However, they do advocate for urgent and expeditious closed reduction either in the emergency or operating room despite not showing a difference in AVN for initial up to 18 hours [2–4]. Type III and type IV fractures may be difficult if not impossible to be reduced closed and often require percutaneous or open approach for reduction.

Surgical Technique

The patient should be placed supine on the operative table. A bolster should be placed underneath the buttock on the affected extremity to prevent excessive external rotation. A pneumatic tourniquet may be placed on the thigh. A ramp or bolster may be used to elevate the operative extremity. Conversely, a triangle may be used for alternative positioning. C-arm fluoroscopy should come in to the surgical field from the opposite side of the table. The authors recommend getting pre-operative fluoroscopic lateral and Canale views of the contralateral side prior to draping for more challenging fracture patterns. In terms of equipment, small stainless steel screws (2.0–3.5 in diameter), small plates accommodating 2.0 and 2.4 screws, along with K-wires are standard implant. The authors have found that small-diameter titanium screws in the particularly dense talar bone are easily stripped or broken. Headless screws – stained or titanium, so long as they have a deep-seated head for a screw driver as well as absorbable K-wires or cut threaded K-wires, may play a role in articular fragment fixation. A headlight, small self-retaining retractors (or handheld retractors), and dental picks are often helpful.

A dual-incision approach is the current standard for open reduction internal fixation of displaced talus fractures. Even minimally displaced fractures on X-ray can be deceiving in terms of rotation and shortening. The visualization afforded from a dual-incision approach ensures accuracy of fracture reduction. There is no evidence to suggest an increased risk of osteonecrosis with a dual-incision approach [3, 4]. The anteromedial approach allows exposure of the medial talar head, the neck, and the anteromedial one third of the body (Fig. 4.2). The superficial landmarks include the medial malleolus, tibialis

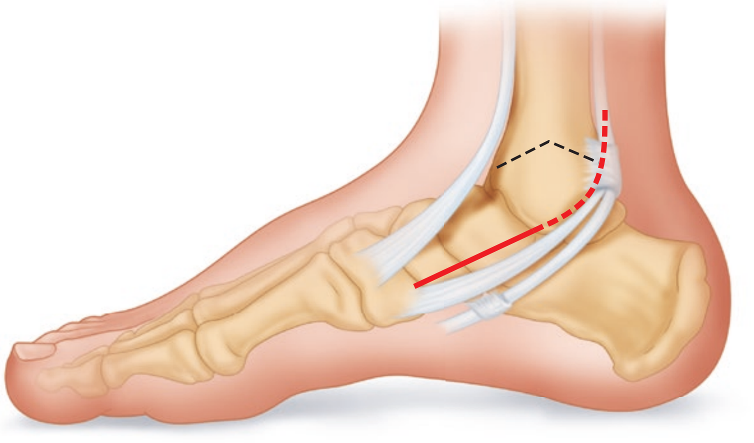


Fig. 4.2 The anteromedial approach to the talar neck

anterior, and tibialis posterior. Skin incision is made starting from the anterior edge of the medial malleolus and continued distally to the medial cuneiform. It should be placed midway between the tibialis anterior and posterior. The saphenous vein and nerve will be encountered in the proximal portion of the incision. Extensive dissection dorsal and plantar should be avoided to preserve the remaining blood supply at the neck of the talus. Proximal extension through the deltoid ligament should be avoided at all costs as this may be the only remaining blood supply for the talar body. Periosteal elevation on the talar neck should be kept to a minimum for fracture reduction. When dorsal and medial comminution is present, care should be taken to preserve the dorsal soft tissue attachments to the comminuted fragments while attempting to correct the medial shortening and varus malpositioning.

The anterolateral approach allows exposure of the lateral process, anterolateral neck, and half of the body (Fig. 4.3a, b). The superficial landmarks are the fourth metatarsal, the fibular, and anterolateral tibia. Skin incision is made between the tibia and fibula and extending distally in line with the fourth ray to the base of the fourth metatarsal, this essentially being the distal extension of the anterolateral pilon approach. A modification can be made where the proximal extent of the incision aims toward the ATFL insertion on the distal fibula and can be thought of as a dorsal sinus tarsi approach. This allows better exposure of the lateral talar process in addition to the lateral talar neck. Care should be taken to maintain an adequate skin bridge between the anteromedial and anterolateral incisions. The skin flap should not be undermined to protect the dorsalis pedis and surrounding vasculature. The superficial peroneal nerve will be encountered and should be protected. The anterior compartment can be elevated and retracted medially. The extensor digitorum brevis is elevated and retracted distally and laterally. The anterior capsule can be elevated off of the distal tibia, and the sinus tarsi fat pad can be removed for more exposure of the talar neck and lateral process.

A medial malleolar osteotomy is utilized when fracture extends into the posterior body or if there is a talar body dislocation that is not able to be reduced. The deltoid ligament should be intact to allow adequate blood supply to the medial malleolus and talus for healing. Disruption of the deltoid ligament is a contraindication for osteotomizing the medial malleolus. First, the anteromedial incision is extended proximally, and the capsule is elevated off of the bone to expose the medial malleolus. Drill holes should be made perpendicular to the planned osteotomy to allow for screw fixation. The osteotomy is then made with an oscillating saw or drill holes and thin osteotomes. An apex-proximal chevron osteotomy can be used to help with subsequent

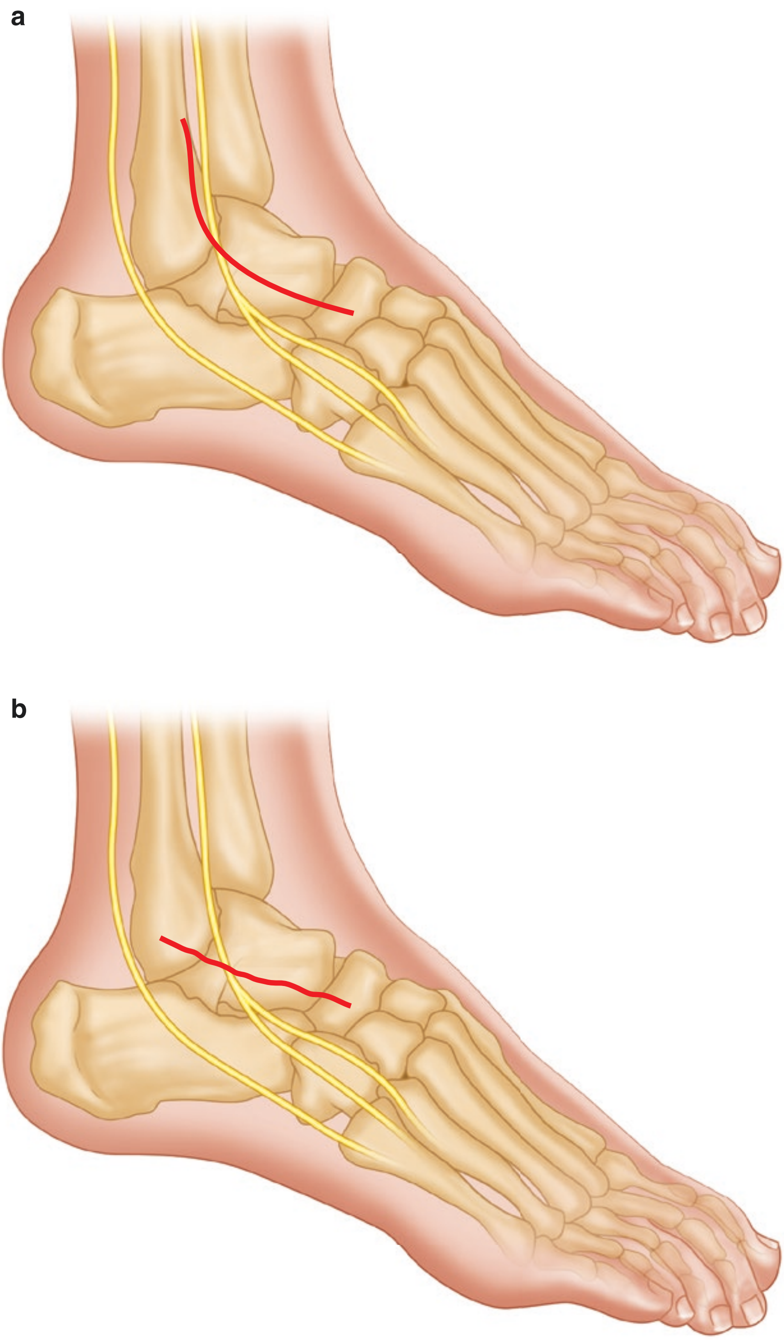


Fig. 4.3 The anterolateral approach to the talar neck. (**a**) shows distal extension of the anterolateral pilon approach. (**b**) shows the incision as a more dorsal sinus tarsi approach

fixation. The trajectory is started proximally and aimed distally in an oblique path to exit the medial colliculus. The posterior tibial tendon and neurovascular bundle should be protected posteriorly. The osteotomy should be finished with an osteotome at the level of the cartilage. The medial malleolus can be flipped distally to expose the talar body. Repair of the osteotomy involves reduction of the medial malleolus and placing small-fragment screws into the predrilled holes fixation with adjunctive small or mini-fragment plating where appropriate.

Once the fracture is exposed, reduction can then be achieved under direct visualization of both the medial and lateral sides. Typically, the fracture can be keyed in on the side with less comminution – typically the lateral side which fails in tension. Once the lateral side is reduced, bone reduction forceps and small K-wires may be used to provisionally stabilize the reduction. The medial side should be examined to appreciate any translational and rotational malreduction, and, if necessary, the reduction should be adjusted to ensure anatomic reduction of the fracture. Medial-sided reduction, in the face of comminution, can be challenging. Often, a series of plantar reads and clues from the articular cartilage to judge rotation are employed. However, these fragments may not be amenable to fixation. In the case of severe comminution, the authors have utilized structural allograft or autograft to maintain medial length and prevent varus malreduction or late varus collapse. Provisional fixation with bone reduction forceps and K-wires can then be used to stabilize the medial side. For simple talar neck fractures, one or two 3.5-mm fully threaded screws may be placed using the anteromedial approach. They are countersunk into the talar head, placed across the fracture into the talar body in the sagittal plane. Care must be taken not to compress the medial side when medial comminution is present to avoid varus malreduction. This is usually only reserved for non-displaced fractures.

Some studies have suggested that screws placed posterior to anterior (PA) have biomechanical advantages over screws placed anterior to posterior (AP). PA screws can be placed down the axis of the talus to provide uniform compression, whereas AP screws are placed eccentrically from the anteromedial side. Whereas AP screws violate the chondral surface of the talonavicular joint, PA screws violate the chondral surface of the posterior talar body. These PA screws are placed using a percutaneous posterolateral approach, placing the sural nerve and flexor hallucis longus (FHL) tendon at risk. The rate of transient sural nerve palsy can be as high as 25% [5]. Additionally, the supine positioning needed to perform the dual-incision approach for anatomic reduction makes placing posterior instrumentation difficult. While some biomechanical studies have demonstrated possible increased stiffness and yield point of PA versus AP screws, clinical outcomes have been shown to be comparable between the two [5–7]. The authors have no experience with this technique.

Headless compression screws are another option, allowing placement of screws through the talar head without need for countersinking. Additionally, the variable pitch of the screws allows for compression across simple fracture patterns. Capelle et al. demonstrated in cadaveric model that cannulated headless compression screws did not have a significant difference in load at failure compared to conventional cannulated screws but trended toward earlier displacement and increased construct stiffness [8]. One thing to consider though is whether or not compression is desirable where the screw is being placed. Again, this relies on a situation with no comminution and no or minimal displacement – an uncommon occurrence.

With increasing comminution and displacement of the fracture, different strategies have been used to augment the fixation construct. Use of mini-fragment plates have been shown to be a stiffer construct than screw fixation alone [9]. These plates may be placed onto the side with greater comminution to buttress the fracture or conversely onto the opposite side to maintain length, rotation, and alignment [10]. Sagittally oriented screws may also be used in addition to further stabilize the fracture. The most common construct utilizes a four-hole mini-fragment plate laterally contoured to fit in the axilla of the talar neck. The distal extent of the plate can come up to the articular margin of the talar head. It is critical that the proximal extent of the plate does not impinge on the tibio-talar-fibular articulation in dorsiflexion. As the foot is often plantarflexed during fixation, this needs to be assessed. Independent fragment screws or wires can be used outside the plate, but constructs which cross the fracture line prior to application of compression should be discouraged. As the obliquity of the screws in reference to the typical fracture line will not itself create compression, compression must be externally applied through clamps and held as hardware is placed laterally. Care must be taken during insertion, as these are unicortical screws.

Medially, when comminution exists, fixation acts as a medial strut to preserve length and prevent shortening. Due to the broad footprint of the medial malleolar articulation with the talus, there is very little room for plate placement. Typically, screws place on the margin of the talar head or through the cartilage of the talar head are used. Abduction of the forefoot and navicular can provide this exposure. Again, care should be taken as to the screws trajectory to keep it unicortical. Lateral and dorsal articular perforation must be avoided. Several screws can be placed from the medial side if needed, but with limited exception due to the broad articulation between the talus and medial malleolus, the medial talus cannot take a plate.

Maceroli et al. examined the results of medial screw fixation augmented with a lateral minifragment construct in 26 patients. They found an 11.5% nonunion rate attributed to open Hawkins type IV fractures. AVN was seen in 27% based on radiographic follow-up. Post-traumatic arthritis developed in 38% of patients, four of which required subsequent arthrodesis [11].

Once fixation has been placed, screw lengths have been verified, and fluoroscopy has been taken to ensure no evidence of malreduction, the tibiotalar articulation is aggressively ranged to ensure fracture stability. Any motion in the fracture site is risky, given the fixation only consists of small sized hardware. Risk of fixation failure needs to be minimized as development of a persistent talar nonunion is catastrophic.

In the event of fixation failure, some "bailout" options do exist but should not be regularly employed. Fibular osteotomy be utilized to expose the posterolateral talus when needed. The anterolateral approach is extended proximally, and care is used to protect the superficial peroneal nerve. The anterior distal tibiofibular ligaments are incised, and the osteotomy is started three centimeters above the articular surface in a transverse or oblique fashion. The osteotomy is made with an oscillating saw, taking care to protect the peroneal tendons posteriorly. The lateral malleolus is then retracted posteriorly. The osteotomy can be fixed with standard small-fragment plates and screws and repair of the incised anterior distal tibiofibular ligaments. As the posterolateral talus is not an area of considerable articulation, particularly on the plantar surface, fixation can be extended with the understanding that hardware removal may have to occur. A small chamfer can be cut in the lateral wall of the talus to recess the plate. This technique is demonstrated in the case studies. A similar technique can be employed medially with a medial malleolar osteotomy if needed, though this osteotomy is usually more common to address articular fractures if the body.

When talus fractures are associated with injuries of the surrounding bones, modifications to the dual-incision approach are made to gain access to each fractured bone. When the tibial plafond requires fixation, the anteromedial and anterolateral incisions may be extended proximally. The sustentaculum tali may be injured and may need independent fixation. If this is encountered, the posterior tibial tendon, flexor digitorum longus, and flexor hallucis longus tendon should be inspected and addressed if injured. If a fleck sign is seen arising from the lateral malleolus, the peroneal tendons should be inspected for injury and addressed. In rare cases where the calcaneus and talus are both fractured, the lateral approach to the calcaneus can be modified into an "S-shaped" curve to incorporate the sinus tarsi and ending in the anterolateral approach (Fig. 4.4).

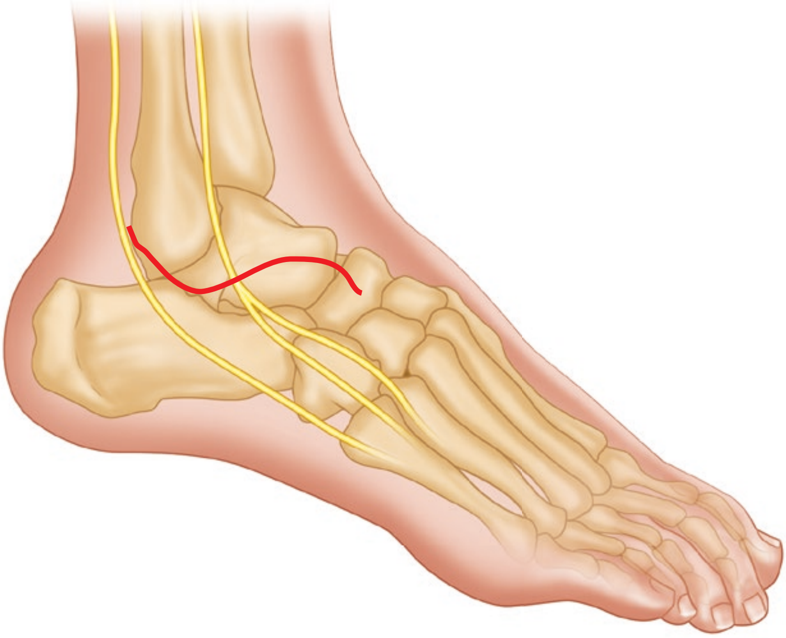


Fig. 4.4 Anterolateral approach modified into an “S-shaped” curve to address calcaneal and talar fractures

Postoperative Course

Immobilization of the foot and ankle is achieved with a well-padded splint. Patients are made non-weight-bearing for 10 to 12 weeks. After the wounds are healed, at approximately the 2-week mark, range of motion can be initiated, and sutures can be removed based on stability of the wound. At the 6–8-week mark, X-rays are taken to evaluate maintenance of reduction, healing, and signs of AVN. The “Hawkins sign,” a subchondral lucency in the talar body, may be seen during this time period and is a positive predictor of talar revascularization. When this sign is present, the risk of AVN is low. However, absence of the “Hawkins sign” does not predict development of AVN. CT scans may be useful to evaluate progress of union when X-rays are indeterminate. The use of MRI is controversial but may be reserved to assess union or development of AVN if reoperation is needed.

Outcomes

Functional outcomes of patients with talar neck fractures vary widely throughout the literature, and there is no standardized modality to assess long-term outcomes. In many studies, the Hawkins clinical evaluation for functional outcome is used to assess pain, limp, ankle motion, and subtalar motion. These studies showed that up to 20% of patients with talar neck fractures had an “excellent” outcome, 35% had a “good” outcome, 22% had a “fair” outcome, and 22% had a “poor” outcome [12]. In these studies, patients with a lower fracture grade in the Hawkins classification tended to have more “excellent” outcomes, and patient with higher grade fractures tended to have more “poor” outcomes. Other studies make use of the Foot Function Index (FFI), Short Form-36 (SF-36), and American Orthopaedic Foot and Ankle Society (AOFAS) Hindfoot Scoring Systems. Vallier et al. showed FFI scores of 25.3 for pain and 34.4 for disability for their patient cohort [2]. Vints et al. reported SF-36 scores of 42.71 for Physical Component Summary and 48.29 for Mental Component Summary [13]. In their study, Annappa et al. reported average AOFAS scores of 79.5 in type II fractures, 69.3 in type III fractures, and 57.5 in type IV fractures [14].

Development of post-traumatic arthrosis is a difficult problem to treat. The incidence of subtalar arthritis varies widely in the literature (4% to 100% with an average of 49%) [15, 16]. This can be a result of chondral damage during the initial traumatic insult or nonanatomic reduction of the talus. Allowing for early range of motion while maintaining non-weight-bearing precautions may decrease postoperative stiffness of the subtalar joint but does not predict the onset of arthrosis. Even the presence of a well-reduced talus does not preclude the development of arthrosis. While subtalar joint stiffness or arthritis can be asymptomatic, it will often lead to a stiff foot that, if stiff in a varus or hyper values posture, may change the biomechanics weight-bearing. For patients who remain symptomatic despite conservative management, arthrodesis is an effective operation for pain relief and foot shape correction.

Avascular necrosis is another common sequela of talar neck fractures. It is primarily a consequence of blood supply disruption during the initial trauma and possibly from the subsequent surgery. The incidence is approximately 25–30% for all fracture types, with newer studies published after the year 2000 showing lower AVN rates especially in Hawkins type II and III fractures [15–17]. Focal AVN without subchondral collapse frequently occurs without major sequelae. In these cases, the cartilage survives and the bone can be replaced over time with creeping substitution. In the cases with collapse of the talar dome, arthrodesis is the main option.

Improper reduction or inadequate fixation of talar neck fractures can lead to malunion or nonunion. Malunion can occur with small amounts of displacement and has been seen in up to 20–37% of cases [17]. Nonunion is more uncommon and can be as high as 4–5% [16]. The common malreductions include leaving the talus shortened and in varus. This leads to medial column shortening in the foot and significantly changes the biomechanics of the peritalar joints. If the talar body is left in plantarflexion, the talar neck will dorsally prominent and can impinge on the anterior tibial plafond. If discovered relatively early, revision open reduction and repeat fixation may be appropriate to correct the issue. An osteotomy may be necessary to regain anatomic reduction. If left untreated, peritalar arthritis will develop. This necessitates salvage arthrodesis to correct the foot deformity and alleviate pain.

Wound and soft tissue complications arise typically due to the high energy nature of talar neck fractures. When using the dual-incision approach, care must be used when handling the soft tissue envelope. In patients with excessive swelling, a staged approach to surgery is reasonable to allow for the swelling to resolve. However, any patients with peritalar displacement, skin tenting, or neurovascular compromise should be immediately reduced. With open fractures accounting for 20–38% of all fractures, wound management is critical to treatment success. Deep infections have been shown to develop in as high as 21% of cases [17]. Management of infections requires serial irrigation and debridement with appropriate antibiotic coverage. Removal of hardware may be required in the process of treating a deep infection.

Subsequent case examples illustrate some common techniques and pitfalls of talar fixation.

Case and Complication Examples

Case 1: A 53-year-old female, status post motor vehicle accident presents to the emergency room as a transfer from an outside hospital after stabilization in an external fixator. Her past medical history includes alcohol abuse and smoking (Figs. 4.5, 4.6, and 4.7).

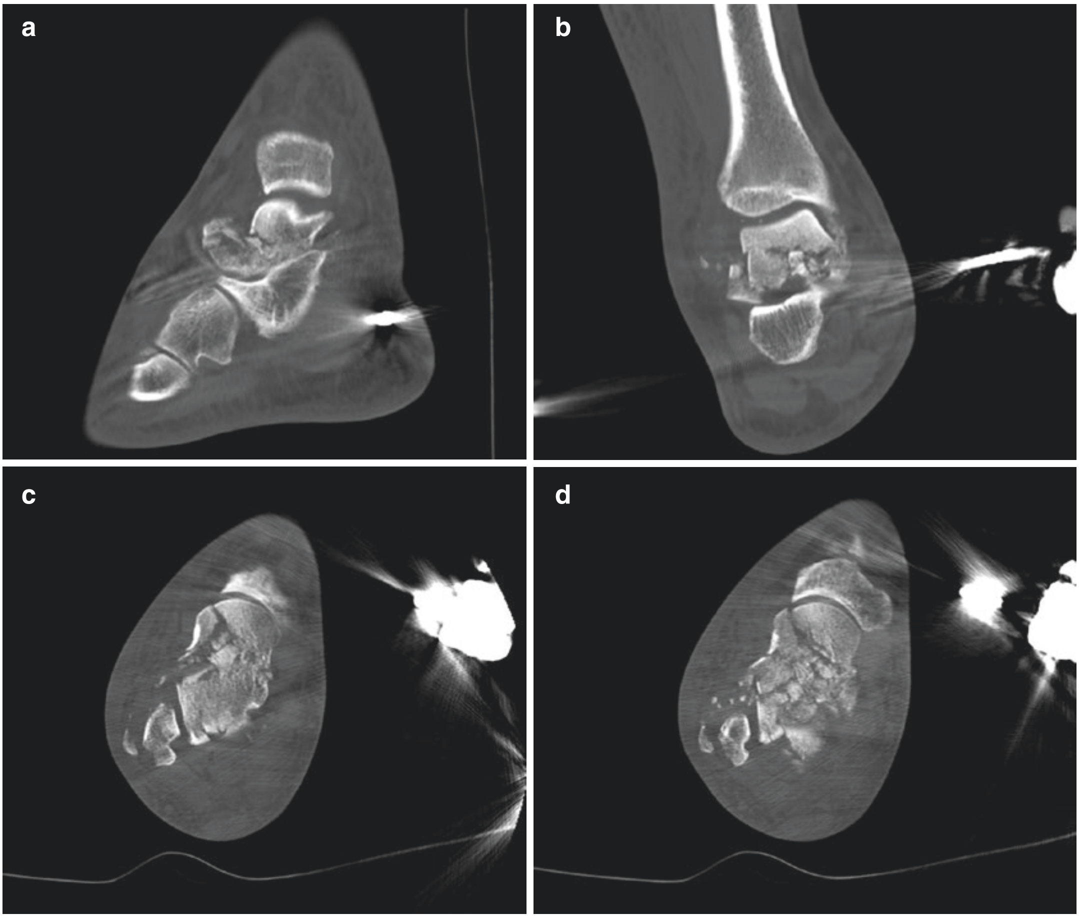


Fig. 4.5 (**a**–**d**) Preoperative CT scans demonstrating marked dorsal and medial comminution with considerable involvement of the subtler surface best appreciated on coronal cut

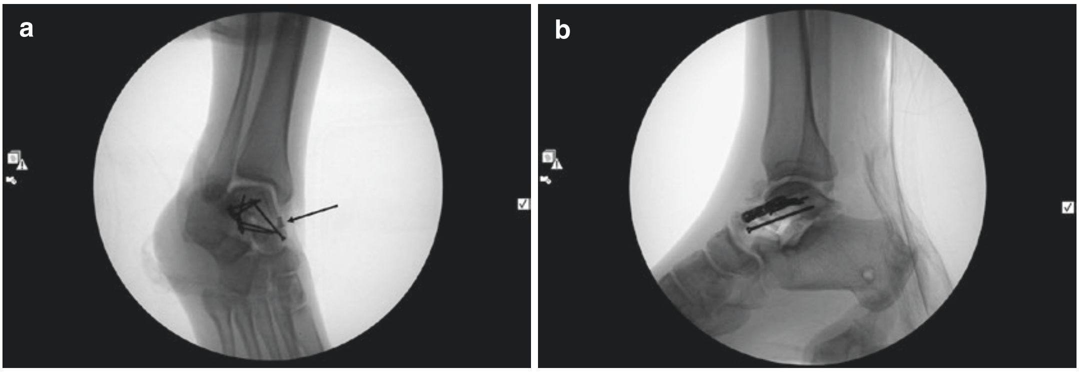


Fig. 4.6 (**a**, **b**) Intraoperative fluoroscopy pictures demonstrating a typical fixation strategy of contoured lateral plate and medial position screw to prevent varus malreduction. Note the inclusion of structural iliac crest bone graft (ICBG) medially to prevent shortening and to fill fracture gap (arrow) with backfilled grafting. The Canale view shows good alignment of the fracture. The lateral view shows considerable subtler articular incongruity

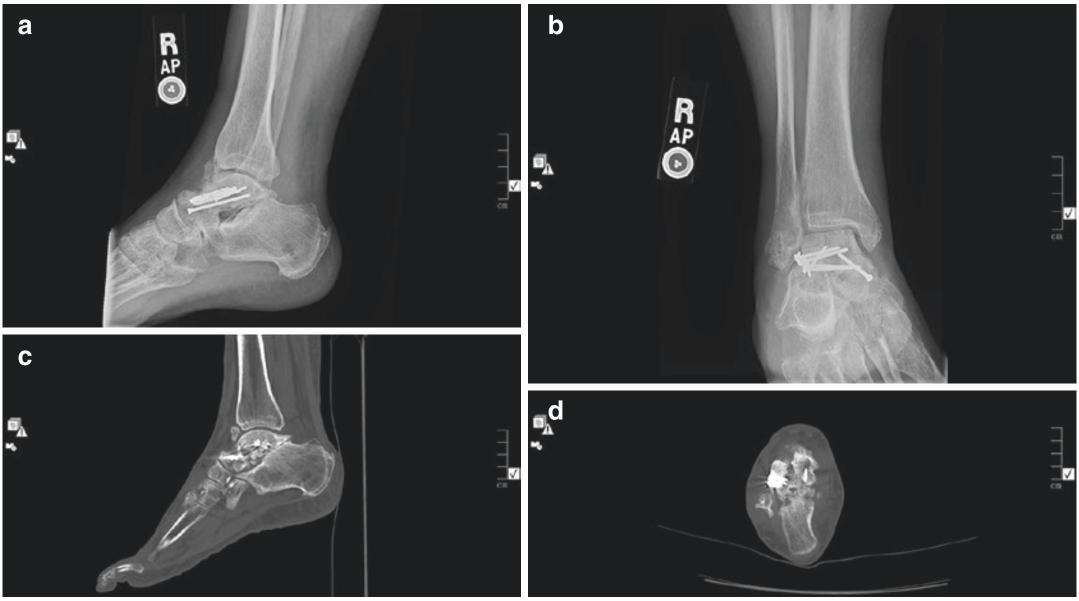


Fig. 4.7 (**a**–**d**) Postoperative films at 18 months with CT confirmation demonstrating integration of ICBG structural graft (best seen on axial CT), union, maintenance of talar blood supply, and severe post-traumatic subtalar arthritis. Patient continues to have severe pain and will undergo anterior ankle debridement and subtalar fusion. No clinical varus is present

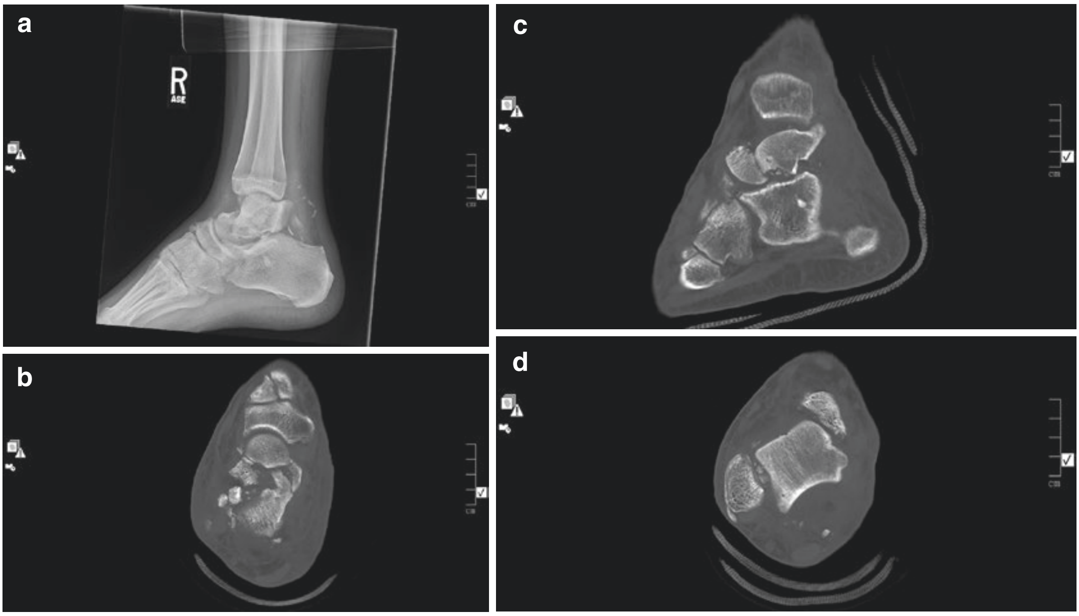


Fig. 4.8 (**a**–**d**) Lateral radiograph, axial and coronal CT images of a displaced talar neck fracture with dislocations of the tibiotalar and subtalar joints

Case 2: A 32-year-old male who is previously healthy, status post motor vehicle accident presents with a severe fracture dislocation of his talus. There is a 90-degree displacement of the talar body with subtalar joint dislocation best noted on axial CT (Figs. 4.8a–d, 4.9, and 4.10). Note that these axial images appear as coronal cuts of the talar body. This fracture pattern has a high likelihood of AVN.

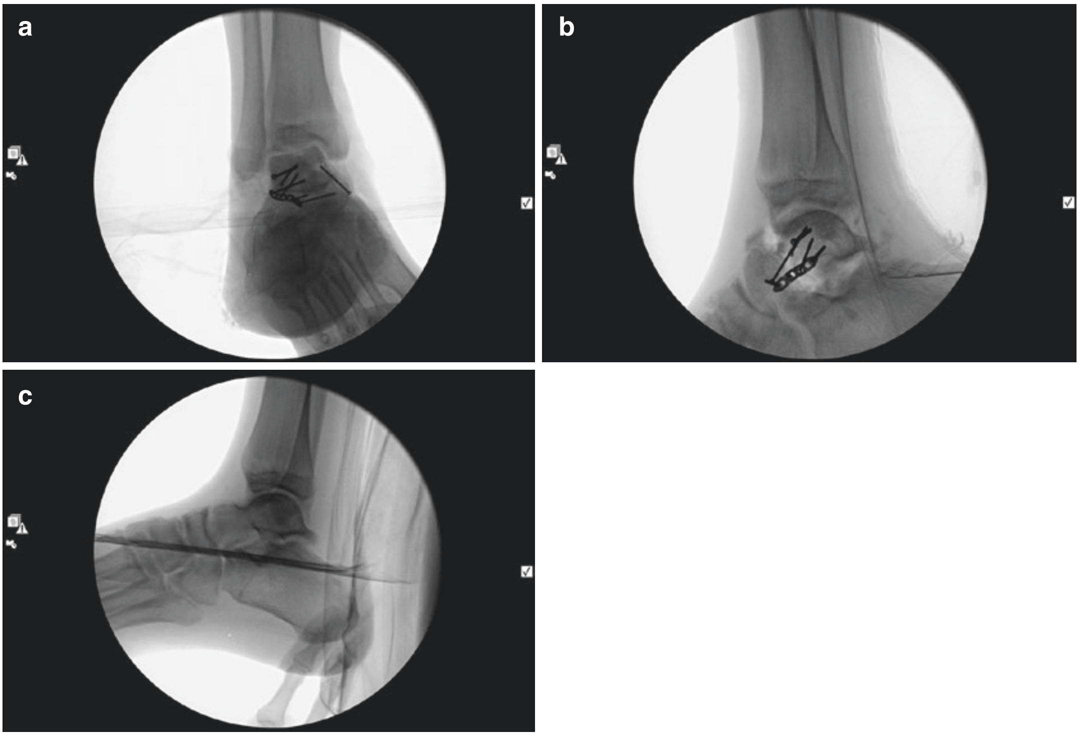


Fig. 4.9 (**a**–**c**) Intraoperative fluoroscopy shows that despite the use of a structural graft measuring 1.5 cm in length, there is still marked shortening of the talar neck. The decision was made to accept the shortening given that structural integrity was present instead of creating a large gap. Contralateral fluoroscopy views are included for comparison

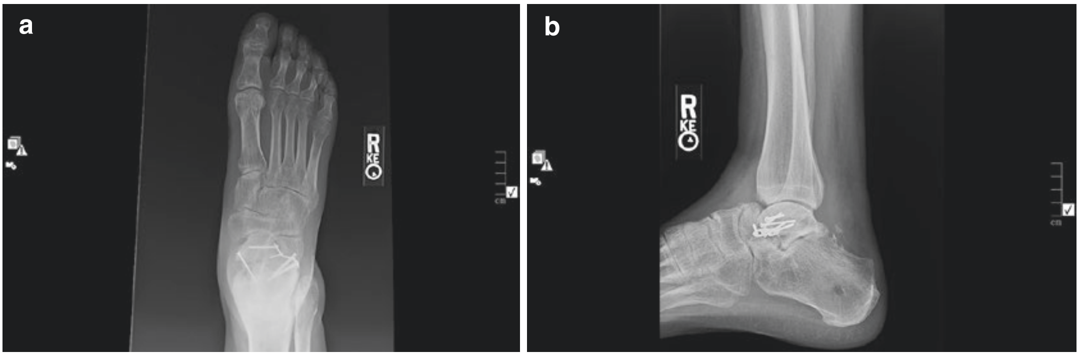


Fig. 4.10 (**a**, **b**) Final X-rays on follow-up demonstrate union with marked shortening of the talar neck at 3 years. The patient, however, is surprisingly ambulating without pain and only has mild residual stiffness. There is no marked deformity of the foot or subsequent collapse of the talar dome, but the decreased joint space is suggestive of AVN

Case 3: A 43-year-old female who is previously healthy, status post poly-trauma in a motor vehicle accident is transferred from an outside hospital following numerous surgeries (Figs. 4.11, 4.12, and 4.13).

Case 4: A 22-year-old female, status post motor vehicle accident with a right talar neck fracture and a left lateral talar process fracture (Figs. 4.14, 4.15, and 4.16).

Fig. 4.11 (**a**–**d**) X-ray and CT scans from the outside hospital show severe comminution and displacement of the talus. A common independent shoulder piece is best seen on axial views, and numerous independent subtalar pieces are seen on sagittal views. These findings are hallmarks of high-energy injuries that involve both columns of the talus

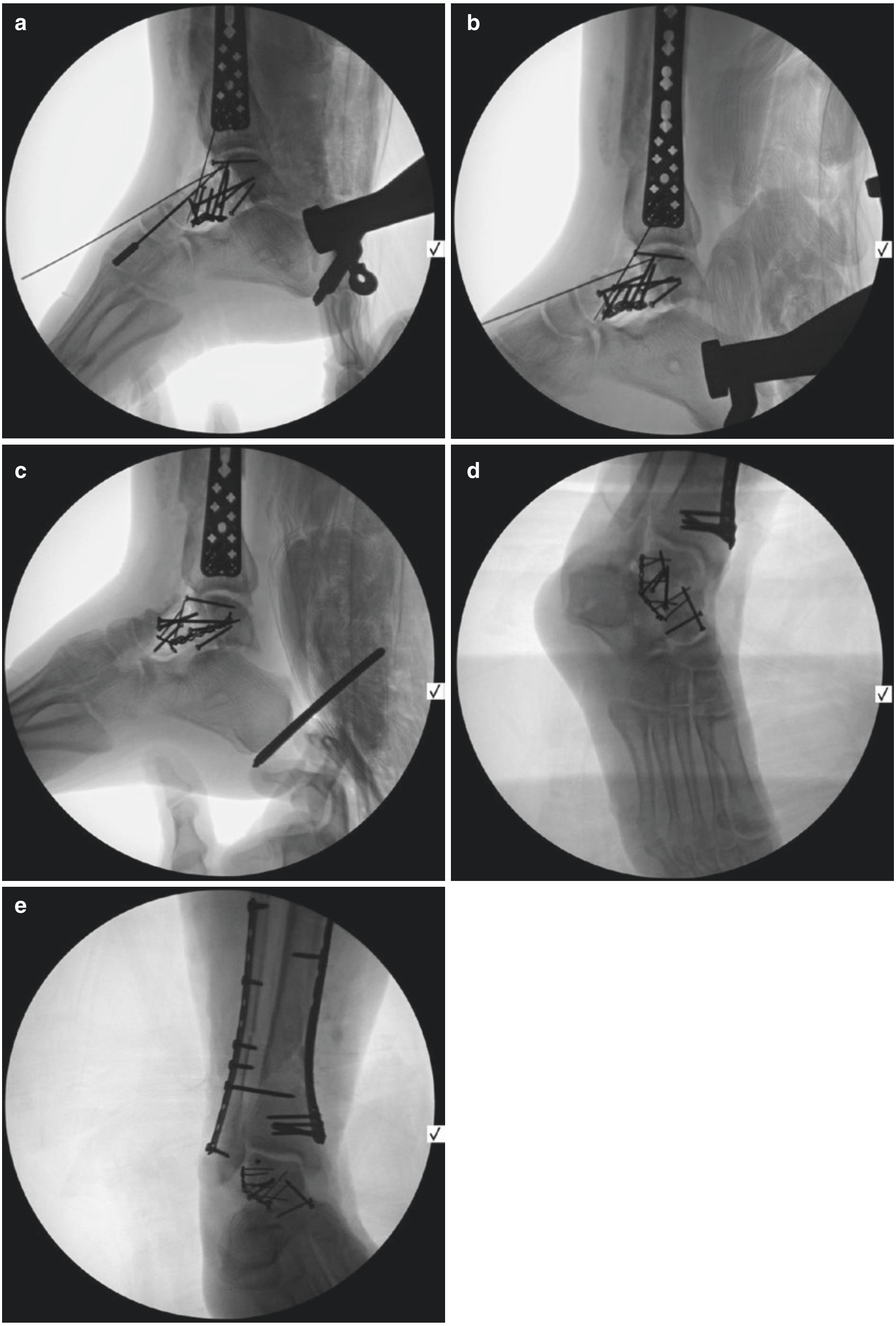

a
b
c
d
e

Fig. 4.12 (**a**–**e**) Intraoperative fluoroscopy shows the process of fixation. Initial attempts at fixation utilized structural allograft in an attempt to restore anatomy. Intraoperative testing revealed gross motion at the fracture due to marked comminution and proximal extent of bone loss under the articular surface of the talar body. Subsequent fibular osteotomy was required to extend the fixation proximally within the articular zone of the talofibular joint to achieve stability. Mild dorsiflexion in the fracture reduction was accepted due to extremely limited bone stock and multiple attempts at stabilization. Revision open reduction internal fixation of tibia was also performed at that time

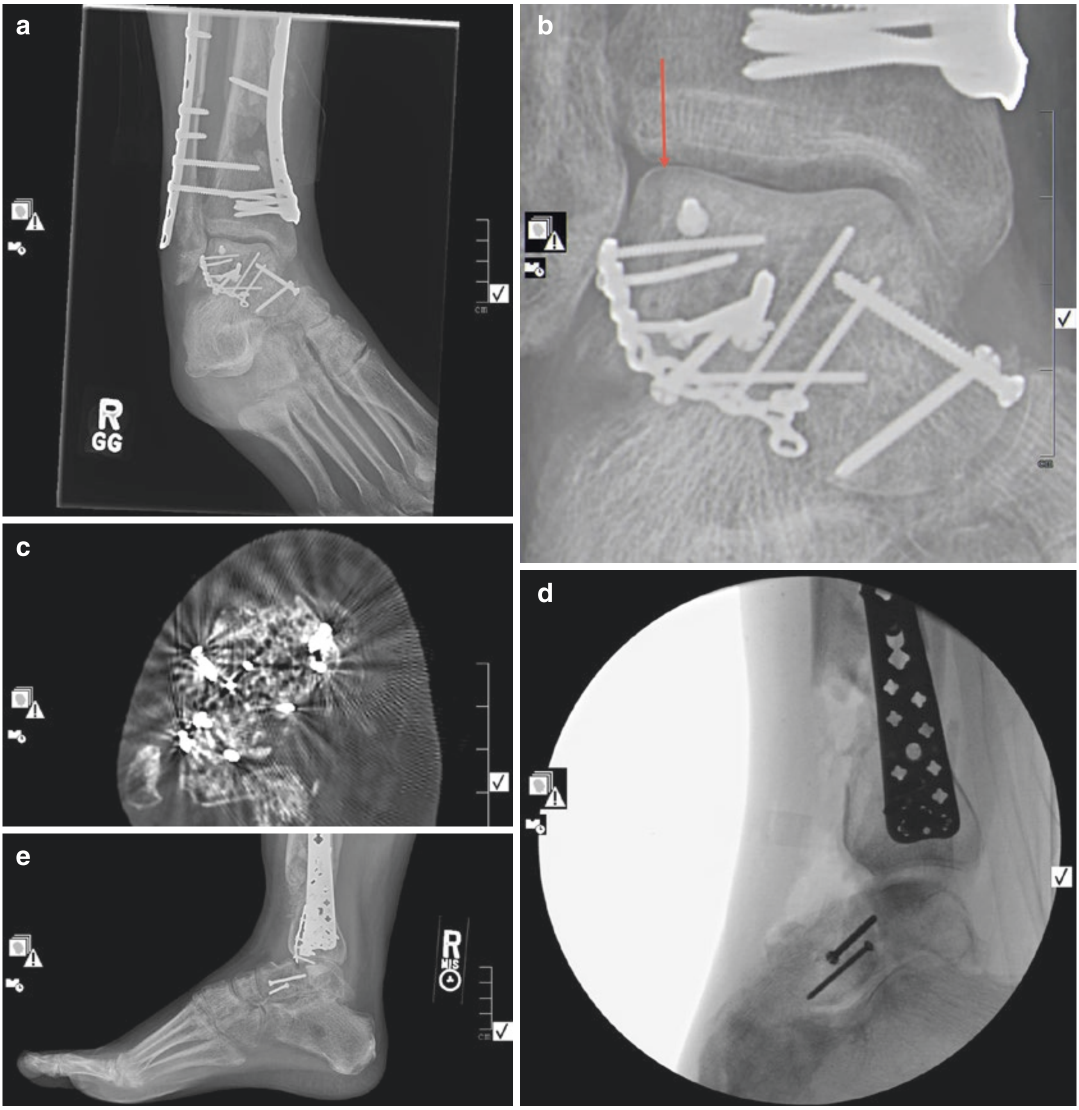


Fig. 4.13 (**a**–**e**) Postoperative follow up at 3 months demonstrates the "Hawkins sign," suggesting revascularization of the talar body. CT scan at 4 months was taken but was difficult to assess union due to hardware scatter. Patient developed mild clinical varus and pain with 2 months weight-bearing. At 6 months, the decision was made to undergo removal of hardware and inspection of union. Partial union with fibrous tissue was encountered and grafted at that time, along with grafting of tibia and removal of lateral talar hardware. Weight-bearing was then reinitiated at 9 months and closely followed with serial radiographs. At the 13th-month follow-up, X-rays showed mild dorsal subluxation and mild varus consistent with postoperative fluoroscopy. Patient is currently ambulating with minimal pain and has reasonable function. He has been able to return to work at a desk job

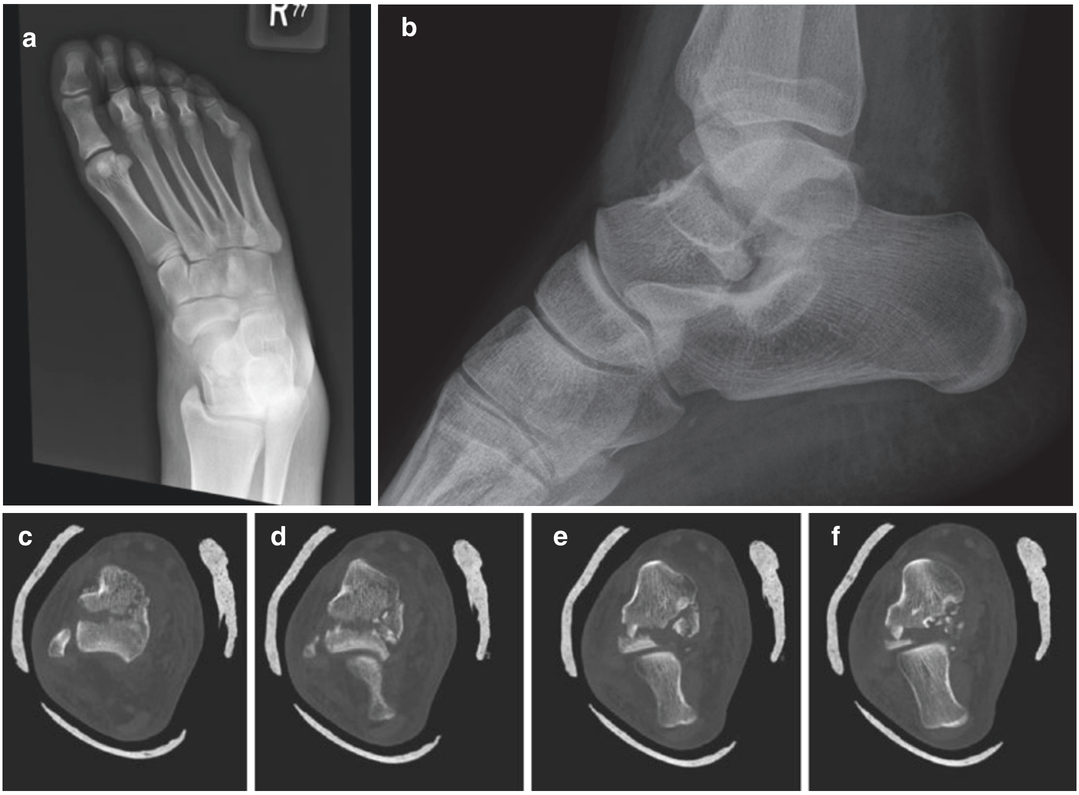


Fig. 4.14 (**a**–**f**) Radiographs and CT demonstrate a displaced talar neck fracture with comminution present at the neck medially and inferiorly, which extends into the subtalar joint. Laterally, the fracture involves the body and is more simple in nature

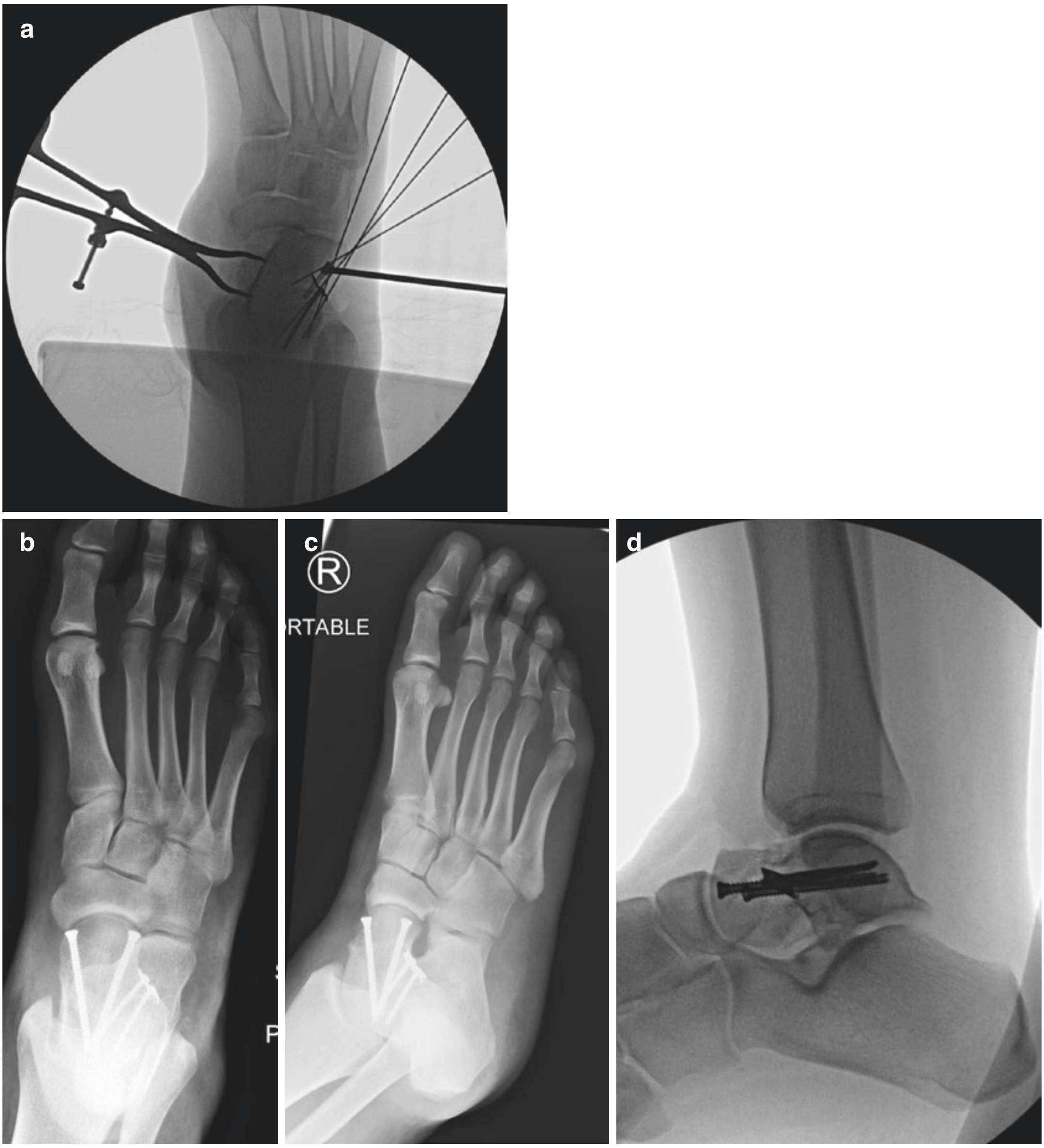


Fig. 4.15 (**a**–**d**) Intraoperative fluoroscopy notes the use of instruments and provisional fixation through the two standard approaches. A modified clamp is in place medially (dorsal to the area of comminution). This clamp is being counteracted by a lag screw which has been inserted laterally as the first item of definitive fixation. This screw will resist any tendencies toward varus during the remainder of the ORIF. The definitive fixation construct consists of two mini-fragment lag screws laterally through a plate that acts as a washer, and two positional fully threaded 3.5 cannulated screws inserted through the talar head. These two screws serve two purposes; they strut the area of inferomedial comminution, while they maintain the compression of the dorsomedial neck that was obtained via the modified clamp

Fig. 4.16 (**a**–**d**) In postoperative follow-up at 6 months, the patient was ambulating without an assistive device and was not reporting pain. She noted difficulty with traversing uneven ground. Her imaging demonstrated union in appropriate alignment without evidence of avascular necrosis. Her subtalar joint had narrowed

References

1. Fortin PT, Balazsy JE. Talus fractures: evaluation and treatment. J Am Acad Orthop Surg. 2001;9(2):114–27.
2. Vallier HA, Nork SE, Barei DP, Benirschke SK, Sangeorzan BJ. Talar neck fractures: results and outcomes. J Bone Joint Surg Am Vol. 2004;86-a(8):1616–24.
3. Vallier HA, Reichard SG, Boyd AJ, Moore TA. A new look at the Hawkins classification for talar neck fractures: which features of injury and treatment are predictive of osteonecrosis? J Bone Joint Surg Am. 2014;96(3):192–7.
4. Vallier HA. Fractures of the talus: state of the art. J Orthop Trauma. 2015;29(9):385–92.
5. Beltran MJ, Mitchell PM, Collinge CA. Posterior to anteriorly directed screws for management of talar neck fractures. Foot Ankle Int. 2016;37(10):1130–6.
6. Attiah M, Sanders DW, Valdivia G, Cooper I, Ferreira L, MacLeod MD, et al. Comminuted talar neck fractures: a mechanical comparison of fixation techniques. J Orthop Trauma. 2007;21(1):47–51.
7. Charlson MD, Parks BG, Weber TG, Guyton GP. Comparison of plate and screw fixation and screw fixation alone in a comminuted talar neck fracture model. Foot Ankle Int. 2006;27(5):340–3.
8. Capelle JH, Couch CG, Wells KM, Morris RP, Buford WL Jr, Merriman DJ, et al. Fixation strength of anteriorly inserted headless screws for talar neck fractures. Foot Ankle Int. 2013;34(7):1012–6.
9. Karakasli A, Hapa O, Erduran M, Dincer C, Cecen B, Havitcioglu H. Mechanical comparison of headless screw fixation and locking plate fixation for talar neck fractures. J Foot Ankle Surg: Off Publ Am Coll Foot Ankle Surg. 2015;54(5):905–9.

10. Fleuriau Chateau PB, Brokaw DS, Jelen BA, Scheid DK, Weber TG. Plate fixation of talar neck fractures: preliminary review of a new technique in twenty-three patients. J Orthop Trauma. 2002;16(4):213–9.
11. Maceroli MA, Wong C, Sanders RW, Ketz JP. Treatment of comminuted talar neck fractures with use of minifragment plating. J Orthop Trauma. 2016;30(10):572–8.
12. Halvorson JJ, Winter SB, Teasdall RD, Scott AT. Talar neck fractures: a systematic review of the literature. J Foot Ankle Surg: Off Publ Am Coll Foot Ankle Surg. 2013;52(1):56–61.
13. Vints W, Matricali G, Geusens E, Nijs S, Hoekstra H. Long-term outcome after operative management of talus fractures. Foot Ankle Int. 2018;39(12):1432–43.
14. Annappa R, Jhamaria NL, Dinesh KV, Devkant, Ramesh RH, Suresh PK. Functional and radiological outcomes of operative management of displaced talar neck fractures. Foot. 2015;25(3):127–30.
15. Dodd A, Lefaivre KA. Outcomes of talar neck fractures: a systematic review and meta-analysis. J Orthop Trauma. 2015;29(5):210–5.
16. Jordan RK, Bafna KR, Liu J, Ebraheim NA. Complications of talar neck fractures by Hawkins classification: a systematic review. J Foot Ankle Surg: Off Publ Am Coll Foot Ankle Surg. 2017;56(4):817–21.
17. Whitaker C, Turvey B, Illical EM. Current concepts in talar neck fracture management. Curr Rev Muscoskelet Med. 2018;11(3):456–74.

5

Talar Body Fractures

Mai P. Nguyen and Heather A. Vallier

Abbreviations

AO	Arbeitsgemeinschaft fur Osteosynthesefragen
OTA	Orthopaedic Trauma Association
PTOA	Post-traumatic osteoarthrosis

Introduction

Epidemiology

Talar body fractures are rare, accounting for less than 1% of all fractures [1–3]. They usually occur when axial compression is applied between the tibial plafond and the calcaneus during high-energy events such as falls from height or motor vehicle collisions. Less common than talar neck fractures, talar body fractures may be difficult to differentiate from talar neck fractures, resulting in a wide range of reported prevalence. Talar body fractures account for between 6% and 40% of talus fractures [2–5]. Talar neck fractures are also frequently associated with fractures of the talar body [4]. Due to their rarity, stringent blood supply, and complex anatomy, talar body fractures are not well understood and are often associated with complications and poor long-term function.

Anatomy

Since the majority of the talar surface is covered by cartilage, its blood supply is relatively sparse, leaving the talus susceptible to osteonecrosis after injuries [5, 7–9]. In addition, because of its vital position, injuries to the talus can alter the alignment, disrupting the functions of ankle, hindfoot, and midfoot.

Inokuchi and colleagues defined talar neck fractures as fractures that occur anterior to the lateral process of the talus, whereas talar body fractures extend into or posterior to the lateral process [6]. This distinction is important as body fractures can affect the congruity of both the tibiotalar and subtalar joints. Even after anatomic reduction and fixation of these fractures, the hinge movements of the ankle and rotation through the subtalar joint can be greatly limited, causing considerable stiffness, secondary arthritis of adjacent joints, and resultant disability.

M. P. Nguyen
Department of Orthopaedic Surgery, University of Minnesota, Minneapolis, MN, USA

H. A. Vallier (✉)
Department of Orthopaedic Surgery, Case Western Reserve University, Cleveland, OH, USA
e-mail: hvallier@metrohealth.org

© Springer Nature Switzerland AG 2020

M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_5

Evaluation

Physical Examination

Most talar body fractures are caused by high-energy events; thus, a thorough history and physical exam according to the Advanced Trauma Life Support guidelines should be performed first, followed by a focused exam of the injured extremity. The exam should include careful neurovascular and soft tissue evaluations. Soft tissue trauma may be severe with talar body fractures, especially if dislocation is associated. Approximately 20–25% of talar body fractures are open fractures, occurring more frequently with greater initial fracture displacement [2, 4, 10].

Imaging

Plain ankle and foot radiographs should be obtained to characterize the fracture pattern and to identify adjacent injuries. The Canale view with the beam angled approximately 75 degrees cephalad and the foot pronated 15 degrees offers an axial view of the talar neck and is especially helpful when there is an associated talar neck fracture [11]. Computerized tomography scans may be helpful for preoperative evaluation of severely comminuted injuries. Magnetic resonance imaging is rarely indicated in the acute setting.

Classifications

AO/OTA Classification

The AO/OTA classification has designated 81-C for talar body fractures. The fractures are grouped according to increasing severity and worse prognosis [12, 13]. C1 fractures are superior talar dome fractures and involve only the tibiotalar joint. C2 fractures have a coronal fracture through the body of the talus, extending into the subtalar joint. Inokuchi has differentiated the coronal talar body fracture and talar neck fracture based on the inferior extent of the fracture and the lateral process, with talar body fractures extending posteriorly, causing more involvement with the subtalar joint (Fig. 5.1) [6]. The posteriorly displaced half of the body likely has been depleted of its blood supply and has a greater risk for osteonecrosis. C3 fractures carry the worst prognosis with both tibiotalar and subtalar involvement (Fig. 5.2).

Fig. 5.1 Coronal fracture through the talus includes the posterior portion of the talar body, as the fracture is posterior to the subtalar joint, and is associated with a subtalar dislocation, as in this lateral injury radiograph

The AO/OTA classification is the newest and most comprehensive fracture classification for the talar body. The patterns represent injuries seen in clinical practice, and the classification promotes consistency in description, which is useful for communication, research, and publication [13].

Sneppen Classification

Sneppen and colleagues, in their series of 51 talar body fractures, described a classification system based on the mechanism and location of injuries [1]. They include three mechanisms of talar body fractures: compression, shearing, and crush. Within shearing types, they identified coronal and sagittal orientation of the fracture lines.

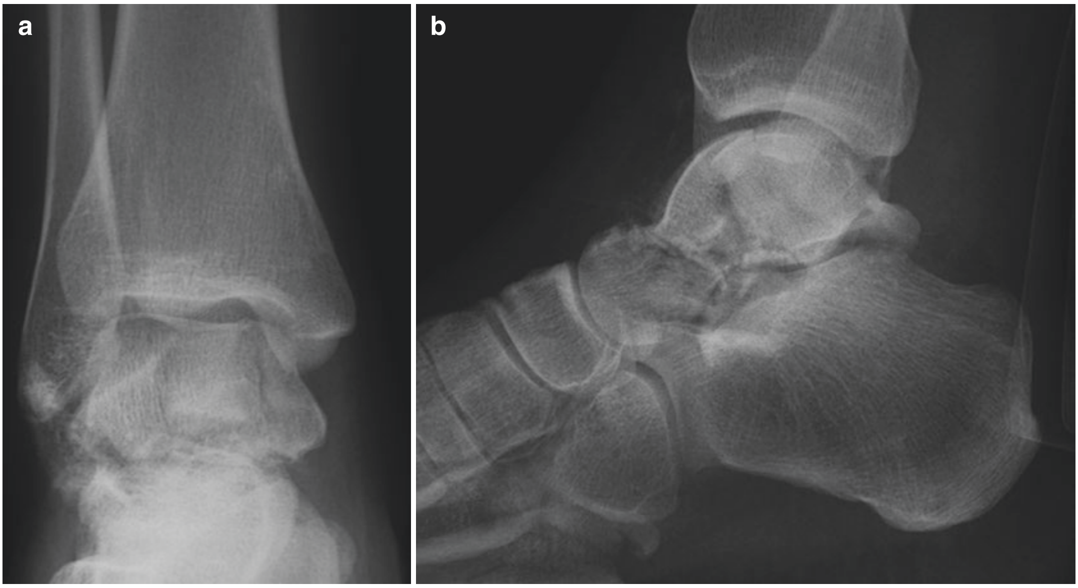


Fig. 5.2 Injury ankle radiographs depict a comminuted talar body and associated talar neck fracture (type C3), seen in the anteroposterior and lateral views

A. Compression fractures exclusively involve the ankle joint.
B. Shearing fractures, coronal type, involve both ankle and subtalar joints.
C. Shearing fractures, sagittal type, involve both ankle and subtalar joints.
D. Posterior tubercle.
E. Lateral tubercle.
F. Crush fractures.

Boyd and Knight Classification

Boyd and Knight classified talar body fractures according to the plane of the fracture line [14]. A type I fracture is a coronal or sagittal shear fracture, while a type II fracture occurs in the horizontal plane.

Treatments

Since the talus has a central role in the functions of the foot and the ankle, reestablishing talar anatomy is essential to optimize function. Treatment goals focus on accurate restoration of the articular surface and osseous mechanical alignment. Optimal treatment of talar body fractures requires a thorough understanding of the anatomy, recognizing the full extent of the bony and soft tissue injuries, and careful handling of soft tissue is paramount to minimizing early complications. With the exception of medically unstable or nonambulatory patients, nonoperative management is typically reserved for non-displaced talar body fractures. Reports of closed management of talar body fractures demonstrate poor long-term results with high rates of osteonecrosis and post-traumatic osteoarthrosis (PTOA), reaching 100% in some series [1, 15–17]. In the vast majority of cases, the standard of care for talar body fractures with any displacement is open reduction and internal fixation to maximize long-term function [2, 4, 10].

Acute Management

Acute treatment of talar fractures necessitates meticulous soft tissue management. Standard treatment of open fractures includes intravenous antibiotics and tetanus prophylaxis, followed by urgent surgical debridement. Associated dislocations can cause tenting of the neurovascular bundle and may present with impending skin necrosis. Thus, urgent reduction in the emergency room or operating room is recommended in order to avoid catastrophic complications.

After provisional reduction, some fractures may be adequately maintained in a short-leg splint or, if needed, additional temporary Kirschner wire fixation or external fixation may be employed for unstable injuries.

Timing of Definite Management

While reduction of dislocations and debridement of open injuries should be performed urgently, timing of definitive surgery should be based on the injury to the surrounding soft tissues, usually from 1 to 3 weeks after the fracture. The extremity should be splinted and elevated to facilitate swelling reduction. Previously, it was believed that urgent fixation would promote revascularization of the talar body and minimize the incidence of osteonecrosis. However, recent reports have demonstrated no association between timing of fixation and development of osteonecrosis [2, 10, 18]. Rather, delaying surgical intervention to optimize the soft tissue envelope has resulted in fewer soft tissue complications than historical reports [2, 4, 10].

Once swelling has subsided and the patient is optimized for surgical intervention, definitive fixation should be performed to restore the anatomy.

Surgical Approaches

Surgical approach is based on the fracture location and pattern. For example, an isolated sagittal fracture in the talar body may be approached through a single incision, anteromedially or anterolaterally, depending on the fracture location. While most talar body fractures can be addressed anteriorly with the patient supine, fractures posterior to the medial malleolus can be accessed through a posteromedial exposure (Fig. 5.3).

Posterior Approach

The posteromedial approach can be performed with the patient positioned supine using a bump underneath the *contralateral* hip, which effectively externally rotates the injured leg to maintain the hindfoot directed toward the surgeon. The surgeon stands on the other side of the table and places a small bump beneath the prepped hindfoot to further optimize visualization and radiography. Intraoperative radiography in this position is performed with the fluoroscopy machine entering on the injured side of the body. The lateral view is most easily obtained, while gentle manipulation of the injured leg, by extending the knee and internally rotating the hip, will facilitate the ankle mortise view without moving the C-arm.

A posteromedial approach may also be performed with the patient in the prone position. Care should be taken to position the injured limb slightly elevated, so that lateral imaging will not be obscured by the contralateral leg.

The incision is made between the posterior edge of the medial malleolus and the medial border of the Achilles tendon. Sharp dissection without undermining of subcutaneous tissue is recommended to minimize iatrogenic trauma. The deep interval can be made either anterior or posterior to the flexor digitorum longus tendon, depending on the fracture location. The adjacent neurovascular bundle should be identified and protected throughout the procedure. The fracture will be visualized once the thick posterior capsule is incised, and screw fixation can be performed in the posterior to anterior direction [4, 20].

Anteromedial Approach

The anteromedial approach utilizes the interval between the tibialis anterior and tibialis posterior tendons with the incision extending from the anterior aspect of the medial malleolus toward the navicular [20]. Once the talonavicular joint capsule is incised, the medial aspect of the talar neck is exposed. Care should be taken to avoid inferior dissection so as not to disrupt talar blood supply. The anterior and medial articular surfaces of the talar body are readily visualized, and the middle facet of the subtalar joint is also visible. Further visualization of the posterior aspect of the medial aspect of the talar body can be obtained through a reflected medial malleolar

Fig. 5.3 Injury radiographs show a comminuted fracture dislocation of the posteromedial talar body (**a**, **b**), with a lateral view demonstrating improved alignment after closed reduction (**c**). Computerized tomography provides details regarding the fracture pattern (**d**, **e**). After resolution of soft tissue swelling to an acceptable level, open reduction and internal fixation were performed through a medial malleolar osteotomy (**f**, **g**). The associated talonavicular dislocation was reduced and temporarily stabilized with a Kirschner wire

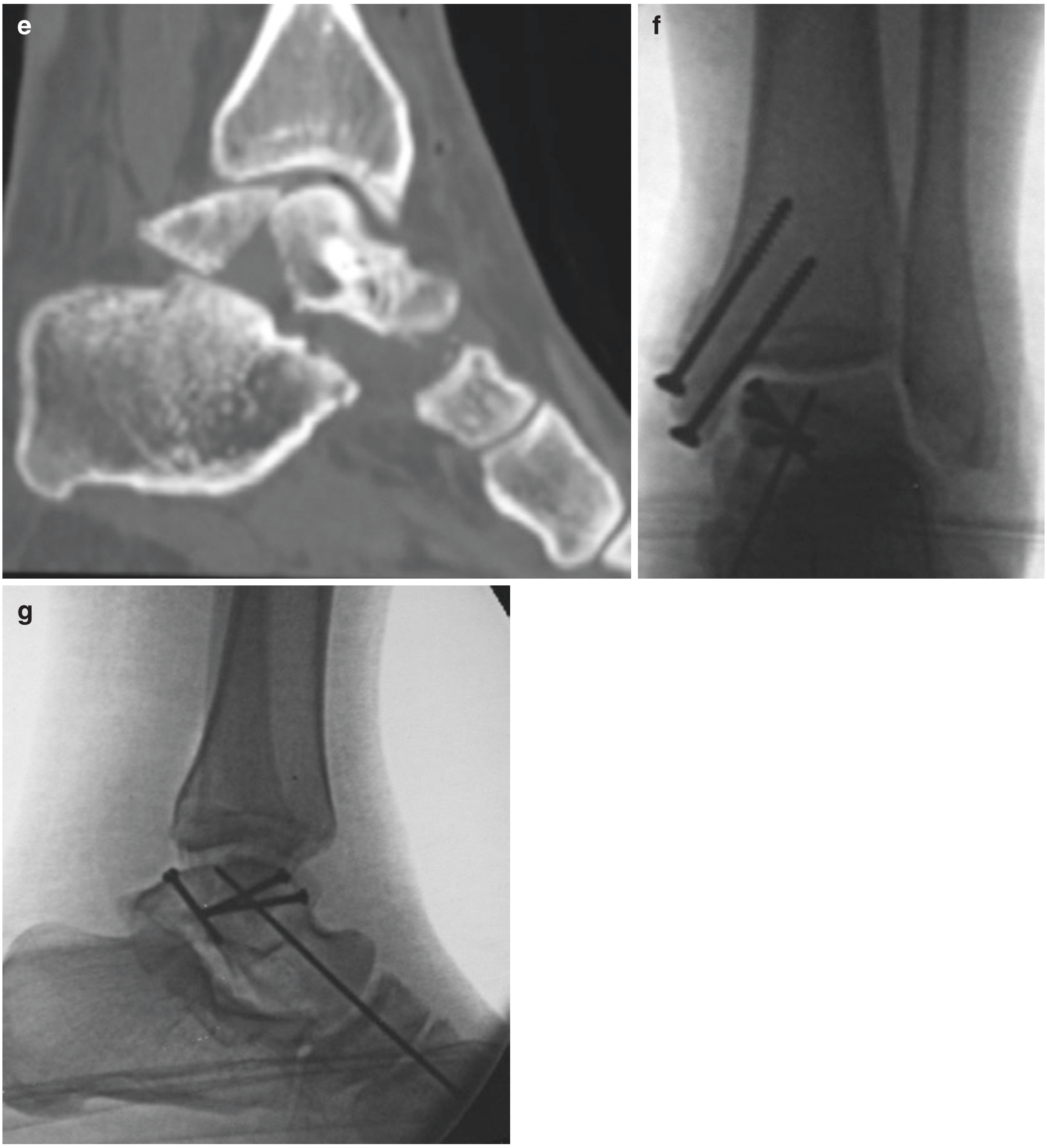


Fig. 5.3 (continued)

fracture or an osteotomy. The oblique medial malleolar osteotomy is performed after predrilling [20, 22, 23]. The deltoid ligament must be carefully protected to maintain the deltoid artery (Fig. 5.4).

Anterolateral Approach

The anterolateral approach is started just proximal to the tibiotalar joint, medial and adjacent to the peroneus tertius tendon, and is directed distally, parallel to the fourth metatarsal [20]. Superficial peroneal nerve branches must be identified and protected throughout. Full thickness skin flaps should be created sharply. The tibiotalar capsule is incised, exposing the ankle joint, and devitalized synovium is excised. Distally, the extensor digitorum brevis is elevated, exposing the lateral cortex of the talar neck. The talofibular gutter, lateral process, and lateral talar neck are now accessible (Fig. 5.5).

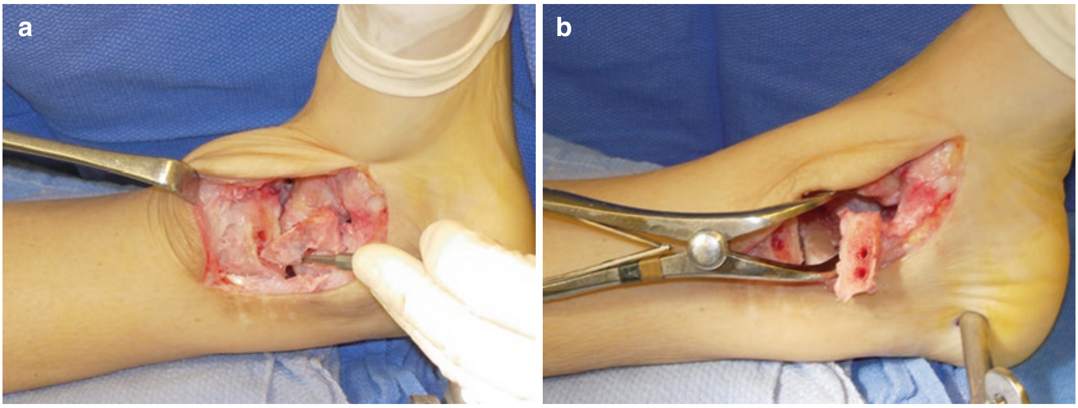


Fig. 5.4 Intraoperative photographs demonstrate the anteromedial approach to a talar body and neck fracture. A medial malleolus osteotomy has been performed after predrilling with a 2.5-mm drill to facilitate later repair (**a**). The medial malleolus remains attached inferiorly to the deltoid ligament. Upon reflection, the talar body is easily visualized and is more accessible for reduction and fixation (**b**)

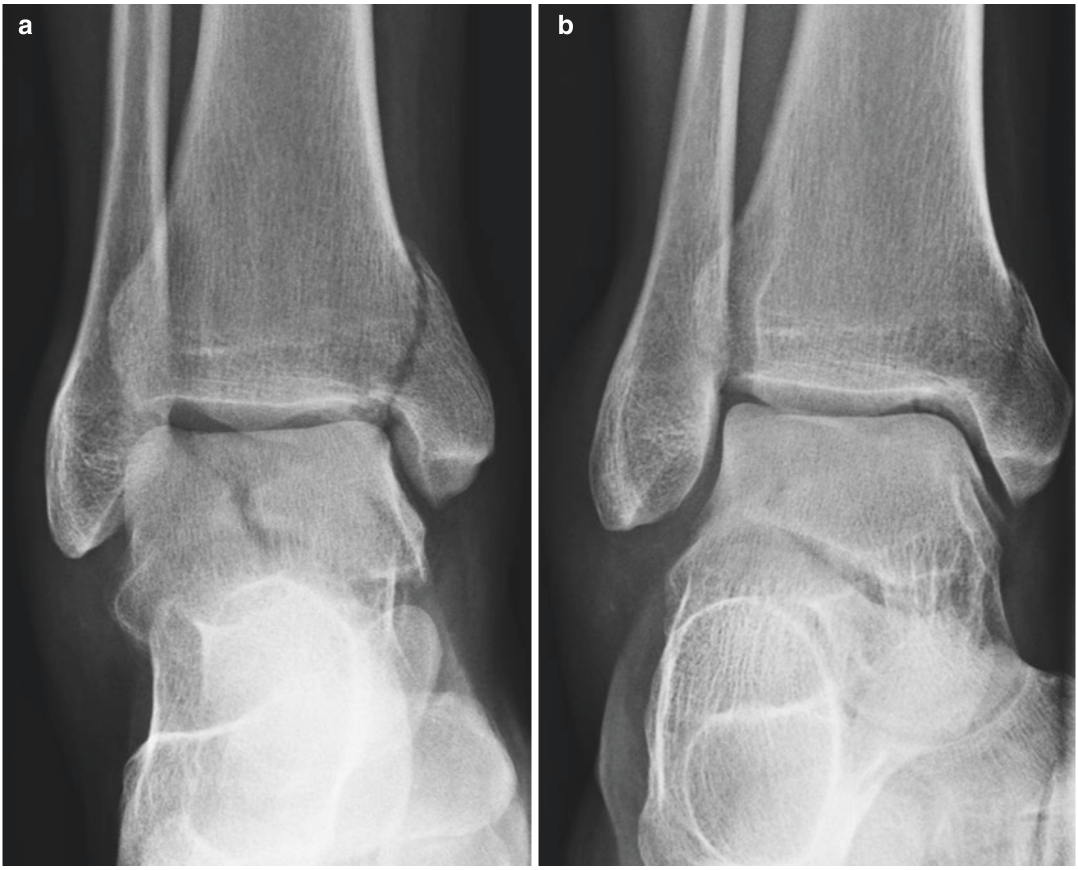


Fig. 5.5 Injury ankle radiographs of a lateral talar body fracture in association with a medial fracture of the tibia plafond. Anteroposterior, mortise, and lateral views are shown (**a**–**c**). Open reduction and internal fixation of the talar body was performed through an anterolateral exposure (**d**, **e**), promoting visualization of the lateral aspect of the talar body including the dome. Direct reduction was obtained, and provisional Kirschner wires were placed, followed by mini-fragment screw fixation. The first screw was placed with interfragmentary compression. Reduction and fixation of the talar body were followed by open reduction and internal fixation of the tibia plafond through an anteromedial exposure. The articular facture was anatomically reduced, and fixation was achieved with a small fragment plate applied as a buttress

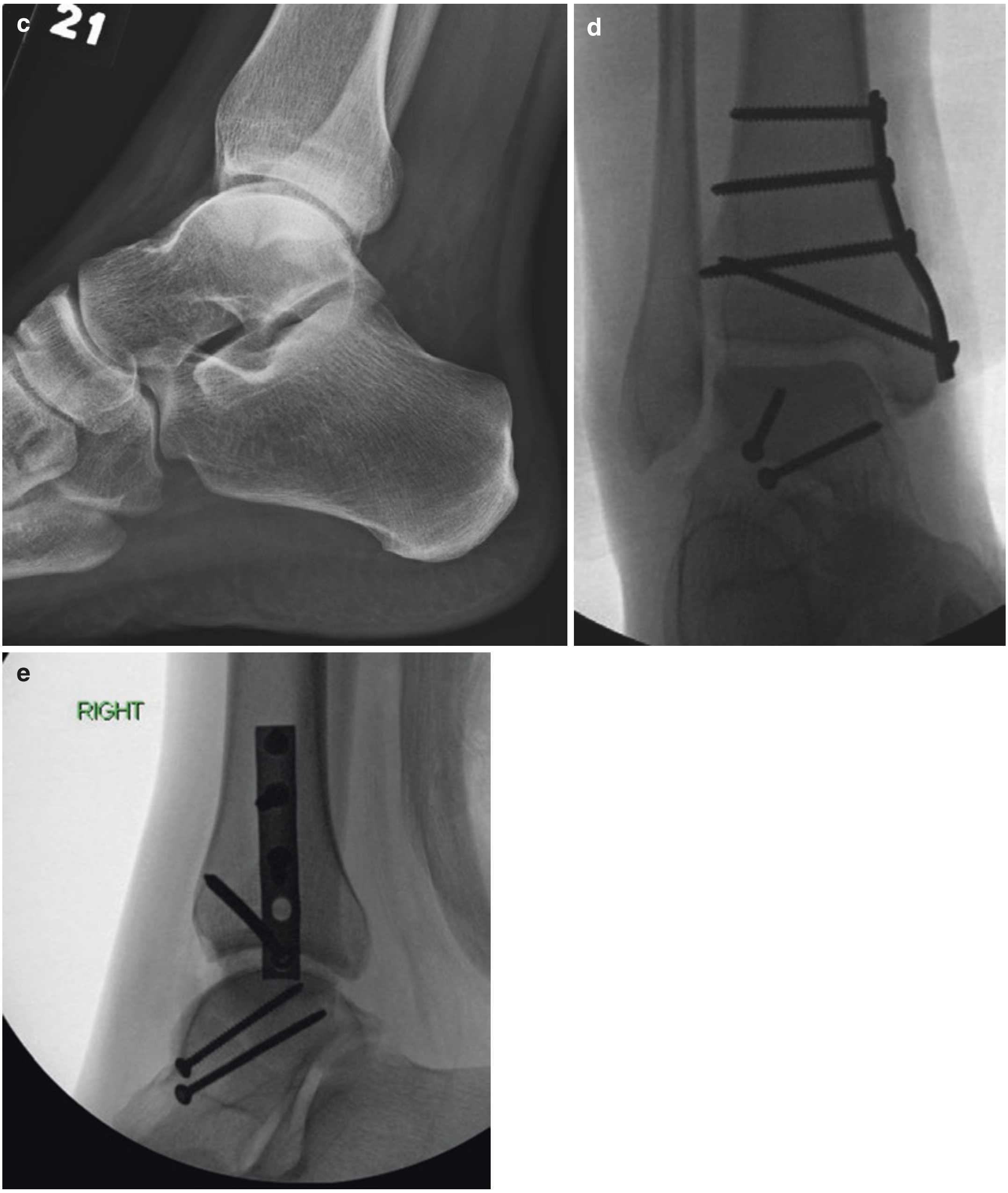


Fig. 5.5 (continued)

Similar to the medial malleolar osteotomy over the medial side, an osteotomy of the distal part of the fibula may be indicated to gain access to the posterior portion of the lateral aspect of the talar body.

Other tactics to increase exposure include plantarflexing the foot to improve visualization of the talar dome. Also, the use of a universal distractor or a temporary external fixator may facilitate intraoperative exposure further (Fig. 5.6).

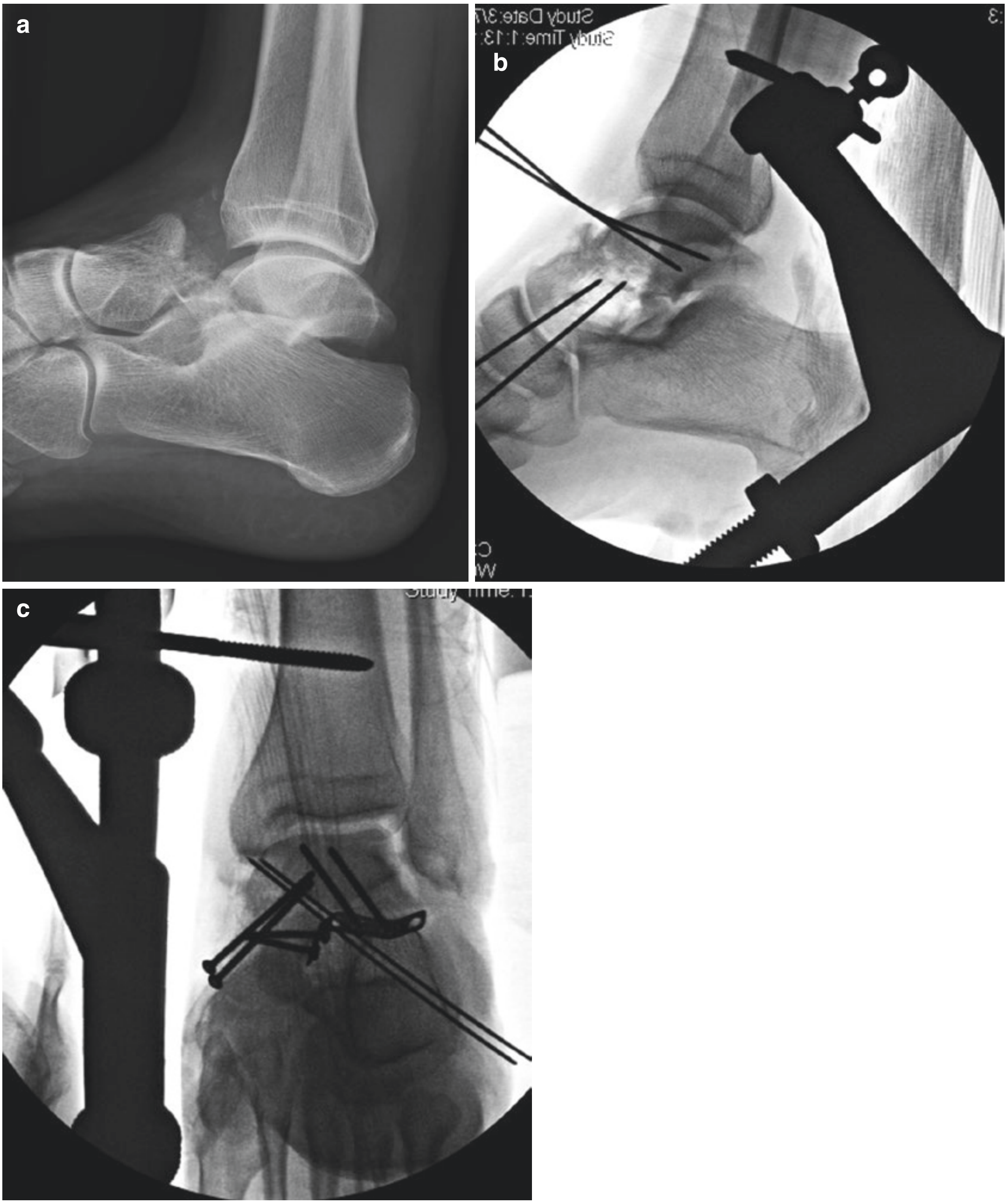


Fig. 5.6 Lateral ankle radiograph shows a talus fracture dislocation (**a**). Often, the talar body will be displaced posteromedially and will not be reducible via closed means. Reduction of the body is prohibited by intervening capsule and by the adjacent posterior tibialis and long toe flexor tendons. Urgent reduction in the operating room is recommended. An anteromedial exposure provides access to the ankle and subtalar joints, with the talar body still displaced. Intraoperatively, a universal distractor may be applied with Schanz pins in the medial tibia and calcaneus to provide distraction and to facilitate reduction of the talar body. This also promotes better intraoperative visualization (**b**, **c**). Consideration should be given to extending the ankle capsulotomy as needed to enlarge the access to the displaced talar body. A Schanz pin or stout Kirschner wires directed into the fractured surface of the talar body may be effective in grasping the talar body to reduce it back to the tibia and calcaneus

Dual Anteromedial and Anterolateral Approaches

Complicated talar body fractures with coronal displacement, comminution, or associated talar neck fractures are more likely to require dual approaches for accurate visualization [4, 19–21]. The patient is usually positioned supine on a radiolucent operating table. A lateral hip bump is helpful to position the foot at a perpendicular to the floor to facilitate direct visualization and imaging.

While the usage of dual surgical exposures has not been shown to increase the risk for osteonecrosis, surgeons must be mindful of the talar blood supply. Plantar dissection along the talar neck is avoided in order to protect the tarsal canal blood supply, and the fibers of the deltoid ligament should also be preserved.

Reduction and Fixation Techniques

The talus is mostly covered by articular cartilage [5]. Anatomic reduction should be the primary goal of surgical intervention, as PTOA may be minimized and function optimized with an accurate reduction. Reduction should be assessed by direct visualization and radiographic evaluation. While Kirschner wire fixation can be done provisionally to hold reduction intraoperatively, rigid fixation with mini-fragment implants (1.8 mm, 2.0 mm, 2.4 mm, 2.7 mm) is advocated to maintain fracture alignment and to promote early range of motion. The small, cruciform head screws can effectively secure osteochondral fractures without being prominent on the articular surface [4]. Devitalized fragments that do not contribute to joint stability or articular congruence may be removed. Associated talar neck fractures may be stabilized with small fragment or mini-fragment axial screws and with mini-fragment plates, depending on fracture orientation and associated comminution [4, 20].

For coronal plane fractures, screws may be effective on the medial side, starting at the edge of the talar head and directed longitudinally into the posterior talar body. Longitudinal screws may also be placed laterally from anterior along the talar neck to posterior within the talar body, depending on the fracture pattern, but often plates are utilized on the lateral side. Plates may aid in stabilizing combinations of talar neck and body fractures, with or without lateral process fractures. In coronal talar body fractures with an intact lateral process, fixation with screws in the retrograde fashion from the firm cortical bone of the lateral aspect of the talar neck into the talar body may be adequate. For fractures with associated lateral process involvement, mini-fragment screws and plates are utilized. Occasionally non-reconstructable osteochondral process fragments are excised, and the lateral process may be medialized, as needed to provide osseous continuity, while minimizing articular offset and gap [4].

For sagittal talar body fractures, lag screw fixation after an osteotomy is appropriate. Screws may be countersunk to prevent implant prominence.

Spanning external fixation or Kirshner wire fixation can be used in adjunct to internal fixation in cases of severe fracture comminution or bone loss. These devices can be removed in the outpatient clinic after 4–8 weeks [4].

Meticulous closure with modified Allgower-Donati sutures or a tension-relieving suture technique is recommended to distribute tension over a larger volume of skin and soft tissue. Suction drainage should be employed liberally to prevent hematoma accumulation, which could contribute to wound dehiscence. Postoperatively, the ankle and foot are immobilized in a splint initially. This provides support for the soft tissues to facilitate wound healing, and it provides relief of pain and anxiety for the patient. Range of motion is initiated once the surgical and traumatic wounds are adequately healed after surgery. No weight-bearing is permitted approximately for the first 12 weeks. Radiographs should be obtained in follow-up for monitoring of union, osteonecrosis, and long-term PTOA.

Treatment Controversies

Although stainless steel implants remain commonplace, some have advocated for titanium screws, which will allow for magnetic resonance imaging to better detect osteonecrosis [21, 24, 25]. Controversy exists regarding this practice, as identification of osteonecrosis will ultimately occur with plain radiography, and activity limitations after diagnosis of osteonecrosis have not been shown to alter the propensity for osseous collapse [3, 4]. Biodegradable implants have also been reported [10]. However, enhanced clinical outcome has never been related to implant composition. Arthroscopic and percutaneous techniques have been described with some success in treatment of non-displaced talar body fractures [24, 26, 27]. However, anatomic reduction should never be compromised regardless of fixation techniques. In rare cases of comminuted talar body fractures that were non-amenable to fixation, primary arthrodesis may be considered [2, 17, 21, 28].

Results

Talar body fractures are often devastating injuries, commonly associated with complications. Recovery lasts for 1–2 years. Early complications are usually soft tissue related, which occur within a few weeks after the injury. Late complications affecting physical functions may not develop for several months after the injury. It is important to counsel patients about their prognosis and long-term expectations. There have only been a few reports describing outcomes of talar body fractures [1–3], while most publications reviewing talus fractures do not distinguish talar body fractures from other fractures of the talus. In Table 5.1, we attempted to isolate the outcomes of talar body fractures from other fractures in each series.

Early Complications

Early literature on immediate surgical management of talar fractures reported high rates of soft tissue complications, up to 77% [1, 17, 29]. These complications included wound dehiscence, skin necrosis, and infection. More recently, protection of the delicate soft tissue envelope around the foot and ankle by urgent reduction of dislocations, administration of intravenous antibiotic prophylaxis for open injuries, and meticulous handling of soft tissues have resulted in a reduction of such early complications to 2–10% in more recent studies [2, 4, 10]. These series advocated for delayed definite surgical procedures until soft tissue swelling improves, usually 1–3 weeks after the injury. Naturally, wound complications correlate with the severity of soft tissue injuries, and open fractures and degloved wounds are associated with greater risk for wound problems [2, 10, 30]. Vallier et al. reported eight early complications among 38 patients, including three superficial infections treated with oral antibiotics, four with partial wound dehiscence, and one with skin necrosis treated with dressing changes [2]. There was one deep infection in an open fracture, which required two irrigation and debridement procedures. In rare cases, amputation is performed due to deep infection, again associated with severe soft tissue injuries [10].

Late Complications and Outcomes

In general, nonunion is rare, ranging from 5% to 12% [4, 10, 18]. Nonunion occurs more often after open fractures versus closed fractures [2, 10]. The mean time to union is approximately 3 months [10]. Malunion ranges from 0% to 37%, and will lead to PTOA, manifested by pain and stiffness of the ankle and subtalar and transverse talar joints [1–4]. However, malunion is likely underestimated in published reports, as it is difficult to adequately evaluate talar alignment based on plain radiographs.

The most common complication of talar body fractures is PTOA, followed by osteonecrosis [2, 4, 10]. Chondral injury and osteochondral loss, and destruction of vascular supply secondary to the initial injury, are clear factors that are related to these complications, respectively. PTOA has been reported in up to 50–100% of patients, despite our best effort with modern techniques of reduction and fixation [2, 10]. Ideally, careful

Table 5.1 Summary of complications and outcomes of published series of talar body fractures

Study	No. of talar body fractures	Follow-up	Infection	Nonunion	Malunion	Avascular necrosis	Post-traumatic arthritis	Outcomes
Coltart et al. (1952) [17]	15					15/15	High	
Mindell et al. (1963) [15]	3 body fractures and 7 fracture dislocation	Mean 4.5 years		0		3/7 with fracture dislocation	6	2/7 satisfactory after fracture dislocation and 3/3 after fracture only
Kenwright et al. (1970) [16]	6	Mean 4 years				1 of 2 with dislocation		2/6 satisfactory
Sneppen et al. (1977) [1]	51	Mean 23 months	2 skin necrosis and infection	3	30/51	8/51	28/51	Complaint severity, disablement assessment, and work status
Elgafy et al. (2000) [21]	11	Mean 30 months	2			3/11	9/10	AOFAS, Ankle-Hindfoot Score, Maryland Foot Score, Hawkins evaluation criteria
Vallier et al. (2003) [2]	38 with minimum of 1-year follow-up	Mean 33 months	3 superficial infection, 4 wound dehiscence, 1 skin necrosis	0	1	10/26 (with complete radiographs)	17/26 tibiotalar, 9/26 subtalar	Mean FFI 32, mean MFA 29.4
Lindvall et al. (2004) [10]	8	Mean 74 months	3/7 open fractures (mixture of talar neck and body fractures)	12%		50%	100%	Mean AOFAS 57.0
Ebraheim et al. (2008) [3]	19	26 months	2 superficial infection, 1 wound dehiscence, 1 skin necrosis, 1 deep infection	1 delayed union	1	7	11/19 tibiotalar, 6/19 subtalar	AOFAS Ankle-Hindfoot scoring, excellent in 4, good in 6, fair in 4, and poor in 5
Bellamy et al. (2011) [18]	< 7 body fractures in 17 patients	Mean 16 months				7/17	5/17	

surgical dissection, followed by accurate articular and axial reduction and fixation will minimize surgical contributions to late complications.

Most patients report pain at long-term follow-up [10]. Prior studies support that PTOA occurs more commonly after talar body fractures than with talar neck fractures, as both the subtalar and tibiotalar joints are involved in most talar body fractures [1, 16, 17, 24]. However, Lindvall et al. demonstrated no differences in union rate, osteonecrosis, or PTOA between talar neck and body fractures in their series of 16 isolated talar neck and 8 isolated body fractures [10]. This study was likely underpowered to identify a difference between these groups. Secondary procedures such as ankle or subtalar arthrodesis or total ankle arthroplasty are effective pain-relieving procedures, as long as mechanical alignment is restored.

The incidence of osteonecrosis is approximately 40% after talar body fractures, with half associated with collapse [2]. Because of progressive damage to the blood supply to the talar body with greater initial fracture displacement, the risk of osteonecrosis is associated with severity of the original injury. Osteonecrosis and collapse usually develop within 14 months of surgery, while revascularization of the talar body without collapse occurs after a mean of 10.4 months [2]. Hawkins described a relative decrease in the density of the talar body versus adjacent structures secondary to osseous resorption during disuse, indicating a present blood supply [29]. Approximately half of the patients with this early finding will undergo revascularization of the talar body without collapse. The absence of Hawkins' sign, however, does not mean that osteonecrosis is imminent, and the presence of the sign does not guarantee complete revascularization of the talus [10].

Previous report of nonoperative treatment of talar body fractures by Sneppen in the 1960s resulted in a high rate of functional disability and PTOA [1]. In the largest series of talar body fractures treated with modern open reduction and internal fixation, even though the authors were able to achieve anatomic reduction on plain radiographs in 21/26 patients, PTOA in the tibiotalar joint occurred in 17 (65%) and in the subtalar joint in 9 (35%), more common after both comminuted fractures and open injuries [2]. PTOA was associated with worse functional outcome scores including the Musculoskeletal Function Assessment (MFA) and the Foot Function Index (FFI). Worse functional outcomes were also seen in association with advanced PTOA and osteonecrosis that progress to collapse in other studies [2, 10, 31]. In general, functional outcome scores for patients with talar body fractures have indicated higher level of impairment compared to patients with other hindfoot injuries [2, 10, 32].

In summary, fractures of the body of the talus are uncommon and poorly defined. With careful attention to surgical timing and technique, complications should be limited to those associated with characteristics of the initial injury including direct damage to the soft tissues, blood supply, cartilage, and bone. Complications are common, and long-term functional outcomes are limited after severe injuries.

References

1. Sneppen O, Christensen SB, Krogsoe O, Lorentzen J. Fracture of the body of the talus. Acta Orthop Scand. 1977;48(3):317–24.
2. Vallier HA, Nork SE, Benirschke SK, Sangeorzan BJ. Surgical treatment of talar body fractures. J Bone Joint Surg Am. 2003;85-A(9):1716–24.
3. Ebraheim NA, Patil V, Owens C, Kandimalla Y. Clinical outcome of fractures of the talar body. Int Orthop. 2008;32(6):773–7.
4. Vallier HA. Fractures of the talus: state of the art. J Orthop Trauma. 2015;29(9):385–92.
5. Higgins TF, Baumgaertner MR. Diagnosis and treatment of fractures of the talus: a comprehensive review of the literature. Foot Ankle Int. 1999;20(9):595–605.
6. Inokuchi S, Ogawa K, Usami N. Classification of fractures of the talus: clear differentiation between neck and body fractures. Foot Ankle Int. 1996;17(12):748–50.
7. Gelberman RH, Mortensen WW. The arterial anatomy of the talus. Foot Ankle. 1983;4(2):64–72.
8. Miller AN, Prasarn ML, Dyke JP, Helfet DL, Lorich DG. Quantitative assessment of the vascularity of the talus with gadolinium-enhanced magnetic resonance imaging. J Bone Joint Surg Am. 2011;93(12):1116–21.
9. Mulfinger GL, Trueta J. The blood supply of the talus. J Bone Joint Surg Br. 1970;52(1):160–7.

10. Lindvall E, Haidukewych G, DiPasquale T, Herscovici D Jr, Sanders R. Open reduction and stable fixation of isolated, displaced talar neck and body fractures. J Bone Joint Surg Am. 2004;86-A(10):2229–34.
11. Canale ST, Kelly FB Jr. Fractures of the neck of the talus. Long-term evaluation of seventy-one cases. J Bone Joint Surg Am. 1978;60(2):143–56.
12. Sanders D. Talus fractures. In: Bucholz RW, Heckman J, Court-Brown CM, Tornetta P, editors. Rockwood and Green's fractures in adults. Philadelphia: Lippincott Williams & Wilkins; 2006. p. 2043.
13. Marsh JL, Slongo TF, Agel J, Broderick JS, Creevey W, DeCoster TA, Prokuski L, Sirkin MS, Ziran B, Henley B, Audige L. Fracture and dislocation classification compendium – 2007: Orthopaedic trauma association classification, database and outcomes committee. J Orthop Trauma. 2007;21(10 Suppl):S1–133.
14. Boyd HB, R K. Fractures of the astragalus. South Med J. 1942;35:160.
15. Mindell ER, E C, Kartalian G. Late results of injuries to the talus. J Bone Joint Surg Am. 1963;45:221.
16. Kenwright J, Taylor RG. Major injuries of the talus. J Bone Joint Surg Br. 1970;52(1):36–48.
17. Coltart WD. Aviator's astragalus. J Bone Joint Surg Br. 1952;34-B(4):545–66.
18. Bellamy JL, Keeling JJ, Wenke J, Hsu JR. Does a longer delay in fixation of talus fractures cause osteonecrosis? J Surg Orthop Adv. 2011;20(1):34–7.
19. Mayo KA. Fractures of the talus: principles of management and techniques of treatment. Tech Orthop. 1987;2:42.
20. Vallier HA, Nork SE, Benirschke SK, Sangeorzan BJ. Surgical treatment of talar body fractures. J Bone Joint Surg Am. 2004;86-A(Suppl 1 (Pt 2)):180–92.
21. Elgafy H, Ebraheim NA, Tile M, Stephen D, Kase J. Fractures of the talus: experience of two level 1 trauma centers. Foot Ankle Int. 2000;21(12):1023–9.
22. Ziran BH, Abidi NA, Scheel MJ. Medial malleolar osteotomy for exposure of complex talar body fractures. J Orthop Trauma. 2001;15(7):513–8.
23. Gonzalez A, Stern R, Assal M. Reduction of irreducible Hawkins III talar neck fracture by means of a medial malleolar osteotomy: a report of three cases with a 4-year mean follow-up. J Orthop Trauma. 2011;25(5):e47–50.
24. Thordarson DB. Talar body fractures. Orthop Clin North Am. 2001;32(1):65–77, viii.
25. Thordarson DB, Triffon MJ, Terk MR. Magnetic resonance imaging to detect avascular necrosis after open reduction and internal fixation of talar neck fractures. Foot Ankle Int. 1996;17(12):742–7.
26. Saltzman CL, Marsh JL, Tearse DS. Treatment of displaced talus fractures: an arthroscopically assisted approach. Foot Ankle Int. 1994;15(11):630–3.
27. Jorgensen NB, Lutz M. Arthroscopic treatment of talar body fractures. Arthrosc Tech. 2014;3(2):e271–4.
28. Ptaszek AJ. Immediate tibiocalcaneal arthrodesis with interposition fibular autograft for salvage after talus fracture: a case report. J Orthop Trauma. 1999;13(8):589–92.
29. Hawkins LG. Fractures of the neck of the talus. J Bone Joint Surg Am. 1970;52(5):991–1002.
30. Marsh JL, Saltzman CL, Iverson M, Shapiro DS. Major open injuries of the talus. J Orthop Trauma. 1995;9(5):371–6.
31. Grob D, Simpson LA, Weber BG, Bray T. Operative treatment of displaced talus fractures. Clin Orthop Relat Res. 1985;199:88–96.
32. Turchin DC, Schemitsch EH, McKee MD, Waddell JP. Do foot injuries significantly affect the functional outcome of multiply injured patients? J Orthop Trauma. 1999;13(1):1–4.

Fractures of the Talar Head

6

James Richman, Adam Gitlin, and Mark R. Adams

Introduction

Fractures of the talus are rare, and talar head fractures are an uncommon subset of talus fractures. Even at its highest incidence, it is involved in less than 10% of all fractures of the talus [1]. Focused examination specific to these fractures has been difficult; this is due to the rarity of the injury and their frequent association with other injuries within the foot.

Anatomy

The head of the talus articulates with the navicular, forming one component of the Chopart joint. The head is rotated 45 degrees laterally in relation to the axis of the talar neck [2]. The plantar spring ligament passes inferiorly to the talar head connecting the calcaneus to the navicular. The talar head forms its main articulation with the navicular in an area called the acetabulum pedis. Detailed by Sarrafian [19], it is composed of the anterior and middle calcaneal sections of the talus and linked to the navicular via the inferior and superomedial calcaneonavicular ligaments (Fig. 6.1). The calcaneonavicular segment of the bifurcate ligament becomes the lateral hinge. The medial side is supported by the spring ligament and posterior tibial tendon [7].

The talar head has vascular supply from two of the three main arteries that supply the talus. The superomedial portion derives its vascularity from branches of the dorsalis pedis (anterior tibial artery). These branches terminate into either directly medial tarsal branches or indirectly as branches of the anteromedial malleolar artery. The inferolateral half derives its vascular supply directly from the lateral sling. The inferior side of the talar neck that forms the anterior boundary of the tarsal sinus serves as the area where the intraosseous blood supply enters the talus bound for the talar head. Anastomotic connections via the soft tissue attachments and ligamentous structures also serve the talar head and navicular [4].

Mechanics of the Talonavicular Joint

The talonavicular joint is one of three essential joints, including the ankle and subtalar joints, which comprise the hindfoot [6]. Gait mechanics and mobility are therefore optimized by the

---

J. Richman
MultiCare Orthopedics & Sports Medicine,
Tacoma, WA, USA

A. Gitlin
Crystal Run Healthcare, Middletown, NY, USA

M. R. Adams (✉)
Associate Professor, Department of Orthopedics,
Trauma Division, Rutgers – New Jersey Medical
School, Newark, NJ, USA
e-mail: Adamsm4@njms.rutgers.edu

© Springer Nature Switzerland AG 2020
M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_6

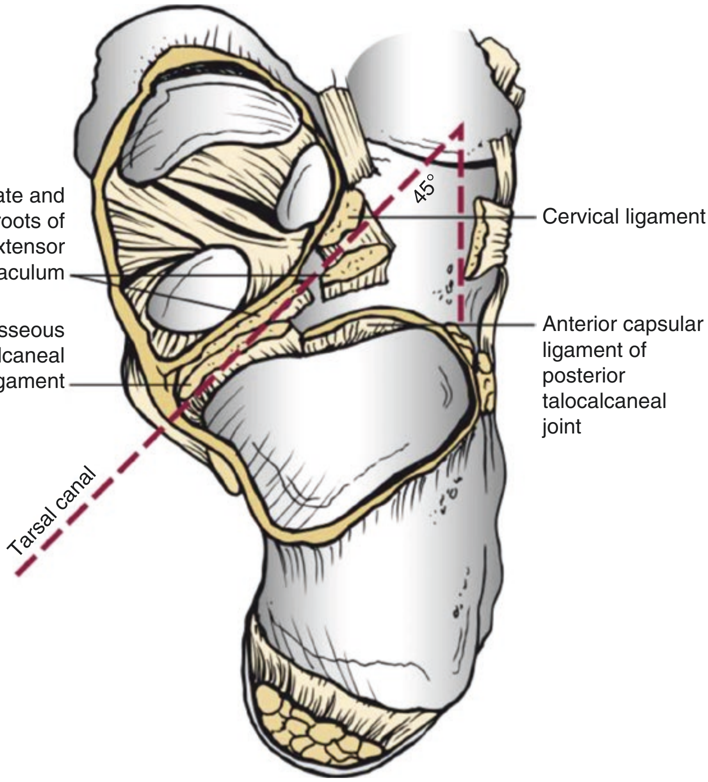


Fig. 6.1 Acetabulum pedis. This socket for the talar head allows the midfoot to swivel about the talar head [19]

preservation of range of motion in these joints. The talonavicular joint, in particular, is crucial in providing a transfer point between the hindfoot and tibia to the midfoot and structures distally.

The talus itself is contained within the malleoli of the ankle joint, between the Chopart joint and subtalar joint. This limits its ability to rotate and thus allows it to help transfer forces across the ankle and foot. The talus rotates medially in relation to the tibia during heel strike and as the forefoot comes into contact with the ground during midstance. As midstance occurs, the talus rotates internally and flexes in relation to the calcaneus and navicular at their respective joints. This allows the forefoot to contact the ground and absorb energy as the arch flattens.

As the foot transitions from midstance to push-off, the talus begins to externally rotate in relation to the rest of the foot. This rotational motion effectively locks the subtalar and talonavicular joints and allows the gastrocnemius-soleus complex to function for push-off through the foot through the hindfoot into the forefoot.

Failure to preserve the congruity of the talonavicular articulation in the setting of trauma either via articular step-off or instability risks the premature development of arthrosis, which may compromise the entire gait cycle of the patient, resulting in permanent dysfunction and disability [3].

Mechanism of Injury

There are two main injury mechanisms that result in fractures of the talar head. Compression injuries are the result of the talar head experiencing an axial load against a plantarflexed foot [2]. This axially directed force generates compression between the navicular and talar head. Energy transmitted through the metatarsals and navicular usually results in a medial-sided crush injury to the talar head. An adducted or abducted forefoot position may also result in subluxation or dislocation of midtarsal joints and has been shown to have an association with talonavicular injuries [8]. A large fracture of the talar head may also result in instability of the talonavicular joint [6].

Shear injuries occur primarily due to an inversion mechanism on the midfoot. The resultant

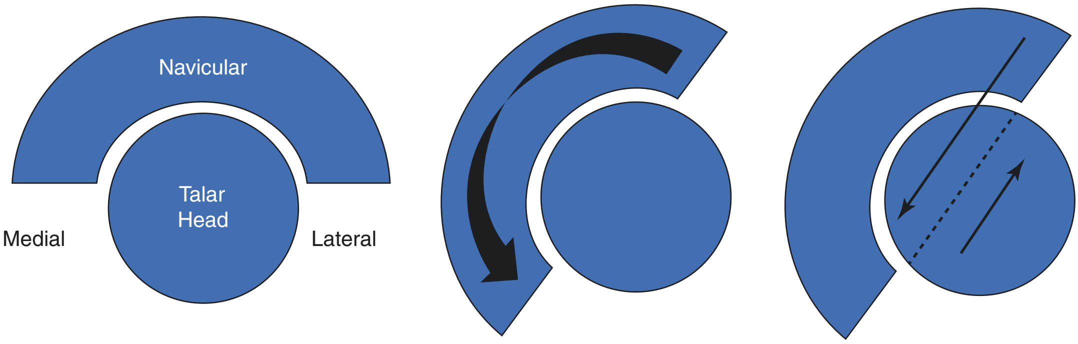


Fig. 6.2 Mechanism of talar head fracture: The navicular adducts around the talar head. With an axial load, a shear force is created across the talar head. This shear force produces the fracture as the talar head dislocates

midfoot adduction causes the navicular to shear off a portion of the medial talar head. This usually generates two distinct fragments but can result in injuries ranging from nondisplaced fractures to comminuted medial head fractures (Fig. 6.2).

Diagnosis

Patients will usually be able to recall a specific injury. They will describe their foot as being in a plantarflexed position at the time of injury[1, 8]. These injuries are typically not associated with high-energy trauma as is the case with talar neck fractures; talar head fractures associated with pantalar dislocations are the exception to this rule. Pain, swelling, and ecchymosis over the dorsum of the foot centered on the midfoot are characteristic, as is difficulty with weight-bearing. Motion at the midfoot may also elicit pain. Furthermore, a stress or insufficiency fracture of the talar head should always be in the differential for patients with chronic midfoot pain [18].

Radiographic evaluation has been controversial. Standard AP, lateral, and oblique radiographs of the foot may not maximize full visualization of the talar head and neck [5]. Other sources have felt complete appreciation of talar head and neck pathology can be shown on a Canale view [6, 10]. This view is obtained with maximum plantarflexion of the foot with 15 degrees pronation, and the X-ray tube directed 15 degrees cephalad from the perpendicular vertical axis allows for better visualization of the talar head and body. In instances where the articular injury and displacement are difficult to visualize, CT is recommended.

Treatment

Early in the history of treatment, Coltart detailed nonoperative management of most talar head injuries in a walking cast. Operative treatment was indicated when displacement of a bony fragment resulted in soft tissue compromise or block to midfoot range of motion. This was treated by excision of the fragment. Pennal advocated for nonoperative management of most fractures, as significant displacement was not common in most patients in his series. These were treated in a walking plaster cast for a period of 4–6 weeks. Small displaced fragments affecting the surface of the talonavicular joint were excised when necessary. Kenwright and Taylor, in their published series, also treated talar head fractures in a short-leg walking cast with early weight-bearing allowed. Excision of any bony fragments preventing talonavicular joint motion was performed.

Treatment of talar head fractures is dependent on the amount of articular step-off, displacement of the fracture fragments, and degree of talonavicular incongruity [12]. The talonavicular joint should be thoroughly assessed for stability during evaluation of the patient. This can be done with stress examination under fluoroscopy or plain AP radiographs of the foot in full inversion and eversion. Talar head fractures can ultimately lead to shortening of the medial column, which can limit subtalar motion and lead to varus deformity [15].

Nondisplaced fractures can be treated by casting and non-weight-bearing for a period of 4 weeks. Progressive weight-bearing can be instituted at that point until fracture healing is evident and the patient no longer exhibits any pain or discomfort.

In instances with displacement, articular incongruity, and/or talonavicular subluxation, surgical fixation is recommended [9]. The main goals for fixation include restoration of the articular surface and medial and lateral column lengths. Medially based injuries including crush and coronally oriented fractures are best approached from a medial extensile or anteromedial incision. As there is difficulty in accessing lateral injuries via a medial approach due to the extent of soft tissue dissection, a dorsolateral incision is preferred for lateral injuries.

Reduction is performed under direct visualization and provisionally held using nonthreaded Kirschner wires. Options for fixation include cortical screws, headless compression screws, and bioabsorbable fixation for areas of small or comminuted articular fragments. Cortical screws are then placed in lag technique across the fracture site. In instances where substantial shortening of the medial column is present, a small external fixator may be placed for restoration of column length and disimpaction of the fracture itself. Proximally, pins may be placed into the talus or calcaneus and into the navicular or medial cuneiform distally. When substantial comminution is present, the external fixator may be left in place to allow for preservation of column length.

Postoperatively, patients are made non-weight-bearing in a well-padded short-leg splint. Pharmacological prophylaxis for deep venous thrombosis is administered until the patient is mobilizing well with the aid of crutches or a walker. They are seen for wound evaluation at 1 week postoperatively and 3 weeks for removal of sutures. They are transitioned into a removable splint as early as 1 week, and motion exercises are initiated. Patients are maintained non-weight-bearing for 12 weeks, and between weeks 12 and 18, progressive weight-bearing occurs in a walking boot. The patient is transitioned to a normal shoe during that time as well; compression socks and orthotics are prescribed as supplementary aids. After week 18 the patient starts doing strengthening and proprioceptive training. The patient is counseled that they can expect to see gradual improvement over the course of 2 years. Additionally, patients should expect to notice a difference in their ability to ambulate over uneven ground, and residual pain is not uncommon.

Outcomes

There are few studies that directly report the outcomes of talar head fractures. Much of the evidence comes from studies of talus fractures as a whole where the authors include a small subset of talar head fractures. The first study that mentions these fractures is from the British Royal Air Force from 1940 to 1945 in which they identified six talar head fractures out of a total of 228 talus injuries reviewed [8]. Four of these six cases occurred in flying accidents where the pilots' feet were in a plantar flexed position. All of the talar head fractures were treated nonoperatively with no mention of outcomes. Another study out of England from 1949 to 1968 reported on 58 civilian injuries around the talus of which there were two talar head fractures noted [11]. One patient was treated nonoperatively, and the other required removal of a displaced dorsal fragment because it was thought that it would restrict midtarsal motion. Both patients regained full function with one patient reporting a good outcome and the other an excellent outcome. They also identified ten midtarsal dislocations with eight of these patients having an associated fracture that in some cases involved the corner of the talar head. Eight of these ten patients had a satisfactory result, and it is unclear whether patients with an associated talar head fracture had worse results. In another subset of patients with pantalar dislocation of the talus, they reported one patient with an associated fracture of the talar head and posterior tubercle. This patient was closed-reduced and pinned with a Kirschner wire for stability. Weight-bearing was restricted for 12 weeks, and the patient had a satisfactory result with minimal symptoms reported at 11-year follow-up.

A more recent study of operatively treated talus fractures from 2002 out of Germany identified 80 talus fractures treated between 1994 and 1997 [16]. This study grouped talar head fractures with distal talar neck fractures, osteochondral flakes, and talar process fractures. Fifteen patients were included in this group with no further demarcation of fracture type. In this subset of patients, approximately half regained full mobility of their subtalar and ankle joints, whereas the other half reported limited mobility of those joints; no patients reported complete stiffness. Also, among operatively treated nondisplaced talar head fractures, no patients developed osteonecrosis. In terms of functional scores, out of 15 patients, eight reported good to very good Hawkins scores, whereas 11 reported good to very good Mazur scores (Mazur scores give more weight to pain, while Hawkins weighs function and pain equally). Of note, only one of the patients required a talonavicular arthrodesis.

The only study to deal directly with talar head fractures comes out of the United Kingdom in 2015 [17]. This study was a systematic review in which eight cases of isolated talar head fractures were identified. Four of the injuries were sports related, two were inversion injuries in a standing position, and two were unreported. There were no comparative studies identified. These cases came from six studies; five were case reports and one was a case series of three patients. Only three patients were treated operatively in the acute setting. There was no incidence of AVN. One patient had a missed talar head injury that resulted in a malunion requiring an osteotomy to restore the talonavicular joint. This patient was able to return to his preinjury activity level 3 months after the surgery. Two of the operatively treated patients reported pain with prolonged activities. The other operatively treated patient was asymptomatic at 1 year with full return to activity.

Overall, the literature is sparse on outcomes of talar head fractures with little to guide the surgeon in determining treatment and counseling patients on expected results of treatment. Therefore, the surgeon must rely on his or her knowledge of the anatomy and biomechanics of the talonavicular joint to determine the appropriate treatment course based on the fracture pattern encountered.

Complications

Complications usually arise when occult or distinct injuries are missed, most typically associated with the evaluation of patients with multiple injuries. While the risk for osteonecrosis is generally low and has been described as less than 10%, the arthritis that results becomes problematic. This arthritis is typically treated with arthrodesis of the talonavicular joint. An arthrodesis is the final common pathway for missed injuries as well, as these can result in post-traumatic arthritis of the talonavicular joint.

Conclusion

While rare, injuries to the talar head present their own unique issues in the treatment of foot and ankle trauma. As the talonavicular joint is an essential joint, there is a low threshold for surgical correction of incongruity. In addition, their treatment must take into account other concomitant foot injuries.

Case Presentation

This case is a 36-year-old female status post motor vehicle collision with a closed fracture dislocation of the right talus. Imaging noted that the talus was displaced posterolaterally and externally rotated 90 degrees, with dislocations of the tibiotalar, subtalar, and talonavicular joints (Fig. 6.3). The talar neck was sitting adjacent to the posterior distal fibula. The talar head fracture was identified on CT scan; the head fragment was from the medial talar head, dislocated from the talonavicular joint and displaced under the tibial plafond (Fig. 6.4)

Closed reduction of the talus was attempted and was unsuccessful. The decision was made to proceed with immediate reduction of the displaced talus and operative fixation of the fracture.

The patient was taken to the operating room and positioned supine on a table with a radiolucent extension distally. A small bump was placed under the ipsilateral hip. To aid with closed manipulation, a 5.0-mm centrally threaded pin was placed through the posterior calcaneus. Closed reduction was repeated with the patient paralyzed. The talus was pushed anterior to the fibula from its posterior position but still remained dislocated laterally (Fig. 6.5)

An anterolateral approach to the talus was marked in line with the fourth metatarsal extending proximally between the tibia and fibula. Dissection

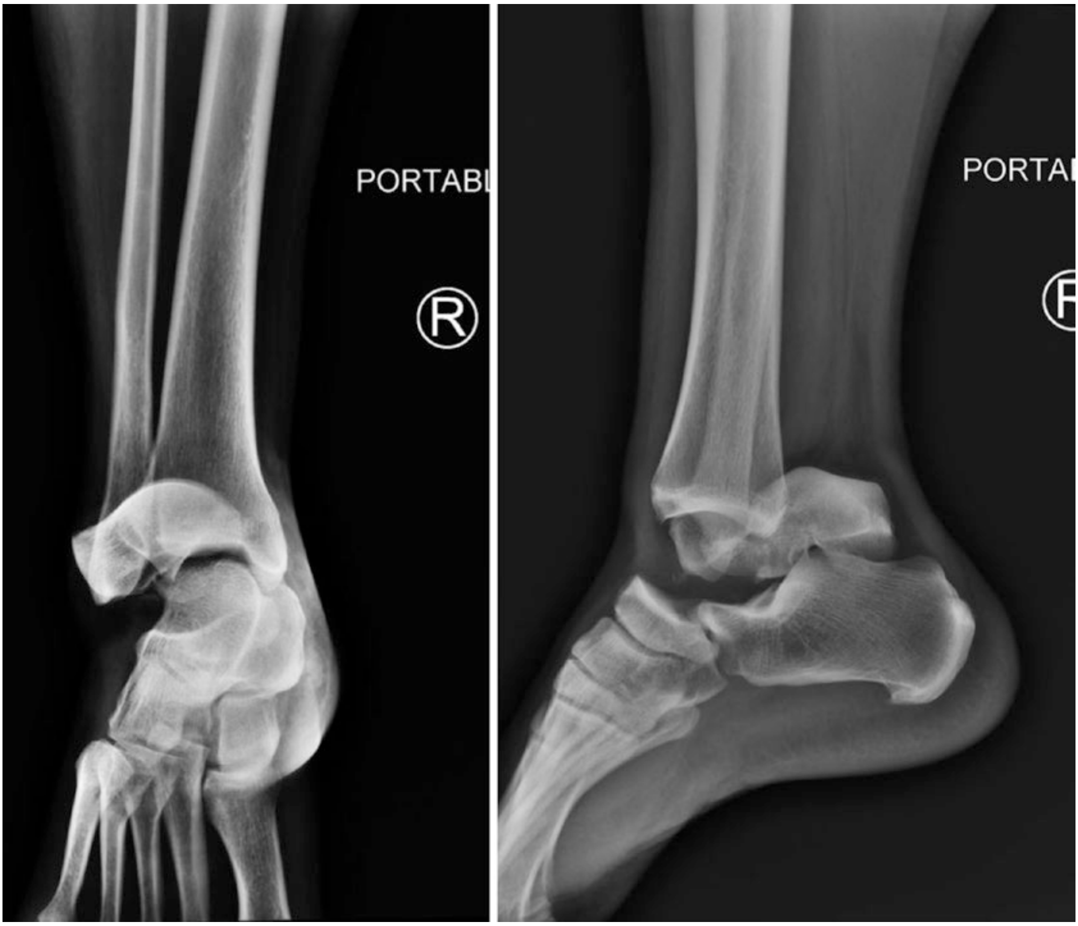


Fig. 6.3 AP and lateral radiographs of the right ankle showing a displaced dislocated talus posterior and lateral to the ankle joint

was carried down to the level of the capsule where traumatic disruption was encountered. The talar head was found extruded through the capsule and buttonholed around the displaced peroneal tendons (Fig. 6.6). Dissection was carried further distally and the extensor digitorum brevis elevated anteriorly to allow for reduction of the talus.

Further extension of the capsulotomy allowed for direct visualization of the displaced talar head fragment that was located between the tibial plafond and posterior facet of the calcaneus. The capsule was tagged anteriorly to act as a retractor and facilitate future repair. There were multiple small osteochondral fragments that were irreparable based on their size and one large free fragment (Fig. 6.7). These fragments were removed and placed on the back table. The talus was maintained in a dislocated position through the anterolateral wound to facilitate access to the head for anatomic reduction.

The large medial fragment was affixed to the lateral head with a 1.25-mm Kirschner wire that was predrilled into the fragment on the back table. Further, a 2.5-mm Schanz pin was placed in the intact talus to allow for controlled manipulation given that the talus was unstable from the pantalar dislocation (Fig. 6.8). The talar head was then definitively fixed with two 2.4-mm screws with low profile heads via lag technique (Fig. 6.9).

Next, the talus dislocation was reduced and the stability of the joints was assessed. The subtalar joint was unstable in supination and varus, indicating that this was a medial subtalar joint dislocation initially. Substantial tibiotalar instability was also noted, as there was significant talar tilt with a varus force applied to the hindfoot. A medial frame was applied with pins in the posterior calcaneus and distal tibia; it was tensioned into valgus to protect the repair of the lateral ligamentous and capsular

Fig. 6.4 Axial, sagittal and coronal cross-sectional images of the right ankle show a dislocated talus posterior and lateral to the ankle joint with a displaced talar head fracture fragment left in the joint

Fig. 6.5 The intraoperative fluoroscopy images above demonstrate placement of a calcaneal transfixion pin to allow for more controlled manipulation of the calcaneus for reduction of the talus

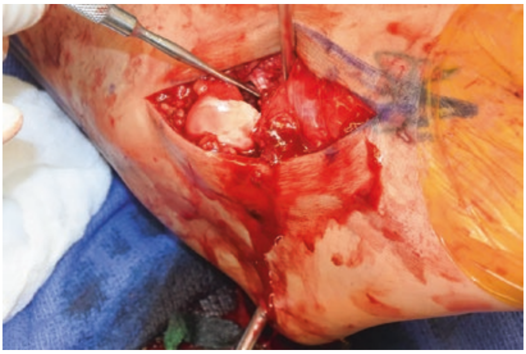


Fig. 6.6 Upon incising through the dermis of an anterolateral approach the talar head was seen extruded through the traumatic arthrotomy. A defect in the medial talar head can be seen in the location of the freer. (Photograph courtesy of Michael S. Sirkin, MD)

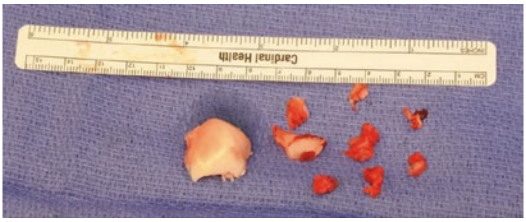


Fig. 6.7 The free talar head fragments were removed and placed on the back table

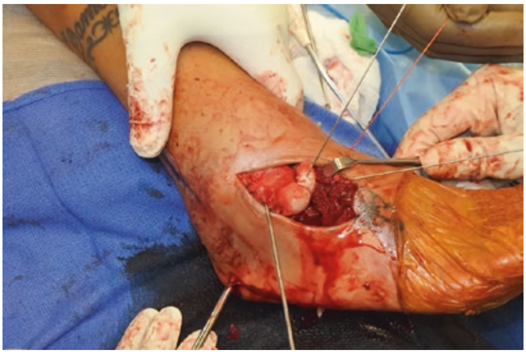


Fig. 6.8. One fragment was large enough for fixation with two 2.4 mm screws placed with a lag technique

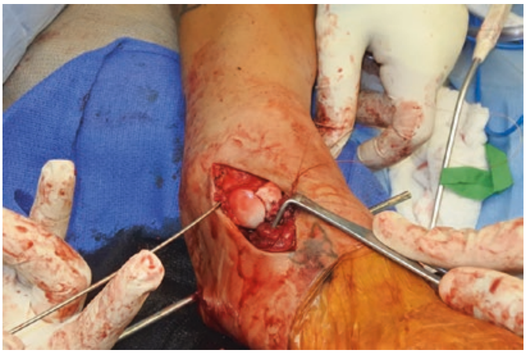


Fig. 6.9. Fixation occurred prior to reduction of the pantalar dislocation to facilitate exposure

structures that could be addressed through the anterolateral approach (Fig. 6.10).

Capsule and fascia were closed using absorbable monofilament sutures and the skin closed with nonabsorbable nylon sutures. A gastrocnemius recession was performed at 6 weeks when the patient returned to have the external fixator removed, as gastrocnemius equinus contributes to this injury in the author's opinion. The patient was non-weight-bearing for a total of 12 weeks after the injury (Figs. 6.11 and 6.12). At 11 months, the patient is asymptomatic with good ankle, hindfoot, and midfoot motion and full return to activity including running (Fig. 6.13).

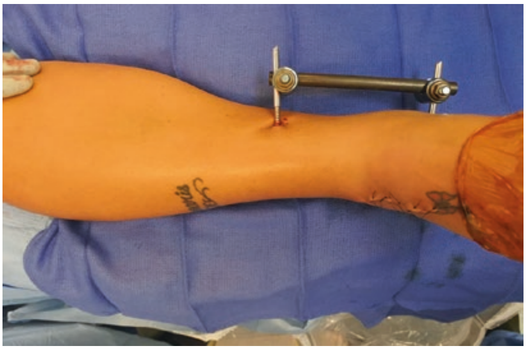


Fig. 6.10 A medial frame was placed given the persistent instability of the tibiotalar and subtalar joints after fixation of the talar head and reduction of the talus

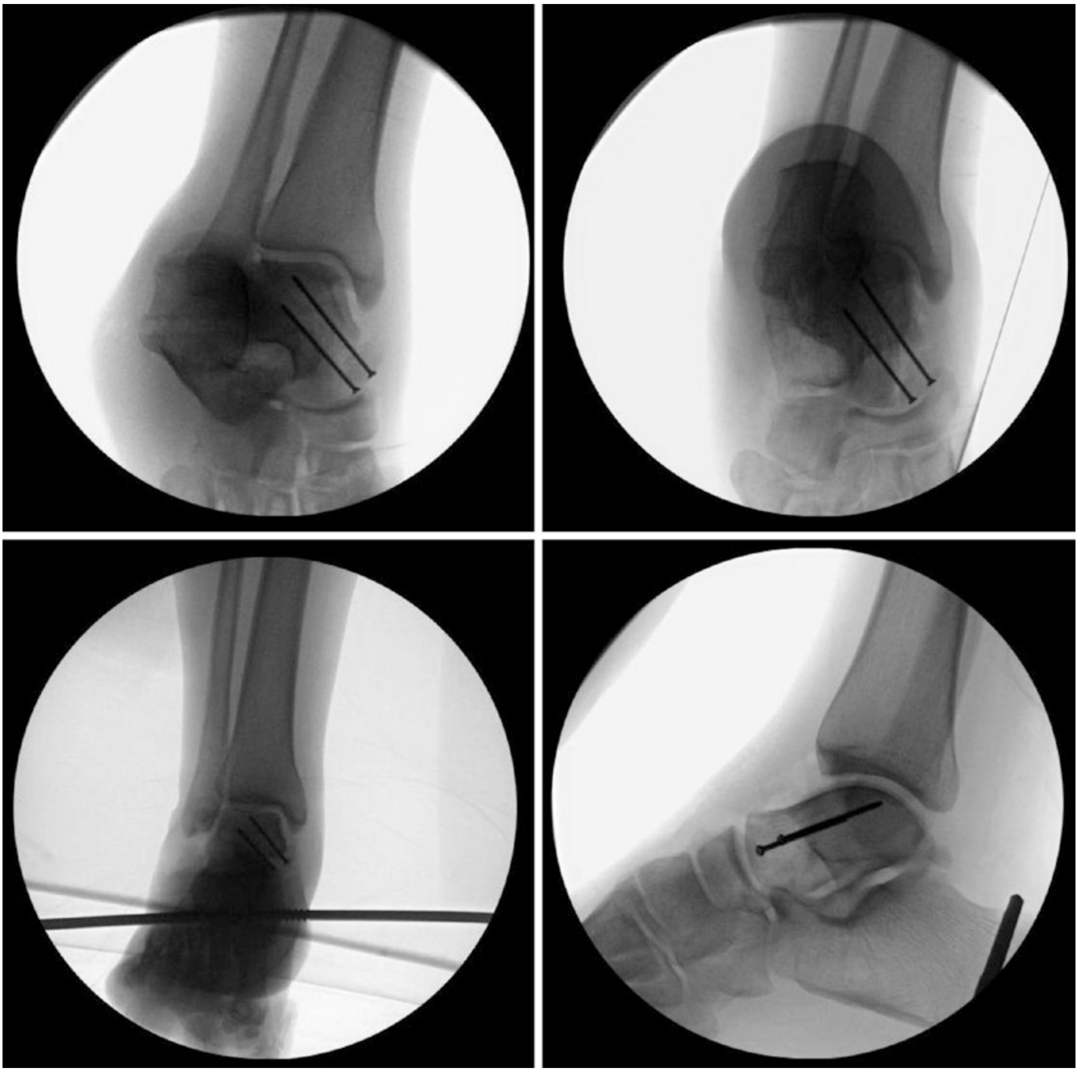


Fig. 6.11 Select Broden's views, AP and lateral intraoperative images show reduction of the talar body, reduction of the talar head fracture and placement of fixation

Fig. 6.12 Postoperative AP, oblique and lateral radiographs of the ankle and foot, respectively, showing reduction of the talus and fracture, along with hardware position

Fig. 6.13 AP, oblique, and lateral images of the ankle and foot at 6 months

References

1. Pennal GF. Fractures of the talus. Clin Orthop Relat Res. 1963;30:53–63.
2. Sangeorzan BJ, editor. Traumatized foot. Rosemont: American Academy of Orthopaedic Surgeons; 2001.
3. Ebraheim N, Sabry F, Nadim Y. Internal architecture of the talus: implication for Talar fracture. Foot Ankle Int. 1999;20:794–6.
4. Mulfinger GL, Trueta J. The blood supply of the talus. JBJS Am. 1970;53B:160–7.
5. Higgins T, Baumgaertner M. Diagnosis and treatment of fractures of the talus: a comprehensive review of the literature. Foot and Ankle Int. 1999;20(9):595–605.
6. Sanders R, et al. Fractures and fracture-dislocations of the talus. Mann's surgery of the foot and ankle. 9th ed. Philadelphia: Elsevier; 2014.
7. Richter M, et al. Foot injuries. Skeletal trauma: basic science, management and reconstruction. 5th ed. Philadelphia: WB Saunders; 2015.
8. Coltart WD. Aviator's astralagus. JBJS Br. 1952;34(4):545–66.

9. Adelaar RS. The treatment of complex fractures of the talus. Orthop Clin North Am. 1989;20(4):691–707.
10. Canale ST, Kelly FB. Fractures of the neck of the talus: long term evaluation of seventy-one cases. JBJS Am. 1978;60(2):143–56.
11. Kenwright J, Taylor RG. Major injuries of the talus. JBJS Br. 1970;52(1):36–48.
12. Early JS. Management of Fractures of the talus: body and head regions. Foot Ankle Clin N Am. 2004;9:709–22.
13. Vallier H. Fractures of the talus: state of the art. J Orthop Trauma. 2015;29(9):385–92.
14. Hansen ST. Functional reconstruction of the foot and ankle. Philadelphia: Lippincott, Williams and Wilkins; 2000.
15. Lamothe JM, Buckley RE. Talus fractures: a current concepts review of diagnoses, treatments, and outcomes. Acta Chir Orthop Traumatol Cechoslov. 2012;79(2):97–106.
16. Schulze W, et al. Surgical treatment of talus fractures: a retrospective study of 80 cases followed for 1–15 years. Acta Orthop Scand. 2002;73(3):344–51.
17. Ibrahim MS, et al. Talar head fracture: a case report, systematic review and suggested algorithm for treatment. Foot. 2015;25:258–64.
18. Long NM, et al. Insufficiency and nondisplaced fractures of the talar head: MRI appearances. Am J Roentgenol. 2012;1999:613–7.
19. Sarrafian S. Anatomy of the foot and ankle. Philadelphia: Lippincott; 1983.

7

Posterior Talar Process Fractures

M. Kareem Shaath and Mark R. Adams

Anatomy

The talar body has five surfaces: lateral, medial, superior, inferior, and posterior. The posterior talar process is composed of a medial tubercle and a larger lateral tubercle. The lateral tubercle is the one most usually seen on a lateral radiograph of the ankle. The inferior portion of the posterior process is covered by articular cartilage, and it forms the posterior 25% of the posterior articular facet of the subtalar joint [1, 2]. This structure therefore contributes to subtalar joint stability [3, 4] and consideration should be made to reduce and fix any displacement to optimize preservation of the subtalar joint.

There is a sulcus between the two tubercles which provides passage for the flexor hallucis longus (FHL) before it reaches the sustentaculum (Fig. 7.1) [5]. Anatomical dissection of this region can be seen in Fig. 7.2 [6], while magnetic resonance imaging (MRI) and anatomical cross sections can be seen in Fig. 7.3 [7]. The posterolateral tubercle when fused to the posterior talar body is referred to as a Stieda process. When the Stieda process is separate from the lateral tubercle, it is known as an os trigonum [8]. It is a congenital, rounded ossicle found in up to 50% of the population [9–11] and may occur unilaterally [1]. The os trigonum may be connected to the lateral talar tubercle by a synostosis which is known as a trigonal process. The posterior talofibular ligament and the fibulotalocalcaneal ligament of Rouviere and Canela Lazaro attach to the lateral tubercle. The posterior third of the deltoid ligament and the medial limb of the bifurcate talocalcaneal ligament attach to the medial tubercle [12].

Wildenaur was the first to describe in detail the blood supply to the talus [13]. Haliburton [14] confirmed his findings and Mulfinger and Trueta [15] provided the most complete description of the complex arterial circulation which has since been studied extensively [16–18]. Greater than half of the surface of the talus is covered by articular cartilage, limiting the area available for vascular perforation. Vascularity to the talus is limited to the talar neck, the medial surface of the talar body, and the posterior process [14]. The blood supply comes from three main arteries and their branches, listed in order of significance: the posterior tibial artery, the anterior tibial artery, and the perforating peroneal arteries [15–17, 19, 20]. There are two discrete vessels that form a sling inferior to the talus, the artery of the tarsal canal (a branch of the posterior tibial artery), and the artery of the tarsal sinus (a branch of the peroneal artery)

M. K. Shaath
University of Texas Health Science Center at Houston, Houston, TX, USA

M. R. Adams (✉)
Associate Professor, Department of Orthopedics, Trauma Division, Rutgers – New Jersey Medical School, Newark, NJ, USA
e-mail: Adamsm4@njms.rutgers.edu

© Springer Nature Switzerland AG 2020

M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_7

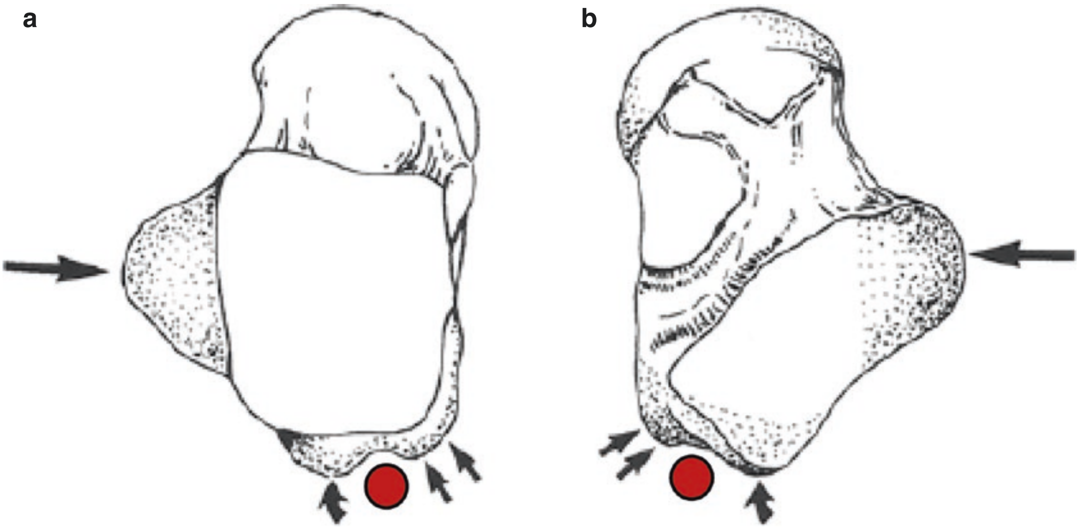


Fig. 7.1 Superior (**a**) and inferior (**b**) views of talus indicate the lateral processes (arrow) and the medial (double arrows) and lateral (curved arrows) tubercles of the posterior process. The FHL tendon is represented by the sphere

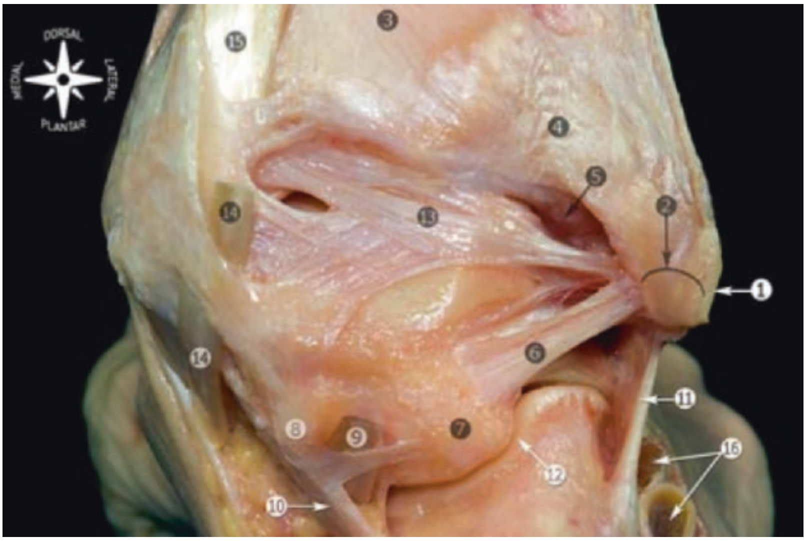


Fig. 7.2 Posterior view of the anatomic dissection of the ankle ligaments. (1) Tip of the fibula; (2) peroneal groove of the fibula; (3) tibia; (4) superficial component of the posterior tibiofibular ligament; (5) deep component of the posterior tibiofibular ligament or transverse ligament; (6) posterior talofibular ligament; (7) lateral talar process; (8) medial talar process; (9) tunnel for flexor hallucis longus tendon; (10) flexor hallucis longus retinaculum; (11) calcaneofibular ligament; (12) subtalar joint; (13) posterior intermalleolar ligament; (14) flexor digitorum longus tendon (cut); (15) tibialis posterior tendon; (16) peroneal tendons

(Fig. 7.4) [17, 19–21]. The main arterial supply to the talus is the artery of the tarsal canal, which provides an additional branch that penetrates the deltoid ligament and supplies the medial wall [20]. Direct branches of the posterior tibial artery via calcaneal branches travel in the connective tissues that attach to the posterior tubercles and supply the posterior process [15, 20].

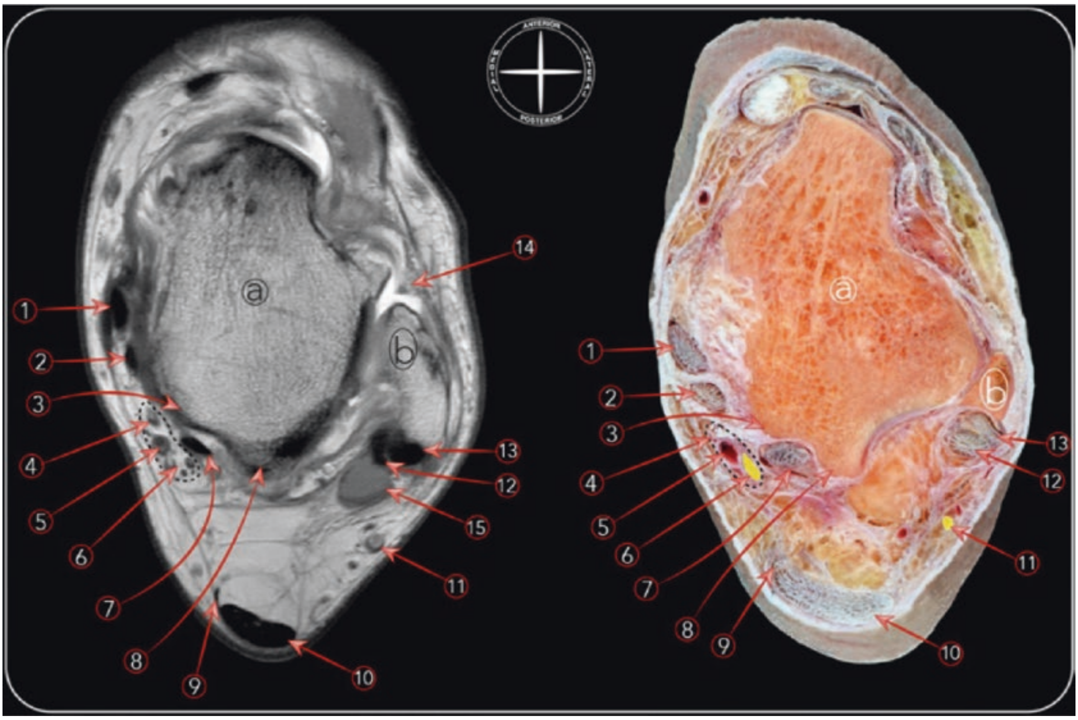


Fig. 7.3 MRI and cross section of a cadaveric specimen showing comparative anatomy at the level of the talus and relationship between the FHL tendon and the posterior tibial neurovascular bundle (highlighted by dotted line). (a) Talus; (b) lateral malleolus; (1) posterior tibial tendon; (2) flexor digitorum longus tendon; (3) posteromedial talar tubercle; (4) tibial vein; (5) posterior tibial artery; (6) tibial nerve (highlighted in yellow); (7) flexor hallucis longus tendon; (8) posterolateral talar tubercle; (9) plantaris tendon; (10) calcaneal tendon; (11) sural nerve (highlighted in yellow); (12) peroneus longus tendon; (13) peroneus brevis tendon; (14) anterior talofibular ligament; (15) hypertrophied peroneus longus muscle belly

Fractures of the Posterolateral Tubercle

Mechanism of Injury

There are two common mechanisms of injury to cause fracture of the posterior process of the talus. First, forced plantar flexion of the foot causes compression of the posterolateral tubercle between the posterior tibial plafond and the calcaneus [1, 22–27]. This may cause a fracture of the posterolateral process, separation through the fibrous attachment of an os trigonum, or if the os trigonum is attached to the talus by bone, a fracture of the resulting trigonal process [22, 28]. This is the most common mechanism and commonly occurs in ballet dancers and soccer players [22, 28–31]. This has been associated with the “pointe” or “demi-pointe” or muscular imbalances such as gastrocnemius equinus [23, 31].

The second mechanism of injury involves excessive dorsiflexion and inversion of the ankle, which results in increasing tension in the posterior talofibular ligament which avulses the lateral tubercle of the posterior facet [32–37]. This is alternatively known as a Shepherd fracture [38]. Some have suggested that pain may be due to a failure of fusion of the secondary ossification center of the posterior process with the talar body [39].

The entire posterior process may fracture from a medial subtalar dislocation [3, 4, 40, 41], which may present as an open injury over the anterolateral ankle as the skin is disrupted by the dislocation. There have been no reports of a posterior process fracture with a concomitant lateral subtalar dislocation.

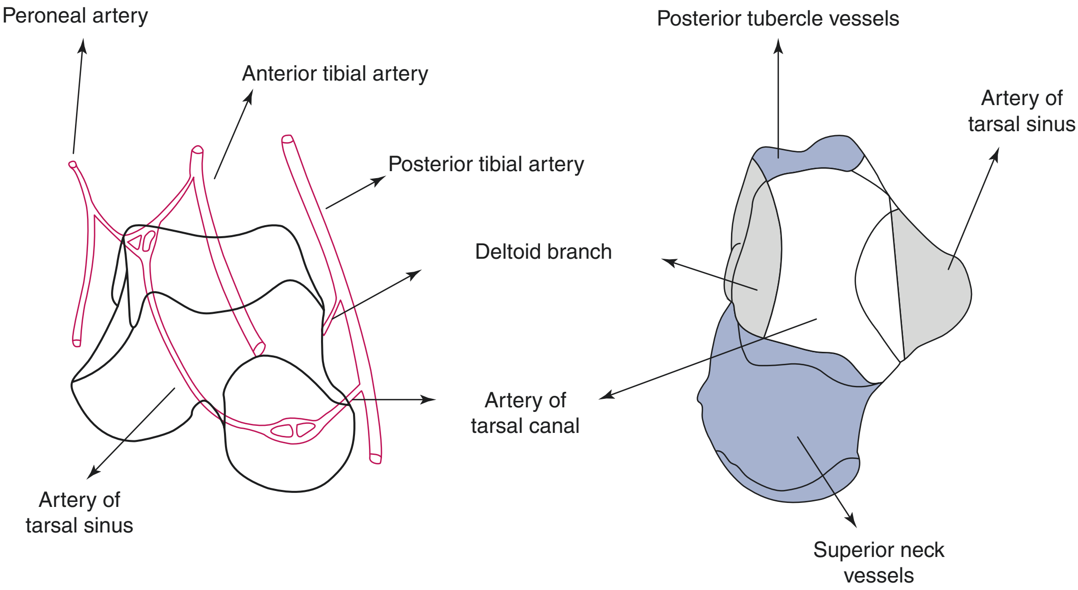


Fig. 7.4 The blood supply to the various regions of the talus. The artery of the tarsal canal provides the predominant blood supply to the talar body

Clinical Evaluation

Patients usually give a history of sudden uncontrolled injuries to the foot, such as from catching the heel on a step when going down stairs, kicking a ball [1], or from impingement pain caused by active ankle plantarflexion during ballet en pointe [29–31, 42]. Continued pain in the posterior ankle after an injury warrants a high level of suspicion for a posterior talus injury. Patients may experience edema in their posterior ankle, pain, and feelings of instability that may be worsened by running, jumping, or descending stairs [12, 43]. Schrock et al. suggest that pain that is aggravated by squatting on a plantar-flexed foot suggest a posterior process fracture [44].

On examination, the patient may exhibit tenderness anterior to the Achilles tendon, posterior to the talus. Crepitus may be palpated with plantar flexion of the foot. Pain may be elicited with motion of the great toe as the FHL is in the groove adjacent to the injured lateral tubercle of the posterior process [12, 28].

Patients with missed fractures may have chronic, unremitting ankle pain which may be due to fracture nonunion and other factors. These other factors include soft tissue impingement, inflammation, micromotion at the nonunion site, and FHL irritation or synovitis. Occult posterior process fractures have been reported to cause symptoms of tarsal tunnel syndrome [45]. Displaced fracture fragments have been found to impinge on the tarsal tunnel structure. Reduction and fixation of the fragment leads to a resolution of symptoms [45].

Radiographic Evaluation

The lateral tubercle of the posterior process of the talus and os trigonum is best seen on a lateral radiographic view of the ankle. One must remember that in an acute fracture, the fracture surfaces are rough and irregular, whereas an os trigonum is characterized by smooth, well-corticated surfaces. Contralateral comparison films may offer value, but the os trigonum is reported to be unilateral in more than two-thirds of cases [1]. Paulos et al. suggest the use of a 30-degree subtalar oblique view to distinguish between an acute fracture and an os trigonum [12]. The posterior process fracture fragment may appear larger and extend farther into the body than an os trigonum.

Technetium-99m (Tc-99m) bone scans are an important technique for evaluating posterior process fractures [46, 47], and they may be used to diagnose an acute fracture of the posterior process of the talus [12]. A technetium bone scan will be positive in all patients with a fracture of the posterior process of the talus [12]. They may also be useful in distinguishing occult fractures from normal ossicles, as an ossicle will not demonstrate an increase in uptake [48].

When suspicion is high, but radiographs are negative, a computed tomography (CT) scan may also provide additional information. Multiplanar CT scanning with fine 1-mm cuts allows accurate assessment of location, size, displacement, and comminution of any fragments [49]. It may demonstrate an irregular anterior border to the fragment, which is suggestive of an acute fracture [49]. If a subtalar dislocation is present, CT scans should always be considered [50]. Subtalar dislocations rarely occur in isolation, and CT scanning may reveal associated posterior process fractures not visualized on plain radiographs [51].

Magnetic resonance imaging (MRI) may be used to delineate soft tissue injury and may identify additional edema [52, 53]. A symptomatic os trigonum secondary to posterior ankle impingement may exhibit bone marrow edema, but edema within the talus itself should raise suspicion for fracture of the posterior process [52, 53]. MRI may also provide detail regarding the condition of adjacent soft tissue structures [54].

Treatment

The treatment recommended for small (<1 cm) and minimally displaced (<2 mm) fractures of the posterior process of the talus is conservative [55]. The patient can be immobilized in a short-leg walking cast with the foot in 15 degrees of equinus for 4–6 weeks [12]. Given that the lateral process of the of talus transfers as much as 16–17% of the weight borne by the foot through the fibula, premature weight-bearing risks fracture displacement [56]. If patients continue to be symptomatic for 6 months after conservative treatment, some authors have suggested surgical excision [12, 23]. If fragments are too small or comminuted for internal fixation, surgical excision has been suggested to allow early mobilization and avoid the risk of painful nonunion [27, 57]. After excision of the fragment, the patient's ankle is immobilized briefly, and subsequently an aggressive stretching and strengthening therapy program is initiated [29–31, 42].

If a large fracture fragment of the posterior process is present, it may be amenable to operative fixation. Large intraarticular fractures (25% of the subtalar facet) are best fixed with an open technique [34, 50, 58]. The preferred surgical approach to the posterior process varies, and CT may be used to determine the most appropriate surgical approach [49]. Howse recommends a medial approach as the lateral approach interferes with the peroneal tendons and may cause postoperative stiffness [23]. Howse recommends making a 3–4-cm incision behind the medial malleolus which allows access to the posterior ankle by retracting the FHL tendon medially, thereby protecting the neurovascular bundle [23]. Figure 7.5 shows the proximity of the neurovascular bundle and FHL tendon [7].

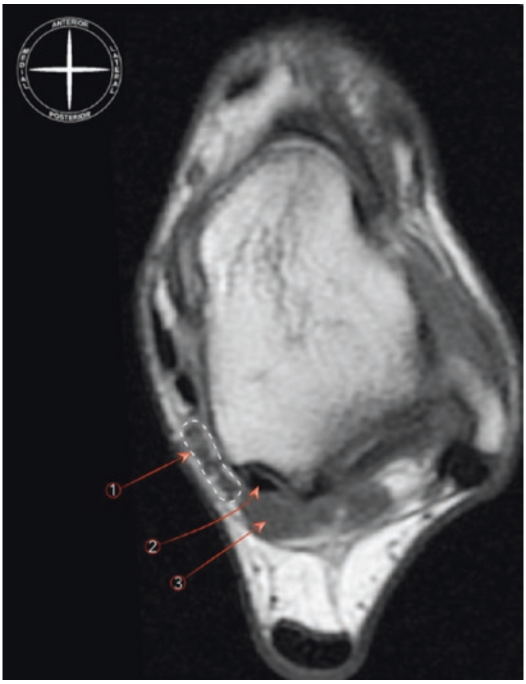


Fig. 7.5 (1) Posterior tibial neurovascular bundle; (2) FHL tendon; (3) Low-lying muscle belly of FHL

Others advocate the use of a posterolateral approach between the peroneal tendons and the Achilles tendon [59]. A 5-cm incision is made between the Achilles tendon posteriorly and the peroneal tendons anteriorly. The sural nerve must be protected and it usually lies medial to the incision. The peroneal tendons are retracted anteriorly and the FHL is retracted medially. The subtalar joint is subsequently incised vertically which exposes the posterior talus. Fragment fixation may be performed with small screws (1.5, 2.0, or 2.4 mm) due to the small area [40, 56, 60]. We have found that a small plate may be used as well. Mao et al. developed a minimally invasive technique for fixation of a posterior talar process fracture [40]. They obtained reduction through closed means and stabilized the fragment with two guide pins. A self-drilling 4.5-mm cannulated screw is then placed directed from posterior to anterior, through the fracture fragment into the body of the talus [40].

Others suggest that an arthroscopic approach may be used [43]. Surgical decompression or fragment excision may be performed arthroscopically through a two-portal posterior approach with the patient prone. The posterior talus may be viewed through posteromedial and posterolateral portals adjacent to the Achilles tendon at the level of the medial malleolus (Fig. 7.6) [7, 61]. Arthroscopic instruments should remain lateral to the FHL tendon to avoid injury to the posterior tibial neurovascular bundle [62]. Arthroscopic approaches are not recommended for anatomic reduction and fixation [56].

Outcomes

Paulos et al. reported that one-third of their patients had relief with conservative treatment of their posterior process fractures and were only symptomatic occasionally [12]. The rest of their cohort failed conservative treatment and underwent steroid injection with an additional 4 weeks of casting. This was unsuccessful in nearly 90% of their patients, and the rest underwent surgical removal of the bony fragment, which relieved their symptoms. Long-term follow-up was not available in this study, and unfortunately there are no comparative studies on excision versus ORIF of these fractures.

Hedric and Mcbryde [63] reported on 30 cases of posterior ankle impingement over 10 years. Greater than half of their patients (63%) had radiographic evidence of an os trigonum or a posterior process fracture. The remaining patients (33%) had an intact posterior process. There were 18% available for follow-up, and greater than half (60%) improved with nonsurgical treatment, while 40% (eight patients) required surgical excision. They had good to excellent results in 18 patients and a fair result in 1 patient.

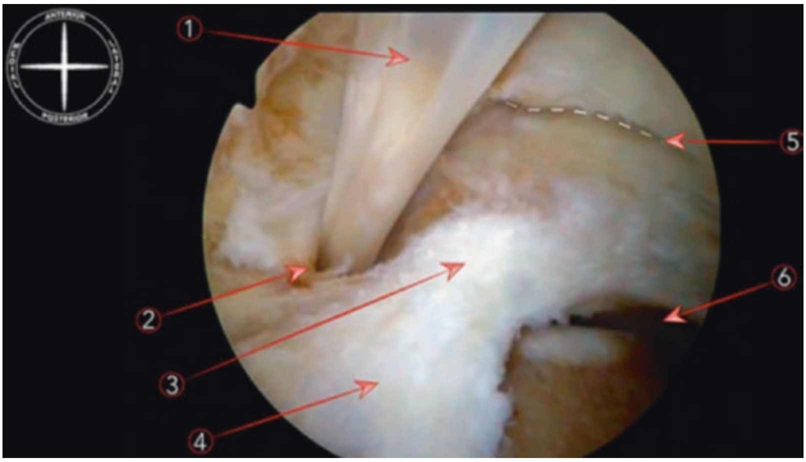


Fig. 7.6 (1) FHL tendon; (2) FHL retinaculum; (3) Posterolateral talar tubercle; (4) Talocalcaneal ligament (posterior fibers of the fibula talocalcaneal ligament); (5) attachment of the posterior ankle joint capsule; (6) subtalar joint; (7) posterolateral talar tubercle (resected)

Marotta and Micheli [30] had 16 dancers who underwent excision of an impinging ossicle (no fracture present) through a posterolateral approach. All their patients were hampered with participation in dance and all failed nonsurgical treatment. Twelve patients who were available for follow-up underwent surveys at an average of 28 months postoperatively, and all had improvement in their symptoms of impingement. Eight patients (67%) had occasional discomfort.

Complications

The primary complications are chronic pain and late arthrosis [54]. Nonunions, which may be symptomatic, are likely when fractures are not diagnosed and treated acutely [12, 64, 65]. Patients may remain symptomatic for a long period of time even with appropriate treatment [12]. Large fragments produce articular incongruity and, consequently, arthrosis of the subtalar joint, necessitating subtalar arthrodesis [51, 66]. As these are articular injuries, further study is required to determine whether ORIF can improve outcomes with regard to arthrosis.

Fractures of the Posteromedial Tubercle

Fractures of the medial tubercle of the posterior process of the talus are much less common than fractures of the lateral tubercle. This fracture was described in 1974 by Cedell, and it now bears his name. These fractures tend to be diagnosed as an ankle sprain and are often not seen on the AP and lateral radiographs of the ankle joint [45, 66–68]. This injury should be suspected when the patient has pain mimicking an ankle sprain after a combined dorsiflexion and pronation injury [67]. Other mechanisms of injury include direct trauma to the posteromedial facet [69], impingement of the sustentaculum tali in supination [70], and forced dorsiflexion in high-energy trauma [71]. To aid in diagnosis, along with a CT Scan, Ebraheim et al. recommend obtaining two oblique views at 45 and 70 degrees of external rotation to expose the posteromedial talus and identify posteromedial tubercle fractures [72].

Cedell reported on four cases of fractures of the medial tubercle that he believed were secondary to avulsion of the fragment by the posterior talotibial ligament with the ankle dorsiflexed and pronated [67]. In this situation, the posterior deltoid ligament avulses the medial tubercle [45, 64, 65, 67, 68]. Cedell's patients were treated by immobilization as they were initially misdiagnosed with an ankle sprain. Although the injuries seemed to heal, when patients resumed athletic activity, they had a recurrence of medial pain and edema. Three-fourths of the patients subsequently required excision of the fragment and returned to normal function.

Stefko et al. reported a case of a painful nonunion causing a tarsal tunnel syndrome. In that case, the fragment was excised, subsequently resolving all symptoms [45]. Ebraheim presented four cases of a Cedell's fracture. Two of the fractures were missed initially and progressed to painful nonunions. Of the two acute fracture patients, one presented with a concomitant tarsal syndrome due to the displaced fracture fragment. Three of the patients sustained a concurrent subtalar dislocation. The two fractures that presented acutely underwent operative fixation, while one patient with a nonunion underwent excision. The last patient refused surgery. All approaches were curved posteromedial incisions centered behind the medial malleolus, first mobilizing the neurovascular bundle, allowing clear access to the fracture [66]. They used a cannulated Herbert screw and Kirschner wires (K-wires) to augment their fixation [2]. They recommend that nondisplaced fractures be treated closed, while displaced fractures undergo operative fixation. They did also note that it was difficult to reduce the medial fragment due to difficulty visualizing the reduction [66].

Conclusion

Posteromedial and posterolateral process fractures of the talus are rare events. Although the literature on the subject is limited, certain elements are consistent. Conservative management frequently fails to achieve a successful outcome, as many patients deal with issues such as nonunion, posterior ankle impingement, and tarsal tunnel syndrome. Various methods of surgery exist for acute management of these injuries. Long-term data is necessary to determine whether ORIF portends a more favorable prognosis than other methods of surgical treatment.

Case Example

The patient was a 37-year-old male who was injured in a motor vehicle collision and presented with right ankle pain and deformity. He sustained a medial subtalar dislocation and underwent closed reduction in the trauma department. For continued concerns of instability of the subtalar joint, he was placed in a medially based external fixator. We routinely obtain AP, mortise, lateral, Broden view, and a "reverse" Broden view to assess the medial ST joint. If any suspicion of a fracture to the posterior talar process is present, a CT scan is obtained as well. A CT scan was obtained, which revealed a posteromedial fracture of the talus with associated marginal impaction. He was indicated for operative stabilization of this fragment to improve subtalar joint congruity and stability.

In the operating suite, the patient was placed prone on a standard bed with a radiolucent foot extension. We have found that a headlight is helpful when performing these procedures. A lower extremity positioner or a knee wedge is placed to assist with patient positioning. A mini-fragment set and Kirschner wires should be available in the room along with a large external fixator with distraction capability or a universal distractor. A fluoroscopic unit with 12″ image intensifier is placed on the contralateral side of the injury. If the patient presents with a concurrent subtalar dislocation (Fig. 7.7), external fixation is employed. External fixation may also be used to distract the joint to assess with visualization. The medially based external fixator is tensioned to resist deformity. If the fracture fragments are amenable to internal fixation and the patient can tolerate surgical treatment, we prefer using the posteromedial approach as it provides a direct approach to the fragments with excellent visualization. The incision is made just medial to the Achilles tendon, and the FHL is moved medially to allow access to the talus and concurrently protects the neurovascular bundle. The axial CT cuts may allow for planning the incision and the eventual approach (Fig. 7.8).

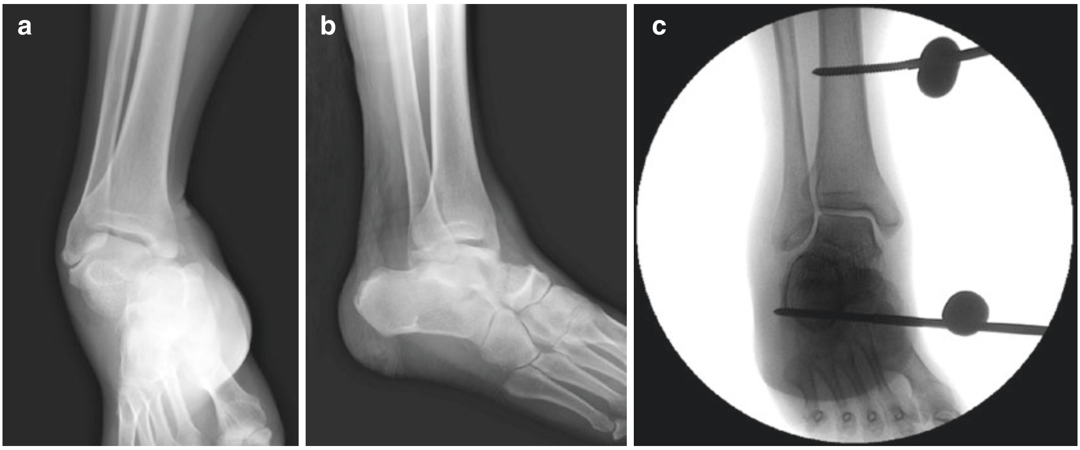


Fig. 7.7 (**a**, **b**) Subtalar dislocation with associated posteromedial talus process fracture. (**c**) Medially based external fixator that is tensioned to resist deforming forces while concurrently off-loading the subtalar joint

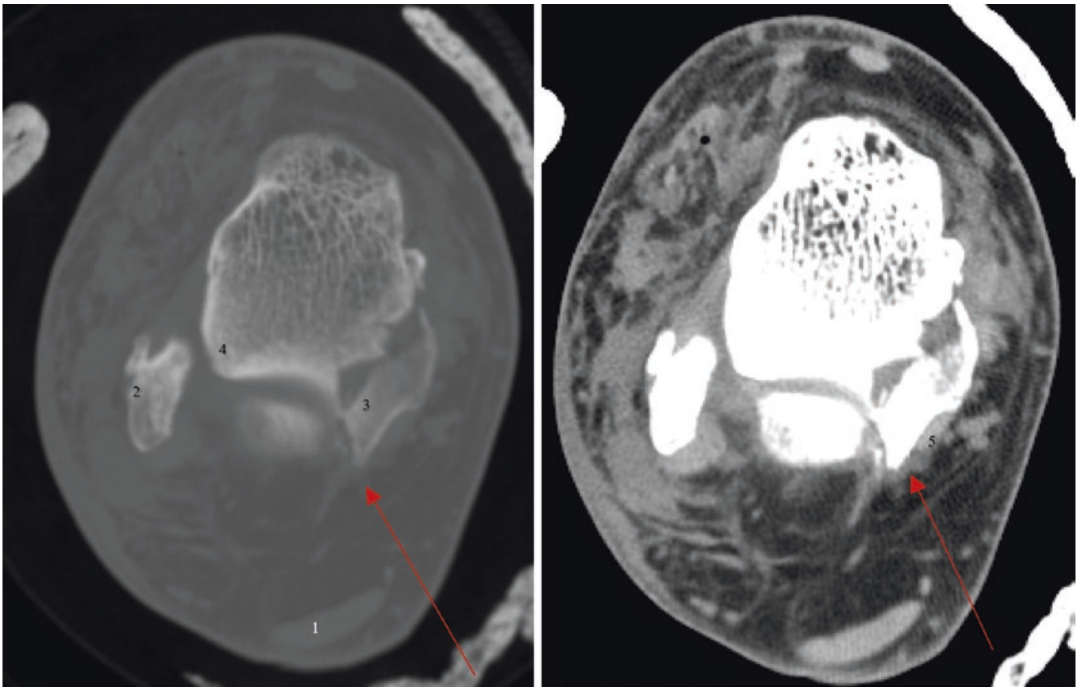


Fig. 7.8 (1) Achilles Tendon; (2) Fibula; (3) Posteromedial and Posterolateral Processes; (4) Lateral Talar Process; (5) FHL Tendon; Red Arrow: Intended Location for Incision and Approach

When approaching the fragments, marginal impaction is addressed first (Fig. 7.9). An osteotome is placed on the superior edge of the talar dome as this location provides cancellous bone to protect the articular segment. The articular fragment is returned to its anatomic position, and provisional reduction is held with small-diameter K-wires (Fig. 7.10). We prefer plate fixation, and use a mini-fragment plate. There is a small, nonarticular, zone on the posterior aspect of the talus upon which the plate may be placed. The plate in this scenario essentially functions as a washer. We have found that when visualizing this fracture pattern under direct visualization, nondisplaced fracture lines are present that are not available on CT scan. Plate fixation allows us to address these

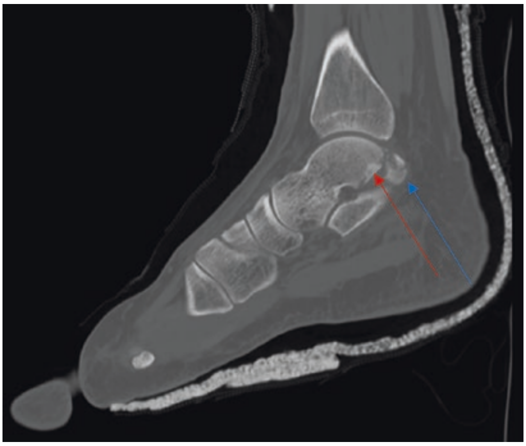


Fig. 7.9 Red arrow, marginal impaction; blue arrow, fracture fragment

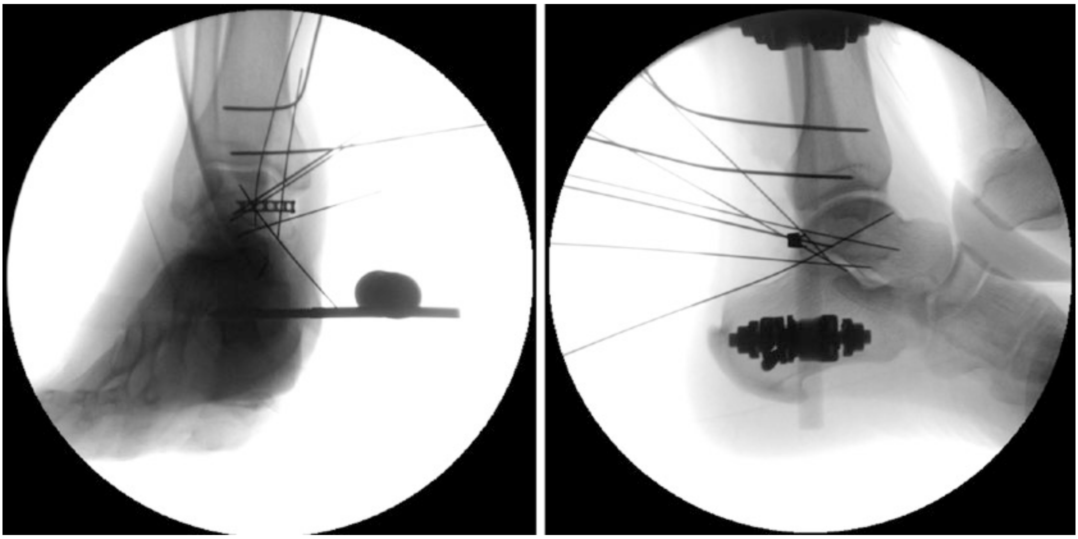


Fig. 7.10 K-wire fixation is used to provisionally stabilize fracture fragments. Distraction can be generated through the external fixator to aid in visualization of the tibiotalar and subtalar joints

fractures by using lag screws to stabilize them into the talar body. If multiple fragments are present, a spring hook plate may be created by using another 2.0 plate. The hooks may be impacted into the fragment and further stabilized with a screw (Fig. 7.11). The reduction is then assessed visually and fluoroscopically. We use Broden and "reverse" Broden views to visualize the subtalar joint (Fig. 7.12). We use Allgower-Donati sutures when closing the skin. Again, if an external fixator is present, it may be tensioned to off-load fracture fixation.

Postoperatively, patients are made non-weight-bearing for 12 weeks. Isometrics of the foot and passive toe range of motion may begin immediately with other modalities to limit edema. External fixation, if present, is removed at 6 weeks, and active range of motion of the ankle may be initiated at that time. If external fixation was not initially utilized, active range of motion of the ankle is initiated in 2–3 weeks after suture removal. The patient begins partial progressive weight-bearing between weeks 12 and 18, and a proprioceptive and strengthening program is initiated from 18 weeks onward. Six-month radiographs of the patient are found in Fig. 7.13.

Fig. 7.11 Plate fixation, stabilizing fracture fragments. Hooks on the plate are impacted into fracture fragments

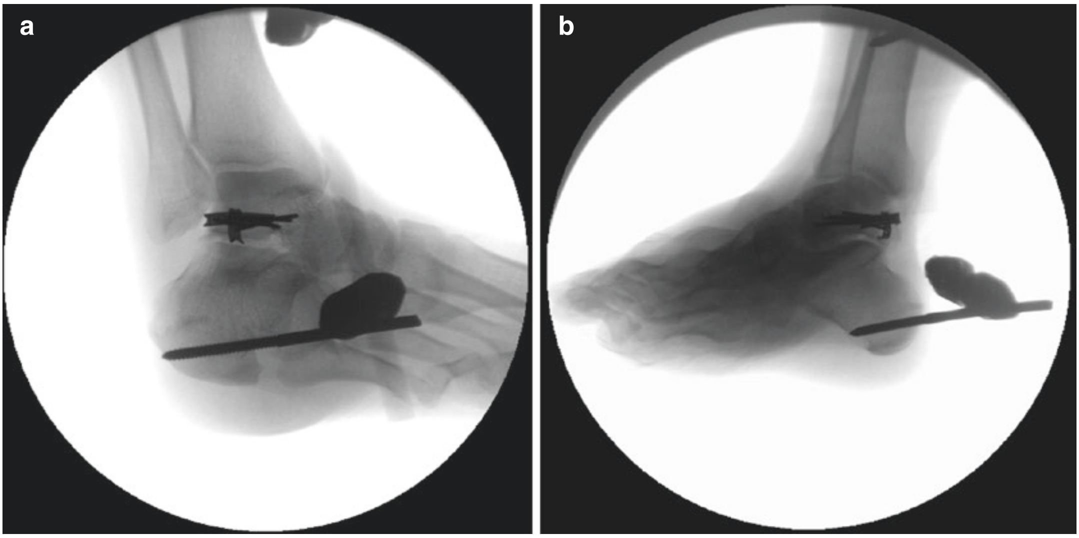


Fig. 7.12 (**a**) Broden view; (**b**) reverse Broden view

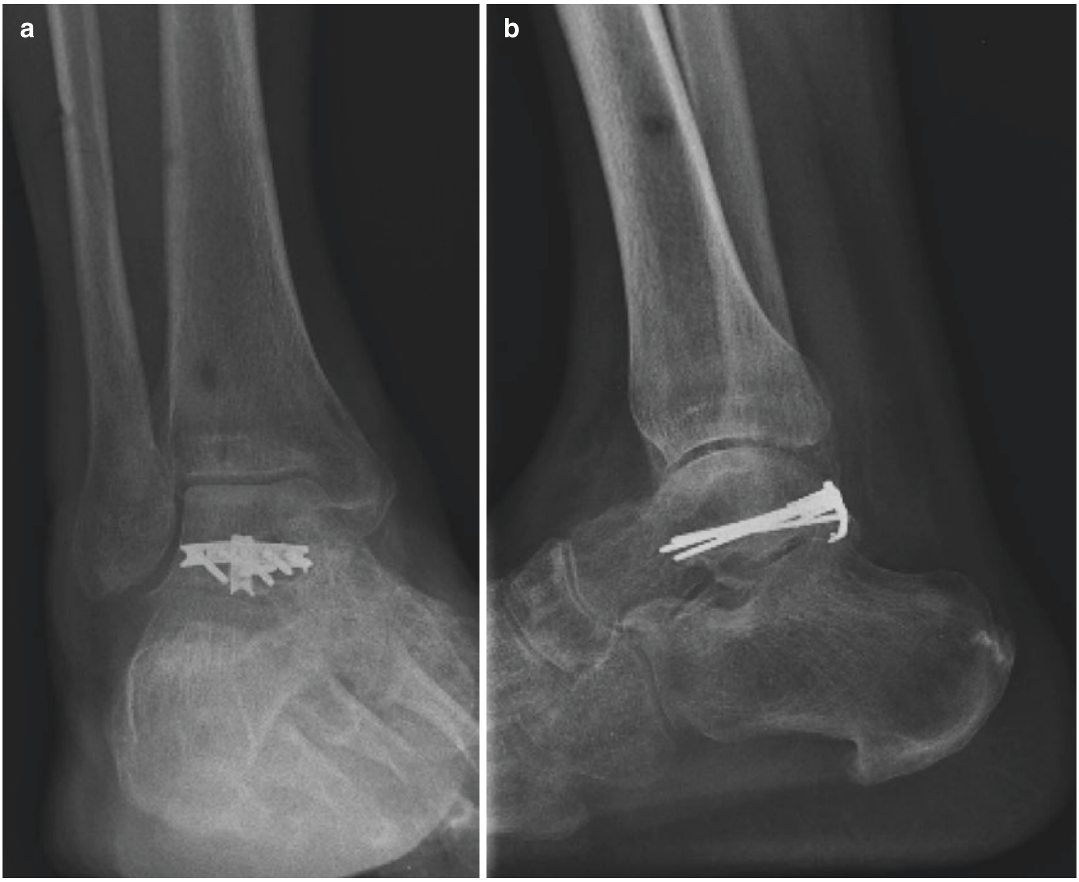


Fig. 7.13 (**a**) Broden’s view of subtalar joint; (**b**) Lateral view

References

1. Mc DA. The os trigonum. J Bone Joint Surg Br. 1955;37-B(2):257–65.
2. Nadim Y, Tosic A, Ebraheim N. Open reduction and internal fixation of fracture of the posterior process of the talus: a case report and review of the literature. Foot Ankle Int. 1999;20(1):50–2.
3. Chen YJ, Hsu RW. Fracture of the posterior process of the talus associated with subtalar dislocation: report of a case. J Formos Med Assoc. 1994;93(9):802–5.
4. Ebraheim NA, Skie MC, Podeszwa DA. Medial subtalar dislocation associated with fracture of the posterior process of the talus. A case report. Clin Orthop Relat Res. 1994;303:226–30.
5. Wechsler RJ, et al. Helical CT of talar fractures. Skelet Radiol. 1997;26(3):137–42.
6. Golano P, et al. Anatomy of the ankle ligaments: a pictorial essay. Knee Surg Sports Traumatol Arthrosc. 2016;24(4):944–56.
7. Vega J, et al. Anatomical variations of flexor hallucis longus tendon increase safety in hindfoot endoscopy. Knee Surg Sports Traumatol Arthrosc. 2017;25(6):1929–35.
8. Grogan DP, Walling AK, Ogden JA. Anatomy of the os trigonum. J Pediatr Orthop. 1990;10(5):618–22.
9. Frey C, Feder KS, DiGiovanni C. Arthroscopic evaluation of the subtalar joint: does sinus tarsi syndrome exist? Foot Ankle Int. 1999;20(3):185–91.
10. Nasser S, Manoli A 2nd. Fracture of the entire posterior process of the talus: a case report. Foot Ankle. 1990;10(4):235–8.
11. Sarrafian SK. Anatomy of the foot and ankle : descriptive, topographic, functional. 2nd ed. Philadelphia: Lippincott; 1993. p. xvii, 616 p
12. Paulos LE, Johnson CL, Noyes FR. Posterior compartment fractures of the ankle. A commonly missed athletic injury. Am J Sports Med. 1983;11(6):439–43.
13. Wildenauer E. Proceedings: discussion on the blood supply of the talus. Z Orthop Ihre Grenzgeb. 1975;113(4):730.
14. Haliburton RA, et al. The extra-osseous and intra-osseous blood supply of the talus. J Bone Joint Surg Am. 1958;40-A(5):1115–20.
15. Mulfinger GL, Trueta J. The blood supply of the talus. J Bone Joint Surg Br. 1970;52(1):160–7.
16. Kelly PJ, Sullivan CR. Blood supply of the talus. Clin Orthop Relat Res. 1963;30:37–44.
17. Peterson L, Goldie I, Lindell D. The arterial supply of the talus. Acta Orthop Scand. 1974;45(2):260–70.
18. Peterson L, Romanus B, Dahlberg E. Fracture of the collum tali–an experimental study. J Biomech. 1976;9(4):277–9.
19. Fortin PT, Balazsy JE. Talus fractures: evaluation and treatment. J Am Acad Orthop Surg. 2001;9(2):114–27.
20. Gelberman RH, Mortensen WW. The arterial anatomy of the talus. Foot Ankle. 1983;4(2):64–72.
21. Ebraheim NA, et al. Clinical outcome of fractures of the talar body. Int Orthop. 2008;32(6):773–7.
22. Hamilton WG. Stenosing tenosynovitis of the flexor hallucis longus tendon and posterior impingement upon the os trigonum in ballet dancers. Foot Ankle. 1982;3(2):74–80.
23. Howse AJ. Posterior block of the ankle joint in dancers. Foot Ankle. 1982;3(2):81–4.
24. Kleiger B. Fractures of the talus. J Bone Joint Surg Am. 1948;30A(3):735–44.
25. Kleiger B. Injuries of the talus and its joints. Clin Orthop Relat Res. 1976;121:243–62.
26. Quirk R. Talar compression syndrome in dancers. Foot Ankle. 1982;3(2):65–8.
27. HAWKINS LG. Fracture of the lateral process of the talus. A review of thirteen cases. J Bone Joint Surg Am. 1965;47(6):1170–5.
28. Jaffe KA, et al. Traumatic talectomy without fracture: four case reports and review of the literature. Foot Ankle Int. 1995;16(9):583–7.
29. Brodsky AE, Khalil MA. Talar compression syndrome. Foot Ankle. 1987;7(6):338–44.
30. Marotta JJ, Micheli LJ. Os trigonum impingement in dancers. Am J Sports Med. 1992;20(5):533–6.
31. Wredmark T, et al. Os trigonum syndrome: a clinical entity in ballet dancers. Foot Ankle. 1991;11(6):404–6.
32. Yan YY, Mehta KV, Tan TJ. Fracture of the os trigonum: a report of two cases and review of the literature. Foot Ankle Surg. 2016;22(4):e21–4.
33. Anderson IF, et al. Osteochondral fractures of the dome of the talus. J Bone Joint Surg Am. 1989;71(8):1143–52.
34. Berndt AL, Harty M. Transchondral fractures (osteochondritis dissecans) of the talus. J Bone Joint Surg Am. 2004;86-A(6):1336.
35. Schuman L, Struijs PA, van Dijk CN. Arthroscopic treatment for osteochondral defects of the talus. Results at follow-up at 2 to 11 years. J Bone Joint Surg Br. 2002;84(3):364–8.
36. Takao M, et al. Osteochondral lesions of the talar dome associated with trauma. Arthroscopy. 2003;19(10):1061–7.
37. Verhagen RA, et al. Systematic review of treatment strategies for osteochondral defects of the talar dome. Foot Ankle Clin. 2003;8(2):233–42. viii-ix
38. Shepherd FJ. A hitherto undescribed fracture of the Astragalus. J Anat Physiol. 1882;17(Pt 1):79–81.
39. Weinstein SL, Bonfiglio M. Unusual accessory (bipartite) talus simulating fracture. A case report. J Bone Joint Surg Am. 1975;57(8):1161–3.
40. Mao H, et al. Minimally invasive technique for medial subtalar dislocation associated with navicular and entire posterior talar process fracture: a case report. Injury. 2015;46(4):759–62.
41. Naranja RJ Jr, et al. Open medial subtalar dislocation associated with fracture of the posterior process of the talus. J Orthop Trauma. 1996;10(2):142–4.
42. Hawkins LG. Fractures of the neck of the talus. J Bone Joint Surg Am. 1970;52(5):991–1002.
43. Marumoto JM, Ferkel RD. Arthroscopic excision of the os trigonum: a new technique with preliminary clinical results. Foot Ankle Int. 1997;18(12):777–84.

44. Schrock RD, Johnson HF, Waters CH. Fractures and fracture-dislocations of the astragalus (talus). J Bone Joint Surg Am. 1942;24(3):560–73.
45. Stefko RM, Lauerman WC, Heckman JD. Tarsal tunnel syndrome caused by an unrecognized fracture of the posterior process of the talus (Cedell fracture). A case report. J Bone Joint Surg Am. 1994;76(1):116–8.
46. Abramowitz Y, et al. Outcome of resection of a symptomatic os trigonum. J Bone Joint Surg Am. 2003;85-A(6):1051–7.
47. Johnson RP, Collier BD, Carrera GF. The os trigonum syndrome: use of bone scan in the diagnosis. J Trauma. 1984;24(8):761–4.
48. Karasick D, Schweitzer ME. The os trigonum syndrome: imaging features. AJR Am J Roentgenol. 1996;166(1):125–9.
49. Ebraheim NA, et al. Evaluation of process fractures of the talus using computed tomography. J Orthop Trauma. 1994;8(4):332–7.
50. Bibbo C, Anderson RB, Davis WH. Injury characteristics and the clinical outcome of subtalar dislocations: a clinical and radiographic analysis of 25 cases. Foot Ankle Int. 2003;24(2):158–63.
51. Giuffrida AY, et al. Pseudo os trigonum sign: missed posteromedial talar facet fracture. Foot Ankle Int. 2003;24(8):642–9.
52. Sanders TG, Ptaszek AJ, Morrison WB. Fracture of the lateral process of the talus: appearance at MR imaging and clinical significance. Skelet Radiol. 1999;28(4):236–9.
53. Wakeley CJ, Johnson DP, Watt I. The value of MR imaging in the diagnosis of the os trigonum syndrome. Skelet Radiol. 1996;25(2):133–6.
54. Berkowitz MJ, Kim DH. Process and tubercle fractures of the hindfoot. J Am Acad Orthop Surg. 2005;13(8):492–502.
55. Coughlin MJ, Saltzman CL, Anderson RB. Mann's surgery of the foot and ankle. 9th.
56. Browner BD, et al. Skeletal trauma : basic science, management, and reconstruction. p. 1 online resource.
57. Mukherjee SK, Pringle RM, Baxter AD. Fracture of the lateral process of the talus. A report of thirteen cases. J Bone Joint Surg Br. 1974;56(2):263–73.
58. Bibbo C, et al. Missed and associated injuries after subtalar dislocation: the role of CT. Foot Ankle Int. 2001;22(4):324–8.
59. Iyakutty PP, Singaravadivelu V. Fracture of the entire posterior process of the talus: a case report. J Foot Ankle Surg. 2000;39(3):198–201.
60. Mehrpour SR, et al. Entire posterior process talus fracture: a report of two cases. J Foot Ankle Surg. 2012;51(3):326–9.
61. Yilmaz C, Eskandari MM. Arthroscopic excision of the talar Stieda's process. Arthroscopy. 2006;22(2):225 e1–3.
62. Sitler DF, et al. Posterior ankle arthroscopy: an anatomic study. J Bone Joint Surg Am. 2002;84-A(5):763–9.
63. Hedrick MR, McBryde AM. Posterior ankle impingement. Foot Ankle Int. 1994;15(1):2–8.
64. Kim DH, Berkowitz MJ, Pressman DN. Avulsion fractures of the medial tubercle of the posterior process of the talus. Foot Ankle Int. 2003;24(2):172–5.
65. Kim DH, Hrutkay JM, Samson MM. Fracture of the medial tubercle of the posterior process of the talus: a case report and literature review. Foot Ankle Int. 1996;17(3):186–8.
66. Ebraheim NA, Padanilam TG, Wong FY. Posteromedial process fractures of the talus. Foot Ankle Int. 1995;16(11):734–9.
67. Cedell CA. Rupture of the posterior talotibial ligament with the avulsion of a bone fragment from the talus. Acta Orthop Scand. 1974;45(3):454–61.
68. Kanbe K, et al. Fracture of the posterior medial tubercle of the talus treated by internal fixation: a report of two cases. Foot Ankle Int. 1995;16(3):164–6.
69. Wolf RS, Heckman JD. Case report: fracture of the posterior medial tubercle of the talus secondary to direct trauma. Foot Ankle Int. 1998;19(4):255–8.
70. Cohen AP, et al. Impingement fracture of the posteromedial process of the talus--a case report. Acta Orthop Scand. 2000;71(6):642–4.
71. Dougall TW, Ashcroft GP. Flexor hallucis longus tendon interposition in a fracture of the medial tubercle of the posterior process of the talus. Injury. 1997;28(8):551–2.
72. Ebraheim NA, et al. Diagnosis of medial tubercle fractures of the talar posterior process using oblique views. Injury. 2007;38(11):1313–7.

8

Fractures of the Lateral Process of the Talus

Matthew P. Sullivan and Reza Firoozabadi

Historic and Contemporary Significance

The earliest reports in the peer-reviewed English literature describing lateral process fractures date back to the 1960s [1–4]. Dimon's seminal work on the topic described three patients treated operatively. He was well ahead of his time, describing the negative sequelae of delayed diagnosis, surgical anatomy, and a hypothesis of the complex injury mechanism that is remarkably similar to that, which is accepted today and has been described in ex vivo biomechanical studies. Early reports describe predominantly delayed diagnoses and the functional disability associated with late treatment. Interestingly, these early publications describing lateral process fractures use anatomic descriptors that differ from those used today. For example, throughout Dimon's manuscript, the lateral process is referred to as the anterolateral aspect of the posterior facet of the talus. By the mid-1990s, the predominant etiology of lateral process fractures was snowboarding misadventures [5, 6]. McCrory and Bladin were the first to describe the so-called snowboarder's ankle [5]. Since that time, numerous authors have reported epidemiologic and case series of snowboarding-related lateral process fractures [7, 8].

In the general population, lateral process fractures account for less than 1% of all ankle injuries [5, 7, 9] and about 10% of all talus factures [10]. In snowboarders, however, they account for greater than 30% of all ankle/hindfoot fractures [8]. Fracture incidence is most likely underreported, as this injury is frequently missed acutely, presenting as chronic ankle dysfunction, pain, and instability [11].

Diagnostic Dilemma

Lateral process fractures are commonly overlooked radiographically due to low index of suspicion by the interpreter and mistaken for severe ankle sprains [11, 12]. This was noted in Dimon's early work in 1961 [1]. Upwards of 15% of "severe ankle sprains" are missed lateral process fractures [5]. Delay or absence of diagnosis of lateral process fractures is the result of low index of suspicion and failure to interpret or obtain appropriate radiographic images. Plain x-rays can be challenging to interpret, and standard ankle views should be scrutinized for lateral process fractures in the correct clinical setting. The

M. P. Sullivan
Orthopaedic Trauma Service, State University of New York, Upstate University Hospital, Oneida, NY, USA

R. Firoozabadi (✉)
Department of Orthopaedics and Sports Medicine, Harborview Medical Center/University of Washington, Seattle, WA, USA
e-mail: rezaf2@uw.edu

© Springer Nature Switzerland AG 2020

M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_8

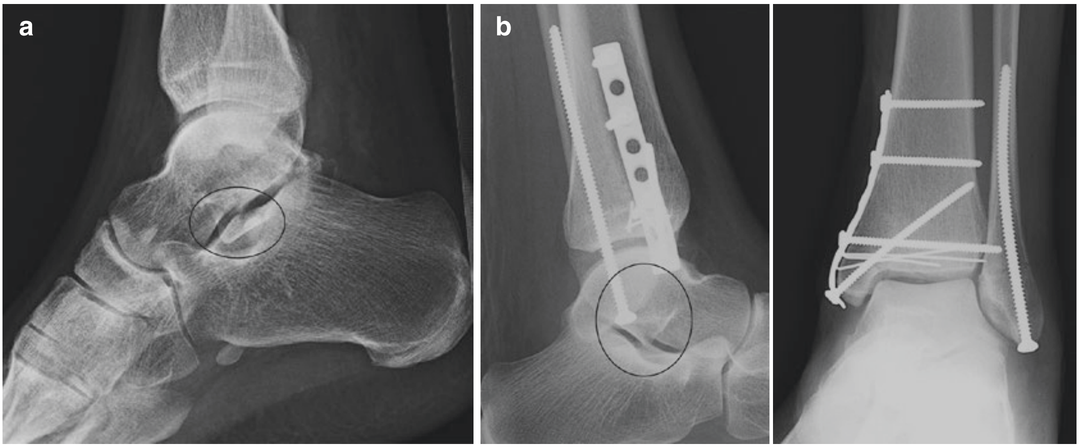


Fig. 8.1 (**a**) Lateral radiograph of the ankle demonstrating a double density, suggestive of a lateral process fracture. Routinely the lateral process is displaced distally when fractured causing the double density. (**b**) Intact lateral process. Notice the lack of a double density. Lateral process is circled in both images

lateral radiograph of the ankle can be very useful for diagnosis. If a double density is noted just distal to the subtalar joint, then one should have a high clinical suspicion of a lateral process fracture (Fig. 8.1). Additionally, a Broden view of the subtalar joint may reveal lateral process pathology [13]. CT scanning is critical to diagnosis and management and should always be obtained when there is suspicion of a lateral process fracture [14, 15]. Multiple small case series suggest that upwards of 50% of lateral process fractures are missed at the time of initial evaluation [2, 16, 17].

The sequelae of delayed diagnosis or nonoperative management of displaced fractures have been well documented in numerous case series and subjectively and objectively result in poor function and pain. Post-traumatic subtalar osteoarthritis is more commonly seen in these patients as well [1, 2, 9, 13, 18, 19]. Missed displaced fractures tend to result in nonunion [18] presumably due to the intra-articular location and the considerable strain present in this area due to ligamentous attachments. Post-traumatic subtalar osteoarthritis likewise can be expected in the setting of missed injuries [20]. Nonunited fracture fragments may displace into the sinus tarsi resulting in severe disability [21] or result in symptomatic lateral ankle impingement [12]. Acute surgical management of displaced fractures result in superior function than those fractures that go on to nonunion in the setting of delayed diagnosis. Subtalar motion is negatively affected in both operative and nonoperative patients.

Local Anatomy and Functional Anatomy

The lateral process is composed of two facets: dorsolateral and inferomedial. The dorsolateral facet articulates with the distal fibula. The inferomedial facet makes up a significant portion of the posterior facet of the talus. It articulates with the posterior facet of the calcaneus, making up the subtalar joint. The ligamentous anatomy about the lateral ankle is highly complex and has been described in great detail. Several anatomic and biomechanical reports suggest at least 11 independent ligamentous structures contribute to lateral ankle stability. The lateral process of the talus serves as the attachment site for four important structures: the anterior talofibular ligament, posterior talofibular ligament, lateral talocalcaneal ligament, and talocalcaneal interosseous ligament [5, 22–25]. Sectioning studies suggest significant lateral ankle stability conferred by these ligaments, specifically, the anterior talofibular ligament in the plantar-flexed position, and posterior talofibular ligament and talocalcaneal

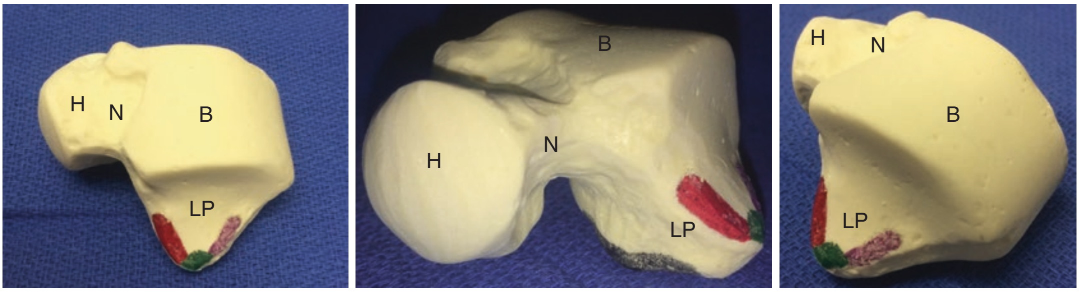


Fig. 8.2 Bone model demonstrating the ligamentous footprints on the lateral process: Red – anterior talofibular ligament. Purple – posterior talofibular ligament. Green – lateral talocalcaneal ligament. Black – talocalcaneal interosseous ligament. H – talar head. N – talar neck. B – talar body. LP – lateral process

interosseous ligament in all ankle positions [23, 25]. An understanding of the clinical anatomy in this region will guide fracture care. Figure 8.2 demonstrates the footprints of the four ligaments that attach to the lateral process. A simulated 1-cm^3 lateral process osteotomy at the apex of the process has been shown in a cadaver model to significantly impact the footprints of the lateral talocalcaneal, anterior talofibular, and posterior talofibular ligaments [26].

Injury Mechanism

The precise hindfoot position and force vector resulting in lateral process fracture has been disputed. The mechanisms in question include forced dorsiflexion plus eversion and external rotation [1, 6, 13, 20, 27] and forced dorsiflexion with hindfoot inversion [2, 4, 5, 9, 18]. Biomechanical cadaveric works performed by Boon et al. and Funk et al. make very convincing arguments against the previously accepted notion that hindfoot inversion is essential for these injuries. Rather, their combined works elegantly identify combined axial load plus dorsiflexion, eversion, and external rotation as the precise mechanism of injury. This is the exact position of the snowboarder's hindfoot during traumatic landing after an aerial maneuver. Dimon hypothesized this mechanism based on his understanding of hindfoot anatomy and the findings at surgery of the three patients he treated with lateral process fractures between 1956 and 1959. Specifically, he suggested forced dorsiflexion, eversion, and external rotation were required to cause lateral process fractures.

Management Principles

Operative indications for lateral process fractures are based exclusively on anecdotal reports, small case series, poor outcomes observed with delayed diagnoses, and the local anatomy of the fracture. Specialists recommend operative management for all displaced fractures and many minimally or nondisplaced fractures [1, 9, 18–21]. Nonoperative treatment should be considered in patterns in which fracture fragments are too small to support fixation. This primarily applies to avulsion fractures that are too small for fixation with mini-fragment plates or Kirschner wires. Exceedingly comminuted fractures, in which open reduction and internal fixation may not be possible, fare better with excision than simple immobilization. Given the significant contribution the lateral process makes to lateral ankle stability and to the articular surface of the subtalar joint, open reduction and fixation are appropriate for most fractures, even when only minimal displacement exists.

Associated hindfoot injuries are very common in these patients and appear to be markedly underreported. Von Knoch et al. reported that 88% (14/16) of their patients who underwent operative fixation of a lateral process fracture had a significant concomitant hindfoot injury identified at the time of surgery [20]. These injuries included posterior facet calcaneus cartilage lesions, calcaneofibular ligament rupture, peroneal tendon dislocation, and anterior talofibular ligament rupture. Klein et al. reported 46% rate of peroneal tendon dislocation associated with lateral process fractures [28]. The surgeon should maintain a high index of suspicion for associated injuries and treat them appropriately as outlined in this text.

Fixation Strategies

Goals of surgery The surgical goals for fixation of lateral process fractures are twofold. The first goal is to restore the congruity of the talar contribution to the subtalar joint (posterior facet). The second goal is to restore lateral ankle stability through stabilizing the ligamentous footprints of the lateral process.

Patient positioning The patient is positioned supine with a bump under the operative hip. A thigh tourniquet is applied, and the operative extremity is propped up on a radiolucent foam ramp. Fluoroscopy comes in from the contralateral side of the patient.

Surgical implants and instrumentation Medium or large external fixator with compression-distraction device

- Dental picks/shoulder hook
- Small sharp osteotomes
- 0.035″ and 0.045″ smooth Kirschner wires
- 2.0/2.4/2.7-mm stainless steel cortical screws
- Nine-hole 2.0-mm T-plate – three or four holes in transverse row
- Small, handheld plate/wire cutter
- Crushed cancellous allograft bone
- Headlight

Surgical approach The lateral process is approached through a straight incision centered directly over the fracture, extending from the distal aspect of the fibula distally toward the center of the cuboid. This is slightly more lateral than the anterolateral approach to the talar neck, which is typically in line with the fourth ray. The lateral process should be localized with fluoroscopic assistance prior to skin incision. This is demonstrated in Fig. 8.3. Once through skin, extensor digitorum brevis is elevated from posterolateral to anteromedial off of the calcaneus. This will give access to the lateral process, the sinus tarsi, and the subtalar joint. The fat is gently removed from the sinus in order to better visualize the anterior extent of the lateral process.

Distraction Once the exposure is complete an external fixator should be applied. This allows the subtalar joint to be easily visualized and

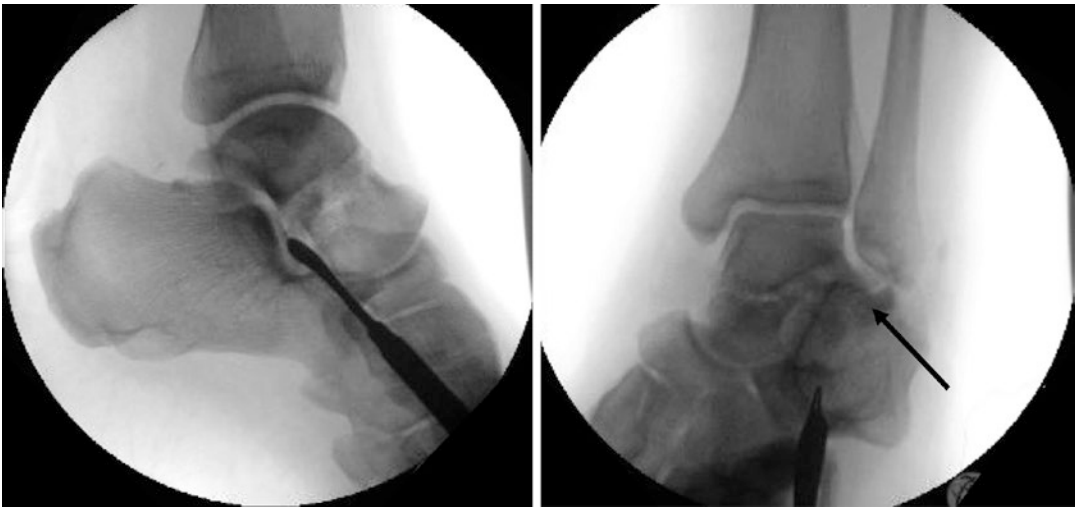


Fig. 8.3 The lateral process is localized on the lateral (freer elevator tip) and mortise view (arrow tip)

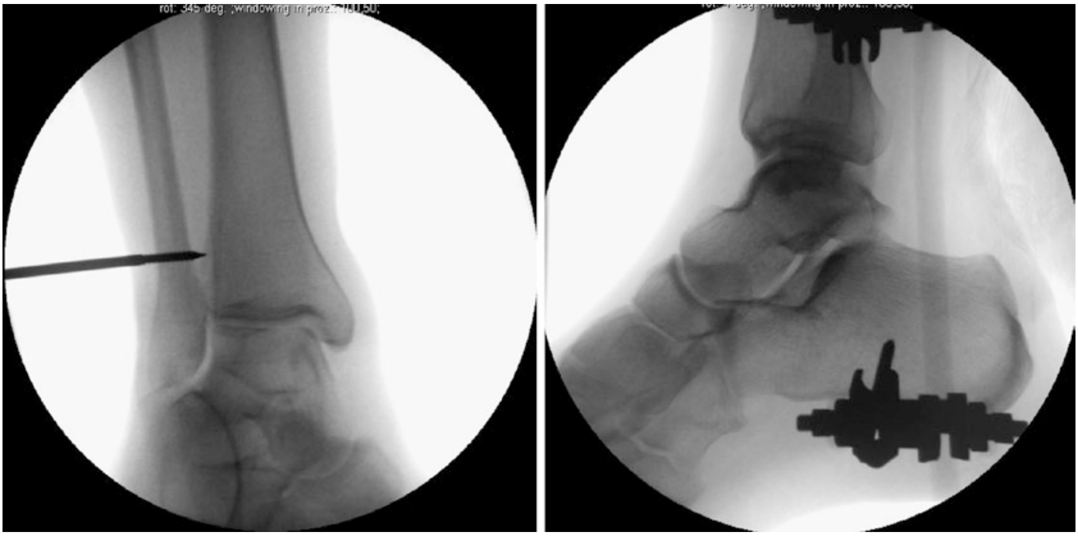


Fig. 8.4 Appropriate pin placement for monorail distracting external fixator. Notice the lateral calcaneal half pin is centered within the calcaneus. This allows for a more appropriate vector for distracting the subtalar joint without having the hardware in the way of the approach and reduction

space to be created in which the surgeon can work in in order to reduce and stabilize the lateral process. Our preference is to build a monorail external fixator to assist in distraction, as opposed to utilizing a universal distractor. We feel that there are numerous benefits to a well-built frame, specifically greater freedom of movement and distraction, as well as its less cumbersome nature and radiolucency. Figure 8.4 demonstrates the most appropriate pin placement. In order to distract across the subtalar joint and provide the greatest visualization of the lateral process, a monorail system is set up from the fibula to the midportion of the calcaneus. A 4 -mm terminally threaded Schanz pin is the most appropriate for the fibula. A 4- or 5-mm Schanz pin may be used for the calcaneal pin. Notice that the lateral calcaneal half pin is placed more anterior than is typical for an ankle spanning external fixator or a medial-based calcaneal pin for a joint depression calcaneus fracture. Figure 8.5 demonstrates the distraction achieved by a laterally based monorail external fixator utilizing the distraction device found on most external fixator sets. The lateral process is very well visualized both fluoroscopically and clinically after distraction is applied.

Reduction strategies, implant selection, and placement The surgeon must scrutinize the preoperative CT scan in order to understand the morphology of the fracture pattern, extent of subtalar involvement, and presence of articular impaction. Restoration of subchondral congruence is only possible after articular impaction is addressed. Figure 8.6 demonstrates posterior facet articular impaction. This is disimpacted with a small brown handle AO elevator, a freer elevator, or a small osteotome, followed by placement of crushed cancellous allograft into the cancellous defect, and fixation with a mini-fragment T-plate with several subchondral screws (Fig. 8.7) with or without Kirschner wires. Alternatively, autograft can be used from the calcaneus or proximal tibia.

Implant selection should be based on the fracture pattern. A single, large fracture fragment may accommodate several 2.4- or 2.7-mm lag screws. A mini-fragment plate may function as a washer in this fracture pattern. Clamping of the lateral process is not optimal due to limited space. As such, the large fracture fragment should be reduced with the assistance of a dental pick, shoulder hook, or elevator, wired in place, and then compressed with lag screws. Figure 8.8 dem-

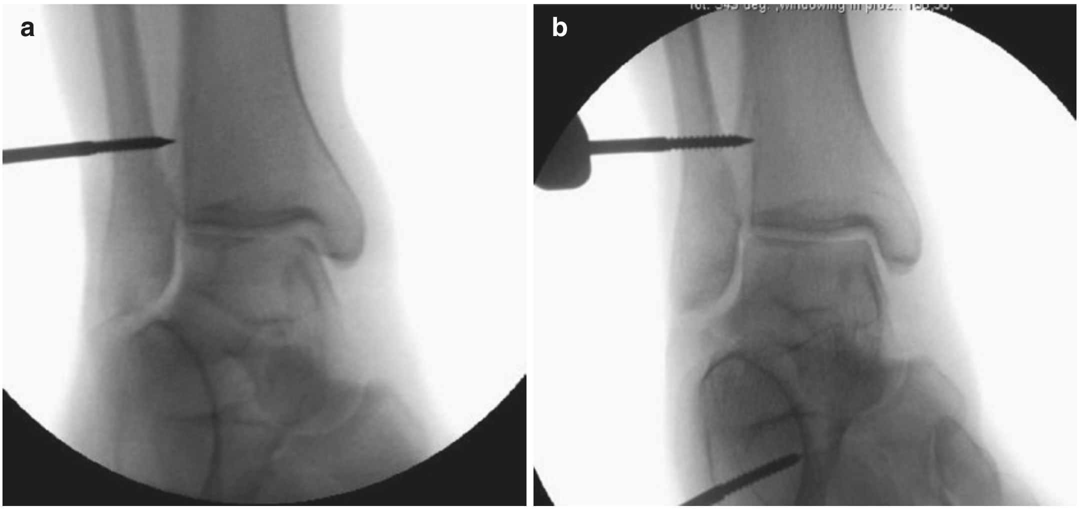


Fig. 8.5 A monorail, lateral-based external fixator is statically applied in (**a**). (**b**) Demonstrates markedly enhanced visualization of the lateral process following distraction. Clinically, there is considerably more space for reduction and implant placement with application of distraction

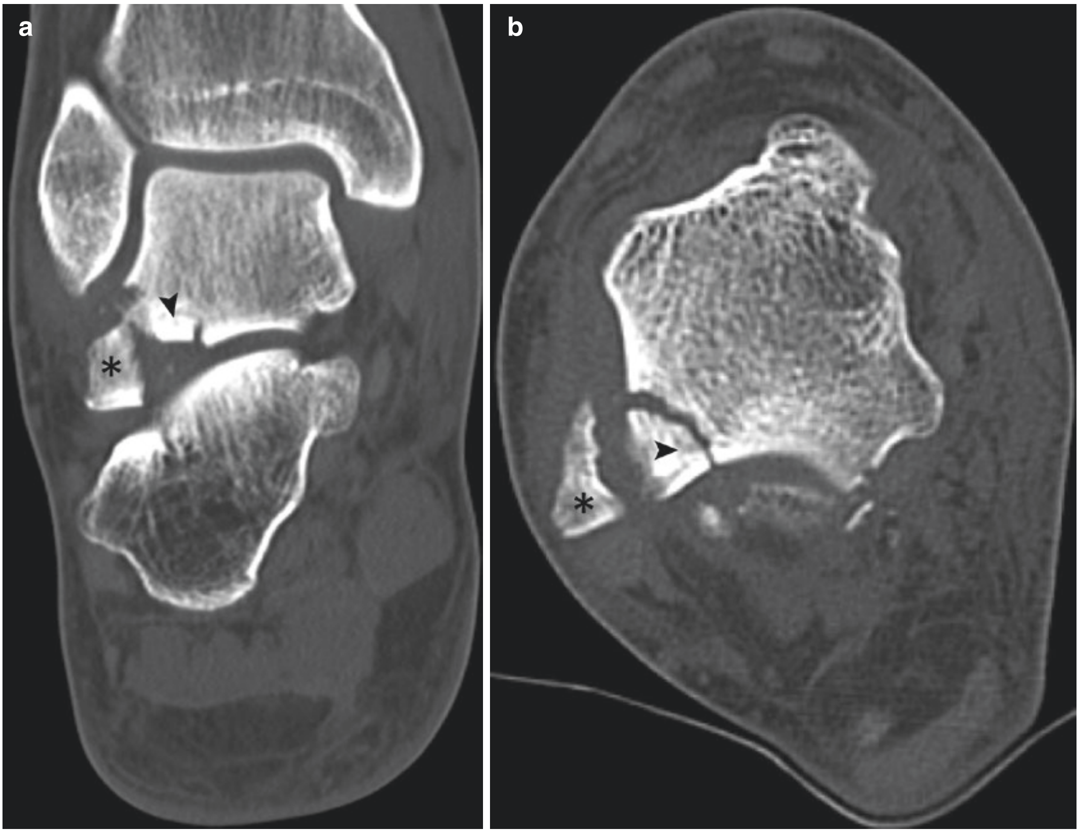


Fig. 8.6 Coronal (**a**) and Axial (**b**) plane CT images demonstrate a large lateral process fracture (∗) with posterior facet impaction (➤)

onstrates a large lateral process fracture reduced and wired into place. Careful wire placement allows the surgeon to wire the fracture together then lay the plate down onto the anterior face of the lateral process (Fig. 8.9). Well-placed subchondral wires can then be cut, bent, and tamped down as described by Firoozabadi et al. order to provide additional fixation [29]. Caution should be used when compressing along comminuted fractures as this may result in over-compression and a loss of reduction. T-plate plus wire fixation is appropriate when significant comminution is present. The typical reduction "reads" are the posterior talar facet articular surface and the anterior aspect of the lateral process.

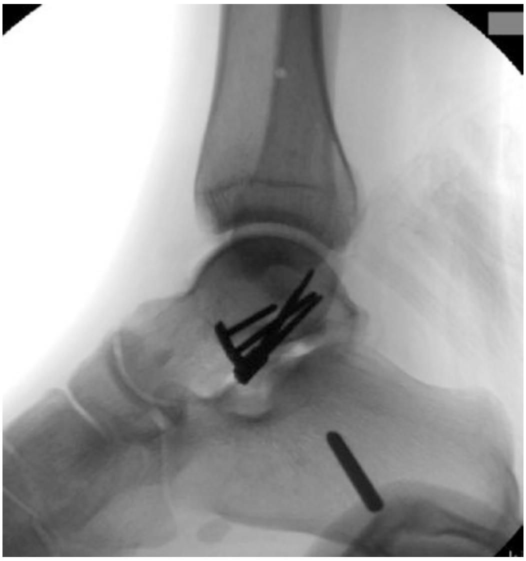


Fig. 8.7 Intraoperative lateral view of a fixation construct for lateral process fracture with subtalar articular impaction. 4 2.4 mm cortical screws are placed through the transverse row of the T plate. These "rafting" screws support the subchondral bone and provide adequate stability until re-vascularization of the articular segment, and creeping substitution of the allograft can take place

There is sufficient room on the lateral process to place fixation without compromising the subtalar joint or talofibular articulation. A 1.5-mm, 2.0-mm, and 2.4-mm T-plates may be contoured to sit on the anterior face of the lateral process. The plate is not to be placed laterally. This will result in impingement of the talofibular articulation. The T is turned upside down such that the transverse row lies distal, which allows for placement of rafting screws. Figure 8.10 demonstrates the safe location for plate placement of lateral process. Notice that the subtalar joint is not violated. The transverse row in the plate is placed parallel to the subtalar joint. We have found that the most appropriate plate for this facture is a nine-hole 2.0-mm nonlocking T-plate with four holes in the transverse row. Typically, this must be cut down to three holes in the shaft of the plate. Distraction of the subtalar joint makes it possible to place the medial most screws into the transverse row of the plate. The surgeon must clinically and radiographically confirm prior to leaving the OR that all wires and screws are fully contained within bone. Furthermore, the underside of a freer elevator can be used to palpate the joint surface of the talus to confirm that no step-off exists.

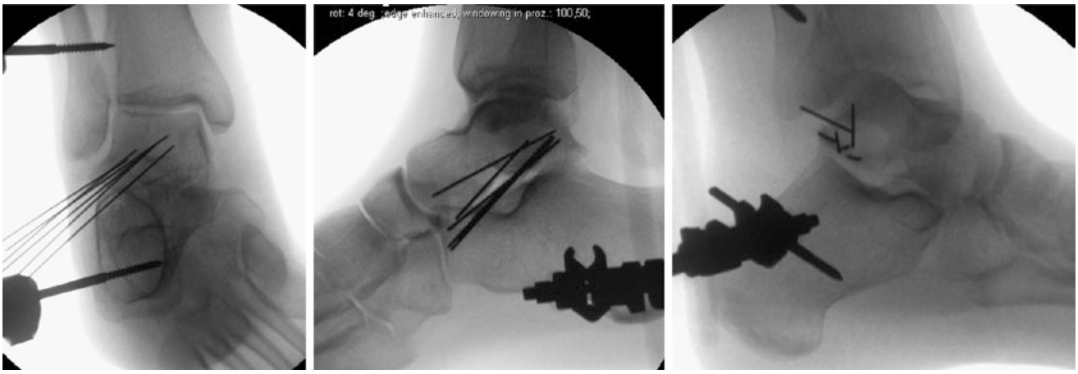


Fig. 8.8 A large lateral process fracture is reduced and provisional held in place with multiple .045" wires. Notice multiple views of the subtalar joint nicely demonstrate "safe" placement of all wires

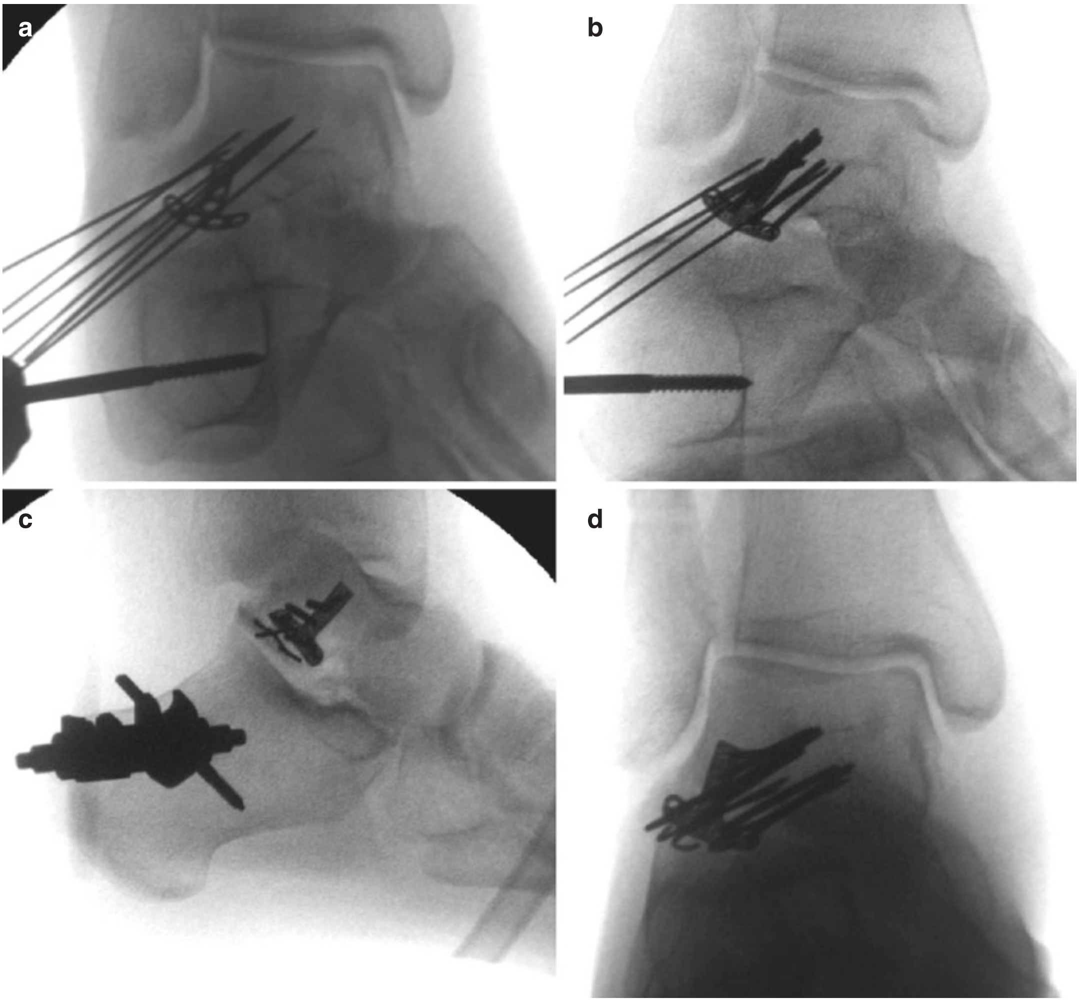


Fig. 8.9 (**a**) 0.045” K-wires are placed thoughtfully such that a contoured 2.0-mm T plate may sit on the anterior face of the lateral process without having to remove wire fixation. (**b**) Screws placed through the transverse distal row of the T plate raft the posterior facet. (**c**) Subtalar view demonstrates rafting wires, and screws are safely placed in an extra-articular location. (**d**) Wires are ultimately cut, bent, and tamped into the cortex of the lateral process

The wound is closed with 4–0 Nylon suture with the Allgöwer sequentially tensioned skin closure technique.

Post op care Postoperatively, the patient is placed in a well-padded plaster splint. The surgeon must pay particular attention to not allow the foot to supinate or plantar-flex as the splint is hardening. A supination equines deformity will severely compromise the patient’s ability to recover from this injury. Once the skin incision is healed and sutures are removed, patients are instructed to begin range of motion, with specific focus on subtalar motion. Non-weight-bearing is maintained for 6–12 weeks after surgery.

Complications

Subtalar arthrosis and stiffness have been described by many authors as occurring in these injuries, even after appropriate management.

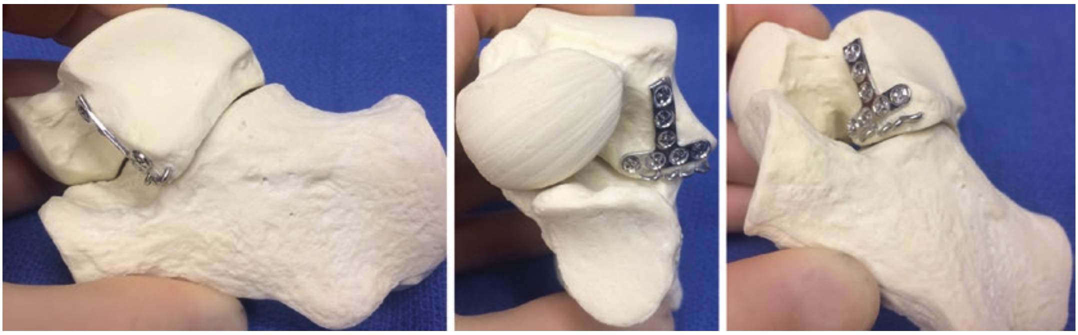


Fig. 8.10 Bone model demonstrating safe plate placement on the lateral process so as to avoid violation of the subtalar joint and the talofibular articulation. The plate is placed on the anterior face of the lateral process. Subchondral rafting wires can safely be placed slightly more lateral. When left in place after plate fixation, these wires will provide added stability to the dis-impacted subchondral bone/bone graft. They should be bent, cut, and impacted into cortical bone so as to prevent loosening and backing out

When appropriate and timely management is performed, roughly 80% of patients return to their pre-injury level of function [13, 20, 30].

References

1. Dimon JH 3rd. Isolated displaced fracture of the posterior facet of the talus. J Bone Joint Surg Am. 1961;43-A:275–81.
2. Hawkins LG. Fracture of the lateral process of the talus. J Bone Joint Surg Am. 1965;47:1170–5.
3. Cimmino CV. Fracture of the lateral process of the talus. Am J Roentgenol Radium Therapy, Nucl Med. 1963;90:1277–80.
4. Fjeldborg O. Fracture of the lateral process of the talus. Supination-dorsal flexion fracture. Acta Orthop Scand. 1968;39(3):407–12.
5. McCrory P, Bladin C. Fractures of the lateral process of the talus: a clinical review. “Snowboarder’s ankle”. Clin J Sport Med. 1996;6(2):124–8.
6. Boon AJ, Smith J, Zobitz ME, Amrami KM. Snowboarder’s talus fracture. Mechanism of injury. Am J Sports Med. 2001;29(3):333–8.
7. Bonvin F, Montet X, Copercini M, Martinoli C, Bianchi S. Imaging of fractures of the lateral process of the talus, a frequently missed diagnosis. Eur J Radiol. 2003;47(1):64–70.
8. Kirkpatrick DP, Hunter RE, Janes PC, Mastrangelo J, Nicholas RA. The snowboarder’s foot and ankle. Am J Sports Med. 1998;26(2):271–7.
9. Mukherjee SK, Pringle RM, Baxter AD. Fracture of the lateral process of the talus. A report of thirteen cases. J Bone Joint Surg Br. 1974;56(2):263–73.
10. Langer P, DiGiovanni C. Incidence and pattern types of fractures of the lateral process of the talus. Am J Orthop (Belle Mead NJ). 2008;37(5):257–8.
11. Young KW, Park YU, Kim JS, Cho HK, Choo HS, Park JH. Misdiagnosis of talar body or neck fractures as ankle sprains in low energy traumas. Clin Orthop Surg. 2016;8(3):303–9.
12. Wang PH, Su WR, Jou IM. Lateral Hindfoot impingement after nonunion of fracture of the lateral process of the talus. J Foot Ankle Surg. 2016;55(2):387–90.
13. Valderrabano V, Perren T, Ryf C, Rillmann P, Hintermann B. Snowboarder’s talus fracture: treatment outcome of 20 cases after 3.5 years. Am J Sports Med. 2005;33(6):871–80.
14. Ebraheim NA, Skie MC, Podeszwa DA, Jackson WT. Evaluation of process fractures of the talus using computed tomography. J Orthop Trauma. 1994;8(4):332–7.
15. Noble J, Royle SG. Fracture of the lateral process of the talus: computed tomographic scan diagnosis. Br J Sports Med. 1992;26(4):245–6.
16. Mills HJ, Horne G. Fractures of the lateral process of the talus. Aust N Z J Surg. 1987;57(9):643–6.
17. Wu Y, Jiang H, Wang B, Miao W. Fracture of the lateral process of the talus in children: a kind of ankle injury with frequently missed diagnosis. J Pediatr Orthop. 2016;36(3):289–93.
18. Heckman JD, McLean MR. Fractures of the lateral process of the talus. Clin Orthop Relat Res. 1985;199:108–13.
19. Perera A, Baker JF, Lui DF, Stephens MM. The management and outcome of lateral process fracture of the talus. Foot Ankle Surg. 2010;16(1):15–20.
20. von Knoch F, Reckord U, von Knoch M, Sommer C. Fracture of the lateral process of the talus in snowboarders. J Bone Joint Surg Br. 2007;89(6):772–7.
21. Bali K, Prabhakar S, Gahlot N, Dhillon MS. Neglected lateral process of talus fracture presenting as a loose body in tarsal canal. Chin J Traumatol. 2011;14(6):379–82.
22. Golano P, Vega J, Perez-Carro L, Gotzens V. Ankle anatomy for the arthroscopist. Part II: role of the ankle

ligaments in soft tissue impingement. Foot Ankle Clin. 2006;11(2):275–96, v–vi

23. Stephens MM, Sammarco GJ. The stabilizing role of the lateral ligament complex around the ankle and subtalar joints. Foot Ankle. 1992;13(3):130–6.
24. DiGiovanni CW, Langer PR, Nickisch F, Spenciner D. Proximity of the lateral talar process to the lateral stabilizing ligaments of the ankle and subtalar joint. Foot Ankle Int. 2007;28(2):175–80.
25. Kjaersgaard-Andersen P, Wethelund JO, Helmig P, Soballe K. The stabilizing effect of the ligamentous structures in the sinus and canalis tarsi on movements in the hindfoot. An experimental study. Am J Sports Med. 1988;16(5):512–6.
26. Langer P, Nickisch F, Spenciner D, DiGiovanni C. Effect of simulated lateral process talus “fracture excision” on its ligamentous attachments. Am J Orthop (Belle Mead NJ). 2009;38(5):222–6.
27. Funk JR, Srinivasan SC, Crandall JR. Snowboarder’s talus fractures experimentally produced by eversion and dorsiflexion. Am J Sports Med. 2003;31(6):921–8.
28. Klein SE, Varner KE, Marymont JV. Lateral talar process fracture and peroneal tendon dislocation: a previously unrecognized injury complex. Foot Ankle Int. 2008;29(10):1020–4.
29. Firoozabadi R, Kramer PA, Benirschke SK. Kirschner wire bending. J Orthop Trauma. 2013;27(11):e260–3.
30. Romeo NM, Hirschfeld AG, Githens M, Benirschke SK, Firoozabadi R. Significance of lateral process fractures associated with talar neck and body fractures. J Orthop Trauma. 2018;32(12):601–6.

Osteochondral Defects of the Talar Dome

9

Daniel Thuillier and David Shearer

Introduction

The talus is a unique bone in that it is nearly completely covered with cartilage (~60%) and has no bony attachments. A large portion of this talar cartilage comprises the talar dome that sits within the ankle mortise and allows for smooth plantar and dorsiflexion of the foot. Injuries to talar dome are relatively rare, with one retrospective study of military recruits demonstrating an incidence of 27/100,000 person years [1]. As with all intra-articular fractures involving the articular cartilage, treatment of osteochondral defects of the talus can be challenging to treat effectively, and treatment continues to evolve both in surgical technique and available modalities.

Anatomy, Pathophysiology, and Natural History

The shape of the talar dome is trapezoidal in nature with the anterior portion wider than the posterior portion by approximate 2.5 mm. This allows for greater stability when the ankle is dorsiflexed or in neutral as the wider portion of the talus is within the mortise. Stability of the talar dome within the mortise is provided by both bone (medial malleolus, lateral malleolus, posterior malleolus) and ligamentous attachments. The talar dome cartilage has a relatively thin articular cartilage layer, which is thought to correlate to how congruent the ankle joint is, as compared to other less congruent joints such as the knee where the cartilage is notably thicker [2]. This congruency is thought to contribute to the relatively low injury rate of the talar cartilage. However, when the ligamentous and bony attachments keeping the talus within the mortise are disrupted, the talar dome may become susceptible to injury as the forces across the cartilage change. It has been demonstrated that shifts in the talus of even 1 mm may change joint forces within the ankle by as much as 40% and Thordarson et al. has demonstrated that fibular malreduction even as little as 2 mm leads to increased contact pressures within the joint [3, 4]. Thus, injuries to either the bony or ligamentous restraints maintaining the congruency of the ankle joint may lead to injury of the articular cartilage, and indeed injury to the talar dome has been demonstrated in 50–73% of patients with malleolar fractures and up to 50% of patients with ankle sprains [5, 6].

D. Thuillier (✉) · D. Shearer
UCSF – Department of Orthopaedic Surgery,
San Francisco, CA, USA
e-mail: Daniel.thuillier@ucsf.edu;
David.Shearer@ucsf.edu

© Springer Nature Switzerland AG 2020

M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_9

Osteochondral defects of the talar dome may occur in any portion of the talus, though most commonly they are seen within the anterolateral and posteromedial portions of the talar dome and both have a strong association with trauma, 93–98% for anterolateral and 61–70% of posteromedial lesion [7]. Anterolateral lesions tend to be shallower and oval in shape indicating a shearing injury to the cartilage and bone as etiology. Posteromedial lesions tend to be deep with a larger cystic component and thus are thought to result from torsional impaction and/or axial loading [2].

Though trauma is considered to be the most common etiology, it is not the only cause. Genetic factors may play a role as osteochondral defects have been noted in twins [8]. In addition, deformity of the ankle may also place abnormal loading forces onto the articular cartilage and contribute to osteochondral defects.

When the cartilage of the ankle is disrupted, the congruency of the joint is disrupted as well. The microfracture or shear fragment of the articular surface may then allow for the forced introduction of joint fluid into the subchondral space. This may lead to the slow formation of cysts and has been proposed as one of the reasons why osteochondral defects become painful as well as the amount of edema present within the bone [2].

The natural history of osteochondral defects of the talus is that of stability. They do not show progression in size or character and only very rarely do they progress to arthritis [9]. Articular cartilage however has demonstrated little capacity for healing, so if present, the lesions may maintain a stable appearance on imaging and also with stable symptoms in patients.

History and Physical Examination

Osteochondral defects of the talus occur most commonly in the setting of trauma, and thus the pain and dysfunction related to that trauma (i.e., malleolar fracture, ankle sprain) will often dominate the early presentation of these patients. As the pain from these injuries becomes quiet, sometimes the pain from the osteochondral defect may become more evident. As a result, an osteochondral defect should be considered in anyone who has had an ankle sprain and continues to have pain longer than 3 months.

The most common symptom is pain in the ankle joint, most commonly anteriorly. It has been noted that patients with posteromedial lesions will sometimes complain of pain in their anterolateral ankle joint. This ankle pain can be diffuse and difficult to fully characterize, though it is most commonly associated with weight-bearing or athletic activities [10]. Patients may complain of mechanical symptoms (clicking or locking), and they may have intermittent swelling of the joint.

Physical examination of these patients may be nonspecific. Mild crepitus may be felt with range of motion of the tibiotalar joint, and occasionally tenderness to palpation can be elicited along the anterior joint line. A joint effusion may be noted though it is not always present. Given that trauma and deformity are potential contributing factors, a stability examination of the ligaments of the ankle and observation of standing alignment and gait should not be neglected.

Diagnosis

As there is no definitive history and physical examination elements that can definitively assess an osteochondral defect, the hallmark of diagnosis is imaging. In order to gain the proper imaging, one must first have an appropriately high index of suspicion based on history and the physical examination.

Imaging

Osteochondral defects may involve the cartilage in isolation and at times a varying degree of the underlying subchondral bone, which means that standard radiographs (three views of the ankle, weight-bearing) is a good starting point for diagnosis. Radiographs can show loose bodies or larger fracture fragments. Often, even if a distinct displaced fragment is not identified, they can also hint at cystic change within the bone or show other injuries. Osteochondral defects, however, can often be missed on plain x-rays (which is one of the reasons that many may go undiagnosed for an extensive period of time), so if suspicion is sufficiently high, then advanced imaging with a CT scan or MRI is warranted. CT scan is very valuable when assessing the size of the bony component of the lesion, as well as displacement of the fragment and the cystic component of the defect. MRI can also be very helpful, in demonstrating edema within the talus and the defect within the talar cartilage, as well as loose bodies that are solely cartilaginous in nature.

Classification schemes for osteochondral defect exist using advanced imaging both for CT scan and MRI [11]. These classification schemes can be helpful in creating criteria for study for the lesions and have some ability to help with treatment, though in general the classification is a less important decision in the treatment as others.

Diagnostic Injections

As symptoms may at times be nonspecific, imaging may sometimes reveal an osteochondral defect that is asymptomatic. This may especially be the case in osteochondral defects seen in MRIs or CT scans that were ordered for the suspicion of other pathology (i.e., peroneal tendon tears, subtalar arthritis). As certain osteochondral defects may indeed be asymptomatic, we would suggest using diagnostic joint injections if questions of symptomatology exist. This involves injecting the tibiotalar joint with a local anesthetic or a local anesthetic and a steroid and then evaluating the response to the injection in terms of the patients' pain. This may help avoid surgeries that do not produce the desired outcome for the patient.

Treatment

The goals of treatment should be creating and maintaining a non-painful joint. Many factors can be helpful in determining appropriate treatment for osteochondral defects including symptomatology, chronicity, size, displacement, character (cartilage, bone), location, and containment (shoulder lesions). In addition, as osteochondral defects are often associated with either bony or ligamentous injuries, consideration should also be given to treating the cause of instability or deformity.

Nonoperative Treatment

As the natural history of these lesions has been shown to be stable over time, a trial of nonoperative treatment is appropriate for most patients [9, 12]. Nonoperative treatment usually consists of a period of non-weight-bearing (4–6 weeks) as well as immobilization to try and eliminate displacement of the fragment. Once immobilization is completed, then weight-bearing and motion are initiated within the ankle. This is commonly seen in patients who have an ankle sprain or non-displaced stable fracture that is amenable to nonoperative care, and initial radiographs show evidence of an osteochondral defect. In the absence of a loose body or a large displaced fragment, nonoperative treatment may be effective in relieving symptoms and allowing them to return to activity.

Nonoperative treatment is often advocated for young patients with a non-displaced osteochondral defect as it is thought that their healing potential is greater, especially if they have open physes. Reilingh et al. looked at 37 of these patients over a period of 4 years and found that 92% of these patients continued to have symptoms and eventually required surgery [13].

****The one caveat is that in patients with a loose body or larger lesions that encompass a greater portion of the articular surface that are potentially amenable to fixation are likely to ben-*

efit from more acute treatment to preserve the articular surface.

Operative Treatment

The goal of operative treatment is to create a stable surface anatomy of the talar dome, and provide stability to the ankle joint in order to neutralize the generation of pain. The decision for operative treatment (of the large fragment representing a substantial portion of the joint surface) is largely related to the symptomatology of the patient. With the exception of large osteochondral fragments with a large bony component, the treatment for acute and chronic lesions is relatively similar.

Operative treatment largely falls into three categories: open reduction and internal fixation, bone marrow stimulation, and transplantation and substitution. No matter which modality is chosen, pre-existing ankle instability, malalignment, or fracture that may have contributed to the osteochondral defect should also be corrected at the time of surgery; otherwise, there is increased risk of failure.

Open Reduction and Internal Fixation

Open reduction and internal fixation should be considered for lesions with a larger bony component as well as stable and healthy-appearing overlying cartilage. Judicious use of this technique may result in favorable outcomes in up to 89% of patients [14]. This of course leaves some discretion to the treating surgeon as what encompasses a “large fragment,” and exactly where the cutoff may be in these acute lesions has not to our knowledge been well studied. However, as bone stimulation techniques have shown good results with lesions <1.5 cm in diameter but poor results with defects that are larger, we would suggest using >1.0–1.5 centimeters as a good starting point for consideration of open reduction and internal fixation and especially if it also represents a deeper bony defect (>7 mm).

Open reduction and internal fixation may potentially be performed using minimal incisions with the assistance of arthroscopy though anatomic reduction of these fragments is a must to maintain the articular surface congruency, so surgeons should be ready to entertain the possibility of open arthrotomies or osteotomies to ensure proper visualization and fixation. Various arthrotomies (anterior, anteromedial, anterolateral, posterolateral, posteromedial) or osteotomies (medial malleolus, posterior malleolus, fibula) may be chosen depending on the location and pattern of the fracture/defect. As always, soft tissue skin bridges, and lesions need to be taken into account, as well as other procedures that need to be performed at the same time. *Temporary external fixation may also be considered if necessary to properly distract the joint in order to access and to improve visualization.* (See Example 9.1.)

Example 9.1: Open Reduction and Internal Fixation of Talar Dome Fracture

Position is supine on a radiolucent operating table. A medium external fixator should be available if not already applied in order to help with distraction across the joint and to help with access to the talar dome. If distraction is deemed necessary, one or two half pins should be placed into the tibial crest and a transfixation pin into the calcaneus to provide temporary distraction through the joint.

Approach should depend on the position of the fracture. For medially based fractures, a surgical approach can be made medial to the tibialis anterior and extended both proximally and distally with a linear arthrotomy to go into the joint. For anterolateral fractures, an anterolateral approach can be made in line with the fourth metatarsal and in between the tibia and fibula. Special care should be taken with this approach to preserve the superficial peroneal nerve. Conversely a traditional direct anterior approach can be taken in between the tibialis anterior and the extensor hallucis longus. This approach provides good access to the entire anterior ankle joint.

Osteotomies – If lesions are more posterior on either the medial or lateral talar dome, then an osteotomy of either the medial malleolus or fibula may be necessary to access the talar dome. These osteotomies should be performed into the shoulder of the joint. Often fixation with a plate and screws can be placed first into the virgin bone and then removed. This often allows for easier reduction after the osteotomy. The hardware is then removed, and a thin sagittal saw is used aimed distally toward the shoulder of the joint. This is best done using the C-arm for guidance. The saw is used down to subchondral bone but just short of the cartilage. An osteotome is then used very carefully to enter the joint. This helps to preserve the cartilage.

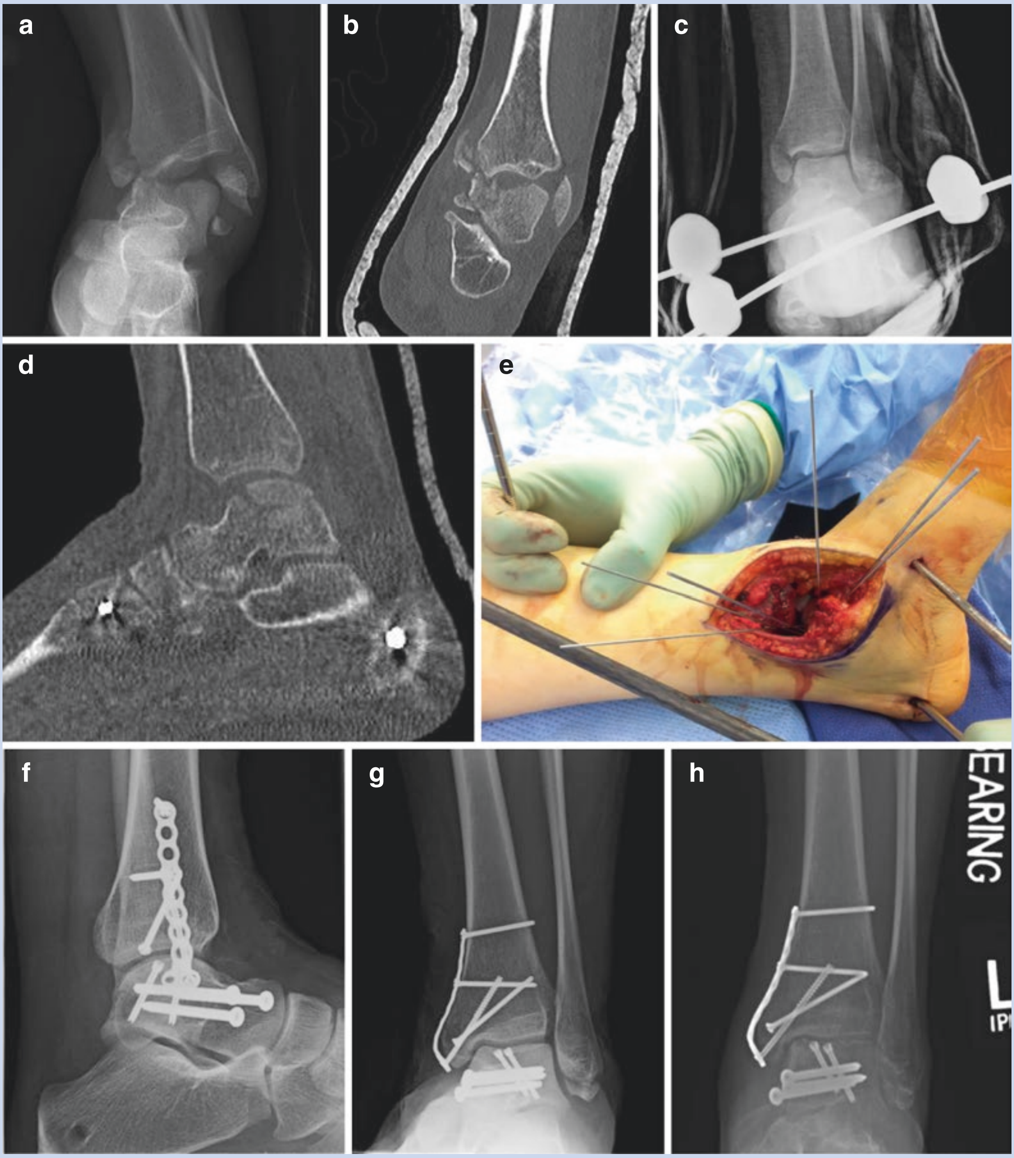
Fixation is performed next. The fracture pieces are identified and cleaned of interposed fibrous tissue. Special care is taken to preserve cartilage. Any cartilage at the edges of the fracture that is loose is trimmed with an effort to preserve as much cartilage as possible. Special care is taken to minimize contact with the articular cartilage directly. The piece is reduced, and if needed, it can be held with small Kirschner wires. If possible, placing these away from the weight-bearing surface is preferred. The fracture reduction should be confirmed both visually and radiographically. Small headless screws are then used to secure the fracture fragment to the talar dome. Be sure to place the heads of the screw several millimeters below the level of the cartilage so that the screws are not into the joint.

Closure is then performed in layers. If an osteotomy was performed, then the osteotomy is reduced and fixation placed. This should again be confirmed visually and using the C-arm.

Postoperative protocol usually involves placing the patient into a short-leg splint for 2 weeks. At 2 weeks, the patient can be taken out of the splint if the wounds are healed and gentle ROM of the ankle is performed. Progressive weight-bearing in a walking boot usually begins at week 6.

Once the articular fragment of the talus is identified, it is anatomically reduced back into its former position. Fixation is usually accomplished with absorbable pins or headless screws. For appropriate lesions, this technique can show favorable results in up to 89% of patients [14]. In subacute or chronic lesions, some authors have advocated lifting these lesions and then drilling the bone of both the fragment and the subchondral region in order to stimulate the healing response of the bone [15, 16].

Timing of the surgery for acute lesions should be related to when the soft tissues around the ankle will allow for safe surgery, especially when open arthrotomies are needed as is usually the case. Though arthroscopy may be planned, an open arthrotomy should always be recognized as a possibility and planned accordingly (see Example 9.1).



A 26-year-old woman in a motor vehicle collision sustaining an open medial malleolar and medial talar dome fracture with a completely displaced fragment (**a**, **b**). An initial irrigation and debridement with temporary reduction of the bony OCD was performed with placement of a temporary spanning external fixator (**c**, **d**). There was noted to be a sufficient bony portion of the OCD, so an ORIF was chosen. Once soft tissues were appropriate, an ORIF of the talar dome and neck were performed using the medial malleolar fracture for exposure (**e**). The talar dome fracture fixed with headless screws and the talar neck and medial malleolus secured with a plate and screws (**f**, **g**). Six months of follow up shows no evidence of collapse of the OCD (**h**)

Bone Marrow Stimulation

Drilling of the Subchondral Bone

A small subset of lesions may have cysts or edema with cartilage overlying that is stable in nature. In these instances, the goal of treatment is to stimulate the bone underlying the cartilage to fill in the defect or to provide a bone substitute filler into the defect. The stability of the lesion itself will need to be confirmed using either arthroscopy or an arthrotomy to ensure that the overlying cartilage is indeed intact and stable. Next, the lesion within the bone itself is addressed. This is most often done using a very small drill or Kirschner wire to puncture the lesion directly or indirectly through the talus and induce bleeding and inflammation into the defect. If a bone substitute (such as calcium sulfate) is to be used, then a drill is used to enter and debride the defect and a syringe used through the same drill hole in order to introduce the bone graft substitute [17]. These lesions represent a small subset of patients; still good results can be achieved in selective patients [18].

Excision and Abrasion

If an unstable lesion is present and fixation is not appropriate, then the goals of excision and abrasion are to remove the unstable portion of cartilage and to excise the bone. This is most often performed using an arthroscopic technique and shavers and/or curettes to remove and smooth the edges of the lesion, as well as the underlying subchondral bone, making it a stable bed for which fibrocartilage may then grow into the lesion. Through this, up to 77% of patients may achieve good results [19, 20].

Excision and Microfracture

For unstable and symptomatic lesions, arthroscopic excision and microfracture have become the gold standards of treatment for smaller (<1.5 cm) lesions. The goals of the treatment are to remove the unstable cartilaginous and bony portion and to stimulate blood flow into the defect. This blood flow from the bone marrow carries mesenchymal stem cells into the defect that will then potentially form fibrocartilage to cover the exposed bone and stabilize the articular surface.

Microfracture is most commonly performed arthroscopically when it is performed as a standalone procedure. Modern arthroscopic techniques, the use of distraction, and multiple portals (including posterior portals) allow for almost all lesions to be accessed and treated arthroscopically [11]. Open techniques may however also be employed, especially if the microfracture is performed in conjunction with another procedure such as a malleolar open reduction or a modified Brostrom procedure, where an open arthrotomy is already performed and the lesion may effectively be visualized and accessed.

Microfracture technique involves first identifying the borders of the lesion. Usually, this is performed using the probe to identify the unstable edge of the cartilage lesion. A shaver or curette is then used to remove the unstable portion of the cartilage down to a stable edge. The bone is then punctured using a small Kirschner wire or microfracture awls down into the subchondral bone (>3 mm deep). Drill holes are typically spaced out approximately 5 mm apart, and one or multiple holes may be indicated depending on the size of the lesion. After puncture, a bleeding response should be noted emanating from the hole to help judge effectiveness. Microfracture into a large cyst may not allow for blood flow into the area and thus is less likely to be effective (Example 9.2).

Example 9.2: Arthroscopic Microfracture

Position should be supine on a radiolucent table with an adjustable foot of the bed that can be lowered. This will allow for effective distraction of the ankle joint. A tourniquet can be placed onto the thigh. A hip bump is placed and possibly a kidney rest laterally to hold the leg. The leg is then placed into a leg holder at an approximately 45-degree angle with the holder secured proximal to the distal segment of the bed. This will allow the distal foot of the bed to be lowered, and the leg rest to remain still. A foam or gel pad is placed onto the leg holder, and special care taken to ensure there are no pressure points. The nonoperative leg is then secured to the distal segment of the bed. The leg is then prepped and draped. The distractor is then placed onto the end of the bed and the foot strap attached to the ankle. Initial manual traction is then placed and the holder secured. The foot of the bed can then be lowered to increase traction. This is usually performed until the straps are slightly taut.

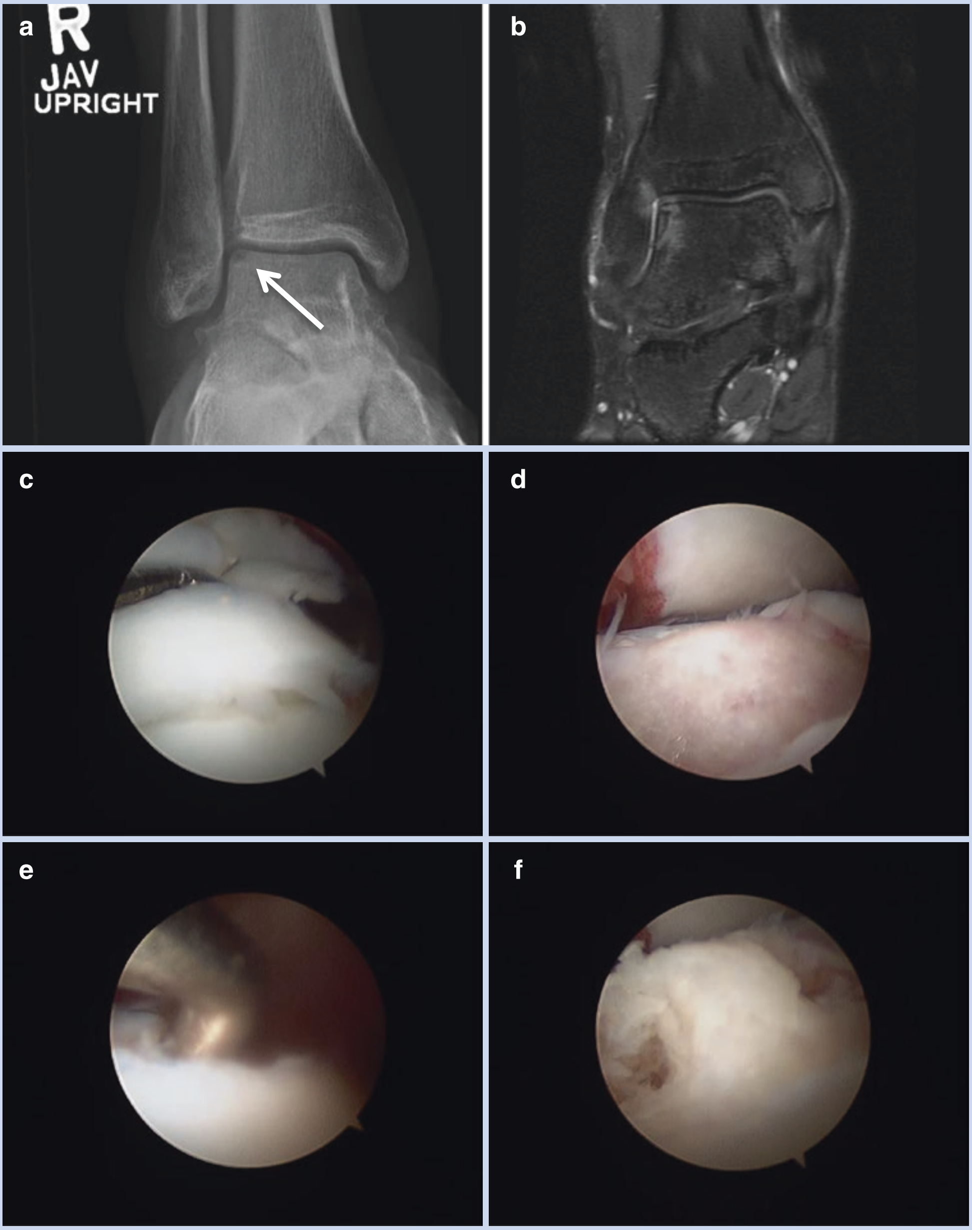
Approach is taken typically through an anteromedial and an anterolateral portal into the joint. Marking portal sites can sometimes be easier before the leg is on traction as the foot can be manipulated. The medial portal is usually established first. A needle is placed just medial to the tibialis anterior tendon at the level of the joint and entered into the joint space. Saline can then be injected into the joint to help with distraction, and the needle is removed. A small incision (~1.5 cm) is then made around the needle hole just through skin. Blunt dissection is then taken down onto the capsule using a clamp, and the trochar is used to enter the joint. The camera is then placed into the joint. A 2.7-mm camera is usually optimal, though for tight joints a 2.5-mm camera can also be used. Once the camera is placed, the anterolateral portal is established. This is usually placed just lateral to the peroneus tertius tendon, slightly proximal to the anteromedial portal. The camera can be used to visualize the anterolateral joint and a needle introduced through the anterolateral joint under direct visualization of the camera to ensure that this portal will allow access to the osteochondral defect. Again, a small incision is made just into skin where the needle was. Blunt dissection is then taken down into the joint.

Microfracture is then performed. The camera is placed in either the anteromedial or anterolateral portal and the probe placed through the other portal in order to access the lesion. A probe is used to palpate the cartilage and find the unstable portion overlying the osteochondral lesion. A small curette and a shaver are then used to remove the unstable cartilage overlying the lesion. The microfracture awl is then introduced through one of the portals into the lesion with the tip onto the bone of the talar dome. Due to the shape and curvature of the talar dome, awls are curved and sometimes even need to be pre-bent in order to access the joint and the lesion. The awl is then placed into the wound and placed perpendicular to the bone. Then, using a small mallet, the awl is punctured down into the subchondral bone. The number of punctures will depend on the size of the lesion attempting to space them out ~3 mm apart. The depth should be deep enough to ensure bleeding from the hole. If done properly, fat globules can be seen emanating from the wound, and if the water turned off or suction turned on, then blood will emanate from the holes as well.

Closure is then performed on the arthroscopy portal sites.

Postoperative protocol usually involves placing the patient into a short-leg splint for 2 weeks. At 2 weeks, the patient can be taken out of the splint if the wounds are healed and gentle ROM of the ankle is performed. Progressive weight-bearing in a walking boot usually begins at week 6.

Results of microfracture are highly correlated with the size of the lesion. Lesions <1.5 cm in diameter have consistently shown good to excellent results, and there appears to be a steep drop-off for lesions above this size [21, 22]. Contained lesions, i.e., ones with a stable edge, also appear to have better outcomes [23]. These good outcomes appear to have fairly good staying power as intermediate-term follow-up has shown continuation of these good results though there may be some evidence of diminishing results in longer-term follow-up [9, 24].



A 23-year-old man with an ankle sprain and continued pain despite physical therapy. X-rays show a possible OCD lesion (**a**). MRI confirms the presence of the lesions (**b**). Intra-operative arthroscopy photos showing the unstable cartilage flap (**c, d**) and the bare surface once the lesion has been debrided back to a stable edge. Microfracture awls then used to puncture two holes into the subchondral surface in order to stimulate the bone marrow and create a fibrocartilage layer (**e**, **f**).

Transplantation and Substitution

Lesions that are larger in diameter (>1.0–1.5 cm) or have a large cystic component do not show good results with microfracture, and thus transplantation/substitution techniques may then be considered. These techniques can also be effective when a patient has a smaller lesion but has failed a previous microfracture surgery [25, 26]. These procedures rely less on stimulation and more on replacement of local tissues.

Bone-Only Transplantation

Lesions with a large cystic region will benefit from bone being placed into the cystic defect. Once the unstable portion of the cartilage is removed, the sclerotic bone forming the outline of the cyst is scraped using a curette, drilled, or reamed. This hole can then be filled with either allograft or autograft bone. This autograft may either be in the form of a dowel or of particulate cancellous bone from either the distal tibia metaphysis or the iliac crest [27]. This bone plug may then be covered with fibrin glue to help stabilize the transplanted bone. The results of bone-only transplantation are questionable with reports showing patient satisfaction as low as 46% [27].

Osteochondral Transplantation

In addition to transplanting bone, a popular technique for larger lesions involves coring out the specific area of cartilage and bone involved in the lesion and replacing with a dowel containing bone as well as overlying cartilage. This can be performed using either autograft or allograft with advantages and disadvantages to each.

Autograft is the more popular option and may be taken from multiple areas, the most common of which is from the trochlea of the ipsilateral knee. Special care needs to be taken to match the contour and depth of the plug as the knee cartilage is thicker and the trochlea curvature is not matched to the talus. The advantage of autograft is the increased healing potential and low cost. The biggest disadvantage is the potential of donor site morbidity (i.e., knee pain) though rates of donor site issues are relatively low [28].

If autograft is not used, either fresh or frozen allograft talus may also be used for these larger lesions. Allograft allows for an easier contour and articular match as the plugs can be taken from the corresponding area of the donor talus. This may be especially helpful in shoulder lesions. Allograft can also be advantageous in especially large lesions where multiple plugs may need to be used; also multiple plugs can theoretically increase donor site morbidity. Disadvantages include cost, graft failure, and availability, especially if a fresh frozen allograft is chosen. Multiple plugs are likely less well tolerated from the knee, and thus allograft may be a better choice when multiple plugs are needed. Though frozen allograft may be employed, there is evidence of increased healing potential with fresh frozen allograft [29, 30].

For both allograft and autograft, special care needs to be taken to match the graft and contour well to the articular surface. Upon impacting the graft, care should be taken to impact the graft to just below the surface of the cartilage. Proud cartilage can lead to shearing of the cartilage, and thus they should be impacted to the level of the cartilage or slightly below. One or two plugs may be utilized depending on the size and location of the lesion. For very anterior lesions, the osteochondral allograft transplantation (OAT) procedure can sometimes be performed using a plafondplasty where the very anterior portion of the plafond is resected to allow for placement of the graft. In most circumstances, an osteotomy of either the tibia or fibula will need to be performed in order to properly access the lesion and to place the graft (see Example 9.3)

Example 9.3: Osteochondral Allograft Transplantation

Preoperative planning should be performed to acquire either a frozen talus or a fresh frozen talus if desired. Same side is preferable but is not a requirement. If these are not possible, then autograft from the ipsilateral knee should be considered and discussed with the patient.

Approach should depend on the position of the fracture. For medially based fractures, a surgical approach can be made medial to the tibialis anterior and extended both proximally and distally with a linear arthrotomy to go into the joint. For anterolateral fractures, an anterolateral approach can be made in line with the fourth metatarsal and in between the tibia and fibula. Special care should be taken with this approach to preserve the superficial peroneal nerve. Conversely, a traditional direct anterior approach can be taken in between the tibialis anterior and the extensor hallucis longus. This approach provides good access to the entire anterior ankle joint.

Osteotomies – If lesions are more posterior on either the medial or lateral talar dome, then an osteotomy of either the medial malleolus or fibula may be necessary to access the talar dome. These osteotomies should be performed into the shoulder of the joint. Often, fixation with a plate and screws can be placed first into the virgin bone and then removed. This often allows for easier reduction after the osteotomy. The hardware is then removed, and a thin sagittal saw is used aimed distally toward the shoulder of the joint. This is best done using the C-arm for guidance. The saw is used down to subchondral bone but just short of the cartilage. An osteotome is then used very carefully to enter the joint. This helps to preserve the cartilage.

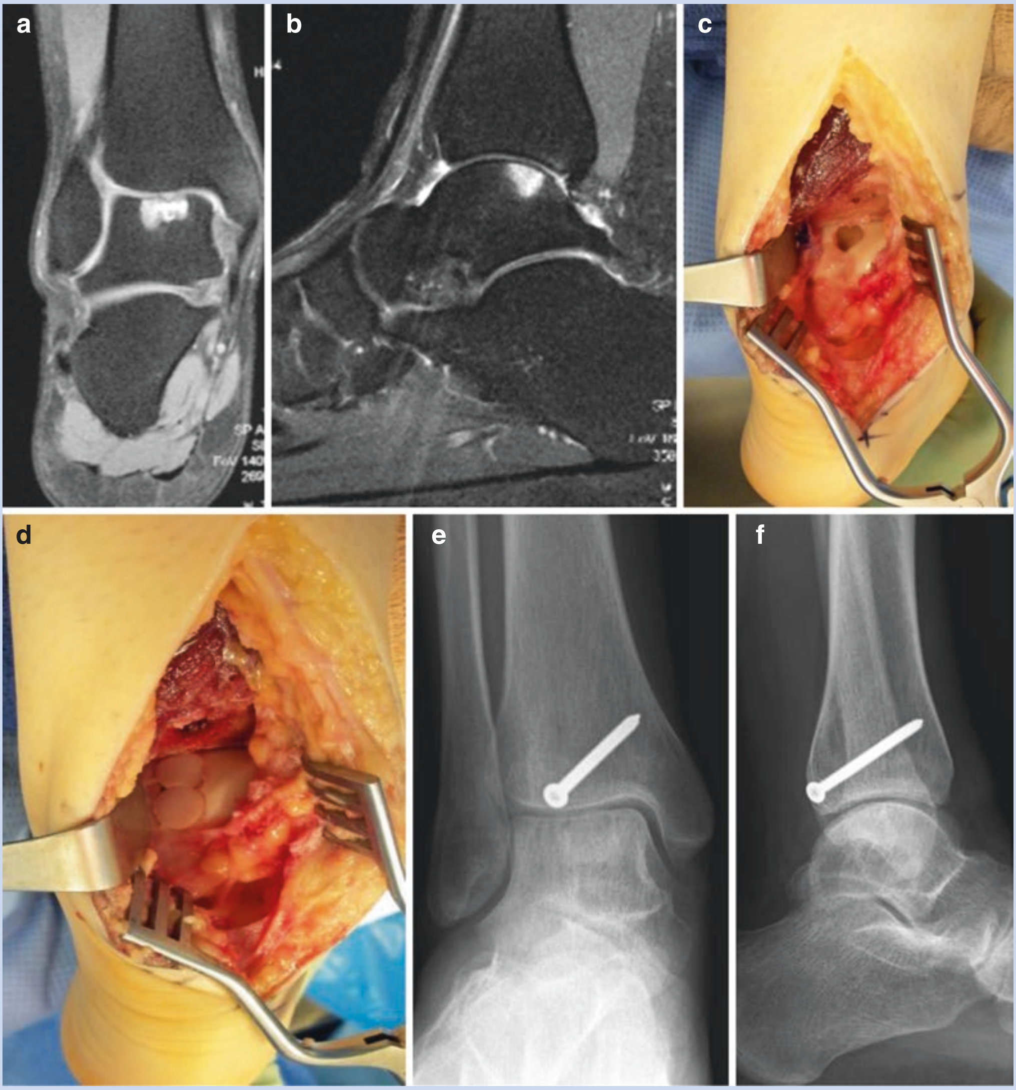
Allograft transplantation is performed next**.** The osteochondral defect is identified, and the sizer used for the small joint OATs is set to establish the size of the lesion, the number of plugs needed, and the best orientation in order to fit the shape of the lesion. Care should be taken to encompass the whole lesion, and for the large lesion, multiple plugs are sometimes needed. The cartilage lesion can then be removed using a curette though this is not necessary. The guidewire is then placed into the center of the lesion where the plug will be placed. The properly sized reamer is then used over the guidewire down to a depth of 10–15 mm. The reamer and wire are then removed, and the sizer is used to measure the depth of the hole.

The allograft plug is then harvested. The allograft can be fresh or frozen, and a whole talus is preferred in order to match the architecture.

Autograft can also be used if preferred or allograft is unavailable. The most common spot is taken from the non-weight-bearing portion of the trochlea of the ipsilateral knee.

The corresponding portion of the allograft talus is then identified. The coring tool is then placed onto the corresponding area of the talus and impacted down onto the proper depth. The plug is then removed and the depth of the plug measured. If need be, extra bone can be removed from the bottom of the plug to ensure that it is the same depth as the hole that is drilled or slightly less. The plug is then placed into the hole trying to match the curvature of the plug to the hole and the talar dome. It is then gently pushed down into place using the twisting mechanism of the inserter. It is then finished using the impactor. The plug should be placed flush to the surface of the talus or slightly depressed compared to the surrounding talar dome. It should not be left proud. If multiple plugs are needed, they should be placed directly next to each other and touching. Both cores should be drilled first and then the plugs placed one at a time.

Postoperative protocol usually involves placing the patient into a short-leg splint for 2 weeks. At 2 weeks, the patient can be taken out of the splint if the wounds are healed and gentle ROM of the ankle is performed. Progressive weight-bearing in a walking boot usually begins at week 6.



A 26-year-old soccer player who has been having intermittent pain and swelling in her ankle after activity for the past year. MRI confirms the presence of a central posterior OCD with a large cystic component (**a**, **b**). Given the cystic nature of the lesion and OATs, procedure was chosen through an open posterolateral approach in between the FHL and peroneals and a posterior malleolar osteotomy (**c**). Two bone plugs were utilized to incorporate the entirety of the defect for both the cartilage and the subchondral portions (**d**). A single screw was used to fix the osteotomy into place, and there was good evidence of healing with return to full activity at 6 months (**e**, **f**). Images courtesy of Michael Brage, MD

Autologous Chondrocyte Implantation (ACI)

ACI utilizes the patient's own cartilage cells in order to create new cartilage to be implanted. This requires harvesting of chondrocytes through a surgical procedure that are then cultured in a lab in order to expand them. Once the cartilage has been expanded, it is then implanted back into the cartilage defect using either a cartilage patch (first generation) or a carrier scaffold (second generation). Cartilage is most commonly harvested from the ipsilateral knee though more recently cartilage harvest within the talar defect has also been described and obviates potential donor site issues with the knee [31, 32]. ACI is typically reserved for young patients with larger defects and a shallower cystic portion of the lesion. It may also be effective in patients who have failed a previous microfracture with good results [25]. The major drawbacks of ACI are the extensive cost and the multiple procedures and time necessary as well as the risk of donor site morbidity though this risk is very low.

Juvenile Chondrocytes (JCs)

Juvenile chondrocytes are allograft donor tissue composed of particulate cartilage from juvenile donors (proprietary product of Zimmer, Warsaw, Indiana). These particulate pieces are placed onto a bed of fibrin glue within the defect and then covered again with fibrin glue. This can be done either arthroscopically or through an osteotomy (see Example 9.4). They are indicated for larger lesions or when prior microfracture has failed. Coetzee has shown good results in the use of juvenile chondrocytes after a failed microfracture surgery with 78% (18/24) patients reporting good results [26]. The main downside with juvenile chondrocytes is cost and availability as they are a donor tissue. Recently other micronized cartilage substitutes have become available.

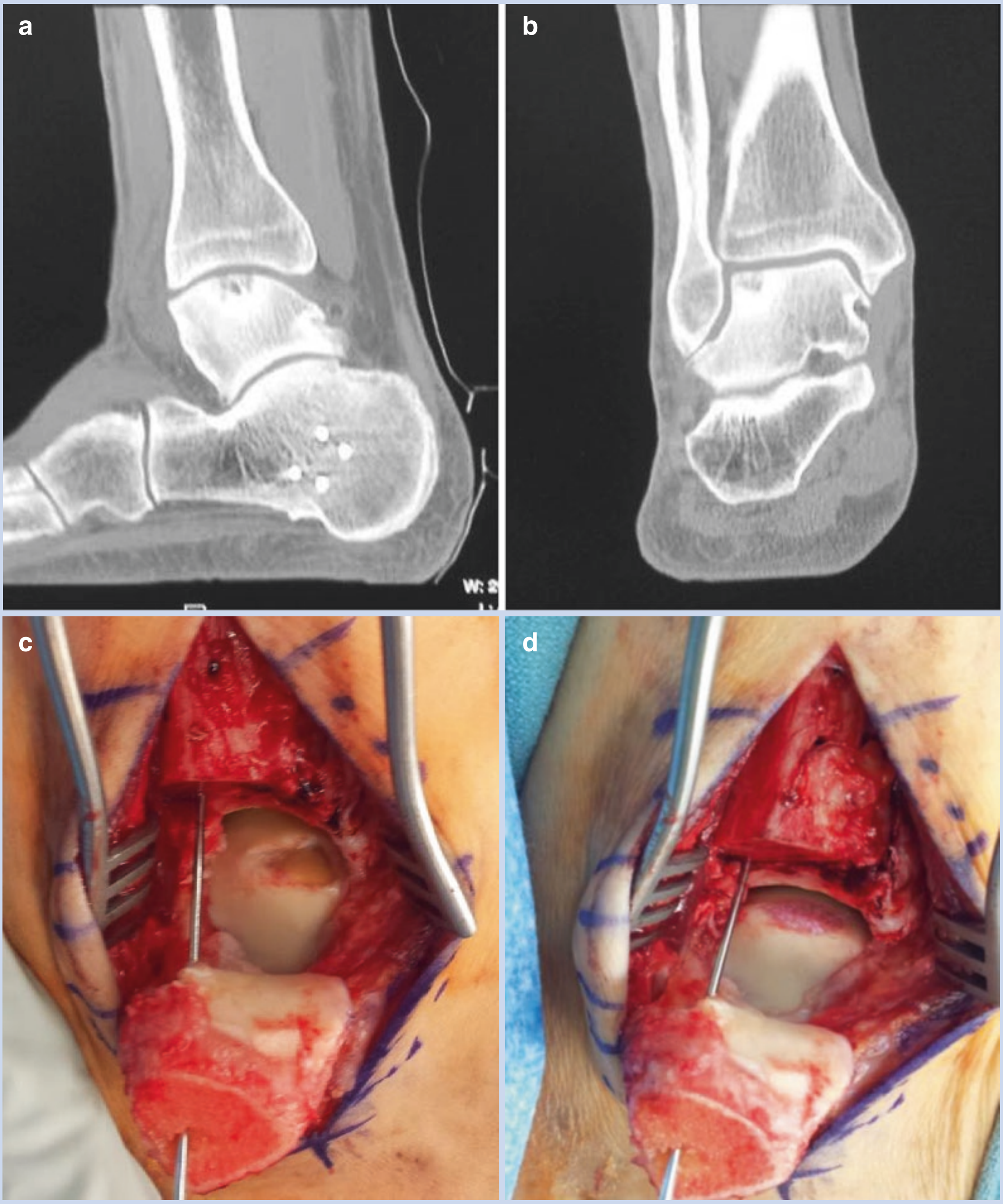
Example 9.4: Juvenile Chondrocytes

Approach can be made through any of the approaches described in Example 9.1 or Example 9.3. This can also be performed using arthroscopy (see section below). Adequate access to the osteochondral defect is necessary, and the approach should be planned according to the position of the osteochondral defect.

Fixation of the juvenile chondrocytes is performed next. Any unstable cartilage flaps are removed sharply using a knife to a stable cartilage edge. If there is a cyst present, this cyst should be debrided using a curette to remove any sclerotic bone. Bone allograft or autograft is then impacted into the cyst to a level a few mm below the cartilage. Fibrin glue is then applied over the top of the bone or bone graft. The juvenile chondrocytes are then laid onto the fibrin glue bed and evenly spread out using a freer. A second layer of fibrin glue is then applied over the top of the juvenile chondrocytes.

If arthroscopic placement is desired, the same protocol is followed for arthroscopic microfracture including removal of the cartilage. The water is then turned off. Using cotton wisps, the area of the osteochondral defect is then dried using cotton wicks. Sometimes the medial or lateral portal will need to be extended slightly to get the wicks into the joint at the proper place. Once the area is dry, then a layer of fibrin glue is placed using the thin tip of the syringe. The juvenile chondrocytes can then be placed by using a metal cannula. It is often best to front-load the cannula with the juvenile chondrocytes before introducing them into the joint and then using the trochar to gently push out the juvenile chondrocytes onto the bed of fibrin glue. The trochar can then be removed, and a small freer can be introduced to carefully smooth out the juvenile chondrocytes. A second layer of fibrin glue is then placed over the top. The camera and trochar are then removed.

Postoperative protocol usually involves placing the patient into a short-leg splint for 2 weeks. At 2 weeks, the patient can be taken out of the splint if the wounds are healed and gentle ROM of the ankle is performed. Progressive weight-bearing in a walking boot usually begins at week 6.



A 32-year-old man with 2 year of pain in his ankle. He had undergone a previous calcaneal osteomy and microfracture but had continued symptoms. Repeat CT scan showed the lesion along the lateral shoulder (**a**, **b**). Given his failed microfracture, juvenile chondrocytes were chosen as this was a relatively shallow lesion. This was performed using a fibular osteotomy (**c**). The cartilage defect was larger than appeared on CT scan and showed a sizable defect once fully debrided to stable edge (**c**). The Juvenile chondrocytes were then packed into the area to completely cover the lesion (**d**).

Large Bulk Allograft

For very large lesions that encompass a very large portion of the talar dome and for which even multiple allograft plugs or juvenile chondrocytes would not be possible, a bulk allograft can be used. This is usually reserved for young patients whose lesions encompass half or more of the talus. Due to the large nature of the graft needed, and to allow for the best chance at healing, fresh allograft (2 weeks or less) is a must. When at all possible, radiographs or a CT scan is used to measure the size of the talus, and a suitable match in size is used to allow for the best match of the talar dome circumference.

In these cases, the lesion is removed carefully using a small sagittal saw and osteotomes to create a stable platform on which to place the graft. A corresponding cut is then made on the allograft to match the removed section of talus. The allograft is then placed into the corresponding defect and secured using pins or headless screws (see Example 9.5).

Example 9.5: Large Bulk Allograft

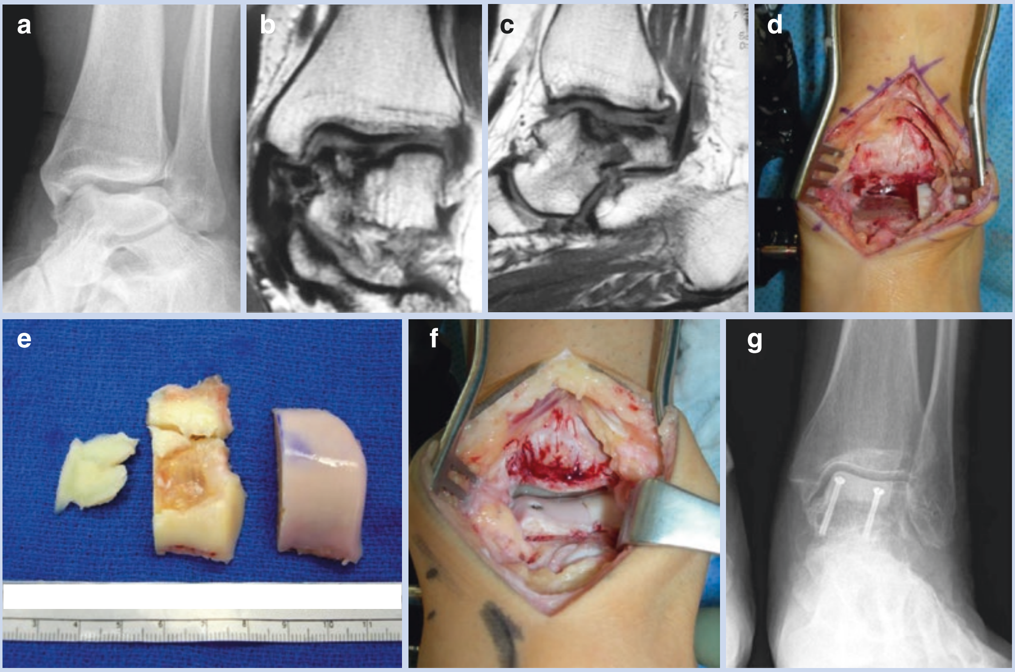
Preoperative planning should be performed to find a fresh frozen allograft with the appropriate dimensions. This can be difficult and sometimes requires the patient to be “on call” for a talus to become available. The talus needs to be size matched. The patient’s talar dome dimensions should be measured on radiographs. A calibration marker may need to be placed onto the radiographs for sizing. AP and lateral views should then be taken to acquire the dimensions of the talar dome. The fresh allograft should closely match the dimensions of the talar dome circumference, especially if the whole dome of the talus is used.

Approach for large bulk allograft is made through a direct anterior approach as described in Example 9.1.

Removal of the damaged portion of the dome is performed first. A very thin sagittal saw is used to remove the portion of the talar dome that is diseased. If the entire dome is to be removed, it can be done using one cut from anterior to posterior to remove the dome and create a flat surface on top of the talus. Special care should be taken with the depth to ensure the cystic portion of the talus is removed and healthy subchondral bone is left. If less than the whole dome is to be replaced, then the saw should be used to make two cuts at a right angle to one another. The corresponding cut is then made in the allograft tendon. The allograft is then placed into the defect and secured using two screws along the anterior portion of the graft. Headless screw or small-headed screws can be used. If using headless screws, be cautious about the depth of the allograft and the depth of the proximal threads on the screw. If a headed screw is used, then it should be placed just below the level of the cartilage onto the bone to secure the allograft in place.

Postoperative protocol usually involves placing the patient into a short-leg splint for 2 weeks. At 2 weeks, the patient can be taken out of the splint if the wounds are healed and gentle ROM of the ankle is performed. Progressive weight-bearing in a walking boot usually begins at 8–12 weeks. Patients should be followed for the first 2–3 years as collapse can happen even at later dates.

The advantages of bulk allograft are the versatility of the graft and the ability to plug very large defects. Cost and donor availability can be especially difficult as getting a size and laterality match can be very important. Outcomes of large allograft have been mixed. Raikin et al. showed 11/15 with good to excellent results at 54 months though this was a small series of 15 patients [33]. Even with mixed results, this may be considered in young patients with very large lesions in an effort to avoid or prolong the need for tibiotalar fusion or arthroplasty.



A 40-year-old woman with a long history of ankle pain and a history of multiple sprains. X-rays and a CT scan showed an osteochondral defect encompassing nearly the entire medial portion of the talar dome (**a**–**c**). Given the size of the lesion, and the patient's strong desire to not have an ankle fusion, a fresh allograft replacement was chosen. An anterior approach is utilized and the defect removed very carefully using a sagital saw and osteotomes (**d**). A defect is then measured and the corresponding graft is cut from the allograft talus (**e**). The graft is then inserted into the defect and secured using buried screws (**f**). Six months of follow up shows no evidence of collapse, and the patient is walking with minimal pain (**g**). Images courtesy of Michael Brage, MD

Postoperative Care

Postoperative cares usually involves a period of non-weight-bearing on the affected limb for a period of 2 to 6 weeks to allow healing of the bone and to protect the forming or healing cartilage. Early motion is likely helpful for developing cartilage and is also helpful in preventing joint stiffness, and thus most postoperative protocols will emphasize range of motion of the joint, once incisions have healed. For this reason, if ligamentous repairs or osteotomies are performed, fixation should be adequate to allow for early range of motion of the joint.

For open reduction and internal fixation, the patient is placed in a well-padded postoperative splint for 2 weeks. At 2 weeks, the splint is taken down, incisions inspected, and sutures removed if the wound is healed. The patient is placed into a removable boot or splint and allowed to start gentle range of motion. At 6 weeks, non-weight-bearing radiographs are obtained, and if stable, the patient is allowed progressive weight-bearing.

A similar postoperative protocol is suggested for juvenile chondrocytes to protect the healing plug though weight-bearing may be initiated at 4 weeks instead of 6 [11]. The non-weight-bearing period is maintained at 6 weeks for both osteochondral allograft transplantation and large bulk allograft in order to allow for appropriate healing of the bone to bone interface prior to stressing the repair.

In the case of arthroscopic microfracture, the most common practice is to keep these patients' non-weight-bearing until 6 weeks to protect the plug. A recent randomized trial however has shown similar results in patients that were allowed progressive weight-bearing at 2 weeks compared with waiting until 6 weeks, which may suggest earlier weight-bearing is safe and effective [34]. Patients may then return to full activity including sports at 4–6 months' time.

Summary

The congruent and contained anatomy of the talus within the mortise of the ankle is protective against injury to the cartilage of the talar dome. When this congruency is disrupted through either trauma or other means, the cartilage of the talar dome may become susceptible to injury. These injuries represent a spectrum of injuries from large fracture encompassing large amount of bone and joint cartilage, to subchondral edema or cyst formation solely, to isolated injury of the cartilage. The natural history presents little evidence of healing, but also little progression. As a result, treatment decisions are largely based on symptomatology except in the case of large acute lesions. Operative treatment is usually reserved for patients with continued pain despite nonoperative treatment. Operative techniques continue to evolve and are best dictated by the location and character of the lesion. With appropriate care, good long-term results can be achieved.

References

1. Orr JD, Dawson LK, Garcia EJ, Kirk KL. Incidence of osteochondral lesions of the talus in the United States military. Foot Ankle Int/Am Orthop Foot Ankle Soc [and] Swiss Foot Ankle Soc. 2011;32(10):948–54.
2. van Dijk CN, Reilingh ML, Zengerink M, van Bergen CJ. Osteochondral defects in the ankle: why painful? Knee Surg Sports Trauma Arthros. 2010;18(5):570–80.
3. Ramsey PL, Hamilton W. Changes in tibiotalar area of contact caused by lateral talar shift. J Bone Joint Surg Am. 1976;58(3):356–7.
4. Thordarson DB, Motamed S, Hedman T, Ebramzadeh E, Bakshian S. The effect of fibular malreduction on contact pressures in an ankle fracture malunion model. J Bone Joint Surg Am. 1997;79(12):1809–15.
5. Hintermann B, Regazzoni P, Lampert C, Stutz G, Gachter A. Arthroscopic findings in acute fractures of the ankle. J Bone Joint Surg. 2000;82(3):345–51.
6. Saxena A, Eakin C. Articular talar injuries in athletes: results of microfracture and autogenous bone graft. Am J Sports Med. 2007;35(10):1680–7.
7. Verhagen RA, Struijs PA, Bossuyt PM, van Dijk CN. Systematic review of treatment strategies for osteochondral defects of the talar dome. Foot Ankle Clin 2003;8(2):233–242. viii–ix.
8. Woods K, Harris I. Osteochondritis dissecans of the talus in identical twins. J Bone Joint Surg. 1995;77(2):331.
9. Schuman L, Struijs PA, van Dijk CN. Arthroscopic treatment for osteochondral defects of the talus. Results at follow-up at 2 to 11 years. J Bone Joint Surg 2002;84(3):364–368.
10. Loomer R, Fisher C, Lloyd-Smith R, Sisler J, Cooney T. Osteochondral lesions of the talus. Am J Sports Med. 1993;21(1):13–9.
11. Wodicka R, Ferkel E, Ferkel R. Osteochondral lesions of the ankle. Foot Ankle Int/Am Orthop Foot Ankle Soc [and] Swiss Foot Ankle Soc. 2016;37(9):1023–34.
12. Klammer G, Maquieira GJ, Spahn S, Vigfusson V, Zanetti M, Espinosa N. Natural history of nonoperatively treated osteochondral lesions of the talus. Foot Ankle Int/Am Orthop Foot Ankle Soc [and] Swiss Foot Ankle Soc. 2015;36(1):24–31.
13. Reilingh ML, Kerkhoffs GM, Telkamp CJ, Struijs PA, van Dijk CN. Treatment of osteochondral defects of the talus in children. Knee Surg Sports Traum Arthros. 2014;22(9):2243–9.
14. Kumai T, Takakura Y, Kitada C, Tanaka Y, Hayashi K. Fixation of osteochondral lesions of the talus using cortical bone pegs. J Bone Joint Surg. 2002;84(3):369–74.
15. Dunlap BJ, Ferkel RD, Applegate GR. The "LIFT" lesion: lateral inverted osteochondral fracture of the talus. Arthroscopy. 2013;29(11):1826–33.
16. Kerkhoffs GM, Reilingh ML, Gerards RM, de Leeuw PA. Lift, drill, fill and fix (LDFF): a new arthroscopic treatment for talar osteochondral defects. Knee Surg Sports Trauma Arthros. 2016;24(4):1265–71.
17. Kennedy JG, Suero EM, O'Loughlin PF, Brief A, Bohne WH. Clinical tips: retrograde drilling of talar osteochondral defects. Foot Ankle Int/Am Orthop Foot Ankle Soc [and] Swiss Foot Ankle Soc. 2008;29(6):616–9.
18. Seo SS, Park JY, Kim HJ, Yoon JW, Park SH, Kim KH. Percutaneous osteoplasty for the treatment of a painful osteochondral lesion of the talus: a case report and literature review. Pain Physician. 2012;15(5):E743–8.
19. O'Farrell TA, Costello BG. Osteochondritis dissecans of the talus. The late results of surgical treatment. J Bone Joint Surg. 1982;64(4):494–7.
20. Zengerink M, Struijs PA, Tol JL, van Dijk CN. Treatment of osteochondral lesions of the talus: a systematic review. Knee Surg Sports Trauma Arthros. 2010;18(2):238–46.

21. Chuckpaiwong B, Berkson EM, Theodore GH. Microfracture for osteochondral lesions of the ankle: outcome analysis and outcome predictors of 105 cases. Arthroscopy. 2008;24(1):106–12.
22. Choi WJ, Park KK, Kim BS, Lee JW. Osteochondral lesion of the talus: is there a critical defect size for poor outcome? Am J Sports Med. 2009;37(10):1974–80.
23. Kim YS, Lee HJ, Choi YJ, Kim YI, Koh YG. Does an injection of a stromal vascular fraction containing adipose-derived mesenchymal stem cells influence the outcomes of marrow stimulation in osteochondral lesions of the talus? A clinical and magnetic resonance imaging study. Am J Sports Med. 2014;42(10):2424–34.
24. Ferkel RD, Zanotti RM, Komenda GA, et al. Arthroscopic treatment of chronic osteochondral lesions of the talus: long-term results. Am J Sports Med. 2008;36(9):1750–62.
25. Kwak SK, Kern BS, Ferkel RD, Chan KW, Kasraeian S, Applegate GR. Autologous chondrocyte implantation of the ankle: 2- to 10-year results. Am J Sports Med. 2014;42(9):2156–64.
26. Coetzee JC, Giza E, Schon LC, et al. Treatment of osteochondral lesions of the talus with particulated juvenile cartilage. Foot Ankle Int/Am Orthop Foot Ankle Soc [and] Swiss Foot Ankle Soc. 2013;34(9):1205–11.
27. Kolker D, Murray M, Wilson M. Osteochondral defects of the talus treated with autologous bone grafting. J Bone Joint Surg. 2004;86(4):521–6.
28. Paul J, Sagstetter A, Kriner M, Imhoff AB, Spang J, Hinterwimmer S. Donor-site morbidity after osteochondral autologous transplantation for lesions of the talus. J Bone Joint Surg Am. 2009;91(7):1683–8.
29. Rubel IF, Carrer A. Fresh-frozen osteochondral allograft reconstruction of a severely fractured talus. A case report. J Bone Joint Surg Am. 2005;87(3):625–9.
30. Ahmad J, Jones K. Comparison of osteochondral autografts and allografts for treatment of recurrent or large Talar osteochondral lesions. Foot Ankle Int/Am Orthop Foot Ankle Soc [and] Swiss Foot Ankle Soc. 2016;37(1):40–50.
31. Kreulen C, Giza E, Kim J, Campanelli V, Sullivan M. Viability of talus osteochondral defect cartilage for chondrocyte harvesting: results of 151 patients. Foot Ankle Int/Am Orthop Foot Ankle Soc [and] Swiss Foot Ankle Soc. 2014;35(4):341–5.
32. Niemeyer P, Salzmann G, Schmal H, Mayr H, Sudkamp NP. Autologous chondrocyte implantation for the treatment of chondral and osteochondral defects of the talus: a meta-analysis of available evidence. Knee Surg Sports Trauma Arthros. 2012;20(9):1696–703.
33. Raikin SM. Fresh osteochondral allografts for large-volume cystic osteochondral defects of the talus. J Bone Joint Surg Am. 2009;91(12):2818–26.
34. Lee DH, Lee KB, Jung ST, Seon JK, Kim MS, Sung IH. Comparison of early versus delayed weightbearing outcomes after microfracture for small to mid-sized osteochondral lesions of the talus. Am J Sports Med. 2012;40(9):2023–8.

Part III

Tarsal Dislocations

10

Fractures and Dislocations of the Talus and Calcaneus: A Case-Based Approach

Michael Jung, Joseph Galloway,
and Jonathan Eastman

Peritalar and Subtalar Dislocations

Introduction/Background

Fractures or dislocations of the talus are uncommon injuries, accounting for approximately 1% of all fractures [1]. These injuries are most commonly seen in the setting of motor vehicle accidents or falls from height. The predominant demographic affected is young adult males aged 20–39 [1, 2]. Approximately 86% of patients with talus fractures have an additional associated fracture. The most commonly associated fracture is that of the malleoli seen in ~22% of cases. Other commonly associated fractures include those of the spine, femur, and, in 4% of cases, the calcaneus [3].

Traumatic injury to the subtalar joint may occur during subtalar dislocations, talus or calcaneus intra-articular fractures, and fracture-dislocations. In fractures and fracture-dislocations of the talus and calcaneus involving the subtalar joint, anatomic reconstruction of joint congruity is paramount for optimizing outcomes. If the subtalar joint is not reduced anatomically, the patient is at risk for chronic instability, subtalar arthritis, and hindfoot deformity. These issues can be symptomatic and cause significant morbidity to the patient [4, 5].

Operative treatment of displaced, intra-articular fractures involving the talus and calcaneus are difficult. Anatomic reduction is essential, and the soft tissues must be respected in order to minimize complications and optimize outcomes. In this chapter, we outline proper methods for diagnosis and surgical management of fractures and fracture-dislocations of the talus and calcaneus.

Diagnosis/Management

A thorough history will typically reveal an acute trauma resulting in immediate pain at the foot or ankle and the inability to bear weight. Examination of the skin is expected to reveal swelling of the hindfoot; in cases of fracture-dislocation, there can be severe deformity with tethering of the skin. Other skin issues that are possible are traumatic wounds and fracture blisters [6]. The status of the neurovascular bundle also has treatment implications and is part of the standard exam.

Initial imaging work-up includes radiographs of the foot and ankle. Computed tomography (CT) scans are also recommended for more

M. Jung (✉) · J. Galloway
Orthopaedic Surgery, Rutgers New Jersey Medical School, Newark, NJ, USA
e-mail: jungmt@njms.rutgers.edu; jdg207@njms.rutgers.edu

J. Eastman
Orthopaedic Surgery, University of California, Sacramento, CA, USA
e-mail: jgeastman@ucdavis.edu

© Springer Nature Switzerland AG 2020
M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_10

detailed evaluation of fracture morphology, displacement, and preoperative planning [1, 7]. There are other radiographic views that have utility in evaluating the hindfoot. Broden's view can be used to visualize the subtalar joint preoperatively and will be used in the operating room with fluoroscopic examination to evaluate the accuracy of joint reduction [8]. The Canale view aids in the visualization of the long axis of the talar neck. The Harris heel view provides an axial view of the hindfoot.

Dislocations should be immediately identified and reduced. The need for immediate reduction is especially pressing in the setting of neurovascular compromise and/or skin ischemia. Medial subtalar dislocations display a medially displaced heel, inversion, and plantarflexion of the foot. Medial dislocations more commonly have an associated fracture. In lateral subtalar dislocations, the heel is displaced laterally and the foot is in eversion and abduction. These are more frequently associated with open injuries [9]. Tongue-type calcaneus fractures can also cause skin breakdown rapidly.

In approximately 10% of peritalar dislocations, there will be a mechanical block to reduction. In medial dislocations, the talar head may buttonhole through the extensor digitorum brevis tendon. Lateral dislocations can be obstructed by interposed tibialis posterior tendon [10]. Multiple closed reduction attempts are not recommended, as this may cause further articular and soft tissue damage.

Emergency operative intervention is indicated in the setting of irreducible dislocations, associated neurovascular impingement/compromise, open fractures and dislocations, or an extruded talus.

If successful reduction of a subtalar or peritalar dislocation is obtained, then management is dictated by the stability of the joint, the involvement of the articular surface, and the condition of the soft tissue envelope. Peritalar fractures can cause residual instability and must be identified. Post-reduction CT examination is recommended as fractures of the posterior talar process or sustentaculum can be missed on plain radiographs [11–13]. After lateral subtalar dislocations, the lateral process of the talus must be carefully inspected for a fracture. As these fractures are articular, ORIF is indicated for displaced articular fractures for fragments of sufficient size [14].

If the joint is stable after closed reduction and there are no associated articular fractures that warrant operative management, then the patient should be immobilized and made non-weight bearing in a short leg cast for 6 weeks. After this, a protocol of progressive weight bearing and physiotherapy is begun. Good results have been obtained in patients with full weight bearing starting at 10–11 weeks from injury [15]. However, if residual instability is identified, options include external fixation and transarticular Kirschner wire fixation for 3–4 weeks [14].

In the case of open dislocations or irreducible dislocations from entrapped soft tissue necessitating open reduction, soft tissue management will dictate immobilization. These merit external fixator immobilization to facilitate wound care. Occasionally massive soft tissue swelling or traumatized skin may prohibit cast treatment after closed reduction even if it is stable. In these, external fixators have also been used with good results leading to weight bearing around 10–12 weeks [15].

Results and Complications

Peritalar injury with subtalar dislocations as a whole are relatively rare, and even more so to occur in isolation. Eighty-eight percent of these injuries are associated with at least one other foot or ankle injury. The most commonly associated injury is fracture to the talus itself, followed closely by injuries to the ankle, found in 60% and 52% of cases, respectively, in one series [16]. Calcaneus fractures were found to occur in up to 16% of cases. Interestingly, the midtarsals and metatarsals are relatively infrequently injured in association with peritalar dislocations [16]. As a result of the high rate of concomitant injuries, studies looking at outcomes are limited and frequently confounded.

Complications reported include post-traumatic arthritis of the subtalar and tibiotalar joint, avascular necrosis of the talus, tendon injuries, neurovascular injury, skin necrosis and wound breakdown, hindfoot stiffness, and with open injuries deep soft tissue and bone infections [9, 14].

Several have reviewed the rates of subtalar arthritis and subsequent subtalar fusion seen in peritalar injury patterns. Subtalar dislocations are reported with a wide range from 39% to 89% developing radiographic subtalar arthritis; however, only about one-third of these will have clinical symptoms requiring fusion [14, 16, 17]. This wide range of data is likely a reflection of the array of severity of these injuries with higher energy, leading to worse arthritis and subsequent reconstructive procedures. The lowest rates of arthritis and subsequent fusion requirement are reported from purely ligamentous dislocations of the subtalar joint [4]. In a series of 23 patients with CT-proven isolated subtalar dislocations, Jungbluth et al. found only 39% developed mild radiographic changes at 5 years, and this did not correlate with patient symptomotology [15]. They emphasize the urgency of reduction in keeping a relatively low rate of arthritis after isolated subtalar dislocations.

Avascular necrosis of the talus is most commonly associated with fractures of the talar neck, but it can also occur with subtalar dislocations. Displacement and open wounds have both been associated with the development of AVN [18, 19]. Rates have been reported from 0% to 10% AVN with closed dislocations, which rises to 50% with open dislocations [14]. However, improved rates have been shown with early reduction and stable fixation [20].

Post-traumatic arthritis most frequently involves the subtalar joint [21, 22]. Contributing factors leading to arthritis are initial chondral damage at the time of injury, altered joint mechanics secondary to malunion, and prolonged immobility. If there are peritalar fractures involving a joint, then restoration of congruity to preserve mechanics is important.

Most outcomes after subtalar dislocations have been reported in small case series. At approximately 5-year follow-up, the mean AOFAS score following the treatment of a subtalar dislocation averages 71–83, with the contralateral as a control averaging 93 [15, 16].

It is clear from the literature that peritalar fracture dislocations are difficult injuries to treat and that knowledge of techniques for precise surgical management are critical for improving outcomes.

Case 1

Clinical history

A 54-year-old female presents s/p pedestrian struck with right-ankle pain, deformity, and open wound. Intubated emergently in trauma bay due to altered mental status and airway protection.

Physical Exam

Right Lower Extremity

Gross deformity at ankle with skin tenting proximal lateral foot, 2 × 1 cm deep wound with oozing blood, palpable DP/PT pulses. Unable to assess motor/sensation due to patient condition.

Imaging

Pre-reduction injury films and select CT cuts after reduction (Figs. 10.1 and 10.2).

Closed reduction performed in trauma bay, post-reduction CT obtained.

Diagnosis

Open right medial subtalar dislocation with posterior talar body fracture.

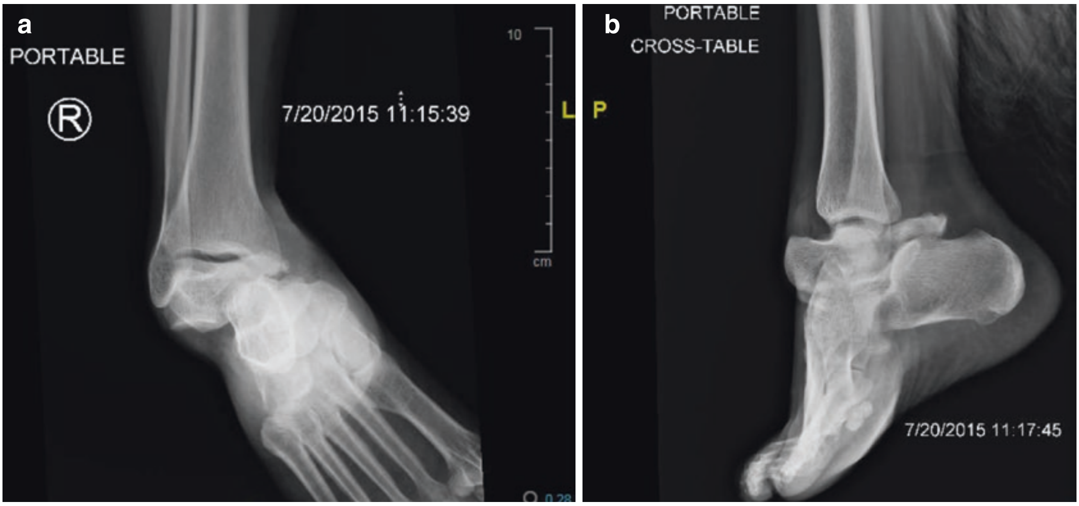


Fig. 10.1 (**a**, **b**) Injury films for Case 1. "Presenting injury radiographs showing a posteromedial subtalar dislocation with associated talus body fracture"

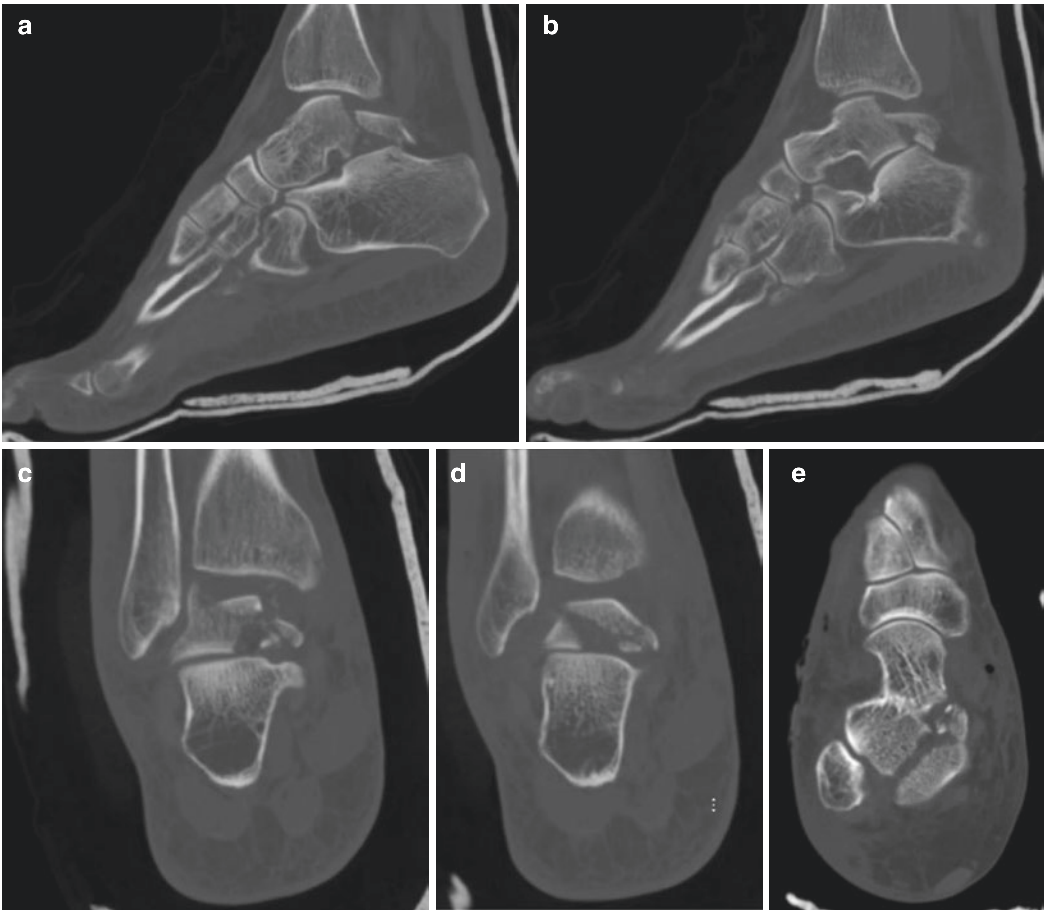


Fig. 10.2 Preoperative CT cuts for Case 1. "Shown are select computed tomography cuts after closed reduction. (**a**, **b**) show select sagittal cuts demonstrating coronal shear of the body. (**c**, **d**) exhibit coronals demonstrating comminution. Axial cut (**e**) shows the oblique fracture line entering the subtalar joint"

1. *Setup (patient position, instruments/implants need)*
    - Supine
    - Radiolucent cantilever table
    - Medium or large external fixator
    - 6.5 mm threaded Schanz pin
    - Tourniquet
2. *Execution – Approach used, reduction maneuvers, how implants used and placed*

    Begin with a gastrocnemius recession. This is an injury that occurs secondary to forced plantarflexion. The gastrocnemius complex functions as a pathologic force in this injury pattern. Therefore, the release of the gastrocnemius is part of this procedure, taking tension off of the area of injury as well as the eventual repair.
    - The incision is ~2 cm posterior to the posteromedial border of the tibia.
    - The gastrocnemius tendon is identified and separated from the soleus.
    - It is released sharply in a medial to lateral direction.

While supine, apply the ankle spanning external fixator. After gastrocnemius recession performed and external fixator applied, flip prone to begin fixation of the talus fracture.

A posteromedial approach can be used, beginning 1 cm medial to the Achilles tendon. Identify the FHL and incise its tendon sheath. The FHL can be swept medial and held out of the surgical field with two 1.6 mm Kirschner wires placed into the medial aspect of the distal tibia. Distraction can then be placed through the external fixator. Provisional fixation of the talus is held with 1.25 mm Kirschner wires. Intraoperative images (Figs. 10.3 and 10.4) and immediate postoperative films (Fig. 10.5) are shown.

Key Points of This Case

- Starting supine with gastrocnemius recession can be useful in neutralizing the deforming forces in subtalar dislocations. Apply your external fixator while still supine before flipping prone.
- Use Kirschner wires anchored in the medial distal tibia to help retract the FHL tendon and neurovascular structures medial and away from your surgical field.

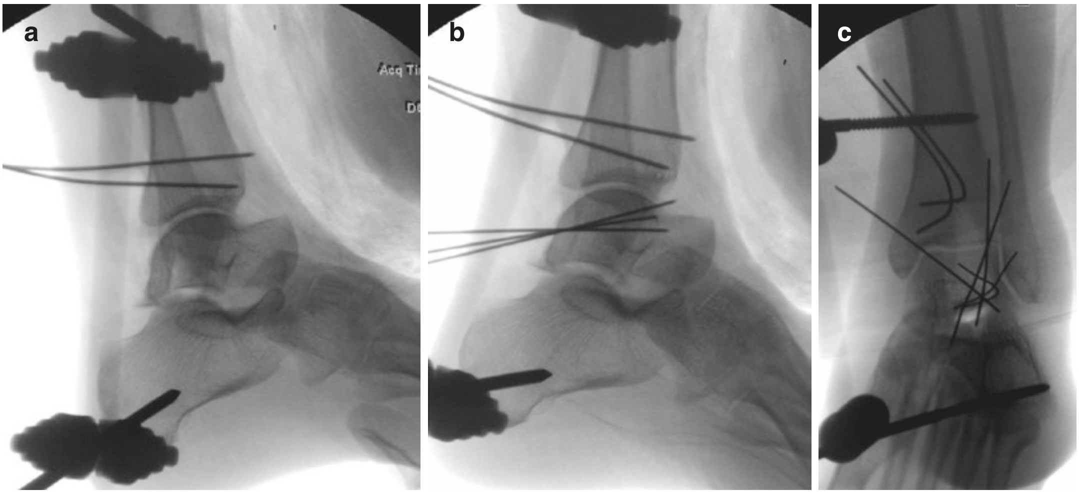


Fig. 10.3 (**a**–**c**) Fluoro shots for Case 1. “Intraoperative fluoroscopy demonstrating stabilizing external fixator and provisional k-wire fixation. Note the k-wires in the tibia for a no-touch soft tissue retraction technique”

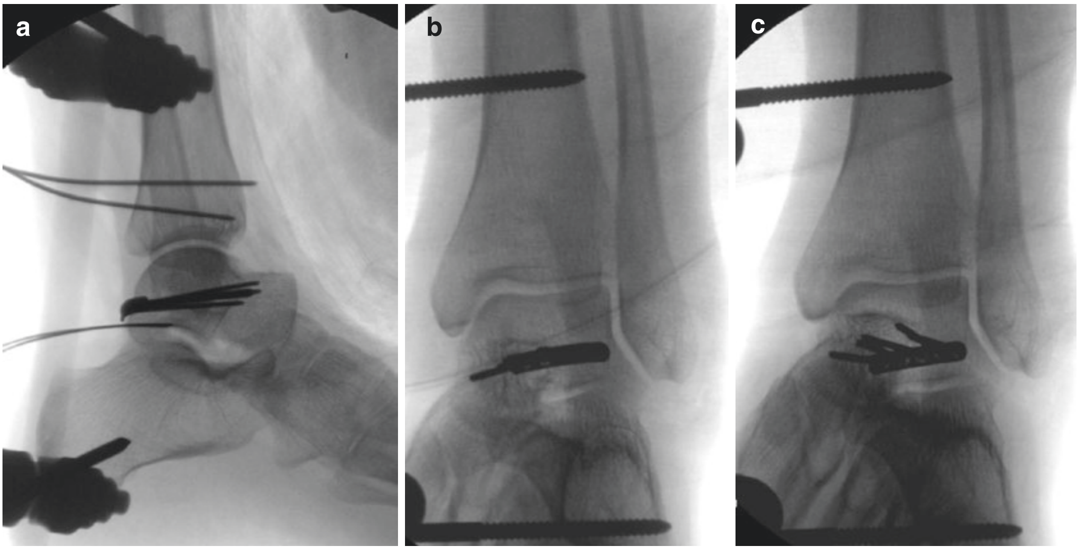


Fig. 10.4 (**a**–**c**) Fluoro shots for Case 1. "Definitive fixation achieved with a 2.0 plate and 2.0 lag screws from posterior to anterior across the fracture site replacing the provisional k-wires"

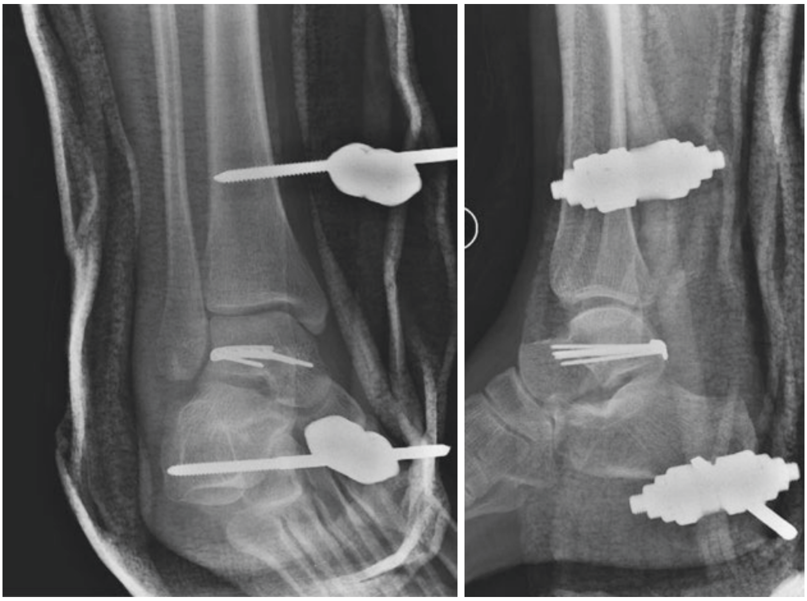


Fig. 10.5 Postoperative films for Case 1. "Note a slight amount of distraction maintained on the medially based frame as this was a medial subtalar dislocation. This is intended to offload the fixation construct and area of articular injury"

- Distract through your external fixator to better visualize the subtalar joint and protect your fixation post-operatively.

Case 2

Clinical History

A 21-year-old male presents status post-traumatic injury to right foot by a power jack. Isolated injury with decreased sensation on plantar aspect of foot.

Physical Examination

Right Lower Extremity

Three large soft tissue lacerations are seen.

- Medial wound extending from the level of the sustentaculum posteriorly and inferiorly around the heel cord at the level of the tuberosity. Calcaneus exposed through the medial wound.
- 10–14 cm dorsolateral laceration of foot extending from the navicular to just posterior to the fibula 4 cm proximal to the tip with exposed tendons.
- Approximately 2 cm wound over sinus tarsi with tendon exposed.

Imaging

Pre-reduction injury films (Fig. 10.6), post-reduction radiographs (Fig. 10.7), and select CT cuts after reduction (Fig. 10.8).

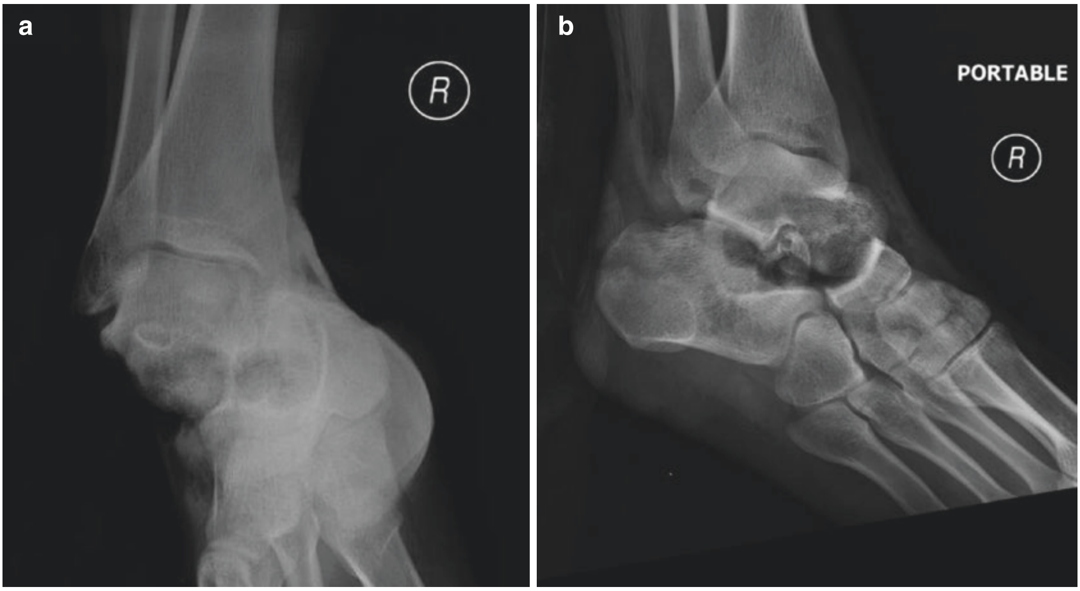


Fig. 10.6 (**a**, **b**) Injury films for Case 2. "Presenting injury radiographs demonstrating a medial subtalar fracture dislocation"

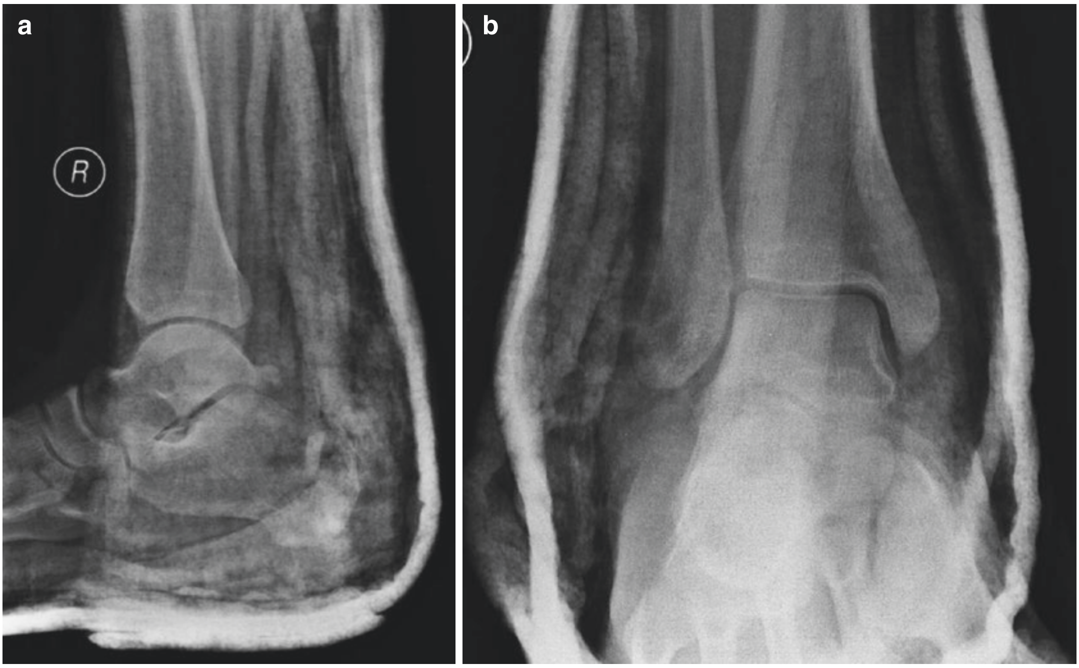


Fig. 10.7 (**a**, **b**) Post reduction radiographs for Case 2. "Post-reduction radiographs show concentric reduction of the subtalar joint"

Fig. 10.8 (**a**, **b**) Select CT injury images for Case 2. "Select axial cut (**a**) shows a fracture of the sustentaculum tali, and coronal (**b**) demonstrates the sagittal nature of the fracture line"

Reduction performed in the Trauma Bay and post-reduction films and a CT scan obtained.

Diagnosis

Right open medial subtalar fracture dislocation with a fracture of the calcaneal sustentaculum.

1. *Setup (patient position, instruments/implants need).*
    - Supine on a cantilever radiolucent table.
    - Saline fluid and tubing for gravity irrigation.
    - Tourniquet
    - Kirschner wires 1.0–1.6 mm.
    - Mini-fragment set.
    - Medium or large external fixator (backup).
2. *Execution – Approach used, reduction maneuvers, implants placement.*
    - Reduction achieved with knee flexion, ankle plantarflexion, and traction applied with a valgus moment on the midfoot. This allowed the talar head to be manipulated back into place.
    - Thorough exploration, irrigation, and debridement of the traumatic wounds were performed.
    - The medial of the three traumatic wounds provided access to the sustentacular fracture, obviating the need for a separate surgical approach. The surgical approach to the sustentaculum involves a small incision 2 cm caudal to the medial malleolus and 2 cm proximal to the navicular [23].
    - The posterior neurovascular bundle was protected and explored to identify any areas of disruption during the time of initial debridement.
    - The FHL was retracted inferiorly to expose the fragment.
    - The mobile fragment of the sustentaculum was manipulated into place using Kirschner wires as joysticks and pinned in place (Fig. 10.9a,b).
    - The fragment was anatomically reduced under direct visualization, and absolute stability was obtained through compression with lag screws.
    - In this case, two 2.4 mm screws were used with lag by technique through a small 2.0 plate as a washer (Fig. 10.9d–f).
    - Fluoroscopic Broden's views were used to confirm non-penetration into the posterior facet. In this case, the lateral wound also allowed direct visualization of the Kirschner wires that were used as drill bits as well as for provisional fixations. These wires were seen to exit the lateral cortex posterior to the sinus tarsi and plantar to the posterior facet.

The stability of the subtalar joint was reassessed. This patient was still able to be dislocated medially through subtalar and talonavicular joints. Therefore, after confirming the reduction of the two joints, the talonavicular joint was pinned retrograde with 1.6 k-wires (Fig. 10.10). These pins were left for 8 weeks in order to maintain the alignment of the joints. Therefore, they were cut below the level of the skin to prevent pin tract infection. Follow-up radiographs show preservation of the subtalar joint with minimal signs of arthrosis (Figs. 10.11 and 10.12).

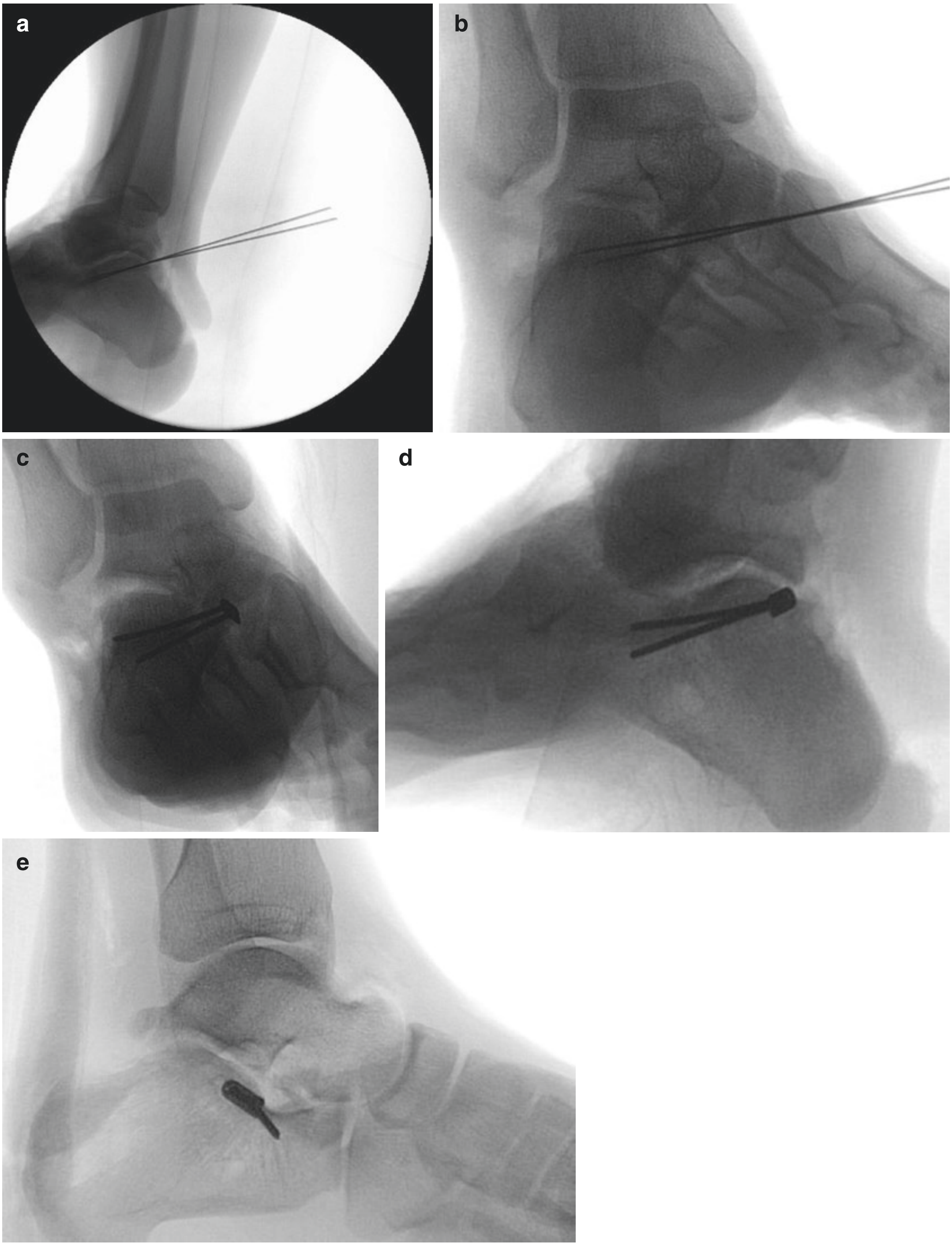


Fig. 10.9 (**a**–**e**) Fluoro shots for Case 2. “Intraoperative fluoroscopy shows provisional k-wire fixation (**a**, **b**). (**c**–**e**) show Broden’s view and talar dome lateral demonstrating definitive fixation with two 2.4 mm screws used with lag by technique through a small 2.0 plate as a washer”

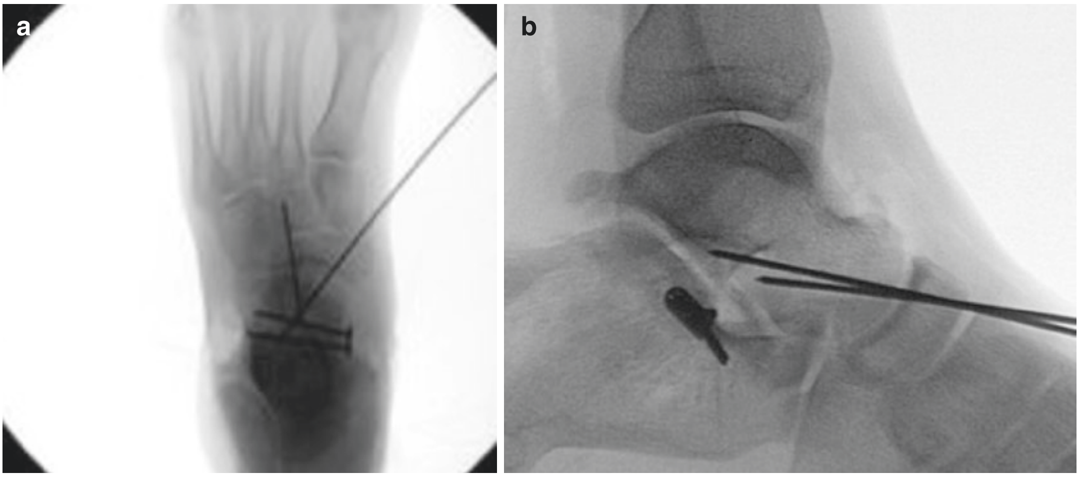


Fig. 10.10 (**a**, **b**) Fluoro shots for Case 2. "Showing AP and lateral views with 1.6 mm k-wire fixation of the talonavicular joint to prevent residual subluxation"

Fig. 10.11 Follow-up for Case 2. "Two-month follow-up radiographs after the removal of k-wires"

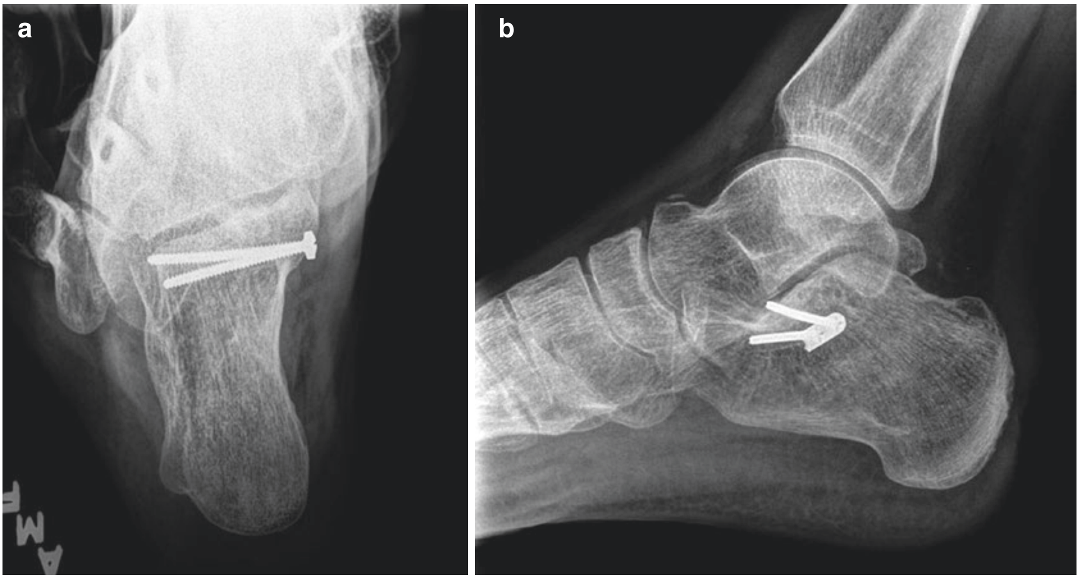


Fig. 10.12 (**a**, **b**) Follow-up for Case 2. “Two-year follow-up radiographs demonstrate preservation of the subtalar joint space on the Harris heel view (**a**) and talar dome lateral (**b**)”

References

1. Dale JD, Ha AS, Chew FS. Update on talar fracture patterns: a large level I trauma center study. AJR Am J Roentgenol. 2013;201(5):1087–92.
2. Vallier HA, Nork SE, Barei DP, Benirschke SK, Sangeorzan BJ. Talar neck fractures: results and outcomes. J Bone Joint Surg Am. 2004;86-A(8):1616–24.
3. Elgafy H, Ebraheim NA, Tile M, Stephen D, Kase J. Fractures of the talus: experience of two level 1 trauma centers. Foot Ankle Int. 2000;21(12):1023–9.
4. Rammelt S, Bartoníček J, Park KH. Traumatic injury to the subtalar joint. Foot Ankle Clin. 2018;23(3):353–74.
5. Rammelt S, Grass R, Zawadski T, Biewener A, Zwipp H. Foot function after subtalar distraction bone-block arthrodesis. A prospective study. J Bone Joint Surg Br. 2004;86(5):659–68.
6. Rammelt S, Biewener A, Grass R, Zwipp H. Foot injuries in the polytraumatized patient. Unfallchirurg. 2005;108(10):858–65.
7. Chan G, Sanders DW, Yuan X, Jenkinson RJ, Willits K. Clinical accuracy of imaging techniques for talar neck malunion. J Orthop Trauma. 2008;22(6):415–8.
8. Broden B. Roentgen examination of the subtaloid joint in fractures of the calcaneus. Acta Radiol. 1949;31(1):85–91.
9. Goldner JL, Poletti SC, Gates HS, Richardson WJ. Severe open subtalar dislocations. Long-term results. J Bone Joint Surg Am. 1995;77(7):1075–9.
10. LEITNER B. Obstacles to reduction in subtalar dislocations. J Bone Joint Surg Am. 1954;36(A:2):299–306.
11. Bibbo C, Lin SS, Abidi N, Berberian W, Grossman M, Gebauer G, et al. Missed and associated injuries after subtalar dislocation: the role of CT. Foot Ankle Int. 2001;22(4):324–8.
12. Dürr C, Zwipp H, Rammelt S. Fractures of the sustentaculum tali. Oper Orthop Traumatol. 2013;25(6):569–78. Epub 2013/12/06
13. Giuffrida AY, Lin SS, Abidi N, Berberian W, Berkman A, Behrens FF. Pseudo os trigonum sign: missed posteromedial talar facet fracture. Foot Ankle Int. 2003;24(8):642–9.
14. Rammelt S, Goronzy J. Subtalar dislocations. Foot Ankle Clin. 2015;20(2):253–64. Epub 2015/03/29
15. Jungbluth P, Wild M, Hakimi M, Gehrmann S, Djurisic M, Windolf J, et al. Isolated subtalar dislocation. J Bone Joint Surg Am. 2010;92(4):890–4.
16. Bibbo C, Anderson RB, Davis WH. Injury characteristics and the clinical outcome of subtalar dislocations: a clinical and radiographic analysis of 25 cases. Foot Ankle Int. 2003;24(2):158–63.
17. Heppenstall RB, Farahvar H, Balderston R, Lotke P. Evaluation and management of subtalar dislocations. J Trauma. 1980;20(6):494–7.
18. Vallier HA, Nork SE, Benirschke SK. Sangeorzan BJ. Surgical treatment of talar body fractures. J Bone Jt Surg Am. 2004;86-A(Suppl 1 (Pt 2)):180–92.
19. Lindvall E, Haidukewych G, DiPasquale T, Herscovici D, Sanders R. Open reduction and stable fixation of isolated, displaced talar neck and body fractures. J Bone Joint Surg Am. 2004;86-A(10):2229–34.
20. Milenkovic S, Mitkovic M, Bumbasirevic M. External fixation of open subtalar dislocation. Injury. 2006;37(9):909–13.

21. Maher MH, Chauhan A, Altman GT, Westrick ER. The acute management and associated complications of major injuries of the talus. JBJS Rev. 2017;5(7):e2.
22. Dodd A, Lefaivre KA. Outcomes of Talar neck fractures: a systematic review and meta-analysis. J Orthop Trauma. 2015;29(5):210–5.
23. Della Rocca GJ, Nork SE, Barei DP, Taitsman LA, Benirschke SK. Fractures of the sustentaculum tali: injury characteristics and surgical technique for reduction. Foot Ankle Int. 2009;30(11):1037–41.

Pantalar Dislocation

11

Michael F. Githens
and Jennifer Tangtiphaiboontana

Introduction

Pantalar dislocations, defined as dislocation of the talus from the tibiotalar, talocalcaneal, and talonavicular joints, are rare injuries and account for 0.06% of all dislocations and 2–3.4% of talar injuries [1, 2]. It is often a result of high-energy trauma such as a fall from height or motor vehicle accident. These injuries are often open dislocations and may or may not be associated with fractures of the talus or fractures of other surrounding bony structures (Fig. 11.1).

Total dislocation of the talus results either from excessive supination or from excessive pronation [3]. Lateral dislocations are the most common pattern of injury and are a result of excessive supination while pronation injuries result in medial dislocations (Figs. 11.2 and 11.3). Posterior and plantar dislocations are rare and are limited to a few case reports in the literature [4, 5].

Approximately 60% of talar surface is covered in articular cartilage, and there are no direct muscle and tendon attachments, but it is tightly bound by ligaments and joint capsules with its articulation to the distal tibia, fibula, calcaneus, and navicular. The talocalcaneal ligament is the major stabilizer of the subtalar joint and attaches to the inferior talar neck. The blood supply to the talus is a rich network of anastomoses fed by the posterior tibial artery, dorsalis pedis, and perforating peroneal artery. The posterior tibial artery gives rise to the artery of the tarsal canal and deltoid branches. The tarsal sinus artery is a branch of the peroneal artery. The amount of articular cartilage that covers the talus restricts the vascular network to the talar neck, medial surface, and posterior process and thus places it in a vulnerable location. Most of blood supply to talar body is supplied in retrograde fashion from the vascular anastomosis at neck, placing it at risk with fracture dislocation/subluxation injuries.

The talus plays an important role in hindfoot motion and foot/gait mechanics. It serves to transmit forces from the hindfoot to the forefoot and allows for unlocking and locking of the transverse tarsal joints during heel strike and toe off, respectively. Restoration of talar and hindfoot morphology is critical in restoring normal foot mechanics.

Diagnosis

Due to the high-energy mechanism of injury, initial evaluation of a patient representing with a pantalar dislocation should follow the advanced

M. F. Githens (✉)
Department of Orthopaedics and Sports Medicine, Harborview Medical Center/University of Washington, Seattle, WA, USA
e-mail: mfg28@uw.edu

J. Tangtiphaiboontana
Department of Orthopaedic Surgery, Harborview Medical Center, Seattle, WA, USA
e-mail: jenntang@uw.edu

© Springer Nature Switzerland AG 2020
M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_11

Fig. 11.1 (**a**, **b**) A lateral X-ray (**a**) and clinical photograph (**b**) demonstrating a plantar pantalar dislocation with associated calcaneus fracture

Fig. 11.2 A clinical photo demonstrating a highly contaminated open lateral talar extrusion

Fig. 11.3 An intra-operative photo demonstrating an open medial talar extrusion with bone loss involving the lateral subtalar joint

trauma life support (ATLS) protocol. Focused examination of the injured extremity should include obvious deformity of the foot, open lacerations of the skin, presence of gross contamination, and a detailed motor, sensory, and vascular exam. Complete talar dislocations are often open injuries and associated with fractures. The most common fractures seen are fractures of the talus followed by the medial and lateral malleoli, midfoot, and calcaneus.

Imaging workup should begin with plain radiographs of the patient's ankle and foot. Specialized views such as the Canale view are often used for the intraoperative assessment of fracture reduction. The Canale view is a true AP view of the talus and aids in the assessment of talar varus malalignment. This image is obtained by maximally plantarflexing the ankle, pronating the foot about 15 degrees and angling the imaging beam 75 degrees cephalad. Post-reduction CT scans are recommended for a more detailed understanding of the fracture pattern, degree of comminution, and identification of intra-articular loose fragments that can help with preoperative planning and treatment recommendations.

There is no classification system for pantalar dislocations without fracture; however, those associated with talar neck fractures are classified as Hawkin's type IV and carries an additional risk of avascular necrosis to the talar head in addition to the talar body.

Management

Immediate closed reduction of closed pantalar dislocations is warranted to prevent pressure necrosis of the overlying skin. Reductions may be attempted in the emergency department; however, general anesthesia and reduction in the operating room may be required to allow for adequate sedation and muscle relaxation. The reduction maneuvers described by Mitchell et al. include knee flexion at 90 degrees to relax the posterior compartment leg muscles by an assistant, longitudinal traction by grasping the hindfoot and forefoot, and applying direct pressure over the talus until reduction is achieved [6]. A calcaneal pin may also be placed if additional traction forces are needed. The primary goal is reduction of the tibiotalar joint first followed by the subtalar and talonavicular joints [7]. The stability of the reduction should be confirmed with fluoroscopic examination, and a post-reduction CT scan is recommended to evaluate for occult fractures and intra-articular loose fragments and to confirm concentric reduction of the tibiotalar, subtalar, and talonavicular joints. Stable reductions may be immobilized in a plaster splint for 1–2 weeks and transitioned to a removal splint to allow for early motion (vs cast immobilization). Patients are kept non-weight-bearing for at least 6 weeks. While closed reduction may be successful, a majority of these injuries often require an open reduction.

Patients with closed injuries that require an open reduction may be done through a single or dual incision approach, depending on the direction of the dislocation and associated fractures. The medial approach is made with longitudinal incision over the dorsal medial foot between the tibialis anterior tendon and posterior tibial tendon. This allows excellent access to the medial talar neck and talonavicular joint. The deltoid ligament should be preserved, thus limiting the proximal extent of the deep exposure. Often, talar extrusion is associated with a medial malleolar fracture, which may be exploited to assist in the reduction. The lateral approach is made with a longitudinal incision over the dorsal lateral foot centered between the tibia and fibula at the level of the ankle joint and in line with the fourth ray, extending from the level of the ankle joint to the navicular. The superficial peroneal nerve and its branches should be identified and mobilized to allow for safe retraction.

Posterior talar dislocations may be accessed through a posteromedial approach with the patient in the prone position. A longitudinal skin incision is made just medial to the Achilles tendon without violating the paratenon. The FHL sheath is then opened and the entire contents of the deep posterior compartment are retracted medially while the Achilles tendon is retracted laterally. Distraction through the external fixator is then applied, improving the visualization of the posterior talar body.

A majority of pantalar dislocations present as open injuries; thus, timely administration of antibiotics and tetanus vaccination is critical. Removal of gross contamination, preliminary irrigation with saline, and reduction of the extruded talus may be performed in the emergency department. Soft tissue wounds should be covered with a sterile, moist dressing to prevent further contamination. The limb should be immobilized in a plaster short leg splint.

In patients with a completely extruded talus without any soft tissues attachments, the talus should be placed in a sterile bacitracin solution and kept for re-implantation during surgery (Figs. 11.4 and 11.5). Sterilization of a contaminated talus with saline-diluted iodine solution and a brief period of freezing has also been described prior to re-implanation [8]. Early stud-

Fig. 11.4 Mortise, oblique, and lateral X-rays demonstrate an open talar extrusion with no associated fractures


[redacted]

Fig. 11.5 The extruded talus is placed in a dilute betadine solution and brought with the patient to the operating room on an urgent basis

ies recommended against talar re-implantation due to the belief that the risk of infection and osteonecrosis was inevitable [9, 10]. However, recent literature has shown that not all pantalar dislocations are destined for failure and support re-implantation [11–17]. This has become our preferred treatment option when possible. Re-implantation of the talus helps to preserve ankle height, peritalar articulations, improve joint mobility, and provide bone stock for later reconstructive procedures[11].

Urgent debridement of open dislocations and reduction in the operating room is recommended once the patient is stable. Meticulous and thorough debridement of any contamination and devitalized soft tissue should be performed. Extruded tali without soft tissue attachments should be sterilized with two to three successive bacitracin solutions and scrubbed gently prior to re-implantation (Fig. 11.6). Fractures of a completely extruded talus may be reduced and fixed prior to re-implantation. Traumatic wounds may be extended proximally and distally to facilitate reduction. Following the reduction of the talus, an ankle spanning external fixator is applied

Fig. 11.6 An intraoperative photo demonstrating sterilization of the extruded talus in a dilute betadine solution in preparation for re-implantation

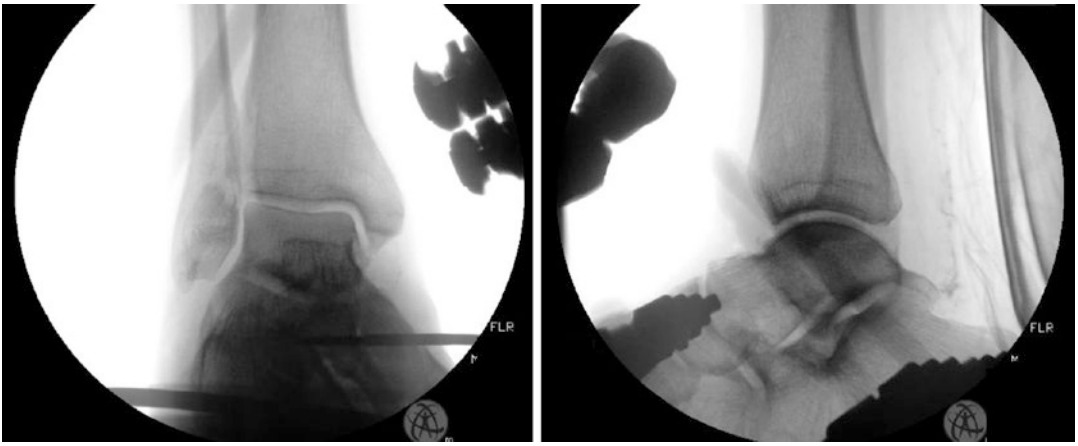


Fig. 11.7 Intraoperative mortise and lateral fluoroscopic imaging after re-implantation of the talus and application of an external fixator

(Fig. 11.7). In the setting of persistent instability after external fixation, supplemental fixation with k-wires passed through the subtalar and talonavicular joint may be deployed. Primary closure of the wound should be completed when possible. The placement of powdered antibiotics into the open wounds for prophylactic coverage against gram-positive and gram-negative organisms is recommended. In the setting of bone loss, an antibiotic spacer or beads are placed.

When a talar extrusion is associated with additional surrounding fractures, treatment proceeds for each injury as indicated when soft tissue conditions allow (Figs. 11.8. and 11.9). If the open wounds are not heavily contaminated and a thorough debridement is completed, it may be advantageous to perform early definitive fixation as possible through the open wounds. Surgical extension of traumatic open wounds for debridement must be planned carefully so as to avoid problems with later incisions for the treatment of associated fractures. The addition of local antibiotics may be helpful for infection prevention. If the traumatic wounds are heavily contaminated, or if complex wound coverage is planned, definitive fixation should be delayed appropriately (Fig. 11.10). Postoperative protocols will vary based on the injury pattern and treatment utilized. Patients who are initially stabilized with an external fixation are placed into a removable prefabricated posterior splint that maintains the ankle at neutral dorsiflexion and allows easy access for pins site and wound care. The external fixator is removed between 6 and 12 weeks depending on the fracture pattern(s) and degree of instability (Fig. 11.11). Follow-up at regular intervals up to 2 years is recommended, given the high incidence of early and delayed complications (Fig. 11.12). Deep infection is not uncommon and should be treated with aggressive debridement and IV antibiotics tailored to intraoperative cultures. If fractures are healed, all involved implants should be removed, but if the fractures have yet to heal, implants should be maintained to provide stability (Figs. 11.12, 11.13, and 11.14). If chronic osteomyelitis develops, the patient may need to be treated with aggressive

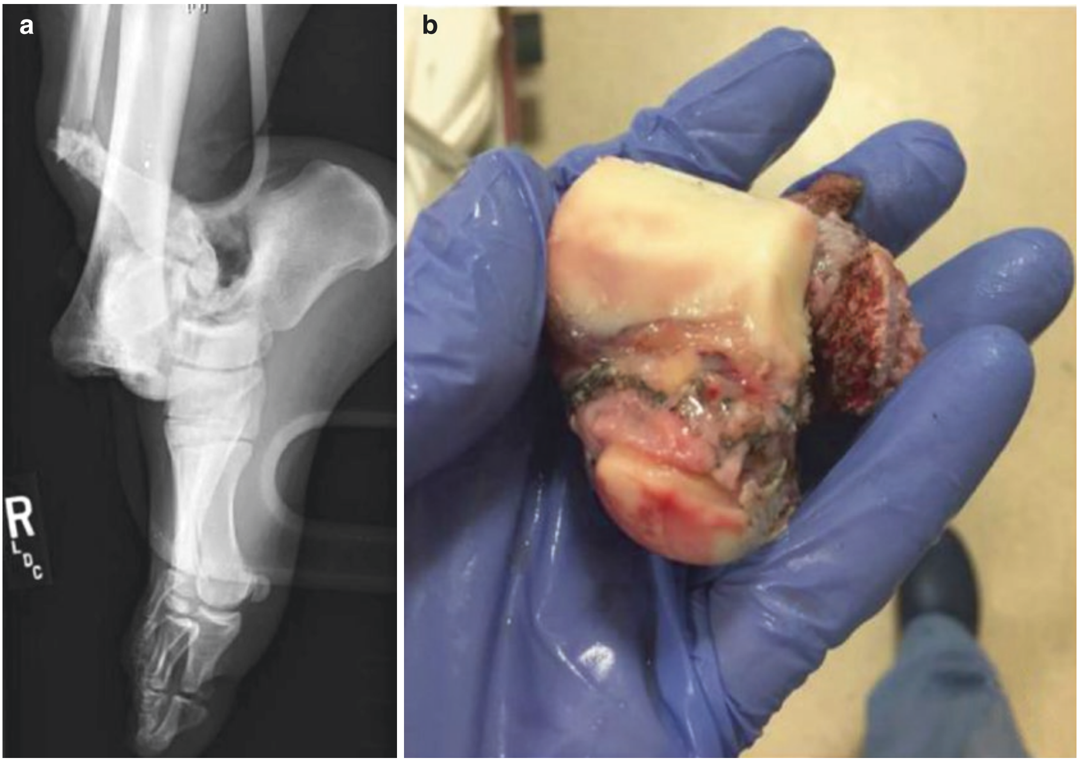


Fig. 11.8 (**a**, **b**) An injury X-ray (**a**) and clinical photo (**b**) demonstrating an open pantalar fracture dislocation with complete extrusion of the talus and an associated bimalleolar ankle fracture

bony debridement, cement spacer placement, and delayed bone grafting for fusion (Fig. 11.15 and 11.16). In this scenario, maintaining coronal and sagittal plane alignment is important and will help facilitate future fusion.

In some cases, patients may present with an absent talus that requires alternative reconstructive strategies (Fig. 11.17). While primary tibiocalcaneal arthrodesis is a treatment option, this approach often results in a 1.5 to 4.0 cm limb-length discrepancy and may result in compensatory pain and arthrosis of the adjacent joints [18–20]. Initial treatment is thorough debridement, placement of an antibiotic beads or spacer in the shape of a talus, and external fixation with the restoration of length and alignment of both the ankle and hindfoot (Figs. 11.18 and 11.19). Techniques and timing for staged bone grafting and fusion depend on bone stock available and condition of the soft tissue envelop. Grafting with autograft obtained via a reamer irrigator aspirator (RIA) system and femoral head allograft with the addition of autograft are both reliable [21]. A tibiocalcaneal intramedullary nail is the implant of choice in this setting (Figs. 11.20, 11.21, 11.22, and 11.23).

Total talar prosthetic replacement for an absent talus with or without a concomitant total ankle

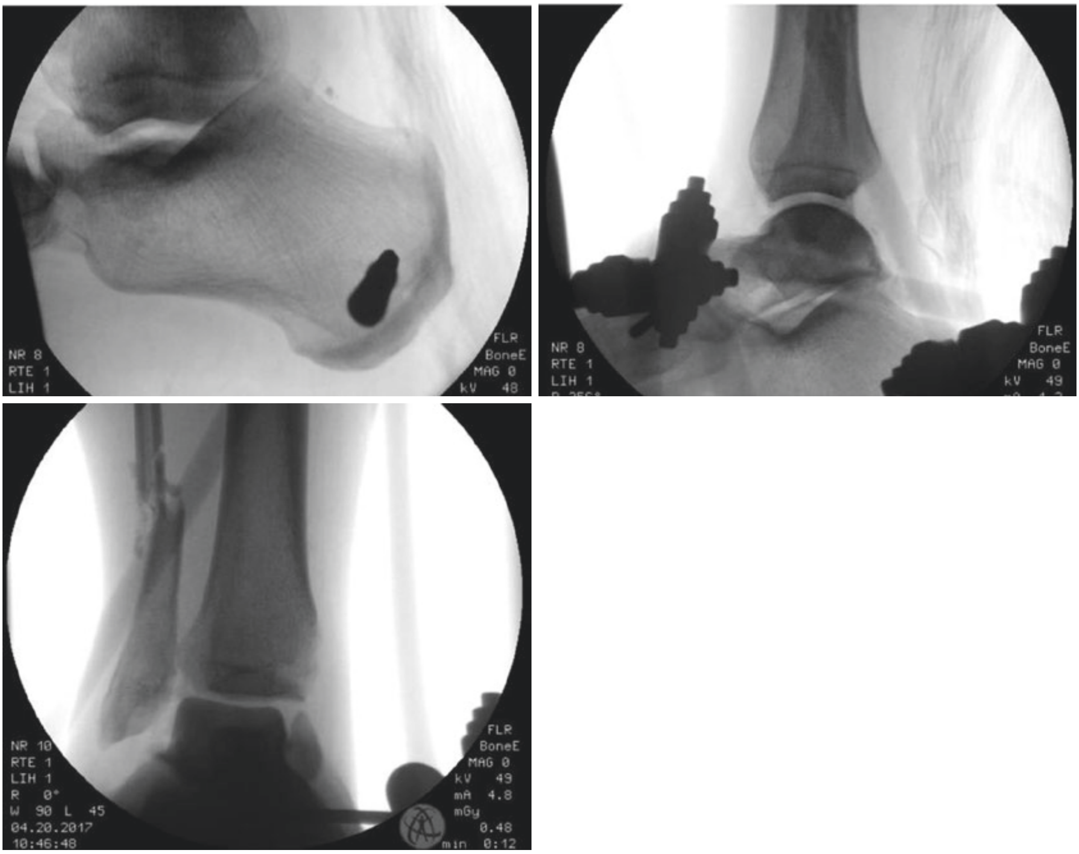


Fig. 11.9 Intraoperative fluoroscopic views before and after the reduction of the extruded talus. Reduction is achieved through the application of and distraction through an ankle spanning external fixator. The bimalleolar ankle fracture was not treated with early definitive care due to severe soft tissue compromise

replacement is another option although the success of this treatment is limited to single case reports [22, 23]. Total talar prosthesis is customized and requires a CT scan of the contralateral talus for reconstruction. The undersurface of the prosthesis may have a microporous surface or hydroxyapatite coating to allow fixation to the calcaneus.

All patients are immobilized in postoperative short leg plaster splint after definitive operative treatment and sutures are removed between 2 and 4 weeks as wounds allow. Patients are made non-weight-bearing for at least 12 weeks. Chemical thromboembolic prophylaxis is prescribed for a minimum of 6 weeks.

Outcomes

Current evidence regarding short- and long-term outcomes of pantalar dislocations are limited to case reports and small case series. Reports of closed pantalar dislocations generally describe favorable outcomes; most patients are asymptomatic and have near-normal ankle function. Rhanim et al. reported on one case of a closed injury that underwent successful closed reduction. They reported satisfactory, painless ankle motion and no signs of avascular necrosis at 1-year follow-up [7]. Taymaz et al. found similar findings in one patient with a closed total talar dislocation treated with closed reduction and

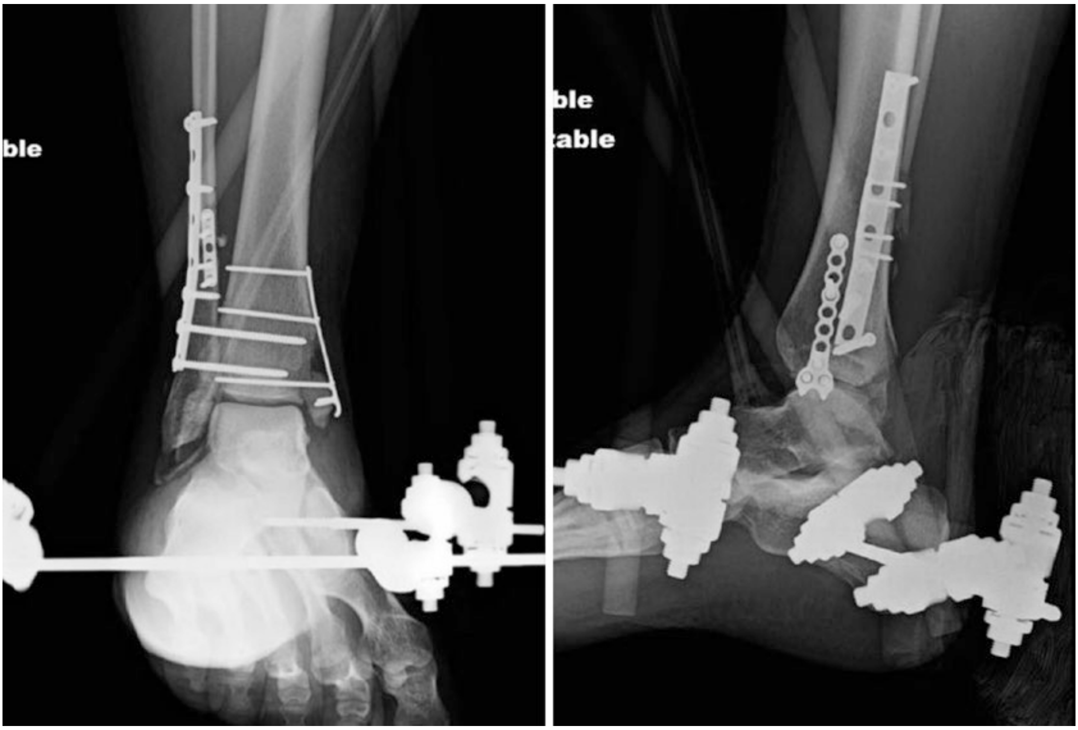


Fig. 11.10 Immediate postoperative radiographs demonstrating definitive fixation of the bimalleolar ankle fracture, syndesmosis, and adjustment of the external fixator 2 weeks after initial injury. Treatment of the associated fractures was delayed due to soft tissue injury and the need for complex wound coverage

immobilization at 9-year follow-up [15]. Although total talar dislocation would imply complete disruption of the vascular supply, some authors speculate that the absence of avascular necrosis observed in closed injuries is a result of some residual capsular or ligamentous attachments that may help preserve the blood supply to the talus. Patients with limited motion were primarily at the tibiotalar and subtalar joints [6, 15]. Those that required open reduction had a slightly higher incidence of avascular necrosis and osteomyelitis compared to those that were successfully closed reduced [2]. A significant dearth of literature on closed pantalar dislocations makes it impossible to make definitive statements regarding long-term outcomes, although it is likely that these patients do more poorly than described.

Open pantalar dislocations carry a higher risk of infection compared to closed injuries. Early studies by Detenbeck and Kelly reported an 89% infection rate in their case series and suggested treatment with primary talectomy and TTC arthrodesis to reduce risk of infection and/or osteonecrosis [9, 10]. Recent studies have challenged these finding and support re-implantation of the talus in the acute management of pantalar dislocations. Smith et al. found that only 2 of 19 patients (11%) developed infection after re-implantation [11]. Karampinas et al. presented a case series of nine patients with open total talar dislocations without fractures with a mean follow-up of 21 months. In their series, the patients underwent stabilization with an external fixator and Steinman pin fixation after debridement and reduction of the talus. They also received

Fig. 11.11 AP and lateral radiographs after external fixator removal at 3 months demonstrate maintained tibiotalar alignment but significant bony resorption and implant loosening

7–10 days of intravenous antibiotics postoperatively. Two of the nine patients (22%) developed an infection after re-implantation. Vallier et al. reported a superficial wound infection rate of 11% that resolved with antibiotics alone and no occurrence of deep infection with mean follow-up of 45 months.

When infections do occur, the result can be devastating and may require several operations to salvage the limb. Marsh et al. reviewed 18 open injuries, of which 12 were complete or partial talar extrusions [13]. The overall rate of infection in their series was 38%, with seven infections occurring in the early postoperative period. Not surprisingly, poor functional outcomes were associated with the occurrence of an infection. Burston et al. found similar results in their case series of eight patients with open total talar dislocations where those who developed infection also had worse outcomes [24]. Although these injuries are associated with a high rate of infection, the risk of developing an infection may be reduced with appropriate and timely administration of intravenous

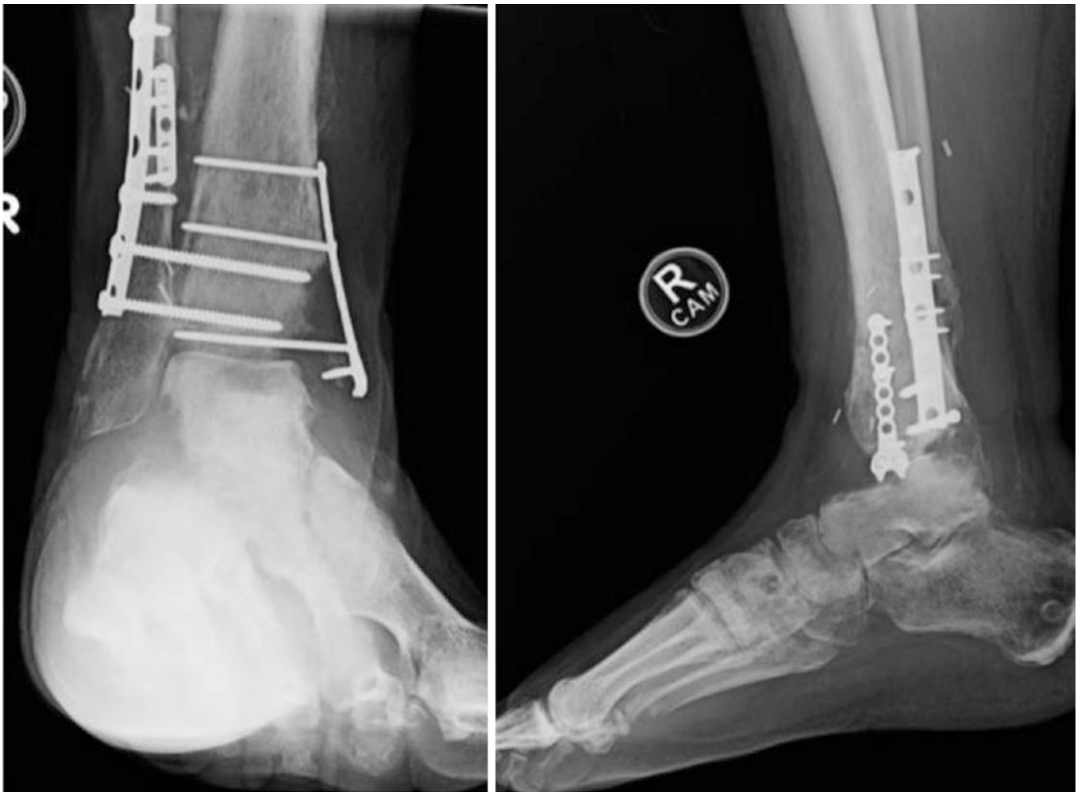


Fig. 11.12 AP and lateral radiographs 4 months after injury demonstrate further bony resorption and in the setting of a clinically diagnosed deep infection. The patient is treated with surgical debridement, maintenance of implants, and IV antibiotics

antibiotics, thorough and meticulous debridement, and careful soft tissue handling [12].

Radiographic evidence of osteonecrosis of the talus ranges from 30% to 88%, but collapse of the talar body does not always occur and ranges from 11% to 53% [11, 12, 24]. Not all patients with talar body collapse require subsequent surgical procedure. The risk of osteonecrosis after pantalar dislocations may also be influenced by the presence of a major fracture of the talus. Smith et al. found that in patients with a major fracture of the body or neck, the incidence of talar collapse, osteonecrosis, or arthritis was 100% compared to 40% in those with a minor fracture or no fracture [11]. There have also been reports of revascularization of the talus after pantalar dislocations. Gerken et al. reported MRI findings demonstrating revascularization of a completely extruded talus with a minor fracture of the head following immediate re-implantation within 4 h from presentation [25]. Vascularity of the talus is assessed by the radio-

Fig. 11.13 AP and lateral radiographs after repeat debridement and implant removal 6 months after injury demonstrate further bony resorption and loss of tibiotalar alignment in both planes

graphic presence of the Hawkins sign, which represents a subchondral radiolucent atrophy in the talar dome seen on the mortise view 6–8 weeks after talar fracture. The Hawkins sign has a sensitivity of 100% and specificity of 58% as reported by Tezval et al. [26] The absence of the Hawkins sign and an unusual increase in bone mineral density of the talus may suggest the development of avascular necrosis. The MRI may be obtained to help delineate cases that are less clear. The management of patients who developed osteonecrosis of the talus remains controversial as some authors support a period of non-weight-bearing to prevent talar collapse while others have shown that weight restrictions do not alter the course of the disease [27, 28].

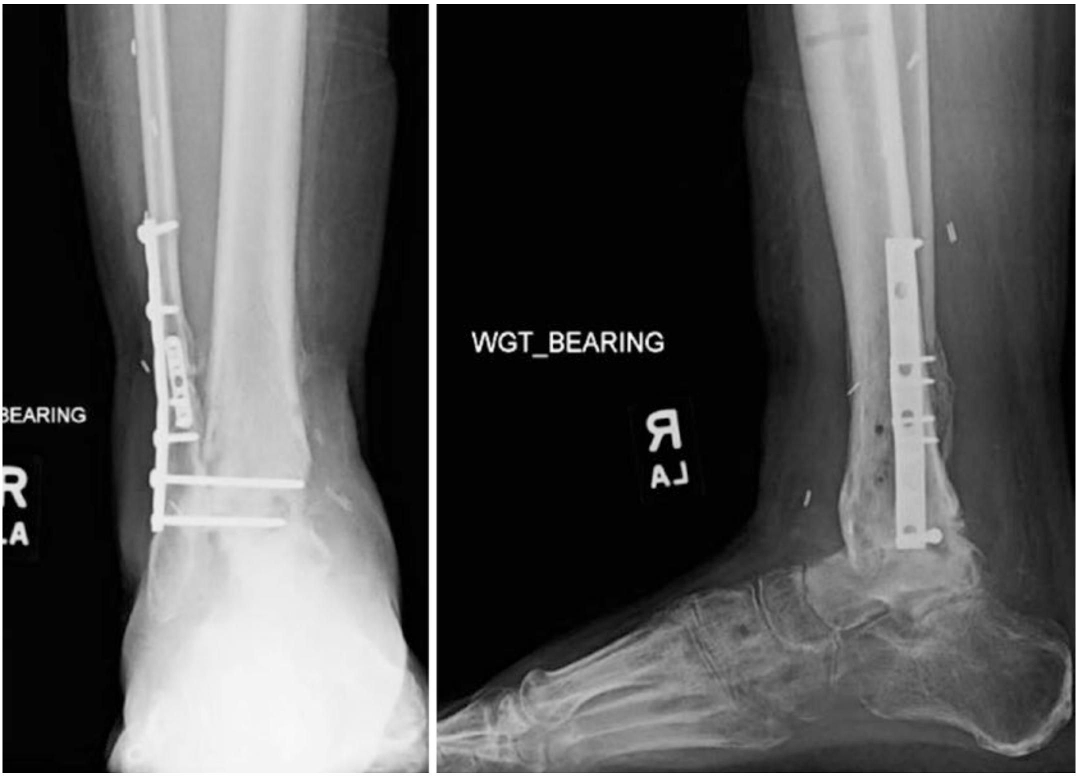


Fig. 11.14 AP and lateral radiographs 1 year after injury demonstrate talar collapse with no further loss of tibiotalar alignment. The patient has been free of infectious symptoms and weight-bearing without significant limitations

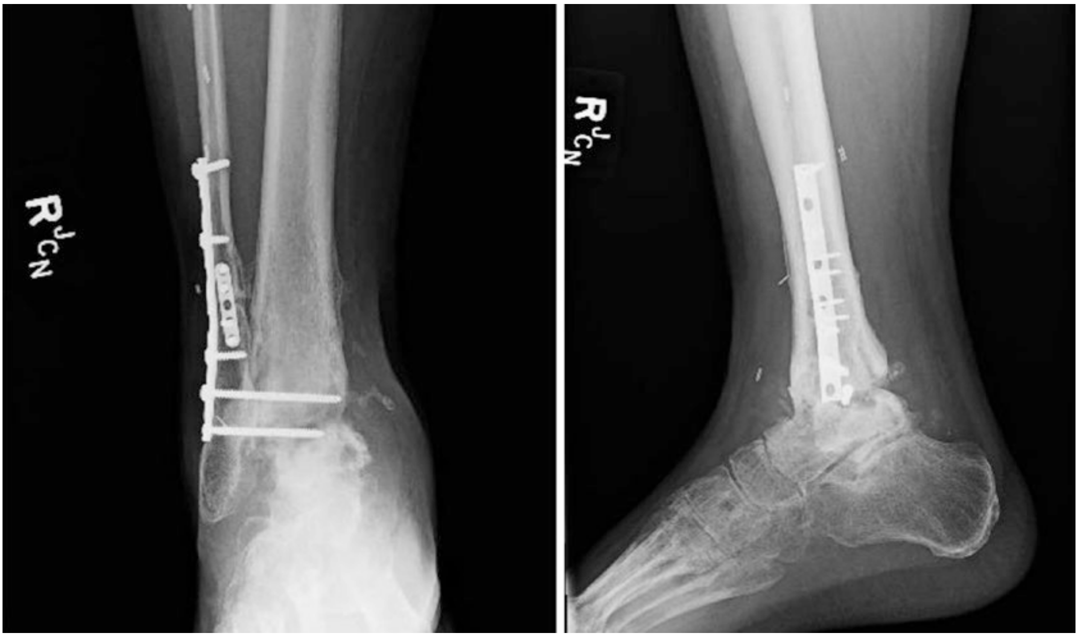


Fig. 11.15 AP and lateral radiographs 17 months after injury demonstrate further talar osteolysis and worsening coronal plane deformity in the setting of new-onset symptoms concerning recurrent infection

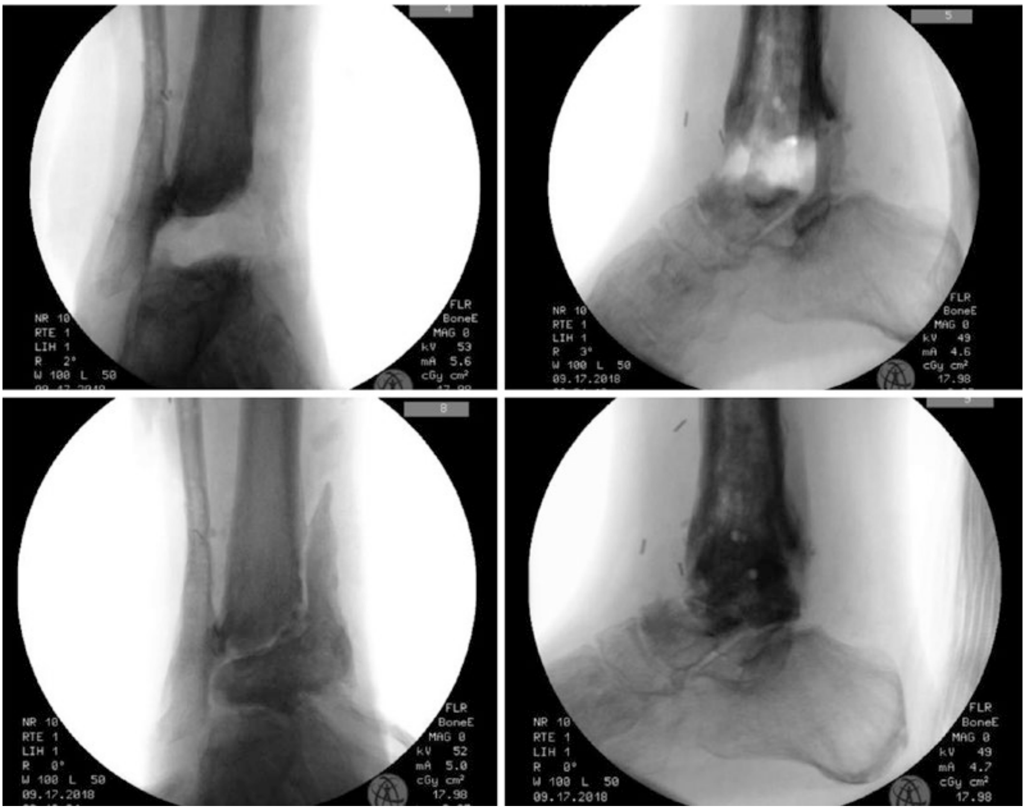


Fig. 11.16 AP and lateral fluoroscopic views post-debridement of avascular talar body in the setting of recalcitrant osteomylitis and placement of an antibiotic eluting cement spacer

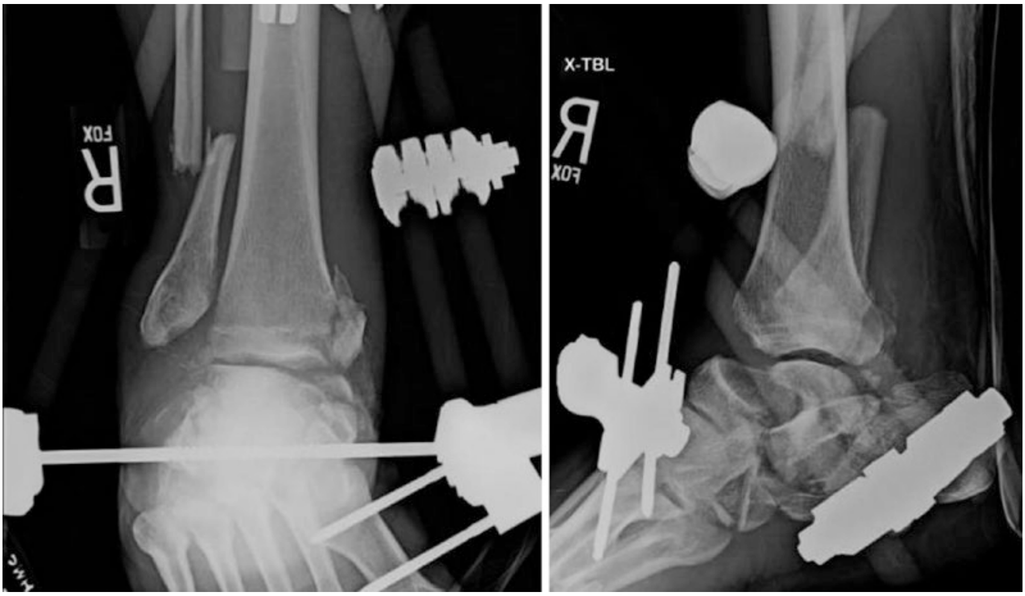


Fig. 11.17 AP and lateral radiographs of a patient status post-external fixation, transferred for the management of a complex ankle and hindfoot injury with near total talar bone loss. Note the shortening through the ankle joint

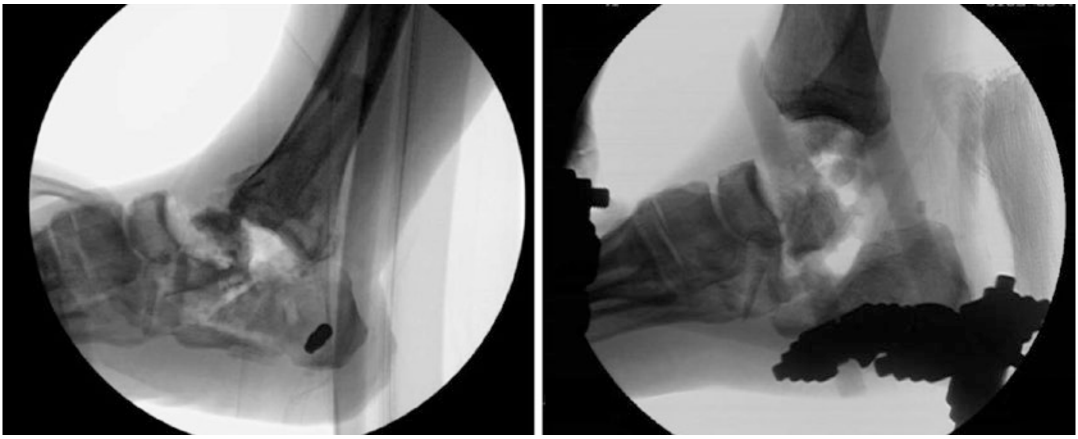


Fig. 11.18 Lateral intra-operative fluoroscopic images before and after revision external fixation with restoration of length and alignment of ankle and hindfoot

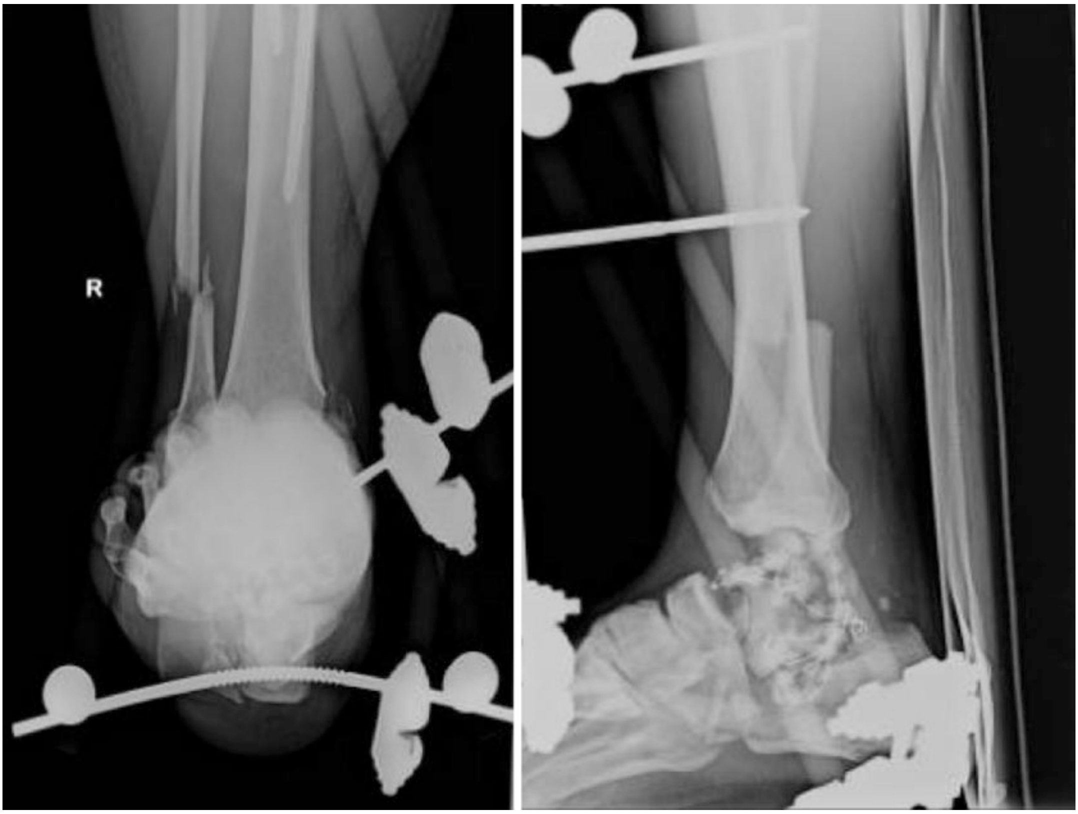


Fig. 11.19 Preoperative hindfoot and lateral X-rays demonstrate accurate alignment in preparation for staged bone grafting and retrograde hindfoot nailing

Fig. 11.20 Immediate postoperative mortise, lateral, AP, and hindfoot X-rays demonstrating the restoration of alignment in all planes and stable fixation with a hindfoot nail

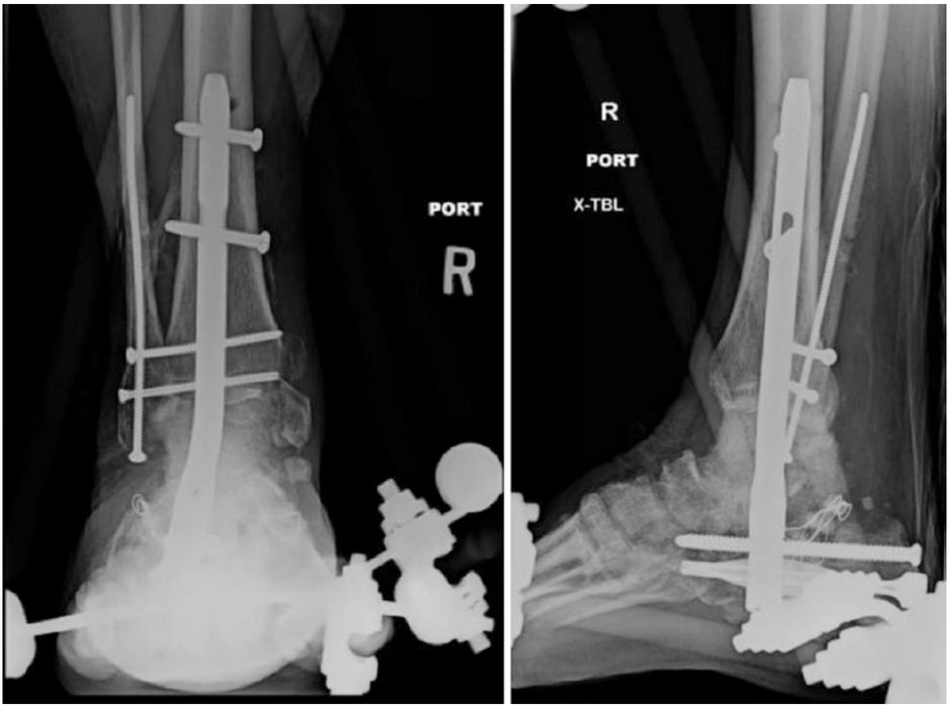


Fig. 11.21 Immediate postoperative AP and lateral X-rays after delayed bone grafting (autograft bone harvested using RIA combined with allograft), 3 months from initial injury

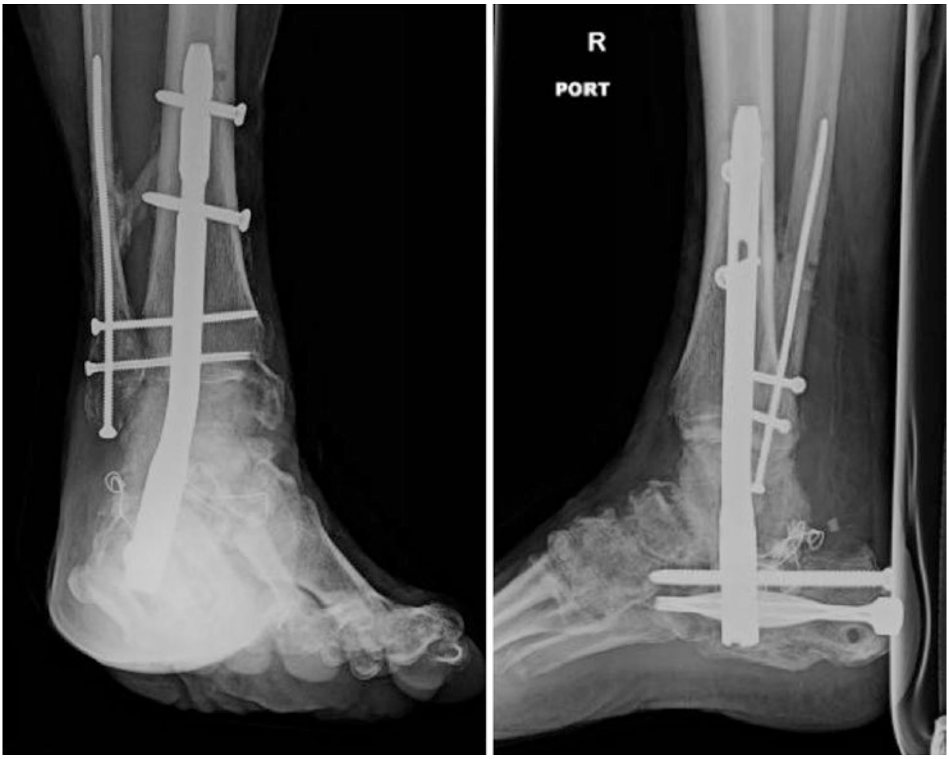


Fig. 11.22 Mortise and lateral X-rays 6 months after injury demonstrate maintained alignment and progression toward fusion

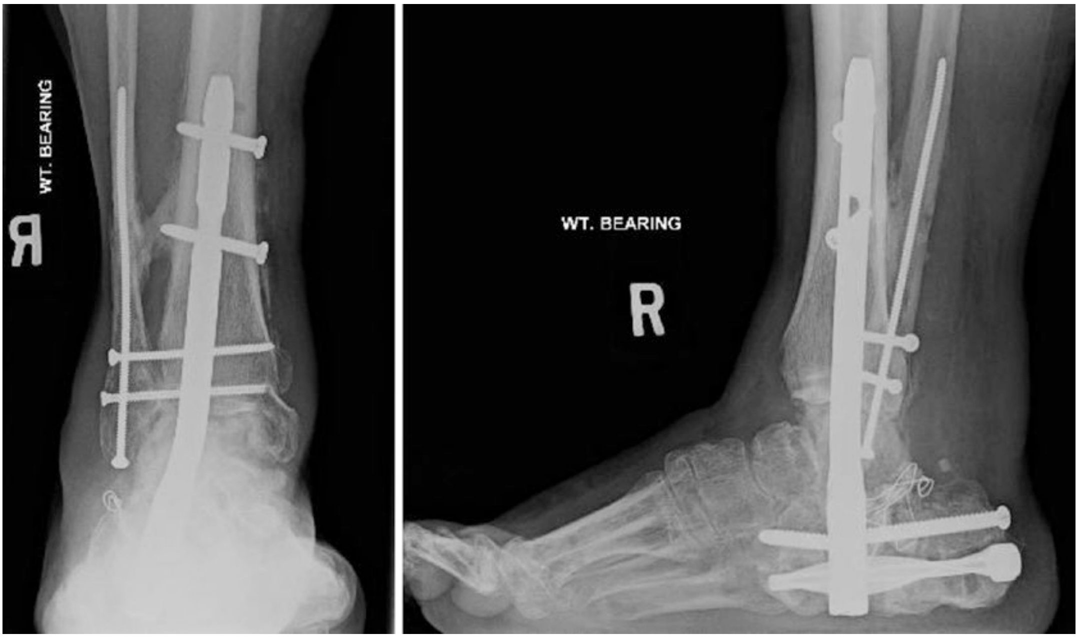


Fig. 11.23 Mortise and lateral radiographs 1 year after definitive treatment demonstrate maintained alignment with a broken interlocking bolt and mild settling of the blade

Conclusion

Pantalar dislocations are a rare injury that is associated with a high rate of complications such as infection, avascular necrosis of the talus, and post-traumatic arthritis. While there are several treatment options described in the literature, the outcomes are limited to single case reports or small case series. The lack of consensus regarding the best treatment option highlights the complex and challenging nature of this injury and the difficult balance between reducing devastating complications while preserving function. As with any surgery, we recommend having an in-depth conversation about the treatment options and expected outcomes with the patient in a shared decision-making fashion.

References

1. Weston JT, Liu X, Wandtke ME, Liu J, Ebraheim NEA. Systematic review of total dislocation of the talus. Orthop Surg. 2015;7(2):97–101. https://doi.org/10.1111/os.12167.
2. Johnson B, Rouholamin N, Patel A. Total dislocation of the talus. Eur J Orthop Surg Traumatol. 2012;22(8):633–7. https://doi.org/10.1007/s00590-011-0881-z.
3. LEITNER B. The mechanism of total dislocation of the talus. J Bone Joint Surg Am. 1955;37-A(1):89–95.
4. Pinzur MS, Meyer PR. Complete posterior dislocation of the talus. Case report and discussion. Clin Orthop Relat Res. 1978;(131):205–9.
5. Katz BE, Yang E. Complete closed posterior talus dislocation without fracture. Orthopedics. 2000;23(8):846–8. https://doi.org/10.3928/0147-7447-20000801-20.
6. Mitchell JI. Total dislocation of the astragalus. J Bone Jt Surg. 1936;18(1):212–4.
7. Rhanim A, El ZR, Ouchrif Y, Hassani ZA, Kharmaz M, Berrada MS. Nonoperative treatment of closed total talus dislocation without fracture: a case report and literature review. J Clin Orthop Trauma. 2014;5(3):172–5. https://doi.org/10.1016/j.jcot.2014.05.010.
8. Burston JL, Brankov B, Zellweger R. Reimplantation of a completely extruded talus 8 days following injury: a case report. J Foot Ankle Surg. 2011;50(1):104–7. https://doi.org/10.1053/j.jfas.2010.10.009.
9. COLTART WD. Aviator's astragalus. J Bone Joint Surg Br. 1952;34-B(4):545–66.
10. Detenbeck LC, Kelly PJ. Total dislocation of the talus. J Bone Joint Surg Am. 1969;51(2):283–8.
11. Smith CS, Nork SE, Sangeorzan BJ. The extruded talus: results of reimplantation. J Bone Joint Surg. 2006; https://doi.org/10.2106/JBJS.E.00471.

12. Boden KA, Weinberg DS, Vallier HA. Complications and functional outcomes after pantalar dislocation. J Bone Jt Surg – Am Vol. 2017; https://doi.org/10.2106/JBJS.16.00986.
13. Marsh JL, Saltzman CL, Iverson M, Shapiro DS. Major open injuries of the talus. J Orthop Trauma. 1995;9(5):371–6.
14. Karampinas PK, Kavroudakis E, Polyzois V, Vlamis J, Pneumaticos S. Open talar dislocations without associated fractures. Foot Ankle Surg. 2014;20(2):100–4. https://doi.org/10.1016/j.fas.2013.12.005.
15. Taymaz A, Gunal I. Complete dislocation of the talus unaccompanied by fracture. J Foot Ankle Surg. 2005;44(2):156–8. https://doi.org/10.1053/j.jfas.2005.01.008.
16. Mnif H, Zrig M, Koubaa M, Jawahdou R, Hammouda I, Abid A. Reimplantation of a totally extruded talus: a case report. J Foot Ankle Surg. 2010;49(2):172–5. https://doi.org/10.1053/j.jfas.2009.09.003.
17. Dumbre Patil SS, Abane SR, Dumbre Patil VS, Nande PN. Open fracture dislocation of the talus with total extrusion. Foot Ankle Spec. 2014;7(5):427–31. https://doi.org/10.1177/1938640014528040.
18. Jaffe KA, Conlan TK, Sardis L, Meyer RD. Traumatic talectomy without fracture: four case reports and review of the literature. Foot Ankle Int. 1995;16(9):583–7. https://doi.org/10.1177/107110079501600913.
19. Lee HS, Chung HW, Suh JS. Total talar extrusion without soft tissue attachments. Clin Orthop Surg. 2014;6(2):236–41. https://doi.org/10.4055/cios.2014.6.2.236.
20. Hiraizumi Y, Hara T, Takahashi M, Mayehiyo S. Open total dislocation of the talus with extrusion (missing talus): report of two cases. Foot Ankle. 1992;13(8):473–7.
21. Huang P, Lundgren ME, Garapati R. Complete Talar Extrusion Treated With an Antibiotic Cement Spacer and Staged Femoral Head Allograft. J Am Acad Orthop Surg. 2018;26(15):e324–8. https://doi.org/10.5435/JAAOS-D-16-00748.
22. Magnan B, Facci E, Bartolozzi P. Traumatic loss of the talus treated with a talar body prosthesis and total ankle arthroplasty. A case report. J Bone Joint Surg Am. 2004;86-A(8):1778–82.
23. Ruatti S, Corbet C, Boudissa M, et al. Total Talar Prosthesis Replacement after Talar Extrusion. J Foot Ankle Surg. 2017;56(4):905–9. https://doi.org/10.1053/j.jfas.2017.04.005.
24. Burston JL, Isenegger P, Zellweger R. Open Total Talus Dislocation: Clinical and Functional Outcomes: A Case Series. J Trauma Inj Infect Crit Care. 2010;68(6):1453–8. https://doi.org/10.1097/TA.0b013e3181d03b73.
25. Gerken N, Yalamanchili R, Yalamanchili S, Penagaluru P, MD EM, Cox G. Talar revascularization after a complete talar extrusion. J Orthop Trauma. 2011;25(11):e107–10. https://doi.org/10.1097/BOT.0b013e318210f236.
26. Tezval M, Dumont C, Stürmer KM. Prognostic reliability of the Hawkins sign in fractures of the talus. J Orthop Trauma. 2007;21(8):538–43. https://doi.org/10.1097/BOT.0b013e318148c665.
27. Ritsema GH. Total talar dislocation. J Trauma. 1988;28(5):692–4.
28. Palomo-Traver JM, Cruz-Renovell E, Granell-Beltran V, Monzonís-García J. Open total talus dislocation: case report and review of the literature. J Orthop Trauma. 1997;11(1):45–9.

12

Other Midfoot Dislocations

Erik A. Magnusson, Jeremy Hreha,
and Lisa Taitsman

Introduction

Isolated hindfoot and midfoot dislocations are rare, potentially devastating injuries. They may result from high- or low-mechanism injuries but are most commonly diagnosed in young patients after high-energy trauma. Midfoot dislocations are prone to missed or delayed diagnosis due to the rarity of the injury, complexity of foot anatomy, radiographic interpretation, and overshadowing by more pressing injuries. Management begins with recognizing the injury, prompt reduction, and immediate or delayed fixation in the setting of instability. Clinical outcomes vary broadly by which joint(s) are involved, the associated soft tissue injuries, and the timing of management.

Anatomy

The calcaneocuboid and talonavicular articulations comprise the transverse tarsal joint, also known as the Chopart joint. The talonavicular and calcaneocuboid articulations are two distinct articulations that function together to invert and evert the midfoot in synchrony with the subtalar joint and to absorb shock and form a rigid lever arm for forward propulsion.

The talonavicular joint is an essential component of the acetabulum pedis that allows the midfoot to move around the talus. The talonavicular joint is composed of the convex talar head, the proximally concave tarsal navicular, the anterior and middle calcaneal facets, and the supporting spring and bifurcate Y ligaments [1]. Distally the tarsal navicular is convex and contains facets for articulation with the cuneiforms linking the hindfoot to the forefoot, forming the medial column of the foot.

The calcaneocuboid articulation links the lateral hindfoot to lateral forefoot, forming the lateral column of the foot. The articulation between the calcaneus and cuboid is biconcave, which allows for increased osseous congruency and stability. Distally the cuboid has two facets for articulation with the fourth and fifth metatarsals. The plantar surface of the cuboid contains a groove for the peroneus longus tendon. The calcaneocuboid articulation is strengthened by an array of dorsal and plantar ligaments that connect the cuboid to the navicular, cuneiform, and proximal aspects of the fourth and fifth metatarsals [2–4].

These two unique articulations function together to perform the primary functions of the Chopart joint, shock absorption, and forward propulsion. When the hindfoot is everted, the two

---

E. A. Magnusson · L. Taitsman (✉)
Department of Orthopaedics and Sports Medicine, University of Washington, Harborview Medical Center, Seattle, WA, USA
e-mail: emagnus@uw.edu; taitsman@u.washington.edu

J. Hreha
Department of Orthopaedics, Rutgers New Jersey Medical School, Newark, NJ, USA

© Springer Nature Switzerland AG 2020
M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_12

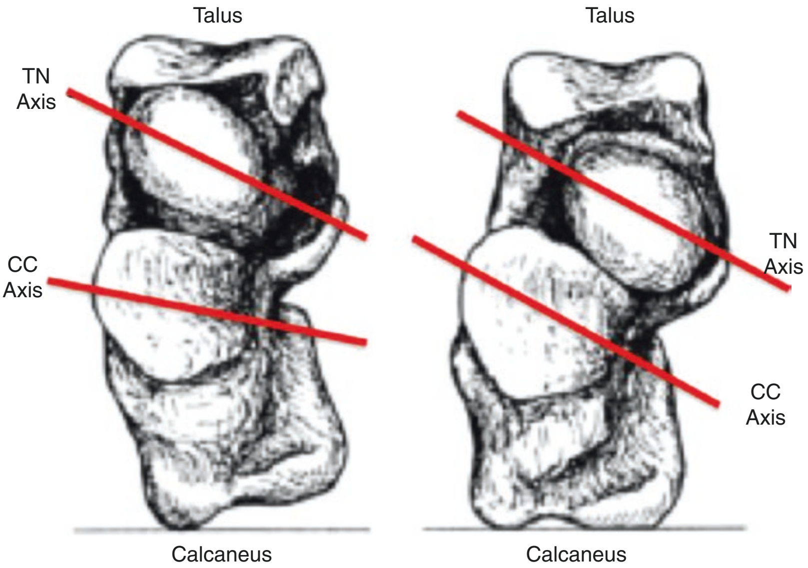


Fig. 12.1 Position of the foot affects the motion of the talonavicular and calcaneocuboid joints. On the image on the left, the foot is in an inverted position causing the joints to be off axis, resulting in a rigid joint. In the right image, when the foot is in a neutral or everted position, the joints are parallel, thus allowing motion between the joints. *TN Axis* talonavicular joint axis, *CC Axis* calcaneocuboid joint axis. (Adapted from Rammelt et al. [28])

articulations are parallel and allow movement across the TNJ and CC, which functions to absorb shock with each heel strike (Fig. 12.1). As the gait cycle progresses, the hindfoot inverts which diverges the axes of the TNJ and CC. In this divergent state, the midfoot "locks" which allows the midfoot to assume a rigid lever arm for the push-off phase of gait [1]. The essential function of the Chopart joints during gait explains the potential for devastating patient outcomes following trauma to the midfoot.

Chopart Dislocation

Isolated fractures and dislocations of the Chopart articulation are rare injuries. Multiple review articles estimate that the incidence of midfoot injuries is around 3.6/100,000 fractures per year [2, 5, 6]. There is a bimodal distribution of patients presenting with midfoot trauma. Most patients are young men who present as polytrauma patients after high-speed motor vehicle collisions while the remainder are seniors who present after low-mechanism injuries [5–7]. Pure dislocations are the rarest presentation of midfoot trauma comprising 10–25% of already rare injuries [7, 8]. Most patients present with concomitant dislocations and fracture to one or more bones of the hindfoot and midfoot.

Midfoot dislocations are frequently missed on primary survey due to their rarity, association with polytrauma, subtle radiographic abnormalities, and the inherent complexity of midfoot and hindfoot anatomy. Main and Jowett reported a 40% delay in diagnosis in 1975. The attributed this error to inadequate radiographs, leading them to suggest standard anteroposterior, lateral, and oblique views of foot for patients with suspected midfoot injury [8]. Thirty-five years later, the rate of delayed diagnosis persists. Van Dorp et al. reported a delay or underestimated injury in 55% of patients who presented to a level II trauma center over a six-year period [5]. Successful diagnosis of midfoot injuries requires a heightened suspicion, full secondary surveys in patients with polytrauma, and appropriate imaging.

Classification

Transverse tarsal joint injuries are classified by the direction of force applied to the midfoot at the time of injury (Fig. 12.2). Main et al. were the

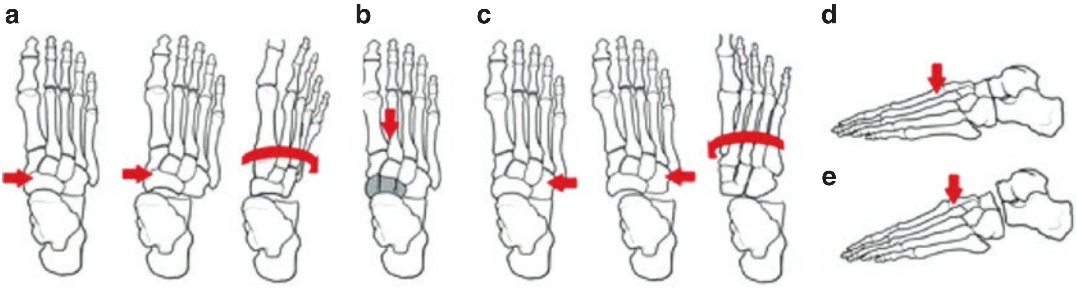


Fig. 12.2 Depiction of the direction of forces that cause the injury to the Chopart joint proposed by Main and Jowett. (**a**) Medial directed force causing the progression of injury from sprain to fracture subluxation or dislocation to swivel dislocation. (**b**) Longitudinal impact that can present with sprain, fracture subluxation or dislocation, or swivel dislocation. (**c**) Lateral directed force causing the progression of injury from sprain to fracture subluxation or dislocation to swivel dislocation. (**d**) Plantar directed force causing crush injuries. (**e**) Plantar directed force causing sprain or fracture subluxation or dislocation. (From Lasanianos et al. [29])

first to provide a comprehensive classification of Chopart injuries. This classification system consists of five patterns of injury resulting from medial forces, longitudinal forces, lateral forces, plantar forces, and crush injuries. Patient presentation after such forces results in a spectrum of injuries from sprains, fracture-sprains, fracture-subluxations, or pure dislocation. Pure Chopart joint dislocations were the rarest presentation and occurred most frequently after medial, lateral, and plantar directed forces.

Outcomes

In addition to classifying midfoot injuries, Main and Jowett were also one of the first groups to publish clinical outcomes following midfoot trauma. Their criteria for grading outcomes were simple; results were graded as excellent, good, fair, or poor based on residual pain, stiffness, and disability [8]. “Excellent” results implied no residual symptoms or impaired function, “good” implied minor symptoms without dysfunction, and “fair” implied continued symptoms and dysfunction and poor outcomes were defined as marked symptoms and disability. Any patient who requested additional surgical intervention or arthrodesis was also deemed a poor result. Patients with Chopart dislocations were a small subset of this cohort, and their clinical outcomes were predominantly “fair” and “poor.” Regardless of the mechanism of injury or direction of displacement, clinical outcomes correlated with the amount of initial displacement, associated soft tissue injury, and the presence of polytrauma.

Twenty-six years later, Richter et al. published their clinical results following the management of patients with midfoot injuries [6]. This cohort was also heterogeneous and included a broad spectrum of midfoot pathology, a subset of which was Chopart dislocations. They treated over 155 midfoot injuries, including 25 isolated Chopart dislocations and 26 patients with concomitant Chopart and Lisfranc fracture-dislocations, over a 25-year period at a major level I Trauma Center in Germany. Most patients were young—average age 32—men ($n = 144$, 73%) involved in a high-speed motor vehicle collision. Ninety-five percent of patients were treated operatively, and of those treated open, 75% received internal fixation with k-wires, screws, and external fixation. Seven patients were treated with primary arthrodesis of the Chopart or Lisfranc joint. Three patients required primary below-knee amputation due to extensive soft tissue injury or polytrauma.

Clinical outcomes were assessed using Hannover Scoring System (HSS), Hannover Outcome-questionnaire (Q), and the American Foot and Ankle Society Score (AOFAS). The mean AOFAS midfoot score was 71, and outcomes were not affected by age, gender, mechanism, or treatment. Patients with fracture-dislocations of the Chopart joint and those with concomitant Lisfranc and Chopart injuries fared the worst on all outcome measures as they were most likely associated with extensive soft tissue injuries and increased rates of postoperative infection.

Three years later, Richter et al. published a retrospective analysis of patients with isolated Chopart joint dislocations, Chopart joint fracture-dislocations, and Chopart-Lisfranc joint fracture-dislocations treated at the same institution [7]. There were 28 patients with isolated Chopart dislocation, 60 patients with Chopart fracture-dislocation, and 22 with Chopart-Lisfranc joint fracture-dislocations. Twenty percent of injuries were open, 88% of patients sustained additional injuries, and 25% were classified as polytrauma. Patients were treated with closed reduction and immobilization, closed reduction and internal k-wire fixation, open reduction and internal fixation, primary arthrodesis, or amputation.

Clinical outcomes were assessed using the HSS, Q, and AOFAS. The mean AOFAS score was 75 at an average follow-up of 9 years. AOFAS outcome scores were significantly impacted by the mechanism of injury, extent of soft tissue injury and the presence of Chopart-Lisfranc fracture-dislocations. Interestingly, patients treated with open reduction had higher outcome scores regardless of injury pattern. The investigators concluded that clinical success was dependent on anatomic reduction regardless of injury type, fixation used or timing of operative intervention. They recommend open reduction for all Chopart fracture-dislocations or Chopart-Lisfranc fracture-dislocations.

Van Dorp et al. published their clinical outcomes following the management of Chopart dislocations and Chopart fracture-dislocations in 2010. In a similar study to Richter, Van Dorp et al. retrospectively reviewed all Chopart injuries presenting to a level II trauma center over a six-year period. They identified nine patients presenting with Chopart injuries. Compared to similar studies, this cohort of patients was predominantly middle-aged women presenting after low-mechanism injuries. Three patients presented with the Chopart dislocation (CCJ + TNJ), three patients presented with the talonavicular dislocation, and three patients presented with the calcaneocuboid dislocation. All dislocations were associated with at least one fracture of the hindfoot or midfoot. Six patients were treated with closed reduction and immobilization; three patients treated with open reduction with K-wire or screw fixation of associated fractures or persistent instability.

Van Dorp et al. also used the AOFAS score in addition to the visual analog scale to assess clinical outcomes. There were seven patients available for outcome analysis, and the mean AOFAS score was 72 at an average of 31.3 months. Using VAS data, four of the seven patients were pain free with daily activities, one patient had moderate pain and two had persistent daily pain. Five patients reported limitations in sporting and leisurely activities secondary to pain. Despite the study's small size and inability to perform statistical analysis, the investigators concluded that Chopart joint injuries may result from high- or low-mechanism injuries and result in long-term functional disability [5].

Isolated Talonavicular Dislocations

The incidence of isolated navicular dislocations is unknown. The literature pertaining to isolated navicular dislocations is limited to a handful of case reports and even fewer case series. The largest series of patients with navicular dislocations remains Main and Jowett's case series published in 1975. Main et al. reviewed a series of 71 patients presenting to their institution with various midfoot injuries including fractures, fracture-dislocations, and isolated dislocations. They were the first to create a midfoot injury classification system based on the direction of deforming force and the resulting displacement of the midfoot [8].

Classification

The classification of midfoot injuries is broken into five categories: medial, lateral, longitudinal, plantar, and crush injuries. These categories are subdivided into sprains, fractures, fracture-dislocations, and isolated dislocation. They identified two unique mechanisms of injury, the "medial swivel dislocation" and "lateral swivel dislocation" which result in isolated talonavicular dislocation (Fig. 12.3). In their description of swivel dislocations, they postulated that a medial

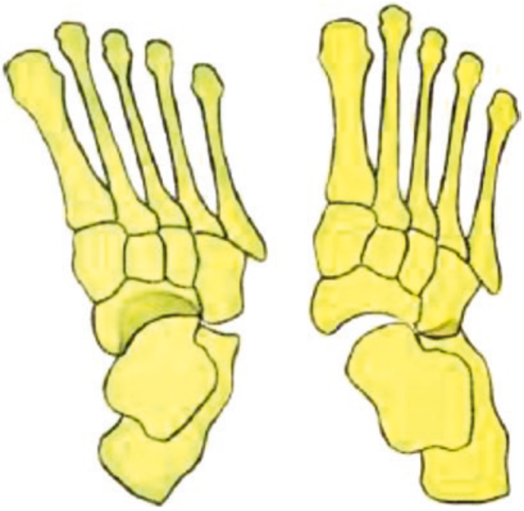


Fig. 12.3 Swivel mechanism postulated by Main and Jowett. In the image on the left, a medially directed force causes compression at the medial aspect of the foot with distraction at the lateral aspect. A laterally directed force, which is depicted in the image on the right, causes compressive forces at the lateral aspect of the force with distraction occurring at the medial structures. (From Rammelt et al. [28])

or lateral force rotates around an axis anterior to the ankle. This axis of energy is centered about the intact talocalcaneal ligament, which disrupts the talonavicular articulation but leaves the calcaneocuboid articulation intact.

Outcomes

Their study included the clinical outcomes of six patients with seven medial swivel dislocations and one patient with a lateral swivel dislocation. They classified outcomes as "excellent" if patients were without symptoms, "good" if there were minimal symptoms and no functional impairment, "fair" if there were residual symptoms and dysfunction, and "poor" if there were marked symptoms requiring further intervention such as delayed arthrodesis. Out of the six patients, there were three "good "results," one "fair," and three "poor." The patient with a lateral swivel dislocation had a good result following closed reduction.

Datt et al. reported the outcome of one patient presenting with a medial swivel dislocation of the talonavicular joint after falling from a motorcycle [9]. The patient presented with an obvious foot deformity, and X-rays revealed medial displacement of the navicular with a counter-coup articular defect on the medial aspect of the talar head. The patient was treated with an open reduction and k-wire fixation of the talonavicular joint. Following reduction, he was non-weight bearing for 6 weeks. At 6 weeks, the k-wires were pulled and the patient progressed to full weight bearing. By the standards proposed by Main et al., this patient had an excellent result as he was pain free and returned to his occupation at full capacity.

Bosman et al. recently reported a case of a lateral talonavicular dislocation following a low-energy trauma [10]. A 69-year-old obese woman presented with left foot pain and a lateral midfoot deformity following a fall from her wheelchair. X-rays showed complete lateral dislocation of the tarsal navicular. She was successfully treated with closed reduction under anesthesia. The reduction was obtained by flexing the knee to relax the gastrocnemius muscle, longitudinal traction, and application of a laterally directed force at the talar head while adducting the forefoot. Post-reduction CT imaging showed small avulsion fractures of the tarsal navicular, lateral cuboid, and lateral cuneiform. The authors propose that lateral swivel dislocations are the result of hyperabduction of the forefoot, which allows a rotating moment about the intact talocalcaneal ligament to laterally dislocate the talonavicular joint.

Dislocations of the navicular without concomitant midfoot fractures may be rarer still, potentially impossible according to several authors [11–13]. Dhillon et al. likened foot stability to a three-legged stool with the calcaneus, middle column, and lateral column as the legs. In this analogy, disruption of one column results in disruption of the adjacent column. If one leg of the stool is injured, the stability is lost. They supported this conclusion with a small case series of six medial swivel dislocations and a review of the available navicular dislocations in the literature.

In their series, each patient presented with a medial navicular dislocation with varying degrees of lateral column injuries ranging from cuboid fractures, subluxation, or dislocation of the calcaneocuboid joint. All but one patient was treated with open reduction and k-wire fixation. Three of six patients were available for review and results varied. One patient had an "excellent" result with minimal symptoms and normal imaging at 3.5 years. A second had persistent pain with standing and required regular analgesics. The final patient developed postoperative instability requiring additional surgeries cumulating in a navicular resection and talocuneiform and calcaneocuboid fusion. This patient had occasional pain but returned to his job as a security guard.

Williams et al. presented a case of a medial swivel dislocation with a tensile cuboid fracture that further supports this claim. They presented a case of a healthy 22-year-old woman who fell while walking and sustained an inversion ankle injury resulting in medial navicular dislocation. She was treated with closed reduction and immobilization. At 18-month follow-up, she had mild intermittent pain and reported that she could not "dance as well as before her injury." Her AOFAS score was 87 at 18 months. The unique aspect of the case was the finding of a tensile fracture along the lateral cuboid. The authors postulated that complete medial dislocation of the navicular is not possible without the disruption of the lateral column.

Isolated Cuboid Dislocations

The available literature pertaining to cuboid dislocations is limited to case reports; the true incidence of dislocation is unknown. The inherent osseous and ligamentous stability of the calcaneocuboid joint prevents routine dislocations outside of high mechanism injuries and ligamentous laxity. The cuboid is nestled between the calcaneus proximally and the fourth and fifth metatarsals distally and secured by many ligamentous and tendinous attachments. There is an array of stout dorsal and plantar ligamentous connections that connect the cuboid to the hindfoot and forefoot. The calcaneocuboid articulation is further supported by tendinous insertions, including the peroneus tertius, flexor digitorum brevis to the fifth toe, and the peroneus longus [14, 15] Despite this stability, there are multiple case reports of isolated cuboid dislocations following high- and low-mechanism injuries.

The integrity of the calcaneocuboid joint weakened in patients with hypermobility syndromes. There are two case reports of patients with Ehlers-Danlos and hyperlaxity who sustained isolated calcaneocuboid dislocations following minor trauma [16, 17] Wainwright and Gregg published a case of a 27-year-old woman with type II Ehlers-Danlos who presented with a calcaneocuboid dislocation following a ground-level fall. She was successfully reduced closed and treated with immobilization. Mcharo and Oschsner reported a similar case of an 18-year-old woman with hyperlaxity who presented with repeated chronic bilateral calcaneocuboid dislocations following supination-plantar flexion injuries. She was successfully treated with staged calcaneocuboid joint reconstruction using plantaris tendon autograft. The authors report that she had no problems years later aside from a hyperesthetic scar [16]

The peroneus longus tendon provides extrinsic stability to the calcaneocuboid joint, but it may also act as an obstruction following dislocation [15]. Dobbs et al. reported two unique cases of delayed presentations of calcaneocuboid dislocation where reduction was blocked by an interposed peroneus longus tendon. Both patients presented to their institution with foot pain after low-energy plantar-flexion inversion injuries. Radiographs revealed a plantar cuboid dislocation. In both cases, the authors attempted closed reduction under anesthesia but were unsuccessful. Open reduction revealed that the peroneus longus interposed between the cuboid and fifth metatarsal. The tendon was freed and the cuboid reduced. Following reduction, one patient was received antegrade and retrograde screws and the other received k-wires to stabilize the calcaneocuboid joint. Both patients had excellent outcomes and returned to previous activities without disability or foot pain.

The treatment of calcaneocuboid dislocations is predominantly open reduction and stabilization. In fact, there is only one reported case of successful closed reduction of a calcaneocuboid dislocation [18]. The available case reports describe varying amounts of interposed tissue within the calcaneocuboid joint, preventing successful reduction. The same capsular, ligamentous, and tendinous attachments that provide stability before injury obstruct successful reduction. All cases required temporary stabilization of the calcaneocuboid or cuboid-metatarsal articulations using screws or k-wires. In all but one case [17], patients made a complete recovery, and one patient returned to professional baseball [14].

Isolated Calcaneal Dislocations

Isolated calcaneal dislocations are the rarest of the midfoot injuries. These injuries are classified as disruptions of the subtalar and calcaneocuboid joints with the preservation of the talonavicular joint. The literature pertaining to calcaneal dislocations is sparse and only includes case reports spanning many decades and several languages [19–23]. In all but one case, the calcaneal dislocation is lateral, and the outlier was a plantar dislocation [24].

The common mechanism behind each dislocation was a twisting or wringing movement about the midfoot and has occurred with high- and low-mechanism injuries. Roa concluded that the wringing moment occurs around an axis located in the midfoot with the forefoot inverted. The pathophysiology is like that seen in isolated calcaneocuboid dislocations, but the axis of rotation is simply more proximal [22]. The result of this wringing movement is disruption of the subtalar and calcaneocuboid joints but preservation of the talonavicular joint.

Historically, the treatment of the reported calcaneal dislocations has been operative. All but one report was treated with closed reduction and k-wire fixation; the case reported by Viswanath was treated with open reduction and temporary pin fixation [19, 21–23, 25]. Many authors reported that the calcaneal dislocation was closed reduced with ease but remained unstable. The ease of reduction and persistent instability are the result of disruption of the stout hindfoot ligaments. Following operative reduction and pinning, all patients were treated with immobilization for a period of 6–12 weeks. Weight bearing and removal of instrumentation were initiated at variable time points following reduction.

The clinical outcomes following the management of calcaneal dislocations have been guarded. The outcomes are described as “satisfactory” as reported by various authors based on residual pain, deformity, and function. Viswanath reported a satisfactory outcome following open reduction and pin fixation of a closed calcaneal dislocation. Two years post injury, their patient had a slight limp and a varus hindfoot deformity, but this did not prevent them from returning to netball [21]. More recently, Rao reported a satisfactory outcome following the treatment of an open calcaneal dislocation. Their patient had residual pain and swelling in the hindfoot and difficulty managing uneven surfaces. Despite these limitations, the patient returned to work as a bus driver [22].

There are no long-term outcome studies pertaining to calcaneal dislocation, but the natural history likely follows those of subtalar dislocations. While there are no series of calcaneal dislocations, there are several case series investigating the outcomes of subtalar dislocations at 5–12 years. Perugia et al. [26] in 2002 and de Palma et al. [27] in 2008 presented the clinical outcomes of 45 and 30 patients, respectively, following conservative management of subtalar dislocations. The mean AOFAS scores were 84 at an average of 7.5 years for Perugia and 78.8 and 8.5 years for de Palma. Twenty patients in Perugia’s study were free of symptoms but had notable decrease in subtalar motion. Twelve patients had difficulty with uneven ground and limitation in daily or recreational activities. De Palma’s series had poorer results: 7 patients were symptom free, 14 patients had mild pain and difficulty with uneven ground, and 6 patients had moderate limitations in daily activities due to pain and poor subtalar motion.

Treatment Strategies

While there are a variety of dislocations discussed in this section, the goal for the management of all of these injuries is obtaining and maintaining an anatomic, stable reduction. This can be accomplished by a variety of means including closed versus open reduction. Once reduced, stability must be assessed clinically and radiographically. This includes physical examination, standard radiographs and frequently CT scan. If the foot is either not concentrically reduced or demonstrates signs of instability, consideration must be given to surgical management.

Given the great variation of these injuries, and the fact that pure dislocations (without fracture) are exceedingly rare, there is no one best surgical solution. The guiding principles however remain constant. Dislocations should be reduced in a timely manner. This is particularly important when skin or other soft tissues are under tension and at risk. Early stabilization is an option if the soft tissue permits and the surgeon fully understands the injury, which can be challenging acutely. More often, the soft tissue injury precludes early definitive management. In such cases, splinting, external fixation, and percutaneous pinning are all good choices and can be used in combination. The goal of the initial surgery is to reduce the dislocation, relieve tension on soft tissues and, if appropriate, provide stability to maintain the provisional reduction while allowing swelling to abate.

Definitive management often requires surgical stabilization. If there are concomitant fractures, those must be addressed in as much as they affect articular congruity, concentric joint reduction, and overall foot alignment. When considering injuries that are primarily dislocations, associated fractures are usually small avulsions or impactions. They may be addressed with small screw, plates, k-wires, and/or suture as appropriate. Occasionally bone graft is useful for managing articular impactions.

Stabilization of a dislocation often requires fixation across the joint. For the essential (mobile) joints, particularly the lateral column, spanning fixation should be temporary when possible. This can include external fixation, k-wires, and/or plates. For the nonessential joints, acute arthrodesis may be considered, especially in the cases of significant articular injury.

Summary of Tarsal Dislocations

In summary, there are several joint dislocations involving the midfoot that occur other than the more common Lisfranc fracture-dislocations. Isolated dislocations, without significant fractures, are very rare. Correctly identifying the injury can be challenging as these injuries are not common. CT scans are often beneficial in addition to standard radiographs to properly diagnose and treat. Small concomitant fractures are often present as well. Treatment principles center on restoring and maintaining anatomic alignment with a concentric joint reduction. In most cases, this requires surgical stabilization, occasionally in a staged manner due to soft tissue injury. For joints that ultimately need to remain mobile, the fixation may need to be temporary, with fusion reserved for the nonessential joints of the foot.

Case Discussions

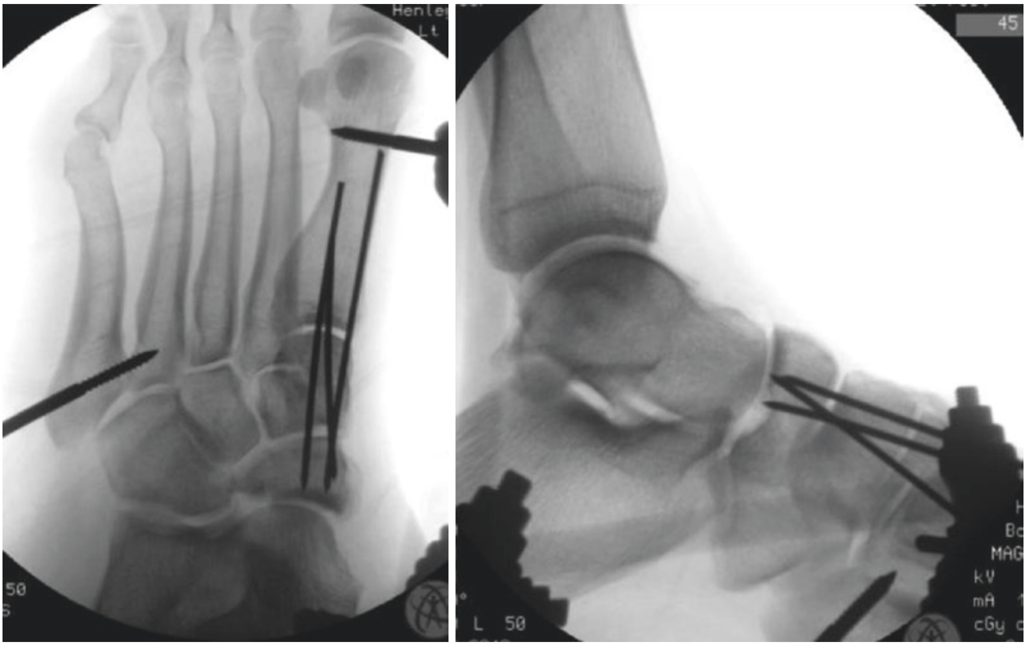
Case Report 1: Navicular Fracture Dislocation

A 35-year-old male presented status post fall from ladder with complaints of left foot pain. Swelling was present at the left foot, with maximal tenderness over the midfoot. No neurovascular deficits were noted. Radiographic examination demonstrated a dorsally displaced navicular, dislocated from the talus and cuneiforms, with fractures at the plantar aspect (Fig. 12.4). Several hours following presentation to the emergency department, the patient was brought to the operating room for closed reduction and percutaneous pinning of his navicular dislocation, as well as spanning external fixation of his foot (Fig. 12.5). He was made non-weight-bearing to the left lower extremity.


AP

Lateral

Fig. 12.4 Radiographs of initial presentation demonstrating a dorsally displaced navicular with fracture fragments at the plantar surface


AP

Lateral

Fig. 12.5 Radiographs demonstrating percutaneous fixation following closed reduction of the navicular. External fixation pins are also seen

Two weeks later, when the soft tissue swelling had improved, he returned to the operating room for definitive fixation. A direct medial approach was used to access the navicular plantar fragments. Multiple Kirschner wires and screws were utilized to compress the dorsal bone to the plantar fragment. A separate anterolateral incision was used to address the lateral fragment and to facilitate plate fixation. A 2.4 T-plate was used to anchor the navicular to the medial cuneiform (Fig. 12.6). In addition, the external fixator was removed. Postoperatively, the foot was immobilized in a splint until sutures were removed, followed by a cast for 6 weeks. Physical therapy for the ankle range of motion was started after the cast was discontinued. The patient was non-weight-bearing for a total of 3 months. The plate was removed at 18 months postoperatively, in addition to a cheilectomy for persistent pain (Fig. 12.7).

Case Report 2: Chopart Fracture-Dislocation

A 22-year-old male with a history of substance abuse presented status post a 2-story fall from a roof in a suicide attempt. He noted pain in his left foot, as well as his back. He incurred multiple injuries, including multiple lumbar vertebrae fractures and a left midtarsal injury. The navicular was dorsally dislocated from the talus, and the anterior process of the calcaneus was fractured through the sinus tarsi, with dorsal displacement (Fig. 12.8). No neurovascular deficits were noted due to either the spine or foot injury.

There was a reduction attempt performed in the Emergency Department under conscious sedation that was unsuccessful, as was a closed reduction attempt in the operating room. A 4.0 mm Schanz pin was then inserted into the

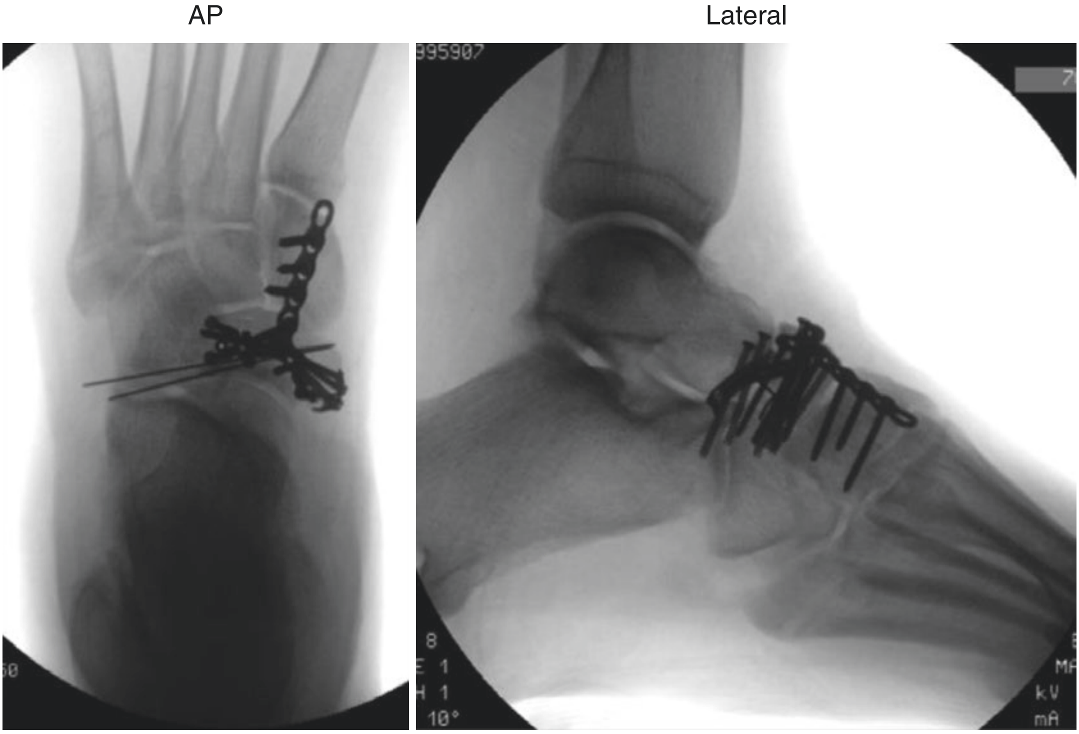


Fig. 12.6 Radiographs of definitive fixation construct. K-wires and independent screws maintain the navicular fracture reduction, and a 2.4 T-plate was used to stabilize the navicular to the medial cuneiform

Fig. 12.7 Radiographs following plate removal and cheilectomy demonstrate mild cavus and narrowing of the talonavicular joint

navicular to act as a manipulative aid to reduction prior to performing an open approach (Fig. 12.9). When this was not successful, an open approach via 5 cm dorsal incision over the talonavicular joint was performed. The navicular was identified, as was the void dorsal to the talar head and proximal to the navicular. A lamina spreader was inserted into this void, with one tine on the distal tibia and one on the navicular. As the tines were spread apart, the talar head reduced to the navicular. A stress examination of the joint noted residual instability after the reduction, as the plantar aspect of the talonavicular joint would widen with a dorsal force applied to the forefoot. A capsular repair was performed, with suture anchors into the talus securing the capsule to the navicular. The talonavicular joint was pinned with two retrograde 0.62 Kirschner wires (K-wires).

By postoperative day nine, the swelling of the skin had resolved and definitive open reduction and internal fixation of the anterior process of the calcaneus through a sinus tarsi approach was performed (Fig. 12.10). The patient was made non-weight-bearing postoperatively for 12 weeks when he was transitioned to weight-bearing-as-tolerated in a CAM boot. The two K-wires traversing the talonavicular joint were removed in the office 4 weeks postoperatively. Physical therapy for ankle and foot range of motion was started at postoperative week eight. He was lost to orthopedic trauma follow-up but was noted to ambulate without pain at his orthopedic spine follow-up a year post-injury.

AP

Oblique

Lateral

Fig. 12.8 Radiographs depicting dorsal navicular dislocation with the fracture of the anterior process of the calcaneus

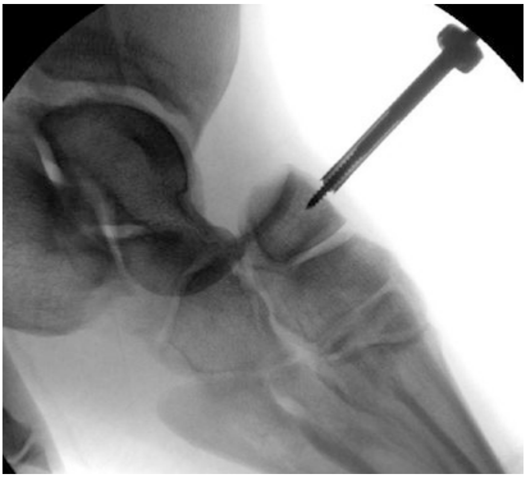


Fig. 12.9 Lateral radiograph with 4.0 mm Schanz pin in the navicular, which was used as a manipulation tool

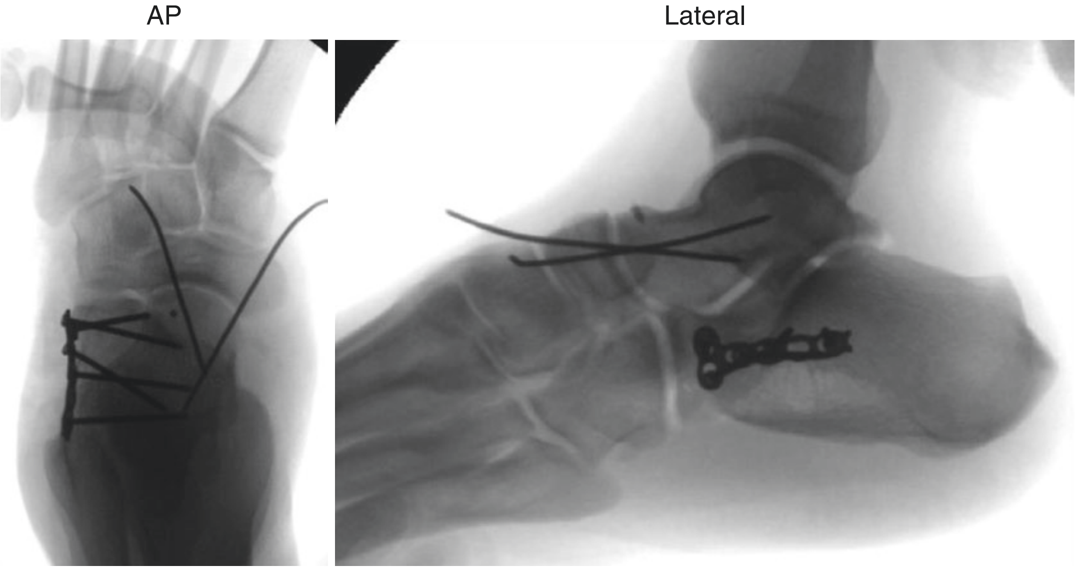


Fig. 12.10 Radiographs of the final fixation construct; two retrograde 0.62 Kirschner wires are through the talonavicular joint and a laterally based T-plate at the anterior process of the calcaneus

References

1. Benirschke SK, Meinberg E, Anderson SA, Jones CB, Fractures CPA. Dislocations of the Midfoot: Lisfranc and Chopart injuries. J Bone Jt Surg (Am). 2012;94(14):1326–37.
2. Klaue K. Chopart fractures. Injury. 2004;35(Suppl 2(2)):SB64–70.
3. Makwana NK, van Liefland MR. Injuries of the midfoot. Curr Orthop. 2005;19(3):231–42.
4. Dorn-Lange NV, Nauck T, Lohrer H, Arentz S, Konerding MA. Morphology of the dorsal and lateral calcaneocuboid ligaments. Foot Ankle Int. 2008;29(8):942–9.
5. van Dorp KB, de Vries MR, van der Elst M, Schepers T. Chopart joint injury: a study of outcome and morbidity. J Foot Ankle Surg. 2010;49(6):541–5.
6. Richter M, Wippermann B, Krettek C, Schratt HE, Hufner T, Therman H. Fractures and fracture dislocations of the midfoot: occurrence, causes and long-term results. Foot Ankle Int. 2001;22(5):392–8.

7. Richter M, Thermann H, Huefner T. Chopart joint fracture-dislocation: initial open reduction provides better outcome than closed reduction. Foot Ankle. 2004;25(5):340–8.
8. Main BJ, Jowett RL. Injuries of the midtarsal joint. J Bone Joint Surg Br. 1975;57(1):89–97.
9. Datt N, Rao AS, Rao DV. Medial swivel dislocation of the talonavicular joint. Ind J Orthop Medknow Publ. 2009;43(1):87–9.
10. Bosman W-M, Prakken FJ, Pijls BG, Ritchie ED. Lateral talonavicular dislocation after low-energy trauma. BMJ Case Rep. 2013:bcr2013200692.
11. Vaishya R, Patrick JH. Isolated dorsal fracture-dislocation of the tarsal navicular. Injury. 1991;22(1):47–8.
12. Dhillon MS, Nagi ON. Total dislocations of the navicular: are they ever isolated injuries? J Bone Joint Surg. 1999;81(5):881–5.
13. Williams DP, Hanoun A, Hakimi M, Ali S, Khatri M. Talonavicular dislocation with associated cuboid fracture following low-energy trauma. Foot Ankle Surg. 2009;15(3):155–7.
14. Smith JS, Flemister AS. Complete cuboid dislocation in a professional baseball player. Am J Sports Med. SAGE Publications Sage: Thousand Oaks. 2016;34(1):21–3.
15. Dobbs MB, Crawford H, Saltzman C. Peroneus longus tendon obstructing reduction of cuboid dislocation. A report of two cases. J Bone Jt Surg (Am). 2001;83-A(9):1387–91.
16. Mcharo CN, Ochsner PE. Isolated bilateral recurrent dislocation of the calcaneocuboid joint. A case report. J Bone Jt Surg Br. Br Editorial Soc Bone Jt Surg. 1997;79(4):648–9.
17. Wainwright AM, Parmar HV, Gregg PJ. Calcaneocuboid dislocation in a case of Ehlers-Danlos syndrome. Injury. 1993;24(4):274.
18. Fagel VL, Ocon E, Cantarella JC, Feldman F. Case report 183. Skelet Radiol. 1982;7(4):287–8.
19. Parcellier A, Chenut A. Un cas de luxation du calcaneum. Rev Orthop. 1928;15:418.
20. Degen IL. Dislocation of the calceneus. Ortop Travmatol Protez. 1968;29(3):79–80.
21. Viswanath SS, Shephard E. Dislocation of the calcaneum. Injury. 1977;9(1):50–2. Elsevier.
22. Rao H. A complete dislocation of the calcaneus: a case report. J Foot Ankle Surg. 2005;44(5):401–5.
23. Hamilton AR. An unusual dislocation. Med J Aust. 1949;1:271.
24. Horand R. Un cas de luxationdu calcaneum en bas “calcaneum cabre”. Lyon Med; 1912.
25. Degen IL. [dislocation of the calceneus]. Ortop Travmatol Protez. Ortop Travmatol Protez. 1968 Mar;29(3):79–80.
26. Perugia D, Basile A, Massoni C, Gumina S, Rossi F, Ferretti A. Conservative treatment of subtalar dislocations. Int Orthop. 2002;26(1):56–60.
27. de Palma L, Santucci A, Marinelli M, Borgogno E, Catalani A. Clinical outcome of closed isolated subtalar dislocations. Arch Orthop Trauma Surg. Springer-Verlag. 2008;128(6):593–8.
28. Rammelt S, Grass R, Schikore H, et al. Verletzungen des Chopart-Gelenks. Der Unfallchirurg. 2002;105(4):374.
29. Lasanianos N, Kanakaris N, Giannoudis P. Trauma and orthopaedic classifications: a comprehensive review. London: Springer; 2015.

13

Hindfoot Sprains

Todd P. Pierce, Kimona Issa,
and Jason Schneidkraut

Introduction

Although rare, with an estimated 2% prevalence reported in cadaveric studies, tears at the ligaments connecting the calcaneus, talus, and cuboid can occur [1]. As many as 10–25% of patients who have been diagnosed with ankle instability may have an injury to the subtalar ligaments [2, 3]. They are responsible for transmitting the forces of the ground through the subtalar, talonavicular, calcaneocuboid, and talocrural joints during heel strike of the walking gait [1]. The mechanism of injury is not well understood; however, forced supination at the ankle joint is believed to play a role [4]. Hence, these injuries are often seen in professional and amateur ballet dancers as they experience repetitive microtrauma to these joints and ligaments [5–7]. If left untreated, damage to these ligaments may result in chronic pain and instability [4]. Therefore, we aim to briefly describe the appropriate diagnosis and treatment of these rare injuries.

Anatomy

The hindfoot is composed of the calcaneus, talus, and cuboid. It is composed of three joints: (1) subtalar, (2) talonavicular, and (3) calacaneocuboid (Fig. 13.1). The subtalar joint is the main articulation for pronation and supination of the foot. It is primarily composed of three ligaments: calcaneofibular, interosseous talocalcaneal, and cervical (Fig. 13.2). The talonavicular and calcaneocuboid joints are a part of the transverse tarsal joint. This joint is responsible for stability during walking gait as it is locked during inversion of the foot and unlocked during eversion.

Fig. 13.1 Lateral foot radiograph locating the subtalar (box), talonavicular (red arrow), and calcaneocuboid (blue arrow) joints. Note that the talonavicular and calcaneocuboid joint spaces also have corresponding ligaments that course with these respective arrows

T. P. Pierce · K. Issa
Department of Orthopaedics, Seton Hall University,
School of Health and Medical Sciences,
South Orange, NJ, USA
e-mail: kissa@buffalo.edu

J. Schneidkraut (✉)
Elite Orthopaedics and Sports Medicine,
Wayne, NJ, USA

© Springer Nature Switzerland AG 2020

M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_13

Fig. 13.2 Lateral foot radiograph showing the three main ligaments of the subtalar joint- calcaneofibular (red line), interosseous talocalcaneal (blue line), and cervical (green line) ligaments

Mechanism of Injury

Patients often report a history of supination injury followed by lateral pain and swelling [8]. As many as 10–25% of patients who have been diagnosed with ankle instability may have an injury to the subtalar ligaments [2, 3].

Diagnosis

Often, patients will present complaining of hindfoot pain with or without swelling. They often describe a twisting ankle injury of some kind. However, this may be pain of an insidious onset where the patient reports no trauma. Their physical exam may show some tenderness to palpation around the calcaneus, cuboid, or talus. However, the physical exam may be completely unremarkable.

Using plain foot and ankle series radiographs with and without stressing the joint in varus (as these injuries often involve a supination component), practitioners may be able to determine if there is damage to these ligaments. A radiographic study of 100 consecutive patients performed by Magerkurth et al. found the mean anteroposterior position of the talus, compared to the plafond, to be 1.7 mm (range, −3 to 8 mm) and the height of the talus to be 28 mm (range, 17–38 mm) [9]. Hence, they concluded deviations in these measurements could indicate ligamentous damage in the ligaments adjoining the talus. These injuries may be associated with other pathologies such as ankle osteoarthritis or osteochondral lesions [1, 10]. Computerized tomography (CT) scan may have some utility in the event and there is concern regarding the size of the bony fragments surrounding the calcaneus and the cuboid [8]. However, this has yet to be proven in diagnostic studies.

In order to appropriate visualize the ligamentous structures, magnetic resonance imaging (MRI) is most useful [11]. In fact, it has become more common to perform MRI if there is a high clinical suspicion of low or high ankle sprains [11, 12]. Tochigi et al. evaluated the MRI studies of those with inversion injuries to the foot ($n = 24$ patients) [12]. In 13 of these patients, they found damage to the talocalcaneal ligament. However, with hindfoot ligamentous injuries, more recently, there has been the exploration of using ultrasound to appropriately visualize the ligaments between the talus, calcaneus, and cuboid, but this imaging modality has yet to be accepted as a diagnostic standard of care [13].

To assist in proper management of these injuries, Andemahr et al. created a classification system for calcaneocuboid ligament injuries that may assist in guiding management (Table 13.1)

Table 13.1 Calcaneocuboid ligament injury classification system [8]

Type	CC angle on stress radiographs	AP radiograph findings	Treatment
1	<10°	No flake	Strapping 4 to 6 weeks
2	>10°	+/− small flake	Walking boot 6 weeks
3	>10°	Large flake	Refixation of flake
4	>10°	Flake with cuboidal compression fracture	ORIF +/− bone grafting of cuboid +/= ligament grafting via peroneus brevis

[8]. It is guided by two particular components of the injury: (1) the presence and/or size of a bone flake; and (2) the degrees of varus stress.

Treatment

Currently, there are no widely accepted guidelines for the treatment of these injuries. However, the vast majority may be treated conservatively [8]. Similar to ankle sprains, they are treated with a period of rest, ice, compression, and elevation (RICE) [14]. More severe ligamentous injuries may be treated with a course of immobilization and protected weightbearing in conjunction with the RICE modalities [14]. If physical therapy is used, it should be focused on Achille's stretching, proprioceptive training, and strengthening of the peroneal muscles [15].

The aforementioned Andemahr classification system may be used to guide treatment. Typically, the presence of the large flake in conjunction with 10° of angulation on stress radiographs is an indication for operative management with the goal of restoring the native anatomy [8]. Large bony flakes as well as gross angulation upon stress views are indicative of instability in the transverse tarsal joint, which is essential for appropriate walking gait.

Conclusion

In conclusion, although quite rare, injuries to the ligaments connecting the calcaneus, talus, and cuboid can occur. They can often be diagnosed using plain radiographs of the foot and ankle with varus stress films. Although a number of these injuries may improve with conservative treatment modalities, operative treatment may be required in the event of gross instability and large bony fragments. Unfortunately, because these injuries are quite rare, they have not been extensively studied and treatment modalities may evolve with future studies that evaluate outcomes.

References

1. Cromeens B, Patterson R, Sheedlo H, Motley TA, Stewart D, Fisher C, Suzuki S, Su F, Reeves R. Association of hindfoot ligament tears and osteochondral lesions. Foot Ankle Int. 2011;32(12):1164.
2. Keefe DT, Haddad SL. Subtalar instability. Etiology, diagnosis, and management. Foot Ankle Clin. 2002;7(3):577.
3. Pisani G. Chronic laxity of the subtalar joint. Orthopedics. 1996;19(5):431.
4. Meyer JM, Garcia J, Hoffmeyer P, Fritschy D. The subtalar sprain. A roentgenographic study. Clin Orthop Relat Res. 1988;226:169.
5. Menetrey J, Fritschy D. Subtalar subluxation in ballet dancers. Am J Sports Med. 1999;27(2):143.
6. van Dijk CN, Lim LS, Poortman A, Strubbe EH, Marti RK. Degenerative joint disease in female ballet dancers. Am J Sports Med. 1995;23(3):295.
7. Jung HG, Kim TH. Subtalar instability reconstruction with an allograft: technical note. Foot Ankle Int. 2012;33(8):682.
8. Andermahr J, Helling HJ, Maintz D, Monig S, Koebke J, Rehm KE. The injury of the calcaneocuboid ligaments. Foot Ankle Int. 2000;21(5):379.
9. Magerkurth O, Knupp M, Ledermann H, Hintermann B. Evaluation of hindfoot dimensions: a radiological study. Foot Ankle Int. 2006;27(8):612.
10. Arokoski JP, Jurvelin JS, Vaatainen U, Helminen HJ. Normal and pathological adaptations of articular cartilage to joint loading. Scand J Med Sci Sports. 2000;10(4):186.
11. Main BJ, Jowett RL. Injuries of the midtarsal joint. J Bone Joint Surg Br. 1975;57(1):89.
12. Tochigi Y, Yoshinaga K, Wada Y, Moriya H. Acute inversion injury of the ankle: magnetic resonance imaging and clinical outcomes. Foot Ankle Int. 1998;19(11):730.
13. Fessell DP, Jacobson JA. Ultrasound of the hindfoot and midfoot. Radiol Clin N Am. 2008;46(6):1027.
14. Mullen JE, O'Malley MJ. Sprains – residual instability of subtalar, Lisfranc joints, and turf toe. Clin Sports Med. 2004;23(1):97.
15. Clanton TO. Instability of the subtalar joint. Orthop Clin North Am. 1989;20(4):583.

Part IV

Fractures of the Calcaneus

14

Intra-articular Calcaneal Fractures

Kenneth L. Koury

Introduction

Calcaneal fractures account for approximately 1–2% of all fractures per year, with an estimated incidence of 11.5 per 100,000 people annually [1]. These fractures, however, can have a dramatic impact on the lives of patients due to the complexity and severity of the injury as well as its potential complications. Thus, there is increasing interest in calcaneal fracture management, with more recent advances focused on improving surgical decision making for these potentially devastating injuries.

Over the past 2–3 decades, orthopedic surgeons have sought to minimize the personal devastation and the societal economic impact of these severe injuries through improved operative management of displaced calcaneal fractures [2–7]. During this time period, such focus lead to new ways of classifying fractures, selecting operative candidates, and modifying surgical approaches [8–11]. The goal of this chapter is to review the important elements of calcaneal fracture treatment by reviewing relevant anatomy and biomechanics, typical fracture patterns, surgical indications and rationale, and temporizing techniques to optimize the soft tissues prior to definitive surgery. Surgical approaches and definitive treatments are discussed in subsequent chapters.

Anatomy and Biomechanics

The calcaneus has an irregular and complex morphology featuring the posterior tuberosity, medial sustentaculum tali, and the anterior and superior articulations. The heel bone serves an important role in weightbearing through its contribution to the longitudinal arch and the lateral column of the foot as well as being the attachment site of the plantar fascia and triceps surae. This section will review the important articulations, muscular attachments, and relevant soft tissue associations.

The calcaneus hosts four articulations: calcaneal-cuboid, anterior facet, middle facet, and posterior facet (Fig. 14.1). The calcaneal-cuboid joint connects the heel bone with the lateral column of the foot, at the anterior-most aspect of the anterior process. The remaining facets on the anterosuperior portion of the calcaneus form the subtalar joint with the talus. The anterior and middle facets of the calcaneus lie on the superior aspect of the sustentaculum tali, while the posterior facet is the largest and functions as the primary weightbearing articulation.

The calcaneus serves as an important site of muscular and ligamentous attachments. The tuber is the attachment site of both the triceps surae and plantar fascia, which are contiguous structures. The

---

K. L. Koury (✉)
Orthopaedic Trauma Surgery, Geisinger Wyoming Valley, Wilkes-Barre, PA, USA
e-mail: kkoury@geisinger.edu

© Springer Nature Switzerland AG 2020

M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_14

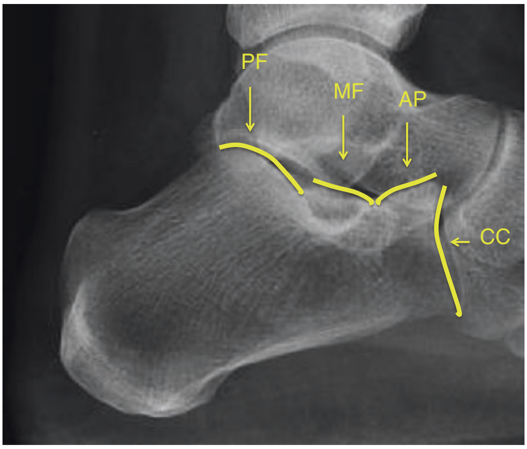


Fig. 14.1 The articulations of the calcaneus as seen on the lateral radiograph: PF posterior facet, MF middle facet (sustentaculum), AP anterior process, CC calcaneocuboid articulation

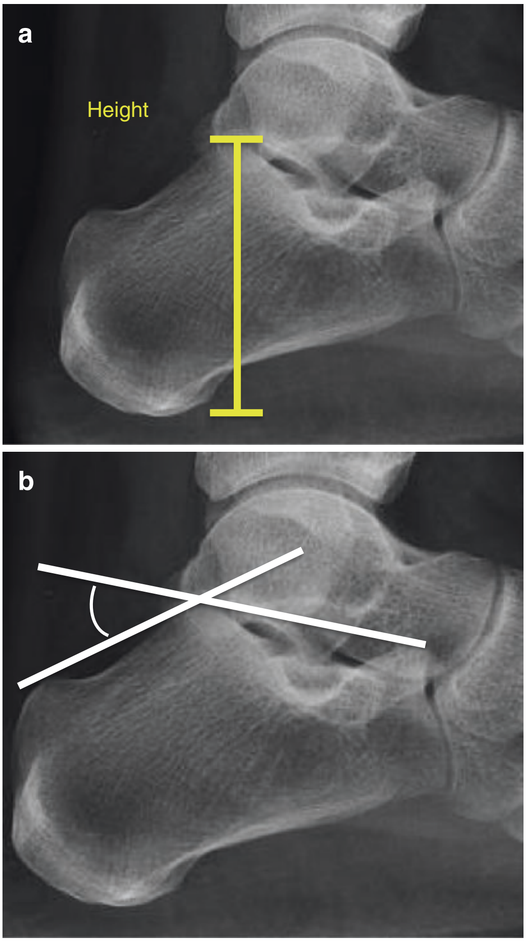


Fig. 14.2 (**a**) Proper height of the calcaneus. (**b**) Tuber angle of Böhler – This is the angle created by the intersection of two lines. One line connects the cranial aspect of the posterior facet to the cranial aspect of the anterior process. The second line connects the cranial aspect of the posterior facet to the cranial aspect of the tuberosity. A normal angle is between 20 and 40°

heel pad is also anchored to the plantar aspect of the tuberosity. Ligamentous attachments medially to the sustentaculum include the superomedial spring ligament, which is critical for the longitudinal arch. Medially and laterally the calcaneus contributes to ankle stability with attachments sites for the tibiocalcaneal portion of the deltoid ligament and calcaneofibular ligaments, respectively.

Fractures of the calcaneus can lead to several biomechanically important deformities. Height of the calcaneus, measured on the lateral x-ray from the superior aspect of the posterior facet to the inferior border of the heel bone, is important for gastrocnemius-soleus lever arm function and avoidance of tibiotalar impingement anteriorly (Figs. 14.2 and 14.3). Likewise, loss of length, measured from anterior to posterior, shortens the lateral column, leading to abduction of the forefoot, pes planus, and talar impingement [12] (Fig. 14.4). Fractures of the calcaneus also typically widen the heel from medial to lateral. This width increase results in peroneal irritation, calcaneofibular ligament abutment, sural nerve entrapment, and difficulties with normal shoe wear. Additionally, the tuberosity is typically in varus, which negatively affects the biomechanics of the foot (Figs. 14.5, 14.6, 14.7, and 14.8). The anterior process typically displaces dorsally. If it heals in this position, then the lateral talar process can impinge on this displaced fragment in pronation (Fig. 14.9). Finally, posterior facet displacement and step off have a relationship with subtalar arthrosis (Fig. 14.10).

There are also many relevant soft tissue structures near the calcaneus which factor into the plan for treatment of these injuries. The peroneal tendons course along the lateral wall of the calcaneus, risking impingement with lateral wall blow out. Also on the lateral side are the sural nerve and the arterial blood supply to the skin of the lateral heel. Understanding the course of the sural nerve is necessary to prevent iatrogenic injury during an ORIF of the calcaneus during either a lateral

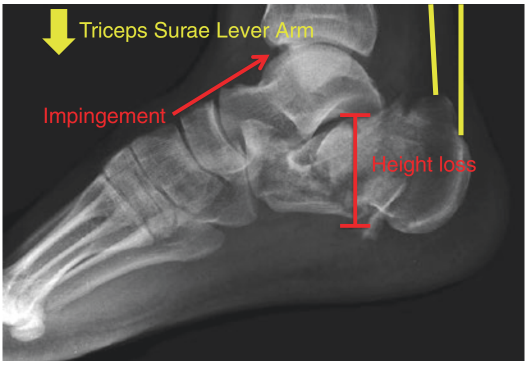


Fig. 14.3 A loss of height of the calcaneus compromises the lever arm of the triceps surae. If the calcaneus were to heal in this position, the talus would assume a more horizontal posture in the sagittal plane when weightbearing. In dorsiflexion, the talar neck would impinge on the anterior aspect of the distal tibia

Fig. 14.4 Proper length of the calcaneus

extensile or sinus tarsi approach. The lateral calcaneal branch of the peroneal artery perfuses the flap of the lateral extensile approach. Medially, the flexor hallucis longus (FHL) courses inferior to the sustentaculum tali. As laterally based hardware is anchored in this area, excessively long screw tips may tether the FHL.

Fracture Patterns and Classifications

Typical mechanisms of injury for calcaneal fractures are axial loading injuries such as falls from height or high-speed motor vehicle accidents [13]. The pattern of primary and secondary fracture lines are reproducible and define the injury and its associated sequelae. The primary fracture line typically runs from the lateral aspect of the sinus tarsi, traversing the posterior facet, and exiting the medial wall posterior to the sustentaculum tali, thus, separating the calcaneus into two fragments: posterolateral and anteromedial. The posterolateral fragment contains the tuberosity, the lateral wall, and the lateral portion of the posterior facet. The anteromedial fragment has the medial portion of the posterior facet and the sustentaculum with the middle and anterior facets. The sustentaculum tali usually retains its relationship with the talus and therefore referred to as the constant fragment.

Fig. 14.5 Proper width of the calcaneus

Essex-Lopresti categorized two subtypes of fractures based on the orientation of the secondary fracture lines on radiographs [13]. In the joint depression type, the tuberosity is no longer in continuity with the posterior facet due to a

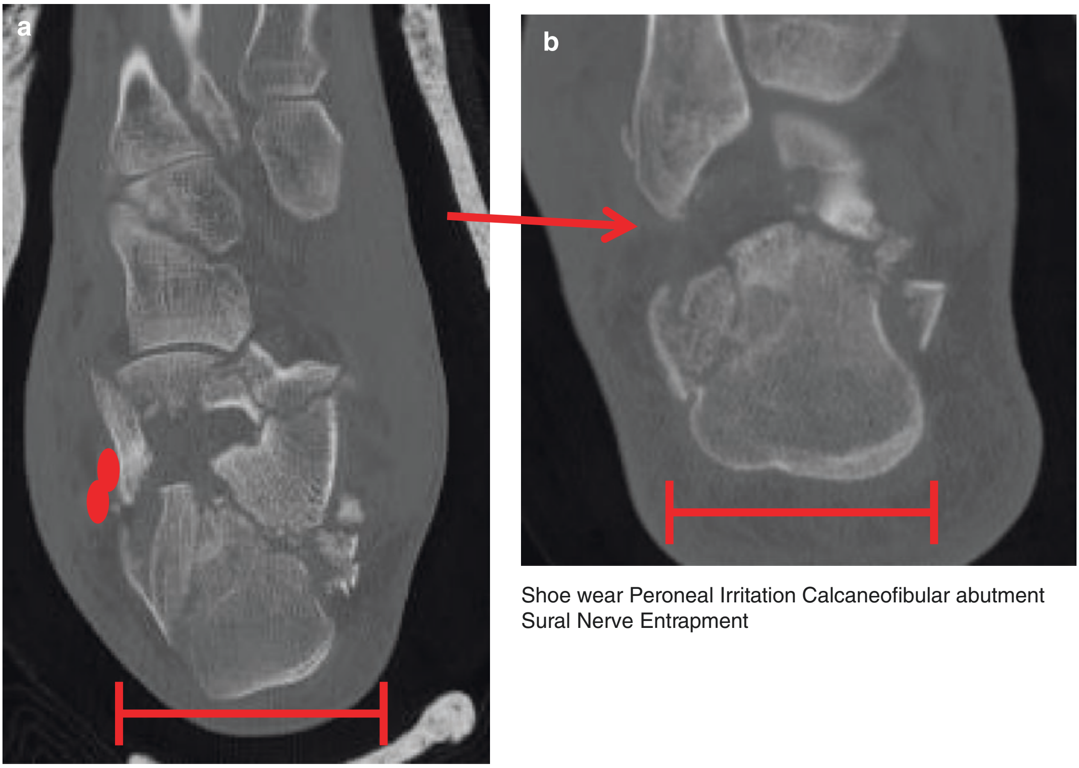


Fig. 14.6 An increase in heel width can create several problems. There can be difficulties fitting the heel into a shoe, and the peroneal tendons can become irritated due to their displaced position on an irregular surface. The sural nerve can become entrapped in the lateral wall blowout. The fibula can impinge on the displaced lateral wall in eversion. The circles on 7a indicate the position of the peroneal tendons. The arrow on 7b draws attention to the area of the fibula that would abut against the laterally displaced lateral wall of the calcaneus

secondary fracture line that separates the two. In tongue type fractures, however, a secondary fracture line with a horizontal orientation plantar to the posterior facet splits the tuberosity, thus keeping the posterior facet in continuity with the tuberosity [13]. Further study supported the reproducibility of this classification system [13–15].

Joint depression fractures have the noted primary and secondary fracture lines described above, as well as additional secondary fractures that may occur in the anterior process extending into the calcaneocuboid joint. Typically this anterolateral fragment deforms into pronation. Due to the separation of the posterior facet and tuber, shortening of the heel height and length occurs, as well as a corresponding increase in width. Additionally, the tuberosity consistently displaces into varus.

Tongue type fractures, in comparison, have a distinct posterior split in the tuber fragment and are superiorly displaced due to the pull of the Achilles tendon. This displacement is important to appreciate as it may pose a severe risk to the posterior skin of the heel due to focal pressure. Timely recognition and urgent treatment can minimize soft tissue complications of this subtype [16].

Several measurements exist to help define posterior facet displacement on the lateral radiograph. Böhler's angle, an angle formed by a line connecting the most superior point of the anterior process and posterior facet and a second line along the superior border of the tuberosity to the superior point on the posterior facet, correlates with outcomes. The angle normally measures 20–40° with decreasing values indicating posterior facet displacement and loss of height [17]. In contrast, the angle of Gissane, an angle

Fig. 14.7 Proper coronal plane alignment of the calcaneus

between two cortical columns inferior to the lateral process of the talus on the lateral x-ray, is not correlated with outcomes. This angle typically ranges from 95 to 110° with increasing values correlated with displacement of the posterior facet [18].

Other classifications exist, most focusing on posterior facet comminution severity and location on CT scan [6, 8, 19]. The utility of these additional classifications remains debated [2]. However, the use of CT scan provides important information on the axial, coronal, and sagittal views for surgical planning.

Fig. 14.8 Varus alignment of the calcaneus

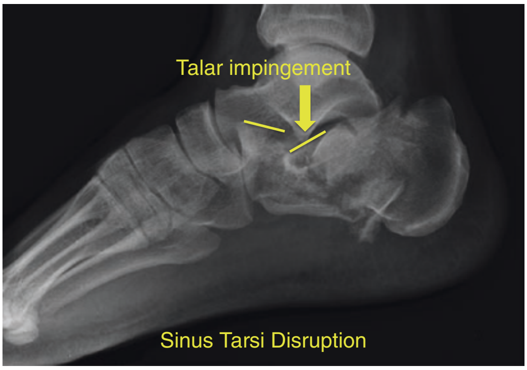


Fig. 14.9 Disruption of the sinus tarsi: The dorsally displaced anterior process fracture fragment will impinge on the lateral talar process in pronation

Initial Treatment

The initial management of calcaneal fractures is critical to the overall outcome. Soft tissue care and optimization are primary concerns initially, as they have great impact on the definitive management. Additionally, it is necessary to obtain patient information and imaging to plan surgical intervention. Issues such as a history of diabetes mellitus and smoking are relevant to the care of the soft tissue envelope.

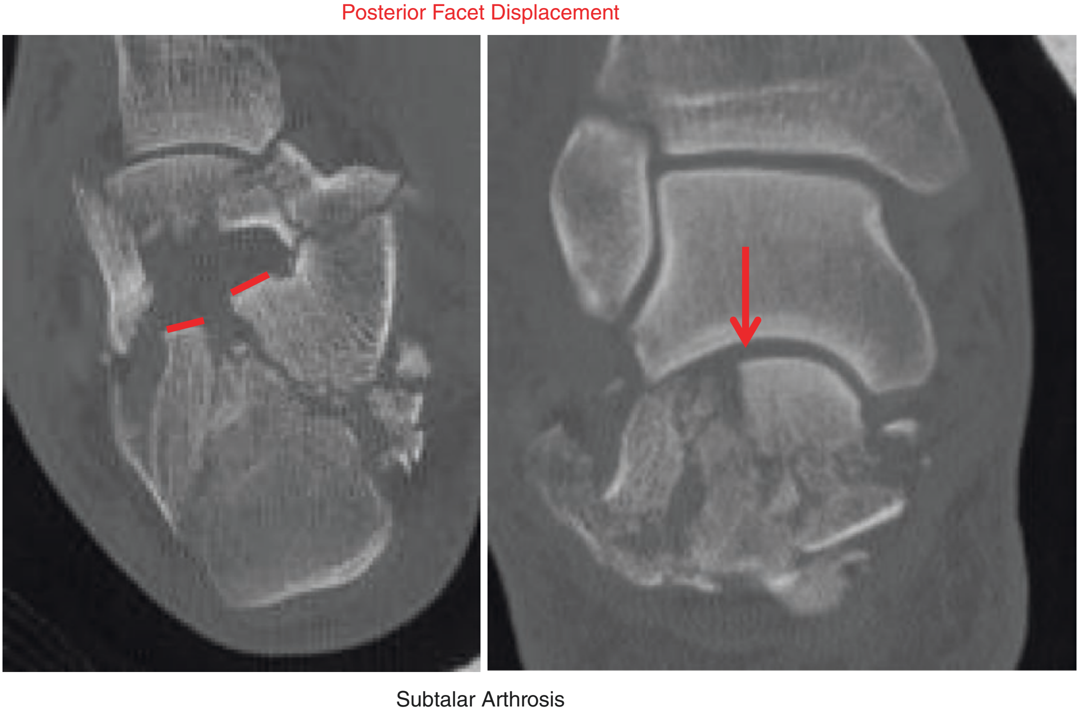


Fig. 14.10 Displacement of the posterior facet is related to post-traumatic subtalar arthrosis

Soft tissue management is critical for all types of calcaneal fractures. The joint depression fracture type rarely has soft tissue injury requiring early operative management unless the injury results in open fracture, but they can swell substantially, which can impact surgical timing. Open fractures, if they occur, most likely exit medially; these require emergent antibiotics, assessment of tetanus status, urgent debridement, irrigation, and temporary fixation [20, 21]. There is also a risk of elevated pressures in the foot, particularly in the calcaneal compartment, as there can be bleeding into the tight fascial envelope. This necessitates heightened awareness and possibly acute compartment release [22, 23].

In closed fractures, which are the majority of cases, early management consists of a layered compressive wrap and splinting to minimize swelling. Patience with the soft tissues is critical, especially with lateral skin blistering [24, 25]. Swelling must resolve prior to consideration of open reduction, which may take several weeks of waiting. An external fixator, placed medially, can stabilize the heel and skin in severe injuries.

Tongue type fractures, however, may necessitate urgent intervention to prevent catastrophic soft tissue insult [16]. The superior displacement of the tuber can lead to erosion of bone through the posterior heel skin. This must be recognized and treated with urgent, percutaneous reduction and fixation to avoid soft tissue compromise [16]. Swelling control and careful attention to padding of the heel is critical, with splinting the foot in equinus to decrease the deformity and its potential risk to the posterior skin.

Providers must evaluate the remainder of the patient as well because several other injuries occur with similar axial load mechanisms. Such injuries include ipsilateral and contralateral talus, tibial plafond, tibial plateau, pelvis, and lumbar spine. Calcaneal injuries can create substantial pain, leading to oversight of these other injuries [1, 26, 27].

Evaluation of calcaneal fractures includes several radiographs and CT scan. The lateral projection provides information on the subtype of fracture and severity of posterior facet displacement. The Harris heel view demonstrates displacement of the tuber, increased width of the heel, and varus deformity. Broden's view is also helpful to assess the posterior facet displacement [28]. This combination of x rays is useful for initial evaluation, but importantly will also be the imaging utilized during surgery as well as patient follow-up. Finally, CT scan of the calcaneus provides invaluable information about fracture fragment number and displacement.

Lastly, several patient characteristics are important for surgical decision making. Advanced age, smoking, male gender, worker's compensation, and manual labor are all predictive of poorer outcomes with surgical intervention [9, 29]. While these factors may not eliminate a patient from surgical consideration, they are important to assess and consider when discussing treatment options with the patient.

Surgical Indications and Rationale

Surgical indications remain controversial in spite of advances in imaging, implant design, biologics, and intraoperative techniques. Limitations in the current literature include comparison of different fracture types, treatment methods, outcome measures, and surgeon experience as well as lack of necessary long-term follow-up, power, and prospective design. Most surgeons agree that nonoperative management of a calcaneus fracture leads to deformity and some intervention should be performed, but the type of surgery and technique remain debated.

The natural history of displaced calcaneal fractures includes deformity, antalgic gait, painful shoe wear, and altered hindfoot mechanics. These sequelae are related to the loss of height, increased width, the loss of lateral column length, varus tuberosity position, and joint incongruity. The goals of surgical treatment are to restore calcaneal anatomy, maintain function across the tibiotalar and subtalar joints, and to allow normal shoe wear.

Multiple factors require review prior to finalizing a treatment plan. Patient selection, fracture-related factors, soft tissue integrity, and surgeon experience must be closely examined before offering a patient operative treatment. During the initial evaluation, the patient's social history regarding tobacco usage, illicit drug abuse, and alcoholism need consideration. Psychiatric problems, diabetes mellitus, peripheral vascular disease, and neuropathy also factor into the patient selection process. These factors do not preclude operative management but should be considered heavily.

While a malunion from closed treatment would be preferable to an infection that cannot be eradicated after surgery, certain groups of surgical patients have significantly better outcomes when compared to those that underwent closed treatment. When evaluating the fracture, studies have shown that displaced fractures have worse outcomes than nondisplaced fractures treated nonoperatively. Also, increasing amounts of posterior facet displacement, more fracture lines, and comminution tend to lead to poorer outcomes. The soft tissue integrity is also paramount in determining operative management. Open fractures, heel pad injuries, and plantar wounds also tend to be associated with higher complication rates and can influence choice of approach and fixation strategies. When determining indications, all mentioned factors must be considered. The social/medical history, patient expectations, bony pathology, soft tissues, and surgeon experience all drive a "successful" outcome and must be used to indicate a specific fracture for surgery.

Temporizing Management Techniques

High-energy trauma that results in calcaneal fractures injures not only the osseous anatomy of the hindfoot but also the soft tissue envelope. Definitive treatment of the osseous injury must wait until the soft tissue swelling has resolved and the blisters or open wounds have re-epithelized. Displacement of the fracture fragments can hinder the healing of the soft tissues. Temporary external fixation has the advantage of grossly reducing the displaced fragments, which potentially minimizes the time to the definitive treatment (formal open reduction and internal reduction) and facilitates incisional wound closure. In joint depression type fractures with significant depression, medial-based external fixation can be utilized to allow soft tissue rest and possibly aid in future reconstruction.

The technique of medial external fixation involves a medially based frame to maintain lateral soft tissues for lateral exposure after resolution of soft tissue swelling. With the patient in a supine position with the injured extremity elevated on a radiolucent ramp, a medial stab wound is made over the medial cuneiform, using fluoroscopic guidance. A 5 × 170 mm Schanz pin is placed transcuneiform, across the medial, intermediate, and lateral cuneiforms. A second 5 × 170 mm Schanz pin is placed into the medial tibia to provide a point of fixation on the tibia, via a percutaneously placed stab incision. A third, 5 × 170 mm Schanz pin is placed in the calcaneal tuberosity via a medial stab wound. Distraction is performed between the medial tibial shaft pin and medial calcaneal pin to restore the height of the calcaneus. The appropriate length of the calcaneus is restored by distraction along the bar connecting the medial calcaneal pin and the cuneiform pin. Both the medial calcaneal and cunieform pins can be pulled in a medial direction, correcting varus of the tuber and pronation of the foot, respectively. After gross correction of the deformity, standard imaging (AP/axial/lateral views) is used to assess alignment (Fig.14.11) (Gardner M, Henley MB, et al. Harborview Illustrated Tips and Tricks in Fracture Surgery. First Edition. Wolters Kluwer Health/Lippincott, Williams and Wilkins. 2010.)

In tuberosity avulsion injuries, “hatchet fractures,” the posterior cranial skin can be impinged, creating an impending open injury. These represent an orthopedic emergency and should be handled expeditiously. With the patient in a lateral or prone position, a percutaneous clamp is applied across the fracture line with stab incisions. One clamp tine is placed on the cranially displaced tuberosity and the other deep to the heel pad. An AO elevator can also be used to disimpact tuberosity fragment near the posterior facet if the fracture extends more distally. Also, a 4 × 150 mm Schanz pin can be placed from posterior to anterior to manipulate the tuberosity into position. Provisional Kirschner wire fixation can be utilized to maintain the reduction until time for definitive ORIF, or percutaneous screw fixation can be performed if the reduction is anatomic [20].

Two-Part Case Example

To elucidate the differences in treatment of distinct intra-articular calcaneal fracture patterns, the remainder of the discussion will use a patient example. The purpose of this example is to highlight to the reader pertinent imaging findings in the setting of a bilateral calcaneal fracture. The deformities present on imaging must be properly understood prior to determining how to reverse the deformities.

On the evaluation of the lateral heel view of the right calcaneus, a loss of height is evident. The angle of Böhler is approximately zero, and this compromises the performance of the gastrocnemius-soleus complex. Furthermore, if the tuberosity were to heal in this position, the talus would assume a more horizontal position, which would cause impingement on the anterior distal tibia in dorsiflexion. On the axial heel view, varus alignment of the tuberosity is noted. Varus tuberosity alignment prohibits pronation of the transverse tarsal joints, which negatively affects foot function through the gait cycle. A perpetually rigid foot is poorly tolerated. Displacement of the posterior facet is evident, but cannot be accurately quantified. Minimal increase in heel width is noted (Fig. 14.12).

The axial CT images demonstrate the primary fracture line, which runs from the sinus tarsi laterally out posteromedially. There are secondary fracture lines are present as well. A secondary fracture line involves the sustentaculum and is minimally displaced. Another secondary fracture line is present in the anterior process, with dis-

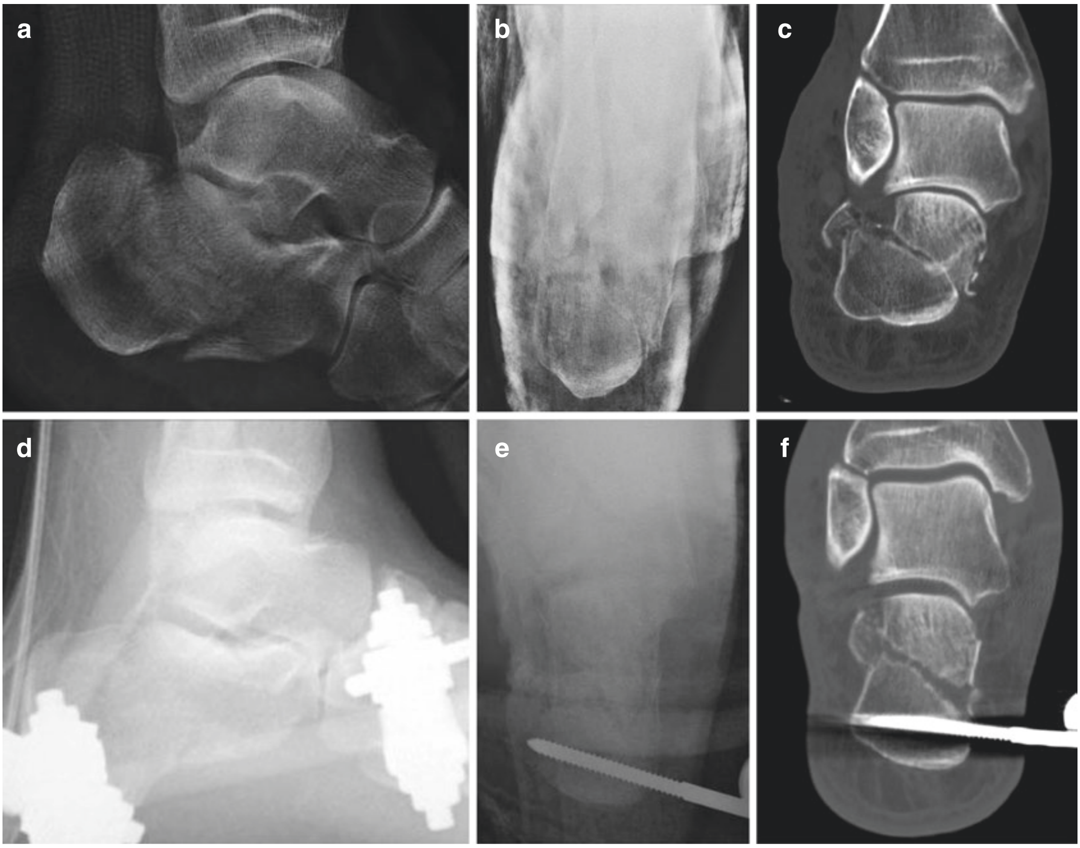


Fig. 14.11 Medial external fixator applied to an intra-articular calcaneus fracture. (**a**) The tuberosity is short in terms of length and height. (**b**, **c**) The tuberosity is in varus and is laterally displaced inferior to the fibula. (**d**) The height and length of the tuberosity are grossly restored. (**e**, **f**) The tuberosity has been adjusted into appropriate alignment in the coronal plane, and its translational deformity has been corrected. The soft tissue envelope has narrowed markedly when compared to **c**

placement in the form of a gap noted at the calcaneocuboid articulation. On these images, one does not get the impression that there is a substantial change in length, as there is no overlap of fragments (Fig. 14.13).

The coronal images provide additional detail on the fracture line involving the calcaneocuboid joint, with the displacement being most substantial dorsolaterally. The step off of the posterior facet is evident on these images, and this would be classified as a Sanders 3AB. A separate avulsion of the plantar-medial tuberosity is also apparent and appears minimally displaced. There is no lateral wall blowout. The sustentaculum maintains its relationship with the talus and is accurately termed the constant fragment (Fig. 14.14).

The sagittal images confirm that this is a tongue type calcaneal fracture, as the posterior facet is in continuity with the tuberosity. The horizontal fracture line that creates the tongue plantar to the posterior facet that exits the tuberosity is a secondary fracture line. The length of the calcaneus is grossly maintained, as the posterior facet with the tuberosity is abutting into the sinus tarsi and cannot shorten further (Fig. 14.15a). There is a small step off, in addition to a gap, at the anterior process fracture, which extends into the calcaneocuboid joint (Fig. 14.15b). The medial sagittal image confirms the minimally displaced nature of the secondary fracture line involving the sustentaculum (Fig. 14.15c).

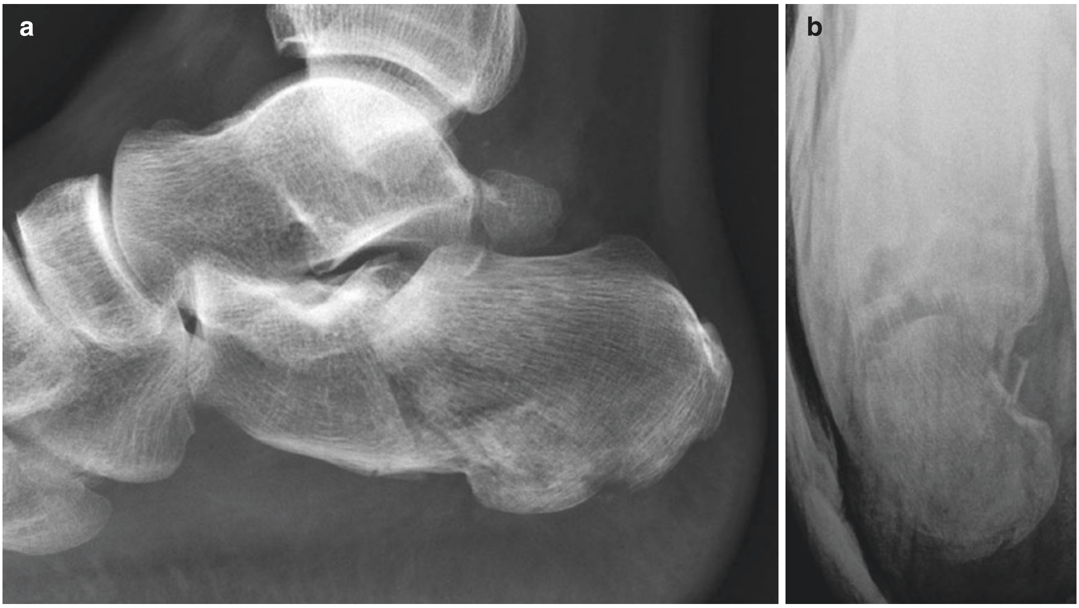


Fig. 14.12 Patient with bilateral calcaneus fractures. Lateral and axial heel view of a tongue type calcaneus fracture

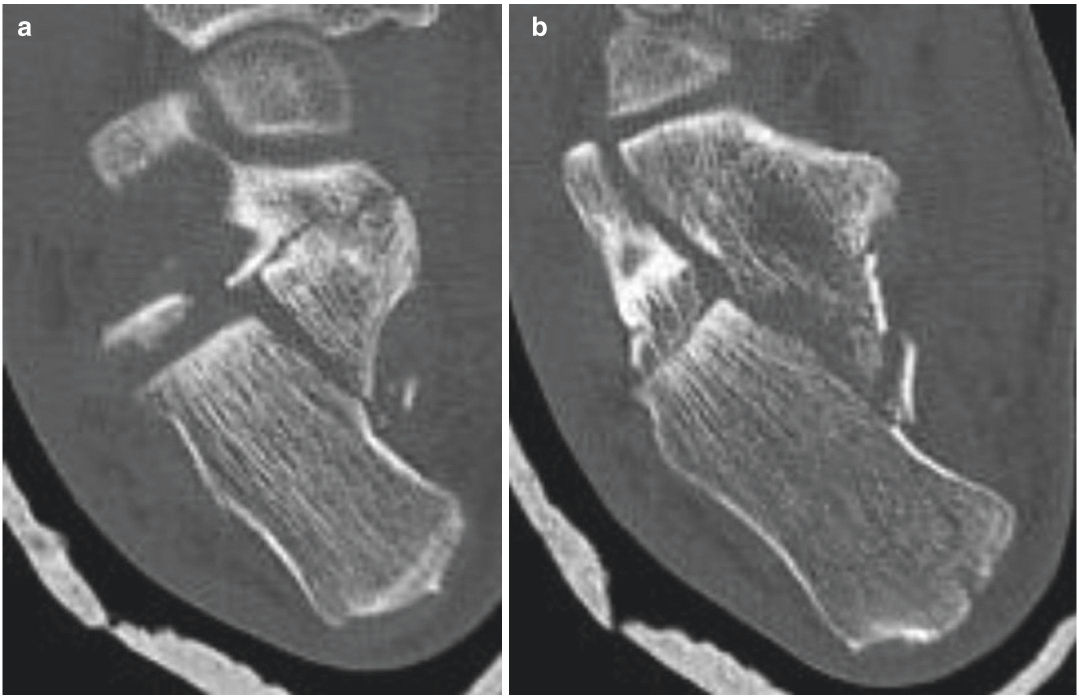


Fig. 14.13 Axial CT images

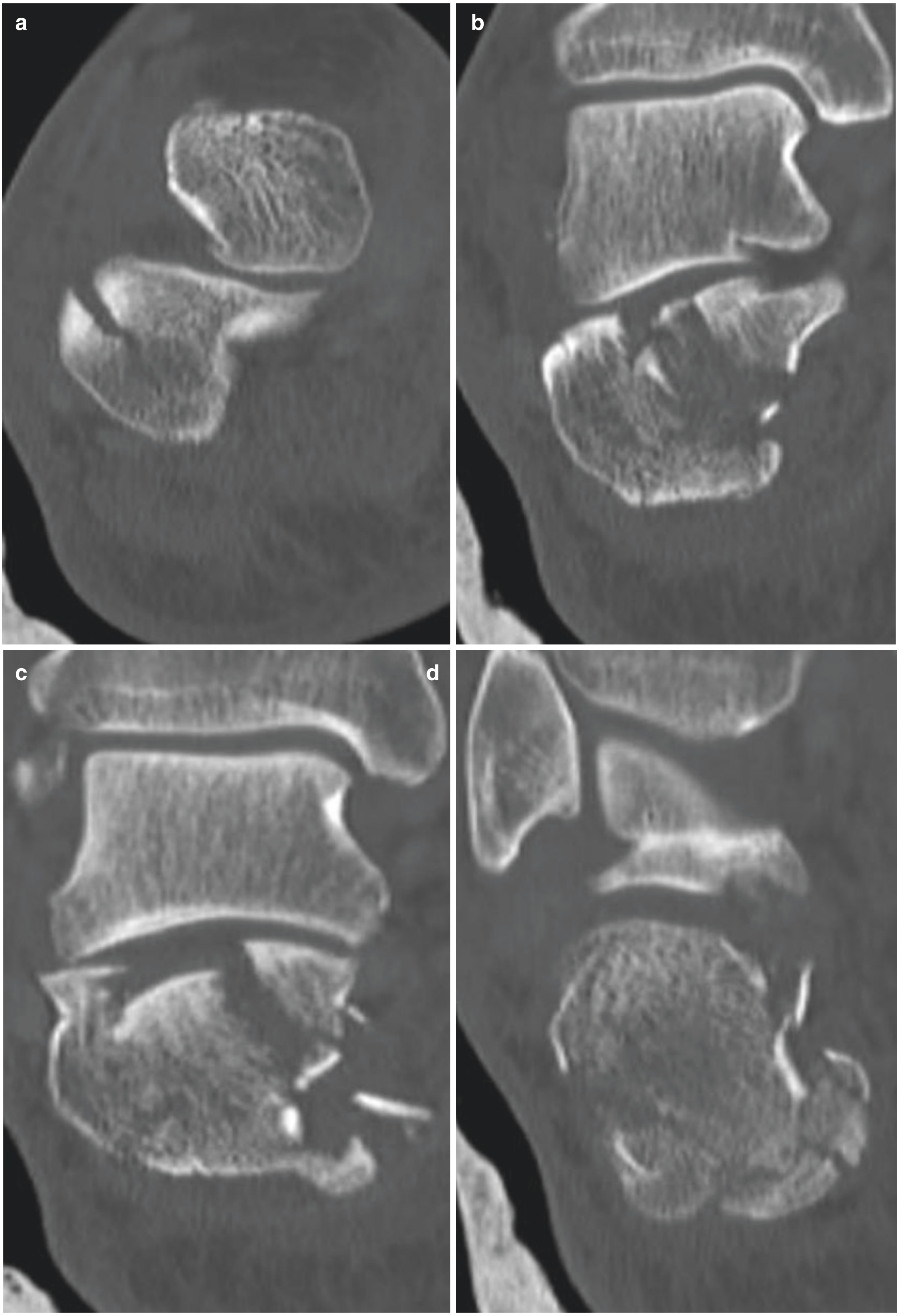


Fig. 14.14 Coronal CT images

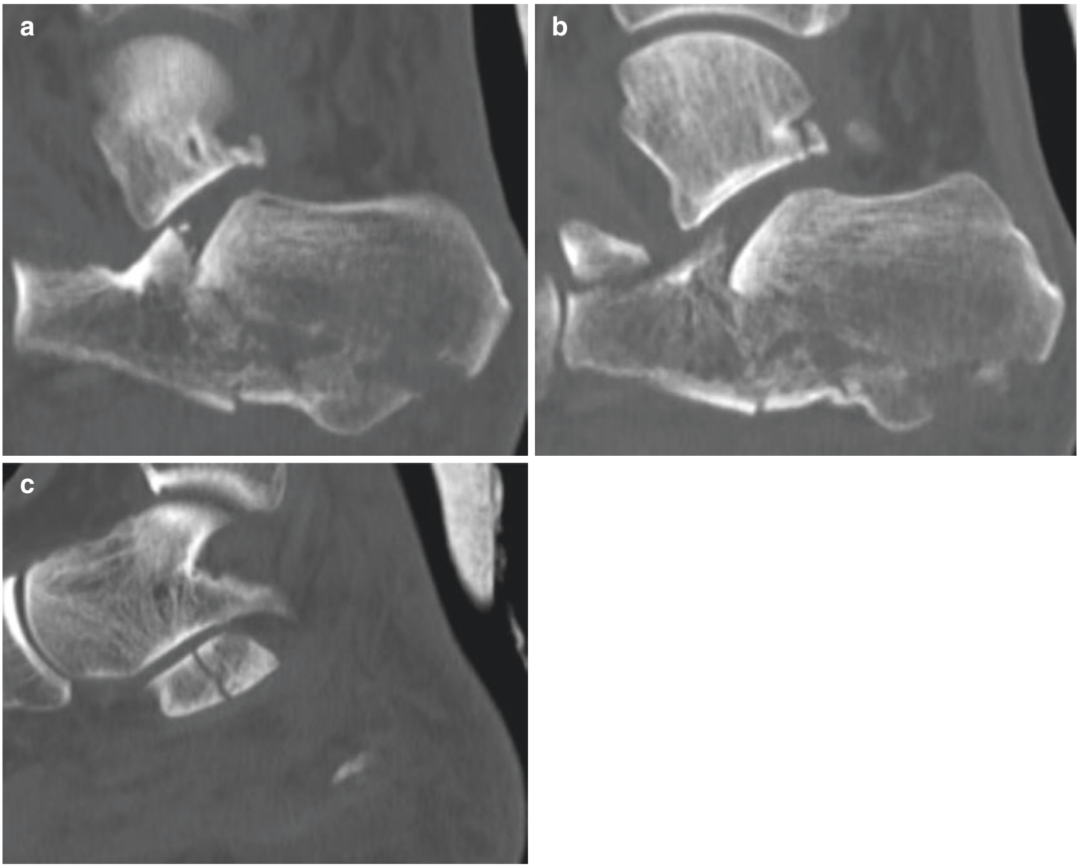


Fig. 14.15 Sagittal CT images

The contralateral calcaneus has more significant displacement. On the lateral view, the Böhler's angle is a negative number (normal: positive 20–40°). The axial heel view shows an increase in heel width, as well as varus of the tuberosity. Two separate posterior facet fracture fragments are noted, with the more lateral demonstrating displacement (Fig. 14.16).

On the axial CT images, the same primary fracture line is present here, running from the sinus tarsi out posteromedially. Note that the posterolateral fragment is displaced in an anterior and lateral direction relative to the sustentaculum. Substantial comminution is noted in the region of the anterior process, with several secondary fracture lines present. Overlap of fragments is noted as one looks from the posterior tuberosity to the anterior process, which indicates a loss of length. The two posterior facet fragments are evident, with the lateral fragment demonstrating significant displacement from the medial posterior facet fragment. The medial fragment of the posterior facet appears minimally displaced. The lateral wall blowout is also noted here (Fig. 14.17).

The coronal images increasingly detail the anterior process comminution. The relationship between the medial posterior facet fragment and sustentaculum is better defined. Lateral wall blowout is appreciated. The sustentaculum once again maintains its relationship with the talus, despite extensive displacement all around it (Fig. 14.18).

The sagittal images contain the same horizontal secondary fracture line as the contralateral side (plantar to the posterior facet and exiting the posterior tuberosity), but there is a vertical fracture line separating the posterior facet from the tuberosity as well. The vertical fracture line likely

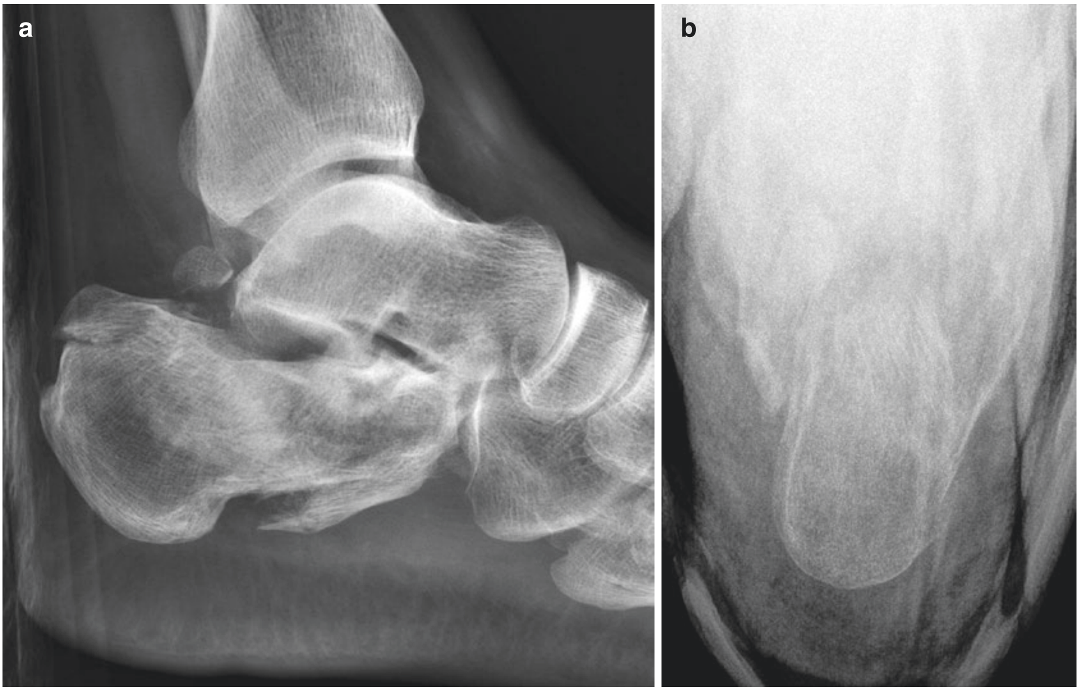


Fig. 14.16 Contralateral lateral and axial heel view

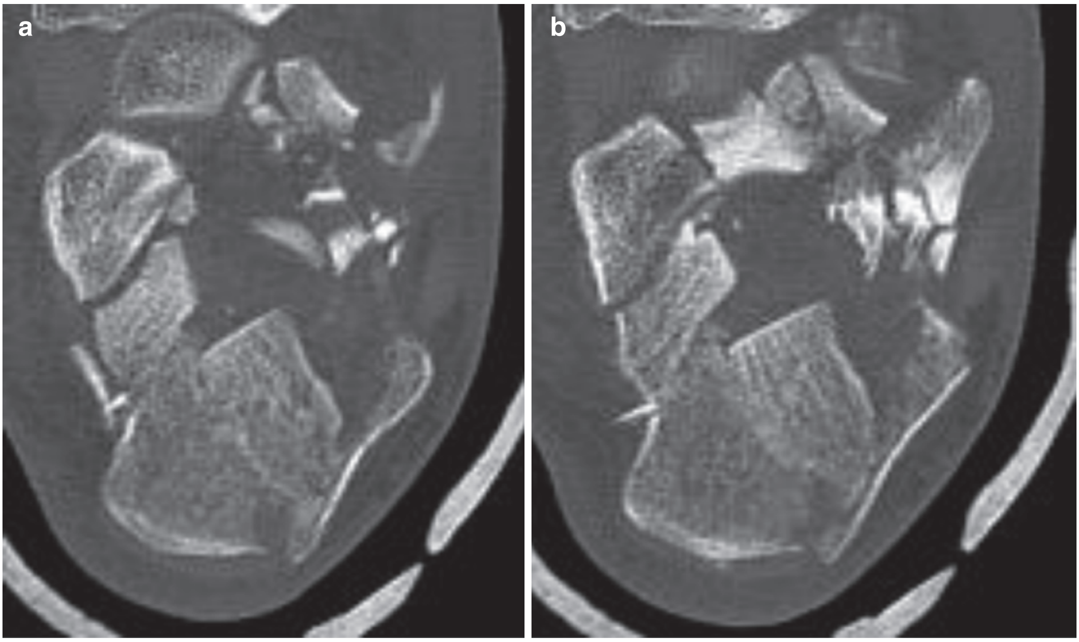


Fig. 14.17 Axial CT images

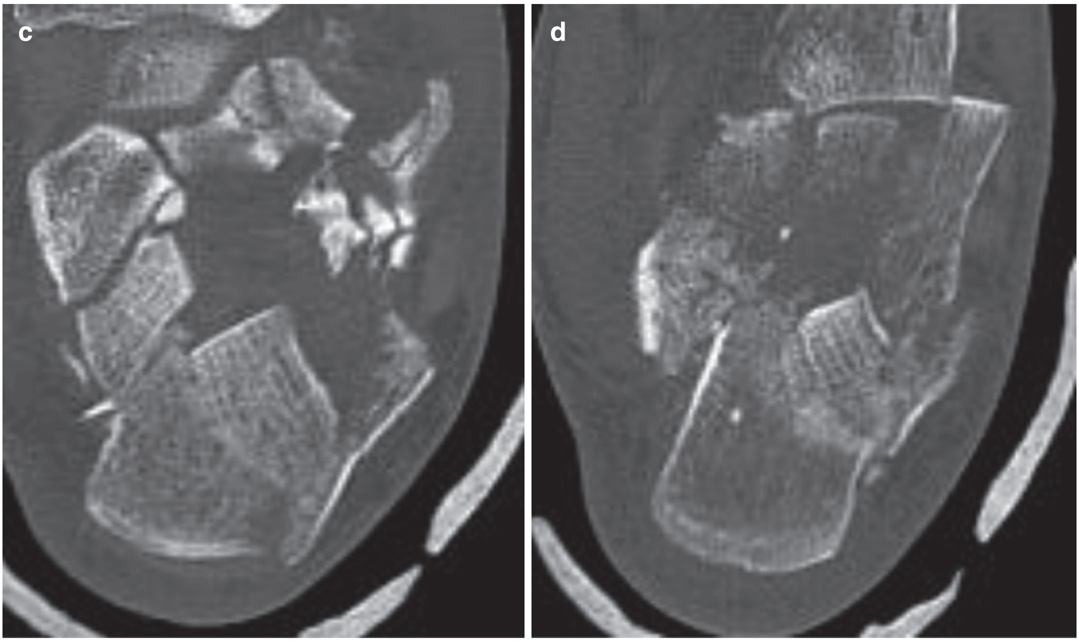


Fig. 14.17 (continued)

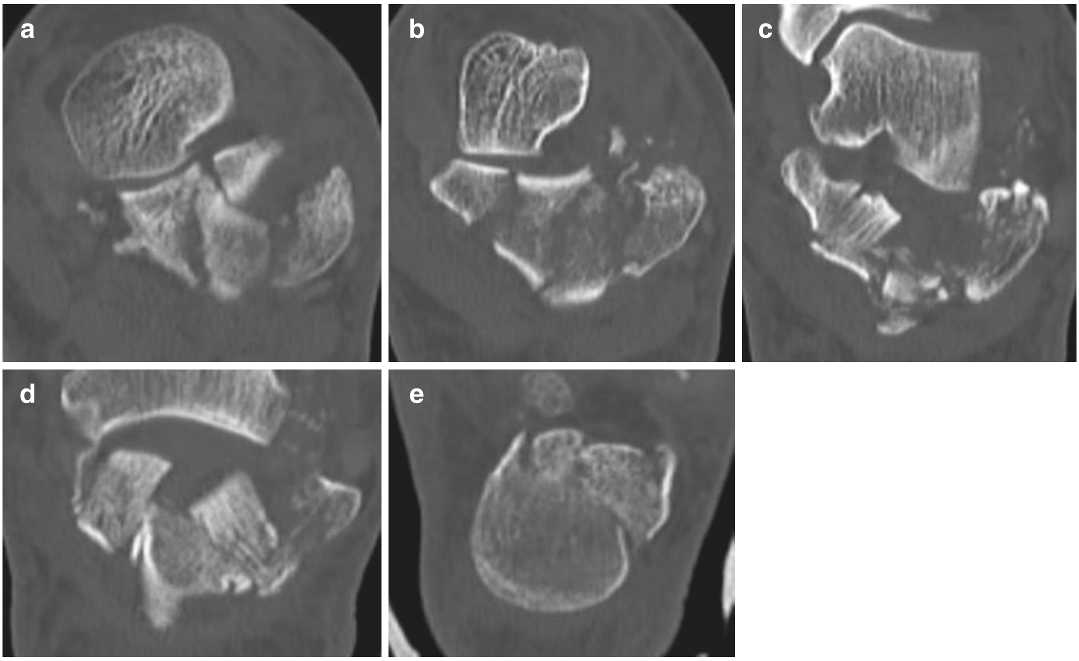


Fig. 14.18 Coronal CT images

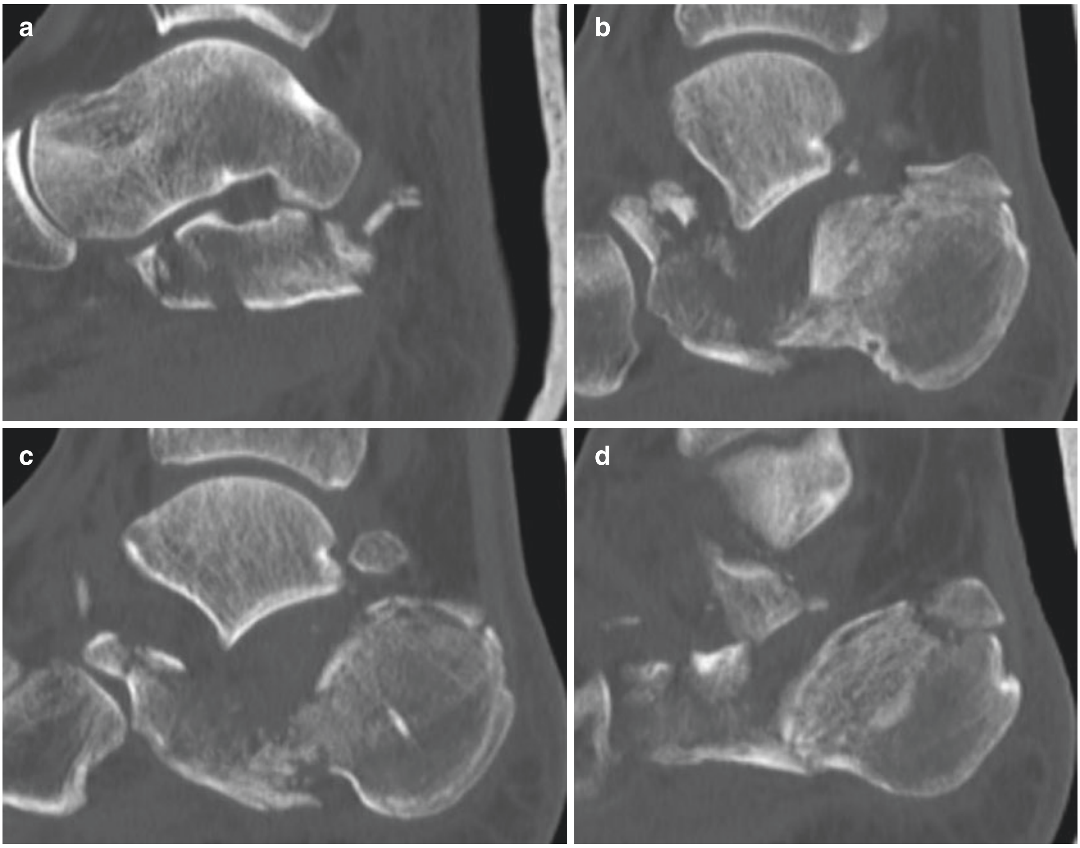


Fig. 14.19 Sagittal CT images

represents a tension failure of this fragment; the entire tuberosity continued to displace cranially while the posterior facet was trapped caudal to the talus. Therefore, this fracture pattern is more consistent with a “broken tongue” than a true joint depression. This distinction is important for surgeons who believe that gastrocnemius equinus contributes to the creation of a tongue type injury, and include a gastrocnemius recession as part of their management protocol for patients with tongue type patterns (Fig. 14.19).

Summary

The overall goal of surgical treatment of displaced calcaneal fractures is a restoration of the morphology of the calcaneus. An understanding of the anatomy, the displaced fracture fragments, and the deformity of each fragment are essential prior to planning a reduction. Evaluation of the soft tissues includes not only the inspection of the tissues on physical examination but a thorough patient history. In certain situations, temporizing techniques can be employed to improve the alignment of the calcaneus, which realigns the soft tissues as a result. Definitive reduction and fixation proceeds when the condition of the soft tissues is appropriate.

References

1. Mitchell MJ, McKinley JC, Robinson CM. The epidemiology of calcaneal fractures. Foot (Edinb). 2009;19(4):197–200.

2. Barei DP, Bellabarba C, Sangeorzan BJ, Benirschke SK. Fractures of the calcaneus. Orthop Clin North Am. 2002;33(1):263–85. x
3. Sanders R. Displaced intra-articular fractures of the calcaneus. J Bone Jt Surg Am Vol. 2000;82(2):225–50.
4. Benirschke SK, Sangeorzan BJ. Extensive intraarticular fractures of the foot. Surgical management of calcaneal fractures. Clin Orthop Relat Res. 1993;292:128–34.
5. Thordarson DB, Krieger LE. Operative vs. nonoperative treatment of intra-articular fractures of the calcaneus: a prospective randomized trial. Foot Ankle Int. 1996;17(1):2–9.
6. Zwipp H, Tscherne H, Thermann H, Weber T. Osteosynthesis of displaced intraarticular fractures of the calcaneus. Results in 123 cases. Clin Orthop Relat Res. 1993;290:76–86.
7. Brauer CA, Manns BJ, Ko M, Donaldson C, Buckley R. An economic evaluation of operative compared with nonoperative management of displaced intra-articular calcaneal fractures. J Bone Jt Surg Am Vol. 2005;87(12):2741–9.
8. Sanders R, Fortin P, DiPasquale T, Walling A. Operative treatment in 120 displaced intraarticular calcaneal fractures. Results using a prognostic computed tomography scan classification. Clin Orthop Relat Res. 1993;290:87–95.
9. Buckley R, Tough S, McCormack R, et al. Operative compared with nonoperative treatment of displaced intra-articular calcaneal fractures: a prospective, randomized, controlled multicenter trial. J Bone Joint Surg Am. 2002;84-A(10):1733–44.
10. Stephenson JR. Surgical treatment of displaced intraarticular fractures of the calcaneus. A combined lateral and medial approach. Clin Orthop Relat Res. 1993;290:68–75.
11. Burdeaux BD. Calcaneus fractures: rationale for the medial approach technique of reduction. Orthopedics. 1987;10(1):177–87.
12. Sangeorzan BJ, Mosca V, Hansen ST Jr. Effect of calcaneal lengthening on relationships among the hindfoot, midfoot, and forefoot. Foot Ankle. 1993;14(3):136–41.
13. Essex-Lopresti P. The mechanism, reduction technique, and results in fractures of the os calcis. Br J Surg. 1952;39(157):395–419.
14. Carr JB, Hamilton JJ, Bear LS. Experimental intra-articular calcaneal fractures: anatomic basis for a new classification. Foot Ankle. 1989;10(2):81–7.
15. Wulker N, Zwipp H, Tscherne H. Experimental study of the classification of intra-articular calcaneus fractures. Unfallchirurg. 1991;94(4):198–203.
16. Gardner MJ, Nork SE, Barei DP, Kramer PA, Sangeorzan BJ, Benirschke SK. Secondary soft tissue compromise in tongue-type calcaneus fractures. J Orthop Trauma. 2008;22(7):439–45.
17. Böhler L. Diagnosis, pathology, and treatment of fractures of the os calcis. J Bone Jt Surg. 1931;13:75–89.
18. Gissane W. Discussion on "fractures of the os calcis." in proceedings of the British Orthopaedic Association. J Bone Jt Surg. 1947;29:254–5.
19. Crosby LA, Fitzgibbons T. Computerized tomography scanning of acute intra-articular fractures of the calcaneus. A new classification system. J Bone Jt Surg Am. 1990;72(6):852–9.
20. Mehta S, Mirza AJ, Dunbar RP, Barei DP, Benirschke SK. A staged treatment plan for the management of type II and type IIIA open calcaneus fractures. J Orthop Trauma. 2010;24(3):142–7.
21. Benirschke SK, Kramer PA. Wound healing complications in closed and open calcaneal fractures. J Orthop Trauma. 2004;18(1):1–6.
22. Fakhouri AJ, Manoli A 2nd. Acute foot compartment syndromes. J Orthop Trauma. 1992;6(2):223–8.
23. Myerson M, Manoli A. Compartment syndromes of the foot after calcaneal fractures. Clin Orthop Relat Res. 1993;290:142–50.
24. Varela CD, Vaughan TK, Carr JB, Slemmons BK. Fracture blisters: clinical and pathological aspects. J Orthop Trauma. 1993;7(5):417–27.
25. Giordano CP, Koval KJ. Treatment of fracture blisters: a prospective study of 53 cases. J Orthop Trauma. 1995;9(2):171–6.
26. Walters JL, Gangopadhyay P, Malay DS. Association of calcaneal and spinal fractures. J Foot Ankle Surg. 2014;53(3):279–81.
27. Worsham JR, Elliott MR, Harris AM. Open calcaneus fractures and associated injuries. J Foot Ankle Surg. 2016;55(1):68–71.
28. Broden B. Roentgen examination of the subtaloid joint in fractures of the calcaneus. Acta Radiol. 1949;31(1):85–91.
29. Tufescu TV, Buckley R. Age, gender, work capability, and worker's compensation in patients with displaced intraarticular calcaneal fractures. J Orthop Trauma. 2001;15(4):275–9.

15

Lateral Extensile Approach for ORIF

Adam Cota and Timothy G. Weber

Introduction

The lateral extensile approach as described and popularized by Benirschke [1, 2] provides access to the entire lateral aspect of the calcaneus with direct visualization of the tuberosity, subtalar joint, posterior facet fragments, lateral wall blowout, fracture extension into the anterior process, and the calcaneocuboid joint. While this approach allows for the direct reduction of the posterior facet fragments, the reduction of the tuberosity to the sustentaculum tali on the medial side needs to be performed indirectly [1–3].

Outcomes

Because of the potential for wound complications with the extended lateral approach, minimally invasive strategies including percutaneous and limited approach techniques have been developed. Few studies have directly compared outcomes between the classic extended lateral approach (ELA) and a more limited sinus tarsi approach (STA) when fixing intra-articular calcaneus fractures.

Schepers et al. examined outcomes for a consecutive series of patients treated with either the extended lateral approach (60 patients) or a sinus tarsi approach (65 patients) [4]. Patients with closed, displaced, intra-articular Sanders type II and III calcaneus fractures were included and the choice of the approach was left up to the treating surgeon. Follow-up at a median of 22 months demonstrated significantly lower rates of wound complications in the sinus tarsi approach (STA) group (4 minor, no major complications) compared to the extended lateral approach (ELA) group (9 minor, 11 major complications; $P < 0.001$). Minor complications included wound edge necrosis and wound dehiscence while major complications included deep infection with a positive culture requiring implant removal or intravenous antibiotics and/or wound debridement. Postoperative CT scans were used to assess the accuracy of reduction on the semicoronal views. There were two cases in the ELA group with a step-off <2 mm and no cases with a step-off in the STA group. Time to surgery was significantly shorter for the sinus tarsi group (median 4 days earlier, $P < 0.001$) and the duration of the surgery was significantly shorter for the STA group (median 105 min) compared to the ELA group (median 134 min, $P < 0.001$). The authors concluded that the sinus tarsi approach allowed

A. Cota (✉)
Rocky Mountain Orthopaedic Associates,
Grand Junction, CO, USA
e-mail: adam.cota@sclhealth.org

T. G. Weber
OrthoIndy, Indianapolis, IN, USA

Department of Orthopaedic Trauma, St. Vincent
Hospital and OrthoIndy Hospital,
Indianapolis, IN, USA

© Springer Nature Switzerland AG 2020
M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_15

for a lower rate of wound complications and decreased operative time without compromising the accuracy of the articular reduction.

Weber et al. retrospectively compared clinical and radiographic outcomes for 50 patients with Sanders II and III displaced intra-articular calcaneus fractures [5]. Twenty-six of the patients were managed with a sinus tarsi approach and screw fixation and 24 patients were treated with a formal extended lateral approach with plate and screw fixation. The mean follow-up was 25 months in the extended-exposure group, and 31 months in those with a limited sinus tarsi approach. The authors reported a significantly shorter duration of surgery in the sinus tarsi group compared to the extensile group (108 min vs. 160 min; $P < 0.001$). At final follow-up, AOFAS scores were not significantly different between groups with the authors reporting mean scores of 82.6 in the extensile approach group versus 87.2 in the sinus tarsi group ($P = 0.17$). Normal alignment of the calcaneus was judged clinically and radiographically, and adequate restoration of the joint surface was obtained in all the patients of both groups. Minor soft tissue complication rates were not significantly different between the treatment groups. Of the 26 patients in the extensile approach group, 1 developed delayed wound healing (3.85%), 1 had hematoma formation (3.85%), and 2 patients developed sural nerve lesions (7.69%). Four patients in the extended approach group were also noted to have developed complex regional pain syndrome (15.4%). The sinus tarsi group had no soft tissue complication but did require removal of hardware in 10 of the 24 patients (41.7%) compared to only 3 of the 26 patients in the extended approach group (11.5%, $P = 0.019$). The authors reported that the sinus tarsi approach had become their standard technique for displaced intra-articular calcaneus fractures due to the equivalent accuracy of reduction and functional outcomes with fewer complications and shorter operative times.

In addition, Kline et al. retrospectively compared the results of 112 Sanders II and III displaced intra-articular calcaneus fractures treated using the extended lateral approach (79 fractures) or the more limited the sinus tarsi approach (33 fractures) [6]. The overall wound complication rate was 23 out of 79 patients (29%) in the extensile approach group versus 2 of 33 patients (6%) in the minimally invasive group ($P = 0.005$). Secondary surgical procedures within the study period were required in 18/79 patients in the extensile approach group (23%) versus 1/33 patients (3%) in the sinus tarsi approach group ($P = 0.007$). Sural nerve symptoms were observed in 3/79 patients in the extended approach group (4%) versus 1/33 patients in the sinus tarsi approach group (3%, $P = 0.66$). A total of 47 of the 112 (42%) patients ultimately returned for a research visit (31 extensile approach, 16 sinus tarsi approach) with an average follow-up for patients of 31 months in the extensile lateral group versus 28 months in the minimally invasive group. In the group of patients who returned for research visits, the average foot function index (FFI) total score was 31 in the extensile group versus 22 in the minimally invasive group (lower score indicates better function, $P = 0.21$). The average visual analog scale (VAS) pain score with activity was 36 in the extensile group versus 31 in the minimally invasive group ($P = 0.48$). In the extensile lateral group, the average SF-36 score was 64 versus 71 in the minimally invasive group (higher score indicates better quality of life, $P = 0.33$). Both groups had 100% union rates, and no differences were noted in the final radiographic Böhler angle and angle of Gissane. The authors concluded that no difference could be shown between groups with regards to the clinical outcomes with the minimally invasive approach demonstrating a lower rate of wound complications.

Moreover, Yeo et al. retrospectively reviewed a cohort of 100 Sanders type II and III calcaneus fractures which included 60 treated with an extensile lateral approach and 40 treated with a sinus tarsi approach. [7] The average follow-up for both treatment groups was approximately 4 years. AOFAS scores at the time of follow-up were not significantly different between groups with median values of 90 points in the sinus tarsi group and 86 points in the extensile lateral group ($P > 0.05$). The wound complication rate (13.3%)

in the extensile lateral group was significantly higher compared to the sinus tarsi group (5%) ($P = 0.022$).

All fractures went on to union in both groups and there was no statistical difference in rates of sural nerve injury, deep infection, and peroneal tendinitis or subtalar stiffness. No patients required reoperation in either treatment group. Radiologic outcomes including postoperative Böhler angle, Gissane angle, and calcaneal height, length, and width were not different between the two approaches ($P > 0.05$). The authors concluded that the final clinical and radiographic outcomes between the two approaches for Sanders type-II and type-III calcaneal fractures were comparable with a lower rate of wound complications seen in the sinus tarsi group.

Complications

Despite proper patient selection and meticulous soft tissue handling, relatively high complication rates have historically been observed with the extended lateral approach. Wound healing complications, including flap necrosis and infection, have been reported most frequently with rates varying from 10% to 37% [8–21]. Skin edge necrosis develops in 7–8% of wounds with the apex/corner of the incision being most commonly affected [22–24]. Serious infections requiring hospitalization, revision surgery, or IV antibiotic treatment have a historical incidence of 0–20% [9, 12, 15, 17–21]. However, with the advent of modern surgical techniques including careful soft tissue handling, lower profile implants, and appropriate patient selection, this has decreased to 2–3% for closed fractures and 8–9% for open fractures [10]. Wound necrosis and dehiscence can be managed with routine dressing changes and frequent observation to monitor for progression and the development of infection. If the flap is felt to be compromised, the surgeon should proceed with operative staged debridement including the evacuation of any underlying hematoma, negative pressure wound therapy, intravenous/oral antibiotics, and delayed closure until fracture union. Full-thickness flap necrosis is a devastating complication that can potentially be addressed with local fasciocutaneous and microvascular free flaps.

Multiple risk factors for wound healing complications and infection after an extended lateral approach have been identified. Patients using tobacco products and patients with multiple medical comorbidities, especially diabetes mellitus and peripheral vascular disease, open fractures, early surgery <7 days from injury, and single-layer closure are factors which need to be recognized as presenting increased risk for wound complications during the postoperative course [8, 9, 11, 25–28]. The presence of multiple risk factors in a single patient results in a cumulative increase in the relative risk for developing a wound complication [11].

Sural nerve injury can occur with the extensile lateral approach due to the close proximity of the nerve in the proximal and distal aspects of the incision. Postoperative sural nerve irritation and neuroma formation have been reported at an incidence of 3–8% after operative treatment utilizing the extended lateral approach [5, 7, 13]. Other complications that arise with both surgical and nonsurgical treatment include fracture malunion/nonunion, post-traumatic arthrosis, compartment syndrome, and peroneal irritation/impingement.

Author's Preferred Method of Treatment

Despite the increasing popularity of addressing intra-articular calcaneus fractures through the sinus tarsi approach, there are still specific instances where our preferred technique is to use the extensile lateral approach. The wider exposure offered by the ELA is useful for fractures where the tuberosity cannot be adequately controlled if one were to use a limited approach. In addition, the ELA is preferred if there are intercalary fragments that block the reduction, for fracture patterns where rotational control in the medial/lateral plane of the foot cannot be controlled adequately through a sinus tarsi approach and when there are multiple fragments of the posterior facet where at least one of the fragments is displaced posteriorly.

Surgical Planning

Imaging

Radiographic evaluation of calcaneus fractures includes an initial lateral, axial, dorso-plantar, and oblique views of the foot in addition to thin-cut computed tomography (CT) imaging [2]. CT scan coronal, axial, and sagittal views allow for an accurate assessment of the fracture pattern when planning for surgery (Figs. 15.1, 15.2, 15.3, and 15.4).

Positioning

The patient is placed in the lateral decubitus position with the operative side up on a radiolucent cantilever table. The patient should be positioned as far down the table as possible. All bony prominences should be well padded including the greater trochanter, fibular head (peroneal nerve), lateral malleolus, and the elbow. An axillary roll is used to protect the brachial plexus of the down arm. Specialty foam pads can be used for positioning which have a cutout relief for the down leg and provide a flat, firm work surface. A proximal thigh tourniquet is used.

Fig. 15.1 Lateral X-ray allows an assessment of the position of the posterior facet relative to the tuberosity

Fig. 15.2 Sagittal CT images demonstrate depression of the posterior facet

Fig. 15.3 CT images allow for visualization of the primary and secondary fracture lines with the typical varus malalignment of the calcaneus

Incision

The approach employs utilizing an L-shaped incision with a vertical and horizontal limb with an acute curve at the corner of the flap (Fig. 15.5). This incision differs from the classic lateral approach described by Palmer [29] which followed the course of the peroneal tendons and is similar to the lateral approach described by Gould [30], Letournel [31], and Benirschke [1, 2].

Fig. 15.4 Semicoronal CT images provide information on the number of intra-articular fracture lines involving the posterior facet as well as the position and number of fragments

Fig. 15.5 The extensile approach uses an L-shaped incision with a vertical and horizontal limb with an acute curve at the corner of the flap. Path of the sural (SN) nerve is marked on the skin

The vertical limb is marked out parallel to the lateral border of the Achilles tendon just posterior to the midpoint between the posterior border of the fibula and the lateral border of the Achilles tendon.

The horizontal limb follows the glaborous skin border along the foot, in line with the base of the fifth metatarsal and extending to the calcaneocuboid joint. The distal aspect of the horizontal limb can be angled superiorly to follow the course of the anterior process.

Prior to initiating the incision, a mini distractor can be applied to the medial aspect of the hindfoot with a threaded 2.5 mm Schanz pin inserted in the medial tibia (Fig. 15.6) and a second inserted in the medial side of the calcaneus (Fig. 15.7). Distraction in this vector corrects the varus malalignment and helps to restore length and height while the dissection is being performed (Figs. 15.8 and 15.9). A sterile bump is placed between the mini distractor pins to elevate them off the sterile drapes (Fig. 15.10).

Sharp dissection is carried down initially just through skin (Fig. 15.11). Full-thickness periosteal-cutaneous flaps are developed by carrying the incision directly down to bone in the corner of the flap. Deep dissection proceeds outward from the corner by sharply elevating periosteum off the lateral surface of the calcaneus while stabi-

Fig. 15.6 Fluoroscopic view of the pin placement in the medial tibia for using a mini distractor to aid reduction

Fig. 15.7 Fluoroscopic view of the pin placement in the medial calcaneus for the mini distractor

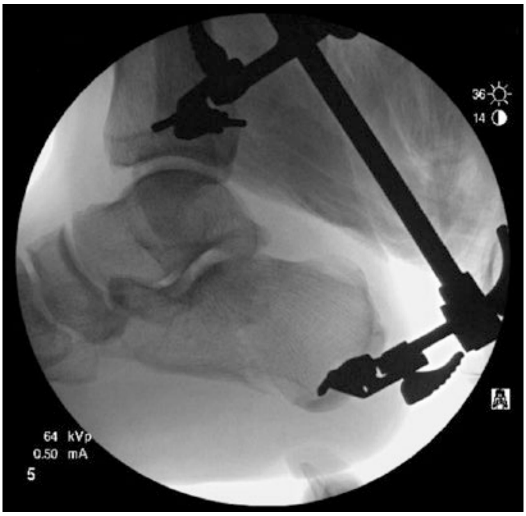


Fig. 15.8 Final position of the pins and position of the mini distractor on the lateral view

Fig. 15.9 Application of a mini distractor with a threaded 2.5 mm Schanz pin inserted in the medial side of the calcaneus and tibia

Fig. 15.10 Lateral positioning of the patient with the operative side up on a radiolucent cantilever table. A specialty foam pad is used for positioning which provides a flat, firm work surface. A sterile bump is placed between the mini distractor pins to elevate them off the sterile drapes

lizing the soft tissue flap. Retraction of the skin edges should be avoided and retraction of the flap should only occur once a sufficient amount of periosteum has been raised to allow the use of small rakes directly on the elevated periosteum (Fig. 15.12).

Proximal extension of the vertical limb needs to be made cautiously due to the close proximity of the lateral calcaneal artery and sural nerve. The lateral calcaneal branch of the peroneal artery crosses the vertical limb of the incision and provides the blood supply to the corner of the soft tissue flap [32]. Localization of the vessel can be performed intraoperatively using a sterile Doppler probe to avoid iatrogenic injury [13]. In addition, the sural nerve crosses the inci-

Fig. 15.11 Sharp dissection is carried down initially just through skin. During the dissection, the flap is stabilized against shearing forces

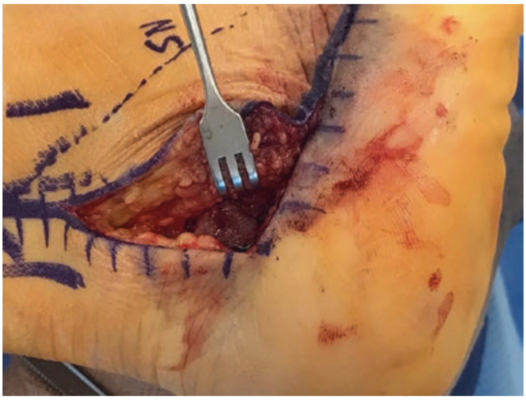


Fig. 15.12 Full-thickness periosteal-cutaneous flaps are developed by carrying the incision directly down to bone in the corner of the flap

sion in the proximal aspect of the vertical limb and distal aspect of the horizontal limb. The approximate course of the nerve can be marked on the skin along a line extending from 2 cm posterior to the distal tip of the fibula toward the base of the fifth metatarsal.

Deep dissection along the horizontal limb of the incision will expose the fascia overlying the abductor digiti quinti muscle belly (Fig. 15.13). The fascia should be preserved with dissection proceeding superiorly to the muscle. As the flap is developed, the calcaneofibular ligament, peroneal retinaculum, and peroneal tendon sheath are elevated from the lateral wall of the calcaneus. Dissection proceeds until the subtalar joint, Angle of Gissane, and calcaneocuboid joint are visualized (Fig. 15.14). To aid in elevation of the flap during surgery, 1.6 mm k-wires can be inserted into the talus to control the position of the flap without the need for constant manual retraction by an assistant [1] (Fig. 15.15).

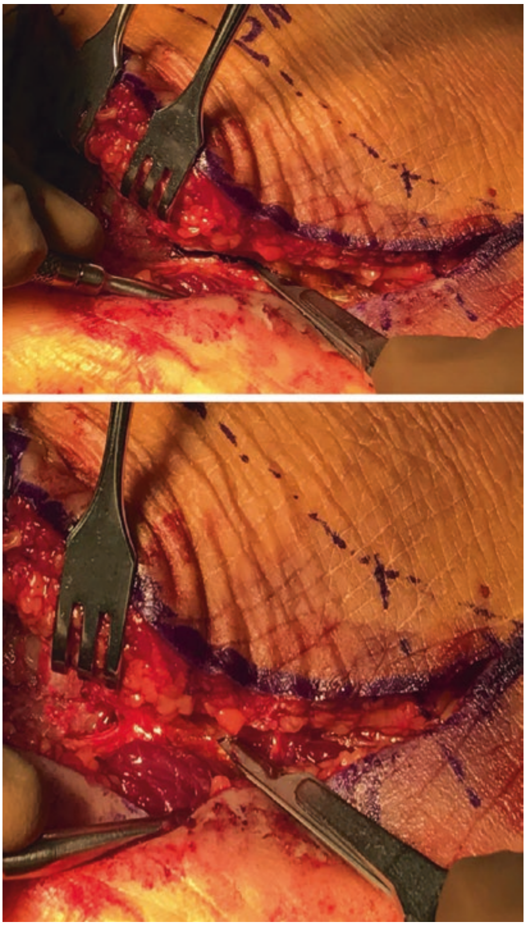


Fig. 15.13 Fascia overlying the abductor digiti quinti is preserved with dissection proceeding superiorly to following the fascia to the bone

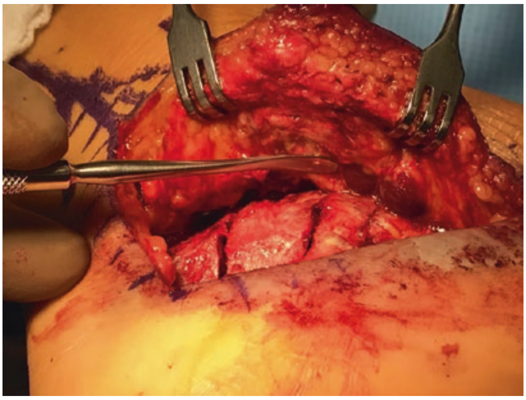


Fig. 15.14 Dissection proceeds until the subtalar joint, Angle of Gissane, and calcaneocuboid joint are visualized

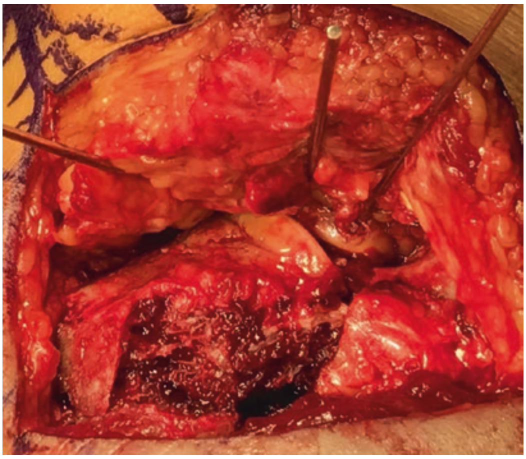


Fig. 15.15 1.6 mm k-wires inserted into the talus to control the position of the flap

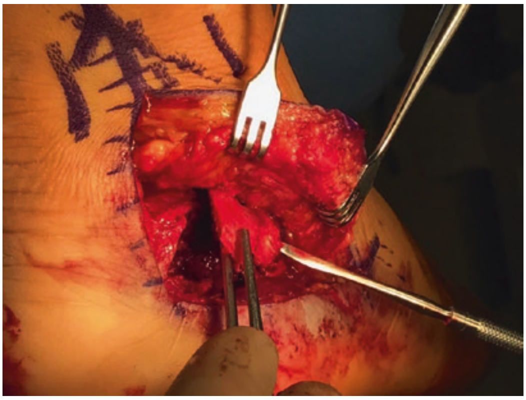


Fig. 15.16 The lateral wall fragment is reflected outward and inferiorly or can be removed and placed on the back table

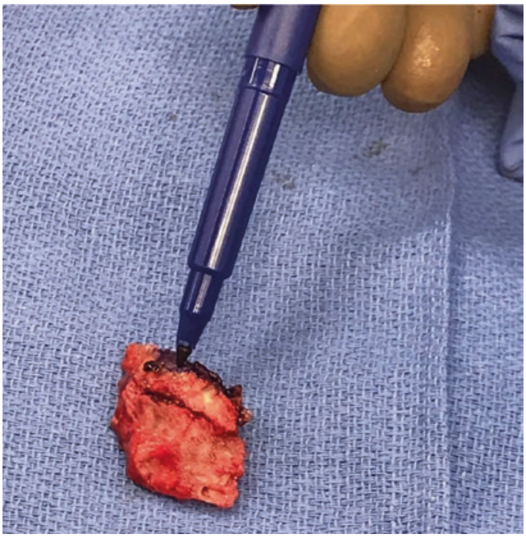


Fig. 15.17 One side of the lateral wall piece is marked to allow for correct orientation at the time of reimplantation

Reduction

Once adequate exposure has been achieved, the reduction sequence can begin. The lateral wall fragment is reflected outward and inferiorly or can be removed and placed on the back table to allow visualization of the posterior facet fragment (Fig. 15.16). One side of the lateral wall piece is marked with a marking pen to allow for correct orientation at the time of reimplantation (Fig. 15.17).

Reduction typically proceeds in an anteromedial to posterolateral direction.

1. In comminuted fracture patterns, the medial aspect of the posterior facet can be separated from the middle facet and displaced inferiorly beneath the sustentaculum tali. This fracture line should be restored first by elevating the medial aspect of the posterior facet until it is reduced to the middle facet [2]. Division of the interosseous talocalcaneal and cervical ligaments in the sinus tarsi can aid in visualization when reducing the medial part of the

posterior facet to the middle facet complex. Sharp dissection using a 15-blade will expose the dorsal cortical bone from the angle to Gissane across to the medial facet. The reduction can then be provisionally held with 1.25 mm Kirschner wires.

This is followed by reduction of secondary fracture lines that extend through the anterior process into the calcaneocuboid joint. Often the anterior process is displaced cephalad relative to the sustentaculum tali and dorsal pressure with a dental pick or small elevator can restore its position. Provisional fixation can be accomplished with 1.25 mm k-wires inserted toward the sustentaculum from the dorsolateral corner of the anterior process. Radiographic evaluation of the anterior process reduction includes a lateral view and anterior-posterior (AP) view of the foot to allow for visualization of the calcaneocuboid joint. Once the anterior process has been reduced and provisionally stabilized to the sustentaculum tali, the tuberosity is then reduced.

2. Due to the oblique anterolateral to posteromedial orientation of the primary fracture line, the impacted tuberosity is typically displaced anteriorly (shortened), lateralized and adopts a varus alignment relative to its normal position. The axial load from the index trauma also contributes to a loss of height of the tuberosity. Restoration of the height, length, and varus misalignment of the tuberosity will create the space needed to reduce the displaced posterior facet.

The posterior facet can be disimpacted from the tuberosity using a laminar spreader or a small elevator and oftentimes it can be completely removed and kept on the back table.

Mobilization of the primary fracture line and removal of any interposed callus along the fracture plane can be accomplished with a small elevator, osteotome, and pituitary rongeur. A laminar spreader with the tines places between the tuberosity and sustentaculum is also a useful adjunct to translate the tuberosity posteriorly and inferiorly to restore height and length.

A 4.0 mm Schanz pin is inserted in the posteroinferior corner of the tuberosity from a lateral to medial direction. This can be placed in the corner of the existing incision or through a separate stab incision. The Schanz pin should be positioned in the stronger cortical bone along the posterior aspect of the tuberosity to minimize the chance of cutting out. A universal T-handle chuck positioned over the Schanz pin will allow manipulation of the tuberosity. The reduction vector requires correction in three planes of movement – posteroinferior translation to correct the loss of height and restore the length, medial translation to reduce the lateral displacement, and valgus rotation to correct the varus malalignment [1].

With the tuberosity held reduced, axial 1.6 mm k-wires are inserted percutaneously from the posteroinferior aspect of the tuberosity into the anteromedial sustentaculum for provisional fixation.

Fluoroscopic views can be used to assess the adequacy of the reduction. The lateral view will show restoration of the length and height (Fig. 15.18), and the axial view will demonstrate restoration of the medial cortex, correction of the varus malalignment, and reduction of the calcaneal width (Fig. 15.19).

Fig. 15.18 The lateral view intraoperatively is used to assess the restoration of length and height of the calcaneus

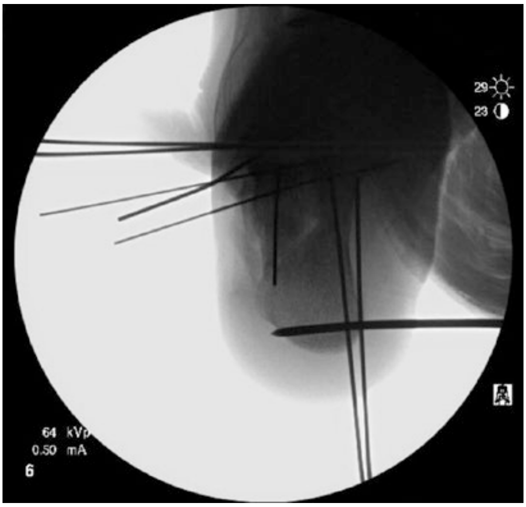


Fig. 15.19 An axial view will demonstrate restoration of the medial cortex, correction of the varus malalignment, and reduction of the calcaneal width

3. The next step is to reconstruct the articular component of the posterior facet fracture. Interposed callus and hematoma are cleaned from the posterior facet fragments and it is manipulated back into position using small elevators and dental picks. For fracture patterns with multiple posterior facet fragments, the pieces can be reduced and the posterior facet reconstructed on the back table prior to reimplantation. Small diameter k-wires can be used as joysticks to manipulate the articular fragments. Central fragments that lie between the medial aspect of the posterior facet and the most lateral fragment of the posterior facet can be reduced to the intact medial facet fragment and provisionally held with k-wires that will not block the placement of the lateral articular fragment.

The critical areas to assess for the quality of the reduction are how the anteroinferior aspect of the posterior facet lines up with the angle of Gissane as well as the posterosuperior aspect of the posterior facet and the tuberosity. A small curved elevator can be used to palpate the articular surface for any residual steps or gaps. Inversion of the foot will also improve visualization of the joint surface.

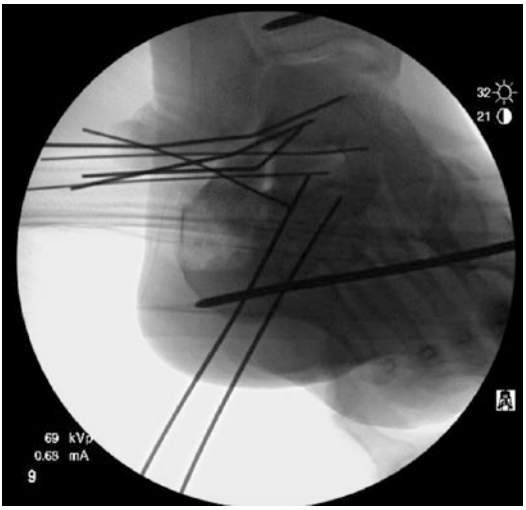


Fig. 15.20 A Broden's view is used to assess the congruity of the posterior facet and subtalar joint

The reduction is provisionally held with 1.25 mm k-wires directed from lateral to medial in the subchondral bone inferior to the posterior facet articular surface. K-wire placement should be outside the planned position of the plate.

Fluoroscopic views including a lateral and Broden's view (Fig. 15.20) are useful to assess the congruity of the posterior facet and subtalar joint.

4. After reduction of the posterior facet, the lateral wall fragments are repositioned. How well the pieces interdigitate with the intact lateral wall provides more information about the accuracy of the reduction with regards to restoring the calcaneal height and length.

Bone grafting can be used to fill cancellous bone voids prior to plate application. While the indications for bone grafting are controversial, there may be a role for supporting the area beneath the posterior facet with bone graft or bone graft substitutes when there is no inherent support for the joint.

Fixation

Definitive fixation involves calcaneal specific plate application to the lateral surface. Plate position is crucial to allow access to the areas of the

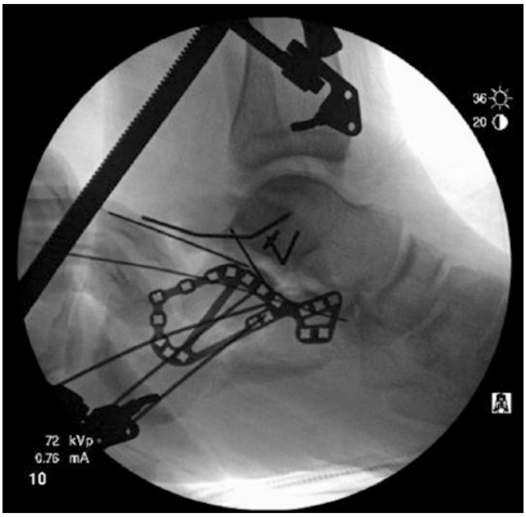


Fig. 15.21 The calcaneal plate is positioned just inferior to the posterior facet and angle of Gissane with the enough length to allow fixation into the anterior process and posterior tuberosity

calcaneus that have dense bone amenable to screw fixation. These areas include the dense bone in the sustentaculum tali, the subchondral bone of the posterior facet, the dorsal aspect of the anterior process, and the posterior border of the tuberosity. The plate is positioned just inferior to the posterior facet and angle of Gissane with the plate length being sufficient to allow fixation into the anterior process and posterior tuberosity (Fig. 15.21). This allows the plate to connect the tuberosity, posterior facet, and anterior process fragments into one construct.

Screw placement begins with cortical lag screws placed in the subchondral bone of the posterior facet. These screws can either be placed independently or through the plate and are directed across the posterior facet aiming slightly anteriorly to achieve purchase in the dense sustentacular bone. This reduces the plate down onto the lateral surface of the calcaneus and generates compression across the posterior facet fragments.

Additional lateral to medial cortical screws through the plate into the posterior cortex of the tuberosity will reduce the calcaneus to the plate, helping to reduce any residual varus alignment of the tuberosity (Fig. 15.22). Screws directed into the anterior process should be cephalad to achieve purchase in the dense bone beneath the anterior process.

Fig. 15.22 Lateral to medially directed cortical screws through the plate into the posterior cortex of the tuberosity will reduce the calcaneus to the plate

Fig. 15.23 A Broden's view will show if any screws have penetrated into the subtalar joint

Radiographic views should be performed to confirm appropriate screw length and position. A Broden's view will show if any screws have penetrated into the subtalar joint (Fig. 15.23). The axial view is used to assess screw length in relation to the medial wall (Fig. 15.24). Due to the proximity of the FHL tendon and medial neuro-

Fig. 15.24 The axial view is used to assess screw length in relation to the medial wall

vascular structures to the medial wall, screws that protrude beyond the medial wall should be exchanged for shorter ones [33]. An AP view of the foot will demonstrate the reduction of the calcaneocuboid joint as well as confirm proper length of the anterior process screws.

Wound Closure

A 1/8 inch Hemovac drain is placed deep in the wound under the flap and brought out through the skin distally (Fig. 15.25). Deep absorbable sutures (0-Vicryl) are then placed in a figure-8 fashion to reapproximate the periosteum and subcutaneous layer (Fig. 15.26). Placement of these sutures begins at the corner of the incision and extends outwardly. Once all these sutures have been placed, then they are hand tied sequentially, again starting at the corner and working toward the ends of the horizontal and vertical limbs. An assistant can stabilize the flap while these sutures are tied. The second layer of closure involves placing Allgöwer-Donati or vertical mattress sutures using 3-0 nylon (Fig. 15.27). Suture placement begins in the apex of the incision and extends outward along each limb. All sutures are placed without tying and clamped with hemostats. In a similar fashion to the deep layer, the sutures are sequentially tied starting at the corner of the incision and proceeding outwardly.

Fig. 15.25 A 1/8 inch Hemovac drain brought out through the skin distally

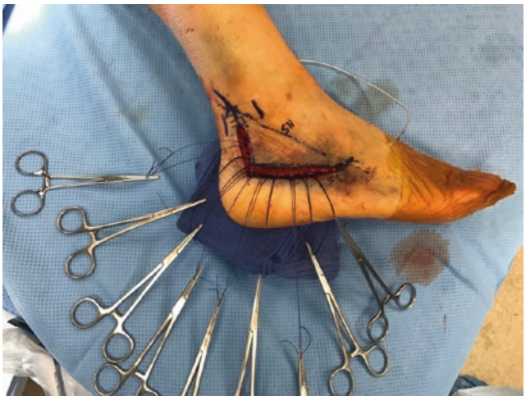


Fig. 15.26 Deep absorbable sutures (0-Vicryl) are placed in a figure-8 fashion to reapproximate the periosteum and subcutaneous layer

Fig. 15.27 The second layer of closure involves placing Allgöwer-Donati or vertical mattress sutures using 3–0 nylon

Fig. 15.28 Lateral X-ray at follow-up demonstrating restoration of the calcaneal height and length

Fig. 15.29 Axial X-ray showing correction of the varus malalignment and reduction of the calcaneal width

A nonstick dressing is applied overtop and the patient is placed in a well padded three-sided splint with and ankle in a neutral position. The patient is kept on strict bedrest for 24 hours after surgery with the foot elevated. Radiographic evaluation in the postoperative follow-up period typically includes lateral, axial, and Broden's views (Figs. 15.28, 15.29, and 15.30).

Fig. 15.30 Broden's view X-ray demonstrating the posterior facet reduction and congruency of the subtalar joint

References

1. Benirschke SK, Sangeorzan BJ. Extensive intraarticular fractures of the foot. Surgical management of calcaneal fractures. Clin Orthop Relat Res. 1993;292:128–34.
2. Sangeorzan BJ, Benirschke SK, Carr JB. Surgical management of fractures of the os calcis. Instr Course Lect. 1995;44:359–70.
3. Barei DP, et al. Fractures of the calcaneus. Orthop Clin North Am. 2002;33(1):263–85, x.
4. Schepers T, et al. Similar anatomical reduction and lower complication rates with the sinus tarsi approach compared with the extended lateral approach in displaced intra-articular calcaneal fractures. J Orthop Trauma. 2017;31(6):293–8.
5. Weber M, et al. Limited open reduction and internal fixation of displaced intra-articular fractures of the calcaneum. J Bone Joint Surg Br Vol. 2008;90-B(12):1608.
6. Kline AJ, et al. Minimally invasive technique versus an extensile lateral approach for intra-articular calcaneal fractures. Foot Ankle Int. 2013;34(6):773–80.
7. Yeo JH, Cho HJ, Lee KB. Comparison of two surgical approaches for displaced intra-articular calcaneal fractures: sinus tarsi versus extensile lateral approach. BMC Musculoskelet Disord. 2015;16:63.
8. Al-Mudhaffar M, Prasad CV, Mofidi A. Wound complications following operative fixation of calcaneal fractures. Injury. 2000;31(6):461–4.

9. Assous M, Bhamra MS. Should os calcis fractures in smokers be fixed? Injury. 2001;32(8):631–2.
10. Benirschke SK, Kramer PA. Wound healing complications in closed and open calcaneal fractures. J Orthop Trauma. 2004;18(1):1–6.
11. Folk JW, Starr AJ, Early JS. Early wound complications of operative treatment of calcaneus fractures: analysis of 190 fractures. J Orthop Trauma. 1999;13(5):369–72.
12. Geel CW, Flemister AS Jr. Standardized treatment of intra-articular calcaneal fractures using an oblique lateral incision and no bone graft. J Trauma. 2001;50(6):1083–9.
13. Harvey EJ, et al. Morbidity associated with ORIF of intra-articular calcaneus fractures using a lateral approach. Foot Ankle Int. 2001;22(11):868–73.
14. Howard JL, et al. Complications following management of displaced intra-articular calcaneal fractures: a prospective randomized trial comparing open reduction internal fixation with nonoperative management. J Orthop Trauma. 2003;17(4):241–9.
15. Huang PJ, et al. Open reduction and internal fixation of displaced intra-articular fractures of the calcaneus. J Trauma. 2002;52(5):946–50.
16. Jiang N, et al. Surgical versus nonsurgical treatment of displaced intra-articular calcaneal fracture: a meta-analysis of current evidence base. Int Orthop. 2012;36(8):1615–22.
17. Raymakers JT, Dekkers GH, Brink PR. Results after operative treatment of intra-articular calcaneal fractures with a minimum follow-up of 2 years. Injury. 1998;29(8):593–9.
18. Shuler FD, et al. Wound-healing risk factors after open reduction and internal fixation of calcaneal fractures: does correction of Bohler's angle alter outcomes? Orthop Clin North Am. 2001;32(1):187–92. x
19. Stiegelmar R, et al. Outcome of foot injuries in multiply injured patients. Orthop Clin North Am. 2001;32(1):193–204, x.
20. Stromsoe K, Mork E, Hem ES. Open reduction and internal fixation in 46 displaced intraarticular calcaneal fractures. Injury. 1998;29(4):313–6.
21. Tennent TD, et al. The operative management of displaced intra-articular fractures of the calcaneum: a two-Centre study using a defined protocol. Injury. 2001;32(6):491–6.
22. Koski A, Kuokkanen H, Tukiainen E. Postoperative wound complications after internal fixation of closed calcaneal fractures: a retrospective analysis of 126 consecutive patients with 148 fractures. Scand J Surg. 2005;94(3):243–5.
23. SANDERS R. Current concepts review - displaced intra-articular fractures of the calcaneus∗. JBJS. 2000;82(2):225–50.
24. Zwipp H, Rammelt S, Barthel S. Calcaneal fractures – open reduction and internal fixation (ORIF). Injury. 2004;35(2):46–54.
25. Abidi NA, et al. Wound-healing risk factors after open reduction and internal fixation of calcaneal fractures. Foot Ankle Int. 1998;19(12):856–61.
26. Berry GK, et al. Open fractures of the calcaneus: a review of treatment and outcome. J Orthop Trauma. 2004;18(4):202–6.
27. Ding L, et al. Risk factors for postoperative wound complications of calcaneal fractures following plate fixation. Foot Ankle Int. 2013;34(9):1238–44.
28. Herscovici D Jr, et al. Operative treatment of calcaneal fractures in elderly patients. J Bone Joint Surg Am. 2005;87(6):1260–4.
29. Palmer I. The mechanism and treatment of fractures of the calcaneus; open reduction with the use of cancellous grafts. J Bone Joint Surg Am. 1948;30A(1): 2–8.
30. Gould N. Lateral approach to the os calcis. Foot Ankle. 1984;4(4):218–20.
31. Letournel E. Open treatment of acute calcaneal fractures. Clin Orthop Relat Res. 1993;290:60–7.
32. Borrelli J Jr, Lashgari C. Vascularity of the lateral calcaneal flap: a cadaveric injection study. J Orthop Trauma. 1999;13(2):73–7.
33. Albert MJ, Waggoner SM, Smith JW. Internal fixation of calcaneus fractures: an anatomical study of structures at risk. J Orthop Trauma. 1995;9(2): 107–12.

16

Minimally Invasive Treatment of Intra-articular Calcaneal Fractures

Thomas M. Large and Bruce Cohen

Introduction

Surgical treatment of calcaneal fractures remains a controversial topic. Several authors have shown little benefit to operative reduction and fixation while others have shown superior outcomes with surgical treatment [1–9]. In a retrospective cohort of 169 patients with displaced Sanders II–IV intra-articular fractures, DeBoer et al. found that those patients with operative treatment, open or percutaneous, had improved American Orthopaedic Foot and Ankle Society ankle-hindfoot (AOFAS) and Foot Function Index (FFI) outcome scores to those treated nonoperatively [7]. Agren et al. in a randomized controlled trial of operative versus nonoperative treatment in 82 patients found no difference in visual analog scale (VAS) pain scores or functional outcomes (SF-36 short, AOFAS, Olerud-Molander) at 1 year, but at 8–12 years postoperatively, the surgically treated patients had better VAS pain and function scores, better physical SF-36 scores, and 41% less subtalar arthritis [8]. Buckley found in a randomized controlled trial of 471 patients to operative or nonoperative treatment that certain patients treated operatively did better: women, those not in the Workers' Compensation system, those less than 29 years old, those with lower injury Bohler angles of 0–14°, comminuted fractures, a light workload, an anatomic surgical reduction, or a step-off of < or = to 2 mm after surgical treatment [9]. We believe that surgical treatment is likely superior to nonoperative treatment for most displaced intra-articular calcaneal fractures (DIACFs) in patients with acceptable risk factors for surgery [10].

Operative treatment was first performed by Bell in 1882 and Morestin in 1902 with significant advances described by Bohler, Palmer, Essex-Lopresti, and Letournel leading to the lateral extensile approach as described by Benirschke and Sangeorzan in 1993, which remains the gold standard for displaced intra-articular calcaneal fractures [11–16]. Concerns over ongoing wound healing complications with the lateral extensile approach have led to renewed enthusiasm for minimally invasive techniques tempered by questions over whether anatomic reductions and equivalent functional outcomes can be obtained with minimally invasive techniques.

While Benirschke and Sangeorzan reported only 2 infections out of 80 patients, wound healing complications and high infection rates have plagued the treatment of these injuries with use of the lateral extensile approach in most reported series [16]. Folk et al. had a wound complication rate of 25% in 190 fractures with even higher

T. M. Large (✉)
Orthopaedic Trauma Services, Mission Hospital,
Asheville, NC, USA
e-mail: thomas.large@hcahealthcare.com

B. Cohen
Atrium Musculoskeletal Institute, Foot and Ankle
Division, OrthoCarolina, Charlotte, NC, USA

© Springer Nature Switzerland AG 2020
M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_16

rates in diabetics, smokers, and those with open fractures [17]. More recent reviews show rates of 4.3–29% [18–20]. While avoiding infection and wound healing complications obviously avoids repeated surgery and morbidity, avoiding postoperative wound infections also improves functional outcomes [21]. All studies discussed below comparing minimally invasive and lateral extensile approaches, show decreased wound healing complication rates in the minimally invasive groups. The quality of the reduction is known to lead to improved functional outcomes, and while an anatomic reduction of the calcaneal fracture is best performed with a lateral extensile approach, more literature is supporting that minimally invasive approaches can result in equivalently accurate reductions, as discussed in detail below [9, 22, 23]. Van Hoeve et al. found that quality of reduction correlated with improved subtalar motion and push-off on gait analysis and better patient-reported functional outcomes on the Foot and Ankle Disability Index and Physical Component SF-36. As Sanders reported in his 1993 landmark article on 120 operatively treated fractures, an anatomic reduction improved functional outcome but it did not guarantee a good result [24].

Clark in 1855 has been credited with the first description of percutaneous calcaneal fracture treatment with a pulley, but a closer review of his report is that he describes the use of a pulley by a Mr. Wormald to treat a talar dislocation and describes his treatment of a calcaneal fracture with gutta-percha (a latex tree extract used to prepare splints in the mid-nineteenth century), not a pulley [25, 26]. Percutaneous techniques were clearly being employed and modified widely in the early twentieth century as reported by many authors, with the distraction method described and modified by Bohler becoming the most widely adopted [11, 27–31]. The forefoot was plantarflexed over a wooden wedge to free the tuberosity, then a 5 mm pin was placed in the tuberosity and distal tibia with 15–20 kg of traction applied through the traction stirrups with the knee flexed in a traction frame, and a plaster cast was then applied over the pins with the reduction held. A compression vise was placed over the medial and lateral heel to reduce width to that measured on the contralateral side [11]. The countertraction in the tibia was later discontinued [32]. McBride, Gill, and Harris described triangular distraction techniques in the mid-1940s which were later modified by Forgon and Zadravecz in 1983 and are still commonly used today with good results recently reported by Schepers et al., deVroome et al., and Tomesen et al. [26, 28, 33–38] Percutaneous leverage techniques with an axial pin in the tuberosity were first described by Westhues in 1934 and modified by Gissane who developed a specific pin and handle for the technique [39, 40]. This technique was most notably described in detail by Essex-Lopresti and the leverage technique with an axial tuberosity pin over a plantarflexed forefoot and ankle bears his name in the English literature while known as the Westhues maneuver in the German literature [41]. It remains useful in tongue type (Sanders IIC) and avulsive fractures and is still in use as part of percutaneous reduction methods today [42, 43]. A percutaneous only treatment of 40 intra-articular fractures was shown by Battaglia et al. to have excellent radiographic and functional outcomes using a Kirschner wire only construct with external clips holding wires from the tuberosity to those in the facet [44]. We do not favor the use of definitive Kirschner wire only constructs due to high rates of pin tract infections and concern for loss of reduction [45, 46].

Most modern minimally invasive treatment options have been developed and modified to minimize wound healing and infection risks [47–51]. Multiple authors have recently reported results with percutaneous techniques modified slightly from the three-point distraction method initially described by Forgon and Zadravecz in 1983. Schepers described and advocated a slight modification of this technique with use of distractors between the calcaneal tuberosity and talus and between the tuberosity and cuboid to restore length and height followed by percutaneous reduction of the posterior facet and percutaneous screw fixation. Only two or three screws were used with 72% good to excellent AOFAS functional outcome scores and a 15% subtalar fusion rate at 1 year with an 11% superficial and 3% deep infection rate [36]. Tomesen used a slight variant of the Forgon/Zadravecz distraction technique with pins in the medial distal tibia and medial calcaneal tuberosity for use with an external fixator as a distractor to correct varus/valgus, height, and width. Percutaneous posterior facet reduction is performed and fixation is achieved with 6.5 mm cannulated screws. Thirty-nine fractures treated with this technique had a 13% infection rate, 73% good and excellent results on AOFAS functional outcome scores, and 81% good/excellent with Maryland Foot Score (MFS) [37]. Their raw mean scores were very similar to those reported by Schepers: 84 versus 83 on AOFAS and 86 versus 79 on MFS. Other recent results with a modified three-point distraction technique were reported by de Vroome et al. using external fixator distractors over Steinmann pins in the tuberosity, cuboid, and distal tibia with a plantar punch to elevate depressed articular segments and then fixation with 2–4 cannulated cancellous screws. They had 1/46 infections (2.4%) and 69% good and excellent AOFAS scores with better results in the tongue type fractures, 100% good/excellent versus 52% good/excellent in the DIACF group [38]. An external fixator only treatment was reported by Magnan et al. with 90.7% good and excellent results (MFS) and a 5.6% pin tract infection rate [49].

Multiple studies have looked at the quality of reductions obtained with minimally invasive techniques and functional outcomes achieved. Hindfoot anatomic relationships can be well restored and the posterior facet fracture lines can frequently be anatomically reduced though a sinus tarsi approach [22]. Nosewicz et al. evaluated the quality of reduction on postoperative CT scans and found good or excellent reductions (<1 mm step, defect <5 mm, angulation <5°) in 14/22 fractures [22]. Rammelt reported excellent functional outcomes (AOFAS mean score 92.1) and no wound complications in 33 patients with Sanders IIA and IIB fractures treated with percutaneous reduction and screw fixation and reductions were verified with subtalar arthroscopy. They reported the importance of early treatment and anatomic reduction, cautioning against the use of percutaneous techniques for more complex fractures [52]. We agree that early surgical intervention within a few days of injury is required to achieve an anatomic articular reduction with minimally invasive techniques before hematoma gelatinizes or fibrous tissue forms in the fracture lines which is difficult to fully clean with minimally invasive techniques.

Many comparative studies between minimally invasive and lateral extensile approaches generally report equivalent or better functional outcomes for Sanders type II and III fractures with decreased wound healing and infection complications [20, 53–58]. DeWall et al. performed a retrospective cohort study of 42 fractures treated with an extensile approach and lateral plating and 83 treated with percutaneous reduction and screw fixation. These included Sanders II–IV DIACFs including some tongue type fractures with a predominance of Sanders II and III fractures in each group. They reported significantly fewer wound complications and equivalent plain radiographic and SF-36 and Foot Function Index (FFI) functional outcome scores in the percutaneous group [53]. A retrospective review of 26 patients treated with an extensile approach and 24 with a minimally invasive sinus tarsi approach for reduction and fixation with a percutaneous plate or screws was performed by Weber et al. in 2008 on roughly 75% Sanders II and 25% Sanders III DIACFs. They reported shorter operative times and equivalent radiographic and functional outcomes (AOFAS) in the minimally invasive group but with a greater need for later hardware removal [54]. Chen et al. performed randomized trial of 90 patients with mostly Sanders II and some III DIACFs, those patients treated with percutaneous reduction and fixation with cannulated screws and calcium sulfate bone graft had radiographically equivalent (Bohler's angle, width, length, height, and articular congruity on plain film and CT) outcomes but improved range of motion and AOFAS and MFS functional outcome scores versus those treated with the extensile lateral approach. The infection rate was 12% in the open group and 3% in the percutaneous group [57]. In a randomized controlled trial between a lateral extensile and sinus tarsi approach for Sanders II and III fractures, Xia et al. found radiographically equivalent outcomes and improved functional outcomes (MFS) in the sinus tarsi group with 0/59 patients experiencing a wound complication versus 8/49 in the extensile approach group [58]. In a prospective trial of 45 fractures between lateral extensile ORIF and percutaneous reduction and fixation, Kumar et al. found significantly fewer wound complications (0% vs 30%) and improved functional outcomes (Creighton Nebraska Health Foundation scale) and slightly earlier return to work in the percutaneous treatment group but there were greater Sanders II fractures and fewer Sanders IV fractures in the percutaneous group [59]. Kline et al. performed a retrospective review of 112 Sanders II and III fractures, 79 treated via an extensile lateral approach and 33 with a sinus tarsi incision for reduction and percutaneous screw fixation. They reported a 29% wound complication rate in the extensile group versus 6% in the sinus tarsi group. Plain radiographic and functional outcomes (FFI, SF-36, and visual analog scale (VAS) pain) were equivalent with less need for secondary surgery and improved patient satisfaction in the sinus tarsi group [20].

More recently, fixation with minimally invasive and percutaneous reductions has also included plating, generally inserted through the sinus tarsi incision or a separate posterior longitudinal incision over the tuberosity. Basile et al. prospectively compared outcomes of ORIF via an extensile lateral approach in 20 patients at one institution with ORIF via a sinus tarsi approach with a plate in 18 patients at a second institution. All fractures were Sanders II and III. They reported equivalent radiographic outcomes on postoperative CT scans and clinical functional outcomes scores (FFI, AOFAS, VAS pain) with equivalent complication rates as well [55]. Cao et al. reported 93% good and excellent results (AOFAS) with 2/33 infections performing a percutaneous reduction followed by locked plating through a longitudinal posterolateral 2–3 cm incision. Their mean VAS pain score was 1.6, AOFAS functional outcome score of 82, and Maryland Foot Score of 89 [60]. Nosewicz et al. reported on 22 fractures treated with a sinus tarsi approach for reduction and application of a 2.4 mm plate augmented with percutaneous screws. 14/22 reductions were rated good or excellent on postoperative CT as discussed above and 16/19 had good or excellent results on AOFAS functional outcome hindfoot scores (mean 86.2). However, they did have a 14% wound complication rate and 50% required hardware removal [22]. Wu et al. performed a retrospective review of 329 patients treated with an extensile ORIF procedure versus a minimally invasive reduction and plating through a longitudinal incision including compression bolts through the plate with nuts over the screws through small stab incisions medially. They reported decreased wound complications (1.88% vs 11.76%) and a trend toward better functional outcomes (AOFAS) in the minimally invasive group [61]. In follow-up, the same group performed a randomized prospective trial comparing a minimally invasive posterior longitudinal approach to the sinus tarsi approach in 130 patients. They found lower wound healing complications in the longitudinal group and equivalent radiographic CT outcomes and functional outcomes (AOFAS) between the two groups for Sanders II and III fractures, but improved radiographic CT and functional outcomes in the sinus tarsi group for Sanders IV fractures [62].

While much of the literature focuses on wound complication rates and functional and radiographic outcomes between extensile and minimally invasive approaches, Haugsdal et al. performed a review of the reported nerve injury complications between different approaches. They found the highest rates of nerve injury and complex regional pain syndrome in patients treated with the extensile lateral approach followed by percutaneous techniques with the lowest reported rates in the sinus tarsi approach [63].

In summary, minimally invasive treatment options clearly have a role in the treating orthopedic surgeon's armamentarium with equivalent radiographic and functional outcomes for Sanders II and III DIACFs and lower wound healing and infection complication rates. We find these techniques especially useful for those patients, even with more complex fractures, at high risk for operative complications such as those with open wounds, diabetes mellitus, neuropathy, tobacco use, substance abuse, vascular disease, and immune-suppressive conditions such as inflammatory arthropathies, renal disease, or those undergoing cancer treatment [51, 64, 65]. There is a learning curve involved with these techniques and certainly having performed many lateral extensile approaches will help the surgeon understand the complex anatomy of the calcaneus and the reduction maneuvers frequently required to reduce the commonly encountered displacement patterns as one moves to minimally invasive techniques. Using the sinus tarsi approach to inspect the reduction after the surgeon believes that they have it perfect under fluoroscopy is also a recommended consideration when transitioning to minimally invasive techniques. For more complex fractures (Sanders IIIBC/IV, significant anterior process comminution, significant tuberosity displacement), especially in younger or high-demand patients with acceptable surgical risks, we still favor the lateral extensile approach to better clean and mobilize these fractures with enhanced visualization to ensure anatomic reduction. What follows are the tips and tricks to help the reader achieve the best possible reductions and outcomes using minimally invasive techniques.

Surgical Planning

Appropriate preoperative imaging must be obtained including quality lateral and axial Harris heel plain radiographs and an axial CT scan with sagittal and coronal reconstructions. An appropriately thorough preoperative history and physical is mandatory including mechanism of injury, vascular and neurologic exam, wound examination, smoking and occupational status, previous ankle or foot surgeries and injuries, and past medical history with a focus on the presence or absence of diabetes mellitus and its microvascular complications such as ophthalmologic, renal, and neuropathic conditions, other neuropathies, tobacco use, vascular disease and immune-suppressive conditions such as inflammatory arthropathies, renal disease, or those undergoing cancer treatment.

Percutaneous surgery is best performed earlier than typically done for the lateral extensile approach. Surgery on the day of injury through 5 days postinjury allows for more mobility of the fracture fragments to make percutaneous reductions most successful. We favor surgery within 3 days of injury when possible but would recommend against surgery in the presence of fracture blisters and would wait until adequate blister healing and then re-evaluate surgical needs and options. Early application of a medially based external fixator should be considered for those patients with fracture blisters or poor soft tissues that the surgeon feels will benefit from operative reduction and fixation of their fractures but are poor candidates for a lateral extensile approach and may require late percutaneous surgery. The medial external fixator is applied with a 5 mm Schanz pin in the distal medial tibia, the medial calcaneal tuberosity, and with a 4 mm pin in the midfoot, typically across the cuneiforms (Fig. 16.1a–c).

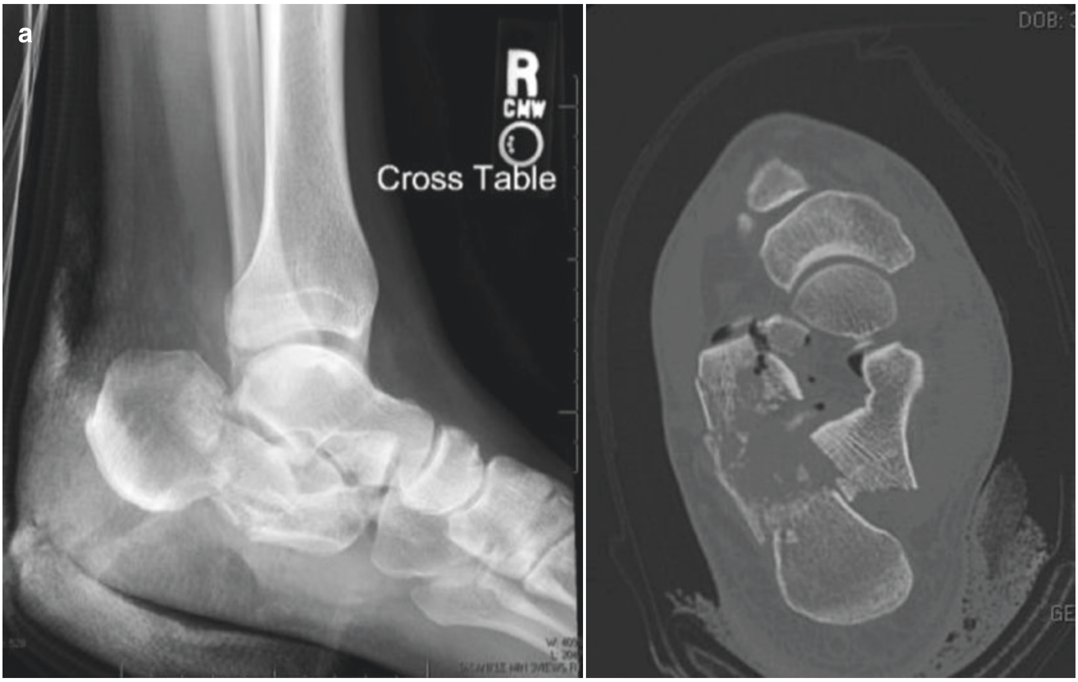


Fig. 16.1 (**a**) This case demonstrates use of a medially based external fixator to hold the reduction of a severe open injury, allowing easier late percutaneous reduction and fixation. A 32-year-old male fell 25 feet from a utility pole cherry picker, sustaining a right intra-articular joint depression Sanders IIA calcaneal fracture with a 12 cm open plantar medial wound and a contralateral closed pilon fracture. (**b**) The open wound is debrided, irrigated, and closed after using it to reduce the primary fracture line with application of a medially based external fixator with a pin in the medial distal tibia, medial calcaneal tuberosity, and the medial midfoot into the cuneiforms. Note the improved reduction of the primary fracture line on the CT versus that in (**a**). (**c**) Initial reduction and external fixation allowed for a late percutaneous reduction and fixation through small incisions to reduce the residual posterior facet fracture displacement. Due to the severe soft-tissue injury, the procedure was done 14 days after injury so a perfect reduction of the posterior facet could not be achieved closed as the step-off was reduced but a small lateral gap remained. The fixator was maintained for 6 weeks. Despite the imperfect reduction, the patient had an excellent clinical outcome and healed his wound and incisions without complication

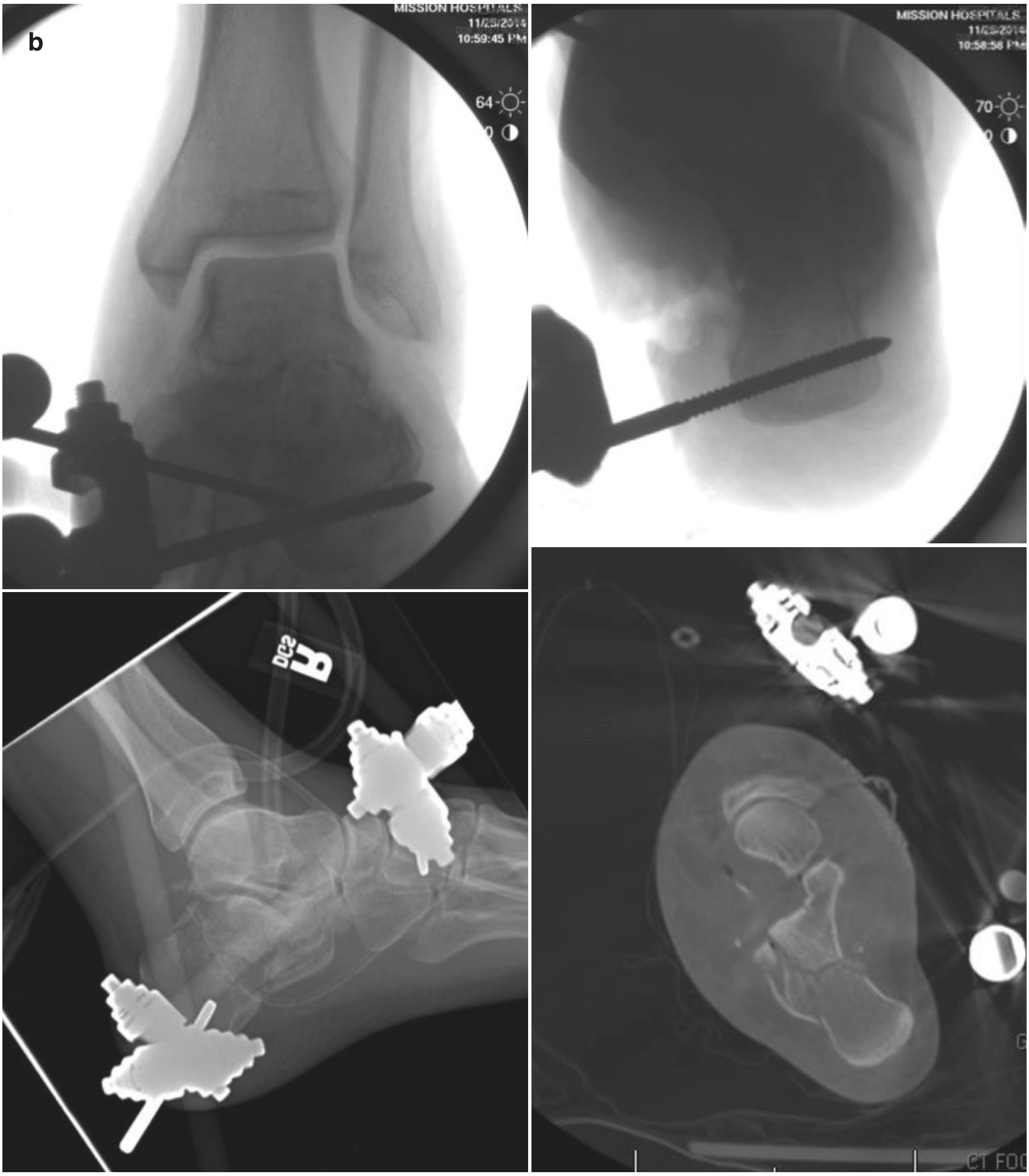


Fig. 16.1 (continued)

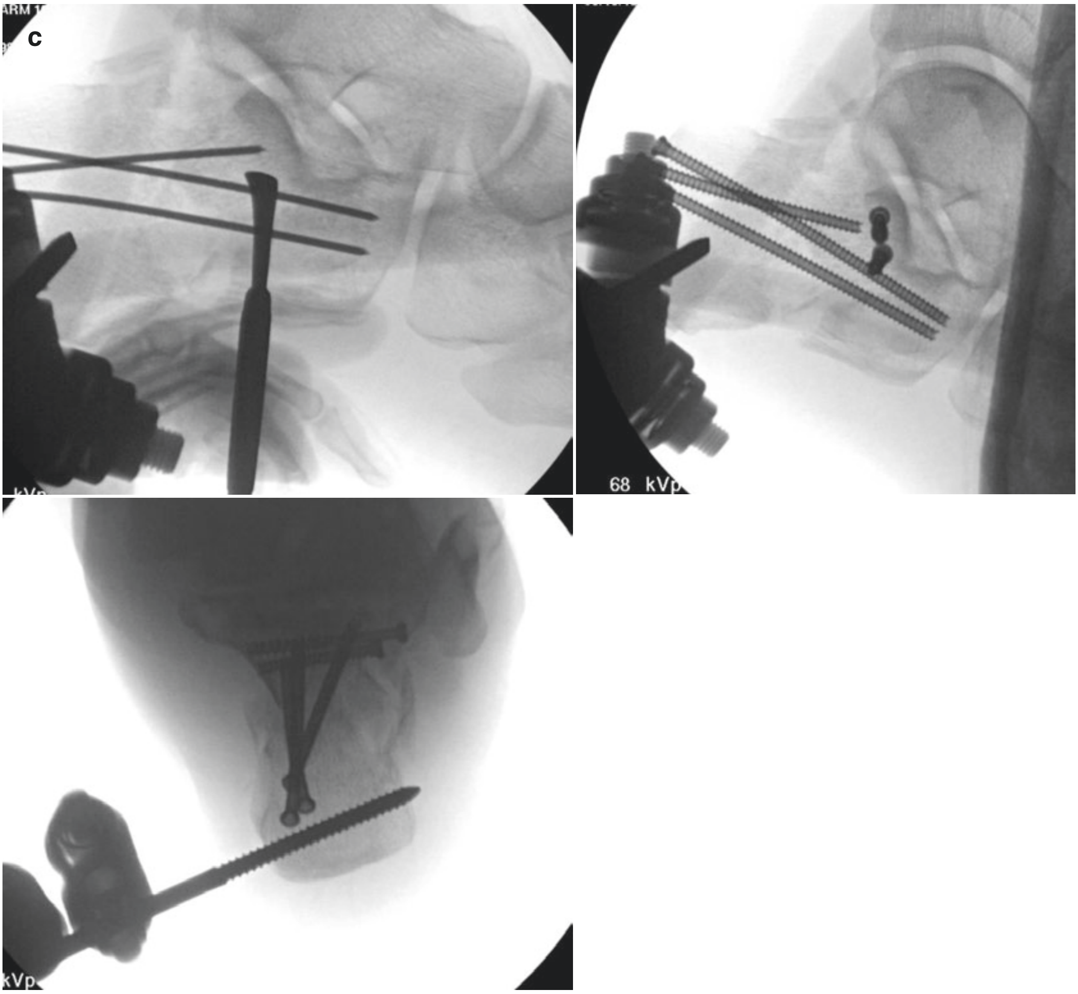


Fig. 16.1 (continued)

Surgical Positioning and Preparation

The patient is positioned in the lateral decubitus position with an axillary roll, on a beanbag or with a lateral positioner such as the Stulberg (Innomed, Inc., Savannah, GA), the down limb well-padded and supported, and the operative limb supported on pillows, blankets, or a Bone Foam platform (Bone Foam, Inc., Corcoran, MN). If bilateral calcaneal fractures are present and being treated simultaneously, the patient can be positioned prone on padded chest rolls with the head and neck held in a neutral position with care to avoid any pressure around the eyes and orbits, with a gel pad under the knees and pillows or a foam ramp to keep the knees flexed approximately 30°. Prone positioning is also useful for avulsive tongue type fractures and can be used for an isolated depressed intra-articular fracture at the surgeon's preference. We prefer the lateral position for an isolated depressed intra-articular fracture. A radiolucent diving-board type table should be used such that there are no supports or bars under the foot of the table to allow for easily obtained radiographic views. A tourniquet is placed on the upper thigh. The limb is washed with chlorhexidine and isopropyl alcohol followed by sterile preparation with Chloraprep (Becton, Dickinson and Co., Franklin Lakes, NJ).

General anesthesia is preferred, with or without a peripheral nerve block as decided by the patient after discussion with the anesthesiologist.

Percutaneous Reduction Techniques of Displaced Intra-articular Fractures and Cannulated Screw Fixation (Figs. 16.2, 16.3, 16.4, 16.5, and 16.6)

Under fluoroscopic guidance on the lateral view, a small incision is made over the plantar posterior tuberosity and the 3.5 mm drill bit is used to penetrate the lateral cortex of the calcaneal tuberosity. A 5 mm Schanz pin is then threaded into the bone of the tuber by hand or carefully on power to act as a joystick. The classic reduction move is performed with the Schanz pin to medialize the tuberosity, restore valgus alignment, length, and height. Length and height should be judged on the lateral radiograph while valgus and medialization should be assessed on the axial Harris heel view with careful attention to the primary fracture line. Medial comminution around the primary fracture line should be assessed on preoperative CT as this may make this assessment more challenging. When satisfactory reduction is achieved, longitudinal Kirschner wires are passed from the posterior tuber into the anterior process and/or the sustentacular fragment, taking care not to block any posterior facet reduction that may need to occur. Based on the fracture pattern, these are typically kept medial and/or plantar of any posterior facet depressed fragments (Fig. 16.2b). These wires can be planned to function as the guidewires for cannulated screws, and typically these screws should be planned to be subcortical on the periphery of the lateral and medial borders of the calcaneus to maximize purchase and act as struts to hold length and hindfoot alignment. The position of k-wires and ultimately screws should be individualized and carefully planned from the preoperative CT scan. Depending on the fracture pattern, a percutaneous small incision parallel to the plantar foot can be made just plantar and posterior to the angle of Gissane to allow for the percutaneous introduction of an elevator to reduce the depressed posterior facet fragments. This is best for a Sanders II fracture with a relatively large fragment that will be easily assessed and followed under fluoroscopy to ensure appropriate reduction. Alternatively, a plantar incision and punch can be used to elevate depressed fragments as described by de Vroome et al. [38]. If there are multiple fracture lines, smaller comminuted fragments, or a need to directly inspect the articular reduction, a sinus tarsi incision should be considered, as described below.

With the posterior facet anatomically reduced, Kirschner wires are placed from lateral to medial to hold the posterior facet reduction and their position should be planned to function as guidewires for cannulated screws if desired (Fig. 16.2b). A final Kirschner wire is now placed from the tuber into the sustentaculum with the facet now reduced and/or an additional wire can be placed from the plantar tuber perpendicular to the posterior facet to act as a kickstand to hold up the now reduced depressed segment (Fig. 16.3d). Fluoroscopy should now be carefully inspected with intraoperative plain film radiographs if needed to assure the reductions are achieved before proceeding with definitive fixation. The lateral and axial Harris heel views are critical but the mortise ankle view and Broden views are also important to evaluate the posterior facet reduction. When satisfied with the reduction, solid or cannulated screw fixation proceeds usually starting with lag screws by technique or design across the posterior facet fracture reduction. These are applied through small incisions, about 5 mm, just enough to accommodate the screw head. Next, the longitudinal screws are placed along the medial and lateral subcortical margins of the calcaneus. Often a medial screw is placed as a partially threaded lag screw to compress the primary fracture line. Typically with the other Kirschner wires present, this will not induce varus or excessive shortening but this should be carefully monitored under fluoroscopy. The other screws are typically fully threaded positional screws to act as struts to hold length and alignment. Finally, the screws from the tuber into the sustentaculum and/or the kickstand screws are applied. This sequence is common, but the individual sequence and location of the screws are dictated by the fracture pattern as shown in the cases below.

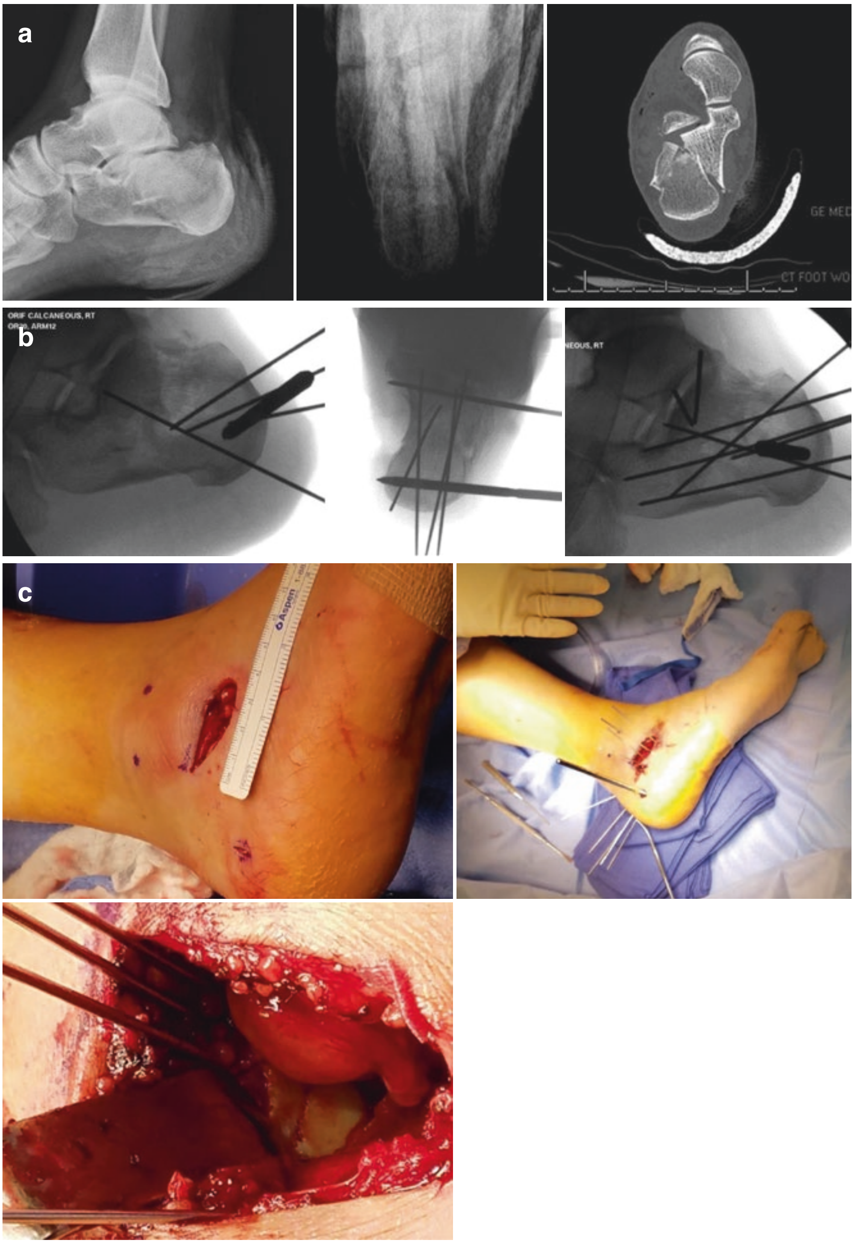


Fig. 16.2 (**a**) This case demonstrates a fairly common fracture pattern, reduction sequence, and fixation pattern in an open fracture. A 65-year-old male fell 6 ft from his deck. He has a 3 cm open medial wound and a Sanders IIA displaced intra-articular fracture with significant tuberosity shortening and loss of height. (**b**) Tuberosity Schanz pin and medial open wound are used to reduce the primary fracture line and hold it with longitudinal K-wires. A sinus tarsi incision is then made and the depressed lateral posterior facet fragment is reduced with an elevator and a joystick k-wire in the fragment, compressed with a shoulder hook and held with two subchondral k-wires. (**c**) Standard sinus tarsi 3 cm incision, Kirschner wire and Schanz pin positions, and visualization of posterior facet reduction of a Sanders IIA Fracture (note this is a similar fracture pattern but different case as these photos are of a lateral, not prone, position). (**d**) Two partially threaded cannulated lag screws are first placed over the subchondral k-wires to compress the posterior facet fracture reduction. A partially threaded longitudinal lag screw is then used medially to carefully compress the primary fracture line from the tuberosity into the sustentacular/posterior facet segment without inducing varus to the hindfoot. (**e**) Fixation is completed with placement of fully threaded screws from the tuberosity into the anterior process to act as struts both medially and laterally and down from the tuberosity to hold length and height. The patient did require a superficial debridement office procedure of a postoperative wound infection of the medial open fracture wound with a course of oral antibiotics. X-rays at 5 months show a healed fracture and he is fully weightbearing without pain with no infection recurrence

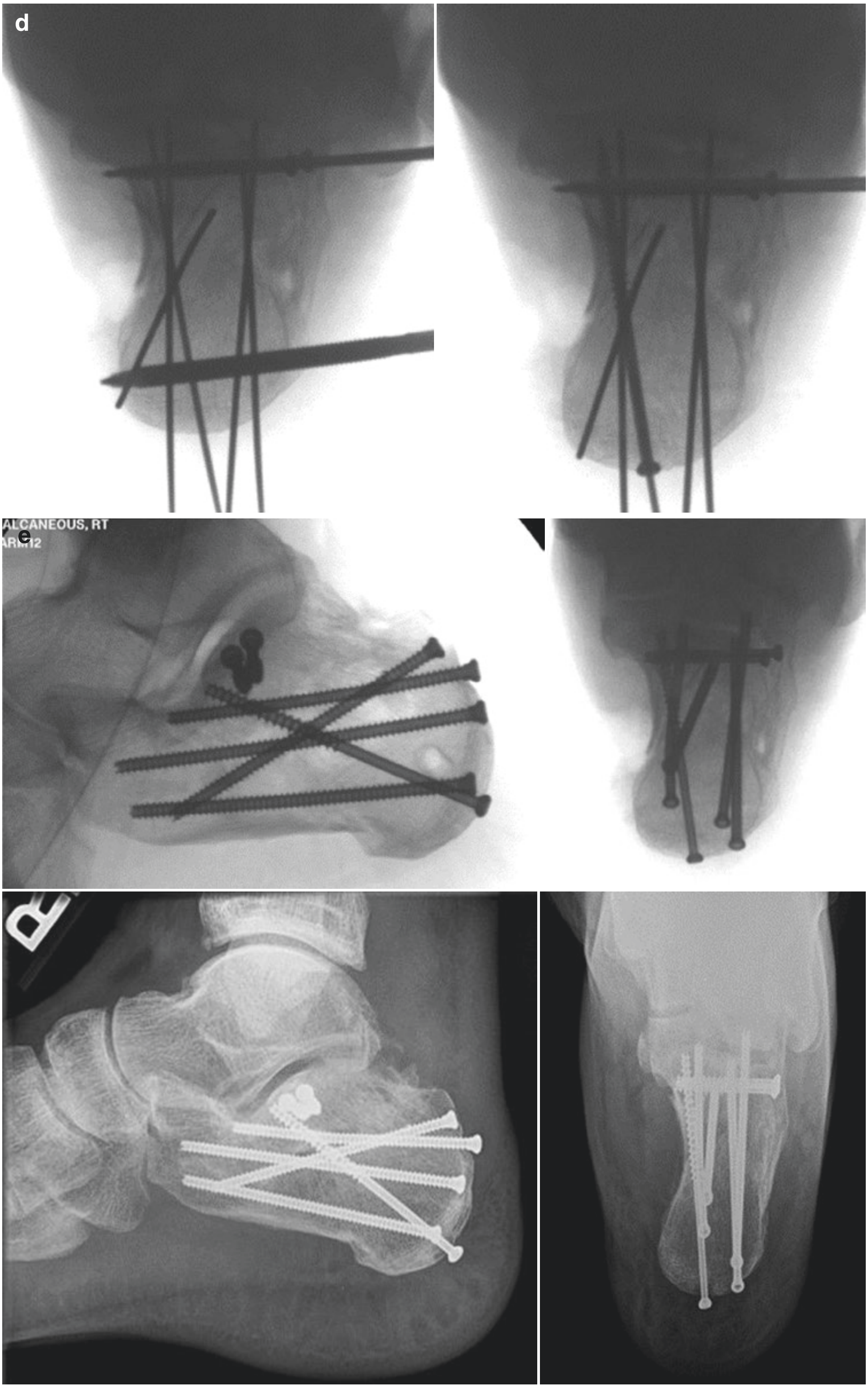


Fig. 16.2 (continued)

Fig. 16.3 (**a**) This case demonstrates use of the periosteal elevator shoehorn in conjunction with reopening a small portion of the medial wound for clamp placement and the use of a screw from the medial side of the sustentaculum into the anterior process. A 41-year-old male fell from a ladder and has an open displaced intra-articular calcaneal Sanders IIA fracture with a 6.5 cm open medial wound. He underwent irrigation and debridement and closure of his open wound on the day of injury by another surgeon and returns on injury day 3 for percutaneous reduction and fixation. Note that the posterior facet involvement is quite lateral and only a small portion of the joint. (**b**) To achieve the reduction, note the use of a Schanz pin joystick in the tuberosity and periosteal elevator as a shoehorn to reduce the primary fracture line followed by opening a small portion of the open fracture wound to use a ball spike pusher and ultimately a large periarticular clamp to obtain an appropriate reduction. Note the revision of the provisional Kirschner wire fixation through this process and placement of a single lag screw from the medial side from the sustentacular fragment into the anterior process to compress this secondary fracture line. (**c**) Clinical photo showing use of a 2.5 mm terminally threaded pin as a joystick medially in the sustentacular fragment, a lateral 5.0 mm Schanz pin in the tuberosity, and a large periarticular reduction forceps to hold the reduction through the medial open fracture wound and a small percutaneous lateral incision. Posterior to anterior Kirschner wires are then placed. (**d**) Note the use of a kickstand screw up from the tuberosity to support the posterior facet/sustentacular segment. Note the peripheral placement of the screws medially to hold length, medialization, and valgus of the tuberosity and the use of a partially threaded screw from the tuberosity into the sustentaculum to compress the fracture. This screw is placed prior to the fully threaded screws. (**e**) His medial open fracture wound healed without complication. X-rays at 18 weeks postoperatively show a healed fracture in good alignment. He has returned to work clearing trees for the power company

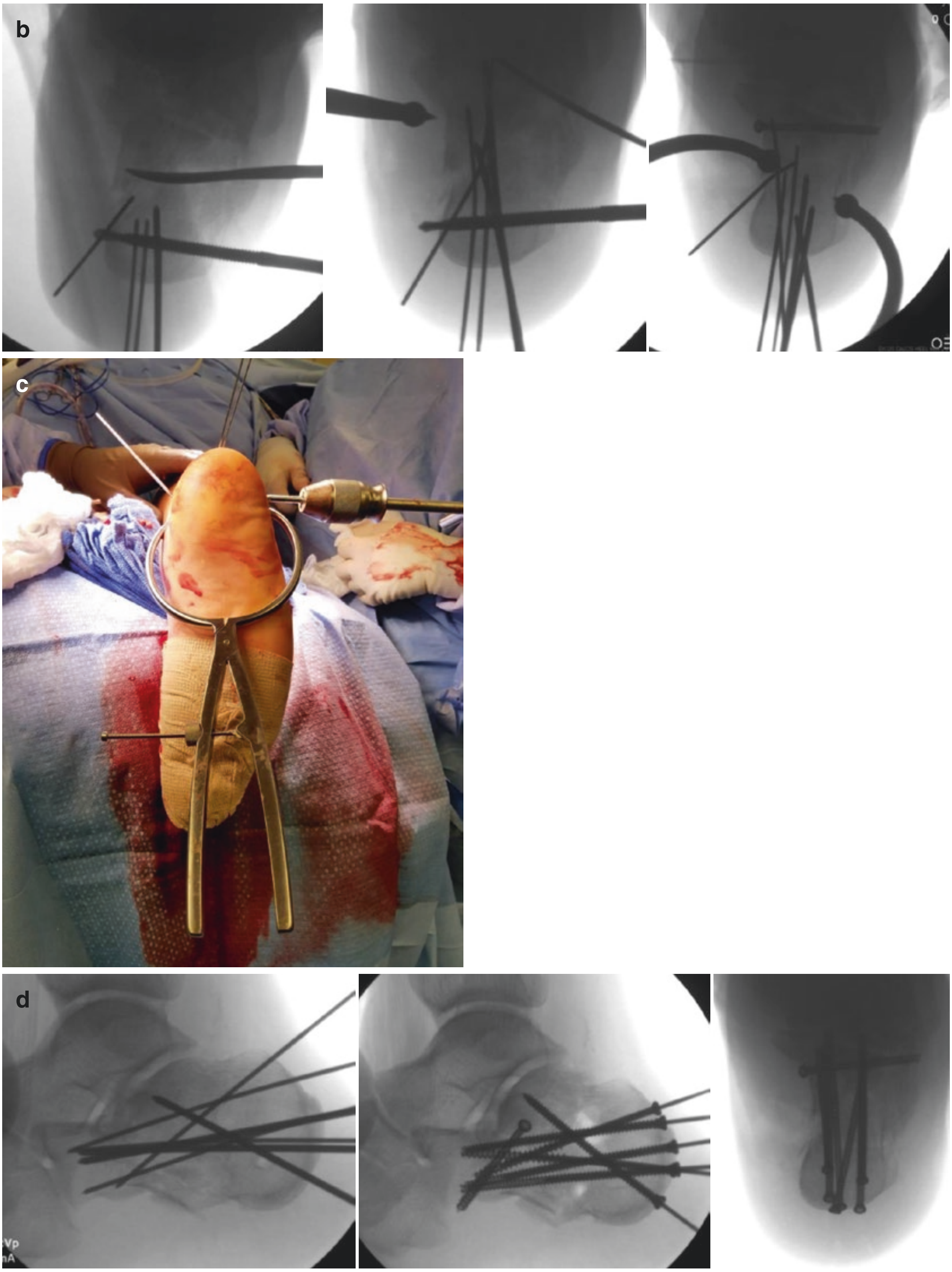


Fig. 16.3 (continued)

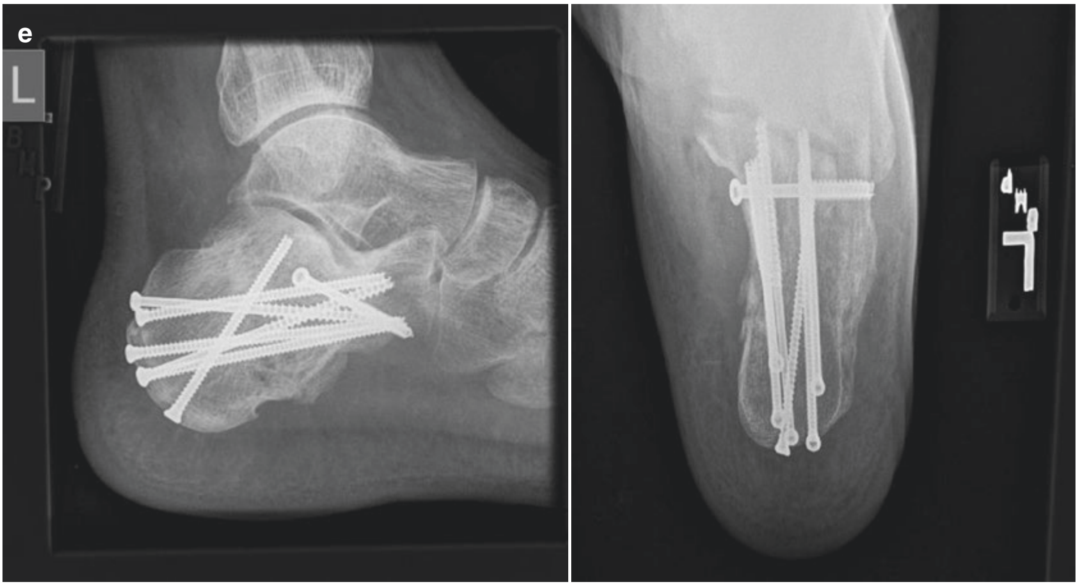


Fig. 16.3 (continued)

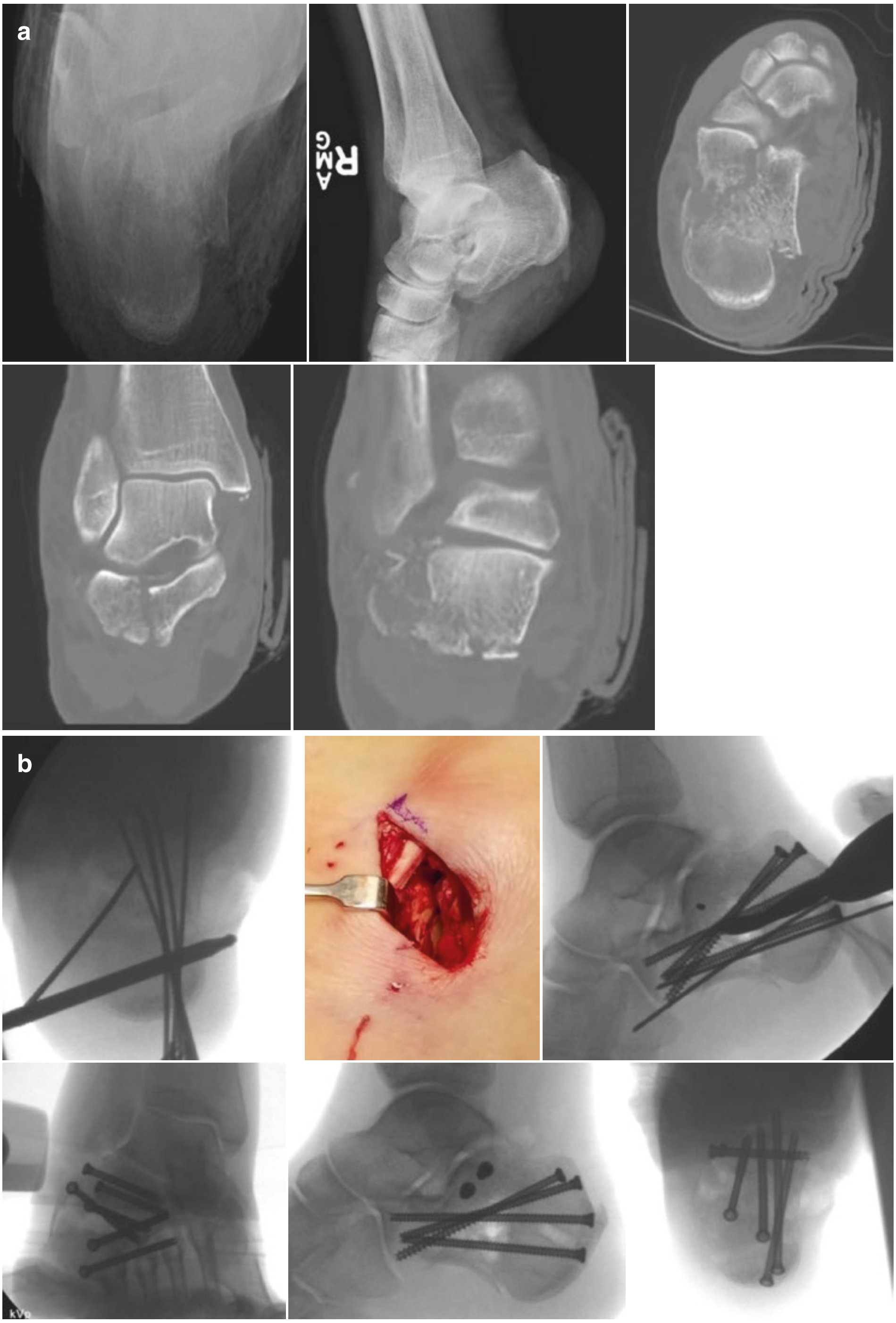


Fig. 16.4 (**a**) This case demonstrates the use of common percutaneous techniques in an elderly patient with a low energy fracture. A 69-year-old female fell from a footbridge into a creek with a 1 cm open medial wound and Sanders IIA intra-articular fracture. (**b**) The primary fracture line was reduced through the medial open fracture wound with use of a tuberosity Schanz pin joystick and a periosteal elevator shoehorn. Reduction is held with longitudinal k-wires and a small sinus tarsi incision is used to reduce the depressed lateral posterior facet and held with a k-wire. The facet is compressed with a lag screw followed by a second fully threaded screw. The tuberosity is compressed to the anterior process with a partially threaded lag screw followed by fully threaded screws to act as struts to complete the fixation. Note screw position based on CT fracture pattern

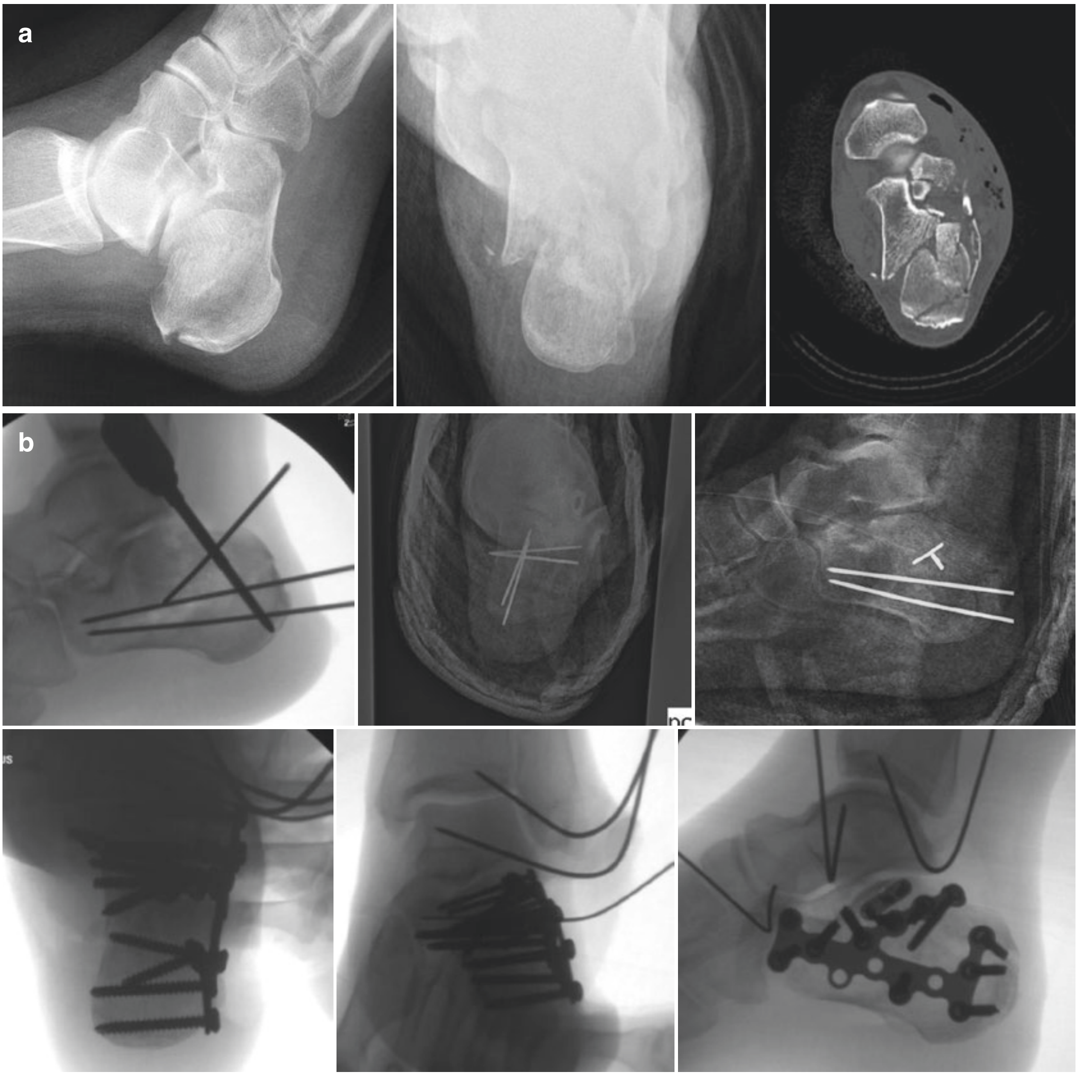


Fig. 16.5 (**a**) This demonstrates the use of provisional percutaneous techniques in an open Sanders IIB fracture to facilitate a later definitive fixation procedure through an extensile approach. Thirty-year-old female in a skateboarding accident with an 8 cm plantar open wound. (**b**) In this 30-year-old healthy patient with anterior process comminution, an anatomic reduction through an open extensile approach was felt to be the best treatment option with acceptable risks. However, percutaneous reduction and fixation techniques were used at the index surgery through the open wound to anatomically reduce the primary fracture line and hold this with Kirschner wires cut under the skin, allowing for a much easier definitive fixation procedure 2 weeks later

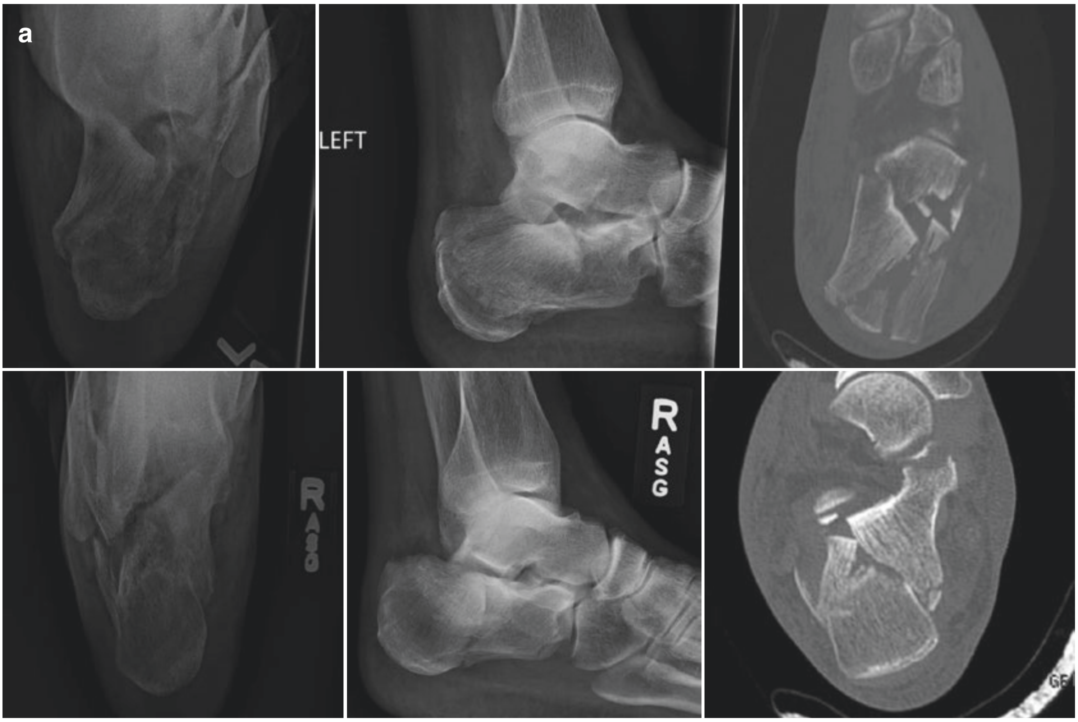


Fig. 16.6 (**a**) This case demonstrates use of minimally invasive techniques in a high-risk patient with bilateral closed injuries. A 60 year-male laborer who is a heavy smoker fell from a ladder sustaining bilateral closed intra-articular joint depression fractures, Sanders IIIAC on the left and IIB on the right with anterior process comminution bilaterally. (**b**) Bilateral fractures treated on postinjury day #3, prone positioning to allow both fractures to be addressed in one setting without repositioning. The left calcaneus is shown in the first three images and the right on the following five. A very similar reduction sequence and fixation pattern was used on both sides. Tuberosity Schanz pins were used in tuberosities as joysticks and a small incision was made medially with blunt dissection onto the sustentaculum to allow use of a clamp as shown in (**b**) above. Sinus tarsi incisions were used for the posterior facet reduction. Note the use of lag screws across the posterior facet and partially threaded screws from the tuberosity down into the anterior process and into the sustentaculum for compression followed by fully threaded positional strut screws. (**c**) His fractures have healed at 7 months postoperatively but he has subtalar degenerative changes on the right. With improved hindfoot alignment from his percutaneous fracture procedure, he is in a position to do well from a straightforward subtalar fusion without osteotomy if his symptoms require

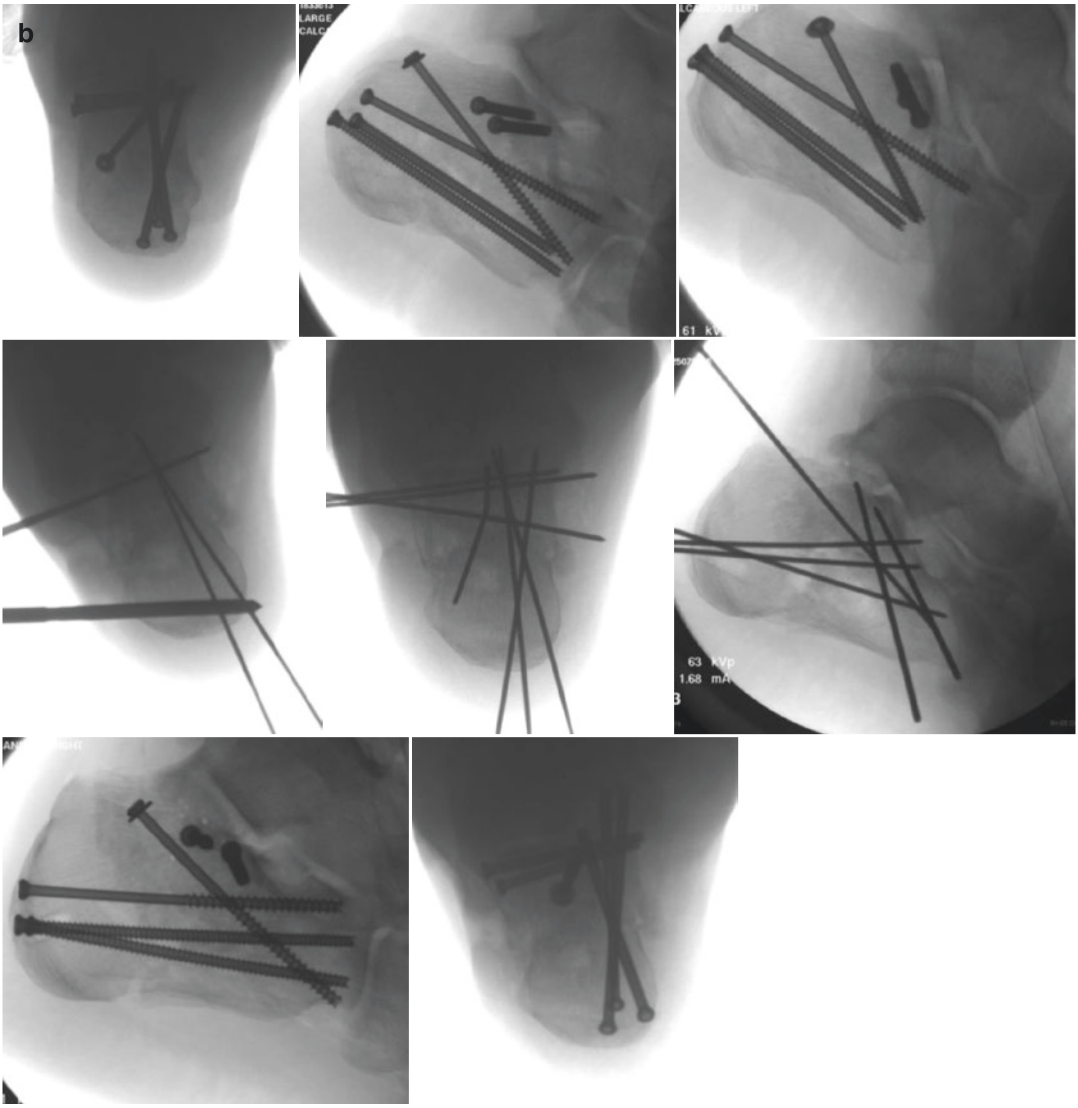


Fig. 16.6 (continued)

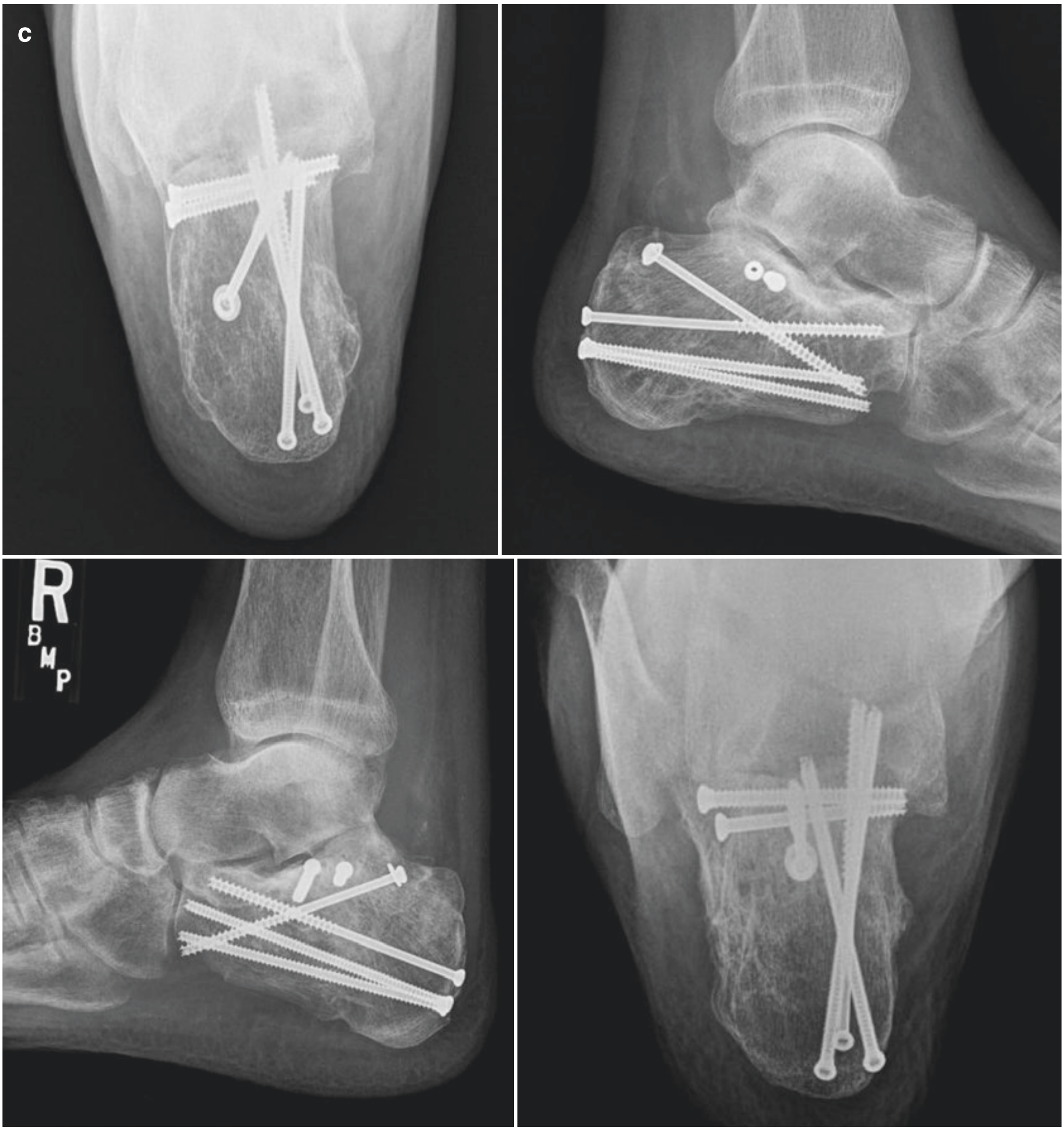


Fig. 16.6 (continued)

Sinus Tarsi Approach

The sinus tarsi approach is frequently used with the percutaneous reduction and cannulated screw technique above (Figs. 16.2c, 16.4b, 16.8c, j). It will also be used for percutaneous plate application discussed later in this chapter. An incision is made from the tip of the lateral malleolus toward the base of the fourth metatarsal, parallel to the plantar foot. This incision is 3–5 cm in length depending on the visualization and access required. The peroneus longus and brevis tendons are retracted plantar and the peroneus tertius is retracted dorsally. The sinus tarsi fat pad is incised and retracted plantar or dorsal. The extensor digitorum brevis can be retracted dorsally or split in line with its fibers or released from its origin under the fat pad and retracted distally, depending on the visualization required. The calcaneofibular ligament is released if needed to improve inversion and joint visualization. The subtalar joint is then irrigated and cleaned of soft tissue with a dental pick, #15 blade or beaver blade scalpel, and pituitary rongeur. This can include excision of the interosseous ligament for visualization all the way to the sustentaculum if there are more medial fracture lines. The intra-articular posterior facet fragments are then elevated and manipulated to achieve an anatomic joint reduction. Small bone hooks, periosteal elevators, and k-wire joysticks are useful to achieve the reduction. Compression can then be applied across the joint with the elevator or a shoulder hook with the reduction held with subchondral Kirschner wires. Use of a lamina spreader anterior to the angle of Gissane can be useful to improve the visualization of the posterior facet. Headlamp visualization is extremely helpful. The Schanz pin in the tuber can also be used to apply traction and improve visualization. Visualization and reduction of displaced anterior process fracture lines is difficult to achieve with a sinus tarsi approach and if it is felt that an anatomic reduction of the anterior process is required, the surgeon should consider a lateral extensile approach or accept that an anatomic reduction of the anterior process fracture lines may not be achieved, accepting restoration of hindfoot alignment with reduction of the primary and posterior facet fracture lines only in exchange for the improved soft-tissue complication rates discussed above.

Percutaneous Technique of Avulsion and Intra-articular Tongue Type Fractures (Fig. 16.7)

These fractures should be carefully assessed for posterior soft-tissue compromise and often need to be addressed on semiemergent basis. If there is no skin tenting or posterior soft-tissue compromise, these fractures do not require emergent treatment but still should be addressed within 3 days or so to maximize the potential of achieving a percutaneous anatomic reduction. Preparation and positioning are as noted above with more consideration for a prone approach to allow for easier percutaneous screw placement medial to the Achilles if desired. A preoperative CT is useful to have a clear understanding of the primary fracture plane and ensure no relevant comminution or additional fracture lines are present. Two large Weber type pointed reduction clamps are generally used to achieve the reduction each with a tine placed through a small incision just superior to the anticipated superior border of the tuber and another just plantar to the tuber. If the fracture is significantly displaced superiorly, blunt dissection with a tonsil hemostat to the superior border of the fracture should be performed followed by use of a shoulder hook or bone hook with one of the Weber clamps to walk the fracture caudally into position. Knee flexion and ankle/forefoot plantarflexion are mandatory during the reduction maneuvers. Joysticks, such as 3.2 mm Steinmann pins, 2.5 mm terminally threaded pins, or 5 mm Schanz pins, can be very useful to obtain a preliminary reduction which can then be fine-tuned and compressed with the bone hooks and clamps. The classic Essex-Lopresti maneuver is performed with one of these large diameter joysticks placed into the tongue fragment to allow for reduction of the tuberosity and posterior facet with traction on the pin with the ankle and forefoot plantarflexed. After the fracture is reduced anatomically and compressed with large pointed reduction clamps, Kirschner wire guidewires are placed from the superior border of the fracture anterior to the Achilles. There should be good spread of the wires and we recommend at least two wires parallel to each other and perpendicular to the fracture site to use as lag screws. Alternatively, two solid lag screws can be placed in the same fashion. These screws are applied through small incisions proximal and lateral or medial to the Achilles. Blunt dissection with a tonsil hemostat should be performed on the lateral side to minimize risk of injury to the sural nerve. A third or fourth positional screw, cannulated or solid, can be placed parallel to the other two screws or divergently to enhance pull-out resistance. Screws are typically 3.5 mm or 4.0 mm screws and a low threshold should be employed to use washers if there is any concern about bone quality to enhance compression of the screws and avoid intrusion of the screw head into the bone.

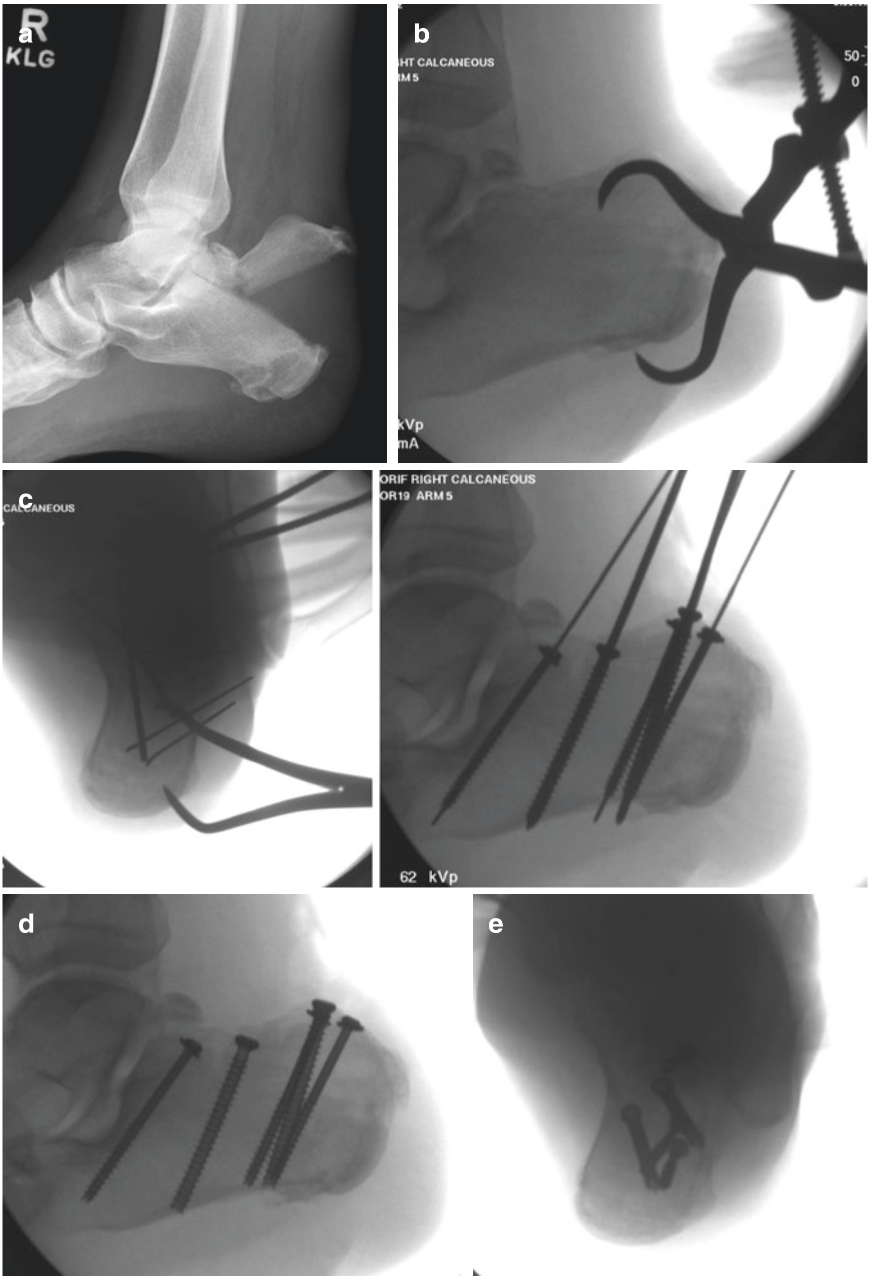


Fig. 16.7 (**a**) A 33-year-old male fell fly fishing, sustaining an avulsive tongue type fracture with minimally displaced posterior facet articular extension. (**b**) The patient is positioned prone on chest rolls with a gel pad under the knees, a pillow under the nonoperative leg, and the operative leg on small intramedullary nailing triangle. This allows access to the medial and lateral side of the Achilles. A large pointed reduction clamp is placed through small percutaneous plantar and dorsolateral incisions. Blunt dissection to the bone through lateral incisions is important to minimize risk to the sural nerve. Steinmann pin joysticks into the displaced tuberosity fragment are also frequently helpful. (**c**) Axial heel view after provisional fixation with Kirschner wire guidepins for cannulated screws ensures safe and appropriately spaced hardware. Lateral view shows compression of the fracture site with lag screws by design (3.5 mm partially threaded) and technique (4.5 mm with overdrilling of near cortex). Washers are used with the 3.5 mm screws but not the 4.5 mm, this is surgeon preference. The number and position of the screws will vary depending on the fracture morphology and bone quality. (**d**, **e**) Final lateral and axial images show anatomic reduction and safe hardware position

Minimally Invasive Reduction and Plating with a Sinus Tarsi Approach (Figs. 16.8 and 16.9)

The rationale behind the limited incision sinus tarsi approach is to minimize soft-tissue dissection while still allowing fracture reduction and stabilization. A small 2- to 4-cm sinus tarsi incision permits direct visualization of the posterior facet fragment for reduction, as well as the anterolateral fragment and the lateral wall. This approach allows for the insertion of a small, low-profile plate if needed and decreases dissection and elevation of the peroneal tendons, thus theoretically lowering the risk of tendon irritation and subluxation. Because the sural nerve is largely avoided, the risk

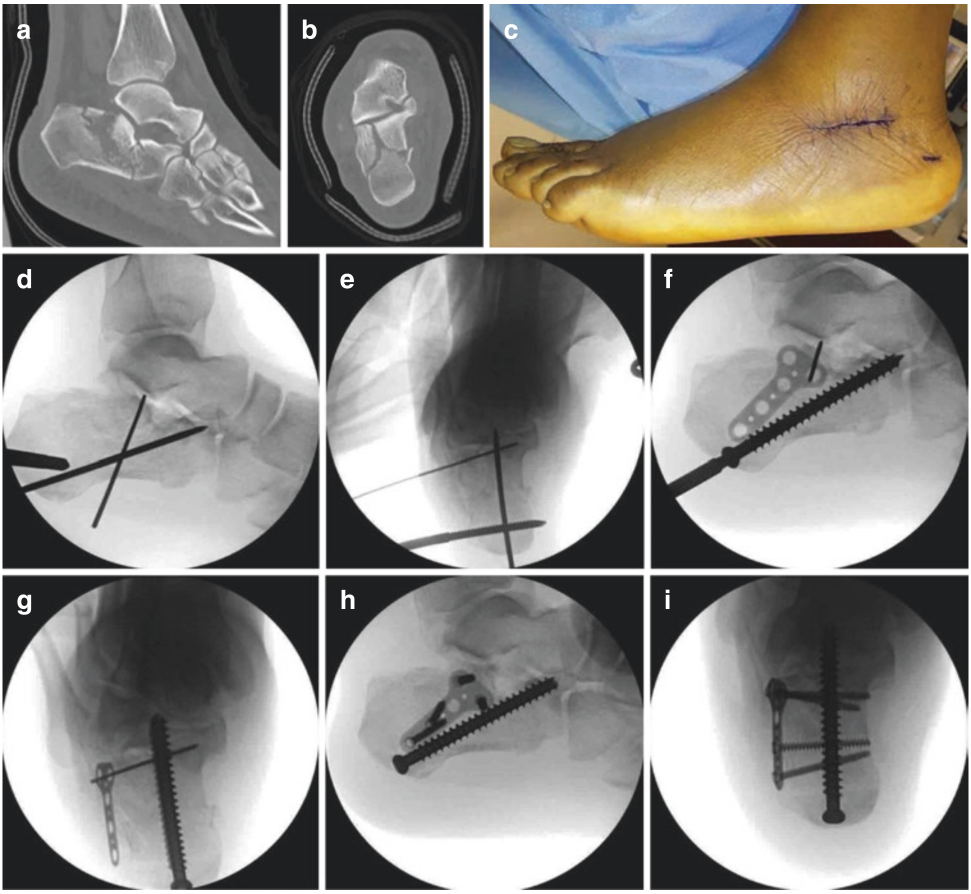


Fig. 16.8 Preoperative (**a**) sagittal and (**b**) coronal CT images of the left calcaneus in a 33-year-old male laborer with a Sanders IIB displaced intra-articular calcaneus fracture after a fall from a 10 ft ladder. (**c**) Clinical photograph demonstrating planned incisions for the sinus tarsi approach and Schanz pin insertion into the posteroinferior aspect of the calcaneal tuberosity. Intraoperative (**d**) lateral and (**e**) axial radiographs of the heel demonstrating provisional fixation of the posterior facet fragment into the sustentaculum with a 1.6-mm Kirschner wire after reduction along with guidewire placement for a large cannulated screw from the posterior tuberosity into the anterior aspect of the calcaneus. (**f**) Lateral and (**g**) axial radiographs of the heel demonstrating insertion of a large fully threaded 7.3-mm cannulated screw and provisional placement of a five-hole T-shaped low-profile calcaneus plate (Acumed, Hillsboro, OR). (**h**) Lateral and (**i**) axial radiographs of the heel demonstrating the final fracture fixation construct with four screws placed through the plate into the tuberosity and sustentacular fragments. The most posterior and inferior screw is placed through the Schanz pin stab incision previously used. (**j**) Clinical photograph of the posterior facet fragment reduction with the final plate and screws in place. (**k**) Postoperative sagittal CT cut at 6-week follow-up demonstrating maintenance of the Böhler angle and calcaneal height. (**l**) Lateral and (**m**) axial radiographs of the heel 3 months after surgery demonstrating fracture union

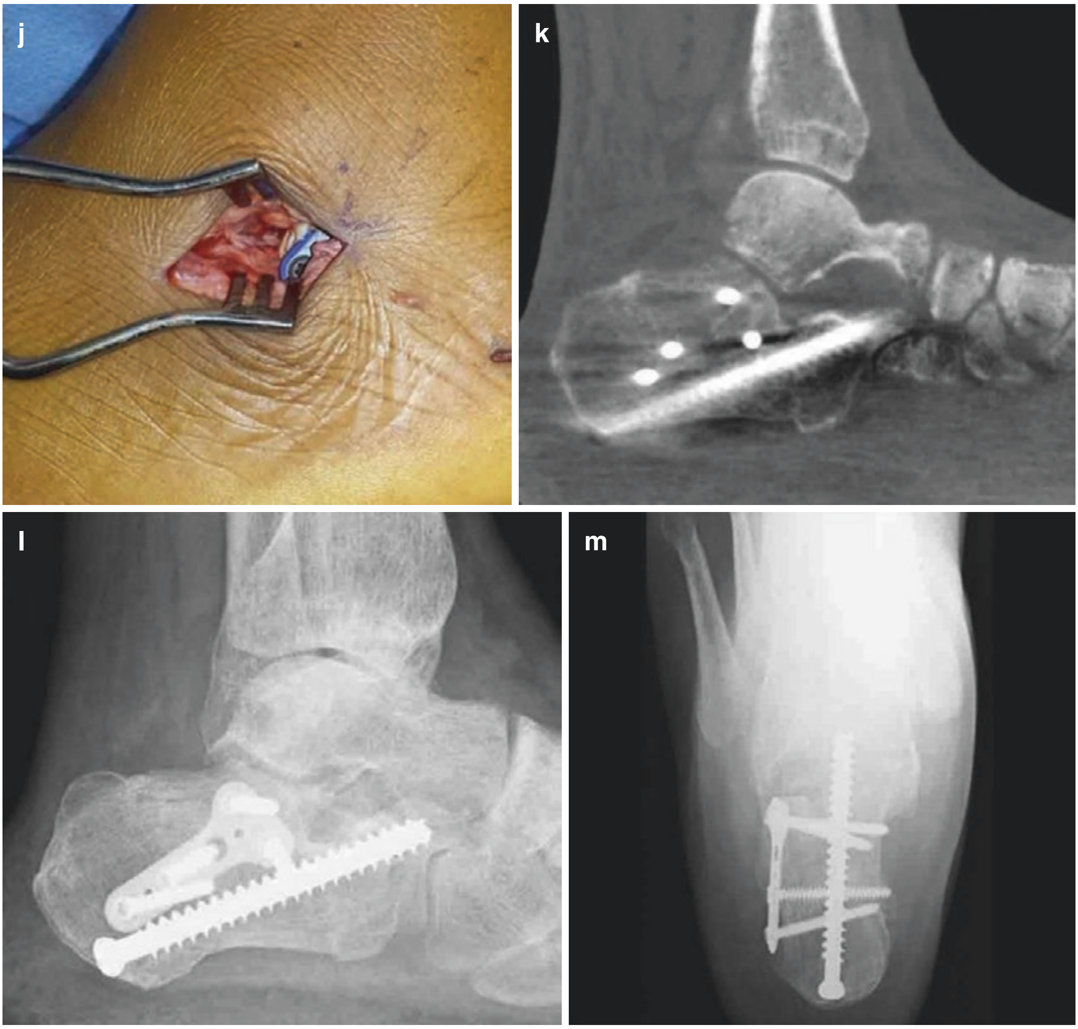


Fig. 16.8 (continued)

of postoperative neuralgia or neuroma formation is minimized. The sinus tarsi incision is an extensile and utilitarian incision that can be used acutely to visualize and treat dislocated peroneal tendons; conversely, the incision can later be used should subtalar arthrodesis or tendon débridement be required. In addition, the sinus tarsi incision may be modified and be of variable length depending on the characteristics of the fracture, as well as the comfort and anticipated learning curve of the surgeon. As such, this incision offers the advantages of being considered less invasive in some cases and minimally invasive in others, with the overall goal of reducing surgical trauma to the patient.

During surgical preparation, patients are placed in the lateral decubitus position using a beanbag or alternative positioner with a thigh tourniquet as outlined above. A Schanz pin is placed through a stab incision in the posteroinferior calcaneal tuberosity from lateral to medial to allow for distraction and reduction through control of the tuberosity. Alternatively, a transcalcaneal pin with a traction bow attached can be utilized. A 2- to 4-cm incision is made over the sinus tarsi along a line from the tip of the fibula to the base of the fourth metatarsal and exposure proceeds as described in detail above. After removing any fibrous debris and fat from the sinus tarsi, the lateral wall and posterior facet fragment are mobilized using a knife or small elevator. Care is taken to avoid significant dissection of the peroneal tendons that are retracted posteriorly as needed. A small elevator or lamina spreader is placed under the depressed facet fragment and the articular surface is reduced as discussed above. Kirschner wires are inserted through the fragment directed toward the sustentaculum to provisionally hold the fragment after it is reduced. Calcaneal alignment and length are restored, along with correction of the varus angulation using the Schanz pin under manual control with fluoroscopic guidance. Additional Kirschner wires are placed as need to hold the tuberosity reduction to the sustentaculum and anterior process.

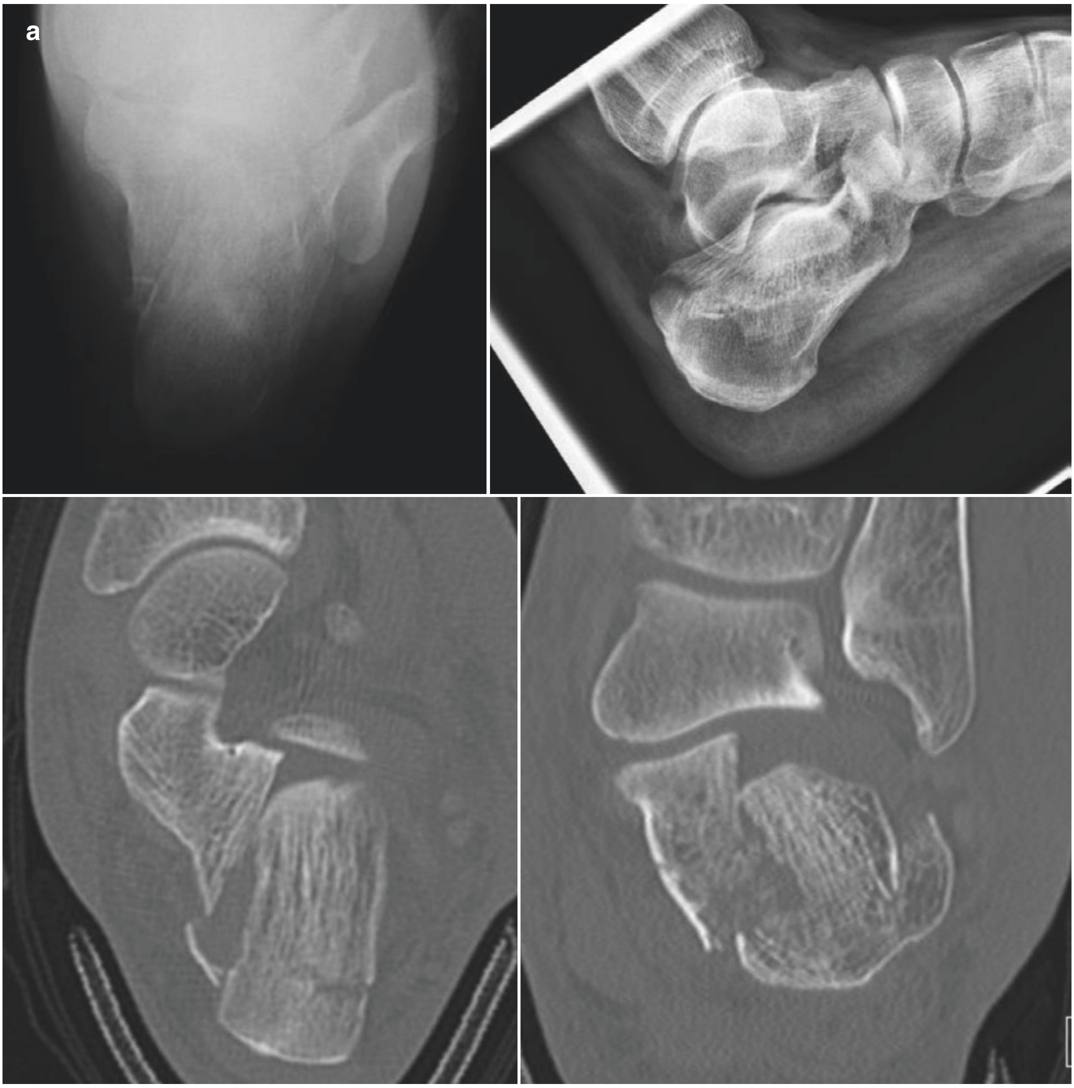


Fig. 16.9 (**a**) A 43 year-old male in motor vehicle collision with a Sanders IIB displaced intra-articular (**b**) A sinus tarsi approach was utilized to reduce the fracture and the posterior facet articular reduction was stabilized provisionally with k-wires followed by an independent lag screw. Using a Schanz pin for distraction, the axial length was restored and stabilized with a guidewire followed by a fully threaded cannulated screw. An anatomic calcaneal plate (Acumed, Hillsboro, OR) was inserted through the sinus tarsi incision with fixation into the tuberosity, sustentaculum, and anterior process to hold these anatomic relationships. The screws in the tuberosity portion of the plate were inserted percutaneously through the incision made for the Schanz pin

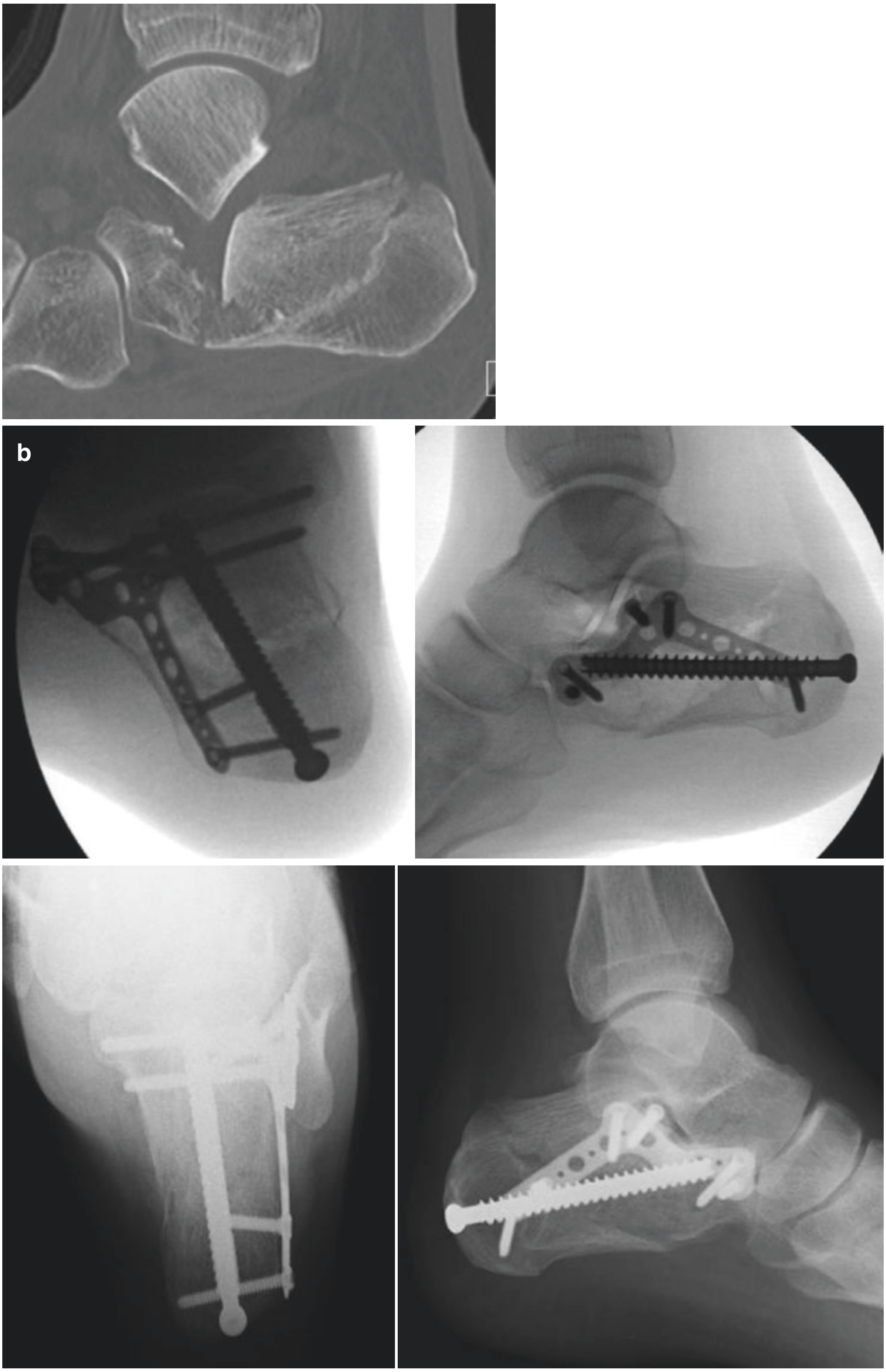


Fig. 16.9 (continued)

Using fluoroscopy to check alignment and length, two guide pins from a large cannulated screw set are placed from the calcaneal tuberosity into the anterior process of the calcaneus. The fracture fixation construct may be tailored to the individual fracture pattern. In general, one or two lag screws are used from lateral to medial to hold the posterior facet reduction to the sustentaculum; in addition, one or more large cannulated screws are inserted percutaneously, running from posterior to anterior. For plate insertion, a small full-thickness envelope of soft tissue is created using an elevator from the posterior facet and directed toward the posterior calcaneal tuberosity and anterolateral fragment (depending on the plate selected). A low-profile calcaneal plate may be inserted through the envelope and positioned in place with the most posteroinferior hole in line with the incision used for the Schanz pin. Plate fixation allows for stabilization of calcaneus height, length, and alignment with three to four screws inserted into the tuberosity fragment and across the posterior facet fracture into the sustentacular fragment. Other plate designs allow fixation into the anterior process and fracture lines extending into the calcaneocuboid joint. Alternatively, a longitudinal posterolateral incision over the tuberosity has been described with subperiosteal dissection to allow percutaneous plate application [60, 62, 66]. At this time we favor the sinus tarsi approach as a single incision can be used for the articular reduction and plate application. The incision is closed in a layered fashion, and patients are placed in a posterior sugartong plaster splint.

Postoperative Treatment

Patients are placed into a bulky Jones-type postoperative dressing and splinted or placed in a tall cam boot. Wound check and suture removal are performed at approximately 2 weeks postoperatively. Postoperative chemical thromboembolic prophylaxis is not used after hospital discharge unless there are other associated injuries or risk factors such as a history of thromboembolic disease or hypercoagulability. Motion is started after the 2 week, office visit including aggressive dorsiflexion stretching and subtalar motion. Organized physical therapy is used initially if the surgeon feels the patient will have difficulty performing a self-directed home program for motion; otherwise, it begins at 8 weeks when progressive weightbearing as tolerated is initiated. After achieving full weightbearing in a boot, patients are transitioned back into regular shoes. Orthotics are not routinely required unless there are other foot conditions present, such as a cavovarus or planovalgus foot.

References

1. Catani F, Benedetti MG, Simoncini L. Analysis of function after intra-articular fracture fo the os calcis. Foot Ankle Int. 1999;20(7):417–21.
2. Crosby LA, Fitzgibbons TC. Open reduction and internal fixation of type II intra-articular calcaneus fractures. Foot Ankle Int. 1996;17(5):253–8.
3. Kundel K, Funk E, Brutscher M, et al. Calcaneal fractures: operative versus nonoperative treatment. J Trauma. 1996;41(5):839–45.
4. Leung KS, Yuen KM, Chan WS. Operative treatment of displaced intra-articular fractures of the calcaneum. Medium-term results. J Bone Joint Surg Br. 1993;75(2):196–201.
5. O'Farrell DA, O'Byrne JM, McCabe JP, et al. Fractures of the os calcis: improved results with internal fixation. Injury. 1993;24(4):263–5.
6. Parmar HV, Triffitt PD, Gregg PJ. Intra-articular fractures of the calcaneum treated operatively of conservatively. A prospective study. J Bone Joint Surg Br. 1993;75(6):932–7.
7. De Boer AS, Van Lieshout EM, Den Hartog D, et al. Functional outcome and patient satisfaction after displaced intra-articular calcaneal fractures: a comparison among open, percutaneous, and nonoperative treatment. J Foot Ankle Surg. 2015;54(3):298–305.
8. Agren PH, Wretenberg P, Sayed-Noor AS. Operative versus nonoperative treatment of displaced intra-articular calcaneal fractures: a prospective, randomized, controlled multicenter trial. J Bone Joint Surg Am. 2013;95(15):1351–7.
9. Buckley R, Tough S, McCormack R, et al. Operative compared with nonoperative treatment of displaced intra-articular calcaneal fractures: a prospective, randomized, controlled, multicenter trial. J Bone Joint Surg Am. 2002;84(10):1733–44.
10. Gougoulias N, Khanna A, McBride DJ, et al. Management of calcaneal fractures: systematic review of randomized trials. Br Med Bull. 2009;92:153–67.

11. Böhler L. Diagnosis, pathology, and treatment of fractures of the os calcis. J Bone Joint Surg Am. 1931;13(1):75–89.
12. Palmer I. The mechanism and treatment of fractures of the calcaneus. J Bone Joint Surg Am. 1948;30(1):2–8.
13. Essex-Lopresti P. The mechanism, reduction technique and results in fractures of the oscalcis. Br J Surg. 1952;39:395–419.
14. Letournel E. Open reduction and internal fixation of calcaneal fractures. In: Spiegal P, editor. Topics in orthopaedic surgery. 1st ed. Baltimore: Aspen Publishers; 1984. p. 173–92.
15. Letournel E. Open treatment of acute calcaneal fractures. Clin Orthop Relat Res. 1993;290:60–7.
16. Benirschke SK, Sangeorzan BJ. Extensive intraarticular fractures of the foot: surgical management of calcaneal fractures. Clin Orthop Relat Res. 1993;292:128–34.
17. Folk JW, Starr AJ, Early JS. Early wound complications of operative treatment of calcaneus fractures: analysis of 190 fractures. J Orthop Trauma. 1999;13(5):369–72.
18. Sanders R, Vaupel Z, Erdogan M, et al. The operative treatment of displaced intra-articular calcaneal fractures (DIACFs): long term (10–20 years) results in 108 fractures using a prognostic CT classification. J Orthop Trauma. 2014;28(10):551–63.
19. Zwipp H, Rammelt S, Amlang M, et al. Operative treatment of displaced intra-articular calcaneal fractures. Oper Orthop Traumatol. 2013;25(6):554–68.
20. Kline AJ, Anderson RB, Davis WH, et al. Minimally invasive technique versus an extensile lateral approach for intra-articular calcaneal fractures. Foot Ankle Int. 2013;3(6):773–80.
21. Backes M, Schep NW, Luitse JS, et al. The effect of postoperative wound infections on functional outcome following intra-articular calcaneal fractures. Arch Orthop Trauma Surg. 2015;135(8):1045–52.
22. Nosewicz T, Knupp M, Barg A, et al. Mini-open sinus tarsi approach with percutaneous screw fixation of displaced calcaneal fractures: a prospective computed tomography-based study. Foot Ankle Int. 2012;33(11):925–33.
23. Van Hoeve S, de Vos J, Verbruggen JP, et al. Gait analysis and functional outcome after calcaneal fracture. J Bone Joint Surg Am. 2015;97(22):1879–88.
24. Sanders R, Fortin P, DiPasquale T. Operative treatment of 120 displaced intraarticular calcaneal fractures: results using a prognostic computed tomography scan classification. Clin Orthop Relat Res. 1993;290:87–95.
25. Clark LG. Fracture of the os calcis. Lancet. 1855;65(1651):403–4.
26. Schepers T, Patka P. Treatment of displaced intra-articular calcaneal fractures by ligamentotaxis: current concepts' review. Arch Orthop Trauma Surg. 2009;129:1677–83.
27. Cotton FJW, Louis T. Fractures of the os calcis. Boston Med Surg J. 1908;159:559–65.
28. McBride E. Fractures of the os calcis; tripod-pin-traction apparatus. J Bone Joint Surg. 1944;26(3):578–9.
29. MacAusland W. The treatment of comminuted fractures of the os calcis. Surg Gynec Obst. 1941;73:671–5.
30. Goff C. Fresh fractures of the os calcis. Arch Surg. 1938;36:744–65.
31. Carraba V. Apparatus for treatment of fractured os calcis. Am J Surg. 1936;33(1):53–9.
32. Bohler L. New light on the treatment of calcaneal fractures. Langenbecks Arch Klin Chir Ver Dtsch Z Chir. 1957;287:698–702. McBride, Gill, and Harris described triangular distraction techniques in the mid-1940s which were later modified by Forgon and Zadravecz in 1983 and are still commonly used today (Schepers, deVroome, Tomesen etc).
33. Gill GG. A three pin method for treatment of severely comminuted fractures of the os calcis. Surg Gynec and Obstet. 1944;78:653–6.
34. Harris RI. Fractures of the os calcis; their treatment by triradiate traction and subastragalar fusion. Ann Surg. 1946;124:1082–100.
35. Forgon M, Zadravecz G. Repositioning and retention problems of calcaneus fractures. Aktuelle Traumatol. 1983;13(6):239–46.
36. Schepers T, Schipper IB, Vogels LM, et al. Percutaneous treatment of displaced intra-articular calcaneal fractures. J Orthop Sci. 2007;12(1):22–7.
37. Tomesen T, Biert J, Frolke JP. Treatment of displaced intra-articular calcaneal fractures with closed reduction and percutaneous screw fixation. J Bone Joint Surg Am. 2011;93(10):920–8.
38. deVroome SW, van der Linden FM. Cohort study on the percutaneous treatment of displaced intra-articular fractures of the calcaneus. Foot Ankle Int. 2014;35(2):156–62.
39. Westheus H. Eine neue behandlungsmethode der calcaneusfrakturen. Arch Orthop Unfallchir. 1934;35:121.
40. Gissane W. News notes: proceedings of the British orthopedic association. J Bone Joint Surg Br. 1947;29:254–5.
41. Essex-Lopresti P. The mechanism, reduction technique, and results in fractures of the os calcis. Br J Surg. 1952;39(157):395–419.
42. Tornetta P. Percutaneous treatment of calcaneal fractures. Clin Orthop Relat Res. 2000;375:91–6.
43. Pillai A, Basappa P, Ehrendorfer S. Modified Essex-Lopresti/Westhues reduction for displaced intra-articular fractures of the calcaneus. Description of surgical technique and early outcomes. Acta Orthop Belg. 2007;73:83–7.
44. Battaglia A, Catania P, Gumina S, et al. Early minimally invasive percutaneous fixation of displaced intra-articular calcaneal fractures with a percutaneous angle stable device. J Foot Ankle Surg. 2015;54(1):51–6.
45. Tornetta P 3rd. The Essex-Lopresti reduction for calcaneal fractures revisited. J Orthop Trauma. 1998;12(7):469–73.

46. Walde TA, Sauer B, Degreif J, et al. Closed reduction and percutaneous kirschner wire fixation for the treatment of dislocated calcaneal fractures: surgical technique, complications, clinical and radiological results after 2–10 years. Arch Orthop Trauma Surg. 2008;128(6):585–91.
47. Levine DS, Helfet DL. An introduction to the minimally invasive osteosynthesis of intra-articular calcaneal fractures. Injury. 2001;32(suppl 1):SA51–4.
48. Carr JB. Surgical treatment of intra-articular calcaneal fractures: a review of small incision approaches. J Orthop Trauma. 2005;19(2):109–17.
49. Magnan B, Bortolazzi R, Marangon A, et al. External fixation for displaced intra-articular fractures of the calcaneum. J Bone Joint Surg Br. 2006;88(11):1474–9.
50. Abdelgaid SM. Foot ankle Surg. Closed reduction and percutaneous cannulated screws fixation of displaced intra-articular calcaneus fractures. Foot Ankle Surg. 2012;18(3):164–79.
51. Arastu M, Sheehan B, Buckley R. Minimally invasive reduction and fixation of displaced calcaneal fractures: surgical technique and radiographic analysis. Int Orthop. 2014;38(3):539–45.
52. Rammelt S, Amlang M, Barthel S, et al. Percutaneous treatment of less severe intra-articular calcaneal fractures. Clin Orthop Relat Res. 2010;468(4):983–90.
53. DeWall M, Henderson CE, McKinley TO, et al. Percutaneous reduction and fixation of displaced intra-articular calcaneus fractures. J Orthop Trauma. 2010;24(8):466–72.
54. Weber M, Lehmann O, Sagesser D, et al. Limited open reduction and internal fixation of displaced intra-articular fractures of the calcaneum. J Bone Joint Surg Br. 2008;90(12):1608–16.
55. Basile A, Albo F, Via AG. Comparison between sinus tarsi approach and extensile lateral approach for treatment of closed displaced intra-articular calcaneal fractures: a multicenter prospective study. J Foot Ankle Surg. 2016;55(3):513–21.
56. Wallin KJ, Cozzetto D, Russell L, et al. Evidence-based rationale for percutaneous fixation technique of displaced intra-articular calcaneal fractures: a systemic review of clinical outcomes. J Foot Ankle Surg. 2014;53(6):740–3.
57. Chen L, Zhang G, Hong J, et al. Comparison of percutaneous screw fixation and calcium sulfate cement grafting versus open treatment of displaced intra-articular calcaneal fractures. Foot Ankle Int. 2011;32(10):979–85.
58. Kumar V, Marimuthu K, Subramani S, et al. Prospective randomized trial comparing open reduction and internal fixation with minimally invasive reduction and percutaneous fixation in managing displaced intra-articular calcaneal fractures. Int Orthop. 2014;38(12):2505–12.
59. Xia S, Lu Y, Wang H, et al. Open reduction and internal fixation with conventional plate via L-shaped lateral approach versus internal fixation with percutaneous plate via a sinus tarsi approach for calcaneal fractures – a randomized controlled trial. Int J Surg. 2014;12(5):475–80.
60. Cao L, Weng W, Song S, et al. Surgical treatment of calcaneal fractures of Sanders type II and III by a minimally invasive technique using a locking plate. J Foot Ankle Surg. 2015;54(1):76–81.
61. Wu Z, Su Y, Chen W, et al. Functional outcome of displaced intra-articular calcaneal fractures: a comparison between open reduction/internal fixation and a minimally invasive approach featured an anatomical plate and compression bolts. J Trauma Acute Care Surg. 2012;73(3):743–51.
62. Zhang T, Su Y, Chen W, et al. Displaced intra-articular calcaneal fractures treated in a minimally invasive fashion: longitudinal approach versus sinus tarsi approach. J Bone Joint Surg Am. 2014;96(4):302–9.
63. Haugsdal J, Dawson J, Phisitkul P. Nerve injury and pain after operative repair of calcaneal fractures: a literature review. Iowa Orthop J. 2013;33:202–7.
64. Beltran MJ, Collinge CA. Outcomes of high-grade open calcaneus fractures managed with open reduction via the medial wound and percutaneous screw fixation. J Orthop Trauma. 2012;26(11):662–70.
65. Hammond AW, Crist BD. Percutaneous treatment of high-risk patients with intra-articular calcaneus fractures: a case series. Injury. 2013;44(11):1483–5.
66. Wang Q, Chen W, Su Y, et al. Minimally invasive treatment of calcaneal fractures by percutaneous leverage, anatomical plate, and compression bolts—the clinical evaluation of cohort of 156 patients. J Trauma. 2010;69(6):1515–22.

17

Open Calcaneus Fractures

Luke A. Lopas, Matthew M. Counihan,
and Derek J. Donegan

Introduction

Calcaneus fractures are a relatively common injury, making up approximately 1% of all fractures [1]. Management of closed calcaneus fractures requires knowledge of the osseous anatomy, careful decision-making, and meticulous surgical technique [2]. However, open calcaneus fractures are considerably more rare, representing anywhere from less than 5% [3, 4] to 11% [5] of overall calcaneal fractures. Within the subcategory of open calcaneus fractures, there is a wide range in severity of injury with a multitude of both osseous and soft tissue considerations and a correspondingly large number of treatment options. These injuries represent a rare and challenging problem for the treating orthopedic surgeon as well as a potentially limb altering and/or threatening injury for the patient. As with any open fracture, there is increased risk of infection, wound healing problems, and possibility for soft tissue coverage needs in complement to fracture management. Open calcaneus fractures impart significant cost to both the individual and society in the form of lost wages, decreased productivity, short and possible long-term disability, and often prolonged treatment courses.

Spierings has recently reported a systematic review of open calcaneus fractures including 616 injuries in 598 patients that represents the most comprehensive evaluation of the open calcaneus literature and serves as good introductory material [6]. In their data, the mean age was 40.8 years, and 65.6% were male. 18.8% of injuries were Gustilo-Anderson [7, 8] (GA) type I, 31.1% GA type II, and 50.1% GA type III. In the strong majority of these injuries, 76.7%, the wound is medial. A lateral wound is a distant second at 8.5%, with the remaining wounds described in a variety of ways and locations. The most common classification system used was the Sanders classification in 250 of these injuries. Sanders type III and IV injuries were the most common, representing 54.8 and 39.6%, respectively. The median time from initial injury to definitive fixation in their data set was 9.8 days. A wide variety of treatment protocols were described with inconsistent levels of detail; however, treatment with ORIF via an extensile lateral approach was the most common definitive treatment method.

In this chapter, we will cover the initial assessment and evaluation of open calcaneus fractures, highlighting key findings that may alter treatment strategies, and discuss the various treatment considerations including both the surgical and nonsurgical aspects. Following this, we will discuss the known (and expected) complications as well

---

L. A. Lopas · M. M. Counihan · D. J. Donegan (✉)
Department of Orthopaedic Surgery, University of Pennsylvania, Philadelphia, PA, USA
e-mail: llopas@floridaortho.com;
Matthew.Counihan@uphs.upenn.edu;
Derek.Donegan@uphs.upenn.edu

© Springer Nature Switzerland AG 2020
M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_17

as the long-term outcomes including infection, osteomyelitis, amputation, delayed salvage/reconstruction, and return to function. We have highlighted a surgical case to breakdown some of the challenging decision-making points as well as key techniques and pitfalls to avoid.

Mechanism of Injury and Associated Injuries

The mechanism of injury producing an open fracture of the calcaneus most often involves a high energy, axial-loading force. The most common mechanisms are motor vehicle collisions (MVCs) [9–14] and falls from height [5, 15, 16]. For studies in which MVC is the dominant mechanism of injury, there is also a preponderance of right-sided fractures over left-sided fractures. It is suggested this is potentially related to the increased risk of impaction of the right foot against the gas/brake pedals [10]. Other often-cited mechanisms of injury include crush injuries, motorcycle collisions, and automobile versus pedestrian injuries, as well as penetrating trauma, most commonly gunshot wounds.

Given the high-energy nature of the injuries causing an open calcaneus fracture, it is to be expected that associated injuries are extremely common and often highly morbid. Multiple series have found up to 91–95% of patients with an open calcaneus fracture present with at least one additional orthopedic injury [10, 14, 17]. The most common associated injuries include femur fractures, with the femoral shaft being the most frequent location and fractures at the femoral neck and intertrochanteric regions being less common. As is frequently noted in closed calcaneus fractures, spinal fractures have a significant association in open calcaneus fractures as well. Additional major sites of associated fractures include the talus, ipsilateral ankle, tibia, and midfoot. Other less commonly associated injuries include pelvic and acetabular fractures and hip dislocations. Up to a third of patients will have an associated upper extremity injury, with the majority found in the forearm as isolated radius, isolated ulna, or both bone forearm fractures. Additionally, 50–60% of these patients present with other nonorthopedic injuries which may include chest trauma (frequently pneumothorax), facial trauma, liver and splenic injuries, and other abdominal trauma. Treatment of the calcaneus injury must take into account the totality of the patient's injury burden to not add unnecessarily surgical and inflammatory insult to a patient who is not stable.

Physical Exam, Imaging Workup, and Anatomic Considerations

Initial physical examination of the patient with an open calcaneus fracture often necessitates a full trauma evaluation given the high-energy nature of these injuries. As stated previously, associated injuries are common and should be expected. As such, a high level of suspicion for additional injury must be maintained by the provider performing not only the initial exam but also close attention should be paid during the secondary and tertiary exams of the patient as well. An open calcaneal fracture can be a distracting injury, such that other closed injuries at the contralateral lower or upper extremities are at an increased risk of being missed on initial exam and not discovered until later in the hospitalization.

Examination of the affected limb requires a thorough evaluation as well as written and pictorial documentation of the location and quality of the open wound, surrounding soft tissue, exposed or extruded bone, and presence of foreign bodies. A thorough neurovascular exam is mandatory, as the rate of neurovascular injury in open calcaneal fractures has been described up to 23% [17]. Given the preponderance of the open wound to be on the medial side, the posterior tibial artery and tibial nerve are at particular risk [17].

All patients should undergo initial plain radiographic evaluation with lateral and axial views of the calcaneus as well as computed tomography scans of the affected limb. As is standard for all open fractures, patients should be treated with systemic antibiotics to be initiated as soon as possible in the emergency department in conjunction with tetanus prophylaxis. Initial debridement of gross and large debris may be undertaken during the initial evaluation in the emergency department as appropriate, along with application of sterile dressings such as betadine-soaked gauze, and provisional reduction and stabilization of the fracture with a plaster splint. A majority of patients with open calcaneal fractures can be expected to be poly-traumatized. As such, visceral and other life-threatening injuries may frequently take precedence over initial fracture care.

The majority of the traumatic wounds in open calcaneal fractures are on the medial side, with multiple studies finding 50% of patients or greater presenting with this wound pattern [5, 6, 18]. The medial wound occurs most commonly due to the sustentaculum tali rupturing through the skin while the hindfoot is being everted and axially loaded [5]. Two subtypes of the medial wound have been described – a tension laceration exposing underlying bone, or a stellate tear in which a portion of the calcaneus protrudes through the skin [12]. This subclassification is pertinent as the stellate type wounds tend to be associated with higher energy mechanisms and may take longer to heal [12], and thus a high index of suspicion should be maintained for short-term wound complications in this subtype of wounds.

It has been noted that the medially based wound in the open calcaneal fracture can be utilized as a portal for medial stabilization with screws, Kirschner wires, or plates [19]. The medial wound can be used during initial stabilization of the fracture, thereby minimizing damage to the remainder of the soft tissue envelope. In this way, the lateral soft tissue can be preserved for use at a later time after swelling has subsided and when definitive fracture fixation is pursued.

Other common open wound classifications include lateral, posterior, and complex. The laterally based wound has traditionally been considered a poor prognostic indicator for soft tissue complications [13]. It has been suggested that when confronted with a lateral wound, utilization of a tibiocalcaneus pin or subtalar screws during the initial fracture management can keep the hindfoot out of equinovarus, which may decrease the risk of necrosis of a lateral wound [5]. With reference to the Gustilo and Anderson classification, majority of the open calcaneus fractures described in literature are classified as Gustilo Type II and Type IIIA medial wounds [12].

Treatment

As with closed calcaneus injuries, there are a variety of available treatment modalities and techniques for open calcaneus fractures that can be called upon by the treating physician. This has lead to the combination of techniques yielding a new set of hybrid treatment options. Several authors have suggested thinking of treatment in several stages, proceeding with the acute treatment, and possible subsequent subacute and reconstructive phases [3, 4]. In accordance with the acute treatment of any open fractures, timely administration of antibiotics and tetanus prophylaxis is indicated [7, 8, 14]. Prompt administration of antibiotics has been shown to reduce the ultimate risk of infection for open fractures [20]. Operative debridement and irrigation of the wound should occur in an expeditious manner, depending on the nature of the soft tissue injury, but the previously quoted 6-h rule does not appear to apply for all injuries [21].

Despite being originally developed in the classification of open tibia fractures, the Gustilo and Anderson (GA) Classification [7, 8] is still the most widely used to describe these injuries and not only drives antibiotic duration, but as you will see imparts prognostic value as well. Once you have addressed the soft tissue injury and open nature of the fracture, your attention can return to treatment principles of calcaneus fractures. Despite being an open injury, limiting operative management to debridement and managing the fracture with immobilization may be the most appropriate method for some injuries.

Operative fixation of open calcaneus fractures introduces several new considerations. What is the appropriate timing of definitive fixation? Can, or more importantly, should the open wound be utilized for reduction and/or fixation? Does this depend on the location of the wound? Does the wound size and location provide meaningful prognostic information for ultimate treatment success? Does percutaneous fixation help avoid further wound complications?

The extensile lateral approach has been the workhorse approach for surgical fixation of calcaneus fractures [22, 23]; however, a variety of approaches including using the traumatic wound for reduction and/or fixation [19], the sinus tarsi approach, limited percutaneous fixation [13, 19], definitive external fixation [24], acute fusion, and amputation [25] have all been advocated. This decision-making has largely been driven the nature and quality of the soft tissue envelope. Numerous authors have clearly described the importance of the soft tissue injury in driving the outcomes of these injuries to a greater extent than the osseous injury [6, 11, 25]. The severity of the soft tissue injury (size and contamination) and importantly the location of the soft tissue injury impart important prognostic information, and in some cases may portend future amputation despite appropriate management [25, 26].

Mehta described a staged treatment strategy for GA type II or IIIA injuries with medial wounds [12]. In their series of 14 patients, all patients got appropriate IV antibiotics, tetanus prophylaxis, temporary splint immobilization followed by surgical irrigation and debridement when cleared for operative management. At the time of this initial debridement, closed or open reduction through the traumatic wound of the calcaneus was performed with Kirschner wire fixation to restore the global geometry of the calcaneus and allow for stabilization of the soft tissues. Definitive fixation was performed via the extensile lateral approach at an average of 18 days after injury. No patients developed infections at the side of the traumatic wound. One patient developed a superficial surgical site infection that was treated with oral antibiotics and dressing changes. One patient developed a deep infection ultimately requiring IV antibiotics and implant removal. All patients healed the fracture.

Beltran and Collinge describe an alternative approach of using the open medial wound for reduction with percutaneous fixation in patients with GA type II or III injuries [19]. In their series of 17 patients, all patients got appropriate antibiotics, and early surgical debridement with repeat debridement as needed until the soft tissues were considered clean and healthy. At this point, the medial wound was used for fracture manipulation and reduction, with a combination of k-wires and Schantz pins used as joysticks to achieve alignment. Definitive fixation was performed with free 3.5 mm screws and possible addition of calcium phosphate cement. One patient developed a wound dehiscence and one developed a deep infection, both of which required surgical debridement, local wound care, and antibiotic therapy. Seven of the 17 patients ultimately required a secondary surgical procedure. Thornton argues that medial wounds less than 4 cm in length can ultimately be treated with ORIF via a lateral approach. However, they caution that large (greater than 4 cm) or unstable wounds should be treated with percutaneous methods [13]. In Spierings' review, the most common definitive treatment was ORIF via an extensile lateral approach [6].

In addition to considering osseous fixation, a critical part of the treatment is management of the soft tissue envelope. There are a wide variety of coverage options available when primary or delayed closure is not possible. Whichever method is chosen, the results need to be a durable soft tissue envelope with the eventual goal of returning to normal shoe wear. Some have argued for a very early and aggressive approach to coverage, akin to coverage for the hand [27]. Several challenging situations have been reported, including significant heel pad injuries, which make preservation of this already vulnerable soft tissue envelope challenging [28]. It is important to remember that any acute treatment is based on soft tissues and ultimate treatment must never compromise the soft tissues [3].

Levin in 1993 described a six type classification system for soft-tissue problems related to calcaneus injuries with suggested treatment options to best reconstruct each type [29]. For the open calcaneus, there are numerous options available for coverage of the GA IIIB injury

[30, 31]. Consultation with an experienced reconstructive surgeon can help identify the best method for each patient.

Short-Term Complications

Early wound complications are a significant consideration in the management of open calcaneal fractures. The incidence of acute wound infection or skin necrosis has an incidence of 4.5–25%, with up to 85% of these wound complications requiring operative intervention [5, 12, 17]. Given the high-energy and often substantial soft tissue damage in these injuries, the early wound complications have the potential to be quite severe. While many case series describe superficial infections or necrosis resolved with local wound care and antibiotics, others have documented fulminant, acute infections requiring amputation [17]. Injury wounds of a stellate, nonlinear pattern, involving a degloving component, >4–5 cm in length, or those wounds with a concurrent neurovascular deficit, have shown a greater association with acute complication as compared to simple, linear wounds <4–5 cm [13, 17]. Smoking and diabetes are noted risk factors in early wound complications in open calcaneal fractures [5, 12].

Outcomes

Many factors influence the ultimate outcomes after treatment of open calcaneus fractures. In order to have a successful outcome, the patient must avoid infection and have successful healing of the soft tissues, the fracture must be accurately reduced and ultimately achieve union, and finally the patient must progress through therapy to ultimately return to an acceptable level of function without chronic pain [3].

Infection after open calcaneus fractures is of significant concern. The literature contains a wide variety of reported infection rates in these injuries [5, 6, 9, 10, 12, 13, 15, 18, 32–35] with some series reporting very substantial rates of infection and complication [16]. Heier et al. report a series of 43 open calcaneus fractures treated at their institution with a specific focus on the soft tissue injury [11]. All patients received IV antibiotics, surgical irrigation and debridement, temporary wound coverage, and provisional stabilization with delay in definitive fixation until the wound was determined to be clean and soft-tissue swelling has subsided. There were 19 medial, five lateral, three plantar, two posterior, and 14 “extensive” wounds. Four patients underwent amputation in the initial hospitalization. Two of these were acute for severe soft tissue and bone loss, a third was after free flap failure for a GA type IIIB injury, and the final was for a nonreconstructable heel pad injury. There were a total on nine GA type I injuries in which there were no complications. There were a total of eight GA type II injuries, of which three infections developed (one superficial, one deep, and one case of osteomyelitis). Three of 12 GA type IIIA fractures, 10 of 13 GA type IIIB fractures (six cases of osteomyelitis requiring amputation), and zero of one GA type IIIC fractures developed infection. They also reported complication rate based on the mechanism of injury and wound location. Penetrating injuries occurred in seven patients, of which six developed an infection, and two underwent early amputation. Medial wounds fared better than lateral, plantar, posterior, or extensive wounds, with the extensive wounds fairing the worst. Fourteen cases with extensive wounds resulted in two deep infections, six cases of osteomyelitis, and four amputations. Other series have noted the poor outcomes associated with plantar wounds as well [32]. Finally, the AOFAS hindfoot score was reported, stratified by GA category. Type I injuries averaged 83, type II injuries 78, and type III injuries 57 points.

Benirschke compared his wound healing complications in closed and open calcaneal fractures over a decade, all treated by the extensile lateral approach [15]. He found an infection rate of 1.8% in closed injuries and a 7.7% rate in open fractures.

This is a relatively low reported rate of infection with open injuries compared to other series, with many reports having substantially higher rates.

Berry reviewed 30 open calcaneus fractures with follow up on 21 patients at an average of 49 months (25–106) [10]. They found that worse functional outcomes were associated with patients with plantar wounds and severe comminution. The best functional outcomes were seen in those with single joint depression. Four patients underwent subsequent subtalar arthrodesis for post-traumatic osteoarthritis and one patient underwent a triple arthrodesis for varus malunion.

Wiersema reviewed 127 open calcaneus fractures with a specific focus on highlighting complications [5]. Eleven percent of all calcaneus fractures in their series were open. They observed an overall complication rate of 23.5%, which they defined as a superficial infection, deep infection, osteomyelitis, or amputation. Fourteen percent of patients required a reoperation after the intended definitive procedure. 9.6% has a superficial infection, and 12.2% had a deep infection. Five percent of patients developed osteomyelitis and 5% ultimately went on to amputation.

Zhang compared ORIF with plates and screws via an extensile lateral approach and cannulated screw fixation via mini sinus tarsi approach in 32 open injuries [34]. The groups were evenly divided, and all had medial wounds. They found no statistically significant differences in radiographic parameters, although the quality of the posterior facet reduction, and Bohler and Gissane's angles appeared to favor the extensile lateral group and may have reached significance with a larger patient number. Similar observations were made regarding functional outcome using the AOFAS hindfoot score.

In Spierings' systematic review, the AOFAS hindfoot score was reported in seven articles, with a median score of 73.7 points [6]. In the prospective articles included, a postoperative infection rate of 26.2% was observed, compared to 19.6% in the retrospective series. Overall, the lowest rate of complications, 11.8%, was observed, not surprisingly, in GA type I injuries, consistent with many reports of the soft tissue injury largely driving patient outcomes.

A particular subset of open calcaneus injuries occur in the combat setting. Not only is the nature of the injury distinct from the injuries seen in the civilian population, but there are also real differences in the patient population that likely affect outcome. Bevevino developed a model to predict limb salvage in this injury population [26]. Using factors that could be assessed at the time of presentation, they found American Society of Anesthesiologist grade, GA type, plantar sensation, Sanders classification, fracture treatment before arrival, vascular injury, male sex, and a dismounted blast mechanism were most predictive of eventual amputation. Dickens reviewed a series of 102 consecutive combat-related open calcaneus fractures, requiring an average of 13.7 procedures for treatment of the open calcaneus injury [25]. Forty-seven of the 102 (46%) developed culture-positive deep infections, and 42% underwent amputation, and 15% underwent delayed amputation (greater than 12 weeks after injury). In their analysis, amputation was associated with a blast injury, more severe GA type, and large, plantar wounds. Plantar wounds greater than 40 cm^2 had a 100% rate of amputation, and even plantar wounds less than 20 cm^2 had a 37% risk of amputation. Interestingly, in their population, patients who underwent amputation had lower pain and higher activity scores than those that underwent limb salvage. It must be taken into account that their population consists exclusively of active military personnel capable of serving in an active combat zone, and presumably have significantly greater baseline functional capacity than the civilian population.

Surgical Case

A 38-year-old female who was a passenger in a motor vehicle accident where she sustained a right open talonavicular dislocation and calcaneus fracture with a medial wound, a left clavicle fracture, and left-sided pneumothorax. She presented to an outside hospital where she underwent placement of a chest tube and urgent surgical irrigation and debridement of her right foot with external fixation (Fig. 17.1). Once she

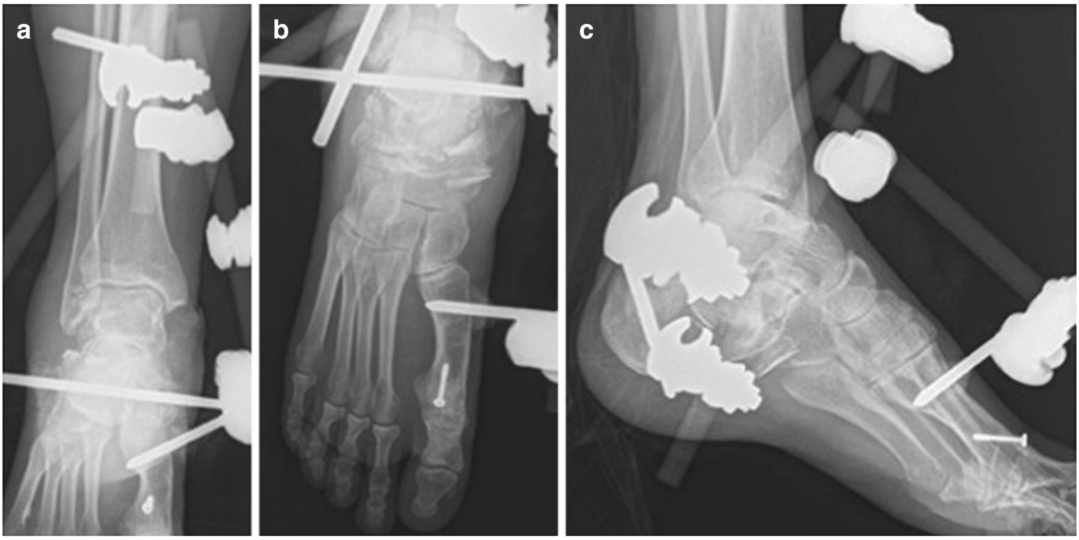


Fig. 17.1 Initial imaging upon arrival at our institution after irrigation and debridement and external fixation at outside hospital. Images, (**a**) AP ankle, (**b**) AP foot, and (**c**) lateral foot XRs demonstrate gross overall reduction and alignment of the foot

was medically stabilized she was transferred to our facility for definitive management of her musculoskeletal injuries.

Decision-Making Point: Is Further Debridement Required or Is the Wound Ready for Definitive Management?

It is our opinion that the surgeon who will definitively manage the injury be prepared to perform at least one irrigation and debridement for personal evaluation of the soft tissue envelope prior to committing to definitive fixation strategies.

Upon arrival to our institution, the right lower extremity soft tissue envelope was inspected and the decision was made to proceed with repeat surgical irrigation and debridement, revision of the external fixation, as well as fixation of the displaced left clavicle fracture to facilitate patient mobilization. During this surgical debridement, the wound was completely opened and extended as needed for appropriate surgical exploration. It was discovered that the sustentacular tali piece was displaced and impinging on the medial neurovascular structures. This piece was mobilized and reduced, thereby alleviating tension on the neurovascular bundle. A thorough irrigation and debridement was then performed, followed by placement of antibiotic eluting calcium sulfate beads for local antibiotic delivery. The external fixation frame was then rebuilt with maintained reduction of the talonavicular joint and improved alignment of the calcaneus. Postoperatively, a CT scan was obtained (Fig. 17.2) to better understand the injury and the patient was maintained on IV antibiotics on the floor until she was taken back to the operating room 4 days later for repeat I&D and definitive surgical fixation.

Decision-Making Point: When Is the Soft Tissue Envelope Ready for Definitive Management?

This requires clinical judgment based on the expertise of the treating surgeon. However, no gross purulence or necrotic tissue should be present in the traumatic wound, and the skin at the area of any planned surgical incisions should wrinkle, indicating that soft tissue swelling has subsided. If there is any concern, it is wise to perform additional irrigation and

Fig. 17.2 (**a**) Axial, (**b**) coronal, and (**c**) sagittal plane computed tomography images demonstrating significant articular comminution and depression

debridements and allow for further soft tissue recovery. At our institution, we have a practice pattern of multiple surgeons performing debridements of severely contaminated wounds to allow for multiple surgeons to evaluate the soft tissues.

The traumatic medial wound was reopened, the antibiotic beads were removed, and the wound was inspected. The wound was found to be clean, with viable soft tissues. Any remaining necrotic tissue was removed and the wound was again irrigated and the external fixator was removed. A sinus tarsi exposure was used to expose and reduce the fracture. The posterior facet was highly comminuted without soft tissue attachments. Therefore, we removed the entire posterior facet from the wound, reconstructed it on the back table, then reintroduced the posterior facet to the surgical field, provisionally fixed it to the talus, and then used it as a template to reconstruct the remained of the calcaneus to. Next, attention was turned to the overall length, alignment, and rotation of the calcaneus. This was achieved with direct manipulation and placement of Schantz pins used as joysticks to maneuver the fracture fragments. Typically this involves a pin into the segment containing the Achilles tuberosity, and a second pin into the posterior-inferior fragment, with the first pin used to restore length and height, and the second pin used to correct a varus/valgus deformity (classically these injuries want to deform in a varus direction). Multiple k-wires were then placed in the long axis to hold the alignment (Fig. 17.3a). Next, the anterior facet was rebuilt and held with k-wires. At this point, with the overall geometry and articular surfaces restored, a large void in the subchondral bone was noted. This was filled with 60 mL of allograft bone chips. Once this was filled, the lateral wall was placed back over this and a variable angle lateral plate was placed. The large k-wires that were holding overall alignment were then replaced with 6.5 mm cannulated screws (Fig. 17.3b,c). Fluoroscopic images were scrutinized to ensure reduction of posterior facet, restoration of Bohler's angle and angle of Gissane, restoration of varus/valgus alignment as well as the safety of all hardware (Fig. 17.3c,d). The medial wound was then explored one last time and wounds were closed in a layered fashion with meticulous soft tissue handling. An incisional vac for edema control was placed and final X-rays were taken prior to splint placement (Fig. 17.4).

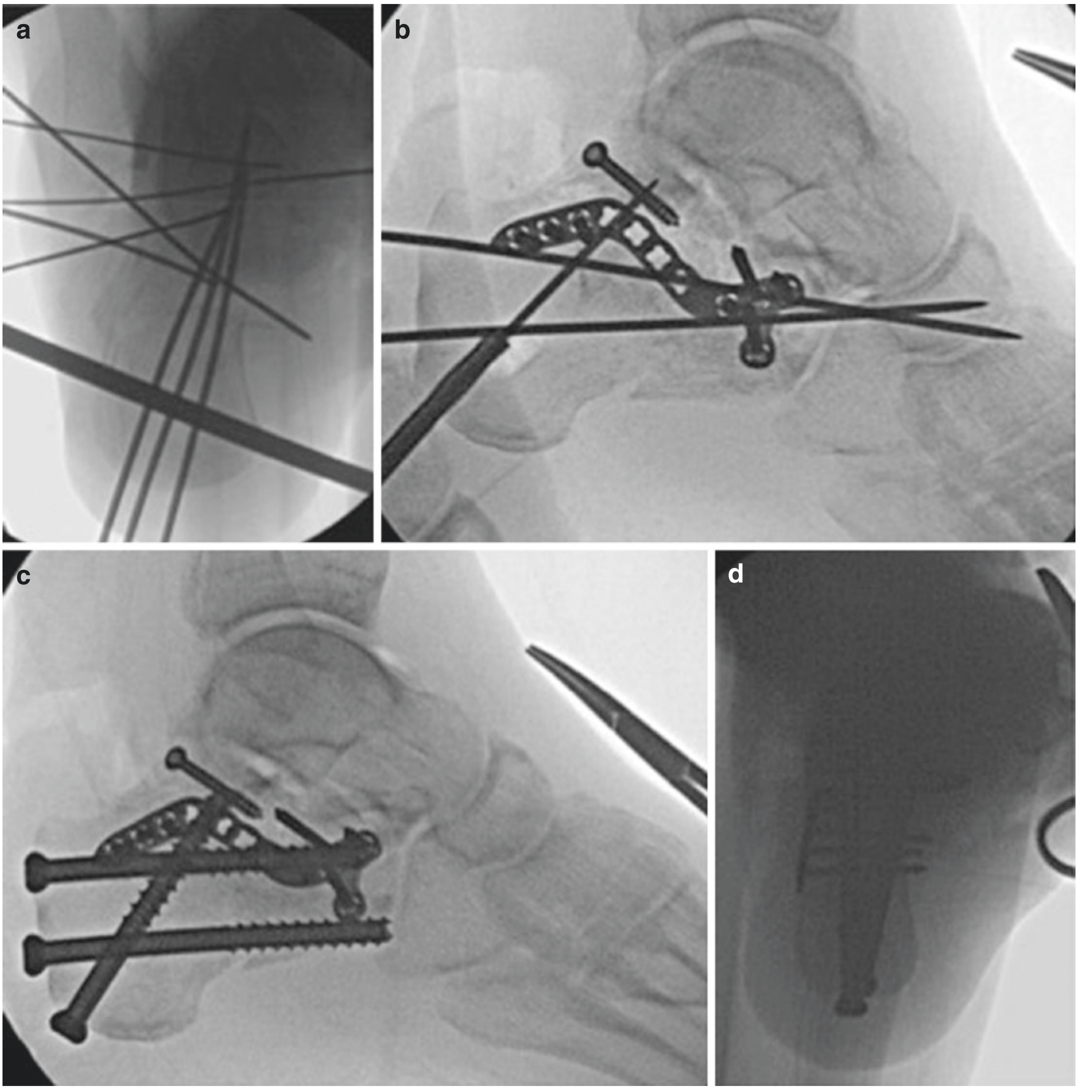


Fig. 17.3 Intraoperative fluoroscopic imaging demonstrating reduction and fixation techniques. (**a**) Use of multiple k-wires and Schantz pin to manipulate and control reduction and provisionally hold alignment. (**b**, **c**) After lateral-based plate is placed, long k-wires are exchanged for 6.5 mm cannulated screws for additional support. (**d**) Final Harris Heel view demonstrates restoration of hindfoot alignment

Key Technique Point: Soft Tissue Management

As the treating physician, you cannot control the trauma to the soft tissues from the initial traumatic insult. However, you can take every effort to minimize the additional trauma imparted from your surgical management. Self-retaining retractors should be avoided as they can unknowingly impart significant pressure on the soft tissues for extended periods of time. Gentle and meticulous handling of all soft tissues is imperative, and full-thickness flaps must be maintained during dissection, fixation, and closure. We often use an incisional vac at the time of definitive closure to assist with edema control.

Postoperatively, the patient was placed in a well-padded splint and given appropriate postop-

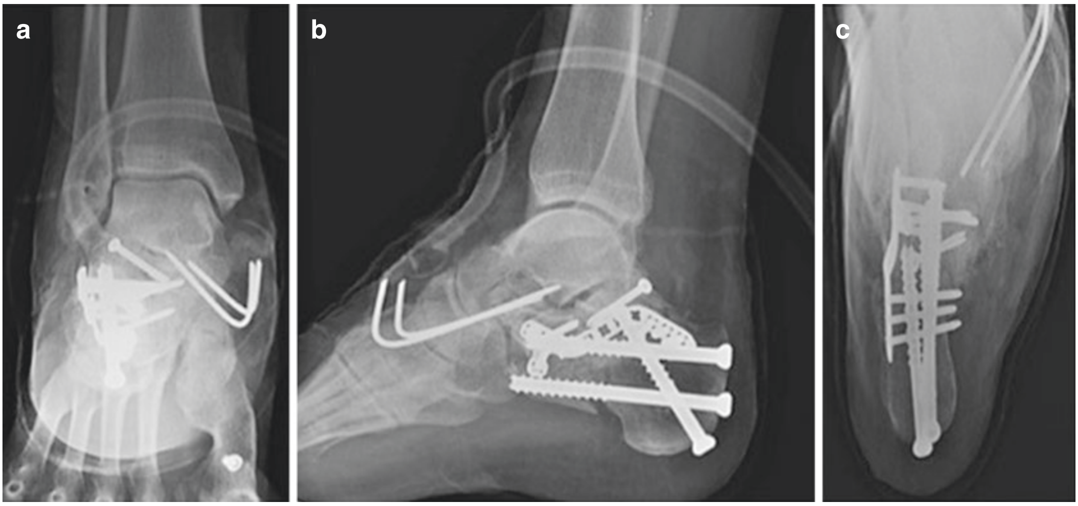


Fig. 17.4 Immediate postoperative final roentographs, (**a**) ankle mortise, (**b**) lateral ankle, and (**c**) Harris axial heel view, are obtained prior to splint application to ensure adequate alignment, hardware safety, and serve as baseline to monitor for healing

Fig. 17.5 Most recent radiographs, (**a**) AP foot, (**b**) oblique foot), and (**c**) lateral foot), status post removal of hardware and subsequent triple fusion with good healing

erative antibiotics. Our standard multimodal pain management protocol was used and she was maintained nonweight bearing for 12 weeks.

Decision-Making Point: When Should a Coverage Surgeon Be Consulted for Soft Tissue Coverage?

In environments where the coverage surgeon is readily available, we recommend early engagement at the first sign that primary coverage may not be possible. This allows for collaborative management of the osseous and soft tissue injuries to optimize the final outcome. In situations where ready access to a plastic and reconstructive surgeon is not available, strong consideration to transferring the patient to a tertiary care center should be given.

The patient progressed to radiographic healing uneventfully at 3 months. However, she continued to have pain and limited range of motion. After exhausting nonoperative management modalities, she elected to undergo hardware removal and tendo-Achilles lengthening at approximately 1 year postoperatively. Due to persistent pain, she ultimately underwent triple arthrodesis by another surgeon at approximately 20 months postoperatively. At her most recent follow-up visit, she has consolidated this fusion (Fig. 17.5).

Conclusion

Open calcaneus fractures remain a challenging clinical problem for even the most skilled orthopedic surgeon. Urgent appropriate antibiotic therapy in conjunction with surgical irrigation and debridement remain the mainstay of early treatment. Various treatment methodologies are available and should be selected on an individual basis taking into account the osseous and soft tissue injuries, the experience and technical comfort of the treating physician, and ultimately, patient preference.

GA type I injuries and those with medial wounds have a lower rate of complication and behave more similarly to closed injuries [9]. Extreme care and guarded prognosis should be taken with lateral and plantar wounds, extreme comminution, and poor host situations. Early collaboration with plastic surgery for coverage considerations is recommended when primary closure is not possible. Patients should be counseled that there is a significant likelihood of treatment requiring multiple operations and that amputation could result from this injury.

References

1. Court-Brown CM, Caesar B. Epidemiology of adult fractures: a review. Injury. 2006;37(8):691–7.
2. Palmer I. The mechanism and treatment of fractures of the calcaneus: open reduction with the use of cancellous grafts. J Bone Joint Surg Am. 1948;30A(1):2–8.
3. Lawrence SJ, Singhal M. Open hindfoot injuries. J Am Acad Orthop Surg. 2007;15(6):367–76.
4. Lawrence SJ. Open calcaneal fractures. Orthopedics. 2004;27(7):737–41; quiz 742–733.
5. Wiersema B, Brokaw D, Weber T, et al. Complications associated with open calcaneus fractures. Foot Ankle Int. 2011;32(11):1052–7.
6. Spierings KE, Min M, Nooijen LE, Swords MP, Schepers T. Managing the open calcaneal fracture: a systematic review. Foot Ankle Surg. 2019;25(6):707–13.
7. Gustilo RB, Anderson JT. Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: retrospective and prospective analyses. J Bone Joint Surg Am. 1976;58(4):453–8.
8. Gustilo RB, Mendoza RM, Williams DN. Problems in the management of type III (severe) open fractures: a new classification of type III open fractures. J Trauma. 1984;24(8):742–6.
9. Aldridge JM 3rd, Easley M, Nunley JA. Open calcaneal fractures: results of operative treatment. J Orthop Trauma. 2004;18(1):7–11.
10. Berry GK, Stevens DG, Kreder HJ, McKee M, Schemitsch E, Stephen DJ. Open fractures of the calcaneus: a review of treatment and outcome. J Orthop Trauma. 2004;18(4):202–6.
11. Heier KA, Infante AF, Walling AK, Sanders RW. Open fractures of the calcaneus: soft-tissue injury determines outcome. J Bone Joint Surg Am. 2003;85-A(12):2276–82.
12. Mehta S, Mirza AJ, Dunbar RP, Barei DP, Benirschke SK. A staged treatment plan for the management of type II and type IIIA open calcaneus fractures. J Orthop Trauma. 2010;24(3):142–7.
13. Thornton SJ, Cheleuitte D, Ptaszek AJ, Early JS. Treatment of open intra-articular calcaneal fractures: evaluation of a treatment protocol based on wound location and size. Foot Ankle Int. 2006;27(5):317–23.
14. Worsham JR, Elliott MR, Harris AM. Open calcaneus fractures and associated injuries. J Foot Ankle Surg. 2016;55(1):68–71.
15. Benirschke SK, Kramer PA. Wound healing complications in closed and open calcaneal fractures. J Orthop Trauma. 2004;18(1):1–6.
16. Siebert CH, Hansen M, Wolter D. Follow-up evaluation of open intra-articular fractures of the calcaneus. Arch Orthop Trauma Surg. 1998;117(8):442–7.
17. Lawrence SJ, Grau GF. Evaluation and treatment of open calcaneal fractures: a retrospective analysis. Orthopedics. 2003;26(6):621–6; discussion 626.
18. Oznur A, Komurcu M, Marangoz S, Tasatan E, Alparslan M, Atesalp AS. A new perspective on management of open calcaneus fractures. Int Orthop. 2008;32(6):785–90.
19. Beltran MJ, Collinge CA. Outcomes of high-grade open calcaneus fractures managed with open reduction via the medial wound and percutaneous screw fixation. J Orthop Trauma. 2012;26(11):662–70.
20. Pape HC, Webb LX. History of open wound and fracture treatment. J Orthop Trauma. 2008;22(10 Suppl):S133–4.
21. Schenker ML, Yannascoli S, Baldwin KD, Ahn J, Mehta S. Does timing to operative debridement affect infectious complications in open long-bone fractures? A systematic review. J Bone Joint Surg Am. 2012;94(12):1057–64.
22. Benirschke SK, Sangeorzan BJ. Extensive intraarticular fractures of the foot. Surgical management of calcaneal fractures. Clin Orthop Relat Res. 1993;292:128–34.
23. Gould N. Lateral approach to the os calcis. Foot Ankle. 1984;4(4):218–20.
24. Besch L, Waldschmidt JS, Daniels-Wredenhagen M, et al. The treatment of intra-articular calcaneus frac-

tures with severe soft tissue damage with a hinged external fixator or internal stabilization: long-term results. J Foot Ankle Surg. 2010;49(1):8–15.

25. Dickens JF, Kilcoyne KG, Kluk MW, Gordon WT, Shawen SB, Potter BK. Risk factors for infection and amputation following open, combat-related calcaneal fractures. J Bone Joint Surg Am. 2013;95(5):e24.
26. Bevevino AJ, Dickens JF, Potter BK, Dworak T, Gordon W, Forsberg JA. A model to predict limb salvage in severe combat-related open calcaneus fractures. Clin Orthop Relat Res. 2014;472(10):3002–9.
27. Brenner P, Rammelt S, Gavlik JM, Zwipp H. Early soft tissue coverage after complex foot trauma. World J Surg. 2001;25(5):603–9.
28. Ahmed S, Ifthekar S, Ahmed Khan RPR, Ranjan R. Partial heel pad avulsion with open calcaneal tuberosity fracture with Tendo-achilles rupture: a case report. J Orthop Case Rep. 2016;6(4):44–8.
29. Levin LS, Nunley JA. The management of soft-tissue problems associated with calcaneal fractures. Clin Orthop Relat Res. 1993;290:151–6.
30. Ulusal AE, Lin CH, Lin YT, Ulusal BG, Yazar S. The use of free flaps in the management of type IIIB open calcaneal fractures. Plast Reconstr Surg. 2008;121(6):2010–9.
31. Christy MR, Lipschitz A, Rodriguez E, Chopra K, Yuan N. Early postoperative outcomes associated with the anterolateral thigh flap in Gustilo IIIB fractures of the lower extremity. Ann Plast Surg. 2014;72(1):80–3.
32. Firoozabadi R, Kramer PA, Benirschke SK. Plantar medial wounds associated with calcaneal fractures. Foot Ankle Int. 2013;34(7):941–8.
33. Loutzenhiser L, Lawrence SJ, Donegan RP. Treatment of select open calcaneus fractures with reduction and internal fixation: an intermediate-term review. Foot Ankle Int. 2008;29(8):825–30.
34. Zhang T, Yan Y, Xie X, Mu W. Minimally invasive sinus tarsi approach with cannulated screw fixation combined with vacuum-assisted closure for treatment of severe open calcaneal fractures with medial wounds. J Foot Ankle Surg. 2016;55(1):112–6.
35. Zhang X, Liu Y, Peng A, Wang H, Zhang Y. Clinical efficacy and prognosis factors of open calcaneal fracture: a retrospective study. Int J Clin Exp Med. 2015;8(3):3841–7.

18

Isolated Fractures of the Anterior Process

Brad J. Yoo

Introduction

Fractures of the anterior process of the os calcis are encountered by the treating orthopedist. Most typically, fractures into the anterior process are the result of secondary fractures that originate from the primary fracture line created during joint depression or tongue type fractures. The orientation of these fractures is in the sagittal plane, typically with extension into the articulation with the cuboid. With greater degrees of displacement, the calcaneocuboid joint can become incongruous. These secondary fractures into the anterior process are to be discussed in the chapter regarding intra-articular calcaneus fractures.

Isolated fractures of the anterior process of the os calcis are uncommon. Generally speaking, anterior process fractures fall into two broad categories. First, such fractures can occur as avulsion injuries from tension on the bifurcate ligament or extensor digitorum brevis insetion site. In other instances, fractures of the anterior process are components of a midfoot fracture-dislocation of varying complexity. The true incidence of isolated anterior process fractures is difficult to ascertain as these fractures are often overlooked [17]. Symptoms of this fracture may be nearly identical to that of an anterior talofibular ligament sprain as both may arise from the same mechanism [12]. Some reports indicate a substantial false identification rate of missed fractures up to 7% [1].

Anatomy

The anterior process is the saddle-shaped terminal portion of the os calcis which articulates with the cuboid via a synovial diarthrodial articulation. This essential joint works in conjunction with the talocalcaneal navicular articulation to permit subtalar movement. The motion is described as screwlike in either a clockwise or counterclockwise manner with rotation centered at the talocalcaneal interosseous ligament [18]. Physiologic subtalar motion has two primary purposes. First, it enables the foot to accommodate to uneven terrain while maintaining upright stance. Second, subtalar motion enables the complex mechanism of forefoot locking and unlocking during toe-off and heel-strike, respectively. This allows the foot to become sequentially a rigid platform for efficient forward propulsion and a supple structure to disperse axially applied load.

The anterior process is intimately associated with the bifurcate ligament. This structure originates from the superolateral aspect of the anterior process. It consists of two bands: the calcaneonavicular ligament (attaching to the lateral navicular) and the calcaneocuboid (attaching to the medial cuboid) (Fig. 18.1). In addition, a portion

---

B. J. Yoo (✉)
Department of Orthopaedics and Rehabilitation, Yale University, New Haven, CT, USA
e-mail: brad.yoo@yale.edu

© Springer Nature Switzerland AG 2020

M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_18

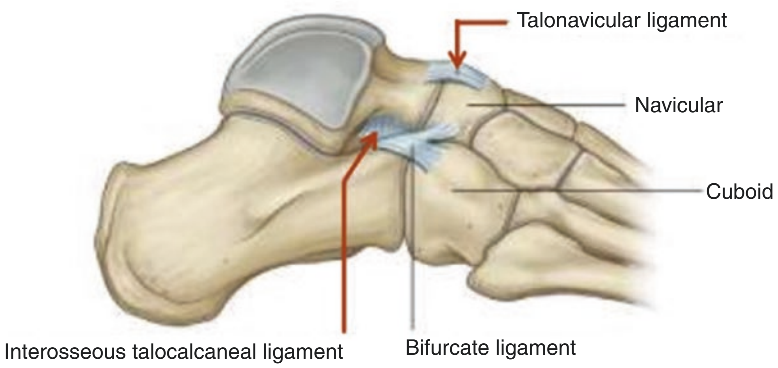


Fig. 18.1 Ligamentous structures about the calcaneal anterior process

of the extensor digitorum brevis (EDB) may have broad attachments to the superior margin of the anterior process.

Avulsion/Shear Fractures

Mechanism of Injury

Inversion and plantarflexion moments are the proposed mechanism of isolated avulsion fractures of the anterior process. First described as a trauma from a plantarflexed foot struck in the posterior calf, a plantarflexion and subtalar inversion moment is experienced. This force moment tightens the bifurcate ligament and EDB, with the osseous attachment of these structures failing in tension (Fig. 18.2).

Another mechanism postulated is one of forced forefoot abduction coupled with hindfoot dorsiflexion [8, 14, 17]. In this instance, the anterior process is sheared from its native position by the pathologic contact of the cuboid with the anterior process. Therefore, the mechanism that produces a shear fracture of the anterior process is essentially the opposite of that which produces the avulsion fracture (Fig. 18.3).

Diagnosis

A high level of suspicion is the first step toward an accurate diagnosis and the prevention of missed injuries. Evaluation begins with a detailed history of the traumatic event. The mechanism, magnitude, duration, and location of the traumatic event will raise the index of suspicion, prompt the examiner to inquire further, and aid in the diagnosis. A complete review of systems should include additional mitigating factors that may impact the treatment. Identifying the presence of diabetic vasculopathy, previous bony or soft tissue injury, or existing arthritic conditions is helpful. The ambulatory status of the patient should be documented. Questions regarding current or previous nicotine use should not be neglected, as a positive history may influence operative decision making. Occupational status and patient expectations are additional important pieces of information.

A detailed neurovascular examination must be performed. A cursory examination is not sufficient, as subtle dysesthesias are frequently present despite the patient reporting “intact sensation.” Even though incomplete, these sensory disturbances can frequently result in postinjury neuropathic pain. All sensory nerves to the foot should be examined. These include the deep peroneal, superficial peroneal, medial plantar, lateral plantar, sural, and saphenous nerves. Motor function should similarly be inspected. The dorsalis pedis and posterior tibial arteries should be palpated and the quality, cadence, and amplitude of the pulses documented.

It is helpful to prompt the patient to be specific regarding the point of maximal pain. The point of maximal tenderness is a relevant diagnostic feature, as the pain is both distal and inferior to the common site of injury to the anterior talofibular ligament during an ankle sprain. This pain is reproducible upon multiple examinations, particularly exacerbated with direct palpation over the anterior process with hindfoot inversion and

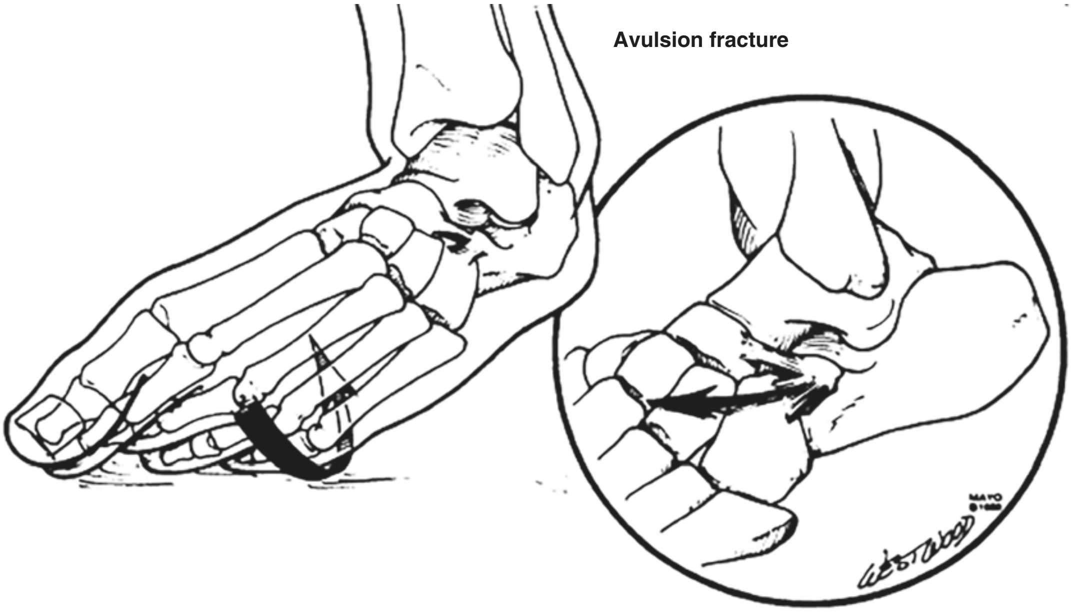


Fig. 18.2 Avulsion mechanism for isolated anterior process fractures [4]

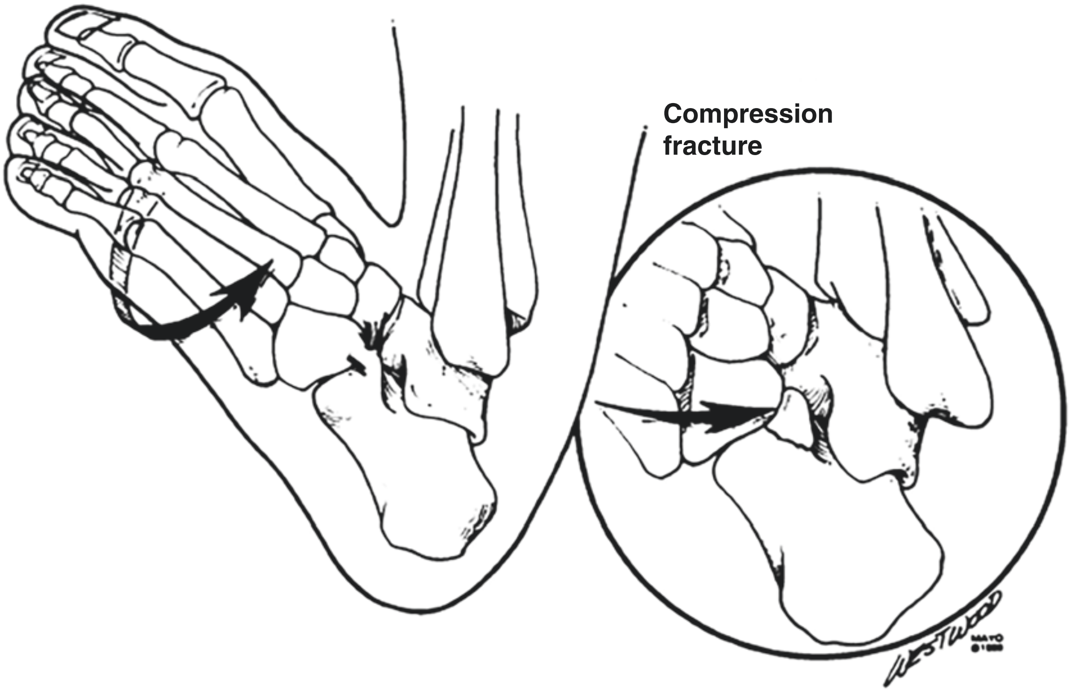


Fig. 18.3 Shear mechanism for isolated anterior process fractures

ankle plantarflexion. Patients with persistent pain in this region that has otherwise been attributed to an "ankle sprain" which does not improve should be imaged with high-quality radiographs of the foot and ankle. The foot series will provide orthogonal views of the anterior process, allowing evaluation of the anterior process and its articulation with the cuboid.

Although a displaced anterior process fragment would be most conspicuous on a lateral radiographic projection, it is frequently overlooked (classically by providers preoccupied with an "ankle sprain"). Computed tomography (CT) would certainly clarify fracture presence, displacement, and morphology more effectively than plain radiographs, but clinical suspicion must be present to prompt such an advanced imaging modality [15]. Due to the resolution of images obtained, CT would enable differentiation of an acute avulsion fracture from anatomic variations, such as an os calcaneum secundarium. Tarsal coalitions, particularly a calcaneonavicular coalition, can also be diagnosed effectively in this manner. Bone scintigraphy may be useful in also determining the presence of an acute process from a more biologically inert condition, such as an os calcaneum, but in general are not used for diagnosis. Magnetic resonance imaging is similarly of limited utility in the acute diagnosis of an anterior process fracture. This imaging modality would be more useful if clarification of associated ligament injury is desired.

The resultant avulsed fragment may exhibit a spectrum of size and degree of displacement; unclear significance is attributed to both. In order to create guidelines for treatment, a classification system of three fracture types was proposed by Degan and Morrey [5]. Type I fractures are not displaced, often only involving the tip of the anterior process. Type II fractures are displaced but do not involve the calcaneocuboid joint. Type III fractures are characterized by a displaced fragment that involves the articular surface.

Treatment

Opinions vary as to the appropriate treatment of the avulsion fragment. Soft cast with immediate weightbearing or more formal immobilization with a nonweightbearing hard cast of varying duration have all been found to be effective. The patient usually becomes asymptomatic regardless of whether the fracture has united or not [2]. The practitioner should keep in mind that it may take a year for patients to become asymptomatic or for the fracture to realize the full extent of recovery.

With continued symptoms despite prolonged observation, excision of small nonunited fragments can be considered. A preoperative diagnostic injection into the sinus tarsi may help determine if there will be an improvement in pain following excision. The fragment removal may be performed either open or arthroscopically depending upon surgeon experience.

Larger fragments, particularly type III fragments that have an attached portion of articular cartilage may be treated with open reduction internal fixation. A lateral sinus tarsi approach can be implemented. This Ollier type incision will avoid the superficical peroneal nerve and long toe extensors superiorly and the peroneal tendons and sural nerve inferiorly. Patients may still exhibit pain following excision or fragment fixation. This persistence of symptoms postsurgically may reflect instability or arthritis at the calcaneocuboid joint. Diagnostic injection into the calcaneocuboid joint may help distinguish between the two entities, but typically the diagnosis is difficult as weightbearing pain is appreciated with both conditions.

Case Example

A 45-year-old female slipped off her front step. She reports an inversion moment upon her ankle with pain and swelling located over her lateral ankle. She was seen by her primary care physician who treated her with a sprain for 6 weeks. The patient continued to exhibit swelling and pain over her lateral distal ankle and was referred to the orthopedic clinic for further evaluation.

On physical examination, the patient demonstrates point tenderness over the level of her anterior process. She exhibits no increased laxity with anterior ankle drawer testing. She presents minimal swelling with the appearance of fine skin wrinkles over her lateral ankle. A computed tomography study is performed which clarifies the dimensions of the anterior process fragment. Due to its large size and intra-articular involvement, a surgical intervention is recommended. The representative images can be seen in Fig. 18.4a–c.

Preoperatively, the following equipment is obtained.

- Small fragment locking “L” configuration plate
- Kirschner wires
- Standard bed with radiolucent foot extension
- Fluoroscopic unit with 12 in. image intensifier.

A perisurgical sciatic nerve blockade should be discussed with the patient. This analgesic technique has been correlated with a significant decrease in the amount of postoperative narcotics required to achieve pain control and is a safe

Fig. 18.4 (**a**–**d**) Open reduction internal fixation of a large type III anterior process fragment

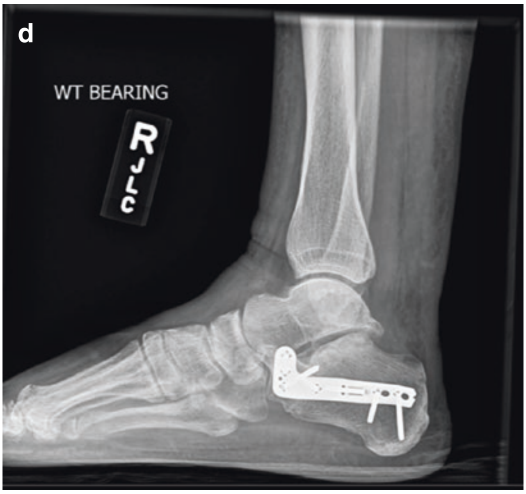


Fig. 18.4 (continued)

intervention as postoperative foot compartment syndrome in this setting is rare [3].

The patient is positioned in a lateral position for a lateral extensile approach. A sterile tourniquet is readily available if needed to control hemorrhage. Headlight illumination is used to enable visualization of the surgical field.

A lateral "L" extensile approach is made, with the descending limb being posterior to the midpoint between the posterior fibular and the Achilles tendon. The lateral aspect of the calcaneus is exposed by sharp dissection and the creation of periosteal cutaneous flaps. The sural nerve, peroneal tendons, and lateral calcaneal artery remain protected within the flap as fixation commences. It is imperative that meticulous gentle soft tissue handling techniques are used on the lateral flap. As the flap is elevated, the dorsal aspect of the anterior process is revealed. The fracture is cleaned of organizing hematoma and the cortical edges of the fracture are exposed. The fragment is manipulated into place using either dental picks or shoulder hooks and temporarily secured with 2.0 mm Kirschner wires. A locking L plate is utilized in this scenario due to the small size of the anterior process segment as well as its relative osteopenia. An AP fluoroscopic view of the foot will ensure proper screw length and decrease the chance for intra-articular screw placement into calcaneocuboid joint. The plate is then secured to the calcaneal body with standard screws. An intraoperative Harris axial view guides proper screw lengths.

Wound closure is a crucial element in the operative treatment. The flap periosteum is annealed to the periosteum of the calcaneus. Placement of accurate sutures is crucial and is aided by the passage of all the sutures prior to knot-tying. A tension-free closure is then performed upon the skin utilizing a modified Allgower mattress stitch. A well-padded splint is placed and the leg is left elevated postoperatively to address swelling.

The patient is initiated on physiotherapy to maintain ankle, subtalar, MTP, and IP joint motion. A strict nonweightbearing prescription for 8 weeks is enforced. Weightbearing is then permitted and physiotherapy works toward foot intrinsic and extrinsic muscle strengthening and gait training. A final 6-month weightbearing lateral radiograph is seen in Fig. 18.4d.

Midtarsal Joint Fracture/Dislocation

Fractures of the anterior process are uncommonly associated with more severe midfoot trauma, particularly a fracture-dislocation through the transverse tarsal joint (Chopart's joint) [13]. Main and Jowett described five patterns of midtarsal fracture-dislocations based upon the applied force vector, subsequent deformity, and presumed mechanism. Longitudinal, medial, lateral, plantar, and crush injuries have been described [11]. Longitudinal injuries are most common, accounting for 41% of all midtarsal fracture-dislocations. This severe, high injury mechanism involves a longitudinal force applied to the metatarsal heads of a plantarflexed foot, with resultant injuries to the navicular or cuneiforms in a sagital orientation. In the original treatise, fractures to the anterior process were not described.

The next most common midtarsal fracture-dislocation is medial, with a 30% prevalence. The forefoot is medially displaced, with injuries to the talonavicular and calcaneocuboid joints. Due to the violence of the trauma and resultant instability, these injuries frequently require stabilization either with Kirschner wire or internal fixation through an open approach.

Lateral injuries occur less frequently, up to 17% in the case series by Main and Jowett. Here an abduction force produces lateral subluxation of the talonavicular joint, with an avulsion fracture of the navicular tuberosity, lateral foot column collapse, and possible comminution of the anterior process or cuboid [6]. Subluxation or dislocations may be addressed with Kirschner wire fixation, while crush injuries to the cuboid may require open reduction and bone grafting. The lateral column height may be maintained with the use of a laterally based external fixator.

Plantar injuries are rare, but potentially devastating injuries. The anterior process injury is hypothesized to occur during severe plantarflexion of the talus through the anterior portion of the calcaneus [10]. The injury film often exhibits a dorsal dislocation of the navicular from the talus, with or without extension into the calcaneal body posteriorly. There is a high prevalence of open fracture and posterior tibial artery laceration with this injury, with subsequent association of chronic osteomyelitis, poor Maryland Foot scores, American Orthopaedic Foot and Ankle Society (AOFAS) ankle-hindfoot scores, and the need for amputation. The difference between this high kinetic energy mechanism with devastating functional outcomes and the less severe avulsion fractures is readily apparent [13].

Crush injuries involve a complete collapse of the midtarsal joint with variable patterns of comminution and displacement. Based upon the fracture pattern, the comminution may be stabilized with Kirschner wires or internal fixation, with length maintenance augmented with medial and/or lateral foot external fixators.

Diagnosis

Clinical History and Exam, Imaging Workup

As discussed for avulsion fractures of the anterior process, the proper recognition of midtarsal joint fracture-dislocations begins with a high index of suspicion. As before, queries to the patient regarding mechanism of injury, location of pain, neurosvascular status, and socioeconomic factors are crucial. Gross dislocations should be realigned immediately prior to imaging. Physical and radiographic evaluations for midtarsal joint fracture-dislocations as described previously are mandatory. As these are high energy injuries, a detailed neurovascular examination is even more critical. Ankle brachial indices are objective measurements to evaluate the vascular competency of the limb compared with the contralateral side. Plain radiography and advanced imaging indications are as indicated for isolated anterior process fracture.

Treatment

Surgical stabilization of instability through the transverse tarsal joint frequently requires operative fixation. Surgical treatment is based upon the fracture pattern and the presence of persistent subluxation/dislocation. Gross dislocations should be gently reduced promptly. If open approaches are planned, definitive surgery should be delayed until the soft-tissue envelope is healed, not swollen, and free of infection [7]**.** This is marked by the disappearance of turgidity from the lateral calcaneal soft tissue and also the appearance of fine skin wrinkles. Skin blistering has a correlation with the degree of soft tissue shearing at the time of trauma [9]. These may emerge immediately or over the course of hours, sometimes days. Two main subtypes of fracture blister have been identified (serous or hemorrhagic), based upon the depth of dermal-epidermal injury. Deroofing or application of silver-based topical ointments has been shown to confer no statistical difference in patient outcomes. Surgery should be delayed until blister beds have been re-epithelialized and incisions across unepithelialized or hemorrhagic blister beds should be avoided [16].

Subluxations or dislocations across the calcaneocuboid joint may be stabilized by either Kirschner wire or screw fixation placed across the calcaneocuboid joint. This transarticular fixation may be supplemented with external fixation as needed. As this articulation is an essential one, staged hardware removal will be required once the injury is healed to permit motion. Compression failure injuries will require length restoration and maintenance with internal fixation. For example, with a lateral injury, the lateral column has become foreshortened with comminution of either the anterior process or cuboid. In this instance, the lateral column length may be restored and maintained with a laterally based external fixator, with pins inserted into the calcaneal tuberosity and fifth metatarsal metadiaphysis. The concomitant fracture of the anterior process or cuboid may then be stabilized with internal fixation and frequently requires bone grafting to facilitate healing of the bone void created during surgical disimpaction. Bicolumnar external fixation may be required in the setting of a crush injury, where both the medial and lateral columns of the foot require support. Fractures of simpler orientation, such as a single sagittal fracture into anterior process may be treated open with lag screw fixation alone or through a plate that will disperse load and prevent migration of a solitary screw through the bone.

Postoperatively, patients are instructed to maintain leg elevation to reduce swelling and maintain nonweightbearing precautions for 6 to 12 weeks depending upon the severity of the injury. Physiotherapy should be initiated early, with attention toward mobilizing all essential joints of the foot including the metatarsophalangeal and tibiotalar joints. If the subtalar or midtarsal joints are free of transarticular fixation, then they should be mobilized early as well. A well-padded removable splint will facilitate frequent range of motion exercises, and in general, full leg casts are to be avoided.

Case Example

A 53-year-old female is involved in a head-on motor vehicle crash with fatalities on scene. She presents with a grossly dislocated foot, consistent with a medial midtarsal fracture-dislocation (Fig. 18.5a).

Her leg is gently reduced into anatomic alignment and advanced imaging is obtained. The representative images are displayed in Fig. 18.5b. She exhibited a comminuted fracture of her anterior process, a sagittal navicular body fracture, and multiple cuneiform base fractures consistent with a Lisfranc fracture.

Her foot was splinted and elevated until soft tissue quiescence was obtained. This was marked by the appearance of fine skin wrinkles over her foot and with mobility of her skin over the deeper tissues. An operative intervention is planned to stabilize the Lisfranc injury, her navicular fracture, and the fracture-dislocation through her calcaneocuboid joint.

Preoperatively, the following equipment was obtained.

- Small fragment limited contact dynamic compression plate (LCDCP)
- Kirschner wires
- External fixator with 4.0 mm Schanz pins
- Standard bed with radiolucent foot extension
- Fluoroscopic unit with 12 in. image intensifier. The fluoroscopic unit is to be positioned on the opposite side of the operative limb, perpendicular to the table to facilitate AP and lateral views.

A perisurgical sciatic nerve blockade should be discussed with the patient. This analgesic technique has been correlated with a significant decrease in the amount of postoperative narcotics required to achieve pain control and is a safe intervention as postoperative foot compartment syndrome in this setting is rare [3].

The patient is placed supine. The ipsilateral hip is bumped. A small elevated platform is fashioned from folded blankets to permit unobstructed lateral foot views without having to move the operative limb. The knee is flexed over a well-padded radiolucent triangle to position the foot in a plantigrade posture during the procedure. A sterile tourniquet is readily available if needed to control hemorrhage. Headlight illumination is used to enable visualization of the surgical field.

The midfoot fracture is addressed first. Two incisions are executed. The first incision is dorsal, targeted longitudinally over the medial cuneiform. This is confirmed with the use of fluoroscopy prior to incision. Once the incision is made through skin and dermis only, branches of the superficial peroneal nerve are searched for and preserved while the deeper dissection commences. Full-thickness flaps are developed and gently retracted with Langenbeck retractors. Due to the degree of soft tissue stripping, the injury over the cuneiforms is readily apparent. In this instance, the tarsometatarsal articulations of the first, second, and third digits are observed and reduced utilizing manual manipulative techniques. The first TMT articulation is found to be reduced, but freely mobile with manual stress and is summarily held in place with two 0.045 in. Kirschner wires. A solitary wire will not control rotational displacement. A minimum of two wires are required to effect this task. The pathologic displacement here involves the second MT base in a dorsal direction. This is reduced and held in place with 0.045 in. Kirschner wires × 2. The intercuneiform articulations, though statically reduced, are assessed to identify occult instability which is identified by applying manual force

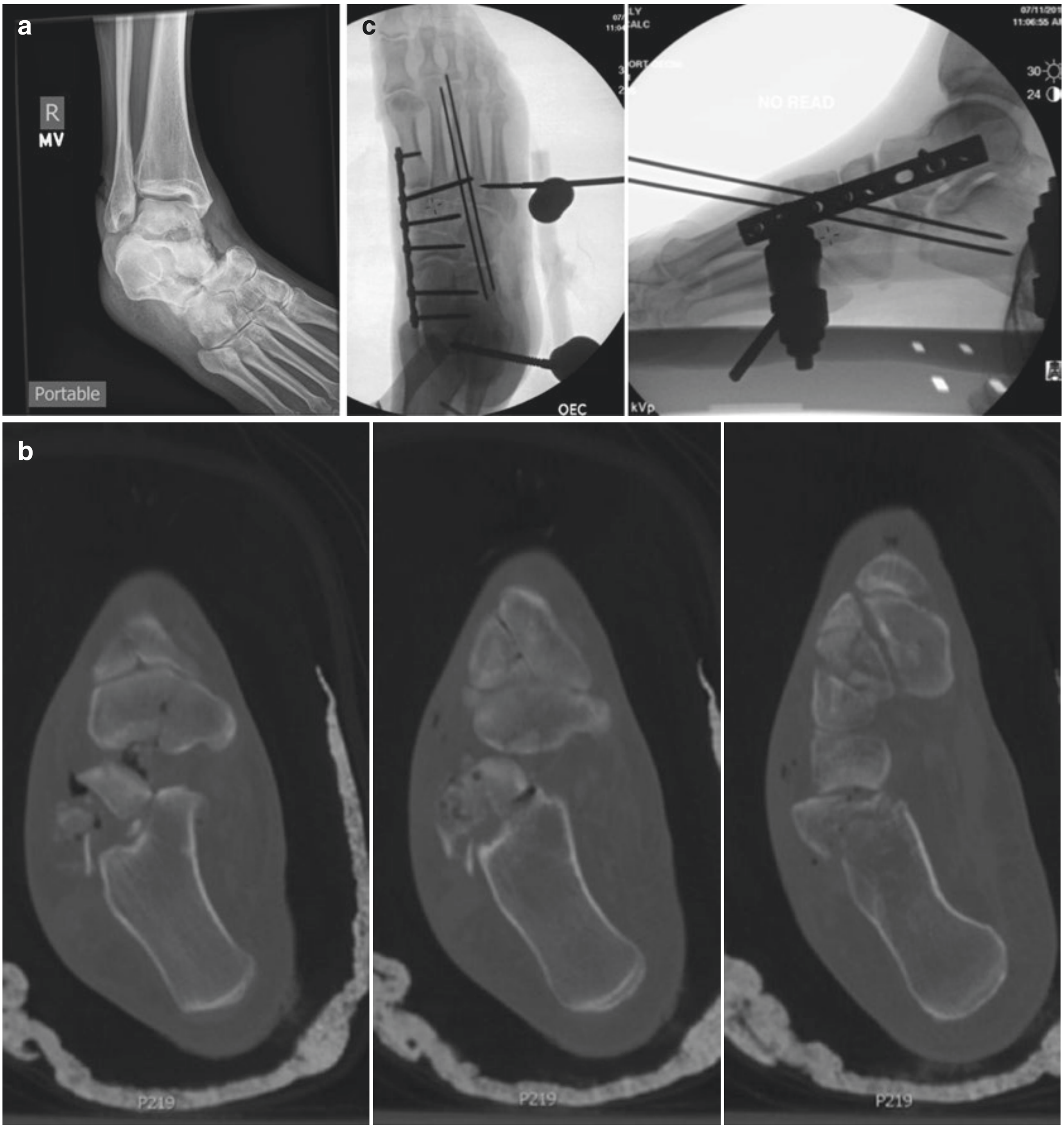


Fig. 18.5 (**a**–**e**) An open midtarsal fracture-dislocation with an isolated anterior process fracture. There is concomitant midfoot fracture-dislocation and navicular fracture. The anterior process fracture was treated with Kirschner wire fixation in addition to a medial column spanning plate for the cuneiform and navicular fractures, plus a lateral foot external fixator to prevent midfoot abduction. The external fixator and Kirschner wires were removed at 6 weeks postoperatively. The plate was removed at 3 months to enable subtalar motion and the patient was subsequently allowed to weightbear

Fig. 18.5 (continued)

across the articulation with a shoulder hook. These intercuneiform articulations are found to have some mild dynamic instability and are held reduced with additional Kirschner wires. The Lisfranc fractures have now been now reduced and preliminarily stabilized.

More proximally, the talonavicular capsule is incised in order to gain intra-articular access. A Hintermann retractor is applied with 0.062 in. Kirschner wires placed into the talar head and lateral cuneiform to allow distraction of the talonavicular joint. The fracture can now be cleaned of hematoma and invaginated tissue and subsequently clamped anatomically reduced with a Weber tenaculum. The articular reduction can only be assessed directly if joint distraction is applied. This reduction is preliminarily held in place with Kirschner wires.

Utilizing the lateral foot fluoroscopy, a planned incision is marked over the medial aspect of the first ray longitudinally. The skin is incised and electrocautery used to control subcutaneous bleeding. Full-thickness flaps are elevated and protected with the Langenbeck retractors. The talonavicular articulation is reduced to re-establish Meary's line on the lateral fluoroscopic image. Pathologic plantarflexion through the talonavicular joint is neutralized with manual manipulation via shoulder hooks on either side of the joint. In addition, a subtle degree of forefoot supination is required to completely reduce the talonavicular joint as well. Once the reduction is in place, 2.0 mm Kirschner wires are preliminarily positioned transarticularly to maintain the reduction. Next, the insertion site of the tibialis anterior tendon is identified on the medial side of the medial cuneiform, and an eight-hole LCDCP is positioned along the medial column of the foot, tunneled deep to the tibialis anterior tendon. Through the corresponding screw hole, a 3.5 mm lag screw by technique is inserted transversely across the navicular fracture. Two screws are inserted into the talus through the proximal portion of the plate to secure the talonavicular reduction. One screw is inserted across the cuneiforms to stabilize the intercuneiform instability. One screw is inserted from the medial cuneiform, through the second and third MT base to stabilize the reduction of the Lisfranc articulation. Additional points of fixation into the first MT diaphysis complete the fixation.

With the supination reduction and anatomic stabilization of the midfoot complete, the anterior process fracture is now approximated into a more anatomic position. Due to the degree of comminution, a percutaneous method of fixation is planned. Two Kirschner wires are inserted percutaneously in a transarticular manner from the cuboid, across the anterior process fracture and into the calcaneal body. Again, two wires are used to more adequately control the fractures propensity for forefoot eversion through the calcaneocuboid joint. In order to further bolster the reduction, a laterally based external fixator with 4.0 mm Schanz pins were used to bolster the stability to the lateral side (Fig. 18.5c).

The wounds are copiously irrigated and then closed with 3–0 nylon in a vertical mattress modified Allgower fashion. Brown steri-strips are positioned across the wound and a well-padded splint is applied with ankle in neutral dorsiflexion. Postoperative nerve blockade through a sciatic nerve catheter is continued for 48 h postoperatively. The patient is left in bed with leg elevation orders until the nerve catheter was removed.

The patient is initiated on physiotherapy to maintain ankle, MTP, and IP joint motion. As the subtalar joint has been temporarily immobilized with fixation, no orders for subtalar motion are given. A strict nonweightbearing prescription for 12 weeks is enforced. At 6 weeks, the lateral external fixator and calcaneocuboid Kirschner wires are removed in clinic. At 12 weeks, the patient is brought back to the operative theater for extrication of the medial column plate. Following this final surgery, weightbearing is permitted and subtalar motion exercises are added to the patient's physiotherapy regimen. The 6-month weightbearing X-rays are depicted in Fig. 18.5d,e.

References

1. Bachman S, Johnson SR. Torsion of the foot causing fracture of the anterior calcaneal process. Acta Chir Scandinavica. 1953;105:406–66.
2. Chapman MW. Fractures and dislocations in the foot. In: Mann RA, editor. Du Vries' surgery of the foot. 4th ed. St. Lluis: CV Mosby; 1978. p. 142–204.

3. Cooper J, Benirschke S, Sangeorzan B, Bernards C, Edwards W. Sciatic nerve blockade improves early postoperative analgesia after open repair of calcaneal fracture. J Orthop Trauma. 2004;18:197–201.
4. Dachtler HW. Fractures of the anterior superior portion of the os calcis due to indirect violence. Am J Roentgenol. 1931;25:926–631.
5. Degan TJ, Morrey BF, Braun DP. Surgical excision for anterior-process fractures of the calcaneus. J Bone Joint Surg Am. 1982;64-A(4):519–25.
6. Dewar FP, Evans DC. Occult fracture-subluxation of the mid tarsal joint. J Bone Joint Surg (Br). 1968;50:386–8.
7. Ebraheim NA, Savolaine ER, Plaey K, Jackson WT. Comminuted fracture of the calcaneus associated with subluxation of the talus. Foot Ankle. 1993;14:380–4.
8. Gellman M. Fracture of the anterior process of the calcaneus. J Bone Joint Surg Am. 1952;33-A:382–6.
9. Giordano CP, Scott D, Koval KJ, Kummer F, Atik T, Desai P. Fracture blister formation: a laboratory study. J Trauma. 1995;38:907–9.
10. Kleiger B. Injuries of the talus and its joints. Clin Orthop. 1976;121:243–62.
11. Main BJ, Jowett RL. Injuries of the midtarsal joint. J Bone Joint Surg Br. 1975;57:89–97.
12. Myers MS, Fadale PD, Trafton PG. Fracture of the anterior process of the calcaneus as a cause of lateral foot pain. Contemp Orthop. 1989;18:445–9.
13. Ricci WM, Bellabarba C, Sanders R. Transcalcaneal talonavicular dislocation. J Bone Joint Surg Am. 2002;84-A:557–61.
14. Robbins MI, Wilson MG, Sella EJ. MR imaging of anterosuperior calcaneal process fractures. Am J Roentgenol. 1999;172(2):475–9.
15. Sanders R, Vaupel ZM, Erdogan M, Downes K. Operative treatment of displaced itnraarticular calcaneal fractures: long-term (10-20 years) results in 108 fractures using a prognostic CT classification. J Orthop Trauma. 2014;28(10):51–63.
16. Strauss EJ, Petrucelli G, Bong M, Koval KJ, Egol KA. Blisters associated with lower-extremity fracture: results of a prospective treatment protocol. J Orthop Trauma. 2006;20:618–22.
17. Trnka HJ, Zettl R, Ritschl P. Fracture of the anterior superior process of the calcaneus; an often misdiagnosed fracture. Arch Orthop Trauma Surg. 1998;117:300–2.
18. Zwipp H. Biomechanics of the ankle joint. Unfallchirurg. 1989;92(3):98–102.

19

Posterior Calcaneal Tuberosity Fractures

Matthew C. Avery and Michael J. Gardner

Background

Fractures of the calcaneal tuberosity, also referred to as tuberosity avulsion fractures, are a rare and distinct variant of calcaneal injury representing only 1–3% of calcaneal fractures [1–3]. While the majority of intra-articular calcaneal fractures typically result from a high energy axial loading of the hindfoot during fall or motor vehicle collision, calcaneal tuberosity fractures occur following excessive loading of the gastrocsoleus complex, resulting in tension failure of the superior portion of the calcaneal tuberosity. The most commonly observed mechanism of injury is forced dorsiflexion of the ankle, usually occurring during a fall from standing. However, concentric contraction of the gastrocsoleus complex, which occurs during push off and blunt force trauma have also been reported. Unlike intra-articular variants typically resulting from high energy trauma in young and healthy patients, calcaneal tuberosity fractures typically occur from relatively low energy injuries in elderly patients with multiple comorbid conditions and subsequent pathologic bone quality [4–6].

When viewed in the sagittal plane, the fracture line often originates from the distal extent of the Achilles tendon insertion posteriorly, and travel obliquely toward the posterior facet where it exits superiorly, resulting in a triangular fragment of bone. A more transverse orientation of the fracture will exit into, or anterior to, the posterior facet, originally described by Essex-Lopresti as a "tongue-type" fracture variant. In contrast to purely extra-articular, avulsion-type posterior tuberosity fractures, tongue-type fractures typically result from high-energy trauma in nonpathologic bone. Tongue-type fractures produce a similar, triangular fragment involving the calcaneal tuberosity and require similar treatment principles when compared to isolated, extra-articular fractures of the tuberosity [2, 7].

Whether an isolated injury to the calcaneal tuberosity or a tongue-type variant, the Achilles tendon asserts the largest deforming force on the fragment, resulting in sagittal-plane rotation of the fragment on its anterior hinge. This rotational displacement orients the long axis of the fragment perpendicular to the axis of the limb and places extreme pressure on the thin, posterior soft tissues of the hindfoot. In the event that

M. C. Avery (✉)
Division of Orthopaedic Surgery and Sports Medicine, Memorial Healthcare System, Hollywood, FL, USA
e-mail: mavery@mhs.net

M. J. Gardner
Orthopaedic Trauma Service, Stanford University School of Medicine, Palo Alto, CA, USA
e-mail: michaelgardner@stanford.edu

© Springer Nature Switzerland AG 2020
M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_19

this pressure is not relieved, vascular insufficiency may result in full-thickness necrosis of the soft tissues within hours of the injury. In contrast to many intra-articular calcaneal fractures, which can be temporized in a well-padded splint, expedient evaluation and treatment are required to minimize the incidence of this complication [8, 9].

Initial Workup/Evaluation

Patients found to have a displaced fracture of the calcaneal tuberosity should receive an urgent evaluation. The patient's history should be thoroughly examined for both the mechanism of injury and time elapsed since the injury. The examiner should determine whether associated medical conditions are present, including osteoporosis, diabetes, peripheral neuropathy, or immunosuppressive therapy, all of which are associated with pathologic bone quality and increased risk of calcaneal avulsion fracture. Tobacco use should be ascertained and counseled accordingly [4].

Physical examination should include a detailed analysis of the soft tissues overlying the hindfoot. Early soft-tissue vascular insufficiency may be indicated by pale and nonblanching skin overlying the displaced calcaneal tuberosity. Late findings of soft tissue compromise may include a dusky appearance of the skin, epidermal slough, or a full-thickness defect exposing the calcaneal tuberosity. Examination of the contralateral extremity may suggest an associated gastrocsoleus contracture, which may predispose to the injury and assist in the development of an effective treatment strategy [10, 11].

Radiographic examination should include AP and lateral projections of the involved foot. The size and displacement of the tuberosity fragment will be best visualized on the lateral projection. In the absence of intra-articular involvement, computed tomography is unlikely to assist in the development or execution of a treatment strategy, thus is typically not required.

Treatment

Goals of Treatment

The goals of treatment for calcaneal tuberosity fractures are:

- Anatomic restoration of the calcaneus
- Restoration of a functional gastrocsoleus complex
- Stable fixation allowing for early range of motion of the ankle and hindfoot
- Minimize soft tissue complications

Acute Treatment

Immediately following the history and physical exam, attention should turn to minimizing pressure on the posterior soft tissues. The foot and ankle should be immobilized in equinus to reduce the deforming force of the gastrocsoleus complex. The splint should avoid contact with the posterior soft tissues. An anterior plaster slab splint will both limit dorsiflexion of the ankle and avoid skin contact posteriorly. Similarly, casting the ankle in plantarflexion and windowing the cast over the posterior heel may accomplish these goals. Placement of several pillows under the affected knee functions to relax the gastrocnemius, further reducing tuberosity displacement in patients with concomitant gastrocnemius contracture.

Nonoperative Treatment

Nonoperative treatment of calcaneal tuberosity fractures should be reserved for minimally displaced fractures: patients who are of low physical demand and/or nonambulatory, and patients whose medical comorbidities preclude either general or regional anesthesia with sedation. In addition, nonoperative treatment should be reserved for patients who lack signs of posterior soft tissue compromise.

Patients who are appropriate for nonoperative management may be treated with a period of nonweightbearing with the ankle immobilized in equinus. Both casting or anterior slab splints may effectively immobilize the extremity. Strict elevation is imperative during the immediate postinjury period to reduce swelling and subsequent risk of soft tissue compromise. Frequent skin checks are required to monitor interval displacement of the fragment and subsequent soft tissue compromise. Gradually, over the course of 8–12 weeks, the patient is transitioned to a plantigrade position of the ankle with evidence of progressive radiographic healing [12, 13].

Operative Treatment

Operative treatment of calcaneal tuberosity fractures should be considered for all fractures displaced >1 cm and in cases of impending soft tissue compromise. The goals of surgical management include stable, anatomic restoration of the calcaneus and gastrocsoleus complex, and immediate relief of undue pressure on the posterior soft tissues. These goals can be accomplished by both percutaneous and open methods. Methods of surgical fixation vary depending on the size of the displaced tuberosity fragment.

Typically, the patient is positioned prone to allow full access to the posterior hindfoot and calf. Alternatively, lateral decubitus positioning also allows excellent fluoroscopic visualization and fracture reduction. A nonsterile tourniquet may be placed on the thigh and utilized if an open approach is required. Pharmacologic muscle relaxation is imperative to minimize the force required for fragment reduction, subsequently minimizing the risk of iatrogenic fragment comminution.

Prior to reduction and fixation of the tuberosity fragment, it is advantageous to inspect for concomitant gastrocsoleus contracture. Although feasible to examine the injured extremity following fixation, forced dorsiflexion of the injured ankle risks compromising tuberosity fixation. Alternatively, the noninjured extremity may be examined. A reduction in ankle dorsiflexion with the knee held in both flexion and extension indicates contracture of the gastrocsoleus complex. If ankle dorsiflexion improves with flexion of the knee, an isolated contracture of the gastrocnemius is identified. Any suspicion of contracture should be managed surgically to reduce undue tension on the tuberosity repair. Isolated gastrocnemius contracture may be managed with recession through a separate incision at the musculotendinous junction. Lengthening of the Achilles tendon will address contracture of the gastrocsoleus complex [14].

Suture Fixation

Calcaneal tuberosity fractures resulting in a small avulsive fragment are typically too small to allow for screw fixation. Small avulsion fragments are less likely to produce posterior soft tissue compromise and may be managed similarly to an isolated Achilles tendon disruption, either operatively or nonoperatively. Potential soft tissue compromise necessitates operative intervention, which typically requires suture fixation of the Achilles to reduce and secure the displaced tuberosity fragment. A variety of fixation strategies have been described, including the use of calcaneal bone tunnels, tension-band wiring, corkscrew anchors, and suture-button devices [10, 15–21].

Percutaneous Reduction and Fixation

Percutaneous methods of tuberosity fixation may be considered when the fragment is of sufficient size to allow for successful screw fixation. Additionally, percutaneous fixation provides a means of urgent surgical treatment in the setting of posterior tissue compromise and avoids extensive surgical dissection through tenuous soft tissues.

Utilizing fluoroscopy, a large pointed-reduction forceps is placed, spanning the displaced fragment and the plantar aspect of the intact calcaneus. Alternatively, two reduction forceps may be placed, each just lateral to the Achilles tendon, which function to better distribute the pressure required for fragment reduction. Small stab incisions allow for insertion of the clamp in a minimally traumatic fashion.

The foot is plantarflexed to reduce the deforming force of the gastrocsoleus complex. The pointed reduction forceps are tightened, affording reduction of the fragment. Fluoroscopy is utilized to confirm successful reduction. If reduction is inadequate, well-planned stab incisions may allow for percutaneous insertion of a Freer elevator or similar instrument, allowing for direct manipulation of the fragment. If reduction is achieved, final fixation of the fragment is completed with multiple screws. Inadequate reduction necessitates conversion to open reduction.

Screw size varies and is dictated by fragment size. Both solid and cannulated screws may be used. Use of washers is advantageous due to the thin cortical bone covering the cephalad tuberosity, as well as the predominance of poor bone quality associated with this injury pattern. Lagging the fracture, either by technique or with the use of partially threaded screws, use of nonparallel screws, and orientation of the screws oblique to the pull of the Achilles tendon in the sagittal plane are ideal to maximize the force required for construct failure.

Open Reduction and Internal Fixation

Failure of percutaneous management necessitates an open surgical approach to afford anatomic reduction of the fragment. Transverse, longitudinal midline, and longitudinal para-Achilles approaches have been described. The ideal surgical approach avoids further injury to compromised soft tissues and allows access for debridement and reduction of the tuberosity fragment. Following reduction with pointed reduction forceps, the fragment is held with multiple screws [17, 22, 23].

MC: 69-Year-Old Female with Heel Pain

Case Presentation

MC is a 69-year-old female who presented to an outside emergency department with the chief complaint of right heel pain after sustaining a fall from standing. Immediately following the injury, she was unable to bear weight on the right lower extremity. She endorsed tripping on a chair approximately 8 hours prior to arrival and denied a loss of consciousness or other extremity injury. On primary survey, she is alert and oriented, with a patent airway, and hemodynamically stable. Secondary survey is completed, which confirms an isolated injury to the right foot.

Her medical history included hypertension, hypothyroidism, and diabetes mellitus. Her hypothyroidism was well controlled. The patient endorsed poor control of her diabetes with a recent hemoglobin A1C of 8.1. She took no other pertinent medications, denied tobacco or alcohol use, and had no allergies to medication.

Physical exam revealed swelling and ecchymosis localized to the posterior aspect of the hindfoot. A bony prominence was palpated just proximal to the ecchymosis. Skin was intact; however, the skin overlying the bony prominence was blanched and adjacent to a 1 cm^2 area of epidermal slough. The patient was exquisitely tender to palpation within this region and was nontender throughout the forefoot and midfoot. Compartments of the foot and calf were soft and compressible. Passive ankle range of motion exacerbated her heel pain, limiting patient cooperation during motor examination of the foot and ankle. Sensation was intact to light touch throughout the foot. The foot was warm with palpable dorsalis pedis and posterior tibial arteries. Examination of the right leg proximal to the ankle was benign.

Radiographs of the right foot were reviewed, revealing a displaced, extra-articular fracture of the calcaneal tuberosity. Due to a lack of orthopedic consultation at the initial facility, the patient was transferred to a tertiary center for further management of this injury.

The patient's clinical (Fig. 19.1) and radiographic (Fig. 19.2) examinations were consistent with a displaced extra-articular fracture of the calcaneal tuberosity with early signs of vascular insufficiency and impending necrosis of the soft tissues overlying the fragment.

Unfortunately, delays prior to initial presentation and transfer to her definitive treatment facility resulted in early ischemic changes in the

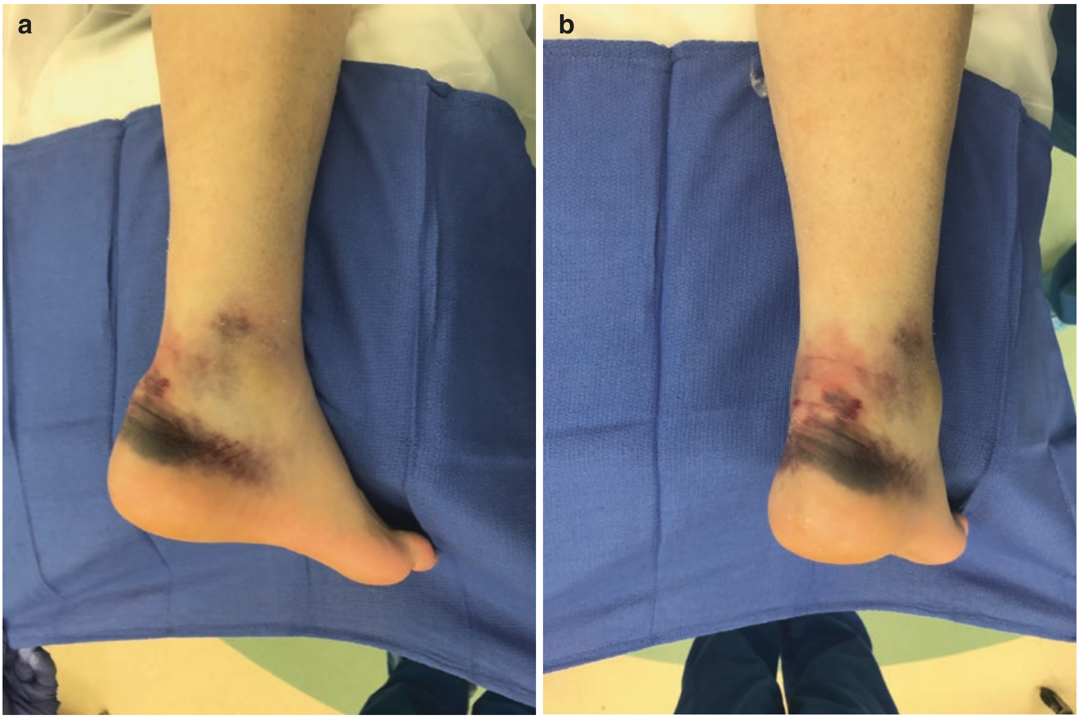


Fig. 19.1 Clinical pictures of the injured foot, from (**a**) lateral and (**b**) posterior

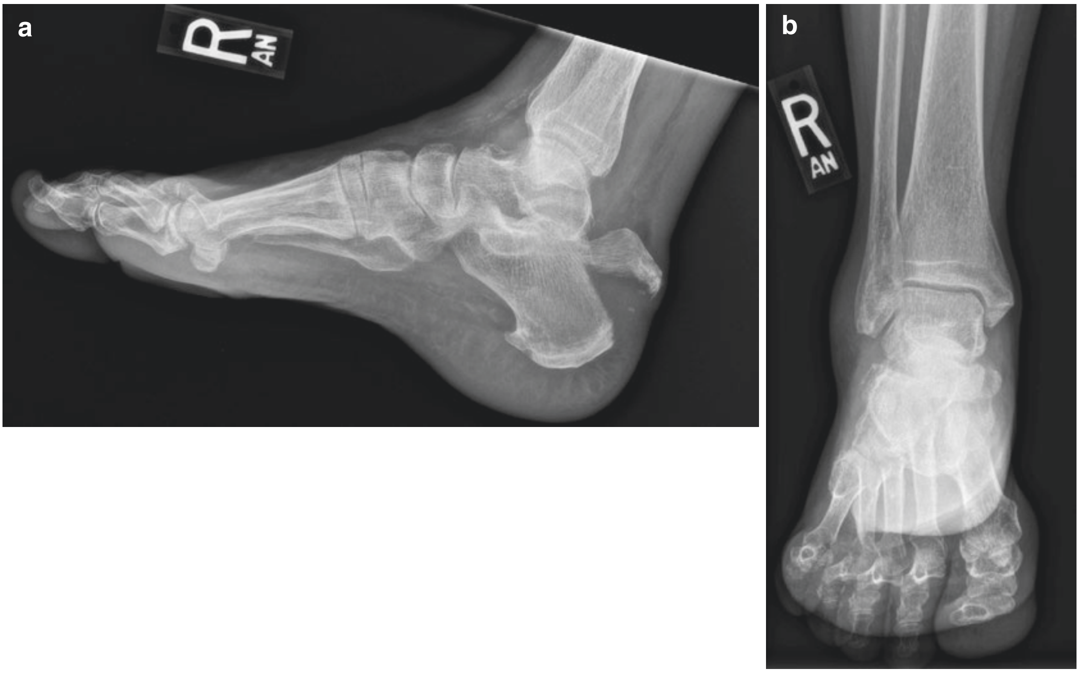


Fig. 19.2 (**a**) AP and (**b**) lateral radiographs of the foot and ankle

posterior soft tissues. The transferring facility immobilized the patient in a plantigrade position, promoting further soft tissue injury. Failure to act urgently placed the patient at an unacceptably high risk of full-thickness soft tissue necrosis. She was indicated for urgent surgical management.

The patient was brought to the operating room where she is placed prone. The operative extremity was placed on a foam leg ramp to facilitate lateral fluoroscopic imaging. The ipsilateral hip was bumped to neutralize rotation of the extremity. Chemical paralysis was confirmed with the anesthesia team. The contralateral extremity was without evidence of gastrocsoleus contracture (Fig. 19.3).

An attempt at percutaneous reduction was made to avoid further soft tissue insult. Small stab incisions were made to allow the placement of two pointed reduction forceps. The foot was plantarflexed and the reduction forceps were sequentially closed, reducing the tuberosity fragment. Reduction was confirmed fluoroscopically (Fig. 19.4).

Fig. 19.3 Clinical picture of the injured extremity after positioning and draping

6.5 mm partially threaded, cannulated screws were selected for definitive fixation. Threaded guidewires are placed across the fragment and measured. The screws were placed, utilizing washers to distribute the compressive force afforded by the 6.5 mm thread size. Final fluoroscopic views demonstrated adequate reduction and positioning of implants. A small, comminuted fragment in the region of the Achilles tendon insertion remained displaced; however, it was not placing undue pressure on the posterior soft tissues. Open management of this fragment would require dissection through tenuous soft tissues and was not required (Fig. 19.5).

The patient was immobilized in equinus utilizing a dorsal blocking splint (Fig. 19.6). She was kept nonweightbearing, advised to elevate the extremity at all times, and avoid any pressure on the posterior aspect of the hindfoot. A skin check was performed 10 days postsurgically, demonstrating some epidermal slough and blistering, but without evidence of full-thickness soft tissue necrosis. In an effort to protect the construct and the posterior soft tissues, she was placed back into the dorsal blocking splint.

At 6 weeks, the ecchymosis resolved, incisions were healing uneventfully, and previous blistering demonstrated progressive epithelization (Fig. 19.7a). Radiographs demonstrated maintenance of reduction of the main tuberosity fragment, with interval displacement of the posterior comminution (Fig. 19.7b). She was kept nonweightbearing and transitioned to a plantigrade position in a removable boot at this time. She was instructed to remove the boot several times per day and begin an ankle range of motion program focusing on both active and passive dorsiflexion to neutral. Neither dorsiflexion past neutral, nor active plantarflexion were allowed.

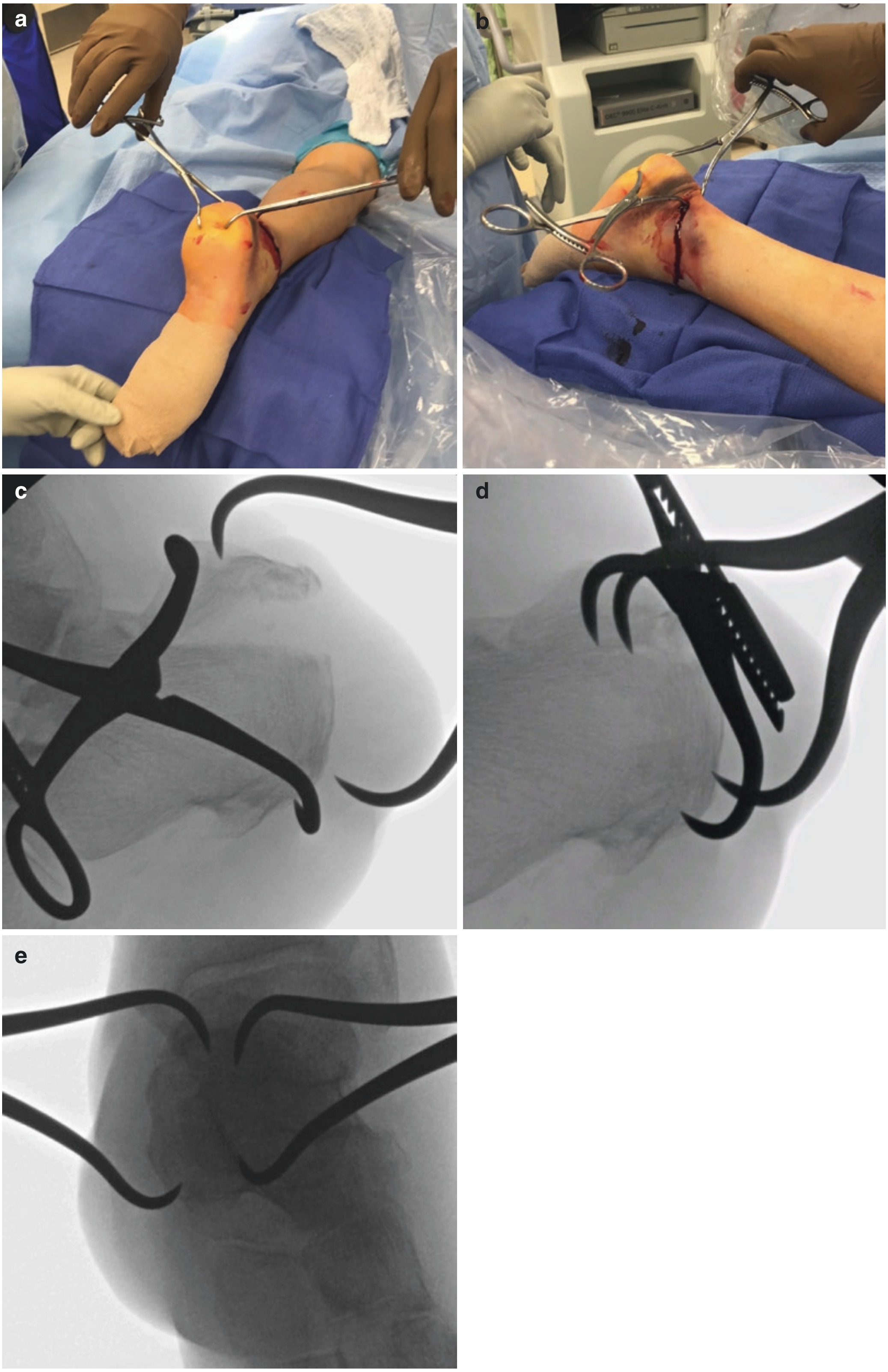


Fig. 19.4 Clinical pictures of the injured foot, from (**a**) distal and (**b**) lateral following percutaneous clamp placement. (**c**, **d**) Lateral and (**e**) AP fluoroscopic imaging demonstrating reduction of the tuberosity fragment

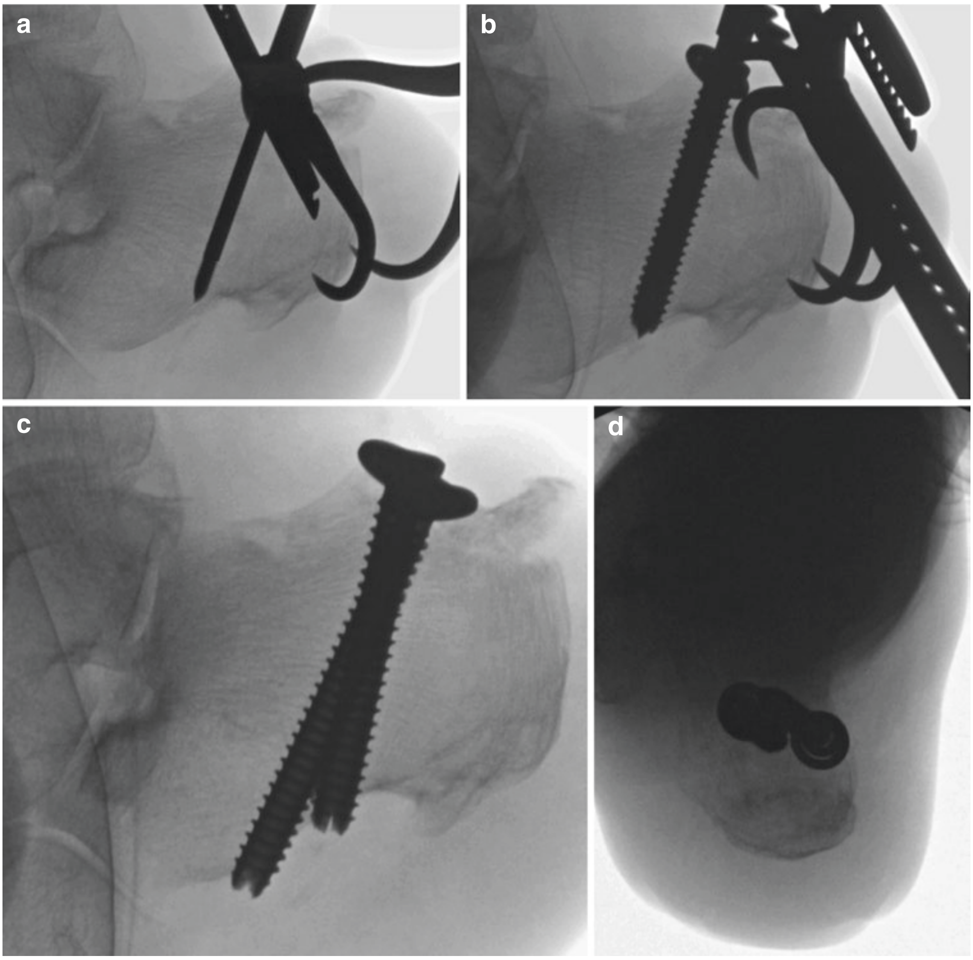


Fig. 19.5 Lateral radiographs demonstrating (**a**) guidewire placement and (**b**) screw placement. Final fluoroscopic (**c**) lateral and (**d**) Harris views

Fig. 19.6 A dorsal blocking splint is fashioned prior to gently wrapping with an elastic bandage. This limits ankle dorsiflexion and protects the surgical construct in the postoperative period

At 12 weeks postoperatively, the soft tissues were benign (Fig. 19.7c). She is allowed to slowly progress to full weightbearing over the next 2 weeks under physical therapy guidance. Range of motion restrictions were lifted. At 16 weeks, the patient was full weightbearing without restriction and was ambulating without assistive devices.

Another example of a closed, extra-articular calcaneal tuberosity fracture requiring urgent treatment is demonstrated in Fig. 19.8. Note the displacement of the large tuberosity fragment and absent posterior soft tissue shadow. Due to impending soft tissue compromise, the patient was urgently treated with closed reduction and percutaneous screw placement.

Fig. 19.7 (**a**) Clinical image of the injured extremity at 6 weeks postoperatively. (**b**) Clinical image and (**c**) lateral radiograph at 12 weeks postoperatively

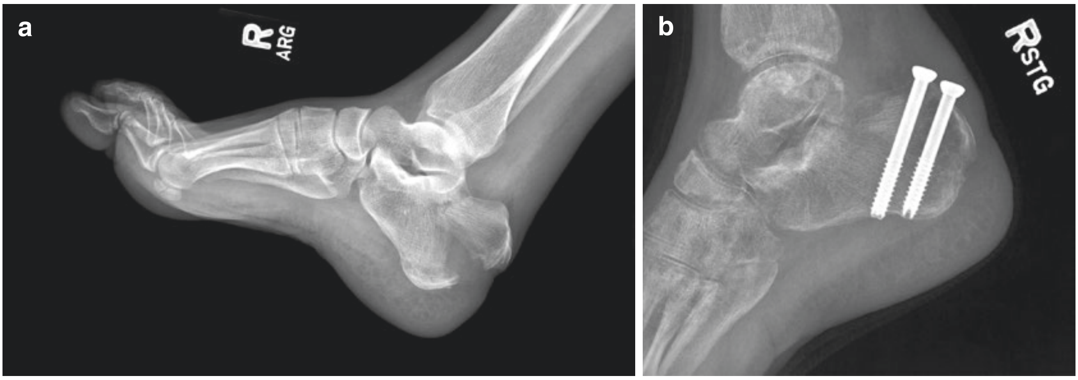


Fig. 19.8 Example of a closed, extra-articular calcaneal tuberosity fracture requiring urgent treatment. (**a**) Lateral radiographs of the foot and ankle preoperatively and (**b**) 12 weeks postoperatively. (*Case examples courtesy of Anna Miller MD, Washington University/Barnes Jewish Hospital in Saint Louis, Missouri.*)

References

1. Lee S, Huh S, Chung J, Kim D-W, Kim Y-J, Rhee S-K. Avulsion fracture of the calcaneal tuberosity: classification and its characteristics. Clin Orthop Surg. 2012;4:134–8.
2. Beavis RC, Rourke K, Court-Brown C. Avulsion fracture of the calcaneal tuberosity: a case report and literature review. Foot Ankle Int/Am Orthop Foot Ankle Soc [and] Swiss Foot Ankle Soc. 2008;29(8):863–6.
3. Lowy M. Avulsion fractures of the calcaneus. Surgery. 1987;69(2):309–11.
4. Gitajn L. Calcaneal avulsion fractures: a case series of 33 patients describing prognostic factors and outcomes. Foot Ankle Spec. 2016;8(1):10–7.
5. Rothberg A. Avulsion fracture of the os calcis. J Bone Joint Surg Am. 1939;21A:218–20.
6. Rijal L, Sagar G, Adhikari D, Joshi KN. Calcaneal tuberosity avulsion fracture: an unusual variant. J Foot Ankle Surg [Internet]. 2012;51(5):666–8. Elsevier Ltd; Available from: https://doi.org/10.1053/j.jfas.2012.05.004.
7. Essex-Lopresti P. The mechanism, reduction technique, and results in fractures of the OS calcis. Clin Orthop Relat Res. 1993;290:3–16.
8. Hess M, Booth B, Laughlin RT. Calcaneal avulsion fractures: complications from delayed treatment. Am J Emerg Med. 2008;26(2):1–4.
9. Gardner MJ, Nork SE, Barei DP, Kramer PA, Sangeorzan BJ, Benirschke SK. Secondary soft tissue compromise in tongue-type calcaneus fractures. J Orthop Trauma. 2008;22(7):439–45.
10. Banerjee R, Chao J, Sadeghi C, Taylor R, Nickisch F. Fractures of the calcaneal tuberosity treated with suture fixation through bone tunnels. J Orthop Trauma [Internet]. 2011;25(11):685–90. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21654526
11. DiGiovanini CW, Kuo R, Tejwani N, Price R, Hansen ST Jr, Cziernecki J, et al. Isolated gastrocnemius tightness. J Bone Joint Surg Am [Internet]. 2002;84–A(6):962–70. Available from: http://www.ncbi.nlm.nih.gov/pubmed/12063330
12. Heckman J. Fractures and dislocations of the foot. Rockwood and Green's fractures in adults, vol 2. 4th ed. 1996. p. 2332–3.
13. Sanders R, Hansen S, McReynolds I. Trauma to the calcaneus and it's tendon. Fractures of the calcaneus. Disorders of the foot and ankle, vol 1. 2nd ed. 1991. p. 2338–9.
14. Abdulmassih S, Phisitkul P, Femino JE, Amendola A. Triceps Surae contracture: implications for foot and ankle surgery. J Am Acad Orthop Surg [Internet]. 2013;21:398–407. Available from: http://www.jaaos.org/content/21/7/398.abstract
15. Harb Z, Dachepalli S, Mani G. An alternative method of fixation of calcaneal tuberosity fractures using the tightrope® technique. J Foot Ankle Surg [Internet]. 2013;52(6):762–5. Elsevier Ltd; Available from: https://doi.org/10.1053/j.jfas.2013.08.005.
16. Wakatsuki T, Imade S, Uchio Y. Avulsion fracture of the calcaneal tuberosity treated using a side-locking loop suture (SLLS) technique through bone tunnels. J Orthop Sci [Internet]. 2016;21(5):690–3. Available from: http://linkinghub.elsevier.com/retrieve/pii/S0949265815000135
17. Lui TH. Fixation of tendo Achilles avulsion fracture. Foot Ankle Surg. 2009;15(2):58–61.
18. Levi N, Garde L, Kofoed H. Avulsion fracture of the calcaneus: report of a case using a new tension band technique. J Orthop Trauma. 1997;11(1):61–2.
19. Greenhagen RM, Highlander PD, Burns PR. Double row anchor fixation: a novel technique for a diabetic calanceal insufficiency avulsion fracture. J Foot Ankle Surg [Internet]. 2012;51(1):123–7. Elsevier Ltd; Available from: https://doi.org/10.1053/j.jfas.2011.09.006.
20. Squires B, Allen PE, Livingstone J, Atkins RM. Fractures of the tuberosity of the calcaneus. J Bone Joint Surg Br. 2001;83(January):55–61.

21. Nagura I, Fujioka H, Kurosaka M, Mori H, Mitani M, Ozaki A, et al. Modified tension band wiring fixation for avulsion fractures of the calcaneus in osteoporotic bone: a review of three patients. J Foot Ankle Surg [Internet]. 2012;51(3):330–3. Elsevier Ltd; Available from: https://doi.org/10.1053/j.jfas.2011.10.049.
22. Banerjee R, Chao JC, Taylor R, Siddiqui A. Management of calcaneal tuberosity fractures. J Am Acad Orthop Surg. 2012;20(4):253–8.
23. Eren A, Cift H, Özkan K, Söylemez S. Transverse incision for calcaneal tuberosity avulsion fractures. J Foot Ankle Surg. 2012;51(1):133–4.

Extraarticular Calcaneal Body Fractures

20

John W. Munz and Stephen J. Warner

Introduction

While the vast majority of literature on calcaneus fractures focuses on intra-articular injuries, approximately 25% of calcaneus fractures are extraarticular [1–3]. Extraarticular calcaneus fractures can include fractures of the anterior process, posterior tuberosity, sustentaculum, and body. Of these, extraarticular calcaneal body fractures have received much less attention. Nonetheless, the extraarticular portion of the calcaneal body has several anatomic features that are critical for maintaining proper ankle and foot function, and fractures that disrupt the architecture of the calcaneal body can lead to significant patient morbidity. An understanding of the native anatomy of the calcaneal body and how alteration of this anatomy can lead to foot and ankle dysfunction is important for optimizing outcomes in patients with these injuries [4–6].

The extraarticular portion of the calcaneal body is critical for maintenance of calcaneus length, height, width, and alignment. Each of these parameters plays significant roles in the biomechanics responsible for proper foot and ankle function [7]. Calcaneal length provides lateral column support leading to the cuboid to help maintain the posteromedial arch of the foot. Calcaneal height maintains the appropriate length-tension relationship of the gastrocnemius-soleus complex with the attachment of the Achilles tendon to the posterior calcaneal tuberosity. The gastrocnemius-soleus complex applies high forces to the calcaneus during midstance and terminal stance phases of the gait cycle. Transmission of these forces to the midfoot and forefoot through the plantar fascia and intrinsic foot muscles is required for the push-off phase and highlights the importance of calcaneal height for a normal gait. In addition, calcaneal height maintains proper talar inclination, which is necessary for full tibiotalar articulation, as well as limb length. Calcaneal width supports the anatomic location for the peroneal tendons and ensures proper gliding of the tendons within their sheath and function of these muscles in everting and plantarflexing the foot. Appropriate alignment of the calcaneus dictates the functional relationships of the surrounding ankle, subtalar, and transverse tarsal joints. The subtalar joint is closely coupled to the architecture of the calcaneal body and allows for proper hindfoot eversion and inversion. These movements of the hindfoot allow foot flexibility during midstance to adapt to the ground as well as foot rigidity during push-off for force transmission [7].

The bony architecture of the calcaneal body significantly impacts the injury patterns seen in

J. W. Munz · S. J. Warner (✉)
Department of Orthopaedic Surgery,
University of Texas Health Science Center,
Houston, TX, USA
e-mail: John.W.Munz@uth.tmc.edu;
Stephen.J.Warner@uth.tmc.edu

© Springer Nature Switzerland AG 2020

M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_20

this location [3, 8]. The cortical shell has a variable thickness, with the thinnest portion occupying the lateral wall of the calcaneal body. Much thicker cortical bone is seen supporting the region by Gissane's critical angle near the anterior aspect of the calcaneal body. Similarly, dense trabecular bone resides around Gissane's critical angle and supports the posterior articular facet. In contrast, the trabecular bone density is relatively osteoporotic elsewhere within the more posterior and plantar aspects of the calcaneal body. This has important implications for optimizing the position of implants for maximum fixation.

Evaluation

Fractures isolated to the calcaneal body occur with similar axial loading and twisting mechanisms as intra-articular calcaneus fractures but are often lower energy. These can also occur from a direct blow to the calcaneus (Fig. 20.1). Patients with fractures of the calcaneal body will present with pain during ambulation and weight-bearing on the injured extremity. They will also have swelling and tenderness to palpation along the medial and lateral aspects of the hindfoot.

The majority of calcaneal body fractures can be diagnosed with conventional calcaneus radiographs, including anteroposterior (AP) and oblique views of the foot, lateral views of the hindfoot, and Harris axial heel views. These views can reveal the location and degree of disruption to the calcaneal body architecture. AP and oblique foot radiographs can reveal shortening of the foot lateral column. A lateral radiographic view of the calcaneal body provides evaluation of Gissane's critical angle (normal 120–145°) for assessing height. Calcaneal width and alignment are best assessed with the Harris axial heel view. An AP view of the ankle can be useful for evaluating potential calcaneal-fibular impingement.

As with other types of calcaneus fractures, computed tomography (CT) imaging can be an integral aspect of evaluating these injuries. In cases where the mechanism of injury and physical exam suggest a calcaneus fracture but radio-

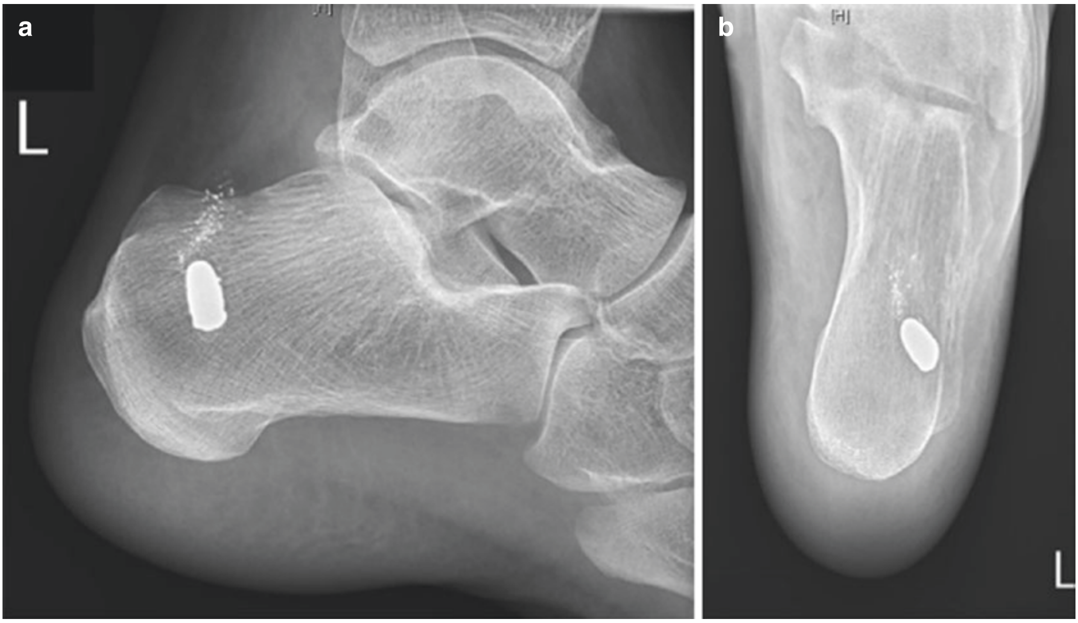


Fig. 20.1 Lateral (**a**) and Harris axial heel view (**b**) of a ballistic extraarticular calcaneal body fracture, which is better delineated on sagittal (**c**) and axial (**d**) CT imaging

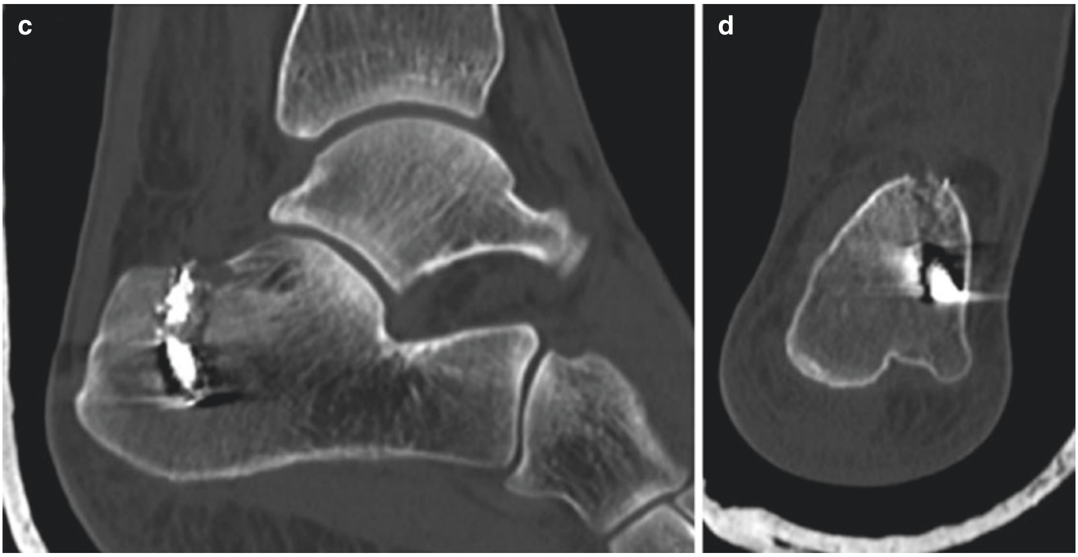


Fig. 20.1 (continued)

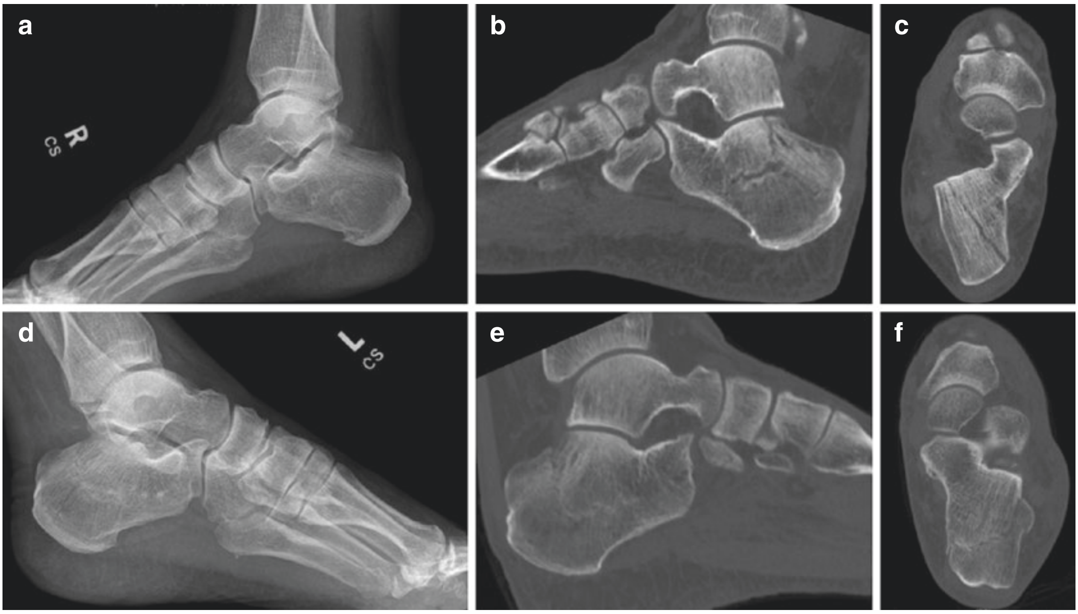


Fig. 20.2 Lateral (**a**, **d**) radiographs and sagittal (**b**, **e**) and axial (**c**, **f**) CT imaging of a patient with bilateral calcaneus fractures. While both appear to be extraarticular on the radiographs, CT imaging demonstrates that the right calcaneus has a fracture line extending into the posterior facet (**b**, **c**), while the left calcaneus fracture is extraarticular (**e**, **f**)

graphs are unrevealing, CT imaging can be used to visualize minimally displaced extraarticular fractures (Fig. 20.2). When there is any concern for articular involvement of the fracture, CT imaging should be performed. Non-displaced articular involvement of a calcaneal body fracture is better evaluated on CT imaging and can alter treatment protocols (Fig. 20.3). In addition, CT can be used to more precisely determine the amount of extraarticular displacement, which is important for deciding on whether surgical intervention is necessary [6, 9, 10].

Fig. 20.3 Lateral (**a**) and Harris axial heel view (**b**) radiographs of a patient with clinical signs and symptoms of a hindfoot injury. While the radiographs did not convincingly demonstrate a calcaneus fracture, sagittal (**c**) and axial (**d**) CT imaging revealed an extraarticular calcaneal body fracture

Treatment

Most extraarticular calcaneal body fractures can be treated nonoperatively with immobilization, early range of motion, and restricted weight-bearing. If significant swelling of the hindfoot is present on presentation, then initial immobilization should consist of a well-padded splint with the ankle in neutral dorsiflexion to protect the soft tissues. When minimal swelling is initially present, a fracture boot immobilizer can be used. Range-of-motion exercises should be initiated early in the treatment process and should focus on maintaining supple ankle and subtalar joints. The patient should remain non-weight-bearing on the injured extremity for approximately 6–10 weeks depending on the extent of the injury and initial fracture displacement.

Indications for operative treatment hinge on the degree of fracture displacement and the resulting alterations in calcaneal length, height, width, and alignment. Evidence does not exist for specific degrees of displacements that warrant operative intervention. One suggestion for defining indications for operative intervention has included injuries with 10° of varus malalignment or more than 1 cm of calcaneal tuberosity medial translation, as well as injuries with 15° of valgus malalignment or more than 1 cm of calcaneal tuberosity lateral translation [6, 11]. However, clinical correlations with these radiographic measurements are lacking.

As with other calcaneal fractures, patient-related factors can have significant influence on determining surgical indications. Medical comorbidities such as diabetes, peripheral vascular disease, and tobacco use can contribute to poor wound healing and often limit the degree of surgical intervention [9, 12, 13].

The goals for operative treatment of extraarticular calcaneus fractures should focus on restoration of calcaneal morphology to prevent functional limitations from the sequelae of altered anatomy [9, 14, 15]. Techniques for reduction and fixation of these fractures follow similar principles used to treat intra-articular fractures.

Outcomes

Published outcomes on patients with extraarticular calcaneal body fractures are limited. However, assessing how alterations in calcaneal body morphology affect patient outcomes can be inferred from studies evaluating the effects of calcaneal body malunions [16–18]. These studies have highlighted that inadequate maintenance or restoration of calcaneal body anatomy can result in significant functional deficits and detrimental effects on patients' quality of life.

Alteration of the individual anatomic components of the calcaneal body can lead to specific pathologic entities [4, 19]. Loss of calcaneal body length leads to poor support of the lateral column with resultant abnormal foot abduction and posterior tibial tendon overload. In addition, a short calcaneus can cause diminished function of the gastrocnemius-soleus complex from a reduced lever arm. Calcaneal body widening can lead to peroneal tendon irritation or dislocation, impingement between the lateral calcaneus and distal fibula, and difficulty with shoe wear. Loss of calcaneus height decreases talar inclination and inhibits tibiotalar articular motion with anterior ankle impingement. Varus malalignment can result in abnormal ankle mechanics and limitations in subtalar function. Other consequences of these abnormal relationships include gait abnormalities and adjacent joint arthritis [20].

Conclusions

Treatment of extraarticular calcaneal body fractures requires knowledge of the important anatomic characteristics of the calcaneal body and the functional consequences that may result when this anatomy is altered. Treatment of patients with these injuries requires evaluation of their injury patterns and displacements in the context of their medical and functional status. Overall the goal of treatment should be restoration of calcaneal morphology to allow hindfoot motion, a stable platform for weight-bearing, painless gait, and normal shoe wear.

References

1. Cave EF. Fracture of the os calcis – the problem in general. Clin Orthop Relat Res. 1963;30:64–6. http://www.ncbi.nlm.nih.gov/pubmed/4385198
2. Warrick CK, Bremner AE. Fractures of the calcaneum, with an atlas illustrating the various types of fracture. J Bone Joint Surg Br. 1953;35-B(1):33–45. http://www.ncbi.nlm.nih.gov/pubmed/13034868
3. Richter M, Kwon JY, Digiovanni CW. Foot injuries. In: Browner BD, Jupiter JB, Krettek C, Anderson PA, editors. Skeletal trauma. 5th ed. Philadelphia: Saunders; 2015. p. 2284–323.
4. Hetsroni I, Nyska M, Ben-Sira D, et al. Analysis of foot and ankle kinematics after operative reduction of high-grade intra-articular fractures of the calcaneus. J Trauma. 2011;70(5):1234–40. https://doi.org/10.1097/TA.0b013e3181dbe5f7.

5. Magnan B, Samaila E, Regis D, Merlini M, Bartolozzi P. Association between CT imaging at follow-up and clinical outcomes in heel fractures. Musculoskelet Surg. 2010;94(3):113–7. https://doi.org/10.1007/s12306-010-0081-8.
6. Rammelt S, Zwipp H. Calcaneus fractures: facts, controversies and recent developments. Injury. 2004;35(5):443–61. https://doi.org/10.1016/j.injury.2003.10.006.
7. Haskell A, Mann R. Biomechanics of the foot and ankle. In: Coughlin M, Saltzman CL, Anderson R, editors. Mann's surgery of the foot and ankle. 9th ed. Philadelphia: Saunders; 2014. p. 3–36.
8. Paul M, Peter R, Hoffmeyer P. Fractures of the calcaneum. J Bone Joint Surg Am. 2004;86(8):1142–5. https://doi.org/10.1302/0301-620X.86B8.15219.
9. Thermann H, Krettek C, Hüfner T, Schratt HE, Albrecht K, Tscherne H. Management of calcaneal fractures in adults. Conservative versus operative treatment. Clin Orthop Relat Res. 1998;353:107–24.
10. Gotha HE, Zide JR. Current controversies in management of calcaneus fractures. Orthop Clin North Am. 2017;48(1):91–103. https://doi.org/10.1016/j.ocl.2016.08.005.
11. Sanders RW, Rammelt S. Fractures of the calcaneus. In: Coughlin MJ, Saltzman CL, Anderson RB, editors. Mann's surgery of the foot and ankle. 9th ed. Philadelphia: Saunders; 2014. p. 2041–100.
12. Agren P-H, Mukka S, Tullberg T, Wretenberg P, Sayed-Noor AS. Factors affecting long-term treatment results of displaced intraarticular calcaneal fractures: a post hoc analysis of a prospective, randomized, controlled multicenter trial. J Orthop Trauma. 2014;28(10):564–8. https://doi.org/10.1097/BOT.0000000000000149.
13. Agren P-H, Wretenberg P, Sayed-Noor AS. Operative versus nonoperative treatment of displaced intra-articular calcaneal fractures: a prospective, randomized, controlled multicenter trial. J Bone Joint Surg Am. 2013;95(15):1351–7. https://doi.org/10.2106/JBJS.L.00759.
14. van Hoeve S, de Vos J, Verbruggen JPAM, Willems P, Meijer K, Poeze M. Gait analysis and functional outcome after calcaneal fracture. J Bone Joint Surg Am. 2015;97(22):1879–88. https://doi.org/10.2106/JBJS.N.01279.
15. Besch L, Radke B, Mueller M, et al. Dynamic and functional gait analysis of severely displaced intra-articular calcaneus fractures treated with a hinged external fixator or internal stabilization. J Foot Ankle Surg. 2008;47(1):19–25. https://doi.org/10.1053/j.jfas.2007.10.013.
16. Myerson M, Quill GE. Late complications of fractures of the calcaneus. J Bone Joint Surg Am. 1993;75(3):331–41. http://www.ncbi.nlm.nih.gov/pubmed/8444911
17. Yu G-R, Hu S-J, Yang Y-F, Zhao H-M, Zhang S-M. Reconstruction of calcaneal fracture malunion with osteotomy and subtalar joint salvage: technique and outcomes. Foot Ankle Int. 2013;34(5):726–33. https://doi.org/10.1177/1071100713479766.
18. Clare MP, Lee WE, Sanders RW. Intermediate to long-term results of a treatment protocol for calcaneal fracture malunions. J Bone Joint Surg Am. 2005;87(5):963–73. https://doi.org/10.2106/JBJS.C.01603.
19. Stephens HM, Sanders R. Calcaneal malunions: results of a prognostic computed tomography classification system. Foot Ankle Int. 1996;17(7):395–401. https://doi.org/10.1177/107110079601700707.
20. Hirschmüller A, Konstantinidis L, Baur H, et al. Do changes in dynamic plantar pressure distribution, strength capacity and postural control after intra-articular calcaneal fracture correlate with clinical and radiological outcome? Injury. 2011;42(10):1135–43. https://doi.org/10.1016/j.injury.2010.09.040.

21

Fractures of the Sustentaculum Tali

Jerad D. Allen and Michael F. Githens

Introduction

The sustentaculum tali is a vital supporting structure for the medial column of the hindfoot. As its Latin name directly states, the sustentaculum tali serves as a veritable “shelf” for the talus. Along with structural support, the sustentaculum serves as a fulcrum for the flexor hallucis longus and provides attachment sites for the deltoid and spring ligaments. Isolated sustentaculum fractures, although rare, are thought to be intra-articular injuries and may lead to subtalar arthritis or tarsal tunnel syndrome if left untreated.

Originally described as a direct impact mechanism by Abel in 1878, isolated sustentacular fractures occur most frequently after a fall from height onto a varus-aligned hindfoot [1, 2]. The sustentaculum is difficult to visualize on plain X-ray (Fig. 21.1); with an incidence approaching 1% of all calcaneus fractures, injury to the sustentaculum tali is often misdiagnosed or frankly missed [3, 4]. No classification system comprehensively describes sustentacular fracture patterns. Many sustentaculum fractures extend into the interval between the anterior and middle facet joints and have therefore been deemed extra-articular fractures. Aside from the documented intra-articular variants, the so-called extra-articular fracture pattern is associated with subtalar incongruency, effectively constituting and behaving as an intra-articular fracture pattern. As such, operative management is warranted to restore joint congruity as would be applicable to other intra-articular fractures [5–7].

Anatomy

The sustentaculum tali is located approximately 2.5 cm distal to the medial malleolus. Morphologically, the sustentaculum is a triangular projection of the medial calcaneus and consists of dense trabecular and cortical bone as opposed to the cancellous bone seen in the remainder of the calcaneus – a composition that is thought to explain the low frequency of isolated sustentaculum fractures [8]. A cadaveric study performed by Olexa et al. further described the shape and position of the sustentaculum as an average 22 × 14 mm elliptical or triangular extension with a 25° cephalad and anterior angle when measured from a line in the midpoint of the calcaneus and parallel to the floor [9].

The middle facet of the calcaneus is the anterosuperior structure supported by the sustentaculum. Interestingly, the anterior and middle facets are confluent in nearly two-thirds of patients and separated by a bony ridge in one-third [9]. This anatomic feature gives further credence to the

---

J. D. Allen · M. F. Githens (✉)
Department of Orthopaedic Surgery and Sports Medicine, University of Washington/Harborview Medical Center, Seattle, WA, USA
e-mail: mfg28@uw.edu

© Springer Nature Switzerland AG 2020

M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_21

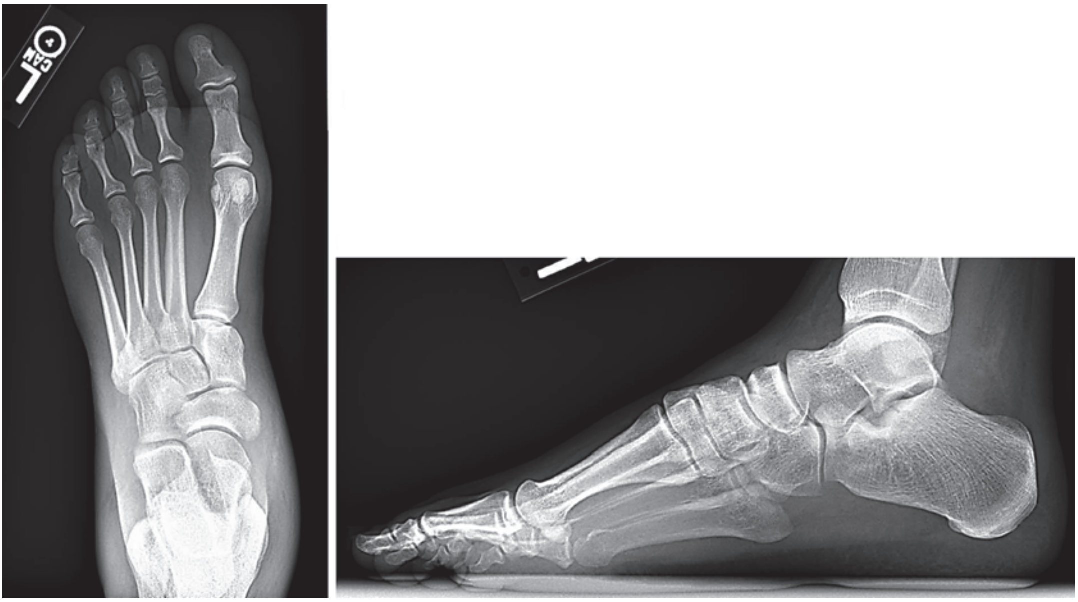


Fig. 21.1 Sustentacular fractures can be subtle and easily missed on plain radiography. AP and lateral foot X-rays demonstrate an isolated sustentaculum tali fracture

argument of sustentaculum fractures being intra-articular in nature.

The sustentaculum tali, together with the flexor retinaculum and the abductor hallucis muscle belly, forms the borders of the tarsal tunnel. The soft tissues contained within this anatomic space, and their relationship to the sustentaculum, are vital when planning surgical fixation. Tendinous structures in immediate proximity include the flexor hallucis longus and the flexor digitorum longus. The tendon of the flexor hallucis longus passes in a fibroosseous corridor on the inferior surface of the sustentaculum and may be impinged upon in the setting of a sustentaculum fracture [7]. The flexor digitorum longus lies immediately superior to the sustentaculum. The tendon of the posterior tibialis, the last of the three tendons of the medial hindfoot, lies superior to the flexor digitorum longus [8].

Two large ligamentous structures share a common attachment site at the sustentaculum. Namely, the tibiocalcaneal portion of the deltoid ligament and the superomedial calcaneonavicular, or "spring" ligament, provide support for the medial tibiotalar and medial arch, respectively [8]. Incompetence of the latter, through a non-anatomic position of the sustentaculum, may lead to pes planovalgus over time [7].

The posteromedial neurovascular bundle, consisting of the posterior tibial artery, posterior tibial vein, and tibial nerve, passes inferior and posterior to the sustentaculum. More specifically, the posterior tibial nerve branches into the medial and lateral plantar nerves superior to the sustentaculum and then courses an average of 8 mm and 16 mm posterior to the sustentaculum on their way to provide innervation for the muscular structures of the plantar foot [10].

Biomechanically, the sustentaculum tali through its support of the middle facet serves as a "pivot-point" for the medial subtalar joint, with the axis of rotation of the posterior calcaneus intersecting the sustentaculum at nearly a 90° angle. This is especially important as the calcaneus shifts into a varus position during the toe-off phase of the gait cycle. Alterations of the intimate relationship of these structures may have downstream effects on the stability of not only the subtalar joint but also the medial longitudinal arch and tarsal tunnel [7, 11, 12]. Wagner et al. performed a cadaveric biomechanical study of the subtalar joint in which contact area and pressure were recorded in various stages of inversion and eversion. They found the anterior/middle facets comprised 31% of the contact area as compared to the posterior facet yet faced 63% of the pressure [13].

Diagnosis

Sustentaculum tali fractures are difficult to diagnose, due in part to their obscurity on plain films. Since sustentaculum fractures often occur as a fall from height, there is a high likelihood of additional and potentially life-threatening injuries. An expedient and systematic primary survey should be performed on all trauma patients to diagnose and treat critical pathologies of the respiratory and cardiovascular systems, per the Advanced Trauma Life Support (ATLS) protocol. The spine should be protected until cleared both clinically and radiographically. Secondary and tertiary surveys ought to be thorough in order to uncover nuanced clues that may indicate further pathology [4].

Suspicion for a sustentacular fracture should be present in the practitioner's mind for any patient with tenderness and/or ecchymosis distal to the medial malleolus, as these can often be the only outward signs of injury. Passive motion of the flexor hallucis longus may also provoke tenderness at the fracture site due to the tendon's position upon the inferior surface of the sustentaculum [3]. The use of plain X-rays for diagnosis can also be inconclusive because of superimposed structures in the area of the sustentaculum. Specifically, the anterior portion of the posterior facet of the calcaneus can obscure observation of the sustentaculum on the lateral view [9]. Of all plain films however, the axial (Harris) view of the calcaneus is most able to visualize the sustentaculum without interference from surrounding structures [3, 5, 7] (Fig. 21.2). If suspected or seen on X-ray, a computed tomography (CT) scan is necessary to fully characterize the extent of sustentaculum tali fractures. Moreover, a CT in the axial and coronal planes can elucidate the extent of the fracture(s), impacted fragments, and articular involvement [3, 7, 14] (Fig. 21.3).

Fig. 21.2 An axial heel view is useful in identifying a sustentacular fracture (red arrows)

Combined Injuries

Isolated sustentaculum tali fractures occur rarely, with the available literature consisting of case reports and case series [3, 5, 7, 12, 15]. However, when present, these fractures occur most frequently alongside of additional fractures of the foot as well as peritalar dislocations [3, 7]. Classically, the sustentacular fragment of a displaced calcaneal fracture has been referred to as the "constant fragment" and is used as an anchoring point for screw fixation. This nomenclature has existed as a result of the strong ligamentous attachments seen in the medial hindfoot, which keep the sustentaculum relatively stable. In the circumstance of highly comminuted calcaneus fractures, Rammelt et al. argue for a direct medial approach to reduce

Fig. 21.3 An axial and coronal plane CT scan formatted in the plane of the hindfoot is used to further characterize the fracture pattern

and stabilize the sustentaculum prior to a traditional extensile lateral approach [16].

Treatment

Treatment of sustentaculum tali fractures is not widely agreed upon, largely based upon the rarity of their occurrence. Traditionally, these injuries in adults were treated nonoperatively with cast immobilization and limited/non-weight-bearing for a period of time [1, 6, 15, 17]. Nonoperative treatment may still be indicated however, especially in the setting of a poor surgical candidate, a non-ambulating patient, a lower extremity with compromised vascularity, and a non-reconstructable fragment [3, 7].

Operative treatment has been gaining favor with the goals being restoration of the articular congruity of the subtalar joint, decompression of the tarsal tunnel, and removing impingement from the tendinous structures. Recommended indications have been described as articular step-off ≥2 mm, polytraumatized patient with multiple operative extremities, depression/impaction of the middle calcaneal facet, fracture extension into the posterior calcaneal facet, and impingement of the flexor hallucis longus, flexor digitorum longus, and/or posterior tibial tendons [3, 5, 7].

Lastly, in situations of delayed presentation or nonunion, fragment excision has been described in case reports with success [12, 15].

Two main approaches to the sustentaculum have been described to both reduce and stabilize the fracture. McReynolds et al., along with alterations by Burdeaux et al., defined the medial approach as longitudinal and parallel to the trajectory of the posterior tibial tendon. The sustentaculum fragment is exposed after retraction of the posterior tibial tendon dorsally and the flexor digitorum longus plantarly [5, 18]. An advantage to this approach lies in its extensibility. Zwipp et al. utilize a 3–5 cm transverse incision directly over the sustentaculum. The flexor digitorum longus and posterior tibial tendon are retracted dorsally, while the flexor hallucis longus is retracted plantarly. Proponents of this approach cite the more proximal incision decreases risk for iatrogenic neurovascular injury [7, 19].

Regardless of the approach, fixation strategies are entirely dependent upon the nature of the fracture. Medial to lateral lag screws, cannulated lag screws, and buttress plating have all been reported [3, 5, 7]. Ultimately, AO/ASIF (*Arbeitsgemeinschaft für Osteosynthesefragen*/Association of the Study of Internal Fixation) principles should dictate appropriate implant use.

Outcomes

Literature concerning outcomes is limited to case reports and case series. No prospective studies to our knowledge have been performed.

Historically, patients presenting with delay after a sustentaculum fracture all but uniformly complained of hindfoot deformity, stiffness, pain, and lost employment. Interestingly, the concluded treatment in 1907 was acute splinting in maximum dorsiflexion and adduction to reduce the fragment [1]. Nonoperative treatment has been described by Carey et al. (1965) following five out of eight sustentaculum tali fractures. The five patients available for follow-up were deemed to have "satisfactory" results, with decreased subtalar motion in one and subtalar arthritis (diagnosed radiographically) in another [17].

Fragment excision in the setting of non- or delayed union has been described with good, albeit subjective results. One adult patient with tarsal tunnel syndrome from a sustentacular nonunion was participating in athletics in 3 months, and one pediatric patient with subtalar pain 1 month after falling off a wall likewise was pain-free and athletic at 3 months postoperatively [12, 15].

Open reduction with internal fixation has been described in case series with positive outcomes. Della Rocca et al. described 15 patients of whom 12 followed up and demonstrated radiographic union in 3 months. Only 6 of the 12 patients were available for follow-up at 1 year. One of those six patients had radiographic signs of subtalar arthritis [5]. Dürr et al. followed 18 out of 31 operatively treated sustentacular fractures, 4 of which were isolated. The American Orthopaedic Foot and Ankle Society (AOFAS) Ankle-Hindfoot Scale, an outcome measure of pain, function, and alignment, was recorded in all patients, with 100 being the maximum score denoting no disability. The AOFAS score for isolated, operatively treated sustentaculum fractures was 100. The mean AOFAS score for the remainder of the patient cohort, who sustained additional foot fractures, was 83.6 [7]. Al-Ashhab et al. described ten patients with sustentaculum tali fractures treated operatively, seven of these were isolated injuries. All patients achieved radiographic union at 6–8 weeks. AOFAS score for isolated injuries was 100, with a mean of 90 for those patients with additional foot fractures/dislocations [3].

Surgical Technique and Case Examples

The preferred method of the authors is a longitudinal approach to the sustentaculum tali as described separately by McReynolds, Burdeaux, and Benirschke [3, 5, 18]. The patient is placed supine on a cantilever radiolucent bed. The ipsilateral hip is not bumped so as to allow maximum access to the medial structures of the hindfoot. A non-sterile tourniquet is placed prior to draping. Preoperative antibiotics are given within 1 h of incision.

The incision follows the longitudinal course of the posterior tibial tendon. Once identified, the posterior tibial tendon sheath is incised in line with the skin incision with the tendon mobilized. Plantar retraction of the tendon will allow access to the cranial portions of the fracture and allow some implant placement. Dorsal retraction of the tendon, followed by developing the interval between the flexor digitorum longus and the neurovascular bundle, will expose the majority of the fracture site. If needed, the flexor hallucis longus may likewise be retracted plantarly. The neurovascular bundle is also retracted plantarly. Proper visualization will therefore facilitate reduction and instrumentation.

Sustentacular fracture morphology is variable. The simplest pattern and easiest to treat is a single fragment shearing pattern with high-quality extra-articular reads plantar to the sustentaculum itself (Fig. 21.4). Reduction of the fragment based upon extra-articular reads leads to a high-quality articular reduction. Typically, dental picks or a small spike pusher can be used to achieve the reduction. Fixation is achieved with a 2.0 mm T-plate functioning as a buttress (Fig. 21.5). After fixing the plate in buttress mode, placement of independent lag screws or lag screws through the plate provides additional interfragmentary compression (Fig. 21.6). An axial heel view is critical to confirm safe screw placement (Fig. 21.7).

When extra-articular reads plantar to the sustentaculum are comminuted, accurate articular reduction becomes more difficult (Fig. 21.8). Adding to this challenge is the inability to directly visualize the intra-articular component of the fracture. In this setting, the surgeon must rely heavily on intraoperative fluoroscopy, particularly a perfect axial (Harris) heel view to

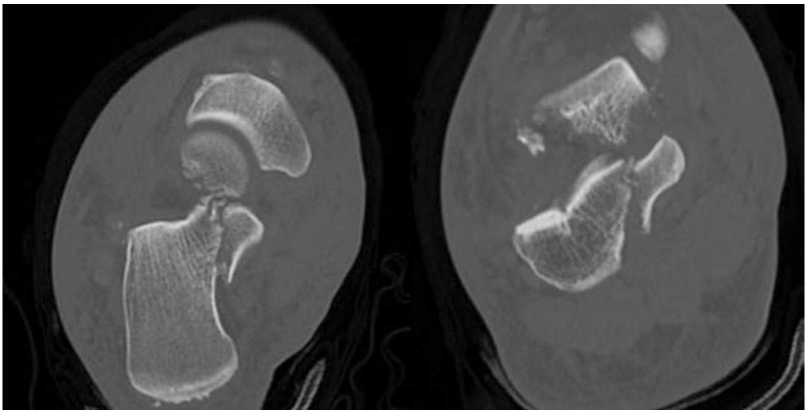


Fig. 21.4 Axial and coronal plane CT scan demonstrating a simple shearing pattern with intact extra-articular reads

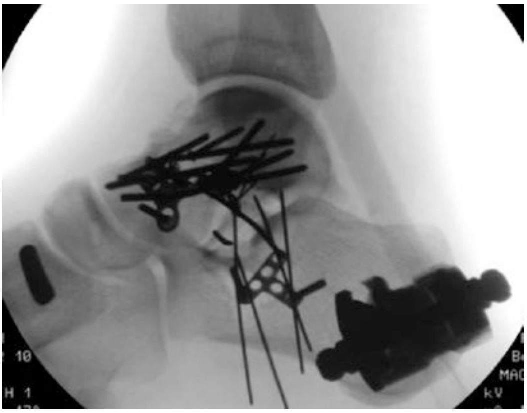


Fig. 21.5 An intraoperative lateral view demonstrating primary fixation with application of a 2.0 mm T-plate functioning as a buttress

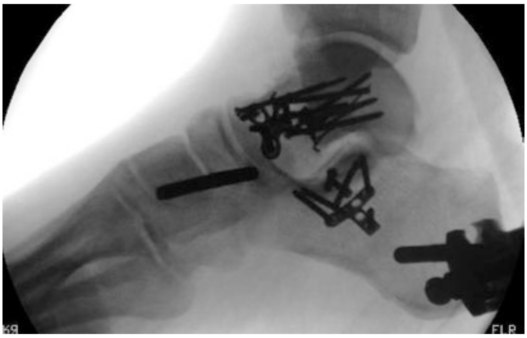


Fig. 21.6 After buttress plate application, 2.0 mm lag screws are placed across the main fracture line for additional interfragmentary compression

Fig. 21.7 An axial heel view ensures safe lag screw placement

judge reduction. Application of a medially based distractor can aid in obtaining a reduction in this situation. If there is a persistent fracture gap after distractor application that cannot be overcome with dental picks or a spiked pusher, a quad clamp can be applied to achieve reduction and fragment compression (Fig. 21.9).

Fig. 21.8 Axial and coronal plane CT demonstrating comminution of the extra-articular reads and articular impaction

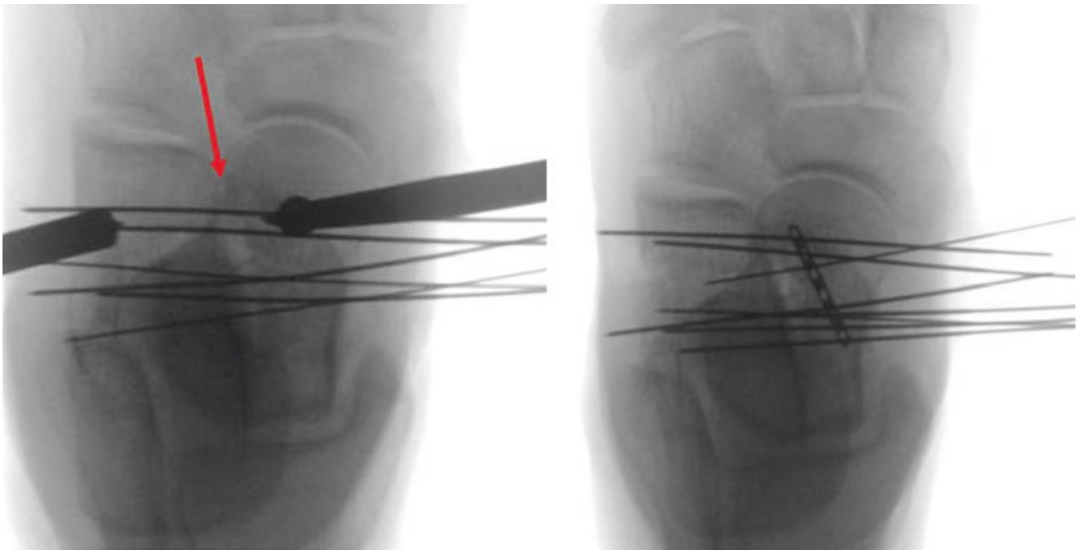


Fig. 21.9 Use of spiked pushers to close a residual gap in the anterior portion of the fracture (red arrow)

Articular comminution or impaction is particularly challenging to manage given the limited ability to directly visualize the intra-articular portion of the sustentacular fracture from the medial approach. Again, the surgeon must rely on high-quality intraoperative fluoroscopy for reduction. Articular disimpaction is typically achieved by using a small freer elevator retrograde through the extra-articular fracture bed. This must be done carefully to prevent displacement of articular fragments into the subtalar joint. Pre-positioned 0.035 inch K-wires are driven across the subchondral surface once disimpaction is achieved for provisional fragment-specific fixation (Fig. 21.10). When small articular fragments will not be captured or supported by the summative implants, provisionally placed K-wires may be bent, cut, and impacted to the appropriate depth and left in place for definitive fragment-specific fixation. Cutting wires flush with the bone in this location is not recommended given the risk for wire migration in close proximity to critical anatomic structures. Multiple plates and independent mini-fragment screws may be needed for fragment-specific fixation in comminuted patterns (Fig. 21.11). Postoperatively, the patients are made non-weight-bearing for 3 months, but early and active ankle and subtalar motion is initiated at 2 weeks postoperatively. Good functional results can be expected when these principles are applied (Fig. 21.12).

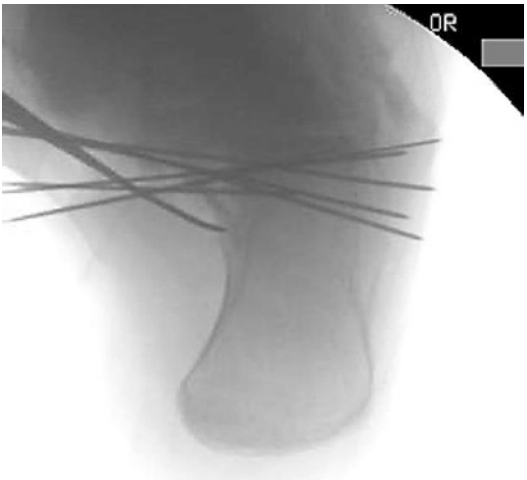


Fig. 21.10 Pre-positioned K-wires are used to raft articular fragments once disimpaction has been achieved

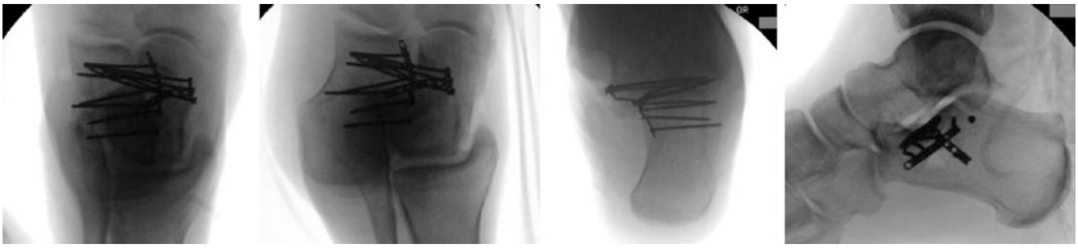


Fig. 21.11 Mini-fragment plates and screws are used to achieve fragment-specific fixation in comminuted fracture patterns

Fig. 21.12 Six-month weight-bearing radiographs demonstrating a well-aligned hindfoot and healed sustentacular fracture

Conclusion

Fractures of the sustentaculum tali are infrequent injuries in the calcaneus and oftentimes are found in tandem with other more common fractures and dislocations. Suspicion and attention to detail are critical in diagnosis as other structures of the hindfoot are superimposed on plain film. Axial (Harris) X-ray and CT scans are critical in verifying the diagnosis. The function of the sustentaculum, namely, as support for middle facet of the calcaneus, is compromised after a fracture – leading to joint incongruity. For this reason, these fractures are treated as intra-articular and surgical stabilization is warranted. A medial longitudinal approach based on the posterior tibial tendon is utilized and fixation varies based on the character of the fracture. Positive outcomes have been reported postoperatively in small retrospective case series.

References

1. Ely LW. Old fracture of the tarsus: with a report of seventeen cases. Ann Surg. 1907;45(1):69–89.
2. Rammelt S, Zwipp H. Calcaneus fractures: facts, controversies and recent developments. Injury. 2004;35(5):443–61.
3. Al-Ashhab ME, Elgazzar AS. Treatment for displaced sustentaculum tali fractures. Foot (Edinb). 2017;35:70–4.
4. Pfeifer R, Pape HC. Missed injuries in trauma patients: a literature review. Patient Saf Surg. 2008;2:20.
5. Della Rocca GJ, Nork SE, Barei DP, Taitsman LA, Benirschke SK. Fractures of the sustentaculum tali: injury characteristics and surgical technique for reduction. Foot Ankle Int. 2009;30(11):1037–41.
6. Schepers T, Ginai AZ, Van Lieshout EM, Patka P. Demographics of extra-articular calcaneal fractures: including a review of the literature on treatment and outcome. Arch Orthop Trauma Surg. 2008;128(10):1099–106.
7. Dürr C, Zwipp H, Rammelt S. Fractures of the sustentaculum tali. Oper Orthop Traumatol. 2013;25(6):569–78.
8. Hall RL, Shereff MJ. Anatomy of the calcaneus. Clin Orthop Relat Res. 1993;290:27–35.
9. Olexa TA, Ebraheim NA, Haman SP. The sustentaculum tali: anatomic, radiographic, and surgical considerations. Foot Ankle Int. 2000;21(5):400–3.
10. Sora MC, Jilavu R, Grübl A, Genser-Strobl B, Staykov D, Seicean A. The posteromedial neurovascular bundle of the ankle: an anatomic study using plastinated cross sections. Arthroscopy. 2008;24(3):258–263.e251.
11. Sarrafian SK. Biomechanics of the subtalar joint complex. Clin Orthop Relat Res. 1993;290:17–26.

12. Myerson MS, Berger BI. Nonunion of a fracture of the sustentaculum tali causing a tarsal tunnel syndrome: a case report. Foot Ankle Int. 1995;16(11):740–2.
13. Wagner UA, Sangeorzan BJ, Harrington RM, Tencer AF. Contact characteristics of the subtalar joint: load distribution between the anterior and posterior facets. J Orthop Res. 1992;10(4):535–43.
14. Daftary A, Haims AH, Baumgaertner MR. Fractures of the calcaneus: a review with emphasis on CT. Radiographics. 2005;25(5):1215–26.
15. Huri G, Atay AO, Leblebicioğlu GA, Doral MN. Fracture of the sustentaculum tali of the calcaneus in pediatric age: a case report. J Pediatr Orthop B. 2009;18(6):354–6.
16. Rammelt S, Zwipp H. Fractures of the calcaneus: current treatment strategies. Acta Chir Orthop Traumatol Cechoslov. 2014;81(3):177–96.
17. Carey DJ, Lance EM, Wade PA. Extra-articular fractures of the os calcis – a follow-up study. J Trauma. 1965;5:362–72.
18. Burdeaux BD. The medical approach for calcaneal fractures. Clin Orthop Relat Res. 1993;290:96–107.
19. Zwipp H, Rammelt S, Barthel S. Calcaneal fractures–open reduction and internal fixation (ORIF). Injury. 2004;35(Suppl 2):SB46–54.

Ipsilateral Talus and Calcaneus Fractures

22

Michael F. Githens and Reza Firoozabadi

Introduction

Although combined talus and calcaneus fractures are largely uncommon, ipsilateral calcaneus fractures are identified in up to 10% of patients with talus fractures [1–4]. Thus, these combined patterns will be encountered by many orthopedic surgeons. Recognition of these injury patterns and the ability to develop a management strategy is important. Each of these injuries in isolation portends a guarded prognosis for long-term functional outcomes [1, 5–7]. Therefore, when seen in combination, prognosis is compromised further due to the extremely high-energy nature of the injury in most cases [4]. Not uncommonly, these injuries occur in combination with additional skeletal and soft tissue injuries in the same limb. A paucity of research has been done documenting outcomes after these injuries due to their relative rarity, although the largest study to date paints a grim picture for expected outcomes [4]. The soft tissue condition, fracture patterns, and management of additional skeletal injuries in the effected limb guide the surgical strategy.

Diagnosis

A combination of a history of injury, careful physical examination, and appropriate X-ray studies is typically sufficient to make the diagnosis of a combined talus and calcaneus fracture. A CT scan reformatted in the plane of the hindfoot is obtained when there is suspicion of a calcaneus or talus fracture to avoid missing subtle fracture patterns and to guide treatment.

Many patients with this combined fracture pattern are multiply injured and will be triaged and treated according to ATLS protocol. History of injury is obtained directly from the patient whenever possible and through the EMS personnel or other providers when the patient cannot respond. The mechanism and associated energy of the injury are helpful in making the diagnosis. These are typically high-energy injuries resulting from an axial load to the limb or forced foot pronation. A fall from significant height and a motor vehicle accident are the most common mechanisms resulting in these combined fractures. Occasionally, low-energy mechanisms including low-level falls and sports-related injuries may result in a combined hindfoot injury. The direction the patient's foot "twisted" or the position the patient "landed in" can be helpful in understanding the injury. A history of associated medical problems including diabetes, peripheral neuropathy, peripheral vascular disease, osteoporosis, and immunocompromising conditions

---

M. F. Githens (✉) · R. Firoozabadi
Department of Orthopaedics and Sports Medicine, Harborview Medical Center/University of Washington, Seattle, WA, USA
e-mail: mfg28@uw.edu

© Springer Nature Switzerland AG 2020

M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_22

should be gathered as these factors will affect treatment decisions. Similarly, a history of medications taken and social habits including tobacco use may guide treatment strategies.

In the multiple injured patient, a primary survey and life-saving measures are employed according to ATLS protocol, followed by a thorough secondary skeletal examination. Particular attention should be paid to examination of the foot and ankle on secondary survey, as foot fractures are the most commonly missed skeletal injury in the polytraumatized patient [8]. The location, size, and condition of any open wounds should be carefully documented. Open wounds should be rinsed with sterile normal saline and dressed with a sterile dressing. If an open fracture is diagnosed, the patient should receive appropriate tetanus administration and early IV antibiotics (first-generation cephalosporin with or without gentamicin and PCN depending on degree and type of contamination).

The degree of swelling and presence, location, and type of blistering should be noted. Gross deformity of the foot in relation to the ankle should cue the examiner into the possible diagnosis of a subtalar fracture dislocation. After inspection of the soft tissues, sensation and motor function are documented if possible. Sensory function of the medial and lateral plantar branches of the tibial nerve is often diminished in patients with subtalar fracture dislocations, posteromedial body of talus fractures, and joint depression-type calcaneus fractures with significant widening.

Imaging should begin with plain radiographs of the patient's ankle and foot. This should include an anterior to posterior (AP), mortise, and lateral view of the ankle and an AP, oblique, lateral, and axial Harris heel view of the foot. Once the diagnosis of a talus and/or calcaneus fracture is confirmed on these X-rays, or if there is suspicion of one on X-ray, a CT scan reformatted in the plane of the hindfoot is obtained. The CT scan allows an intimate understanding of the fracture patterns and is critical for guiding treatment.

There is no classification system designed to describe combined talus and calcaneus fractures. The classification systems specific to each the talus and calcaneus fracture may be used to describe the fracture patterns. Use of the Hawkins classification for talar neck fracture dislocations and the Sanders classification for intra-articular calcaneus fractures adds prognostic value to the diagnosis, but both classifications are limited to specific fracture patterns [9, 10]. Many of the fracture patterns observed in both the talus and calcaneus do not fit well into any specific classification; thus, the fractures can be described based on the anatomical involvement (authors' preference).

Combined Fracture Patterns

To date, no study has accurately characterized the distribution of combined talus and calcaneus fractures or the causative mechanisms of injury. In the largest series to date, in which follow-up limited the accurate recording of fracture pattern incidence, talar neck fractures in combination with joint depression-type calcaneus fracture were the most common combined pattern [4]. A lateral process talus fracture was associated with these injuries not infrequently. In an unpublished review of our institutional database, we consistently observed the following combined patterns:

- Talar neck + sustentaculum fracture
- Neck and lateral process fractures of the talus + sustentaculum fracture
- Medial subtalar dislocation with talar head shear fracture + sustentaculum fracture
- Medial subtalar dislocation with talar head shear fracture + anterior process calcaneus fracture (often combined with cuboid compression-type fracture)

Less commonly observed patterns include subtalar dislocation with talar head and tongue-type calcaneus fractures, posteromedial talar body fracture combined with anterior process calcaneus fracture, talar neck and posteromedial tuberosity calcaneus fractures, and a variety of extremely high-energy patterns with complete or partial extruded talus and severely comminuted calcaneus fractures.

Treatment

In general, surgical techniques for fractures of the talus and the calcaneus in isolation may be employed to treat these combined injuries successfully. Oftentimes, staged management with urgent reduction and external fixation or provisional percutaneous pinning followed by delayed definitive open treatment is required for optimal management of the soft tissue envelope. Indications and techniques for urgent manipulative reduction and external fixation are discussed in detail later in the chapter.

Talar neck fractures are treated with standard dual-incision approaches. The medial approach utilizes a longitudinal incision over the dorsal medial foot and exploits the deep interval between the tibialis anterior tendon and posterior tibial tendon. This allows excellent access to the medial talar neck and talonavicular joint. The deltoid ligament should be preserved, thus limiting the proximal extent of the deep exposure. The lateral incision is a longitudinal incision over the dorsal lateral foot centered between the tibia and fibula at the level of the ankle joint and in line with the fourth ray, extending from the level of the ankle joint to the navicular. The proximal portion of the incision is biased laterally toward the tip of the fibula if there is an associated lateral process of talus fracture that requires fragment-specific reduction and fixation. Talar head fractures are approached from one or both of these incisions depending on the location of the fracture.

Posterior talar body fractures and fractures with significant posterior facet involvement are typically treated through a posteromedial approach with the patient in the prone position. A medially based ankle spanning external fixator is first applied for creation of tibiotalar joint distraction which allows the surgeon improved visualization of the articular surface of the talar body. Distraction is not applied until the deep approach is complete and the fracture is identified. A longitudinal skin incision is made just medial to the Achilles tendon without violating the paratenon. The FHL sheath is then opened and the entire contents of the deep posterior compartment are retracted medially while the Achilles tendon is retracted laterally. This allows excellent exposure of the posterior process of the talus. Distraction through the external fixator is then applied, improving visualization of the posterior talar body.

Rarely, talar body fractures are inaccessible through the posteromedial approach, and an osteotomy of either the medial or lateral malleolus is required to accurately reduce and stably fix the fracture. No clear indications have been established for when an osteotomy will be required and a surgeon's best judgment must be used in deciding when to use one. As general rule, a talar body fracture with extension anterior to the midline of the tibial plafond on the sagittal CT scan will be inaccessible from a posterior approach and will require an osteotomy (with medial or lateral, depending on fracture morphology). Injuries involving the talar head or neck and talar body may require dorsal and posterior approaches. During the first stage, the surgeon must carefully position screws so that they do not interfere with fragment reduction during the second stage.

Joint depression and intra-articular tongue-type calcaneus fractures are most often treated with an extensile lateral approach given the typical high degree of comminution and articular displacement. Prior to performing this approach, the peroneal artery should be confirmed intact with Doppler ultrasound as this is the singular blood supply to the lateral hindfoot flap. A standard L-shaped subperiosteal flap is created with the longitudinal limb following the lateral border of the distal Achilles tendon and the distal limb following the glabrous border of the lateral foot, in line with the fifth metatarsal and extending to the cuboid body.

In certain cases, such as simple articular and extra-articular tongue-type patterns, limited incision or percutaneous reduction and internal fixation is appropriate. Less common calcaneus fracture patterns including sustentaculum fractures, plantar medial tuberosity fractures, and anterior process fractures require specific surgical approaches and are described later in the chapter.

When the articular surface of the posterior facets is deemed not to be reconstructible, an acute subtalar arthrodesis may be performed. In cases of severe soft tissue injury, an acute or delayed below knee amputation (BKA) may be required [4].

The treatment strategy for these injuries is dictated by surgical indications for each individual fracture. Non-displaced fractures may be appropriate for nonoperative management, depending on their location. While indications for operative fixation of talus fractures are well established, indications for operative fixation of calcaneal fractures remain controversial. Despite these controversies, evidence supports operative treatment of displaced calcaneus fractures in specific patient populations [5]. The overarching goal of surgical treatment for these fractures is restoring calcaneal morphology and anatomic reduction of the articular surface with stable fixation to allow for early ankle and subtalar motion. In patients who require secondary operations for the sequela of a calcaneus fracture, those treated initially with ORIF have better functional outcomes and less complications than those initially managed nonoperatively due to the early restoration of calcaneal morphology [11]. When multiple incisions are needed, care must be taken in planning them to avoid narrow skin bridges and acute angles. An intimate understanding of the angiosomes of the foot will allow the surgeon to plan and place multiple incisions safely [12].

In high-energy injuries, staged management is often necessary. Typically, this involves closed reduction and application of an external fixator (Fig. 22.1a,b). Occasionally a subtalar fracture dislocation is not reducible using closed techniques and will require either percutaneous manipulation or limited open techniques for reduction (Fig. 22.2). If an urgent open reduction for an irreducible fracture dislocation is required, the incision should be made thoughtfully in anticipation of the incisions needed for the definitive

Fig. 22.2 Radiographic example of a subtalar dislocation that required a limited open reduction due to entrapped posterior tibial and flexor digitorum tendons

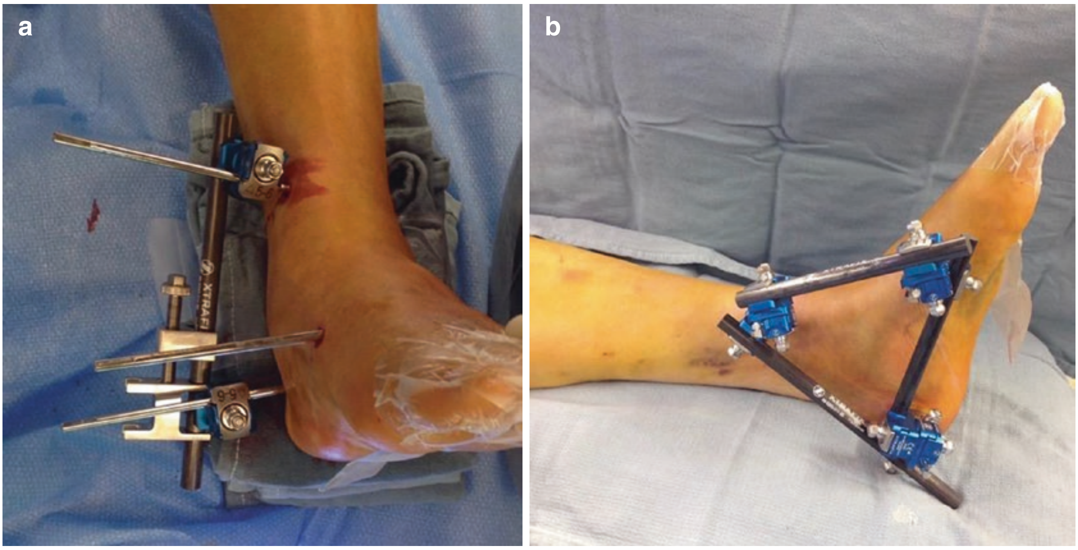


Fig. 22.1 Application of a medial distractor (**a**) for closed manipulative reduction of a subtalar dislocation. Note distracting device on medial side to restore height. After closed manipulative reduction, the medial external fixator is left in place (**b**) until definitive surgery can be safely performed

fixation. In certain cases, percutaneous K-wires are deployed to maintain a provisional reduction either in isolation or in combination with an external fixator (Fig. 22.3a–c*). When severe soft tissue injury precludes an open approach entirely, definitive treatment may be an external fixator with buried percutaneous K-wires. In employing this strategy, the surgeon accepts a higher risk of early or late loss of reduction, malunion, or nonunion as compared to treatment with anatomic reduction and stable fixation in trade for soft tissue preservation (Fig. 22.4a–c).

Fig. 22.3 Lateral (**a**) and mortise (**b**) X-rays and axial CT scan (**c**) demonstrating a talar body fracture with extrusion of the posteromedial fragment. This injury required urgent limited open reduction, external fixation and provisional stabilization with percutaneously placed K-wires. A postoperative sagittal CT scan (**d**, **e**) demonstrating provisional reduction and fixation with percutaneous K-wires and external fixation

Fig. 22.4 An injury X-ray (**a**) demonstrating plantar talar extrusion and a highly comminuted calcaneus fracture. A postoperative X-ray (**b**) demonstrating reduction, percutaneous pin fixation, and external fixation of the injury seen in (**a**). The severity of the soft tissue injury prevented definitive open treatment of these injuries. A lateral foot X-ray 6 months post-op demonstrating midfoot collapse (**c**)

The duration the external fixator is kept in place is at the discretion of the surgeon, but often with a target between 6 and 12 weeks. Oftentimes, pin site problems require external fixator revision or earlier removal.

Rarely, the talus fracture or calcaneus fracture is so highly comminuted that stable internal fixation is tenuous. In this setting, or when there are additional unstable ipsilateral foot injuries, the external fixator and/or K-wires are maintained in the postoperative setting. Typical duration for maintaining an external fixator or buried wires in this setting is 6 weeks. When this strategy is deemed necessary, the surgeon accepts a higher risk of ankle and subtalar joint stiffness. Manual manipulation of these joints under anesthesia at the time of fixator removal may be performed.

While anatomic reconstruction of articular surfaces for preservation of physiologic foot mechanics is the primary goal of surgical treatment, this may not always be possible. The decision to perform an acute subtalar arthrodesis is based on an expert foot and ankle surgeon or traumatologist's opinion that the articular surfaces are not reconstructible (Fig. 22.5a–c). When an acute arthrodesis is performed, the goal is to recreate normal hindfoot architecture in order to optimize foot mechanics and avoid adjacent joint arthrosis over time. Restoration of physiologic calcaneal height optimizes talar declination. If the calcaneus is left flat, the talus assumes a horizontal position, resulting in altered gait due to an alteration in talocrural mechanics as well as a decrease in push-off strength. A horizontal talus also may result in painful anterior tibiotalar impingement. Calcaneal width should be restored to avoid symptoms of subfibular impingement and peroneal tendinopathy. If varus alignment of the tuberosity is not corrected, the transverse tarsal joint will remain locked, altering forces on adjacent the midfoot joints and ankle joint, thereby leading to progressive arthrosis. Thus, to restore normal hindfoot morphology

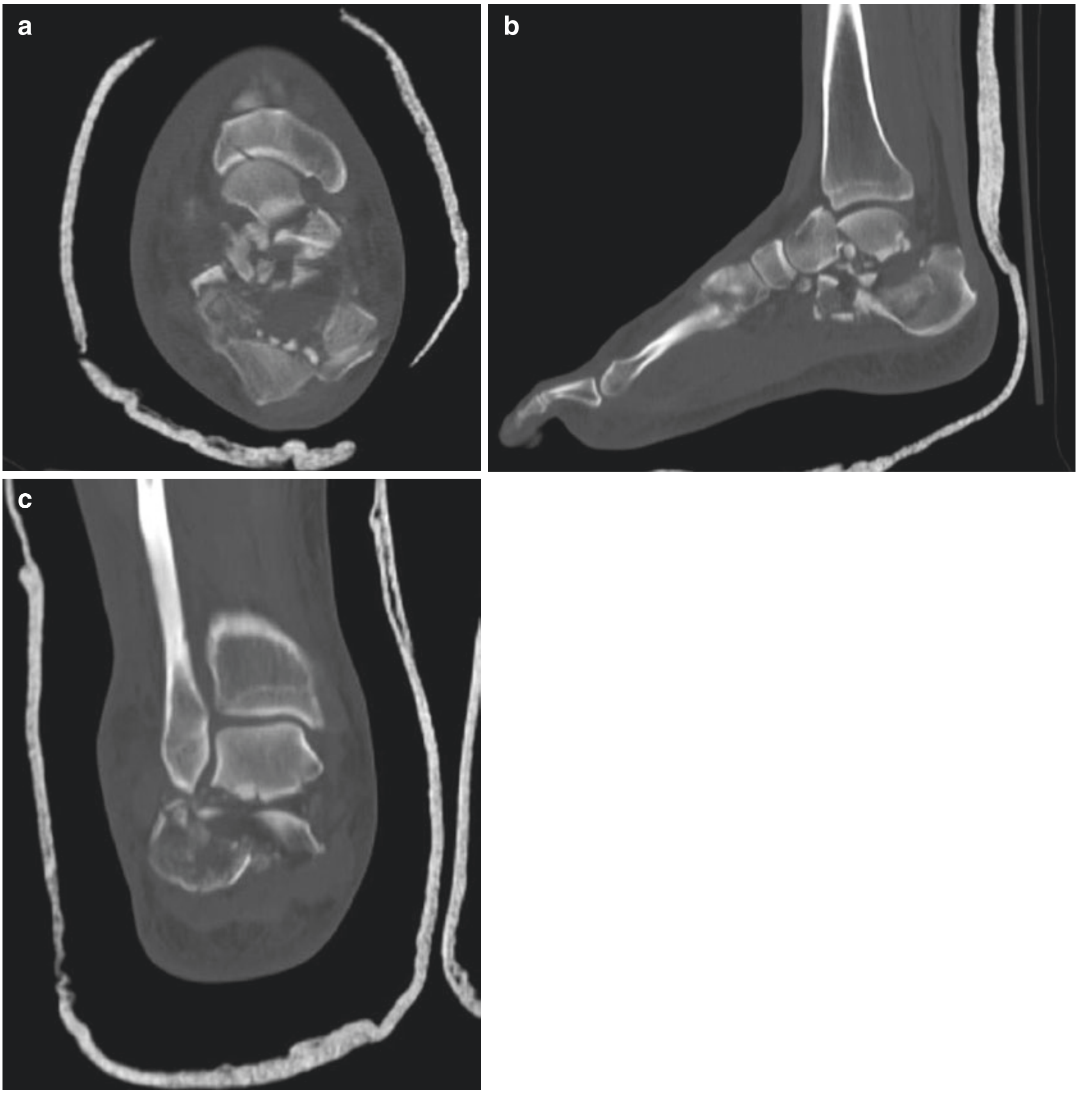


Fig. 22.5 Axial (**a**), sagittal (**b**), and coronal (**c**) CT scan of a combined injury where the posterior facet of the calcaneus is determined not to be reconstructible. Based on imaging, ORIF calcaneus and subtalar arthrodesis is planned

and minimize chances of adjacent joint arthrosis, a combination of open reduction and internal fixation (ORIF) plus joint arthrodesis is necessary.

Postoperative protocols depend on the treatment strategy deployed. Whenever possible, early active and passive ankle and subtalar motion is initiated. Our postoperative protocol involves splint takedown and suture removal at 2–4 weeks. The patient is placed into a removable prefabricated posterior splint that maintains the ankle at neutral dorsiflexion. The splint is removed three times a day at a minimum for ankle and foot motion. Patients are made non-weight-bearing for 12 weeks. Chemical thromboembolic prophylaxis is prescribed for 6 weeks.

Outcomes

Given the overall rarity of these injuries, published outcomes after treatment of combined talus and calcaneus fractures are limited to case reports, small case series, and a single retrospective review. In 1996 Gregory et al. published outcomes after treatment of 9 patients with ipsilateral talus and calcaneus fractures identified from a cohort of 78 talus and 338 calcaneus fractures treated over a 4-year period [2]. All of the combined injuries were a result of a high-energy mechanism, with four patients undergoing primary subtalar arthrodesis and one treated with acute BKA. Fracture morphology of both the talus and calcaneus was highly variable. Standard surgical strategies for each injury in isolation were deployed, and there were no complications related to the multiple surgical approaches. The Maryland Foot Score was reported in five patients, four of which were treated with subtalar arthrodesis, with a mean score of 86 at an average of 39 months. All of these patients returned successfully to their previous jobs. This was the first case series to report on these combined injuries, highlighting the severity of these injuries and their guarded prognosis.

More than a decade later, Seybold et al. reported on 11 patients with combined injuries, noting that their cohort sustained primarily "extra-articular" calcaneus fractures in combination with a talus fracture as a result of lower-energy mechanism as compared to the series from Gregory et al. [2, 3]. The dominant calcaneus fracture patterns were anterior process (5) and sustentaculum fractures (4), while only two patients had intra-articular patterns. These were associated with either a talar neck (7) or body (4) fracture in all cases. At a mean follow-up of 6 years, average AOFAS score was 79, with a range of 50–100. All patients with extra-articular calcaneus fractures had excellent scores and returned to their pre-injury work and sport. In contrast, the two patients with intra-articular calcaneus fractures had AOFAS scores of 50 and 64 respectively, with one of the patients developing AVN of the talar body and talar neck nonunion. Based on the study findings, the authors suggest that talus fractures in combination with sustentacular or anterior process fractures may result from lower-energy mechanisms and that long-term prognosis is directly related to the severity of the calcaneus fracture and presence of articular involvement.

The largest study published to date corroborates previous case series, demonstrating that high-energy mechanism, severe soft tissue injury, and significant articular comminution portend an ominous prognosis [4]. In this series published in 2009, all patients sustained their injuries from a high-energy mechanism, and 40% of the patients had additional ipsilateral lower limb injuries including pilon, ankle, midfoot, and forefoot fractures. An open fracture of either the talus or calcaneus occurred in 29% of the patients, and of the patients with an open fracture, 62% required BKA either acutely or in a delayed fashion. Five patients were treated with primary subtalar arthrodesis due to extensive comminution of the articular surface. Of those patients not treated with primary subtalar arthrodesis or BKA, 80% developed subtalar arthritis and 17% went on to require a delayed subtalar arthrodesis for symptomatic subtalar arthritis. Two-thirds of the patients in this series required at least one reoperation related to a complication.

Conclusion

Ipsilateral talus and calcaneus fractures are rare but an important combined injury to recognize. Typically the result of a high-energy mechanism, these injuries are often associated with severe soft tissue injury. Treatment is dictated by the condition of the soft tissue envelope and the indications for surgical treatment of each of the fractures in isolation. Staged management with manipulative reduction and external fixation followed by delayed definitive surgical treatment is a frequently deployed strategy. Careful incision planning is important to avoid iatrogenic wound complications. Published outcomes are limited, but paint a grim picture, with the majority of patients developing subtalar arthrosis, many requiring additional operations, and the most severely injured requiring a below knee amputation.

Case Examples

Cases 1, 2, and 3: Direct Axial Load

High-energy direct axial loading and axial loading with midfoot dorsiflexion results in combined talar neck + joint depression-type calcaneus fractures (Fig. 22.6a,b). These injuries are often complicated by severe soft tissue injury and other ipsilateral skeletal injuries and require staged management. Figures 22.7, 22.8, 22.9, and 22.10b demonstrate staged management of the injury seen in Fig. 22.6a,b. Initial deformity correction to restore calcaneal and talar morphology with medial external fixation facilitates soft tissue recovery and is useful in both open and closed fractures (Fig. 22.7). Care should be taken to place the pins appropriately to avoid causing problems with planned incisions for definitive treatment. In particular the medial calcaneal pin should be bicortical but not transcutaneous on the lateral side if an extensile lateral approach to the calcaneus is planned (Fig. 22.8). Strategies for calcaneal reduction and external fixation for joint depression calcaneus fractures

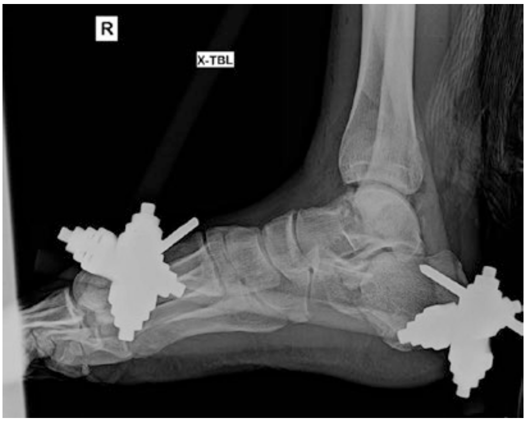


Fig. 22.7 The lateral X-ray demonstrates provisional reduction and medial ankle spanning external fixation of the pilon, talar, neck, and joint depression calcaneus fracture seen in Fig. 22.6a,b

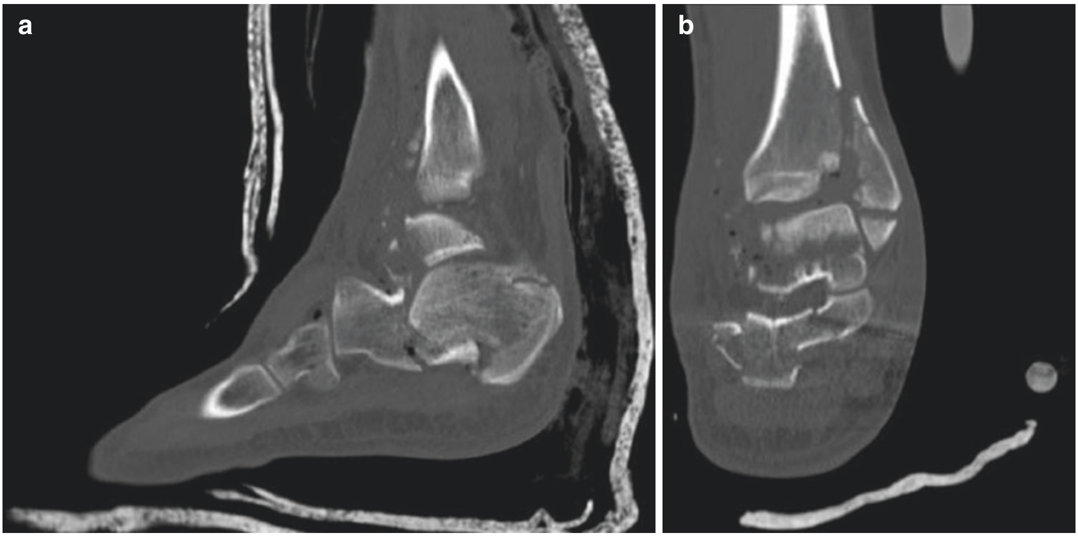


Fig. 22.6 A sagittal (**a**) and coronal (**b**) CT scan of a patient who fell from significant height who sustained a combined pilon, talar, neck, and joint depression calcaneus fractures

Fig. 22.8 An AP X-ray after reduction and external fixation demonstrating the medial calcaneal pin bicortical but not transcutaneous on the lateral side for the injuries seen in Fig. 22.6a, b

are found in Chaps. 15, 16, 17, 20. When soft tissue condition allows, standard dual-incision technique is employed for reduction and fixation of the talar neck fracture as described in Chap. 4 (Fig. 22.9a,b). If there is an associated lateral process of the talus fracture, the lateral incision should be extended to allow access to the lateral process as described in Chap. 8. The calcaneus may be treated under the same anesthetic or further staged depending on the complexity of the fractures. The calcaneus fracture is treated when the soft tissues allow, typically with open reduction and internal fixation through an extensile lateral approach as described in Chap. 15 (Fig. 22.10a,b).

An axial load may result in an isolated lateral process talus fracture in association with a joint depression calcaneus fracture. Not uncommonly these patients also sustain an ipsilateral pilon fracture. In these cases, the lateral process talus fracture should not be neglected and, if displacement has occurred, should be fixed along with the calcaneus (Fig. 22.11a–c).

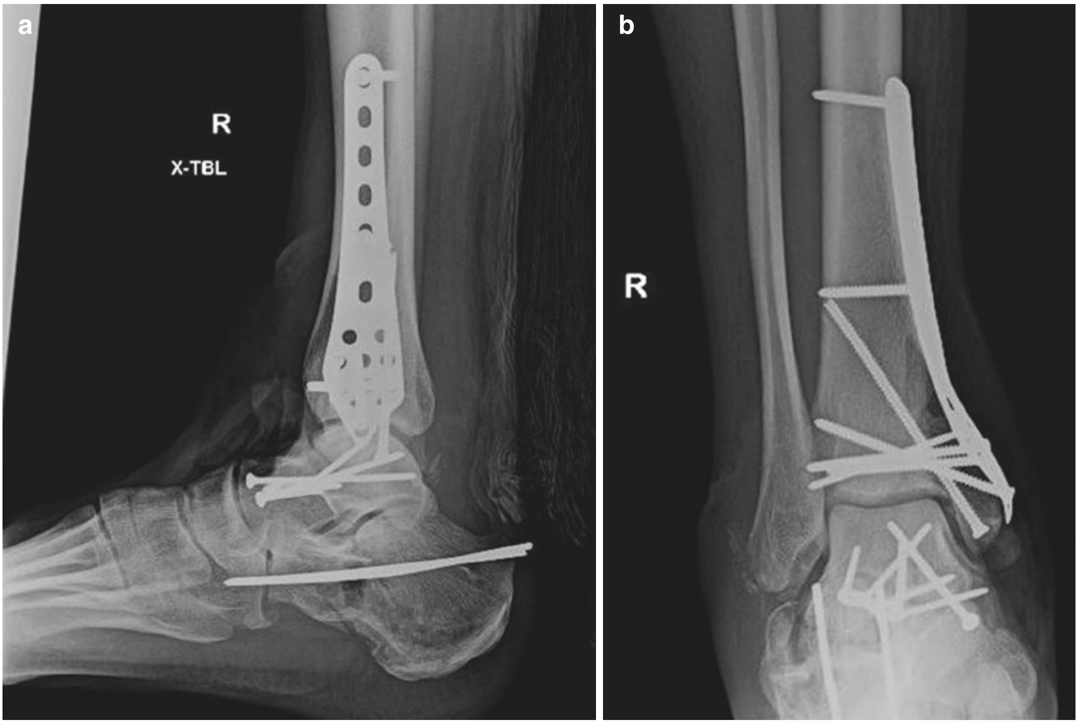


Fig. 22.9 A lateral (**a**) and AP (**b**) X-ray demonstrates staged fixation in the injuries seen in Fig. 22.6a,b. The pilon and talar neck fractures were treated with open reduction and internal fixation while the calcaneus fracture was provisionally pinned and the external fixator was removed

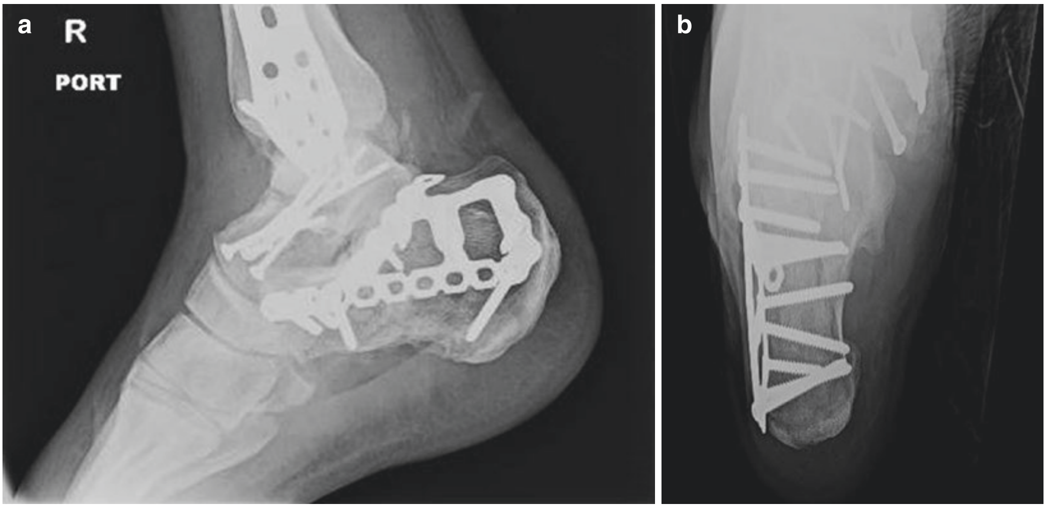


Fig. 22.10 A lateral (**a**) and AP (**b**) X-ray demonstrating final fixation of the pilon, talus, and calcaneus fractures seen in Fig. 22.6a,b

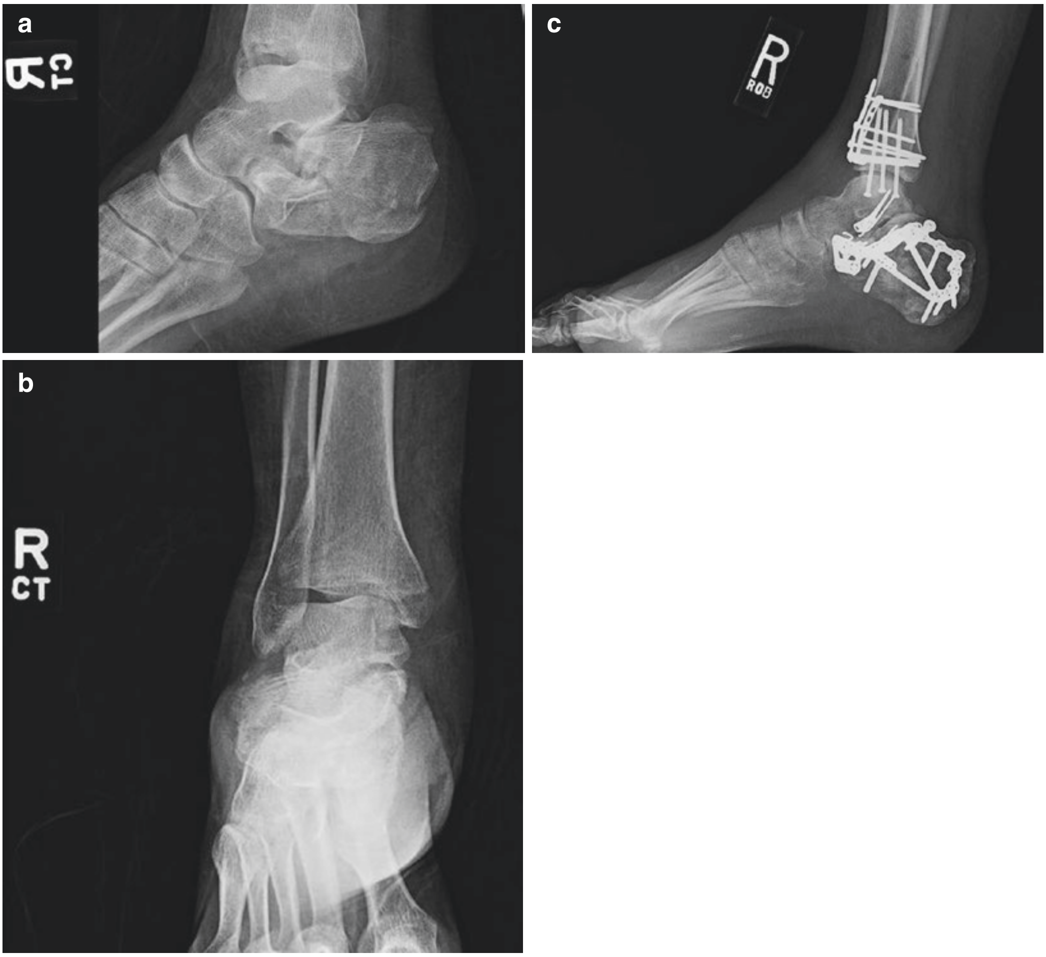


Fig. 22.11 A lateral (**a**) and AP (**b**) X-ray of a patient who sustained a closed combined pilon, lateral process talus, and calcaneus fracture after a fall from height. A lateral (**c**) X-ray after definitive fixation of this combined injury

Many of the most severe combined patterns result from an extremely high-energy axial load. Presenting patterns are usually variations of an open transcalcaneal talar extrusion through the plantarmedial surface of the foot. These open wounds take an extended time to heal and correlate with significantly higher complication rates including a relatively increased amputation rate [13]. Occasionally, these injuries are not reconstructible due to the significant bone loss and articular comminution. Open reduction to restore hindfoot morphology and subtalar arthrodesis are a common strategy for salvage in this setting. This technique is described in detail in Chaps. 24, 25 (Fig. 22.12a,b). The timing of arthrodesis is dependent on the condition of the soft tissues and is delayed as necessary. If the injury severity prevents reconstruction or arthrodesis, a BKA is strongly recommended. Prior to performing an amputation, a conversation discussing the rationale, benefits, and expected functional outcome after amputation is held with the patient whenever possible.

Case 4: Pronation Injuries

Pronation mechanisms can result in a variety of combined talus and calcaneus fracture patterns. The most commonly observed of these is a talar neck with an associated sustentaculum fracture (Fig. 22.13a,b). Oftentimes, the lateral process of the talus is also fractured and displaced. These patterns may be amenable to early definitive fixation but often require a period of soft tissue rest. Fixation of the talar neck and lateral process is performed through a dual anteromedial and anterolateral approach, again taking into account the potential need for individual fixation of the lateral process. When the sustentaculum is displaced, the authors recommend surgical fixation to prevent late hindfoot collapse and subtalar arthrosis [14]. The indications and techniques for ORIF sustentaculum fractures are detailed in Chap. 21.

When treating a combined talar neck and sustentaculum fracture, incision placement on the medial side of the foot must be planned carefully. The medial incision for the talar neck utilizes the interval between the tibialis anterior and tibialis posterior tendons and should be biased slightly more dorsal than usual. The incision for the sustentaculum is plantar to the tip of the medial malleolus and parallel to the inferior border of the posterior tibialis tendon. The posterior tibialis tendon is mobilized, and reduction and fixation are performed above and below the tendon as needed. The flexor digitorum tendon may be mobilized and retracted cranially along with the posterior tibialis tendon to view the plantar fracture exit and facilitate placement of a mini-fragment buttress plate if needed (Fig. 22.14a–c).

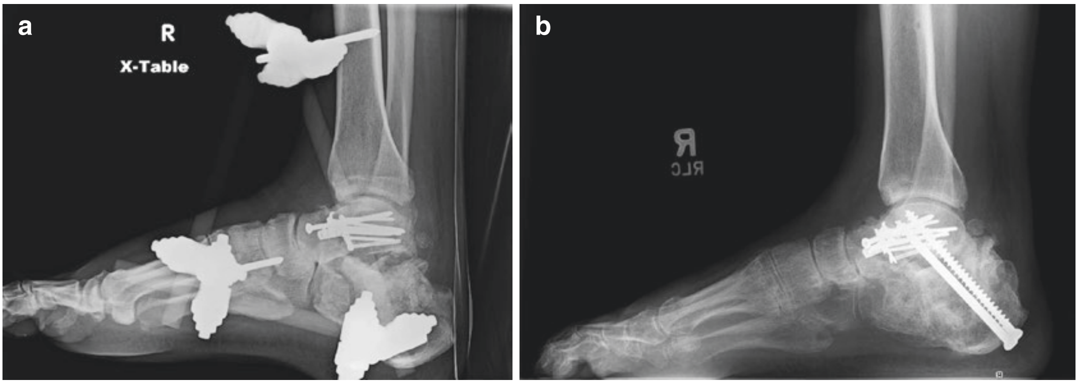


Fig. 22.12 An injury X-ray (**a**) demonstrates a combined talus and calcaneus fracture with a highly comminuted posterior facet. Open reduction to restore the talar and calcaneal morphology is performed followed by acute subtalar arthrodesis. A lateral (**b**) X-ray 1 year postoperatively demonstrated a healed talus fracture with subtalar arthrodesis

Cases 5, 6, and 7

Medial subtalar dislocations result in a consistently observed series of combined fracture patterns. As the forefoot dislocates, the talar head fractures under shear stress may incarcerate on the lateral corner of the navicular. As this occurs, the anterior process of the calcaneus, and oftentimes the cuboid, fracture under compressive load (Fig. 22.15a,b). The resulting pattern often requires closed manipulative reduction under general anesthesia and may require percutaneous or open techniques to reduce the pantalar dislocation. Talar head fractures are fixed through a dual incision approach with buried lag screw fixation. Fixation of the anterior process

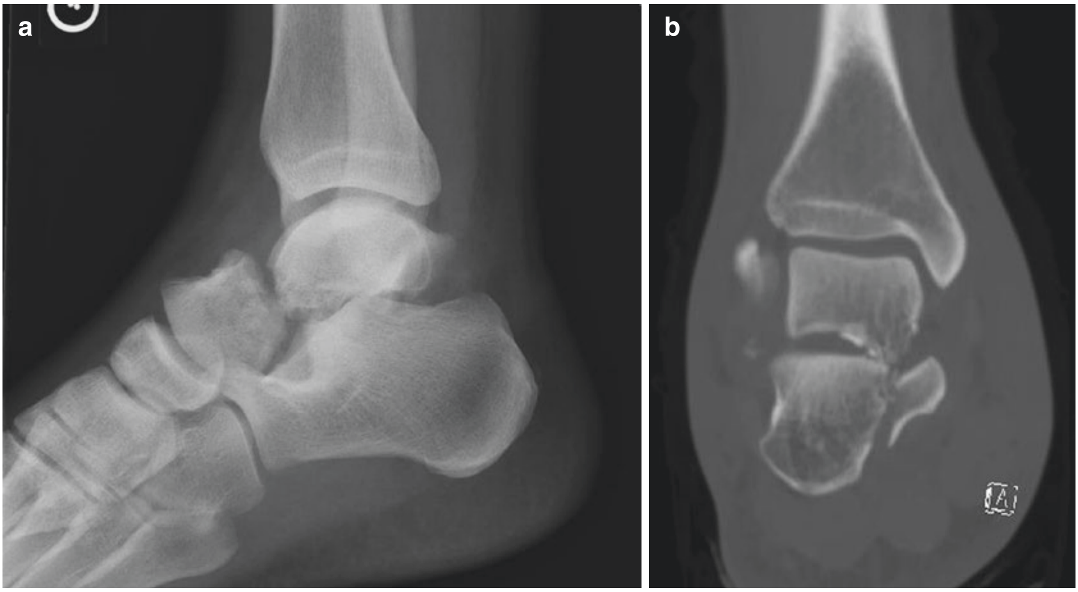
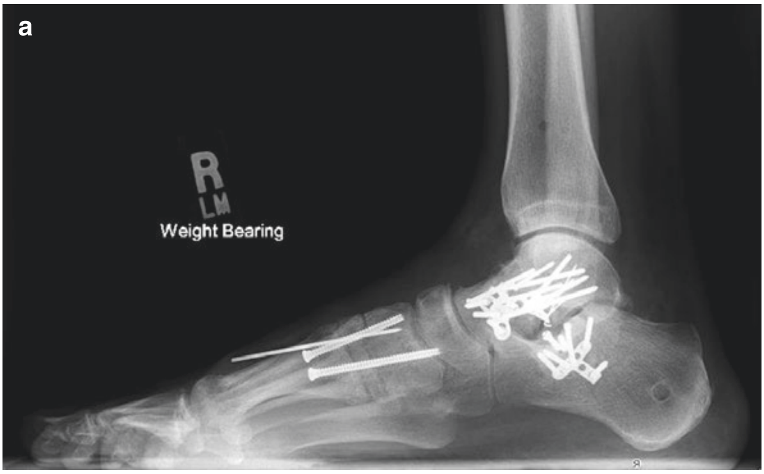


Fig. 22.13 A lateral X-ray (**a**) and coronal CT scan (**b**) demonstrate a combined talar neck, lateral process talus, and sustentaculum fracture

Fig. 22.14 A lateral (**a**), AP (**b**), and axial heel view (**c**) X-ray demonstrates definitive fixation of the talar neck lateral process and sustentaculum seen in Fig. 22.13a,b



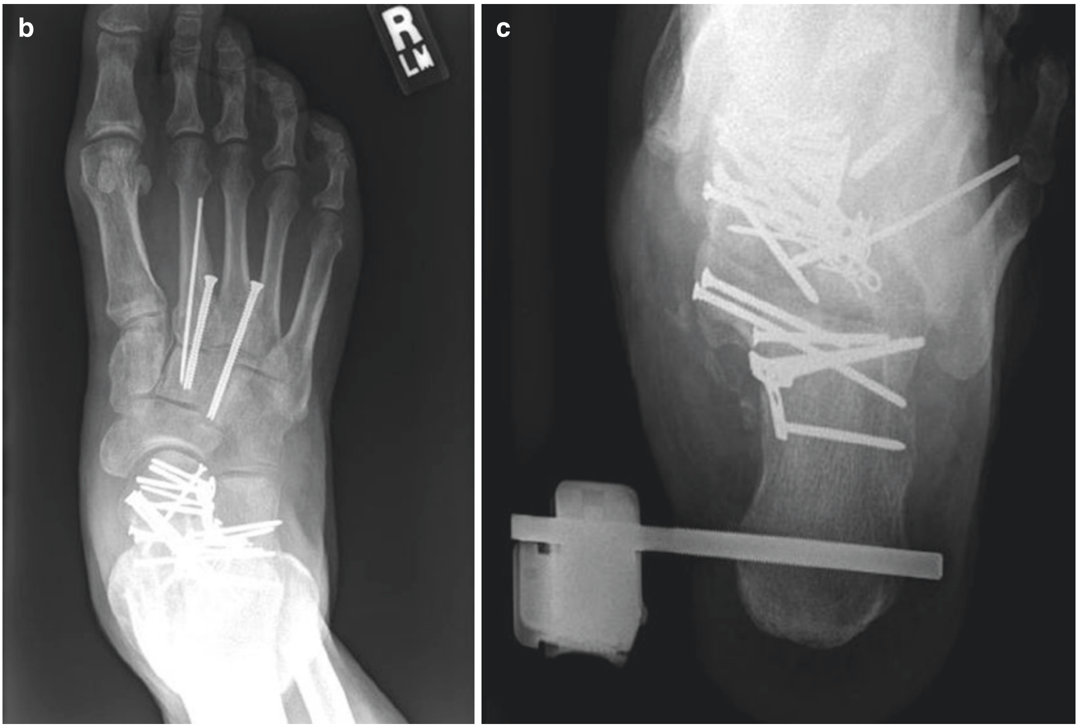


Fig. 22.14 (continued)

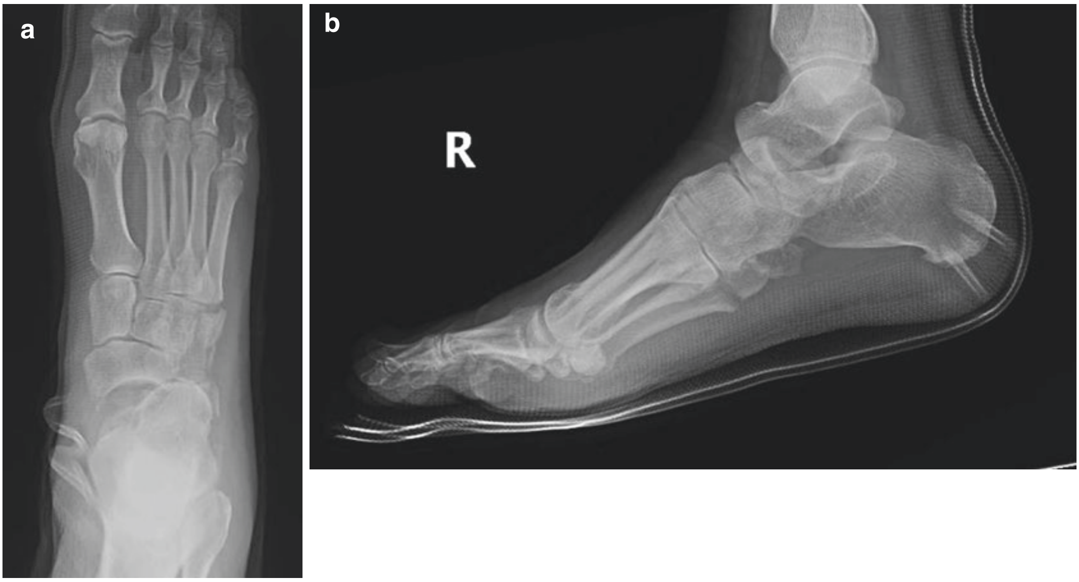


Fig. 22.15 An AP (**a**) and lateral (**b**) X-ray demonstrates a medial subtalar dislocation with talar head shear fracture, anterior process calcaneus, cuboid, and fifth metatarsal fractures

calcaneus fracture is dictated by displacement and articular involvement, with the goals being restoration of anterior process morphology, calcaneocuboid (CC) articular congruity, and lateral column length. Anterior process fixation is discussed in detail in Chap. 18. If the fracture involves proximal extension to the critical angle of Gissane or if there is significant distortion of the anterior process requiring wide exposure for reduction, an extensile lateral approach is used. If the fracture primarily involves the calcaneocuboid articulation, a longitudinal incision directly over the CC joint is utilized. Fixation is typically obtained with mini-fragment screws and straight or T plates (Fig. 22.16a-b). If the patient also has a cuboid fracture, it is addressed through the same incision. Use of a laterally placed distractor facilitates articular reduction and restoration of normal lateral column length. A lateral column external fixator may be left on postoperatively to protect internal fixation in the setting of highly comminuted lateral column fractures.

Alternatively, a medial subtalar fracture dislocation may result in a sustentaculum fracture rather than lateral column compression injury (Fig. 22.17a,b). These injuries are treated as described above (Fig. 22.18).

Less commonly, a subtalar fracture dislocation results in a posteromedial talar body fracture and may be seen in association with a variety of calcaneus fracture patterns. Treatment of posteromedial body fractures (described in Chap. 7) requires a posterior approach and may be performed with the patient either in a prone or supine position with the leg in a figure of four positions. Prone positioning is ideal for fracture visualization and fixation but requires repositioning supine or lateral to address the associated calcaneus fracture. A medial distractor is very useful in facilitating talus fracture visualization, fixation, and assessment of the talocalcaneal and tibiotalar articulating surfaces.

An uncommonly observed pattern is a tongue-type calcaneus fracture associated with a subtalar fracture dislocation or talus fracture (Fig. 22.19). These injuries likely result from a combined pronation and dorsiflexion mechanism, and patients with pre-existing gastrocnemius equinus may be predisposed to these patterns. The treatment strategy for associated tongue-type calcaneus fractures depends on the presence and degree of posterior facet articular involvement, and the timing depends on whether the posterior skin is open or at risk. Injuries with skin at risk

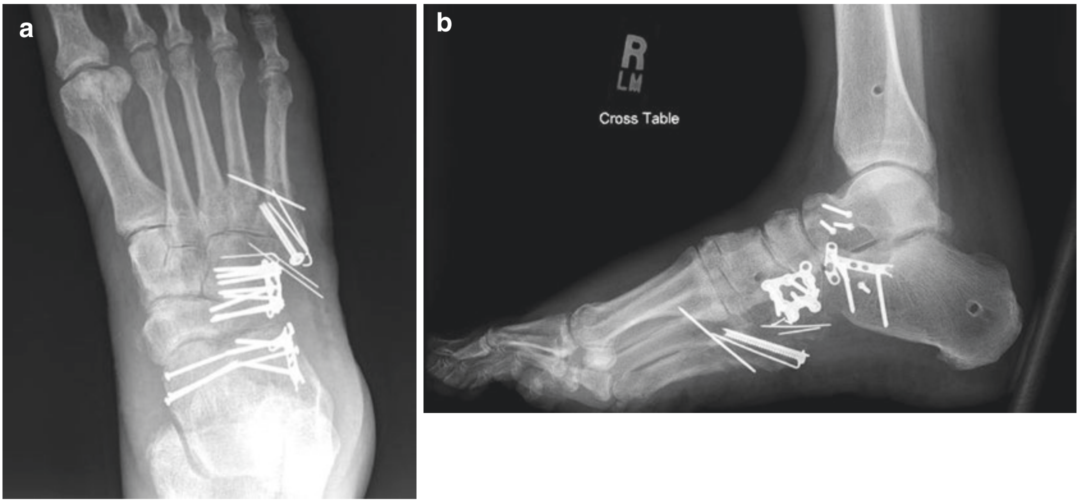


Fig. 22.16 An AP (**a**) and lateral (**b**) X-ray demonstrating final fixation of the talar head and lateral column injuries seen in Fig. 22.15a,b

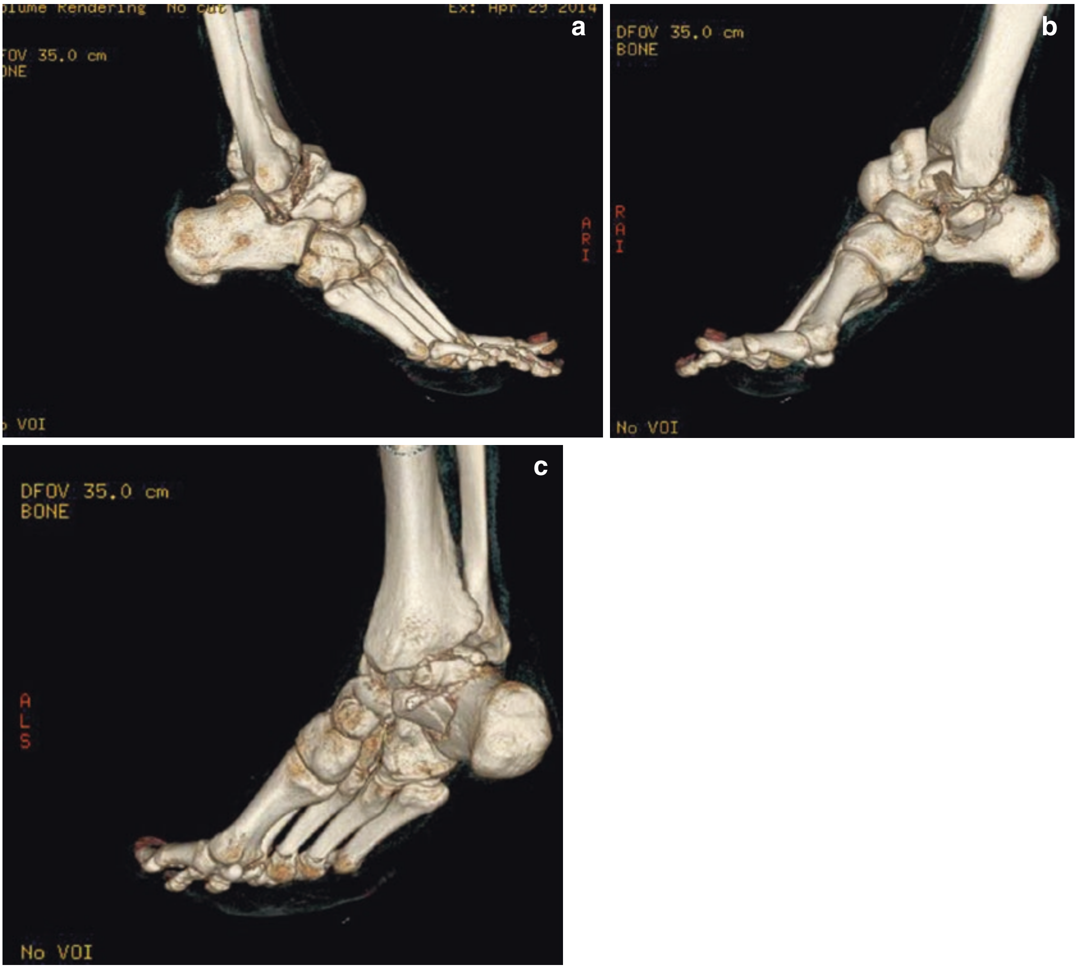


Fig. 22.17 (**a**–c) A 3D CT reconstruction demonstrating a talar body and neck fracture with talar dislocation and sustentaculum fracture

Fig. 22.18 A lateral X-ray demonstrates final fixation of the combined talus and sustentaculum fracture seen in Fig. 22.17a,c

should be treated emergently to decrease the risk of skin necrosis. Extra-articular and simple articular (single split, no comminution) tongue-type fractures may be treated with percutaneous reduction and screw fixation. Fractures with significant articular involvement should be treated with an extensile lateral approach to ensure accurate articular reduction if the patient is an appropriate surgical candidate. Because of the relatively poor bone quality of the calcaneus and the extremely strong deforming force of the gastrocnemius complex on the fracture fragment, all screws should be bicortical to prevent fixation failure (Fig. 22.20). A gastrocnemius recession should strongly be considered to protect the internal fixation.

Fig. 22.19 An injury X-ray demonstrates a talar head shear fracture and tongue-type calcaneus fracture

Fig. 22.20 A lateral X-ray at 6-month follow-up demonstrating healing of the talar head and tongue-type calcaneus fracture seen in Fig. 22.19

Many other combined patterns occur from a variety of mechanisms. As consistent with the examples above, the surgical indications and techniques for each of the injuries in isolation may be combined for associated patterns in most cases.

References

1. Vallier HA, et al. Talar neck fractures: results and outcomes. J Bone Joint Surg Am. 2004;86-A(8):1616–24. ISSN 0021–9355. Disponível em: https://www.ncbi.nlm.nih.gov/pubmed/15292407.
2. Gregory P, et al. Ipsilateral fractures of the talus and calcaneus. Foot Ankle Int. 1996;17(11):701–5. ISSN 1071–1007. Disponível em: https://www.ncbi.nlm.nih.gov/pubmed/8946186.
3. Seybold D, Schildhauer TA, Muhr G. Combined ipsilateral fractures of talus and calcaneus. Foot Ankle Int. 2008;29(3):318–24. ISSN 1071–1007. Disponível em: https://www.ncbi.nlm.nih.gov/pubmed/18348829.
4. Aminian A, et al. Ipsilateral talar and calcaneal fractures: a retrospective review of complications and sequelae. Injury. 2009;40(2):139–45. ISSN 1879–0267. Disponível em: https://www.ncbi.nlm.nih.gov/pubmed/19200538.
5. Buckley R, et al. Operative compared with nonoperative treatment of displaced intra-articular calcaneal fractures: a prospective, randomized, controlled multicenter trial. J Bone Joint Surg Am. 2002;84-A(10):1733–44. ISSN 0021–9355. Disponível em: https://www.ncbi.nlm.nih.gov/pubmed/12377902.
6. Benirschke SK, Sangeorzan BJ. Extensive intraarticular fractures of the foot. Surgical management of calcaneal fractures. Clin Orthop Relat Res. 1993;292:128–34. ISSN 0009-921X. Disponível em: https://www.ncbi.nlm.nih.gov/pubmed/8519099.
7. Benirschke SK, Kramer PA. Wound healing complications in closed and open calcaneal fractures. J Orthop Trauma. 2004;18(1):1–6. ISSN 0890–5339. Disponível em: https://www.ncbi.nlm.nih.gov/pubmed/14676549.
8. Pfeifer R, Pape HC. Missed injuries in trauma patients: a literature review. Patient Saf Surg. 2008;2(20). ISSN 1754–9493. Disponível em: https://www.ncbi.nlm.nih.gov/pubmed/18721480.
9. Sanders R, et al. Operative treatment in 120 displaced intraarticular calcaneal fractures. Results using a prognostic computed tomography scan classification. Clin Orthop Relat Res. 1993;290:87–95. ISSN 0009-921X. Disponível em: https://www.ncbi.nlm.nih.gov/pubmed/8472475.
10. Vallier HA, et al. A new look at the Hawkins classification for talar neck fractures: which features of injury and treatment are predictive of osteonecrosis? J Bone Joint Surg Am. 2014;96(3):192–7. ISSN 1535–1386. Disponível em: https://www.ncbi.nlm.nih.gov/pubmed/24500580.
11. Radnay CS, Clare MP, Sanders RW. Subtalar fusion after displaced intra-articular calcaneal fractures:

does initial operative treatment matter? J Bone Joint Surg Am. 2009;91(3):541–6. ISSN 1535–1386. Disponível em: https://www.ncbi.nlm.nih.gov/pubmed/19255213.

12. Attinger CE, et al. Angiosomes of the foot and ankle and clinical implications for limb salvage: reconstruction, incisions, and revascularization. Plast Reconstr Surg. 2006;117(7 Suppl):261S–93S. ISSN 1529–4242. Disponível em: https://www.ncbi.nlm.nih.gov/pubmed/16799395.
13. Firoozabadi R, Kramer PA, Benirschke SK. Plantar medial wounds associated with calcaneal fractures. Foot Ankle Int. 2013;34(7):941–8. ISSN 1071–1007. Disponível em: https://www.ncbi.nlm.nih.gov/pubmed/23478886.
14. Della Rocca GJ, et al. Fractures of the sustentaculum tali: injury characteristics and surgical technique for reduction. Foot Ankle Int. 2009;30(11):1037–41. ISSN 1071–1007. Disponível em: https://www.ncbi.nlm.nih.gov/pubmed/19912711.

Part V

Post-traumatic Care and Reconstruction

Rehabilitation After Fractures and Dislocations of the Talus and Calcaneus

23

Janet M. Hobbs

Hindfoot Fracture Rehabilitation

Talus and calcaneus fractures are serious injuries with potential for long-term detriment to function and well-being. Trauma to the hindfoot can alter the ability to perform activities as simple as standing or as difficult as elite sports. The recovery process after injury is prolonged, with several months of non- or limited weight bearing required for bone healing adequate to support standing [66]. Concurrent injuries and complications are frequent and add to rehabilitation challenges [28].

The etiology of talus and calcaneus fractures is typically a fall from a height or high-impact motor vehicle accident. The injuries commonly occur in men between ages 21 and 45, but there is a gradual increase in incidence in post-menopausal women [44]. People with hindfoot fractures frequently have associated lower extremity, spine, or head trauma, which may be missed during initial assessments. The type and degree of force required to fracture bone usually injures surrounding soft tissue; the broken bone itself can also cause damage [22]. Peroneal tendon damage is linked to calcaneus fractures and flexor tendon injury with talus fractures [21]. Up to 75% of patients with calcaneus fractures have concurrent lower extremity fractures [6].

Common early complications include swelling, fracture blisters, compartment syndrome, wound dehiscence, and infection [28]. Compartment syndrome occurs most often in the setting of a crush injury and can result in intrinsic muscle damage, permanent neuromuscular dysfunction, and toe flexion contractures [31, 62]. Obesity, diabetes, anemia, depression, and malnutrition increase the risk for complications [47, 55]. Avascular necrosis is a particular risk with talus fractures, especially talar neck fractures [38]. Later complications include post-traumatic osteoarthritis (OA), joint stiffness, muscular weakness, and chronic pain [57]. The acute damage at the time of injury and subsequent chronic abnormal loading patterns leads to cartilage damage and OA [7].

The majority of hindfoot fractures occur in people in their prime working years. Many people have difficulty returning to their pre-injury level of employment or activity [44]. Some suffer life-altering joint pain and stiffness for several years after injury and may never return to full function [16]. Patients with displaced calcaneus fractures have quality of life measure scores similar to people post-myocardial infarction [64]. The disability resulting from post-traumatic OA is comparable to end-stage kidney disease and heart failure [56]. Overall, the outcomes of talus and calcaneus fractures are guarded, with long-term implications for the patient's ability to perform functional activities and participate in social roles [28]. Early, appropriate surgical intervention may improve outcomes.

J. M. Hobbs (✉)
Sigvard T. Hansen Jr. Foot and Ankle Institute,
Harborview Medical Center/UW Medicine, Seattle,
WA, USA

© Springer Nature Switzerland AG 2020

M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_23

The hindfoot complex is integral to human locomotion. In gait, the foot and ankle must serve the competing interests of mobility and stability: To allow transmission of force, accommodate a variety of surfaces, and dampen proximal torque [37]. The calcaneus bears weight, provides a lever arm for forward propulsion, and supports the lateral column of the foot via the cuboid [67]. The talus acts as an intercalated segment between the lower leg and the foot, connecting to the medial column via the navicular [37]. The talonavicular joint (TNJ) contributes significantly to overall supination and pronation [37]. The shape of subtalar joint surfaces and location of ligaments convert tibial transverse plane rotation to frontal and sagittal plane motion necessary for forward locomotion [27].

There is close interdependence of motion in foot and ankle joints. Midtarsal and subtalar joint (STJ) motion is linked and usually associated with ankle joint movement [27, 49]. Malunion, post-traumatic arthrosis, and ligament damage secondary to hindfoot fractures disrupt the intricate partnership between bony surfaces. Hindfoot joints have limited tolerance of variances, increasing the risk of long-term disability after injury [54]. Decreased mobility in one joint will impede mobility in others [27]. If the subtalar joint (STJ) is stiff, the transverse tarsal joint will also be restricted [33]. A varus orientation of the calcaneus, often seen after calcaneus fracture, impedes Chopart's joint motion and diminishes the foot's ability to absorb shock [51].

A model that adequately explains the properties and relationships of foot and ankle joints, particularly the subtalar and talonavicular joints, has proved challenging to develop [12, 67]. Hindfoot joint motion is difficult to measure clinically and varies significantly between people [33, 36]. Many assessment protocols have used STJ neutral (STJN) as a landmark, but measurement of STJN has shown poor inter-rater reliability [12]. The foot does not operate around STNJ, and further, static measurements do not predict dynamic function [8, 29, 43]. Okita et al. [50] have challenged the concept that transverse tarsal joint locking contributes to the development of a rigid lever during stance-phase push-off. Not surprisingly, further studies are necessary to enhance the evolving understanding of foot and ankle joint mechanics.

Rehabilitation

The return to wellness for patients after hindfoot fractures involves more than just healing of bone. Rehabilitation crosses biological, personal, and social domains [30]. Skilled rehabilitation professionals are important members of the multidisciplinary team working to restore or optimize function and promote full inclusion and participation in all aspects of life [61].

According to the International Classification of Functioning, Health and Disability (ICF; [68]), *function* encompasses body structures (anatomy), body functions (physiology), activities of daily living (ADLs), and participation in social roles (see Fig. 23.1). Personal and environmental factors are important functional determinants [68].

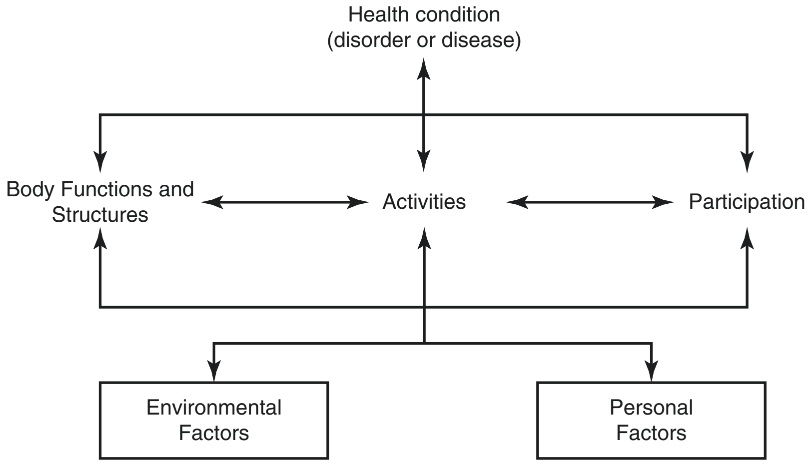


Fig. 23.1 Components of the ICF model [35], open access

The use of the ICF taxonomy facilitates communication and collaboration of disciplines [30, 61]. Depending on a patient's unique contextual factors, the rehabilitation team may include physical therapists, occupational therapists, rehabilitation psychologists, vocational rehabilitation counselors, pain management specialists, and nutritionists. As movement systems specialists [3], physical therapists are uniquely qualified to help a patient to reach optimal functional mobility outcomes. Patients with lower extremity trauma treated with physical therapy scored higher in mobility and gait quality measures 2 years after injury [10].

Rehabilitation after hindfoot fractures can be divided into five phases. Phase 1 begins immediately after surgery or at the time of injury if no surgical repair is indicated. Many surgeons will have post-injury protocols. Good communication between a therapist and a surgeon or managing physician regarding individual patient characteristics and precautions will enhance patient care and safety. Phase 1 lasts 1–3 weeks and includes the initial response to injury and/or surgery and adjustment to mobility constraints (see Table 23.1). Phase 2 covers approximately weeks 2–6 (see Table 23.2). Usually by week 3, any sutures have been removed, and the range of motion exercises

Table 23.1 Physical therapy rehabilitation protocol Phase 1: weeks 1–3

Presentation/ precautions	Anticipated limitations or impairments	Interventions
Splint, cast, or protective boot; NWB-affected foot; surgical wound		Initial examination, systems review, and evaluation. Measure contralateral foot and ankle ROM for comparison purposes Patient education: precautions, expected rehabilitation course, pain mitigation, edema management, relaxation techniques, instruction on benefits of physical activity
Body structures and functions	Pain (acute, surgical), edema, impaired skin integrity, limited ROM, decreased strength, altered balance and proprioception, potential for cardiopulmonary deconditioning	Compression, cryotherapy, elevation for edema Wound and fracture protection Assess for pressure related to cast or splint Initiate desensitization if indicated AROM-unaffected joints of ipsilateral leg/toes, UEs and contralateral LE Gentle submaximal isometrics of foot intrinsic and calf musculature Resistance band exercises for UEs and contralateral LE Core musculature activation and deep breathing Begin AROM of ipsilateral ankle, subtalar joint (high repetitions, low intensity) with physician clearance, 1–2 weeks post-op Exercise examples: gluteal sets, ipsilateral hip/knee flexion extension (bicycles), sidelying and prone ipsilateral leg lifts, toe ad- and abduction, MTPJ flexion with IPJ extension
Activities	Impaired mobility (bed, transfers, and gait) Impaired ADLs, including management of splints and dressings Increased fall risk Inability to drive	Bed mobility, transfer, and gait training Assistive device assessment and fitting: gait device, bath or shower chair, toilet frame with armrests or bedside commode OT consult if applicable Develop transportation strategies
Participation	Potential for altered work, family, or recreational roles, including caring for children	Social work or vocational rehabilitation counseling referral if indicated Begin process of developing return to work strategies
Environment and personal factors		Assess medical history, lifestyle, and subjective information including facilitators and barriers Rehabilitation psychologist referral if indicated

Note: ADLs activities of daily living, *AROM* active range of motion, *IPJ* interphalangeal joint, *LE* lower extremity, *MTPJ* metatarsal phalangeal joint, *NWB* non-weight bearing, *OT* occupational therapy, *PROM* passive range of motion, *STJ* subtalar joint, *TCJ* talocrural joint, *TNJ* talonavicular joint, *UE* upper extremity, *WB* weight bearing are allowed, but weight-bearing restrictions continue. Phase 3 spans weeks 6–16 and includes return to weight bearing and gait without splints or assistive devices (see Table 23.3). Phase 4, months 4–6, begins the work of fine-tuning gait and balance (see Table 23.4). Phase 5 covers return to higher-level vocational or avocational activities, typically 6–9+ months after injury (see Table 23.5).

Table 23.2 Physical therapy rehabilitation protocol Phase 2: weeks 2–6

Presentation/ precautions	Anticipated limitations or impairments	Interventions
NWB-affected foot removable boot Sutures removed at 2 weeks post-op		Initial examinations, systems review, and evaluation if not completed previously Patient education: same as Phase 1
Body structures and functions	Pain (sub-acute), edema, scar sensitivity and adherence, limited osteo- and arthrokinematic ROM of TCJ, STJ, TNJ, decreased LE strength, decreased excursion of toe plantarflexors	Initiate compression stockings when wounds healed. Electrical stimulation for edema, pain management Measure ipsilateral foot/ankle ROM, assess long toe flexor, and extensor glide Scar massage, desensitization if indicated Continue AROM ipsilateral foot/ankle (high repetition, low intensity) Add PROM ipsilateral ankle, subtalar, toes with gentle overpressure Consider nerve mobilization exercises
Activities	Impaired gait Potential for falls	Continue gait training with assistive device, progress terrain difficulty, stairs
Participation	Potential for altered work, family, or recreational roles	Assess potential for return to work, out of home activities, transportation

Table 23.3 Physical therapy rehabilitation protocol Phase 3: weeks 6–16

Presentation/precautions	Anticipated limitations or impairments	Interventions
Progressive WB on affected foot in protective boot or supportive shoe Talus fractures usually start WB later (12 weeks) Criteria for progression of weight bearing or activity level: radiographic evidence of bone healing and no significant increase in pain or swelling with increased weight		Patient education: signs of tissue overload—increased pain that does not resolve over the next 12 hours, increased redness or warmth of injured area, decreased functional ability of the foot or ankle Pain physiology, if indicated
Body structures and functions	Pain (sub-acute), edema (chronic), potential for adherent, sensitive scar, limited ROM (decreased osteo-and arthrokinematic motion) TCJ, STJ, TNJ, MTPJs, decreased tendon glide, decreased muscle strength, and recruitment	Scar massage, retrograde massage if edema present. Continue with compression stocking Soft tissue mobilization Calf, long toe plantarflexor stretching Progressive resistance band exercises for calf/ankle musculature Gentle grade I joint mobilization (distraction, glides without resistance) if level of bone healing is appropriate as determined by physician. Progress to grade II joint mobilization after 8 weeks, with the permission of the physician [42] Modalities as indicated

Table 23.3 (continued)

Presentation/precautions	Anticipated limitations or impairments	Interventions
Activities	Gait deviations	Training in progressive weight bearing once cleared by surgeon/physician. Once comfortably full WB, transition gradually to sturdy shoe. Some physicians will progress WB in a shoe Functional exercise examples: floor/mat exercises (quadruped, bridging) Seated balance board, add perturbations (see Fig. 23.8) Stationary bike with resistance once cleared for weight bearing Swimming if incision healed (no fins due to increased torque). Water walking for progressive WB. Height of water corresponds to load on foot (see Table 23.7) Return to driving when in shoe
Participation	Potential for altered work, family, or recreational roles	Return to work if job is sedentary

Table 23.4 Physical therapy rehabilitation protocol Phase 4: months 4–6

Presentation/precautions	Anticipated limitations or impairments	Interventions
Full WB, avoid high-impact activities		Patient education focus: reinforce criteria for progression and signs of tissue overload
Body structures and functions	Pain (sub-acute-chronic), edema (chronic), limited ROM TCJ, STJ, TNJ (decreased osteo- and arthrokinematic motion) Decreased balance, proprioception, coordination, endurance	Stretching, joint mobilization to improve ROM Begin closed-chain exercises for ipsilateral leg once full WB Non-impact balance and proprioception exercises, progressing from double-leg to single-leg stance (e.g., mini-squats, leg press, partial lunges) Progressive strength training (free weights, weight machines) Muscle recruitment and coordination training, including response to perturbations Modalities as indicated
Activities	Gait and balance deviations Difficulty with stairs, uneven terrain	Progress to full WB, wean to sturdy shoe if not already in one Static balance assessment, observe for hip, knee, and first ray control Gait analysis—address gait quality and coordination Low-impact endurance training, e.g., stationary bike with resistance Return to driving if not already
Participation	Potential for altered work, family, or recreational roles	Return to work if job is sedentary Begin return to light or modified recreational activities (e.g., walking, putting, light gardening with a seat)

In Phase 1, the healthcare team's focus is on medical stabilization, pain management, protection of injured tissues, and promotion of mobility. Bed rest is deleterious to most body systems, causing cardiac deconditioning, reduced lung function, diminished oxygen transport, venous stasis, decreased metabolism, skeletal muscle atrophy, integumentary damage, and psychological distress [34]. Protective immobilization of the injury site, while necessary for healing, has detrimental local effects. Immobilization is stress deprivation [48]. Without the stimulus of tensile or compressive loading, connective tissues rapidly become disorganized and weak [37, 42].

Table 23.5 Physical therapy rehabilitation protocol Phase 5: months 6–9+

Presentation/precautions	Anticipated limitations or impairments	Interventions
No high-impact activities until cleared by the physician		Patient education: criteria for progression: No signs of tissue overload. Risks/benefits of higher impact activities
Body structures and functions	Residual joint stiffness and muscle weakness Chronic pain, decreased endurance, agility, power	Continue work on ROM, muscle strength, recruitment, joint mobilization as indicated Assess for gastrocnemius equinus, which can alter gait mechanics. Gastroc equinus recalcitrant to stretching may require surgical release Assess for shoe inserts, orthotics
Activities	Gait deviations	Functional testing for flexibility, strength, balance, and coordination Progress strength, balance/proprioceptive, and endurance training Establish normal gait pattern before starting an aggressive closed-chain program [42] Examples: timed SLS, heel raises, foam/wobble board progression
Participation	Potential for altered work, family, or recreational roles	Return to sports, work in physically demanding jobs at 6–9 months or later Return to sports training when gait pattern is normal, free of compensations; strength is 85%–90% of contralateral LE; able to walk 4–5 miles per hour on treadmill for 30 minutes, pain free [42] High-impact activities may increase risk of post-traumatic arthrosis [7]

Prolonged immobilization affects the ground substance in connective tissue, resulting in decreased lubrication and development of adhesions between collagen fibers [42]. Restricted joint movement results in adaptive shortening and fibrotic changes of soft tissue, and bone density loss may occur secondary to weight-bearing restrictions [42]. Unfortunately, while tissue mechanical properties diminish quickly, recovery requires gradual reloading, and may take over a year [37]. Six weeks of immobilization can require more than 4 months of remobilization to recover tissue mechanical and structural properties [22].

The point of contact with the patient will direct the focus of the initial therapy examination and plan of care. A patient first seen in the hospital or emergency room will have different concerns than a patient seen in an outpatient clinic 6 weeks after injury. Activities too stressful to be assessed early in recovery will need to be addressed later. No matter when the point of contact, the initial physical therapy (PT) visit will include examination, evaluation, and development of PT diagnoses, interventions, and outcome measurements [2]. In the evaluation, a physical therapist identifies impairments in body structures and functions, activity limitations, and participation restrictions toward which interventions and goals will be directed [2]. Given the rate of associated trauma with talus and calcaneus fractures, a therapist should be alert for occult injuries during examination.

Early physical therapy goals are to facilitate upright posture and active mobility, protect healing tissue, and minimize pain and swelling. Patient priorities will include strategies for independent bed mobility, transfers, and locomotion. An assistive device will be required to substitute for the support and balance normally provided by the injured leg. The choice of an appropriate device is not as simple as it may seem. Correct fitting of a device to a patient is important for safety and ease of use. It requires the assessment of the patient's condition and abilities, while balancing energy costs and balance requirements of the device [13]. Ambulating with an assistive device increases metabolic demand due to changes in gait speed, altered arm swing, and increased demand on upper extremities [17]. A three-point (swing-through) crutch gait pattern can increase energy consumption by three to nine times over normal gait, creating a severe exercise challenge for the average sedentary adult [13, 26, 65]. The use of standard (pick-up) walkers can increase oxygen consumption by more than 200% [52].

To use crutches and walkers requires the ability to bear full body weight on hands or forearms during the swing phase of the non-injured leg. The use of forearm crutches reduces the risk of brachial plexus injuries that can occur with axillary crutches but requires greater upper body strength and shoulder stability. A front-wheeled walker provides greater stability than crutches but results in slower gait speed and greater oxygen cost [13]. A four-wheeled walker demands less energy and allows greater speed but is not recommended for three-point gait because it requires firm application of hand brakes during each contralateral leg swing and while standing still.

Devices are available that allow upright ambulation without weight bearing on the hands (see Fig. 23.2). Knee scooters (or knee walkers) support body weight via the ipsilateral tibia. Knee scooters are usually easy to use;

Fig. 23.2 Examples of crutch alternatives. (**a**) Knee scooter. (Photographs Courtesy of Knee Walker Central). (**b**) Peg-Leg. (Courtesy of IWALKFree)

Fig. 23.3 Transfers to knee scooters. For safety, always engage brakes before transferring from chair or bed to the knee scooter. The patient's knee should be firmly on the platform before releasing hold of the stable seating surface

first-time consumers may require training in transfers to and from the device (see Fig. 23.3). For people who have the balance and strength to use them, peg-leg devices are available. Peg-leg devices also use the ipsilateral tibia for weight bearing; the tibia rests on a platform with the femur strapped to an upright peg. The user should remove the device periodically to extend the knee. Patients with concurrent midshaft tibia or proximal injuries will not be able to use a knee scooter or peg leg. A wheelchair (WC) may be necessary for patients with contralateral lower extremity injuries, weakness, or cardiovascular limitations and may be a better choice for longer distance ambulation as a WC requires less energy expenditure than crutch-assisted gait [65]. Anyone dependent on a WC knows that even with environmental modifications such as ramps or widened toilet stalls, accessibility can be onerous. Loading a WC into a car is cumbersome. Prolonged sitting in a WC can carry physiological and psychological risks similar to bed rest. Ultimately, the best assistive device will be the one that meets an individual patient's needs. Most people with calcaneus or talus fractures will be non-weight bearing on the affected limb for 6–12 weeks.

Therapeutic exercise, designed considering the patient's fracture, medical condition, fixation, and precautions, can begin as soon as the patient is able to participate. Exercise serves many purposes. Movement and exercise promote recovery from anesthesia by stimulating respiration and circulation [19]. Therapeutic exercise can increase the range of motion (ROM), strength, flexibility, and endurance [22]. Exercise has known psychological benefits and can reduce anxiety and depression [63].

While the patient may not be able or allowed to move the ankle or subtalar joints, it is important for him or her to perform active range of motion (AROM) exercises at each of the surrounding, uninjured joints including the ipsilateral hip, knee, and toes (see Fig. 23.4). Movement enhances systemic fluid dynamics, oxygen transport, and nutrition of articular cartilage [22]. Contralateral strength training improves ipsilateral muscle and/or motor-neuron function [9]. Gentle isometric activation of immobilized segments, especially foot intrinsic muscles (Fig. 23.5), promotes neuromuscular activation,

Fig. 23.4 Early post-injury exercises. Physical Therapist training patient in bed exercises. Time spent in prone will help stretch hip flexors

reduces edema, and may offer pain relief [22]. When permitted by the physician, early AROM of the ipsilateral ankle, subtalar, and talonavicular joints may be initiated. Early AROM is associated with reduced incidence of DVTs and post-traumatic OA [1, 66]. When the patient is at rest, elevation of the foot to heart level supports edema management. Extreme elevation can risk elevation ischemia, especially in patients with low blood pressure [23].

Tissue healing guides the progression of therapeutic exercise and techniques. While each tissue type has individual characteristics, healing generally follows an orderly and timely process of inflammation, repair, and remodeling [18]. The physical therapist must determine optimal loading to augment the healing process. Overload can be destructive and perpetuate the inflammatory response. Underload can result in weak, disorganized collagen, decreased tensile strength, adhesions, and motion loss [22, 37]. Signs of tissue overload include increased pain that does not resolve over the next 12 hours, increased redness or warmth of the injured area, and decreased functional ability of the foot or ankle [22]. Any signs of severe swelling, disproportionate pain, or decreased sensation may be indicative of DVT, compartment syndrome, occult injury, or infection and should be reported promptly to the patient's physician.

If not started earlier, therapeutic AROM exercises should be started for the ipsilateral ankle and STJ in the second phase of rehabilitation (see Table 23.2), when inflammation has resolved and the incision is closed [1]. Early AROM can minimize later joint stiffness associated with gait deviations such as compensatory knee and hip motion, reduced gait speed, and shortened stride length [41]. At least 8°–10° of ankle dorsiflexion and 25°–30° of plantarflexion are required to walk on level surfaces without a limp (Levangie and Norkin 2005). Calcaneal inversion and eversion, measured posteriorly compared to the tibia, are typically 20° and 10°, respectively [37]. STJ and talonavicular (TNJ) motions are linked, crossing all three cardinal planes. The combined ROM is challenging to measure [33]. Centering a goniometer anteri-

Fig. 23.5 Foot intrinsic muscle activation. (**a**) MTP flexion with IP extension. (**b**) Toe abduction/adduction

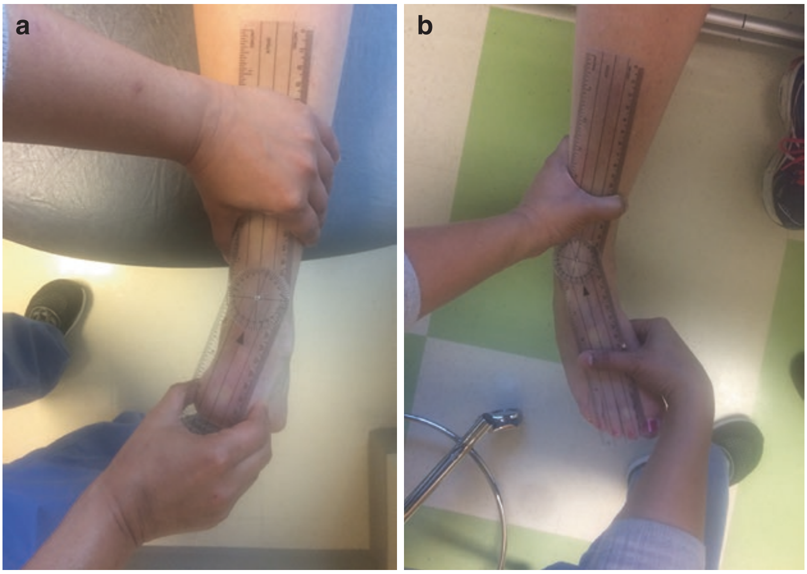


Fig. 23.6 Goniometric ROM measurement. (**a**) Calcaneal inversion measured relative to tibia: patient is prone, goniometer at mid-Achilles'; proximal arm centered over tibia, distal arm mid-calcaneus [14]. (**b**) Combined forefoot-midfoot-hindfoot inversion: patient is sitting with knee flexed, goniometer centered over talar head, proximal arm parallel to tibia, and distal arm parallel to the second ray [15]. Goniometry is considered moderately reliable when measured by the same therapist (Elveru et al. [15])

orly over the talar head, with one arm parallel to the tibia and the other to the second ray (see Fig. 23.6), allows comparison to the contralateral lower extremity with acceptable intra-rater reliability [15, 41].

Phase 2 is an appropriate time for soft tissue mobilization. Scar massage is most effective during the fibroblastic stage of tissue healing, which usually occurs between 3 and 8 weeks following surgery or injury, depending on tissue quality and vascularity [42]. Early soft tissue work helps normalize the foot and ankle's response to stimuli, reducing the risk of hypersensitivity.

When a patient is cleared for progressive weight bearing, usually between 6 and 12 weeks post-operative or post-injury, Phase 3 of rehabilitation begins. The surgeon or physician will determine a progressive weight-bearing schedule based the condition of bone and the type of fixation (see Table 23.6 for schedule examples and Fig. 23.7). Patient comfort must be monitored as weight bearing progresses; loading should be reduced if signs of tissue overload occur. A patient who has been using an alternative gait device will need crutches or a walker to allow the ipsilateral foot to contact the ground. Some physicians will have a patient wear a protective boot, and others will allow a supportive shoe. Patients with bilateral injuries will need to progress weight bearing by walking in a pool (see Table 23.7) or access body-weight-supported treadmills or harnesses at a local rehabilitation clinic. Propelling a WC with one's feet allows partial weight bearing equivalent to approximately 25% of body weight; the load can be measured by stepping on a standard bathroom scale.

Table 23.6 Examples of progressive weight bearing and transition from protective boot to shoe

20 lb. increments	Body weight percentage
Using crutches or a walker, patient starts with 20 lb. WB on ipsilateral foot and adds 20 lbs. every 3 days as comfortable Example: A 160 lb. woman starts at 20 lbs. She adds 20 lbs. every 3 days. With first attempt at 80 lbs., she experiences increased pain. She returns to 60 lbs. for 3 days, then tries 80 lbs. again, successfully. She continues until she is able to bear 160 lbs. (needed for stance phase of gait), then weans off crutches	Using crutches or a walker, patient starts with 25% of body weight load on ipsilateral foot; increases at 25% per week until FWB Example: A 220 lb. man starts with 55 lbs. allowed on foot. If comfortable, increases to 110 after 1 week, adding 55 lbs. per week until full weight bearing (220 lbs.), then weans off crutches
Weaning from CAM boot once FWB[a].	
Patient exchanges boot for sturdy, well-cushioned shoe for 1 hour on the first day. Add 1 hour per day until fully into shoe. Crutches or a cane may be needed for stability at first.	

Note: *FWB* full weight bearing

[a] Some physicians may choose to progress weight bearing in a shoe instead of protective boot

During Phase 3, work on ROM and therapeutic exercise continues. Elastic-type resistance bands can be added to progress strengthening. For outcome assessment, hand-held dynamometry is a

Fig. 23.7 Measuring partial weight bearing. Measuring the load on ipsilateral foot during stance, using a standard scale

Table 23.7 Partial weight bearing in water

Water height	Equivalent WB on land
Nipple line to clavicle	25% of body weight
Waist to xyphoid	50% of body weight
Hip to anterior superior iliac spine	75% of body weight

Harrison et al. [24]

reliable and valid tool for the measurement of muscle strength in the clinical setting [60]. With the permission of the physician, a therapist may initiate gentle Grade I and Grade II joint distraction and glides to improve arthrokinematic motion (see Table 23.8). Seated wobble board perturbation exercises allow partial weight-bearing proprioceptive training (see Fig. 23.8).

Once a patient has reached full weight bearing, Phase 4 begins, with a focus on gait quality and closed-chain (weight-bearing) activities. The patient gradually reduces reliance on assistive gait devices and protective boots and works on normalizing gait on level surfaces. Progressive closed-chain strengthening, balance, and proprioceptive exercises are added with the focus on coordination, muscle flexibility, motor recruitment, and endurance (See Fig. 23.9). Foot posture, range of motion, and strength should be measured and compared to the contralateral foot. With clearance from the physician, Grades III–IV physiologic joint mobilization may be used to improve TCJ, STJ, and TNJ ROM.

In Phase 5 of rehabilitation, when a patient is able to walk without a device and with minimal pain or limp, treatment focuses on meeting participation goals; that is, returning to full work and recreational activity. Treatment can include advanced dynamic balance and proprioceptive work as well as appropriate power and agility training [39]. There is not a clear consensus on return to sports (RTS) criteria [4]. A patient and his or her health care team need to weigh tissue-

Table 23.8 Maitland grades of joint mobilization

Grade1	Small amplitude mobilization[a] at the beginning of available ROM for pain reduction
Grade II	Larger amplitude movement within available range without reaching limit for pain reduction and increased ROM
Grade III	Large amplitude movement through available range, into tissue resistance to stretch joint capsule and increase ROM
Grade IV	Small amplitude mobilization at end-range of movement, into tissue resistance to stretch joint capsule and increase ROM

[a] Accessory joint motion using rhythmic, oscillating techniques [25]

Fig. 23.8 Partial weight proprioceptive training. Partial weight-bearing perturbation for neuromuscular training

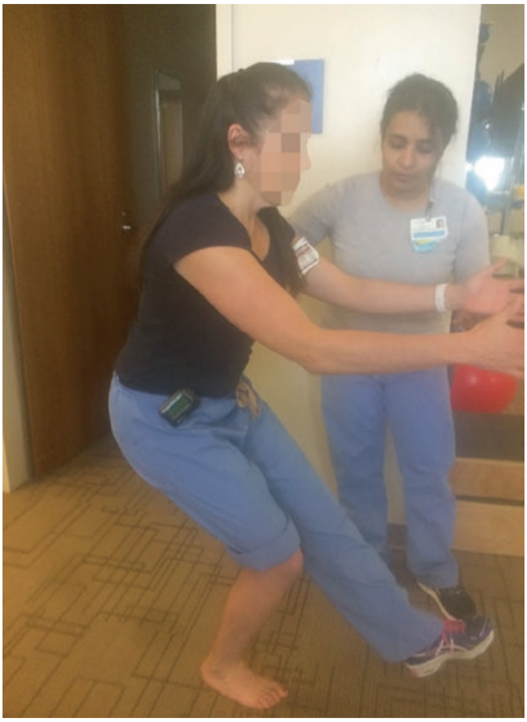


Fig. 23.9 Proprioceptive training. Single-leg squat for dynamic stability and strengthening

healing status, the demands of the sport, and the risks involved [59]. Some authors recommend clinical and functional testing of the ipsilateral leg reach at least 80%–90% of the contralateral side before RTS [11, 42]. However, as noted previously, the severity of calcaneus and talus fractures may preclude return to previous functional levels. Many patients may need to avoid higher impact activities, such as running or tennis, due to the potential for cartilage damage from altered joint mechanics [7]. Some people may not be able to return to prior employment. Referral to vocational counseling or a rehabilitation psychologist may help a patient adapt to a new normal.

Patients with chronic pain or other disability related to calcaneus or talus fractures benefit from PT intervention for pain management, joint protection, and strengthening of proximal musculature. The heel fat pad is often damaged with hindfoot injuries; accommodative heel cushions and circumferential distal heel taping can relieve pain. Stiffness at the subtalar joint can increase stress at the midfoot. Posterior tibialis and peroneal muscle strengthening, as well as appropriate supportive shoe inserts, can reduce tarsometatarsal pain. Some patients with post-traumatic arthrosis benefit from splinting to reduce joint motion. Maintaining strong proximal musculature, especially at the hip, provides additional support and shock absorption for the foot.

Case Studies

Rehabilitation after calcaneus and talus fractures benefits from the expertise of a multidisciplinary team. The following case examples demonstrate how physical therapy promotes optimal recovery.

Case 1: Brianna

Brianna is a 35-year-old woman who suffered a left joint depression calcaneus fracture and a left distal radius fracture secondary to a fall while pruning a tree. A branch punctured her left anterior ankle during the fall. Imaging revealed no injuries beyond left calcaneus and radius fractures. She was referred to PT on day 2 post open-reduction internal fixation (ORIF) of her calcaneus fracture. Her left forearm and wrist were casted after closed reduction of her radius. Precautions included non-weight bearing (NWB) on the left forearm and left foot.

Brianna works as a high school teacher. She rides a bus to work, walking four blocks to and from the bus stop each day. For recreation, she enjoys gardening and running 2–3 miles per day. She is right hand dominant. She follows a vegan diet. She lives alone in a one-story home with three steps to enter (no handrail). Her bathroom is small, with a walk-in shower. She reports anxiety about being "cooped-up" at the hospital and needing to get back to work: "I am used to being very active and independent."

A systems review was negative for cardiovascular, pulmonary, neuromuscular, endocrine, or integumentary disorders. Analog pain scale scores were 5/10 for the left ankle and 4/10 for the left forearm; she denied pain elsewhere. Her self-reported outcome measure scores were 5/85 (6%) on the Foot and Ankle Ability Measure (FAAM; [40]) and 8/80 (10%) on the Lower Extremity Functional Scale (LEFS; [5]).

Examination

At her first PT visit, Brianna was found resting supine on her bed. Her vital signs were within normal limits. Her visible skin was warm and dry; her calcaneus incision and puncture wound were not visible due to splinting.

Right upper and lower extremity ROM and manual muscle test (MMT) strength results were within functional limits (WFL). Right ankle dorsiflexion was 5° knee straight, 12° knee bent; ankle plantarflexion 45°; combined hindfoot-forefoot inversion (see Fig. 23.6) 24°, combined hindfoot-forefoot eversion 12°; and first toe dorsiflexion at metatarsal phalangeal joint (MTPJ) 75°. Lesser toes were fully flexible without evidence of clawing.

Left shoulder, elbow, hip, and knee ROM tested within WFL, with strength at least against gravity. Further resistance testing was deferred.

Brianna's left fingers were mildly swollen, limiting metacarpal-phalangeal and interphalangeal (IP) flexion to approximately 80% of the right hand. ROM and strength testing of the left foot and ankle was deferred due to precautions. Her left toe motion was limited by swelling and pain, but strength was at least 3−5.

Functional Abilities

Examination revealed that bed mobility (moving in, and to edge of, bed) required one-person moderate assist and use of an over-bed trapeze. Stand pivot transfers to a wheelchair required two-person moderate assist; one to keep left foot off the ground, the other for balance. No apparent limitation in gross spinal movement was visible during functional activities.

Brianna's impairments included pain; swelling; limited left wrist, ankle, and subtalar joint ROM and strength; inability to bear weight on left forearm and left foot; and impaired balance and postural control. Activity limitations included standing, transfers, walking, stairs, dressing, and driving. She was unable to use crutches or a walker due to weight-bearing precautions. Participation restrictions included work, transportation, recreation, and household chores. Knowledge deficits included lack of health literacy about infection, deep vein thrombosis, pain mitigation, edema management, and community disability support options.

Brianna's PT plan was two therapy sessions per day while in the hospital, then transition to home-health PT until no longer homebound. With her injuries, she would likely need PT at varying levels of frequency for several months.

Interventions

To increase Brianna's functional independence, she needed a temporary side-rail for bed mobility, a transfer pole for transfers in and out of bed, a knee scooter for ambulation, and a wheelchair for longer distances and work. In the bathroom, she needed a shower chair, hand-held showerhead, grab bars, and waterproof cast covers. For entry to her home, she needed a ramp and a handrail added to her front entrance. For other stairs, she needed training in an alternate method of ascent and descent (see Fig. 23.10). Therapy staff assisted Brianna to contact a local medical supply store for equipment. Her insurance covered only one gait device, so community loaner options were accessed to obtain a wheelchair. OT was brought in to treat ADL and self-care deficits. A social worker provided for assistance with insurance and return-to-work issues.

Functional Training

The first PT visit included training in bed mobility, transfers, and gait using adaptive equipment. After training, she was able to transfer from bed

Fig. 23.10 Alternate stair methods. Patients with multiple injuries may require creative solutions for going up- and downstairs. The patient uses her contralateral leg and arm to push herself up one step at a time. A patient using this method will need to be able to get up and down from the floor safely, while maintaining NWB precautions on the ipsilateral foot and arm. An alternative is to face the steps and use the ipsilateral knee as a weight-bearing surface

to knee scooter with contact guard assist (using a transfer pole), ambulate 3 meters, and turn with one-person moderate assist. She was able to propel a wheelchair independently 40 feet using her uninjured extremities.

Therapeutic Exercise

Brianna was trained in AROM for unimpaired joints and toe intrinsic exercises (IP extension, MTPJ flexion, abduction/adduction of toes) to be performed every 1–2 hours during the day to promote circulation and mobility. She was instructed in gentle passive ROM (PROM) and retrograde massage to her toes to promote toe flexibility and reduce edema. Written instructions were provided and each technique video-recorded (with her permission) on her smart phone to promote adherence. Resistance band exercises for her RUE and RLE were planned for a later PT visit.

Patient education was provided about the rehabilitation plan, precautions, edema reduction, pain management, and simple relaxation exercises (to assist with anxiety). The signs and symptoms of infection and deep vein thrombosis were reviewed with instructions to notify her physician if any occur. Because of Brianna's vegan diet, a dietician consult was requested to ensure adequate nutrient intake for healing; vegans have potential for insufficient vitamin D, B-12, protein, iron, and zinc [63]. Home health PT and OT were prescribed at discharge from the hospital.

Goals

By discharge from hospital, Brianna will:

- Transfer to and from bed to wheelchair or knee scooter with standby assist of one family member.
- Transfer to and from a car to WC or knee scooter with the assistance of one family member.
- With therapist assistance, procure a WC, knee scooter, and shower chair for use at home.
- Arrange for help at home. Brianna's mother and sister were able to stay with her for 1 week each, after Brianna's discharge from the hospital. After that, friends were able to assist with occasional transportation, grocery shopping, and laundry.
- Return-demonstrate her home exercise program with the assist of written materials and videos.

By 4–6 week post-op, Brianna will:

- Return to work part-time, with assistance for transportation.
- Be upright, using the knee scooter for 20–30 minutes at a time.
- Self-manage edema.
- Report pain level decreased to 3/10 or less.
- Improve left ankle ROM at least 5° ankle dorsiflexion (DF), knee straight, 12° combined hindfoot-forefoot inversion, 8° eversion, and 60° first MTP joint dorsiflexion in preparation for gait.

By 6 months post-op, Brianna will be able to:

- Stand and walk in standard shoes at work, full time, with a pain level of 1/10 or less.
- Walk for 30 minutes at a pace of 4 miles per hour without pain.
- Improve FAAM ADL subscale score to at least 63/85 (8 points is the minimally clinically important difference; [40]).

Case 2: Roberto

Roberto is a 28-year-old man 6 weeks post-ORIF of a right tongue-type calcaneus fracture secondary to a motor vehicle accident. Since his injury, he has lived at home with the help of his wife and his mother, who moved in to help with his care. He was referred to physical therapy by his surgeon, with instructions to start progressive weight bearing. His X-rays showed full bone healing.

Roberto works as a computer programmer but has not yet returned to work. He has been using a wheelchair as his main ambulatory device but has a walker available at home. His recreational activities prior to injury were playing video games and occasionally going to a casino with his wife. Roberto was diagnosed with insulin-dependent diabetes at age 18 and used insulin daily. Since his injury, his wife or his mother has assisted him with blood sugar testing and insulin injections; he was independent before. His last hemoglobin A1c level was 6.1%, indicating well-managed insulin levels. He weighs 180 lbs.

During his patient interview, Roberto reported that he has been keeping his foot wrapped in an elastic compression wrap (that his wife applied) but not wearing a protective boot because it was painful to don and doff. His analog pain level was 10/10. He stated looking at his foot made him nauseous. He stated, "I don't see how I can work with this pain." He reported he does not feel safe using crutches.

His Fear-Avoidance Components Scale score was 57/100, indicating a moderately severe level of fear avoidance behaviors [20]. His FAAM ADL sub-score was 12/85 (14%). A systems review was negative for cardiovascular, pulmonary, neuromuscular, or integumentary disorders.

Examination

Roberto was found sitting in a wheelchair with his right foot elevated. His wife supported his right leg as he performed a left leg pivot transfer to a mat table. A scan exam of upper and lower quadrants was normal except for the right lower leg. Roberto's contralateral (right) lower leg range of motion measurements were ankle dorsiflexion 10° knee straight; 15° knee bent; plantarflexion 45°; combined hindfoot-forefoot inversion 36° (see Fig. 23.6), combined hindfoot-forefoot eversion 18°; and first toe dorsiflexion at the MTPJ 90°. Left foot and ankle MMT strength were 5/5.

The skin over the dorsum of his right foot was pale, cool, and clammy. The incision was healed but showed signs of adherence. Minimal swelling was present. Roberto held his right foot quite stiff and stated it was very sensitive to touch. Right ankle, STJ, and toe ROM were very limited. Ankle dorsiflexion was −15° knee straight and −9° knee bent (indicating tight gastrocnemius and soleus), and ankle plantarflexion was 25°. Inversion, eversion, abduction, and adduction were limited to a few degrees in each direction. His toes showed signs of clawing. Manual muscle testing was grossly 2+/5; he would not allow any resistance or overpressure. Based on Well's Criteria, he did not exhibit signs of a DVT [45].

Roberto's impairments included pain/hyperalgesia, limited range of motion, decreased strength right lower leg, adherent scar, stiff soft tissue, and restricted arthrokinematic motion at the TCJ, STJ, and TNJ. Activity limitations were standing, transfers, walking, and ADL performance. He was unable to work, drive, or perform household or yardwork (participation restrictions). Personal and environmental contextual factors affecting Roberto were a moderately high level of fear avoidance behaviors. Fear avoidance beliefs are significantly associated with reduced activity levels and increased perception of disability [20]. His self-efficacy for healthcare appeared low, based on his dependence on his mother and wife. Knowledge deficits were present about the physiology of pain and the benefits of exercise.

The plan for Roberto was physical therapy three times per week for 2 weeks followed by one time per week for 6 weeks, at which time skilled PT needs would be reassessed.

Treatment

At Roberto's first treatment, techniques to modify hypersensitivity (desensitization) were initiated along with training in relaxation techniques and self-management of pain. *Explain Pain* [46] was used to help Roberto re-conceptualize pain. Grade I joint mobilization of TCJ, STJ, and TNJ was initiated for pain reduction and ROM improvement. As part of his desensitization program, he was instructed in contrast bathing and progressive manual contact.

For therapeutic exercise, Roberto was started with contralateral leg ROM and strengthening exercises, taking advantage of contralateral effects of unilateral strength training and over-flow principles to initiate ipsilateral movement [9]. His initial home exercise program consisted of AROM exercises for the ipsilateral foot to be performed hourly while awake (e.g. alphabets). Other than set-up and encouragement by his family members, he was instructed to perform the exercises and desensitization independently. Due to Roberto's discomfort with a CAM boot, his physician was contacted for permission to wear a shoe during progressive weight bearing. As part of his desensitization program, Roberto was instructed to increase his time in a shoe by 30 minutes per day, to increase his tolerance of footwear.

Plans for his next PT visit included manual stretching of his calf and toes, and light resistance band exercises. Progressive weight bearing would be initiated at 20 lbs. on his right foot and progressed in 20 lb. increments every 3 days. Future patient education would include instruction in monitoring his feet for signs of injury and neuropathy related to diabetes.

Goals

In 2 weeks, Roberto will be able to:

- Tolerate a shoe for 6 hours per day.
- Improve right foot ROM by 25%.
- Walk for 5 minutes at a time, using crutches, bearing 80 lbs. on his right foot.
- Visit a casino with his wife for 1–2 hours, using a WC.

In 3 weeks, Roberto will be able to:

- Hold a calf-stretch in double-leg stance for 30 seconds at a time, to improve ankle dorsiflexion range of motion.
- Return to work for 4 hours per day.

In 4 weeks, Roberto will be able to:

- Drive independently.
- Walk short community distances, using a cane in the contralateral hand, with pain level 3/10 or less.
- Stand in right single-leg stance (SLS) for 30 seconds with fingertip support.
- Work full time.

In 6 weeks, Roberto will be able to:

- Walk without a device while walking on level surfaces and demonstrate a gait pattern free of compensation via knee or hip flexion to clear his right foot during swing.

In 8 weeks, Roberto will be able to:

- Walk outdoors, short community distances without a device, and complete a grocery shopping trip.
- Spend 3 hours at a casino with his wife, walk to and from the parking lot, and stand for 30 minutes at a slot machine with pain level 2/10 or less.
- Improve FAAM ADL subscale score to at least 40/85.

Case 3: Vikram

Vikram is 6 months post-ORIF of a left intra-articular calcaneus fracture. Per his physician, the fracture is fully healed. Vikram was cleared to progress physical activity, and his physician has referred him to physical therapy. Vikram is interested in returning to recreational soccer. He works as a journalism professor in a local college.

In a patient interview, Vikram revealed he has been walking in a shoe without an assistive device for 2 months. He has worked his way up to walking 3 miles per hour on a treadmill, for 15 minutes per day. His pain level when walking on level surfaces is 0/10. He reports a pain level of 3/10 when walking on uneven terrain; the pain is located in his plantar heel and in his midfoot near the first tarsometatarsal (TMT) joint. His FAAM ADL score was 40/85, and FAAM Sport Subscale 3/32.

A systems review was negative for cardiovascular, pulmonary, neuromuscular, endocrine, or integumentary disorders, with no history of chest pain or dizziness. His only prior musculoskeletal (MSK) problem was turf toe, affecting his left (kicking) foot, in high school.

Examination

A general MSK scan exam revealed tight left iliopsoas, hamstrings and gastroc-soleus plus weak gluteals, and hip abductors and rotators. Left foot examination revealed mild swelling distal to the TCJ. He had decreased left foot and ankle range of motion compared to right side. Left ankle dorsiflexion was limited to −10° knee straight or bent, with decreased posterior glide of the talus in the ankle mortice. Combined left hindfoot-forefoot inversion was one-half that of the right foot, and eversion reached just slightly past neutral. Subtalar and talonavicular joints exhibited diminished arthrokinematic motion. His left lesser toes were mildly clawed. The first metatarsophalangeal (MTP) joint was limited to 45° but not painful. The tarsometatarsal (TMT) joint was slightly hypermobile.

His right (uninjured) foot was quite flexible, with 12° dorsiflexion knee straight, 20° knee bent, 60° plantarflexion, 35° combined hindfoot-forefoot inversion, and 18° combined forefoot-hindfoot eversion. First MTP joint dorsiflexion was 75° and plantarflexion 40°. Foot Posture Index score on the right was +1 (slightly pronated) and on the left, −2 (slightly supinated [53]).

Functional Testing

Vikram was wobbly in tandem stance. When performing double-leg stance (DLS) heel lifts, he shifted 75% of his weight onto the right leg. Right single-leg stance (SLS) time was more than 30 seconds; on the left, it was 3 seconds. He could perform 20 SLS right heel raises and one on the left. Bridge, plank, and quadruped testing showed decreased stability through the left leg.

Gait observation revealed Vikram walked with a mild limp, with decreased left forefoot push-off at the end of stance, early lift off, and left hip hiking to clear his foot during swing.

Assessment

Vikram exhibited deficits in ROM, strength, core stability, balance, proprioception, endurance, and gait quality. Decreased hindfoot motion and toe extension cause increased stress on remaining articular structures. Compensatory hypermobility at the TMTJ may be the source of his midfoot pain.

Vikram lacked the neuromuscular control to create adequate dynamic joint stability for sports participation. He would need to improve his left lower extremity functional strength to at least 80% of that on the right and be able to walk aggressively on a level surface for 30 minutes before jogging, plyometric training, or simulated sports activities [42]. He was educated that high-impact activities may accentuate discrepancies in joint shape and function, increasing the risk of post-traumatic arthrosis [7].

Treatment

A heel cushion was added to Vikram's shoes to reduce heel pain and compensate for hindfoot stiffness. He was trained in proper tissue loading and signs of tissue overload. He was instructed to monitor tissue tolerance as his activity level increased by keeping an activity log.

Treatment included progressive strengthening, joint mobilization, and tissue stretching to improve ROM. Proprioceptive neuromuscular training progressed from static DLS activities to dynamic SLS tasks (see Fig. 23.11), using wobble boards, tilt boards, and perturbations. Patient education was provided regarding the risks of high-impact activities to his foot and ankle joints. When left leg functional testing reached 80% of right leg, he decided to accept to risk of progressing to soccer-specific activities and plyometric training was added.

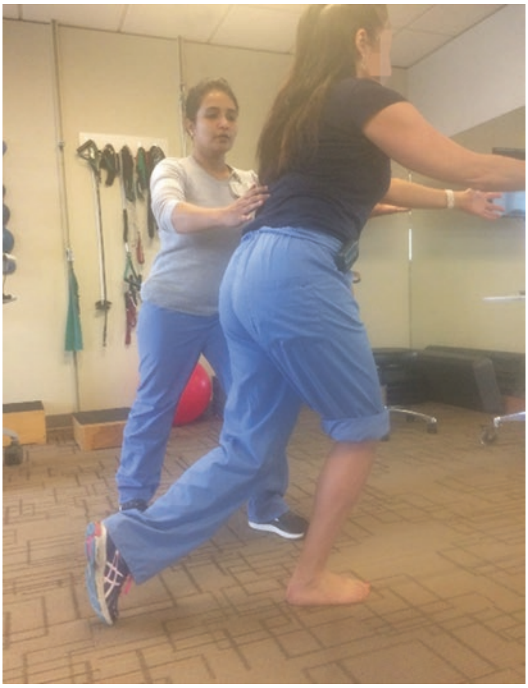


Fig. 23.11 Reaching contralateral leg posteriorly while balancing on ipsilateral foot

Goals

In 4 weeks, Vikram will be able to:

- Perform 10 left heel raises.
- Hold left SLS balance for 30 seconds with fingertip support.
- Hold pelvis level while performing a right leg lift in bridge position.
- Demonstrate left ankle ROM within 95% of right, and left combined STJ/TNJ motion within 80% of right.

In 6 weeks, Vikram will be able to:

- Hold left SLS on balance foam for 15 seconds.
- Perform 10 left SLS quarter squats, with knee maintained in sagittal plane.
- Perform left leg dynamic balance testing, such as the Y-Balance test, within 80% of the right, to demonstrate dynamic postural control [32].

In 8 weeks, Vikram will be able to:

- Perform 20 left heel raises with good form, with fingertip support.
- Walk 30 minutes on a treadmill at 4.2 miles per hour, without pain or loss of gait quality.
- Perform agility testing, such as the Balsom Agility Test without loss of balance or pain [58], to demonstrate coordination and agility necessary for sport.

In 12 weeks, Vikram will be able to:

- Participate in low-impact jogging for 10-minute intervals without residual pain.
- Participate in a low-intensity, recreational soccer game.
- Improve FAAM ADL subscale score to 75/85 and sports subscale to 16/32 (9 points is the minimally clinically important difference [40])

References

1. Albin SR, Cleland J, Brennan GP. Should range of motion exercise be initiated early or late following talus and calcaneus fractures: a comparison study. J Orthop Sports Phys Ther. 2009;39(1):A42. Retrieved from https://www.jospt.org/.
2. American Physical Therapy Association. Guide to physical therapist practice 3.0. 2014. Retrieved from http://www.apta.org/Guide/.
3. American Physical Therapy Association. Vision statement for the physical therapy profession and guiding principles to achieve the vision. 2015. Retrieved from http://www.apta.org/Vision/.
4. Ardern CL, Glasgow P, Schneiders A, Witvrouw E, Clarsen B, Cools A, et al. 2016 Consensus statement on return to sport from the First World Congress in Sports Physical Therapy, Bern. Br J Sports Med. 2016;50(14):853. https://doi.org/10.1136/bjsports-2016-096278.
5. Binkley JM, Stratford PW. The lower extremity functional scale (LEFS): scale development, measurement properties, and clinical application. Phys Ther. 1999;79(4):371. https://doi.org/10.1093/ptj/79.4.371.
6. Bohl DD, Ondeck NT, Samuel AM, Diaz-Collado PJ, Nelson SJ, Basques BA, et al. Demographics, mechanisms of injury, and concurrent injuries associated with calcaneus fractures: a study of 14,516 patients in the American College of Surgeons National Trauma

Data Bank. Foot Ankle Spec. 2016;10(5):402–10. https://doi.org/10.1177/1938640016679703.

7. Buckwalter JA, Anderson DD, Brown TD, Tochigi Y, Martin JA. The roles of mechanical stresses in the pathogenesis of osteoarthritis. Cartilage. 2013;4(4):286–94. https://doi.org/10.1177/1947603513495889.
8. Buldt AK, Murley GS, Levinger P, Menz HB, Nester CJ, Landorf KB. Are clinical measures of foot posture and mobility associated with foot kinematics when walking? J Foot Ankle Res. 2015;8(1):63. https://doi.org/10.1186/s13047-015-0122-5.
9. Carroll TJ, Herbert RD, Munn J, Lee M, Gandevia SC. Contralateral effects of unilateral strength training: evidence and possible mechanisms. J Appl Physiol. 2006;101(5):1514–22. https://doi.org/10.1152/japplphysiol.00531.2006.
10. Castillo RC, MacKenzie EJ, Archer KR, Bosse MJ, Webb LX. Evidence of beneficial effect of physical therapy after lower-extremity trauma. Arch Phys Med Rehabil. 2008;89(10):1873–9. https://doi.org/10.1016/j.apmr.2008.01.032.
11. Chinn L, Hertel J. Rehabilitation of ankle and foot injuries in athletes. Clin Sports Med. 2010;29(1):157–67. https://doi.org/10.1016/j.csm.2009.09.006.
12. Cornwall M, McPoil T. Effect of ankle dorsiflexion range of motion on rearfoot motion during walking. J Am Podiatr Med Assoc. 1999;89(6):272–7. https://doi.org/10.7547/87507315-89-6-272.
13. Deathe AB. Canes, crutches, walkers and wheelchairs: a review of metabolic energy expenditure. Can J Rehabil. 1992;5(4):217–30. Retrieved from https://www.capmr.ca/.
14. Dutton M. Introduction to physical therapy and patient skills [electronic resource]. New York: McGraw-Hill; Medical; 2013.
15. Elveru R, Rothstein J, Lamb R. Goniometric reliability in a clinical setting. Phys Ther. 1988;68(5):672–7. https://doi.org/10.1093/ptj/68.5.672.
16. Epstein N, Chandran S, Chou L. Current concepts review: intra-articular fractures of the calcaneus. Foot Ankle Int. 2012;33(1):79–86. https://doi.org/10.3113/fai.2012.0079.
17. Foley M, Prax B. Effects of assistive devices on cardiorespiratory demands in older adults. Phys Ther. 1996:76(12):1313–9. https://doi.org10.1093/ptj/76.12.1313.
18. Franz MG, Robson MC, Steed DL, Barbul A, Brem H, Cooper DM, et al. Guidelines to aid healing of acute wounds by decreasing impediments of healing. Wound Repair Regen. 2008;16(6):723–48. https://doi.org/10.1111/j.1524-475x.2008.00427.x.
19. Frownfelter DL, Dean EW. Cardiovascular and pulmonary physical therapy: evidence to practice. 5th ed. Philadelphia: Mosby; 2012.
20. Gatchel RJ, Neblett R, Kishino NY, Ray CT. Fear-avoidance beliefs and chronic pain. J Orthop Sports Phys Ther. 2016;2:38–43. https://doi.org/10.2519/jospt.2016.0601.
21. Golshani A, Zhu L, Cai C, Beckmann NM. Incidence and association of ct findings of ankle tendon injuries in patients presenting with ankle and hindfoot fractures. Am J Roentgenol. 2017;208(2):373–9. https://doi.org/10.2214/ajr.16.16657.
22. Hall CM, Brody LT. Therapeutic exercise: moving toward function. Philadelphia: Lippincott Williams & Wilkins; 2005.
23. Hansen ST Jr. Functional reconstruction of the foot and ankle. Philadephia: Lippincott Williams & Wilkins; 2000.
24. Harrison R, Hillman M, Bulstrode S. Research report: loading of the lower limb when walking partially immersed: implications for clinical practice. Physiotherapy. 1992;78:164–6. https://doi.org/10.1016/S0031-9406(10)61377-6.
25. Hengeveld E, Banks K. Maitland's peripheral manipulation: management of neuromusculoskeletal disorders, vol. volume 2. 5th ed. London: Churchill Livingstone Elsevier; 2014.
26. Houglum PA, Bertoti DB. Brunnstrom's clinical kinesiology. 6th ed. New York: McGraw-Hill; 2012.
27. Huson A. Biomechanics of the tarsal mechanism. A key to the function of the normal human foot. J Am Podiatr Med Assoc. 2000;90(1):12–7. https://doi.org/10.7547/87507315-90-1-12.
28. Ishikawa SN. Fractures and dislocations of the foot. In: Campbell WC, Beaty JH, Canale ST, Azar FM, editors. Campbell's operative orthopaedics [electronic resource]. Philadelphia: Elsevier; 2017. p. 4276–350.
29. Jarvis HL, Nester CJ, Bowden PD, Jones RK. Challenging the foundations of the clinical model of foot function: further evidence that the root model assessments fail to appropriately classify foot function. J Foot Ankle Res. 2017;10(1):7. https://doi.org/10.1186/s13047-017-0189-2.
30. Jette AM. Toward a common language for function, disability, and health. Phys Ther. 2006;86(5):726–34. https://doi.org/10.1093/ptj/86.5.726.
31. Kalsi R, Dempsey A, Bunney EB. Compartment syndrome of the foot after calcaneal fracture. J Emerg Med. 2012;43(2):e101–6. https://doi.org/10.1016/j.jemermed.2009.08.059.
32. Kang M-H, Kim G-M, Kwon O-Y, Weon J-H, Oh J-S, An D-H. Relationship between the kinematics of the trunk and lower extremity and performance on the Y-Balance Test. Phys Med Rehabil. 2015;7(11):1152–8. https://doi.org/10.1016/j.pmrj.2015.05.004.
33. Kingwell S, Buckley R, Willis N. The association between subtalar joint motion and outcome satisfaction in patients with displaced intraarticular calcaneal fractures. Foot Ankle Int. 2004;25(9):666–73. https://doi.org/10.1177/107110070402500912.
34. Knight J, Nigam Y, Jones A. Effects of bedrest 1: cardiovascular, respiratory and haematological. Nurs Times. 2009;105(21):16–20. Retrieved from https://www.nursingtimes.net
35. Kostanjsek N. Use of the International Classification of Functioning, Disability and Health (ICF) as a con-

ceptual framework and common language for disability statistics and health information systems. BMC Public Health. 2011;11(Suppl 4):S3. https://doi.org/10.1186/1471-2458-11-S4-S3.

36. Krähenbühl N, Horn-Lang T, Hintermann B, Knupp M. The subtalar joint. EFORT Open Rev. 2017;2(7):309–16. https://doi.org/10.1302/2058-5241.2.160050.
37. Levangie PK, Norkin CC. Joint structure and function: a comprehensive analysis. 5th ed. Philadelphia: F.A. Davis Co.; 2011.
38. Lim EVA, Leung JPF. Complications of intraarticular calcaneal fractures. Clin Orthop Relat Res. 2001;391:7–16. https://doi.org/10.1097/00003086-200110000-00003.
39. Manske R, Reiman M. Functional performance testing for power and return to sports. Sports Health. 2013;5(3):244–50. https://doi.org/10.1177/1941738113479925.
40. Martin RL, Irrgang JJ, Burdett RG, Conti SF, Swearingen JMV. Evidence of validity for the foot and ankle ability measure (FAAM). Foot Ankle Int. 2005;26(11):968–83. https://doi.org/10.1177/107110070502601113.
41. Martin RL, McPoil TG. Reliability of ankle goniometric measurements. J Am Podiatr Med Assoc. 2005;95(6):564–72. https://doi.org/10.7547/0950564.
42. Maxey L, Magnusson J. Rehabilitation for the postsurgical orthopedic patient. St. Louis: Elsevier/Mosby; 2013.
43. McPoil TG, Cornwall MW. The relationship between static lower extremity measurements and rearfoot motion during walking. J Orthop Sports Phys Ther. 1996;24(5):309–14. https://doi.org/10.2519/jospt.1996.24.5.309.
44. Mitchell MJ, McKinley JC, Robinson CM. The epidemiology of calcaneal fractures. Foot. 2009;19(4):197–200. https://doi.org/10.1016/j.foot.2009.05.001.
45. Modi S, Deisler R, Gozel K, Reicks P, Irwin E, Brunsvold M, et al. Wells criteria for DVT is a reliable clinical tool to assess the risk of deep venous thrombosis in trauma patients. World J Emerg Surg. 2016;11:1–6. https://doi.org/10.1186/s13017-016-0078-1.
46. Moseley GL, Butler DS. Critical review: fifteen years of explaining pain: the past, present, and future. J Pain. 2015;16:807–13. https://doi.org/10.1016/j.jpain.2015.05.005.
47. Moucha C, Clyburn TA, Evans RP, Prokuski L. Modifiable risk factors for surgical site infection. J Bone Joint Surg. 2011;93(4):398–404. Retrieved from https://www.jbjs.org/.
48. Mueller MJ, Maluf KS. Tissue adaptation to physical stress: a proposed "physical stress theory" to guide physical therapist practice, education, and research. Phys Ther. 2002;82(4):383–403. https://doi.org/10.1093/ptj/82.4.383.
49. Nester CJ, Findlow AF, Bowker P, Bowden PD. Transverse plane motion at the ankle joint. Foot Ankle Int. 2003;24(2):164–8. https://doi.org/10.1177/107110070302400211.
50. Okita N, Meyers SA, Challis JH, Sharkey NA. Midtarsal joint locking: new perspectives on an old paradigm. J Orthop Res. 2014;32(1):110–5. https://doi.org/10.1002/jor.22477.
51. Parvizi J. High yield orthopaedics. Philadelphia: Elsevier/Saunders; 2010.
52. Powers CM, Burnfield JM. Normal and pathologic gait. In: Placzek JD, Boyce DA, editors. Orthopaedic physical therapy secrets. Philadelphia: Hanley & Belfus; 2001. p. 98–103.
53. Redmond A. The foot posture index: six item version FPI-6. 2005. Retrieved from https://www.leeds.ac.uk/medicine/FASTER/z/pdf/FPI-manual-formatted-August-2005v2.pdf.
54. Richter M, Kwon JY, DiGiovanni CW. Foot injuries. In: Anderson P, Krettek C, Jupiter JB, Browner BD, editors. Skeletal trauma: basic science, management, and reconstruction. Philadelphia: Elsevier/Saunders; 2015. p. 2251–387.
55. Rosenberger PH, Jokl P, Ickovics J. Psychosocial factors and surgical outcomes: An evidence-based literature review. J Am Acad Orthop Surg. 2006;14(7):397–405. https://doi.org/10.5435/00124635-200607000-00002.
56. Saltzman CL, Zimmerman MB, O'Rourke M, Brown TD, Buckwalter JA, Johnston R. Impact of comorbidities on the measurement of health in patients with ankle osteoarthritis. J Bone Joint Surg. 2006;88(11):2366–72. https://doi.org/10.2106/jbjs.f.00295.
57. Sanders RW, Clare MP. Calcaneus fractures. In: McKee MD, Tornetta PI, Ricci WM, McQueen MM, Heckman JD, Court-Brown CM, editors. Rockwood and Green's fractures in adults. Philadelphia: Wolters Kluwer Health; 2015. p. 2640–88.
58. Sayers A, Sayers BE, Binkley H. Preseason fitness testing in National Collegiate Athletic Association soccer. Strength Cond J. 2008;30(2):70–5. https://doi.org/10.1519/ssc.0b013e31816a8849.
59. Shrier I. Strategic Assessment of Risk and Risk Tolerance (StARRT) framework for return-to-play decision-making. Br J Sports Med. 2015;49(20):1311–5. https://doi.org/10.1136/bjsports-2014-094569.
60. Stark T, Walker B, Phillips JK, Fejer R, Beck R. Hand-held dynamometry correlation with the gold standard isokinetic dynamometry: a systematic review. Phys Med Rehabil. 2011;3(5):472–9. https://doi.org/10.1016/j.pmrj.2010.10.025.
61. Stucki G, Cieza A, Melvin J. The international classification of functioning, disability and health (ICF): a unifying model for the conceptual description of the rehabilitation strategy. J Rehabil Med. 2007;39(4):279–85. https://doi.org/10.2340/16501977-0041.
62. Thakur NA, McDonnell M, Got CJ, Arcand N, Spratt KF, DiGiovanni CW. Injury patterns causing isolated foot compartment syndrome. J Bone Joint Surg

Am. 2012;94(11):1030–5. https://doi.org/10.2106/jbjs.j.02000.

63. Thompson CR. Prevention practice and health promotion: a health care professional's guide to health, fitness and wellness. Thorofare: Slack Incorporated; 2015.
64. Van Tetering EAA, Buckley RE. Functional outcome (SF-36) of patients with displaced calcaneal fractures compared to SF-36 normative data. Foot Ankle Int. 2004;25(10):733–8. https://doi.org/10.1177/107110070402501007.
65. Waters RL, Campbell J, Perry J. Energy Cost of Three-Point Crutch Ambulation in Fracture Patients. Journal of Orthopaedic Trauma [Internet]. Ovid Technologies (Wolters Kluwer Health); 1987;1(2):170–3. Available from: http://dx.doi.org/10.1097/00005131-198702010-00007.
66. Wei S, Okereke E, Esmail AN, Born CT, DeLong WG Jr. Operatively treated calcaneus fractures: to mobilize or not to mobilize. Univ Pennsylvania Orthop J. 2001;14:71–3. Retrieved from http://upoj.org/wp-content/uploads/v14/v14_13.pdf.
67. Wolf P, Stacoff A, Stüssi E. Modelling of the passive mobility in human tarsal gears implications from the literature. Foot. 2004;14(1):23–34. https://doi.org/10.1016/j.foot.2003.09.002.
68. World Health Organization. How to use the ICF: a practical manual for using the International Classification of Functioning, Disability and Health. 2013. Retrieved from: http://www.who.int/classifications/drafticfpracticalmanual2.pdf?ua=1.

24

General Principles of Reconstruction

James Meeker

In fracture care, the focus is on bone and joint reconstruction. The hindfoot complex offers an example of how soft tissue structures play a critical role in the mechanics of gait. The proper function of osseous hindfoot structures depends on support from leg muscle tendon units (posterior tibial) as well as intrinsic ligaments (calcaneonavicular/spring).

An understanding of limb alignment assists successful reconstruction. The contralateral side, when unaffected, can serve as a guide in fracture care. Obtaining contralateral radiographs may be useful as a template. In absence of this, knowledge of general norms becomes important.

Alignment

Coronal Plane

Standing body weight travels through the tibia across the talus and into the foot. The tibia's mechanical axis travels through the center of the ankle mortise in both the sagittal and coronal planes. The talus serves as the central axis for both load transmission and motion of the foot and ankle. In the coronal plane, the ankle mortise has a slight valgus tilt.

While standing at rest, the calcaneal tuber is generally in neutral with respect to the mechanical axis of the limb [1–3] (Fig. 24.1). When the coronal plane axis is shifted into varus or valgus, asymmetric joint loading occurs and the mechanics of gait may suffer [4]. In unaffected adults, heel position is neutral in the coronal plane; however, 5–10° of valgus may improve function in patients with hindfoot fusion [5].

Sagittal Plane

The talus functions as the fulcrum of the sophisticated lever mechanism of the foot. The talus serves a dual role by providing a stable pivot point for ankle sagittal motion, but also accommodates the majority of hindfoot motion via the subtalar and transverse tarsal joints. The talus rests on the calcaneus with sagittal declination angle of 29° [6]. The downward slope of the talus in the sagittal plane permits optimal motion arc of the ankle. At the talonavicular joint, the calcaneonavicular (spring) ligament complex supports the talar head from sagging into increased declination seen with pes planus. The Meary-Tomeno axis (Fig. 24.2) describes a linear relationship in sagittal alignment from the talus through the first metatarsal. Angular deviations in this axis indicate a heightened or fallen arch as with cavus and planus, respectively.

J. Meeker (✉)
Department of Orthopaedics and rehabilitation,
Oregon Health and Sciences University,
Portland, OR, USA
e-mail: meekerj@ohsu.edu

© Springer Nature Switzerland AG 2020
M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_24

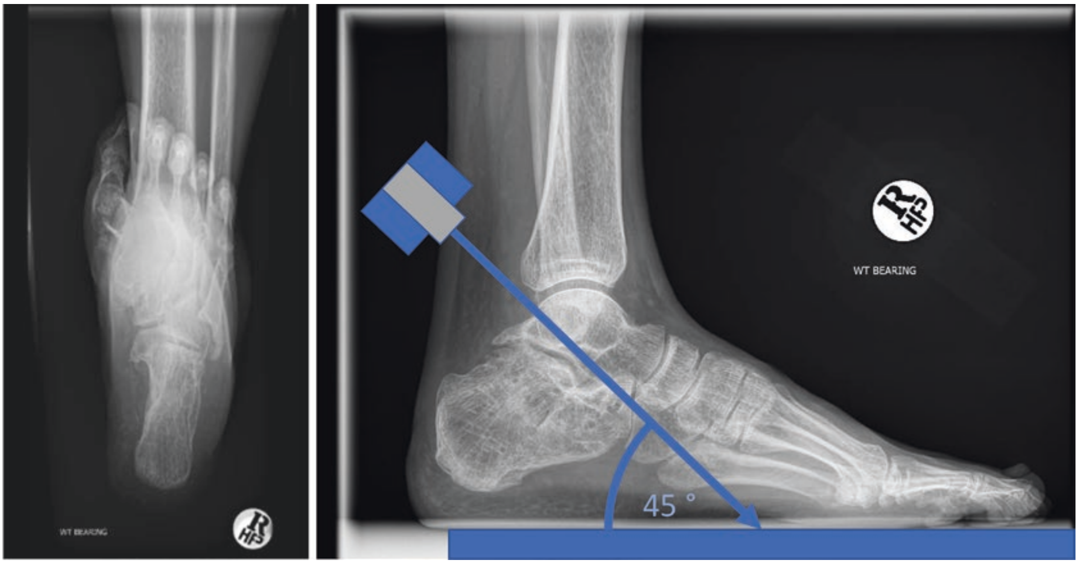


Fig. 24.1 Left panel shows long axial alignment view. Right panel shows orientation of the X-ray beam and plate as described by Reilingh et al. [1]

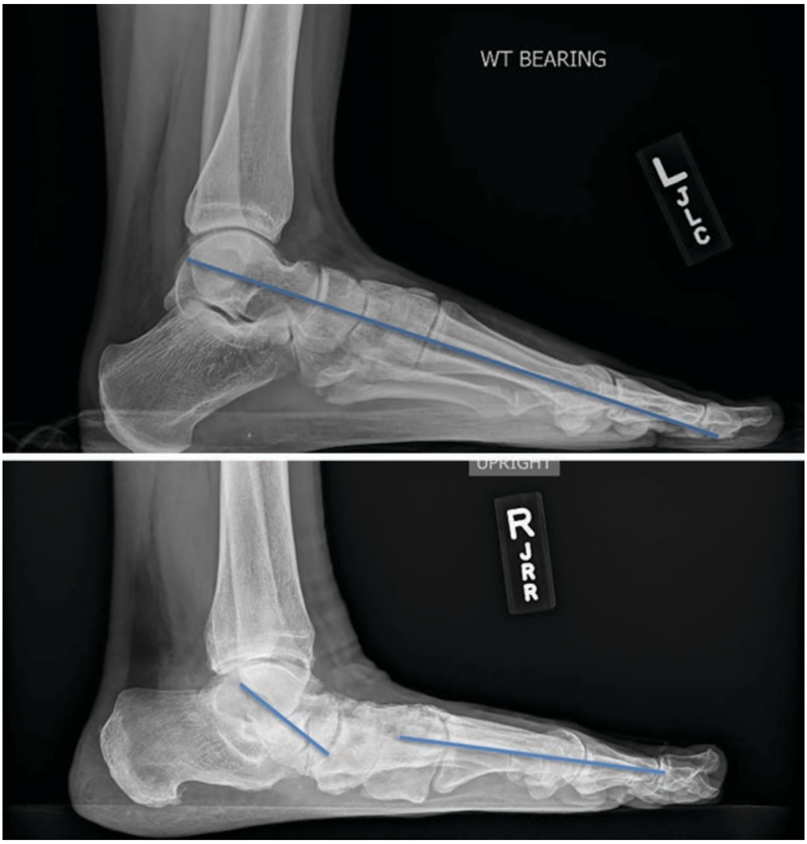


Fig. 24.2 Upper panel demonstrates intact linear Meary-Tomeno axis. The lower panel shows disruption of the sagittal alignment of the talus and first metatarsal

Transverse Plane

Foot inversion and eversion involve multiple planes of motion, but are commonly attributed to the transverse plane. Combined motion through the subtalar, tibiotalar, talonavicular, and calcaneocuboid joints accommodates inversion and eversion. The critical joint is the talonavicular joint, without which hindfoot motion is severely restricted [7].

Examination of the Foot in the Setting of Post-traumatic Arthrosis

An uninjured foot has the capacity to withstand broad demands ranging from the explosiveness of a jumping athlete to the balance of a ballerina en pointe. In contrast, the injured foot may lose suppleness of motion, stability, strength, and proprioceptive feedback. The reconstructive surgeon has three tasks: (1) identifying and quantifying the injured foot's limitations, (2) ascertaining the patient's goals, and (3) presenting the patient possible solutions.

Physical Examination

A thorough evaluation involves inspection of anatomy as well as function in gait.

Inspection

- First consider total limb alignment. Assess for knee varus or valgus. Also evaluate limb length discrepancy.
- On standing, how does the foot meet the floor? Does the foot reveal cavo-varus or planovalgus alignment? Do the toes claw or grip the floor?
- Is there an unusual prominence or apparent bony deformity?
- Skin evaluation
  - Locations of callosity inform the examiner of how the foot bears weight.
  - Scar location; location of prior surgical incisions may determine feasibility of future interventions
  - Wounds and ulcers: Plantar or dorsal? Presence of wounds gives information about possible infection, load-bearing alterations, vascular insufficiency, or loss of protective proprioception.
  - Is there skin discoloration suggestive of systemic disease (pretibial myxedema)?

Vascular Examination

- Palpation for the dorsalis pedis and posterior tibial arteries. It is important to characterize pulse as either absent, diminished, or readily palpable.
- Does the extremity display elements of stasis or venous congestion?
- Is pitting edema present?

Sensory Examination

- Evaluation of five major nerves to the foot:
  - Superficial peroneal (dorsum of the foot)
  - Deep peroneal (first web space)
  - Saphenous (medial ankle and foot)
  - Sural (lateral border of the foot)
  - Plantar (medial and lateral plantar foot)
- Sensation to gross touch.
- Proprioception.
- Monofilament testing with 4.5 g suggests protective sensation [8].

Motor Examination

- Grading motor strength 0–5
  - Dorsiflexion and plantarflexion sagittal plane motion occurs predominantly via the tibiotalar joint. Also involved to a lesser degree are the subtalar, talonavicular, and naviculocuneiform joints.
  - Inversion and eversion demonstrate motion in the coronal and transverse planes. This involves the subtalar, talonavicular, and calcaneocuboid joints.
  - Toe flexion and extension.
- Ability to perform single leg heel rise
  - Ability to perform 25 repetitions is expected [9].

Range of Motion

Considerable debate surrounds the best and most accurate way to assess functional range of motion.

- In a robotic simulation of gait, the following motion parameters were observed [2]:
  - Sagittal plane motion 60°
  - 20 combined degrees of inversion and eversion
- Equinus contracture. With the transverse tarsal joint held in a reduced position, the foot should comfortably achieve a neutral position with the knee fully extended.
  - The Silfverskiold test assesses the relative contribution of the gastrocnemius to the diagnosis of equinus contracture.

Comprehensive assessment is not complete without an examination of gait. This is an opportunity to piece together how any abnormal clinical observations affect function in vivo. Both shoes and socks should be removed and pant legs rolled up or in shorts.

1. Consider whether gait abnormalities are the result of primary foot pathology or more proximal disorders.
   - Proximal
     - Circumduction (knee arthritis, ankylosis, or arthrodesis)
     - Trendelenburg (hip abductor weakness)
     - Steppage (foot drop and hereditary motor neuropathy)
     - Scissoring (congenital diplegia, spine trauma)
   - Foot and ankle specific
     - External rotation of the foot; in absence of proximal deformity or limitation, this is compensatory. It represents an extreme foot progression angle whereby stress across the foot is minimized; external rotation requires less motion from critical joints in the foot and ankle.
     - Knee hyperextension can reflect compensation for inadequate ankle dorsiflexion due to equinus contracture or ankylosis of the ankle/hindfoot joint structures.

       Silfverskiold test can help determine source of equinus.
     - Toe walking may reflect a variety of issues (equinus, hindfoot arthrosis, heel pain).
2. Evaluate the impact on the various stages of gait.
3. Sixty percent of time is spent in the stance phase and 40% is spent in swing.
4. The stance phase is divided into five segments, each bearing consideration for how the foot and ankle complex functions
   - *Heel strike* occurs in neutral or slight varus. The tibialis anterior muscle is contracted, prior to eccentric lengthening.
   - *Loading response* occurs with initial load transfer to the whole foot. The foot pronates as it absorbs load (unlocking of transverse tarsal joints, heel neutral to slight valgus).
   - *Midstance* occurs when the body's weight is centered over the foot. The foot supinates as the posterior tibialis contracts to lock the transverse tarsal joint.
   - *Terminal stance* occurs when the heel begins to lift off the ground. The gastrocsoleus complex propels motion forward.
   - *Toe-off* primarily engages the hallux for balance and strength as the foot leaves the ground.

Each of the above intervals can be affected by post-traumatic deformity. Consider a patient with subtalar arthritis following talar or calcaneal fracture. This patient may walk with an externally rotated foot; the stance phase will be shortened, and discrete phases of gait may be inapparent. Alternately, another patient might walk on her toes following treatment for calcaneal fracture.

She may be avoiding heel weight-bearing to avoid loading a painful hindfoot.

A careful evaluation of gait is critical to understanding and addressing a patient's problem. In many cases, a gait abnormality is the most noticeable manifestation of a patient's concern and may be the central reason they present for treatment.

Imaging of the Foot and Ankle

A common mistake in evaluating foot pathology is to overlook the ankle while focusing on the foot and indeed vice versa. The advent of weight-bearing computed tomography (CT) makes this the most desirable method of evaluating the structure and position of osseous anatomy. However, with or without weight-bearing CT, plain film radiographs are necessary for diagnosis, preoperative planning, intraoperative assessment, and postoperative evaluation. Depending on the deformity, different radiographs are indicated. In cases of combined proximal and distal deformity, obtain full-length limb alignment films. Consider also imaging the contralateral side for planning purposes.

1. Calcaneus: Anterior-posterior (AP) and lateral foot, Harris axial heel, hindfoot axial alignment view, and Broden's views
2. Talus: Anterior-posterior (AP) and lateral foot, Canale view, and AP and mortise ankle

References

1. Reilingh ML, Beimers L, Tuijthof GJM, Stufkens SAS, Maas M, van Dijk CN. Measuring hindfoot alignment radiographically: the long axial view is more reliable than the hindfoot alignment view. Skelet Radiol. 2010;39(11):1103–8.
2. Whittaker EC, Aubin PM, Ledoux WR. Foot bone kinematics as measured in a cadaveric robotic gait simulator. Gait Posture. 2011;33(4):645–50.
3. Barg A, Harris MD, Henninger HB, Amendola RL, Saltzman CL, Hintermann B, et al. Medial distal tibial angle: comparison between weightbearing mortise view and hindfoot alignment view. Foot Ankle Int. 2012;33(8):655–61.
4. Apostle KL, Coleman NW, Sangeorzan BJ. Subtalar joint axis in patients with symptomatic peritalar subluxation compared to normal controls. Foot Ankle Int. 2014;35(11):1153–8.
5. Frigg A, Nigg B, Davis E, Pederson B, Valderrabano V. Does alignment in the hindfoot radiograph influence dynamic foot-floor pressures in ankle and tibiotalocalcaneal fusion? Clin Orthop Relat Res. 2010;468(12):3362–70.
6. Ellis SJ, Yu JC, Williams BR, Lee C, Chiu Y, Deland JT. New radiographic parameters assessing forefoot abduction in the adult acquired flatfoot deformity. Foot Ankle Int. 2009;30(12):1168–76.
7. Astion DJ, Deland JT, Otis JC, Kenneally S. Motion of the hindfoot after simulated arthrodesis. J Bone Joint Surg Am. 1997;79(2):241.
8. Saltzman CL, Rashid R, Hayes A, Fellner C, Fitzpatrick D, Klapach A, et al. 4.5-gram monofilament sensation beneath both first metatarsal heads indicates protective foot sensation in diabetic patients. J Bone Joint Surg Am. 2004;86(4):717.
9. Lunsford BR, Perry J. The standing heel-rise test for ankle plantar flexion: criterion for normal. Phys Ther. 1995;75(8):694–8.

Post Traumatic Arthrosis

25

James Meeker

Introduction

Reconstruction following injury to the talus and calcaneus requires attention to osseous alignment, joint condition, and soft tissue viability. The function of the hindfoot is reliant entirely upon the talus, a bone with limited blood supply and complex articular relationships involving most surfaces. The talus plays a crucial role in permitting motion in all planes, and yet possesses no tendinous attachments to guide its movement. It is the lynchpin of foot and ankle function in normal gait. Traumatic injuries involving the talus and calcaneus frequently result in arthrosis, altered alignment, and impairment in function. This can affect any of the hindfoot joints including the ankle. A variety of treatments have been proposed; reconstruction frequently involves restoration of osseous relationships via corrective osteotomy and/or arthrodesis [1–5].

Part 1

Ankle Arthritis Following Fractures in the Hindfoot

Ankle Osteophytes

Developing ankle osteophytes after talus fracture can result from malreduction, loss of fixation, collapse, and chondral injury. The resultant ankle impingement may cause pain and loss of motion. In situations where joint damage is limited, treatment may include an arthroscopic evaluation of the ankle joint with debridement of impinging bone and soft tissue (Fig. 25.1). There are no studies of arthroscopy to address osteophytes following talus fracture, but improvement is seen in reports of arthroscopic debridement of osteophytes that arise from other causes [6–8].

Ankle Arthrosis Due to Talar Avascular Necrosis

Avascular necrosis of the talar body has been reported in 15–30% [9–12] of talar neck fractures. Many patients go on to collapse and require a secondary procedure (Table 25.1) [9–15]. Avascular necrosis (AVN) should be differentiated from avascular collapse. The former may indeed cause symptoms, but does not involve joint collapse and fragmentation. Diagnosis can be apparent on plain film radiographs where the body is opacified or fragmented. More subtle

J. Meeker (✉)
Department of Orthopaedics and rehabilitation,
Oregon Health and Sciences University,
Portland, OR, USA
e-mail: meekerj@ohsu.edu

© Springer Nature Switzerland AG 2020

M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4_25

Fig. 25.1 Lateral weight-bearing image of a patient with anterior ankle bony impingement following treatment for talar neck fracture

Table 25.1 Compilation of studies reporting arthritic sequela of talar neck fracture

Ankle and subtalar arthritis following talus fracture				
Study of talar neck fractures	AVN (%)	Ankle arthritis (%)	Subtalar arthrtitis (%)	Subsequent fusion
Maceroli JOT 2016 [12]	27%	23%	27%	15%
Vallier JBJS 2014 [13]	25%	29%	38%	11%
Ohl Int Ort 2011 [14]	20%	76%	87%	25%
Vallier JBJS 2004 [9]	31%	18%	15%	31%
Sanders JOT 2004 [11]	12%	NA	NA	29%
Lindvall JBJS 2004 [10]	50%	60%	40%	NA
Elgafy FAI 2000 [15]	26%	25%	53%	NA

changes can be assessed by MRI, but utility is limited when implanted metal creates artifact.

Ankle Avascular Necrosis Without Joint Collapse

The optimal treatment of AVN without collapse remains uncertain. This patient group may have variable symptoms and is at potential risk of collapse. It is somewhat difficult to predict which patients will progress to collapse, and this uncertainty has led to a spectrum of treatments. Size of the area of avascular bone is likely the determining factor. Observation and protected weight-bearing is proposed as a method of reducing stress and permitting revascularization by creeping substitution; the efficacy and duration of treatment needed remains uncertain. Treatments with extracorporeal shock wave therapy and ultrasound therapy remain unproven. Efforts to perform core decompression [16] and even vascularized grafting may provide some benefit [17]. It is also possible for blood supply to return by creeping substitution [18].

Options for surgery in symptomatic avascular necrosis of the tibiotalar joint include replacement and arthrodesis. Arthrodesis is considered the safer solution given concerns over arthroplasty implant subsidence into avascular bone leading to joint failure. However, total ankle arthroplasty can be successful in setting of prior avascular necrosis provided adequate bone stock and also that time is given for successful revascularization by creeping substitution [18]. A series of 16 patients achieved 93% union via arthroscopic arthrodesis [19].

Ankle Avascular Collapse

Avascular collapse of the talus usually occurs in highly comminuted fractures where fixation fails. The result is an incongruent joint. The degree of collapse is variable. The deformity tends toward varus and adductus. Arthrodesis following avascular collapse presents technical problems. If there is inadequate talar bone stock, a standard tibiotalar fusion may not be possible due to bone loss. Early solutions to talar body collapse were proposed by Blair and later Lionberger [20, 21]; this arthrodesis fuses the tibia to the talar neck. A successful Blair arthrodesis transmits body weight through the talar head and neck into the rest of the foot. The advantage of this technique is that it preserves some hindfoot motion.

As materials and techniques have improved, the tibiotalocalcaneal (TTC) fusion represents a better option than Blair fusion. A successful TTC fusion provides a stable weight-bearing surface for ambulation and can provide considerable pain relief. Unfortunately nonunion is problematic in hindfoot fusions. In instances where bone loss is prominent, the risk is magnified.

A variety of solutions have been proposed to address the issue of fusion in the setting of bone loss. Addressing bone void should involve a three-step process:

1. Evaluation of impact of bone loss: extent of limb shortening and deformity in sagittal and coronal planes. This requires preoperative limb alignment imaging.
2. Evaluation of host factors that may affect healing and successful arthrodesis; this includes consideration of nicotine consumption, diabetes/glycemic control, vitamin D deficiency, consideration of infectious cause, and dietary adequacy of nutrition.
3. Evaluation of soft tissues surrounding the ankle that will guide a successful approach and closure.

After consideration of the above, planning may begin for a successful procedure. Most instances of bone void involve some degree of angular deformity and require structural graft for successful arthrodesis. While it would seem expedient to use bulk allograft to fill large voids, low fusion rates (50%) question its efficacy and advisability [22, 23]. Structural autograft is preferable whenever possible.

Iliac crest bone graft remains the best source of structural autograft, especially when addressing large voids. In some instances, fibular strut autograft may provide an alternative to iliac crest. In cases where additional autograft is needed, intramedullary reamer irrigator aspirator (RIA) can yield roughly 40 mL graft [24]. Qualitatively, RIA graft may have improved biologic properties over iliac crest [25]. Recent efforts with RIA graft-filled cages offer a way to avoid need for structural autograft; efficacy remains unproven [26].

After addressing the deformity and need for graft, consideration is given to surgical stabilization. There are numerous implant options, each with their advocates: anterior plating, lateral plating, posterior blade plate, thin wire fixation, cannulated screws, and hindfoot nailing. Implant choice should account for suitability of host soft tissue and the ability to provide stable fixation. Surgeon preference often dictates fixation method. Hindfoot nails are appealing since they are low profile, provide axial compression, and create reamings for graft.

Adjuvant treatment with biologic agents and low-intensity pulsed ultrasound (LIPUS) may be warranted. In the United States, only recombinant platelet-derived growth factor (PDGF) is approved as an adjuvant biologic treatment for healing arthrodesis in the ankle [27, 28]. LIPUS role for arthrodesis is unclear; it may have beneficial effects on fracture healing that may be extrapolated to arthrodesis, but this remains unproven [29, 30]. Off-label usage of bone morphogenetic proteins may confer some benefit [31, 32].

The development of total talar replacement is appealing and has been proposed for instances of severe avascular collapse and displaced talar nonunion [33]. It remains experimental and relies upon customized patient-specific implants.

Ankle Pathology Due to Talar Malunion

Malunion of talus fractures is fortunately rare. It is usually the result of a neglected displaced fracture, but can occur despite operative treatment. Typical manifestation of malunion involves shortening of the medial column that results in forefoot varus and adductus. This can lead to gait disturbance and uneven wear of adjacent joints. A classification system has been proposed to delineate candidates for osteotomy [4, 34] (Table 25.2).

Results of osteotomy are limited to case reports and small series. Rammelt published on ten (three revisions) patients undergoing correction for misalignment; AOFAS scores improved from 38 to 86 [4]. Another group reported a

Table 25.2 Classification of talus fracture malunion [4]

Classification of talus fracture malunion	
Type I	Malunion and/or joint displacement
Type II	Nonunion with joint displacement
Type III	Types I/II with partial AVN
Type IV	Types I/II with complete AVN
Type V	Types I/II with septic AVN

Fig. 25.2 Talar neck collapsed nonunion

series of seven (four revisions) patients undergoing corrective osteotomy to lengthen the talar neck; AOFAS scores improved from 40 to 84 [35]. Nonunion may also occur following talar neck fracture with similar patterns of deformity (Fig. 25.2).

Combined ipsilateral injuries to both the talus and calcaneus have been described. These are often high-energy injuries with high rates of complication. The majority of patients develop subtalar arthritis. Rates of below knee amputation approach 20% [36].

Part 2

Subtalar Arthritis Following Talar and Calcaneal Fracture

A patient who presents with pain after treatment for calcaneal fracture requires thoughtful evaluation. Careful consideration should be given to the patient's perceived limitations and future goals. A thorough evaluation of gait and suppleness of motion is needed. Ultimately, imaging (often CT) is necessary to provide an objective view of the osteoarticular structures of the calcaneus. Arthrosis, malalignment, and nonunion are all possible explanations and are not mutually exclusive.

Development of subtalar arthritis following talus and calcaneus fractures occurs frequently in cases of comminuted fracture, incomplete reduction, loss of fixation, and avascular collapse. For talar neck fractures, it occurs in 20–50% of patients and results in additional procedures in many of those. For calcaneus fractures, short-term treatment of subtalar arthritis is reported in 2–3% of cases [37, 38]. This figure does not account for long-term rates which are closer to 30%, even in patients treated by experienced surgeons [39]. This is unsurprising given the high rates of reported functional impairment observed after successful surgery [38, 40]. This is corroborated given acknowledged frequency of malunion following surgical treatment of calcaneal fractures [41].

Manifestations of Subtalar Arthrosis Following Calcaneal Fracture

Calcaneal fractures involve a complex quartet of articular surfaces. In fracture reduction, most attention is focused on the posterior facet. Anatomic reduction of the posterior facet is critical to avoiding arthritic degenerative changes, but other factors contribute also. Anterior process reduction, middle facet elevation, restoration of Bohler's angle, and reduction of the tuber are all critical factors in restoring the anatomy and function of the calcaneus. Given the complexity of these fractures and also the high demands placed on the calcaneus, it follows that seemingly minor occurrences of misalignment and joint incongruity can have a major effect on joint congruence and function.

Subtalar Arthritis Without Malalignment

Symptomatic subtalar arthritis often occurs following a healed, well-aligned calcaneal fracture [39]. After consideration of bracing, surgical treatment may be appropriate. Selective injections may be employed to help clarify the diagnosis. Depending on severity, surgical options include arthroscopic debridement versus in situ fusion. Treatment of early arthrosis arthroscopically has been described for mild arthrosis, but has limited application other than joint debridement [42, 43]. For more advanced cases, in situ arthrodesis may be required to address subtalar arthrosis. In fractures eventually requiring subtalar arthrodesis, ultimate results appear to be better when initial fracture management involved surgery [44].

Malunited Calcaneal Fractures

Malunion of the calcaneus is not clearly defined. The most common occurrence is presentation with persistent pain following initial nonsurgical management. Malunion also frequently occurs in operatively treated incomplete reduction followed by internal fixation. Also possible is loss of fixation in the postoperative period. Common observations when diagnosing symptomatic calcaneal malunion include depression of Bohler's angle, malposition of the tuber, subfibular impingement, loss of talar declination, and foot eversion/abduction. When calcaneal fractures malunite, the outcome will be predictably poor [37, 45].

Restoring Talar Declination in Calcaneal Malunion

One of the manifestations of pain and dysfunction in calcaneal malunion can involve loss of talar declination and resultant anterior ankle impingement (Fig. 25.3).

In situ fusion for malunited calcaneal fractures yields poor results. In a study of 33 patients with post-op talar declination angles of 8 degrees, the average Maryland foot score was 56 [46].

Stephens and Sanders described a CT classification system for nonsurgically treated calcaneal fractures. Type I malunions include lateral arthrosis of the posterior facet; type II includes cases of subfibular impingement; type III includes varus alignment of the tuber. A later study of 40 patients evaluated outcomes directed by this classification system and reported generally good outcomes with average Maryland foot scores of 79 where the average talar declination was 14 degrees [47]. Another study reported in 37 patients undergoing bone block distraction subtalar arthrodesis where reported AOFAS scores improved from 22 to 69 after surgery [48]. The talar declination improved from 10 degrees to 24 degrees. Another classification system has been proposed that incorporates multiplanar alignment and presence of nonunion and osteonecrosis (Table 25.3) [5, 34].

Indications for treating calcaneal malunion are generally regarded as relative. It is likely that a misaligned hindfoot will have long-term deleterious effects on joints throughout the affected extremity. Treatment is often driven by specific symptomatic complaints and may include a combination of the following:

1. Pain associated with an arthritic subtalar joint (lateral hindfoot and sinus tarsi pain)
2. Anterior ankle bony impingement related to loss of talar declination associated with depressed Bohler's angle
3. Pain related to lateral/subfibular impingement into the lateral calcaneus

Surgical solutions include the following:

1. In situ subtalar fusion, possible double and triple arthrodesis. Suitable for minor deformity where minimal correction is needed
2. Subtalar fusion with bone block distraction to restore hindfoot height and alignment
3. Subtalar fusion with osteotomy and grafting to restore hindfoot height and alignment
4. Joint-preserving osteotomy and revision open reduction internal fixation

The planning of an operation to address malunion involves anticipation of the following:

1. Equinus contracture that prevents adequate length of the calcaneal tuber. Lengthening the gastroc and even soleal fascia may be necessary.

Fig. 25.3 This image demonstrates loss of talar declination and resultant anterior ankle impingement. This is due to severe flattening of Bohler's angle. Intraoperative elevation of the subtalar joint followed by bone block arthrodesis

2. Competent and safe execution of the extensile lateral approach. A surgeon must be familiar with this approach and also experienced in meticulous closure technique.
3. Bone graft for bone block arthrodesis may be obtained from a variety of sources. The subfibular lateral wall may be used. However, if this is inadequate one should be prepared to obtain iliac crest structural graft.

Revision Open Reduction Internal Fixation

Unfortunately, calcaneal fracture surgery may result in incomplete restoration of anatomy. As

Table 25.3 Classification of calcaneal malunion [5]

Type Characteristics	Treatment options	Quality
0	Extra-articular or intra-articular malunion without arthrosis	A. Solid malunion
I	Subtalar joint incongruity with arthrosis subtalar in situ fusion	B. Nonunion
II	Additional hindfoot varus/valgus subtalar bone block fusion (+ osteotomy)	C. Necrosis
III	Additional loss of height subtalar bone block fusion (+ osteotomy)	
IV	Additional lateral translation of the tuberosity	
	Oblique calcaneal osteotomy with subtalar fusion	
V	Additional talar tilt at the ankle joint ankle revision, subtalar bone block fusion, and osteotomy	

such, some patients may be candidates for revision open reduction internal fixation (ORIF). The decision to perform revision ORIF may be pursued if there is evidence that the joint is viable, the soft tissues are amenable, and the patient wishes to undergo an additional procedure. The added surgical challenge involves working through or around prior incisions and hardware [3].

Part 3

Chopart Joint Injuries

Chopart joint injury comprises a broad spectrum of disorders that can have a profound impact on foot function. The Chopart joint is comprised of the talonavicular and calcaneocuboid joints. This is occasionally termed the transverse tarsal or midtarsal joint also. The Chopart joint is vertically aligned in the sagittal plane, subjecting it to considerable shear forces during forward propulsion in gait.

The Chopart joint complex receives support from the strong calcaneonavicular (spring) and calcaneocuboid ligaments [49]. These plantar ligaments are critical to the integrity of the foot. When insufficient, the foot collapses into a rocker-bottom shape (Fig. 25.4). Medial and lateral restraints include the posterior tibial tendon and bifurcate ligament, respectively. Fractures and dislocations frequently occur from high-energy mechanisms and frequently result in high rates of eventual arthrosis.

Fig. 25.4 The image shows a ligamentous dorsal Chopart dislocation

Patterns of Arthrosis Following Chopart Injury

For acute injury, knowing the mechanism is important in achieving a stable reconstruction. A classification of acute injuries by mechanism was proposed [50] and has been updated [51, 52]. Initial management with open reduction has been advocated as providing superior results to closed reduction [53], but occurrences of post-traumatic arthrosis are common. A classification system of late dysfunction following Chopart injury focuses on presence and location of arthrosis, misalignment, and nonunion (Table 25.4) [54].

Optimal Management of Chopart Injury Sequelae

It is worth reiterating that the goals of initial management are the same as for those with chronic symptoms. Treatment of acute injuries should involve anatomic reduction of osseous and articular structures. Directing attention to joint congruity and alignment can help in avoiding misalignment in sagittal, coronal, and transverse planes.

Table 25.4 Classification of post-traumatic deformities at the Chopart joint [54]

Type	Pathology
I	Joint incongruity
II	Nonunion
III	I/II with arthritis at the calcaneocuboid joint
IV	I/II with arthritis at the talonavicular joint
V	Bilateral arthritis and complex deformity

Long-term data on Chopart injuries is sparse and lacks meaningful measures of functional outcome. AOFAS scores, pedobarographic data, and proof of union often belie patients who experience notable limitations and disability [55, 56]. Rammelt et al. have devoted considerable effort to advancing the understanding of Chopart injuries. Their investigation reveals a majority of injuries involve fractures of the navicular and cuboid [52].

Certain patients with chronic disability from Chopart injuries may benefit from corrective osteotomy and/or joint arthrodesis [54]. The talonavicular joint is considered essential to hindfoot motion and function [57]. Ankylosis and arthrosis of the talonavicular joint are common following Chopart injuries. Arthrodesis of the talonavicular joint restricts motion throughout the hindfoot, reducing inversion and eversion by 86% [58]. It remains a matter of expert opinion to avoid primary fusion in acute Chopart injuries; however in cases of purely ligamentous injuries, acute arthrodesis should be considered.

For patients with painful arthrosis with minor misalignment, the option of advanced bracing may offer pain relief and improved function. Studies are lacking on this subject, but early results have proved anecdotally promising. An example of such a brace was developed in the US military to address severe combat-related injuries [59] (Fig. 25.5).

Fig. 25.5 Intrepid Dynamic Exoskeletal Orthosis (IDEO/EXOSYM). (Courtesy Ryan Blancke). Energy-storing carbon fiber ankle-foot orthosis

Summary

- Care for post-traumatic deformity in the hindfoot should address osseous alignment and preserve joint function where possible.
- Knowledge of normal anatomy and alignment can guide reconstruction.
- Surgery to correct alignment may involve osteotomy and/or joint arthrodesis.
- Careful planning coupled with meticulous technique is required for successful execution of corrective procedures.

Case (Fig. 25.6)

A Chopart fracture dislocation with failure through the calcaneus and posterior tibial tendon/calcaneonavicular ligament. Acute care involved fracture reduction and bridge plating of the calcaneocuboid joint in a reduced position. Medially, a repair of the posterior tibial tendon and calcaneonavicular ligament was performed with suture anchors in the navicular. His foot healed

Fig. 25.6 Case. Injury is a lateral transcuboidal fracture dislocation. The CT demonstrates avulsion of plantar and medial navicular structures. Fixation involved bridge plating and primary repair of the posterior tibial tendon and the spring ligament with suture anchors. He also underwent gastrocnemius recession. Following removal of hardware, there are signs of arthrosis at 1 year. He was fitted with an energy-storing brace (Fig. 25.5), and this has brought symptomatic relief and improved function. He has returned to work in farming

in plantigrade alignment with preservation of joint spaces. Symptoms persist and he does not wish to undergo arthrodesis. Significant pain and functional improvement with fitting of a custom-molded, energy-storing orthosis.

References

1. Klaue K, Hansen ST. Principles of surgical reconstruction of the mid- and hindfoot. Foot Ankle Surg. 1994;1(1):37–44.
2. Carr JB, Hansen ST, Benirschke SK. Subtalar distraction bone block fusion for late complications of os calcis fractures. Foot Ankle Int. 1988;9(2):81–6.
3. Benirschke SK, Kramer PA. Joint-preserving osteotomies for malaligned intraarticular calcaneal fractures. Foot Ankle Clin. 2016;21(1):111–22.
4. Rammelt S, Winkler J, Heineck J, Zwipp H. Anatomical reconstruction of malunited talus fractures: a prospective study of 10 patients followed for 4 years. Acta Orthop. 2005;76(4):588–96.
5. Rammelt S, Zwipp H. Corrective arthrodeses and osteotomies for post-traumatic hindfoot malalignment: indications, techniques, results. Int Orthop. 2013;37(9):1707–17.
6. Osti L, Del Buono A, Maffulli N. Arthroscopic debridement of the ankle for mild to moderate osteoarthritis: a midterm follow-up study in former professional soccer players. J Orthop Surg [Internet]. 2016;11(1).
7. Parma A, Buda R, Vannini F, Ruffilli A, Cavallo M, Ferruzzi A, et al. Arthroscopic treatment of ankle anterior bony impingement: the long-term clinical outcome. Foot Ankle Int. 2014;35(2):148–55.
8. Walsh SJ, Twaddle BC, Rosenfeldt MP, Boyle MJ. Arthroscopic treatment of anterior ankle impingement: a prospective study of 46 patients with 5-year follow-up. Am J Sports Med. 2014;42(11):2722–6.
9. Vallier HA, Nork SE, Benirschke SK, Sangeorzan BJ. Surgical treatment of talar body fractures. J Bone Joint Surg Am. 2004;86-A(Suppl 1 (Pt 2)):180–92.
10. Lindvall E, Haidukewych G, DiPasquale T, Herscovici D, Sanders R. Open reduction and stable fixation of isolated, displaced talar neck and body fractures. J Bone Joint Surg Am. 2004;86–A(10):2229–34.
11. Sanders DW, Busam M, Hattwick E, Edwards JR, McAndrew MP, Johnson KD. Functional outcomes following displaced talar neck fractures. J Orthop Trauma. 2004;18(5):265–70.
12. Maceroli MA, Wong C, Sanders RW, Ketz JP. Treatment of comminuted talar neck fractures with use of minifragment plating. J Orthop Trauma. 2016;30(10):572–8.
13. Vallier HA, Reichard SG, Boyd AJ, Moore TAA. New look at the Hawkins classification for talar neck fractures: which features of injury and treatment are predictive of osteonecrosis? J Bone Joint Surg Am. 2014;96(3):192–7.
14. Ohl X, Harisboure A, Hemery X, Dehoux E. Long-term follow-up after surgical treatment of talar fractures: twenty cases with an average follow-up of 7.5 years. Int Orthop. 2011;35(1):93–9.
15. Elgafy H, Ebraheim NA, Tile M, Stephen D, Kase J. Fractures of the talus: experience of two level 1 trauma centers. Foot Ankle Int. 2000;21(12):1023–9.
16. Mont MA, Schon LC, Hungerford MW, Hungerford DS. Avascular necrosis of the talus treated by core decompression. J Bone Joint Surg Br. 1996;78(5):827–30.
17. Kodama N, Takemura Y, Ueba H, Imai S, Matsusue Y. A new form of surgical treatment for patients with avascular necrosis of the talus and secondary osteoarthritis of the ankle. Bone Jt J. 2015;97-B(6):802–8.
18. Lee KB, Cho SG, Jung ST, Kim MS. Total ankle arthroplasty following revascularization of avascular necrosis of the talar body: two case reports and literature review. Foot Ankle Int. 2008;29(8):852–8.
19. Kendal AR, Cooke P, Sharp R. Arthroscopic ankle fusion for avascular necrosis of the talus. Foot Ankle Int. 2015;36(5):591–7.
20. Blair HC. Comminuted fractures and fracture dislocations of the body of the astragalus. Am J Surg. 1943;59(1):37–43.
21. Lionberger DR, Bishop JO, Tullos HS. The modified Blair fusion. Foot Ankle. 1982;3(1):60–2.
22. Jeng CL, Campbell JT, Tang EY, Cerrato RA, Myerson MS. Tibiotalocalcaneal arthrodesis with bulk femoral head allograft for salvage of large defects in the ankle. Foot Ankle Int. 2013;34(9):1256–66.
23. Bussewitz B, DeVries JG, Dujela M, McAlister JE, Hyer CF, Berlet GC. Retrograde intramedullary nail with femoral head allograft for large deficit tibiotalocalcaneal arthrodesis. Foot Ankle Int. 2014;35(7):706–11.
24. Belthur MV, Conway JD, Jindal G, Ranade A, Herzenberg JE. Bone graft harvest using a new intramedullary system. Clin Orthop. 2008;466(12):2973–80.
25. Sagi HC, Young ML, Gerstenfeld L, Einhorn TA, Tornetta P. Qualitative and quantitative differences between bone graft obtained from the medullary canal (with a reamer/irrigator/aspirator) and the iliac crest of the same patient. J Bone Joint Surg Am. 2012;94(23):2128–35.
26. Hamid KS, Parekh SG, Adams SB. Salvage of severe foot and ankle trauma with a 3D printed scaffold. Foot Ankle Int. 2016;37(4):433–9.
27. Daniels TR, Younger ASE, Penner MJ, Wing KJ, Le ILD, Russell IS, et al. Prospective randomized controlled trial of hindfoot and ankle fusions treated with rhPDGF-BB in combination with a β-TCP-collagen matrix. Foot Ankle Int. 2015;36(7):739–48.
28. DiGiovanni CW, Lin SS, Baumhauer JF, Daniels T, Younger A, Glazebrook M, et al. Recombinant human

platelet-derived growth factor-BB and beta-tricalcium phosphate (rhPDGF-BB/β-TCP): an alternative to autogenous bone graft. J Bone Joint Surg Am. 2013;95(13):1184–92.

29. Watanabe Y, Matsushita T, Bhandari M, Zdero R, Schemitsch EH. Ultrasound for fracture healing: current evidence. J Orthop Trauma. 2010;24:S56–61.
30. Rubin C, Bolander M, Ryaby JP, Hadjiargyrou M. The use of low-intensity ultrasound to accelerate the healing of fractures. J Bone Joint Surg Am. 2001;83-A(2):259–70.
31. Fourman MS, Borst EW, Bogner E, Rozbruch SR, Fragomen AT. Recombinant human BMP-2 increases the incidence and rate of healing in complex ankle arthrodesis. Clin Orthop Relat Res. 2014;472(2):732–9.
32. Bibbo C, Patel DV, Haskell MD. Recombinant bone morphogenetic Protein-2 (rhBMP-2) in high-risk ankle and hindfoot fusions. Foot Ankle Int. 2009;30(7):597–603.
33. Taniguchi A, Takakura Y, Sugimoto K, Hayashi K, Ouchi K, Kumai T, et al. The use of a ceramic talar body prosthesis in patients with aseptic necrosis of the talus. Bone Jt J. 2012;94–B(11):1529–33.
34. Zwipp H, Rammelt S. Posttraumatische Korrekturoperationen am Fuß. Zentralblatt Für Chir. 2003;128(3):218–26.
35. Suter T, Barg A, Knupp M, Henninger H, Hintermann B. Surgical technique: talar neck osteotomy to lengthen the medial column after a malunited talar neck fracture. Clin Orthop Relat Res. 2013;471(4):1356–64.
36. Aminian A, Howe CR, Sangeorzan BJ, Benirschke SK, Nork SE, Barei DP. Ipsilateral talar and calcaneal fractures: a retrospective review of complications and sequelae. Injury. 2009;40(2):139–45.
37. Buckley R, Tough S, McCormack R, Pate G, Leighton R, Petrie D, et al. Operative compared with nonoperative treatment of displaced intra-articular calcaneal fractures: a prospective, randomized, controlled multicenter trial. J Bone Joint Surg Am. 2002;84–A(10):1733–44.
38. Potter MQ, Nunley JA. Long-term functional outcomes after operative treatment for intra-articular fractures of the calcaneus. J Bone Joint Surg Am. 2009;91(8):1854–60.
39. Sanders R, Vaupel ZM, Erdogan M, Downes K. Operative treatment of displaced Intraarticular calcaneal fractures: long-term (10–20 years) results in 108 fractures using a prognostic CT classification. J Orthop Trauma. 2014;28(10):551–63.
40. van Hoeve S, de Vos J, Verbruggen JPAM, Willems P, Meijer K, Poeze M. Gait analysis and functional outcome after calcaneal fracture. J Bone Joint Surg Am. 2015;97(22):1879–88.
41. Gonzalez TA, Lucas RC, Miller TJ, Gitajn IL, Zurakowski D, Kwon JY. Posterior facet settling and changes in Bohler's angle in operatively and nonoperatively treated calcaneus fractures. Foot Ankle Int. 2015;36(11):1297–309.
42. Elgafy H, Ebraheim NA. Subtalar arthroscopy for persistent subfibular pain after calcaneal fractures. Foot Ankle Int. 1999;20(7):422–7.
43. Rammelt S, Gavlik JM, Barthel S, Zwipp H. The value of subtalar arthroscopy in the management of intra-articular calcaneus fractures. Foot Ankle Int. 2002;23(10):906–16.
44. Radnay CS, Clare MP, Sanders RW. Subtalar fusion after displaced intra-articular calcaneal fractures: does initial operative treatment matter? J Bone Joint Surg Am. 2009;91(3):541–6.
45. Ågren P-H, Mukka S, Tullberg T, Wretenberg P, Sayed-Noor AS. Factors affecting long-term treatment results of displaced Intraarticular calcaneal fractures: a post hoc analysis of a prospective, randomized, controlled multicenter trial. J Orthop Trauma. 2014;28(10):564–8.
46. Schepers T, Kieboom BCT, Bessems GHJM, Vogels LMM, van Lieshout EMM, Patka P. Subtalar versus triple arthrodesis after intra-articular calcaneal fractures. Strateg Trauma Limb Reconstr 2010 Aug;5(2):97–103.
47. Clare MP, Lee WE, Sanders RW. Intermediate to long-term results of a treatment protocol for calcaneal fracture Malunions. J Bone Jt Surg. 2005;87(5):963–73.
48. Trnka H-J, Easley ME, Schon LC, Myerson MS, Lam PW-C, Anderson CD. Subtalar distraction bone block arthrodesis. J Bone Jt Surg. 2001;83(6):849–54.
49. Kelikian AS, Sarrafian SK, Sarrafian SK, editors. Sarrafian's anatomy of the foot and ankle: descriptive, topographical, functional. 3rd ed. Philadelphia: Wolters Kluwer Health/Lippincott Williams & Wilkins; 2011. 759 p
50. Main BJ, Jowett RL. Injuries of the midtarsal joint. J Bone Joint Surg Br. 1975;57(1):89–97.
51. Zwipp H. Chirurgie des Fußes. Wien: Springer; 1994. 405 p
52. Rammelt S, Schepers T. Chopart Injuries. Foot Ankle Clin. 2017;22(1):163–80.
53. Richter M, Thermann H, Huefner T, Schmidt U, Goesling T, Krettek C. Chopart joint fracture-dislocation: initial open reduction provides better outcome than closed reduction. Foot Ankle Int. 2004;25(5):340–8.
54. Rammelt S, Zwipp H, Schneiders W, Heineck J. Anatomic reconstruction of malunited Chopart joint injuries. Eur J Trauma Emerg Surg. 2010;36(3):196–205.
55. van Dorp KB, de Vries MR, van der Elst M, Schepers T. Chopart joint injury: a study of outcome and morbidity. J Foot Ankle Surg. 2010;49(6):541–5.
56. Bibbo C, Anderson RB, Davis WH. Injury characteristics and the clinical outcome of subtalar dislocations: a clinical and radiographic analysis of 25 cases. Foot Ankle Int. 2003;24(2):158–63.
57. Hansen ST. Functional reconstruction of the foot and ankle. Philadelphia: Lippincott Williams & Wilkins; 2000.

58. Wülker N, Stukenborg C, Savory KM, Alfke D. Hindfoot motion after isolated and combined arthrodeses: measurements in anatomic specimens. Foot Ankle Int. 2000;21(11):921–7.
59. Patzkowski JC, Blanck RV, Owens JG, Wilken JM, Kirk KL, Wenke JC, et al. Comparative effect of orthosis design on functional performance. J Bone Joint Surg Am. 2012;94(6):507–15.

Index

A
Acetabulum pedis, 30, 37
Active range of motion (AROM) exercises, 318, 319
American Academy of Orthopaedic Surgeons (AAOS) instruments, 11–13
American Orthopaedic Foot & Ankle Society (AOFAS), 163, 164, 211, 257
  Ankle-Hindfoot scale, 5
  clinical rating system, 4
  Hallux Metatarsophalangeal-Interphalangeal Scale, 5
  Lesser Metatarsophalangeal-Interphalangeal Scale, 5
  Midfoot Scale, 5
Amputation, 240, 242–244, 249
Andemahr classification system, 177
Angle of Böhler, 188
Angle of Gissane, 184, 198, 203, 246
Ankle arthritis, fractures in hindfoot
  ankle avascular necrosis without joint collapse, 340
  ankle necrosis, 339
  ankle osteophytes, 339, 340
  avascular collapse, 340, 341
  malunion of talus fractures, 341, 342
Ankle avascular necrosis, 340
Ankle-hindfoot scores, 257
Ankle joint complex, 3
Ankle osteophytes, 339
Anterior process of the os calcis
  anatomy, 251, 252
  avulsion/shear fractures
    diagnosis, 252, 254
    lateral "L" extensile approach, 256
    mechanism of injury, 252
    patient positioning, 256
    physical examination, 254
    physiotherapy, 256
    preoperative procedure, 255
    treatment, 254
    wound closure, 256
  midtarsal joint fracture/dislocation
    clinical history, 257
    crush injuries, 257
    imaging, 257
    lateral foot fluoroscopy, 261
    lateral injuries, 257
    longitudinal injuries, 256
    medial injuries, 256
    midfoot fracture, 258
    open midtarsal fracture dislocation, 259
    patient positioning, 258
    physical examinations, 257
    plantar injuries, 257
    preoperatively equipment, 258
    supination reduction and anatomic stabilization, 261
    treatment, 257, 258
  symptoms, 251
AO/OTA classification, 58, 59
Autologous chondrocyte implantation (ACI), 119
Avascular collapse of talus, 340, 341
Avascular necrosis (AVN), 38, 45, 339, 340

B
Below knee amputation (BKA), 293
Bimalleolar ankle fracture, 147–149
Böhler's angle, 184, 192, 198, 199, 246
Bone and joint reconstruction
  alignment
    coronal plane, 333
    sagittal plane, 333
    transverse plane, 335
  foot examination
    bearing consideration, 336
    careful evaluation, 337
    comprehensive assessment, 336
    foot and ankle imaging, 337
    inspection, 335
    motor examination, 335
    physical examination, 335
    proximal disorders, 336
    range of motion, 336–337
    sensory examination, 335
    vascular examination, 335
  limb alignment, 333

© Springer Nature Switzerland AG 2020

M. R. Adams, S. K. Benirschke (eds.), *Fractures and Dislocations of the Talus and Calcaneus*,
https://doi.org/10.1007/978-3-030-37363-4

C
Calcaneal avulsion fracture, 264
Calcaneal fractures
  anatomy, 181
  angle of Gissane, 185
  articulations, 181
  biomechanics, 181–183
  Böhler's angle, 184
  incidence, 181
  joint depression fractures, 184
  ligamentous attachments, 182
  primary fracture line, 183, 188
  secondary fracture line, 184, 188, 189
  societal economic impact, 181
  tongue type fractures, 184
  treatment
    evaluation, 186
    initial evaluation, 187
    layered compressive wrap and splinting, 186
    patient characteristics, 187
    soft tissue integrity, 187
    soft tissue management, 186
    surgical indications, 187
    temporizing management techniques, 187, 188
Calcaneal malunion classification, 345
Calcaneocuboid articulation, 161, 165, 166
Calcaneo-cuboid ligament injury classification system, 176
Calcaneus and talus fracture rehabilitation
  AROM exercises, 318, 319
  assessment protocols, 312
  assistive device, 316, 317
  bedrest, 315
  calcaneal inversion and eversion, 319
  compartment syndrome, 311
  complications, 311
  crutches and walkers, 317
  elastic-type resistance bands, 321
  etiology, 311
  foot intrinsic muscle activation, 318, 320
  goniometric ROM measurement, 320
  incidence, 311
  initial physical therapy visit, 316
  intra-articular calcaneus fracture
    assessment, 328
    clinical examination, 328
    functional testing, 328
    goals, 329
    pain level, 327
    treatment, 328, 329
  joint depression calcaneus fracture and distal radius fracture
    clinical examination, 323, 324
    functional abilities, 324
    functional training, 324
    goals, 325
    interventions, 324
    pain scale scores, 323
    precautions, 323
    stair methods, 324
    therapeutic exercise, 325
  knee scooters, 317, 318
  Maitland grades of joint mobilization, 322
  mobility and stability, 312
  peg-leg devices, 318
  personal and environmental factors, 312
  phase 1, 313, 315
  phase 2, 313, 314, 320
  phase 3, 314–315, 320, 321
  phase 4, 314, 315, 322
  phase 5, 314, 316, 322
  physical therapy goals, 316
  protective immobilization, 315, 316
  recovery process, 311
  restricted joint movement, 316
  standard (pick-up) walkers, 317
  surgical intervention, 311
  therapeutic exercise, 318
  three-point (swing-through) crutch gait pattern, 317
  tissue healing, 319
  tissue overload and underload, 319
  tolerance of variances, 312
  tongue-type calcaneus fracture
    clinical examination, 326
    Fear-Avoidance Components Scale score, 326
    goals, 327
    physical therapy, 325
    treatment, 326, 327
  type and degree of force, 311
  vocational counseling/rehabilitation, 323
  weight bearing in water, 321
  weight-bearing proprioceptive training, 322
  weight-bearing schedule, 321
  wheelchair, 318
Canale view, 19
Chopart dislocation, 162–164
Chopart joint, 161–164, 256
  arthrosis patterns, 345, 346
  motion, 312
  optimal management, 345, 346
  plantar ligaments, 345
Chopart-Lisfranc fracture-dislocations, 164
Classic Essex-Lopresti maneuver, 230
Compartment syndrome, 311
Constant fragment, 283
Creighton Nebraska Health Foundation scale, 214

D
Displaced intra-articular calcaneal fractures (DIACFs), 211, 213, 215
Dorsalis pedis, 141

E
Extended lateral approach (ELA), 197
Extensile lateral approach
  clinical outcomes, 197–199
  complications, 199
  reduction, 204–206

  - surgical planning
    - fixation, 206, 207
    - imaging, 200, 201
    - incision, 200–203
    - patient positioning, 200
    - wound closure, 208, 209

- Extensor digitorum brevis (EDB), 252
- Extraarticular calcaneal body fractures, 263, 266, 270, 272
  - calcaneal height, 275
  - calcaneal length, 275
  - calcaneal width, 275
  - clinical outcomes, 279
  - cortical shell, 276
  - evaluation, 276, 277
  - treatment, 278, 279

F

- Flexor hallucis longus (FHL), 18, 183
- Foot and Ankle Disability Index, 212
- Foot Function Index (FFI), 5, 8, 11, 12, 69, 198, 211, 213
- Forgon/Zadravecz distraction technique, 213

G

- Gastrocnemius equinus, 85
- Gastrocnemius-soleus complex, 275, 279
- Gastrocsoleus complex, 263–266
- Gissane angle, 199, 276
- Gustilo and Anderson (GA) classification, 241
- Gutta percha, 212

H

- Hannover Scoring System (HSS), 163
- Hatchet fractures, 188
- Hawkins classification, 292
- Hawkins sign, 44, 152
- Hindfoot fracture rehabilitation, *see* Calcaneus and talus fracture rehabilitation
- Hindfoot fractures
  - calcaneus
    - imaging, 22, 23
    - initial management, 23
    - lower extremity injuries, 20
    - signs and symptoms, 20, 22
  - initial management, 17, 18
  - talus
    - extremities and organs, 18
    - imaging, 19
    - initial management, 19, 20
    - signs and symptoms, 18, 19
- Hindfoot sprain
  - anatomy, 175, 176
  - calcaneo-cuboid ligament injury classification, 176, 177
  - computerized tomography scan, 176
  - injury mechanism, 175, 176
  - magnetic resonance imaging, 176
  - physical examination, 176
  - prevalence, 175
  - radiographic study, 176
  - treatment, 177

I

- Intra-articular calcaneal fractures, 212
  - anatomic reduction, 213, 226, 231
  - avulsive tongue type fracture, 231
  - bilateral fracture treatment, 227
  - Forgon/Zadravecz distraction technique, 213
  - healed fracture, 222
  - intra-articular tongue type fractures, 230
  - minimally invasive reduction, 232, 233
  - modified three point distraction technique, 213
  - nonoperative treatment, 211
  - operative treatment, 211
  - patient positioning, 218, 231
  - patient preparation, 218
  - percutaneous leverage techniques, 212
  - percutaneous reduction techniques and cannulated screw fixation, 219
  - percutaneous technique of avulsion, 230
  - postoperative treatment, 236
  - Sanders IIA fracture, 222, 225
  - Sanders IIB fracture, 226, 227
  - Sanders IIIAC, 227
  - sinus tarsi approach, 229, 230, 233, 234, 236
  - surgical planning, 215, 216
  - triangular distraction techniques, 212
  - wound healing complications, 211
  - *See also* Calcaneal fractures
- Intrepid Dynamic Exoskeletal Orthosis (IDEO), 346
- Ipsilateral talus and calcaneus fractures
  - clinical outcomes, 298
  - combined fracture patterns, 292
  - diagnosis, 291, 292
  - direct axial loading, 299, 300, 302
  - medial subtalar dislocations, 303, 305
  - prognosis, 291
  - pronation injuries, 302
  - tongue type calcaneus fracture, 305
  - treatment
    - below knee amputation, 293
    - dual incision approach, 293
    - extensile lateral approach, 293
    - incision/percutaneous reduction, 293
    - medial distractor application, 294
    - operative treatment, 294
    - percutaneous K-wires and external fixation, 295
    - posteromedial approach, 293
    - post-operative protocols, 298
    - reduction, percutaneous pin fixation and external fixation, 296
    - subtalar arthrodesis, 297
    - subtalar dislocation, 294
- Isolated calcaneal dislocations, 167
- Isolated cuboid dislocations, 166, 167
- Isolated sustentaculum fracture, 281–283
- Isolated talonavicular dislocations, 164–166

J

Juvenile chondrocytes (JCs), 119

L

Lateral extensile approach, 197
Limb salvage, 244
Limited contact dynamic compression plate (LCDCP), 258
Lisfranc and Chopart injuries, 163
Low-intensity pulsed ultrasound (LIPUS), 341

M

Malunited calcaneal fractures, 343
Maryland Foot Score (MFS), 214, 257, 298
Meary-Tomeno axis, 333
Midfoot dislocations, 161, 162
Midtarsal fracture dislocation, 258, 259
Modified three point distraction technique, 213
Musculoskeletal Function Assessment (MFA), 69

O

Open calcaneus fractures
  articular comminution and depression, 246
  associated injuries, 240
  clinical outcomes, 243, 244
  coverage surgeon, 248
  definitive management, 245, 246
  imaging, 240, 241
  mechanism of injury, 240
  medial wound, 241
  neurovascular examination, 240
  open wound classifications, 241
  physical examination, 240
  post removal of hardware, 248
  reduction and fixation techniques, 247
  Sanders classification, 239
  short term complications, 243
  soft tissue management, 247
  surgical irrigation and debridement, with external fixation, 244, 245
  traumatic wounds in, 241
  treatment
    definitive fixation, 242
    GA classification, 241
    operative fixation, 241
    ORIF, 242
    osseous fixation, 242
    percutaneous fixation, 242
    soft tissue injury, 242
    surgical fixation, 242
  wound ready for definitive management, 245
Open pantalar dislocations, 149
Osteochondral defects
  anatomy, 107, 108
  bone marrow stimulation
    abrasion, 113
    ACI, 119
    bulk allograft, 121
    JCs, 119
    microfracture, 113–115
    post operative care, 122, 123
    subchondral bone, 113
    transplantation/substitution techniques, 116, 117
  diagnosis, 108, 109
  history of, 108
  imaging, 108, 109
  physical examination, 108
  treatment
    factors, 109
    non-operative treatment, 109, 110
    open reduction and internal fixation, 110, 111
    operative treatment, 110
Os trigonum, 30

P

Pantalar dislocations
  advances trauma life support protocol, 143
  calcaneus fracture and, 142
  definition, 141
  Hawkin's type IV, 143
  open lateral talar extrusion, 141, 142
  outcomes, 148–152
  plain radiographs, 143
  posterior tibial artery, 141
  post reduction CT scans, 143
  talocalcaneal ligament, 141
  tarsal sinus artery, 141
  treatment
    antibiotics and tetanus vaccination, 144
    bony resorption, 151, 152
    closed reduction, 143
    external fixator removal, 146, 150
    follow-up, 146
    hindfoot nailing, 155
    lateral approach, 143
    medial approach, 143
    open wounds, 146, 147
    posterior talar dislocations, 143
    primary tibiocalcaneal arthrodesis, 147
    recalcitrant osteomylitis, 154
    sterilization, extruded talus, 144, 145
    talar collapse, 153
    talar osteolysis, 153
    talus reimplantation, 145, 146
Percutaneous leverage techniques, 212
Peritalar fractures
  complications, 128, 129
  diagnosis/management, 127, 128
Peroneal artery, 141
Peroneal tendons, 182
Peroneus longus tendon, 161, 166
Platelet derived growth factor (PDGF), 341
Posterior calcaneal tuberosity fractures
  acute treatment, 264
  nonoperative treatment, 264, 265
  operative treatment

    - gastrocsoleus complex, 265
    - goals, 265
    - open reduction and internal fixation, 266
    - patient positioning, 265
    - percutaneous reduction and fixation, 265, 266
    - suture fixation, 265
  - physical examination, 264, 266
  - radiographic examination, 264, 266
  - surgical management
    - closed, extraarticular calcaneal tuberosity fracture, 270, 272
    - dorsal blocking splint, 268
    - guidewire placement, 270
    - patient positioning and draping, 268
    - percutaneous clamp placement, 269
    - percutaneous reduction, 268
    - postoperative soft tissues, 270
  - treatment goals, 264
- Posterior talar process
  - ankle ligaments, 84
  - blood supply, 86
  - Broden's View, 93
  - clinical evaluation, 86
  - complications, 89
  - FHL tendon, 85
  - k-wire fixation, 92
  - lateral tubercle, 83
  - mechanisms of injury, 85
  - medial tubercle, 89
  - outcomes, 88, 89
  - patient history, 90–93
  - plate fixation, 92
  - posterior tibial neurovascular bundle, 85
  - radiographic evaluation, 86, 87
  - reverse Broden’s view, 93
  - subtalar dislocation, 90
  - subtalar joint, 83
  - sustentaculum, 83, 84
  - tarsal canal, 83
  - tarsal sinus, 83
  - treatment, 87, 88
  - vascular perforation, 83
- Posterior tibial artery, 141
- Post-operative foot compartment syndrome, 258
- Post traumatic arthrosis
  - ankle arthritis (*see* Ankle arthritis, fractures in hindfoot)
  - Chopart joint (*see* Chopart joint injury)
  - subtalar arthritis (*see* Subtalar arthritis)
- Post-traumatic osteoarthrosis (PTOA), 59
- Primary tibiocalcaneal arthrodesis, 147

R

- Reamer irrigator aspirator (RIA) system, 147
- Rest, ice, compression, and elevation (RICE), 177

S

- Sanders 3AB, 189
- Short Form-36 (SF-36) health survey, 4, 9
- Silfverskiold test, 336
- Sinus tarsi approach (STA), 197–199
- Snowboarder’s fracture, 33
- Stieda process, 83
- Subtalar arthritis
  - calcaneal fractures and, 342
  - malunited calcaneal fractures, 343
  - restoring talar declination in calcaneal malunion, 343, 344
  - revision open reduction internal fixation, 345
  - short term treatment, 342
  - without malalignment, 342, 343
- Subtalar fractures
  - arthrosis, 135, 137, 138
  - calcaneal sustentaculum, 135, 136
  - complications, 129
  - diagnosis/management, 127, 128
  - k-wires, 135, 137
  - mental status and airway protection, 129, 130
  - posterior talar body fracture, 129, 131, 132
  - post reduction films, 133–135
  - pre-reduction films, 133
  - stability, 135
- Sulcus tali, 30
- Sural nerve injury, 199
- Sustentaculum tali fractures, 181, 183
  - anatomy, 281–283
  - clinical outcomes, 284, 285
  - combined injuries, 283
  - diagnosis, 283
  - extra-articular fractures, 281
  - incidence, 281
  - surgical technique
    - after buttress plate application, 286
    - extra-articular reads comminution and articular impaction, 285, 287
    - incision, 285
    - lag screw placement, 286
    - multiple plates and mini-fragment screws, 288
    - pre-positioned K-wires, 288
    - primary fixation, 286
    - simple shearing pattern, 285, 286
    - spiked pushers, 286, 287
    - weightbearing radiographs, 288, 289
  - treatment, 284

T

- Talar body fractures
  - acute treatment, 59, 60
  - anatomy, 57
  - AO/OTA classification, 58, 59
  - biodegradable implants, 67
  - Boyd and Knight classification, 59
  - definite management, timing of, 60
  - early complications, 59
  - epidemiology, 57
  - imaging, 58
  - osseous collapse, 67
  - osteonecrosis, 67

Talar body fractures (*cont.*)
  physical examination, 58
  reduction and fixation techniques, 66
  results, 68
    early complications, 67
    late complications and outcomes, 67, 69
    prognosis and long-term expectations, 67
  Sneppen classification, 58, 59
  surgical approach
    anterolateral approach, 62–66
    anteromedial approach, 60, 62, 63, 66
    fracture location, 60
    posteromedial approach, 60
    posteromedial exposure, 60, 61
Talar head
  anatomy, 71, 72
  anterolateral approach, 75
  axial, sagittal and coronal, 77
  Broden's views, 79
  capsulotomy, 76
  closed reduction, 75
  complications, 75
  diagnosis, 73
  dislocation, 76
  fixation, 78
  hindfoot and midfoot motion, 79, 81
  injury mechanisms, 72, 73
  intraoperative fluoroscopy, 78
  ipsilateral hip, 75, 78
  lag technique, 76
  lateral ligamentous and capsular structures, 76–79
  medial fragment, 76
  medial frame, 79
  nonabsorbable nylon sutures, 79
  non weightbearing, 79
  osteochondral fragments, 76, 78
  outcomes, 74, 75
  pantalar dislocation, 76
  peroneal tendons, 76, 78
  postoperative AP, oblique and lateral radiographs, 80
  talonavicular joint, 71, 72
  tibial plafond, 75, 77
  tibiotalar, subtalar and talonavicular joints, 75, 76
  traumatic arthrotomy, 78
  treatment, 73, 74
Talar neck collapsed nonunion, 342
Talar neck fractures
  alcohol abuse and smoking, 45–47
  anatomy, 37
  classifications, 37, 38
  evaluation and treatment, 39
  left lateral talar process fracture, 49, 53, 54
  outcomes, 44, 45
  post-operative course, 44
  post poly-trauma, 49, 51
  subtalar joint dislocation, 47, 48
  surgical technique
    anterior to posterior, 42
    anterolateral approach, 40
    anteromedial approach, 39, 40
    comminution, 42
    excessive external rotation, 39
    fibular osteotomy, 43
    fixation construct, 42, 43
    fixation failure, 43
    headless compression screws, 42
    headless screws, 39
    lateral minifragment, 43
    medial malleolar articulation, 43
    medial malleolar osteotomy, 40, 41
    open reduction internal fixation, 39
    posterior to anterior, 42
    "S shaped" curve, 43
    sustentaculum tali, 43
    tibial plafond, 43
Talocalcaneal ligament, 141
Talonavicular joint, 161, 165, 167
Talus
  anatomy, 29, 30
  blood supply, 31, 32
  imaging, 33, 34
  injury mechanism, 32, 33
  lateral process
    complications, 105
    delayed diagnosis, 97, 98
    fixation of, 100, 101, 103, 104
    history, 97
    injury mechanism, 99
    local anatomy and functional anatomy, 98, 99
    management, 99, 100
Talus fracture malunion, 341
Tarsal dislocation
  Chopart dislocation, 162
  classification system, 163
  clinical outcomes, 163, 164
  isolated calcaneal dislocations, 167
  isolated cuboid dislocations, 166, 167
  isolated talonavicular dislocations
    lateral swivel dislocation, 164, 165
    medial swivel dislocation, 164, 165
    outcomes, 165, 166
  talonavicular and calcaneocuboid joints, 161, 162
  treatment, 168
Tarsal sinus artery, 141
Tarsal tunnel syndrome, 89, 285
Tibiotalocalcaneal(TTC) fusion, 340
Total talar prosthesis, 148
Transverse tarsal joint injuries, 162
Triangular distraction techniques, 212
Trigonal process, 83

V

VAS pain score, 214
Visual analog scale (VAS) pain score, 198, 211

W

Westhues maneuver, 212
Workers' compensation system, 211