Displaced Intra-articular Fractures of the Calcaneus

with an emphasis on minimally invasive surgery

Tim Schepers

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Verplaatste intra-articulaire hielbeenbreuken
met de nadruk op minimaal invasieve chirurgie
T. Schepers

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Chapter 1

Introduction and outline of the thesis

INTRODUCTION

Calcaneal fractures are one of the most disabling fractures in men, with frequent occurrence during the wage-earning period of life.[1] The rehabilitation process can be time-consuming, and take up to 9 months and even longer in 20 percent of patients. With an estimated average health related costs between 20,000 and 30,000 Euro per patient calcaneal fractures are a large economic burden to society.[2,3,4]

Incidence and distribution

The incidence of intra-articular calcaneal fractures is currently unknown. Calcaneal fractures are estimated to comprise approximately 1 to 2 percent of all fractures.[1] Of all calcaneal fractures, 70% has involvement of the posterior subtalar joint, and approximately 80% of all fractures occur in male patients. Calcaneal fractures are rare in childhood; only 5% of all calcaneal fractures are seen in children.[1,5]

Treatment modalities

There is a considerable amount of literature on calcaneal fractures and their treatment; however the best management approach has yet to be determined.

The treatment of calcaneal fractures is complex and has to be individualized depending on patient characteristics and fracture type. Patient characteristics (e.g., age, comorbidities, substance abuse, smoking habits, psychological condition, and anticipated non-compliance) and the condition of the soft tissues are at least as important as the type of fracture as seen on the radiographs and CT-scan.[6-9]

The therapeutic modalities for displaced intra-articular calcaneal fractures can be divided into conservative and operative management. The latter comprises both the open reduction and internal fixation (ORIF) and percutaneous reduction and internal fixation (PRIF).

Conservative treatment, either functional or using Plaster-of-Paris, is generally applicable in fractures with minor displacement and compromised soft-tissues, as well as in patients with certain physical (i.e., diabetes, peripheral vascular disease) or psychological characteristics (i.e., low anticipated compliance or substance abuse).

Since the mid nineties, ORIF is considered the gold standard treatment for displaced intra-articular fractures of the calcaneus by most experts, as it generally provides overall good to excellent results and the ability to anatomically restore the subtalar joint.[1] Several open surgical techniques have been described in the past, of which the extended lateral approach has been applied most frequently.[10-14] Alternative operative techniques include a medial approach,[15,16] plantar approach,[17] combined lateral and medial approach,[18-20] limited posterior approach,[21] and the sinus tarsi approach.[22-24] Disadvantages of the open repair include wound dehiscence and infectious complications, which may occur in up to 30 percent of patients.[25,26]

In an attempt to lower the complication rates encountered with ORIF, various minimal invasive techniques were introduced to reduce and fixate displaced fragments.[27] By combining different closed methods, Forgon and Zadravecz from the university clinics from Pécs in Hungary, developed a three-point distraction technique that enables restoration of the calcaneal anatomy.[28,29] Three Kirschner-wires are drilled through the tuberositas of the calcaneus, the talar neck and the cuboid. Subsequently, two distractors are mounted on both sides of the foot, which provide a distracting force. Any widening of the heel is compressed with the Böhler bone-press. Upon reduction of the fracture, the fragments are finally stabilised with crossed Kirschner wires or with percutaneous screws.[28] A modification of the technique as described by Forgon and Zadravecz was introduced in our clinic in 1998 and forms the basis of this thesis.

Determining the best treatment option and quantification of clinical outcome is mainly hampered by a lack of agreement on the best classification and outcome scoring systems.[30] The results of ORIF and conservative treatment have been described and compared in several studies.[31,32] These studies show improved outcome after operative treatment in subgroups and a higher rate of failed initial treatment with an increased need for a subtalar arthrodesis in conservatively treated patients.[33] There is however insufficient data on outcome after a subtalar versus triple arthrodesis. A secondary arthrodesis is also the therapeutic modality of choice in nonunions of intra-articular calcaneal fractures.

At present, there is only a limited amount of data available on the outcome after percutaneous reduction and subsequent internal fixation of calcaneal fractures. PRIF appears to reduce the rate of infectious complications compared with ORIF. However, most available studies lack sufficient patient numbers or duration of follow-up. Similar as described above, the high variability in outcome scoring systems and fracture classification systems complicates the inter-study comparison.

Aims of the thesis

The aim of this thesis is threefold:

1. To set a basis for improved translatability of outcome in future trials by identifying:
    - 1.1. The most reliable classification system
    - 1.2. The radiographic measures that correlate best with outcome
    - 1.3. The outcome scoring system with the highest reliability and validity
2. To determine the outcome of percutaneous reduction and internal fixation using the modified method of Forgon and Zadravecz.
3. To determine the best practice for delayed complications after displaced-intra-articular calcaneal fractures.

OUTLINE OF THE THESIS

Chapter 2 contains a literature review on the history, current concepts and future perspectives of intra-articular calcaneal fractures. The incidence, trauma mechanism, clinical presentation, radiological work-up, treatment options, and outcome as described in the literature are discussed. In **Chapter 3** the results of a nationwide survey on treatment of intra-articular calcaneal fractures are shown, aiming to estimate the incidence, treatment preferences, and socio-economic costs of this complex fracture in the Netherlands.

Comparing different fracture types, therapeutic options, radiographic measurements, and the results of various treatment modalities is hampered by a lack of consensus on calcaneal fracture classification and outcome scoring systems. After decades of using various assorted validated and non-validated outcome scoring systems, there is an obvious need to improve methodological uniformity for future assessment of efficacy of treatment in displaced intra-articular calcaneal fracture. The use and interobserver variability of different calcaneal fracture classification systems is displayed in **Chapter 4**, identifying the interobserver reliability of frequently used classification systems and determining the correlation with treatment and clinical outcome. The correlation between radiographic findings and functional outcome in patients with a unilateral intra-articular calcaneal fracture is described in **Chapter 5**. Similarly, the use, reliability and validity of clinical outcome scoring systems is discussed in **Chapter 6**, in an attempt to identify the reliability and validity of the most cited outcome scores described in the literature.

The percutaneous treatment of intra-articular calcaneal fractures is the oldest operative technique, which has regained popularity in recent years. A literature review on distractional approaches for displaced intra-articular calcaneal fractures, in which the results of eight studies using similar techniques are combined, is presented in **Chapter 7**. The history, technique, anatomical and fracture considerations, limitations, and the results of different distractional approaches reported in the literature are reviewed. At our institute, a modified percutaneous method of the Forgon and Zadravecz technique has been used since 1998. A detailed technical description of this method is further elaborated on in **Chapter 8**. The results in a cohort of 50 patients treated percutaneously at the Erasmus MC between 1998 and 2004 are displayed in **Chapter 9**. The outcome and complication rates of this treatment method are shown. **Chapter 10** shows the results of plantar pressure and foot position variables after percutaneous treatment of displaced intra-articular calcaneal fractures.

The most common delayed complication encountered after initial treatment of displaced intra-articular calcaneal fractures is arthrosis at the subtalar joint. In painful cases an arthrodesis is usually performed. There is however insufficient data on which salvage procedure will yield the best result. The outcome after subtalar versus triple arthrodesis is reported on in **Chapter 11**. A limited number of patients develop a pseudarthrosis after initial treatment of their intra-articular calcaneal fracture. Three cases and a literature review on this rare complication are presented in **Chapter 12**.

Finally, a summary, conclusions, and future considerations are given in **Chapter 13**.

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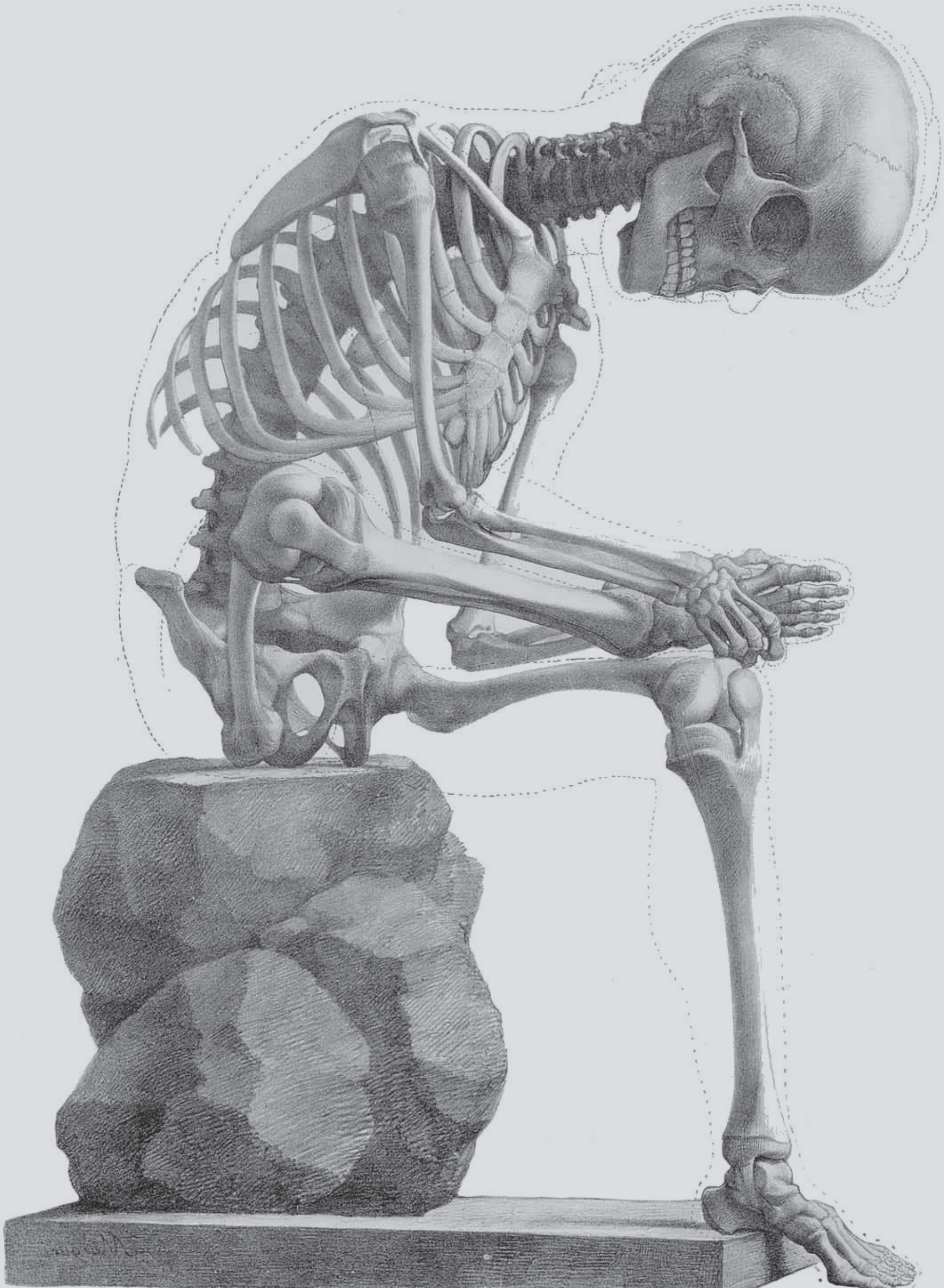
Part 1

Current treatment of intra-articular calcaneal fractures



Chapter 2

Intra-articular calcaneal fractures; A review of the literature

Translated and adapted from
T. Schepers, P. Patka
Intra-articulaire calcaneusfracturen

Ned Tijdschr Trauma 2008;16(2):40-47

ABSTRACT

Intra-articular calcaneal fractures represent less than 1% of all fractures. Patients often suffer from additional injuries, and returning to work may take up to one year. The diagnostic work-up consists of three standard radiographic views of the foot: an anteroposterior and lateral radiograph as well as an axial calcaneal view of the heel. Often, an additional CT-scan in three planes is needed. Because of the multiple classification systems and outcome scoring systems, it is difficult to measure and compare outcomes and therefore determine the best treatment modality. More randomised controlled trials are needed in the future in order to determine the best treatment modality for the different types of intra-articular calcaneal fractures.

INTRODUCTION

Intra-articular calcaneal fractures represent a relatively rare type of injury. This complicates the diagnostic process and the choice of the right treatment approach. In this review the most relevant aspects of calcaneal fractures are described. Additional insight into this complex fracture may enable surgeons to provide better information to their patients, and even more importantly, allow surgeons to provide a more standardized treatment.

EPIDEMIOLOGY

With a reported incidence of 1-2% of all fractures, the calcaneal fracture is a rare injury.[1] Recent estimates suggest that the incidence of calcaneal fractures in the Netherlands is 0.6.[2] Approximately 75% of these fractures are located intra-articular. These fractures are associated with a worse outcome compared with extra-articular fractures.[3] A fall from height, like a fall down stairs or an attempted suicide, accounts for more than 80% of the trauma mechanisms of intra-articular calcaneal fractures. Work related injuries make up half of this group.[4] Motor-vehicle accidents or direct impact injuries account for the remaining 20% of intra-articular fractures. The majority of calcaneal fractures (80-90%) occur in male patients of 30-45 years of age.[1] Only 5% of all calcaneal fractures occur in children.[5] Twenty to 60% of patients present with additional fractures and other injuries, mainly contra- or ipsilateral lower extremity fractures. Bilateral calcaneal fractures are seen in 10% of patients.[4,6,7] Also, in 10% of patients with a calcaneal fracture an injury of the lumbar spine is seen.[5] Another well-known combination is a fracture of the calcaneus, combined with a fracture of the distal radius and lumbar spine. This is called the 'Lovers triad', and occurs in male patients jumping of the balcony of their loved ones when caught in the act.

Calcaneal fractures are prevalent amongst middle-aged patients and many of these injuries are work-related. Most injuries also require an extended time of rehabilitation before the patient is able to return to work. This scenario carries a costly burden at a socio-economic level.[8] In the Netherlands, the annual cost for displaced intra-articular calcaneal fractures is estimated to be 20.5 to 30.7 million Euro.[2]

TRAUMA MECHANISM

The mechanism of intra-articular calcaneal fractures has been described by several authors, the most famous of which are Böhler, Palmer, Essex-Lopresti, and Warrick and Bremner.[8-12] The axial forces, caused by an upright landing on the foot, drive the lateral process of the talus through the calcaneus, thereby splitting the calcaneus at the sinus tarsi. This is shown as a fracture-line starting at the angle of Gissane running to the plantar side of the calcaneus. [Figure 1a] Essex-Lopresti named this fracture line the primary fracture line.[11] Because the axis of the talus is located slightly more medially than the axis of the calcaneus, the primary fracture line will split the calcaneus into two parts: the posterolateral tuberosity fragment and the anteromedial sustentaculum fragment.[13] The latter fragment is firmly attached to the talus and the medial malleolus by several strong ligaments (interosseous talocalcaneal ligament and the medial talocalcaneal ligament of the deltoid ligament), and will dislocate only slightly. The axial force will subsequently create the secondary fracture line, which runs from the angle of Gissane through the tuberosity. The direction of this secondary fracture line forms the basis of the Essex-Lopresti classification. [Figure 1b-d]. Higher forces may form additional fracture lines, which will create more fragments, with involvement of the calcaneocuboid joint in approximately 50% of intra-articular calcaneal fractures.[13]

CLINICAL PRESENTATION

Patients with a calcaneal fracture present at the Emergency Department, or, less frequently, at the office of their primary care physician, because of pain and intolerance to weight-bearing.

During the physical exam, the patient will exhibit tenderness to palpation around the heel, which is often oedematous and ecchymotic. This ecchymosis tends to spread to the sole of the foot, which is known as 'Mondor's sign'. This sign is rarely seen in fractures of the ankle and is very indicative of a calcaneal fracture.[10,14] The oedema can lead to the formation of fracture blisters.[10] Approximately 10% of intra-articular calcaneal fractures are open fractures.[15] Increasing pain can be indicative of an acute compartment syndrome of the foot.[16] Each patient should therefore be monitored very carefully. Practitioners must give consideration to the possibility of concomitant injuries in patients with calcaneal fractures.

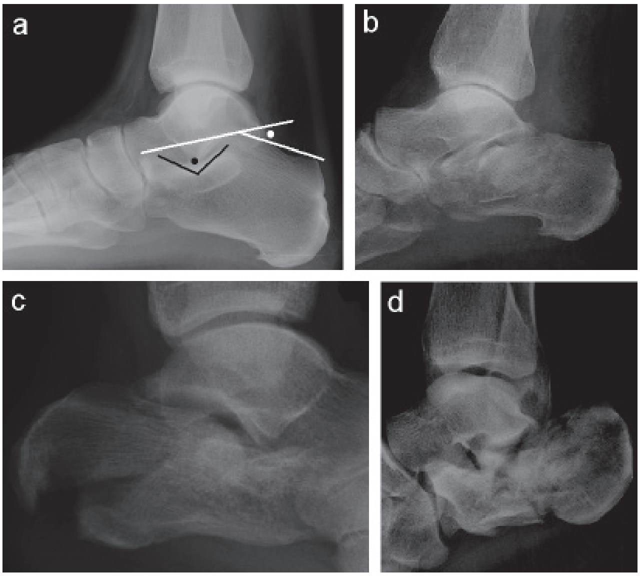


Figure 1. Conventional radiographs
a. A normal calcaneus, with the angles according to Böhler (white line; reference 25-40 degrees) and Gissane (black line; reference 120-145 degrees), b. Joint-depression fracture, c. 'Tongue-type' fracture, d. Comminuted calcaneal fracture according to Essex-Lopresti

RADIOLOGY AND CLASSIFICATION

The initial radiographic work-up for a suspected calcaneal fracture consists of an anteroposterior and lateral view of the foot and an axial view of the calcaneus. In most cases these views will be sufficient for detecting a calcaneal fracture. Two angles can be calculated from the lateral radiological projection [Figure 1]. The 'tuber-joint angle' according to Böhler is formed by the bisection of a line running from the tip of the anterior process to the highest point of the posterior talocalcaneal joint and the line which runs from the highest point of the calcaneal tuberosity to the highest point of the posterior joint. Normally, this angle ranges from 25 to 40 degrees.[10] The second angle is the 'crucial-angle of Gissane'. This angle is formed by the bisection of a line running along the lateral border of the posterior facet and a line along the anterior process. This angle is normally between 120 and 145 degrees.[11] These two angles delineate the amount of depression and displacement of the subtalar joint.

Standard lateral and axial views only partially depict the injury present at the posterior talocalcaneal joint.[17] Therefore, various additional views (according to Brodén, Isherwood, Anthonson, and Harris-Beath) were proposed to provide a more complete view of this joint.[9,18-22] Upon implementation of CT-scanning in the early eighties, the aforementioned supplemental views became obsolete. A CT-scan is usually performed when the plain radiographs show a fracture of the calcaneus. Reconstructions are done in three planes, i.e., the: axial, semicoronal and sagittal plane [Figure 2]. These views show the extent of the fracture, the number of fragments, the amount of displacement, as well as widening and overall condition of the posterior subtalar joint.[9,22-32]

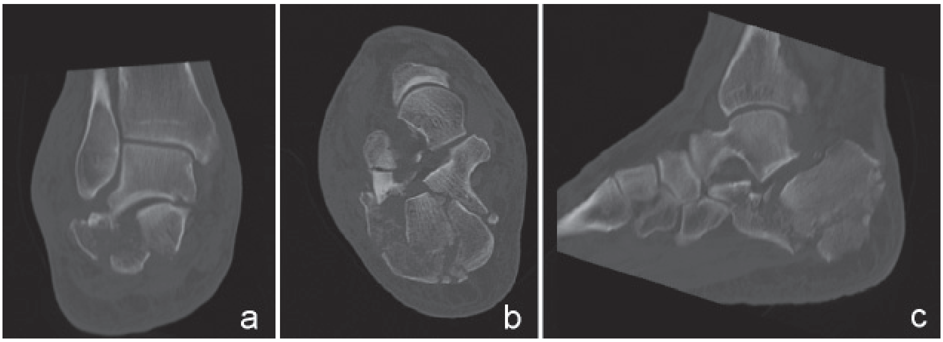


Figure 2. Example of a CT-image of a Sanders type IIB type intra-articular calcaneal fracture
Reconstructions are shown in the: a. axial, b. semicoronal, and c. sagittal plane

Classifications for calcaneal fractures can be divided into those based on plain radiographs and those based on CT-scans. The earliest classification systems divided fractures into intra- and extra-articular calcaneal fractures. This review focuses on intra-articular calcaneal fractures.

Conventional radiographs

One of the earliest classifications of calcaneal fractures was described by Böhler in 1931.[10] Over twenty different classifications have been described based on plain radiographs since that time.[8] The Essex-Lopresti classification was described in 1952 and is the most frequently used classification system. It is relatively simple and reproducible, and correlates, at least partially, with the choice of treatment and the outcome. Essex-Lopresti recognised two types of intra-articular calcaneal fractures, based upon the direction of the secondary fracture line: the 'Joint-depression' and the 'Tongue' type [Figure 1b-d]. Fractures with additional fracture lines are described as comminuted fractures.[11]

CT-scans

More than ten different classification systems have been described based on computed tomographic scans of intra-articular calcaneal fractures.[32-37] Each describes the amount of displacement and/or angulation at the posterior talocalcaneal joint. The most frequently applied classification system was proposed by Sanders.[35] This classification uses the (semi-) coronal reconstruction, where the posterior subtalar joint is at its widest and the sustentaculum tali is visible, and is based on the number of fracture lines with more than 2mm displacement. If there is no displacement of the fracture fragments, the fracture is considered a type I fracture. A fracture with one fracture line extending through the posterior joint is called a Sanders type II fracture. Fractures with two fracture lines are considered type III fractures, and type IV fractures display three or more fracture lines. The fracture lines are lettered from lateral to medial (ABC). Three different forms of type II and III fractures exist, depending upon the location of fracture lines [Figure 2 and 3].[8,35] Multiple studies have shown that the Sanders classification system is relatively simple, and has an acceptable inter-observer variability.[38] There is also some degree of predictive value towards the patient's long-term outcome. Patients with a type II fracture perform better than those with type III fractures, who have a better outcome than patients with type IV fractures.[35]

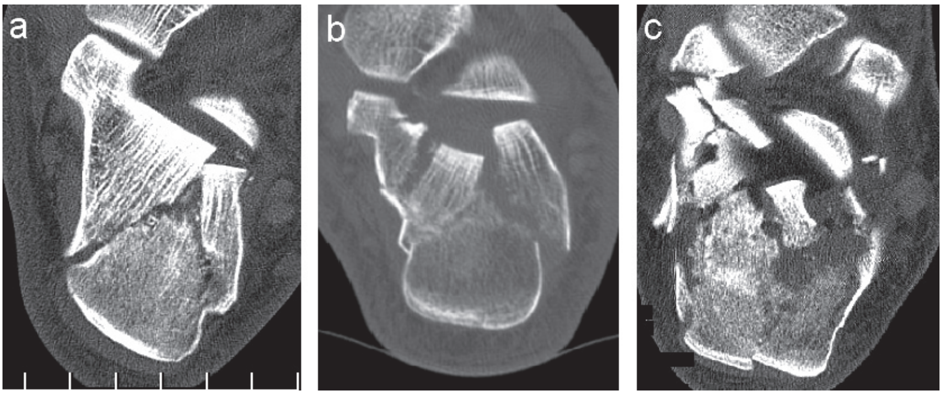


Figure 3. CT-classification according to Sanders: a. type IIA, b. type IIIAC, en c. type IV fracture

THERAPY

Intra-articular calcaneal fractures can be treated with nonoperative or operative intervention. Conservative treatment consists of rest, elevation, one to two weeks of plaster splinting until initial swelling has settled, and early active range of motion exercises. These early active exercises have been shown to result in a better outcome when compared to prolonged immobilization in plaster.[11,39] Conservative treatment is preferable for the treatment of non-displaced fractures. Nonoperative management is also recommended for the treatment of fractures in non-compliant patients, with regards to follow-up and ability to adhere to non-weight-bearing recommendations. The condition of the soft tissues plays a major role in the outcome of patients, as does the overall condition of the patient (e.g. comorbidities). In the Netherlands, approximately 40% of intra-articular calcaneal fractures is treated conservatively.[40]

The primary goal of operative management of intra-articular calcaneal fractures is the restoration of the congruence of the subtalar joint. The secondary goal is to restore height, width, and alignment of the calcaneus. The endpoints of treatment are pain free ambulation, the ability to return to work and the ability to wear regular shoes. Many different operative procedures have been described in the literature, which can be divided into closed, percutaneous, and open techniques.

The closed, or manual, technique consists of non-invasive manipulation of the fracture in order to improve the alignment of the fracture fragments, especially by reducing the width and varus-angulation.[41] One of the earliest percutaneous techniques was devised by Westhues. This was subsequently further developed by Essex-Lopresti, especially for the 'tongue-type' fractures. This method consists of the insertion of a metal pin, the 'Gissane spike' or a Steinmann pin, via the posterior portion of the calcaneal tuberosity in order to reduce the depressed fragments.[11] Another frequently applied percutaneous technique is the three-point distraction according to Forgon en Zadravecz.[7,42-44]

The 'open' operative techniques are classified by their approach: the lateral, medial, and combined approaches are the most frequently applied. The most commonly used method, which is also described or supported by Arbeitsgemeinschaft für Osteosynthesefragen, is the 'extended lateral approach'.[45] By making an L-shaped incision, an adequate exposure of the posterior talocalcaneal joint is obtained, This allows restoration of the joint congruence. Some foot and ankle surgeons believe that restoring a severely comminuted subtalar joint is not feasible and favor a primary arthrodesis.[8]

The timing of operative intervention of intra-articular calcaneal fractures is extremely important. The closed and percutaneous techniques need to be performed within a few days, as the fragments are still mobile at that time and, therefore, can be reduced by distraction and minimally invasive manipulation.[7,41] The 'open' technique has a poor reputation due to wound healing problems. If the soft tissues have had enough time to settle, wound healing is improved.[8] The 'wrinkle test' according to Sanders is a good indication that the swelling has sufficiently settled. This is performed by maximally plantar flexing the ankle. Skin wrinkles present when the foot is brought back to a neutral position suggests the oedema has adequately resolved.[8] Moreover, smoking will lead to a higher rate of wound complications.[46] The use of a intermittent foot-pump reduces swelling more quickly, and may improve outcome.[47-49]

The indications for surgical intervention include displacement of fragments at the subtalar joint of more than 2 mm, 5 degrees or more of varus, 10 degrees or more of valgus, widening of more than 5mm, or a Böhlers angle of 15 degrees or less. There are no absolute contraindications for the operative treatment of displaced intra-articular calcaneal fractures. There are, however, some relative contraindications, especially for the 'open' operative treatment. Severe comorbidities, pre-existent or trauma-related, can place these patients at a high risk. Peripheral vascular disease, insulin dependent diabetes and smoking are also relative contraindications for open surgery, due to an increased risk of wound complications. Trauma related soft tissue problems, such as open fractures and fracture blisters in the operative field, are also related to a higher incidence of postoperative infections. In such cases, a non-operative or percutaneous reduction and fixation should be considered.

The average duration of non-weight bearing recommendations for both conservative and operative treatment is 8 to 12 weeks.[1,4,7,8,35,50-52] The benefit of angle-stable plating has been investigated, and shows, mainly in cadaver testing, less secondary displacement of fracture fragments.[53-55] The use of bone cement can significantly decrease the amount of time the patient is kept non-weight bearing (from twelve to three weeks), which is especially beneficial in bilateral fractures.[56-59]

OUTCOME

In order to determine the outcome of various treatment modalities, several hundred studies have been published in the last century. The most important outcome measures are pain, limitations in activities of daily living, ability to walk, ability to wear regular shoes, ability to return to work, and postoperative range of motion of the foot and ankle. More than thirty disease-specific outcome scoring systems have been developed. The American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot score is the most frequently used scoring system. It consists of nine items: pain, limitations, walking pattern, walking distance, walking surface, and physical exam (range of motion of the ankle and hindfoot joint, stability and alignment). The maximum score is 100 points, and a score exceeding 75 points is considered to be a good to excellent result.[60,61] Poor results are more common in severely comminuted, as well as in open fractures. In addition to subjective questions, the AOFAS hindfoot score also includes a physical exam in which the range of motion (ROM) of the ankle and subtalar joint is measured using a goniometer. In unilateral fractures, the contralateral foot can be used as a control, whereas normal values can be used in case of bilateral fractures. The normal ROM of the ankle joint in the sagittal plane is 40-55 degrees of plantar flexion, and 20-30 degrees of dorsiflexion.[62] The subtalar joint has a ROM of 5 degrees eversion and 20-25 degrees inversion.[62] The correlation between functional outcome and control radiographs remains subject to debate.[63]

In the literature, a 25-75% good to excellent result is obtained in patients treated non-operatively. Approximately 50% of patients treated conservatively have an acceptable outcome.[13,64] Patients that have undergone closed reduction score slightly better than those treated without manipulation; a 45 to 90% good to excellent result.[41,65] After percutaneous reduction and fixation, the results are good to excellent in 60 to 80% of patients.[7,11,42] Open reduction and internal fixation provides the highest scores in retrospective series. Seventy to 90% of patients score good to excellent results.[8,12,50,52] The outcome after a primary arthrodesis is satisfactory in 50 to 74% of patients.[66]

In a meta-analysis by Bajammal (2005), the results of four randomised studies (O'Farrell, Parmar, Thordarson and Buckley) were combined, comparing conservative versus open reduction and internal fixation.[4,67-70] Conclusions from this meta-analysis (Grade B) are:

- There is no significant difference in pain and functional outcome between patients treated operatively and those treated conservatively.
- Operatively treated patients tend to do better with respect to return to work and in wearing normal, non-adapted, footwear.
- There is a significant reduction in the need for a secondary arthrodesis in operatively treated patients.
- From a socio-economic perspective, operative treatment is less costly compared with conservative treatment.
- The complication rate in the operative group is higher than in the conservative group. This is most pronounced for infectious complications.

In total, 40-85% of all patients who were working before the accident return to work within 9 months, although sometimes with slight activity modifications.[1] Approximately 20% of patients are unable to return to work within one year of their injury.[64]

COMPLICATIONS

On average 2-10% of all intra-articular calcaneal fractures are complicated by the development of a compartment syndrome of the foot.[1,4,8,40,71] This is characterised by substantial swelling, disproportionate pain, and paresthesia of the sole of the foot (plantar nerve), and requires immediate decompression.[71] When left untreated, compartment syndrome can lead to claw toes and short-foot syndrome.[71] Superficial infection, osteomyelitis and other wound complications represent the largest group of post-operative complications. Superficial infections occur in 10-27% of operated cases, and osteomyelitis is seen in up to 2.5%.[8,72] Open fractures form a separate entity, with worse outcomes and a higher chance of wound complications.[15] Close collaboration with a plastic surgeon should be considered in order to achieve adequate closure of an open fracture or soft tissue defects after an extended lateral approach.[15,73]

Arthrosis is diagnosed in up to 75% of patients and is the most frequently occurring long-term complication. An arthrodesis is not necessary in every case of arthrosis. The need for an arthrodesis in conservatively and operatively treated patients is 20-40% and 5-15%, respectively.[3,7,35,65,72] It is currently unclear which type of arthrodesis, in-situ subtalar, distraction or triple, will provide patients with the best relief from a painful hindfoot.[74]

CONCLUSION

The intra-articular calcaneal fracture is a rare fracture, for which, even after decades of research, there is not a straight-forward treatment strategy. There seems to be a trend towards operative treatment, which results in an earlier return to work. On the other hand, increased complication risks are encountered after operative treatment. It should be noted that the best results are seen in high volume centers.[75] A learning curve of 35-50 fractures has been reported.[35] According to a Dutch national survey among 70% of 137 centres, this learning curve will take more than four years in most centers, as only three hospitals treat more than 20 fractures annually. [35,40]

There is a need for a gold standard in fracture classifications and outcome scoring systems, which would allow for pooling of data in a meta-analysis. Also, there is a need for prospective randomised trials in order to determine the best management approach for the different fracture subtypes. In the Netherlands, such a study was recently started: the Closed Reduction vs ORIF vs Non-Operative Study (CRONOS). Information about this trial can be found on the website www.calcaneus.nl.

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Chapter 3

Current concepts in the treatment of intra-articular calcaneal fractures; Results of a nationwide survey

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ABSTRACT

Introduction

The treatment of intra-articular calcaneal fractures is controversial and randomised clinical trials are scarce. Moreover, the socio-economic cost remains unclear. The aim of this study was to estimate the incidence, treatment preferences and socio-economic cost of this complex fracture in the Netherlands. This data may aid in planning future clinical trials and support education.

Method

The method of study was of a cross-sectional survey design. A written survey was sent to one representative of both the Traumatology and the Orthopaedic staff in each hospital in the Netherlands. Data on incidence, treatment modalities, complications and follow-up strategies were recorded. The socio-economic cost was calculated.

Results

The average response rate was 70%. Fracture classifications, mostly by Sanders and Essex-Lopresti, were applied by 29%. Annually, 920 intra-articular calcaneal fractures (0.4% incidence rate) were treated, mainly with ORIF (46%), conservative (39%) and percutaneous (10%) treatment. The average non-weight-bearing mobilisation was 9 weeks (SD 2 weeks). An outcome score, mainly AOFAS, was documented by 7%. A secondary arthrodesis was performed in 21% of patients. The annual socio-economic cost was estimated to be €21.5–30.7 million.

Conclusion

Dutch intra-articular calcaneal fracture incidence is at least 0.4% of all fractures presenting to hospitals. Better insight into treatment modalities currently employed and costs in the Netherlands was obtained.

INTRODUCTION

Since the 1950s, the frequency of calcaneal fractures has been presumed to be around 2% of all fractures presenting to emergency departments and the proportion of intra-articular calcaneal fractures with involvement of the posterior subtalar joint approximately 75%.[1-6]

Controversy on the treatment of this type of fracture remains, as several different operative and non-operative strategies exist.[3,7-9] Intra-articular fractures carry a high morbidity; 40–85% of patients return to work within 9 months, but approximately 20% are not able to return to work within a year, rendering intra-articular calcaneal fractures costly on a socio-economic level.[10-12]

Determining the socio-economic cost of intra-articular calcaneal fractures in the Netherlands requires knowledge of the incidence and an overview of the treatment approaches used. In addition, these data may support education, provide the basis for a consistent treatment guideline and may aid in planning future clinical trials.

The objective of this study was to assess the number of intra-articular calcaneal fractures seen by trauma surgeons and orthopaedic surgeons annually in the Netherlands. The second aim was to identify surgeons' preferences in the treatment of calcaneal fractures. Based upon these data, the socioeconomic burden of this type of fracture was estimated.

METHODS

A postal survey was developed according to the guidelines as provided by a meta-analysis of randomised studies of postal surveys to optimise response rates.[13] Attention was paid to the recommendations of the American Association for Public Opinion Research (AAPOR).[14] Four trauma surgeons from a level-1 trauma centre aided in the development of the questionnaire. The questions included in the survey were derived from the existing literature on the subject and are shown in Table 1. The choice of treatment was limited to the six most frequently mentioned modalities in the literature: conservative treatment (functional and plaster of Paris), manual reduction, Essex-Lopresti manoeuvre, Forgon and Zadravecz (percutaneous) distraction technique, open reduction and internal fixation (ORIF), and primary arthrodesis. Morbidity registration was limited to compartment syndrome of the foot, wound dehiscence, superficial wound infection and deep infection (osteomyelitis and pin-track infection). The survey was sent to one representative of the trauma surgery staff and one representative of the orthopaedic surgery staff in each hospital in the Netherlands. Recipients were selected by contacting all hospitals prior to the survey.

The goals of the survey were explained in a personally addressed accompanying letter. A stamped returning envelope was provided. A total of 274 surveys were sent to 137 hospitals. After three weeks, a reminder was sent, including a copy of the survey and a returning envelope. To assess the incidence of intra-articular calcaneal fractures, the total number of patients with any type of fracture seen at the emergency departments in the Netherlands was retrieved from the Dutch Injury Information System (LIS, Letsel Informatie Systeem; http://www.veiligheid.nl). This number is an estimate, calculated by extrapolating the number of

Table 1.	Questions of the closed reduction vs. open reduction and internal fixation (ORIF) vs. non-operative study (CRONOS) of the displaced intra-articular calcaneal fractures (DIACF) survey
Questions of the CRONOS survey	
1.	Is your profession Trauma Surgeon or Orthopaedic Surgeon?
2.	In what hospital are you currently employed?
3.	How many new patients with a DIACF are treated in your hospital annually?
4.	What fracture classification do you use?
5.	What treatment modality do you use?
6.	What type of osteosynthesis material do you apply? Do you use bone grafting? How many weeks do patients mobilize non-weight bearing?
7.	How frequently do you encounter the following complications: Compartment syndrome, superficial and deep infection, wound dehiscence?
8.	Do you apply a standardized outcome score? If yes, which?
9.	How many patients need a secondary arthrodesis?
10.	How many patients return to work?
10.	Would you consider participation in a RCT?

RCT, Randomised Controlled Trial; DIACF, displaced intra-articular calcaneal fracture.

patients seen at 14 representative emergency departments in the Netherlands. In addition, the number of patients with a calcaneal fracture, both intra- and extra-articular, admitted to the hospital was retrieved from the Dutch National Medical Registration (LMR, Landelijke Medische Registratie; http://www.prismant.nl). The LMR is a database in which diseases and injuries of hospital admissions are gathered and coded according to the International Classification of Diseases (ICD). The average number of patients admitted to the hospital from 2002 to 2004 with a calcaneal fracture was retrieved from this database.

Analysis

All of the data of the survey was gathered in a Microsoft Access database. The socio-economic cost was calculated with the use of the "per patient costs," as determined by Brauer et al.[11] In this Canadian study, the costs per patient treated conservatively or operatively were calculated on the basis of quality adjusted life years (QALY), including the costs of a secondary arthrodeses, complication and time lost from work.[11] The average costs per patient treated operatively were CAN$32,000 (~€19,000; benefit of 2.50 QALYs). For the non-operatively treated patients, the costs were CAN $51,000 (~€30,000; benefit of 2.43 QALYs).[11]

RESULTS

The response rate (number of sent surveys divided by the number of received surveys) after 8 weeks was 69% for the trauma surgeons and 70% for the orthopaedic surgeons. The responding trauma surgeons treated 593 intraarticular calcaneal fractures annually, with an average of 6.4 fractures per hospital per year. The responding orthopaedic surgeons saw 327 fractures, with an average of 3.5 fractures per hospital per year (Table 2).

Table 2.	Estimated numbers of fractures seen annually by trauma and orthopaedic surgeons	
Number of fractures	**Number of centres in the Netherlands**	
	Trauma surgeons	**Orthopaedic surgeons**
None	30	35
1-2	3	12
3-5	12	25
6-10	28	17
11-15	9	5
16-20	7	1
More than 20	3	0

According to data from the Dutch registries, 230,000 patients are treated for any type of fracture of the skeletal system at emergency departments annually in the Netherlands (http://www.veiligheid.nl). Calcaneal fractures do not represent a distinct group in this database.

The estimated number of hospital admissions of patients with any type of fracture was 59,194, of which 486 patients had an intra- or extra-articular calcaneal fracture (http://www.prismant.nl). These data imply that 0.8% of all patients with a fracture admitted to the hospital were admitted due to a calcaneal fracture.

The application of one or more fracture classification systems was reported by 29% of the responding trauma and orthopaedic surgeons. The Sanders computed tomography classification was used in 37% of these cases, the Essex-Lopresti conventional radiographic classification in 32%, the Zwipp computed tomography classification in 25%, the Eastwood-Atkins computed tomography classification in 5% and the classification by Rowe in 1%. The majority of patients were treated with ORIF (46%), conservatively (39%) or percutaneously according to Forgon and Zadravecz (10%), as shown in Table 3.

Table 3.	Number of patients treated per treatment modality by the responding orthopaedic and trauma surgeons	
Treatment modality	**Number of patients**	**%**
Manual reduction	6	1
Primary arthrodesis	8	1
Essex-Lopresti manoeuvre	30	3
Forgon-Zadravecz distraction	94	10
Conservative	356	39
ORIF	426	46
Total	920	100

Large differences exist in the number of patients treated using these three most used techniques per province (Figure 1). The definite use of bone grafts in the ORIF group was reported by 20% of respondents, a total of 42% used grafting when deemed necessary and 38% did not use bone grafts at all. Five different types of calcaneal plates were used in the Netherlands in the ORIF group (Synthes AO Plate, Biomet, AO cervical H-plate, New Deal and Stryker) and two different types of fixation in the percutaneous group (cannulated screws and Kirschner wires). Patients remained non-weight bearing for a mean period of 9 weeks (range 0 to 12 weeks; SD=2 weeks). Seven percent (7%) of the respondents used one or more

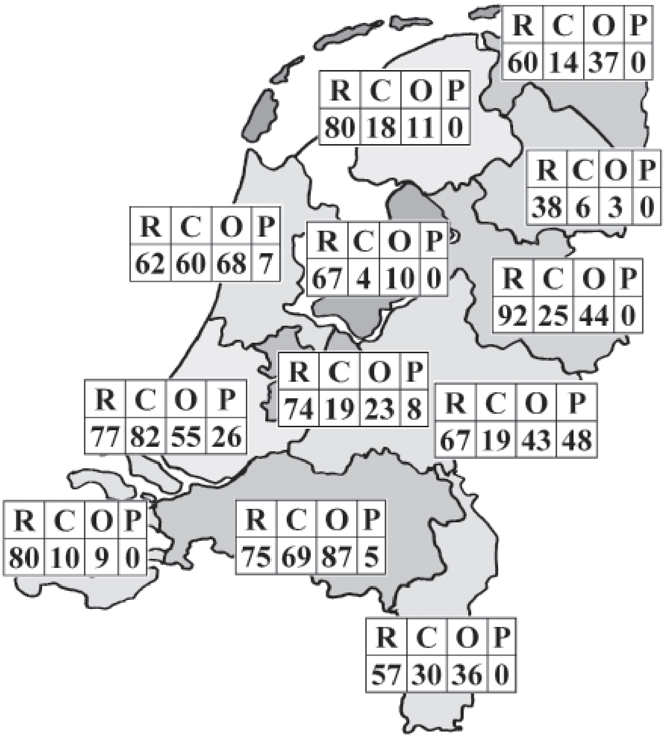

Figure 1. Response rates and the number of patients treated using the three most frequently applied modalities per province in the Netherlands
R=response rate in percentage; C=absolute number of patients treated conservatively; O=absolute number of patients treated using ORIF; P=absolute number of patients treated percutaneously, as described by Forgon and Zadravecz.

standardised outcome scores; the AOFAS hindfoot score (47%), the Creighton-Nebraska score (21%), the Maryland Foot Score (16%) and the Short Form-36 (16%). The reported rate of superficial wound infections was 16%. Lower rates were reported for foot compartment syndrome, wound dehiscence and deep infectious complications (Table 4). Seventy-two of the responding trauma and orthopaedic surgeons reported the performance of a late arthrodesis in 125 patients annually with persisting complaints after an intra-articular fracture. These respondents treated a total of 603 fractures combined annually, giving an annual arthrodesis rate of 21%. Of all respondents, 151 surgeons, treating 606 fractures annually, estimated the return to work in 459 patients (76%). In this sample of 920 patients, 60% (n=558) were treated operatively and 40% (n=362) non-operatively. The Canadian data indicated that the average cost for these patients were CAN$32,000 (€19,000) and CAN$51,000 (€30,000) for these groups, respectively. Therefore, the annual total costs for these 920 patients with intra-articular calcaneal fractures approximated €21,462,000. Assuming that the relative numbers of patients treated operatively and non-operatively for the 30% of non-respondents equals that of the respondents, the total annual cost for intra-articular calcaneal fractures in the Netherlands as a whole would be ~ €30,660,000.

Table 4.	The number of complications after intra-articular calcaneal fracture treatment	
Complication	**Number of patients**	**%**
Foot compartment syndrome	14	2
Wound dehiscence	52	9*
Superficial infection	90	16*
Deep infection	13	2*

Percentages with an asterisk (*) are calculated for operated fractures only

DISCUSSION

This study was initiated to assess the incidence and the socio-economic cost of intra-articular calcaneal fractures in the Netherlands and to make an inventory of management approaches. In total, 920 fractures were treated by the respondents, representing 0.4% of all fractures seen at the emergency departments. The annual socio-economic cost was estimated to be around €21.5–30.7 million.

The overall response rate of this study was 69%, representing an above average response. A meta-analysis on 68 survey response rates showed that physicians have a mean response rate of 54±17%.[15] The influence of non-response bias was, therefore, low. The 920 fractures found in this survey represent 0.4% of all fractures seen in the emergency departments. Adjusting for 30% of non-responders, the intra-articular calcaneal fracture incidence is 0.57%. This is below the presumed incidence of 2%.[4,5] It is unclear whether the latter percentage includes extra-articular calcaneal fractures. If the incidence of calcaneal fractures from our study is adjusted to include non-responders (30%) and extra-articular fractures (25%), the overall incidence of calcaneal fractures would be 0.75%. The latter approximates the 0.8% incidence calculated by dividing the number of patients with a calcaneal fracture admitted (n=486) by the total number of patients with any type of fracture admitted to the hospital (n=59,194) (http://www.prismant.nl). Few respondents used classifications (29%) or outcome scoring (7%) systems. The classifications used most frequently were the Sanders computed tomography classification and the Essex-Lopresti classification for plain radiography. Both systems have previously shown to be of prognostic value, or showed a trend towards this, which indicates that these classification systems may be used when determining prognosis.[8] An explanation for the limited use of a classification and an outcome scoring system might be that these tools are mainly designed for research purposes. It must be noted that, of the responding academic hospitals, 100% used one or more classification systems and over 70% applied an outcome scoring system. In most of the academic hospitals, research is being conducted concerning calcaneal fractures.

In total, 95% of intra-articular calcaneal fractures were treated with ORIF, conservative treatment and percutaneous distraction in the Netherlands, according to Forgon and Zadravecz. A secondary arthrodesis rate of 21% was calculated for all treatment modalities combined, which lies within the reported range for conservatively treated patients (16–30%)[8,16] and at the upper end of the reported rates for surgically treated patients (1–22%).[8,17] The variation in arthrodesis rates in surgically treated patients can be explained by the small number of patients in some studies and treatment variation in specialised centres.[17] The rate of infectious complications in the survey, 16% superficial and 2% deep infections, is similar to complication rates reported in a study by Howard et al., in which a superficial wound infection was reported in 16% and a deep infection in 5% of patients, mainly secondary to a superficial infection.[18]

Calculation of the socio-economic cost is based upon a study using Canadian health care parameters[8], which limits the interpretation of the Dutch socio-economic cost calculation. In Canada, only patients with proper insurance receive workers' compensation. Multiple studies indicated that patients receiving this workers' compensation have poorer outcome compared with patients not compensated.[8,19,20] In the Netherlands, every patient is compensated for sickness leave for a full year before procedures are started for a disability allowance. The return to work rate of 76% is in accordance with estimates in the literature.[10]

The higher percentage of secondary arthrodeses, but comparable numbers of infectious complications, suggests an underestimation rather than an overestimation of the total costs calculated. In the Canadian study, ORIF was used as the sole surgical technique.[11] Cost estimations for patients treated percutaneously are lacking; however, there are no indications that costs for patients treated with ORIF or percutaneous techniques will differ.[21] Therefore, costs for all Dutch patients treated operatively (ORIF, percutaneous treatment and primary arthrodeses) in the survey could be based upon the Canadian ORIF group costs. Due to obvious differences between the Dutch and Canadian health care systems, the calculated socio-economic cost (€21.5–30.7 million) should be interpreted as estimation for the Netherlands.

CONCLUSIONS

The total number of intra-articular calcaneal fractures in this survey comprises 0.4% of all fractures seen in the emergency departments in the Netherlands and the total Dutch incidence is estimated at 0.8%.

For the treatment of intra-articular calcaneal fractures, surgeons in the Netherlands prefer the use of open reduction and internal fixation (ORIF) over conservative and percutaneous treatment. Bone grafting is only infrequently used and the non-weight bearing period is 9 weeks on average. The Sanders and Essex-Lopresti fracture classifications are favoured over other classification systems. Outcome-scoring systems are infrequently applied. The Dutch annual socio-economic cost of calcaneal fractures is estimated to be in the range €21.5–30.7 million.

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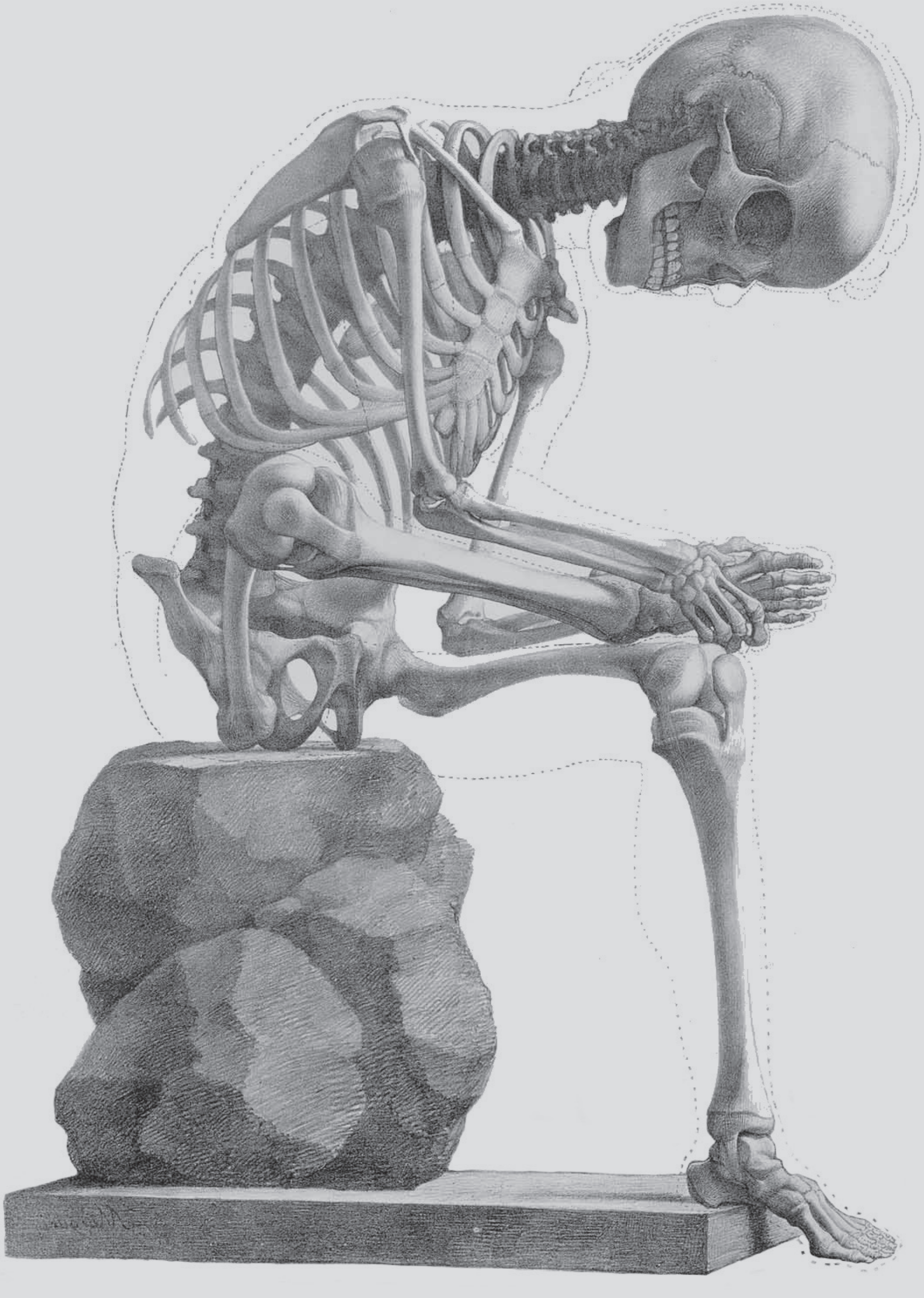
Part 2

Uniformity in treatment of intra-articular calcaneal fractures



Chapter 4

Calcaneal fracture classification; A comparative study

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ABSTRACT

Objectives

Comparing different types of calcaneal fractures, associated treatment options, and outcome data is currently hampered by the lack of consensus regarding fracture classification.

Methods

A systematic search for articles dealing with calcaneal fracture was performed, and the prevalence of use of each classification system determined. Twelve observers classified 30 intra-articular calcaneal fractures according to the 3 most prevalent classification systems; interobserver reliability (kappa statistic) and the correlation of the system with the choice of treatment and clinical outcomes were calculated.

Results

Forty-nine conventional and 15 computerized tomographic scan classification systems were identified. The most prevalent systems were the Essex-Lopresti, Zwipp, Crosby, and Sanders classifications; and none of these showed a direct correlation with treatment, although each of these systems showed positive correlations with outcome. Moderate interobserver agreement and variability were found for the Crosby and Sanders classifications (overall kappa 0.48), whereas interobserver reliability among radiologists was poor for the Essex-Lopresti classification (overall kappa 0.26).

Conclusions

Four classifications systems showed positive correlations with outcome, but no correlation with choice of treatment. The Sanders and Crosby classifications displayed comparable, moderate interobserver variability among surgeons and radiologists, and both of these systems are likely to be useful for classification of intra-articular calcaneal fractures.

INTRODUCTION

The classification of fractures may be defined as the systematic arrangement of fractures of the same group according to their relative differences and resemblances, in order to provide useful information for the user. Most radiological classification systems for calcaneal fractures are based on the pathological anatomy, and focus on features such as the location of fracture lines, the number of fragments, or a combination thereof, or the system emphasizes the mechanism of injury.[1] The effectiveness of classifying fractures has been debated, and was characterized by Cotton, in 1916, as "...being as useful as classifying cracks in a walnut, after the nut-cracker is through with it".[2] In general, a fracture classification can be useful only if it considers the severity of the bone lesion and serves as a basis for treatment and for the evaluation of the results.[3] A good classification system should also facilitate communication between surgeons[4], be easy to remember and use and thus show low variability between observers using the system to classify fractures.[5]

Because of the lack of a uniform system for the radiographic evaluation of calcaneal fractures, and the large number and variety of classifications systems that have been described for this injury, it can be difficult for readers of the calcaneal fracture literature to interpret and compare the results of different studies.[6-9]

The aim of the investigation described in this article was threefold: (1) to assess the number of available classification systems and their citation frequency (prevalence) in the literature; (2) to determine the reliability of the three most prevalent radiological classification systems in terms of interobserver agreement and variability; and (3) to determine the operational characteristics of the classification systems identified in the literature, in regard to whether or not the systems (a) facilitate communication, (b) guide treatment, and (c) prognosticate clinical outcome.

MATERIALS AND METHODS

1) Literature survey

A literature search was conducted to determine the number of different calcaneal fracture classification systems, and the prevalence of each system, mentioned in the biomedical literature. Biomedical publications electronically stored in the Cochrane Library and Pubmed, up to September 2006, were searched using the following terms and Boolean operators: 'calcaneus' OR 'os calcis' OR 'calcaneum' OR 'calcaneal' AND 'fracture'. There were no language or starting date restrictions. Publications were requested at the university medical (internet) library and were reviewed by two authors (TS and MH). In addition, a comprehensive search of reference lists of the manuscripts retrieved was conducted to find additional studies. In the event that multiple classifications were used in one manuscript, all of the classifications were included. Classifications abstracted from these studies were divided into two categories: classifications for conventional radiographs and classifications for computerized tomographic (CT) scans. Because of the introduction of the CT scan in the mid-1980s,[10,11] only classification systems actively used after 1980 were used for further analysis. Additional classifications that were mentioned in the literature but not used by the authors, were considered to be primarily of historical importance, and were not used in the analyses.

2) Interobserver agreement and variability

Interobserver agreement and variability were calculated for the three most prevalent calcaneal fracture systems, namely the Essex-Lopresti[12], Crosby[13] and Sanders[14] classifications. Thirty lateral plain radiographs and axial and coronal CT images were randomly selected from 72 patients with 86 known displaced intra-articular calcaneal fractures treated between January 1998 and December 2005. For the Crosby and Sanders classification systems, a single representative CT image was selected by two authors (TS and AZG) in accordance with the original descriptions of the classification systems.[12-14] The observers were blind to the patients' identification and digital presentations were created for the assessment. To ensure unambiguous application of each of the fracture classification system, a comprehensive written and illustrated explanation of each class of fracture was provided for each of the observers. Six radiologists, including three residents and three staff members, each of whom specialized in trauma and musculoskeletal radiology, as well as six trauma-surgeons, including two junior residents, one senior resident and three attending staff members, all of whom had experience in foot and ankle trauma, all of whom worked at a level-1 trauma centre, classified all 90 fractures. Perfect agreement (6/6 observers agreed), and near perfect agreement (5/6 observers agreed), was determined for each specialty, as previously described in the literature.[15] The interobserver reliability was calculated by using the weighted kappa (κ) statistic, and graded according to Landis and Koch's strength of agreement: less than 0, poor; 0 to 0.2, slight; 0.21 to 0.4, fair; 0.41 to 0.6, moderate; 0.61 to 0.8, substantial; and 0.81 to 1.0, almost perfect to perfect agreement.[4,15-18] This calculation was made per specialty as well as for all 12 observers combined (overall κ). Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 11.0 (SPSS, Chicago, IL, USA). A post hoc calculation was made to determine the power to detect statistically significant reliability based on the sample and effect sizes observed in this study.

3a) Facilitating communication

The frequency (prevalence) of citation in the literature was used as a measure of use of the classification system as a mechanism for communication between observers, and considered, for the purposes of this investigation, as a measure of the overall acceptance of the classification system.

3b) Classification-based treatment selection

An important feature of a calcaneal fracture classification system is that it guides surgeons in regard to the choice of a therapeutic plan. Bernstein et al. developed a grading system, including grades A, B-1, B-2, and C, to assess the degree to which treatment is guided by a classification system.[5] In their grading system, classifications are ranked as being grade A when each category indicates a unique treatment modality. For grade B-1, at least one category in the classification system can be managed by more than one treatment modality. In grade B-2, two or more fracture types are best managed by a single treatment modality. In grade C, none of the fracture types is correlated to a single, distinct treatment modality. This grading system was used to categorize calcaneal fracture classification systems described in manuscripts retrieved from our literature search and still in active use after 1980.

3c) Association of classifications with patient outcome

In the list of active radiographic classifications, the prognostic value of a system was defined as significant correlation with outcome. Correlation with outcome was considered 'definite' (+), if two or more studies described a significant correlation between the classification and the functional outcome of the study population. If correlation with outcome was identified in one study, or a trend was found in more than one study the correlation was classified as 'possible' (+/-). The correlation with outcome was titled 'unclear' (0) if insufficient data were available, or if only a single manuscript was found with a correlation or trend, or no mention of correlation was made. If more than two studies stated that no correlation with outcome was found, then the correlation was 'none' (-).

RESULTS

1) Literature search

A total of 375 full-text manuscripts and 248 abstracts, 623 citations overall, describing calcaneal fracture classification systems, were retrieved from the databases up to September 2006.

From this search a total of 49 different classification systems were identified. Of these, 30 classification systems were determined to be of historical significance only (Table 1), and 19 were identified as being in use after 1980, and considered to be current (Table 2). Several of the classification systems were noted to overlap, or existed as modifications of older classifications.

A total of 15 CT-classifications were identified in the literature (Table 3).

Table 1. Conventional radiographic classifications for intra-articular calcaneal fractures, left unused or only mentioned after 1980 (N = 623 biomedical publications)

First author(s) (year)		
Malgaigne (1843)[19,20]	Ehalt (1952)[21]	Monet (1976)[1]
Hoffa (1888)[21]	Widen (1954)[22]	Kempf -Touzard (1978)[1]
Destot (1902)[1]	Allan (1955)[23]	Ostapowicz (1978)[21]
Cabot (1907)[24]	Sikand (1957)[25]	Burghele (1979)[26]
Conn (1926)[27]	Arnesen (1958)[28]	Slätis (1979)[29]
Paitre-Boppe (1935)[1]	Köhnlein-Weller (1961)[30]	Noble-McQuillan (1979)[31]
Hosford (1936)[32]	Thorén (1964)[33,§]	Haid (1979)[30]
Ahlberg (1940)[7]	Gaul-Greenberg (1966)[34]	Letournel (1984)[35]
Key-Conwell (1942)[36]	Weber (1974)[1]	Carr (1989)[37,§]
Palmer (1948)[38]	Decoulx (1975)[1]	Regazzoni (1993)[30]

§Classifications developed by experimentally fracturing cadaver feet.

Table 2.	Conventional radiographic classifications for intra-articular calcaneal fractures, used at least once after 1980 (N = 623 biomedical publications)		
First author(s) (year)	**Number of citations**	**Bernstein Grade**	**Correlation with Outcome**
Böhler (1931)[39]	1		0
Jiméno-Vidal (1935)[1]	1		0
Essex-Lopresti (1952)[12]	66	B2	+
Warrick-Bremner (1953)[40]	4	C	+/-
Watson-Jones (1955)[41]	2	C	0
Lindsay-Dewar (1958)[42]	1	B2	+/-
Rowe (1963)[43]	1		0
Judet (1964)[44]	1	C	0
Duparc (1967)[45]	7	C	0
Soeur-Remy (1975)[46]	1	C	0
Schmidt-Weiner (1982)[47]	4	C	0
Nakaima (1983)[48]	1	C	0
Heuchemer (1988)[49]	1		0
Uthéza (1988)[45]	4	C	0
Forgon-Zadravec (1990)[50]	4	C	0
Teubner (1992)[51,§]	2		0
Burdeaux (1993)[52]	2	C	0
Paley-Hall (1993)[8]	3	C	+/-
Kuner (1995)[30]	1	C	0

[§]Classifications developed by experimentally fractured feet.
Citation index, grading of classifications according to Bernstein (see text for explanation), and correlation with outcome.
0: Insufficient data to correlate classification with outcome.
+: Definitive correlation with outcome (at least two manuscripts).
+/-: Possible correlation; correlation with outcome in one manuscript.
-: No correlation with outcome found (at least two manuscripts).

2) Interobserver reliability

In 25% of 90 calcaneal fractures, perfect agreement for the Essex-Lopresti, Crosby and Sanders, without and with subgroups, classifications was observed when trauma surgeons categorized the fractures. Near-perfect agreement was observed in 31% of the fractures categorized by trauma surgeons. Radiologists reached perfect and near-perfect agreement in 20% and 16% of calcaneal fractures, respectively (Table 4).

In regard to interobserver reliability, trauma surgeons displayed moderate agreement for the Essex-Lopresti (κ=0.48), Crosby (κ=0.50), Sanders without subgroups (κ=0.46), and Sanders with subgroups (κ=0.52) classification systems. For the radiologists, the interobserver kappa values were 0.15, 0.43, 0.43 and 0.30, respectively. These values were indicative of slight agreement for the Essex-Lopresti system, and fair agreement for the Sanders classification with subclasses, and moderate agreement for the Crosby and Sanders classification without subclasses (Table 4).

Post hoc power calculations performed revealed the power to detect a statistically significant difference to be 86.2% (β = 0.862) for the Sanders classification without subclasses

Table 3.	Computed tomography classifications identified in the literature after 1980 (N = 623 biomedical publications)		
First author(s) (year)	**Number of citations**	**Bernstein Grade**	**Correlation with Outcome**
Vollrath (1987)[53]	1		0
Lowrie (1988)[54]	3	C	0
Zwipp (1989)[55]	18	B2	+
Johnson (1990)[56]	1		0
Crosby (1990)[13]	12	B2	+
Sanders (1992)[14]	75	B2	+
Brunner (1992)[57]	2	B2	0
Eastwood-Atkins (1993)[19]	6		+/-
Häberle (1993)[58]	1		0
Letournel (1993)[59]	0		0
Corbett (1995)[60]	1	C	+/-
AO/OTA(1996)[61]	6	C	0
Schwall (2000)[62]	1	B1	0
Stürmer (2004)[63]	1		0
DeSouza (2004)[64]	1	B2	0

Citation index, grading of classifications according to Bernstein (see text for explanation), and correlation with outcome.
0: Insufficient data to correlate classification with outcome.
+: Definitive correlation with outcome (at least two manuscripts).
+/-: Possible correlation; correlation with outcome in one manuscript.
-: No correlation with outcome found (at least two manuscripts).

Table 4.	Interobserver reliability (Kappa) and agreement statistics (N = 90 calcaneal fracture cases)			
Classification	**Essex-Lopresti**	**Crosby**	**Sanders -**	**Sanders +**
Traumatologists				
Kappa mean ± SEM	0.48 ± 0.04	0.50 ± 0.05	0.46 ± 0.05	0.52 ± 0.04
Perfect agreement	7 (23.3)	9 (30.0)	10 (33.3)	4 (13.3)
Near perfect agreement	13 (43.3)	12 (40.0)	6 (20.0)	6 (20.0)
Radiologists				
Kappa mean ± SEM	0.15 ± 0.03	0.43 ± 0.04	0.43 ± 0.02	0.30 ± 0.02
Perfect agreement	2 (6.7)	9 (30.0)	10 (33.3)	3 (10.0)
Near perfect agreement	5 (16.7)	6 (20.0)	3 (10.0)	5 (16.7)
Overall				
Kappa mean ± SEM	0.26 ± 0.03	0.48 ± 0.02	0.48 ± 0.02	0.49 ± 0.02

Interobserver reliability and agreement among trauma surgeons and radiologists of the Essex-Lopresti, Crosby and Sanders classification
The number of cases is given, with the percentage between brackets.
Perfect agreement: score was identical for all 6 observers.
Near-perfect agreement: score was identical for 5 out of 6 observers.
Sanders -, classification without subclasses; Sanders +, classification with subclasses.
SEM, standard error of the mean.

(2-sided test, α= 0.05). For the Sanders classification with subclasses, as well as for the Essex-Lopresti and Crosby classifications, the post-hoc power was 100% (2-sided test, α= 0.05).

3a) Facilitating communication (Prevalence of use)

The standard radiographic classification system described by Essex-Lopresti was used 66 times (prevalence = 66/623 = 10.6%), whereas the CT scan classification systems described by Sanders, Zwipp, and Crosby were used 75 (prevalence = 75/623 = 12%), 18 (prevalence = 18/623 = 2.9%), and 12 (prevalence = 12/623 = 1.9%) times, respectively (Table 2 and 3).

3b) Classification-based guidance of treatment

To ascertain the relation of the classification system to treatment, the Bernstein grading system was determined for all conventional radiographic classifications (Table 2). A Bernstein grade B-2 or C was found for 2 and 12 standard radiographic classification systems, respectively. For 5 standard radiographic classifications, data were too limited to determine the Bernstein grade. In the group of CT-based classifications, there was one Bernstein grade B-1, five B-2, and three grade C classification systems identified (Table 3). For six of the CT-based classifications, insufficient data were available to grade the system.

3c) Association of classifications with patient outcome

Only the Essex-Lopresti classification showed a correlation with outcome, and this was observed in several studies that considered conventional radiographic classifications (Table 2).

Three CT scan classifications showed a positive correlation with outcome, namely the Zwipp, Crosby, and Sanders systems (Table 3).

DISCUSSION

There is no uniform protocol for the radiographic evaluation of calcaneal fractures, and the large variety of classification systems, in general, renders it difficult to compare the results of different studies. The aim of the current investigation was to evaluate the currently available classification systems for intra-articular calcaneal fractures, and to determine their usefulness.

A total of 49 conventional fracture classification systems, as well as and 15 CT scan classification systems, were identified. Average kappa statistic values were 0.26 for the Essex-Lopresti, 0.48 for the Crosby, and 0.48 for the Sanders classifications, indicative of only moderate agreement between there three calcaneal fracture classification systems.

The most frequently cited classifications were those described by Essex-Lopresti, Zwipp, Crosby, and Sanders. No classification showed a direct correlation with the choice of treatment, and the CT-based classification systems showed improved correlation with treatment in comparison with classification systems predicted on conventional radiographs. Interestingly, three of these four classifications were also highly correlated with outcome in a previously reported large, randomised controlled trial.[65]

The kappa statistics calculated in the current study concur with those previously published in the literature.[4,15,17,18] Kappa statistics for the Sanders classification without subgroups ranged from 0.33 to 0.55, despite substantial differences in research methodology between the different publications.[4,15,17,18] When subgroups were included in the Sanders system, the kappa statistics ranged from 0.32 to 0.56.[4,15,17,18] Post hoc power calculations indicated that the number of radiographs (sample size), and the number of observers, was sufficient to determine interobserver reliability at the 5% level of statistical significance. In one previously reported investigation, the kappa statistic for the Crosby classification system was 0.63[15], whereas the overall interobserver agreement was moderate for the Sanders and Crosby classification and fair for the Essex-Lopresti classification. This level of agreement is found for most radiological classifications in the foot and ankle trauma realm.[66]

In our investigation, the kappa values were lower for radiologists when compared with those for the trauma surgeons. Earlier studies have shown that level of experience of the observers, and the complexity of the classification system, do not usually affect interobserver reliability.[4] One other previously published study, investigating fractures of the acetabulum, found a higher classification agreement among surgeons in comparison with radiologists.[67] An explanation for this observation might be related to the experience of surgeons with three-dimensional views of the different fracture patterns gained during open reduction and internal fixation operations. Less familiarity with the classification systems among radiologists may also provide further explanation of the observed differences in inter-rater agreement.

The classification systems that stand out because of their prevalence in the literature seem to show prognostic value in regard to outcome.[12-14,65,68] However, most of the correlations were found in small studies and may actually be more because of chance than to a definite interaction, thus making the results more difficult to interpret than correlations observed for larger series. Study populations of over 100 patients were encountered in only a few studies, and this seems to be relatively common in the foot and ankle surgical literature. A large study (n = 309 patients) found a trend for the Essex-Lopresti, Crosby and Sanders classifications in terms of prognostic value.[65]

The current study was not intended to validate any of the existing calcaneal fracture classification systems, nor was it designed to test the accuracy of these systems. Instead, this study was designed to compare the interobserver variability, and the correlation with treatment prognosis, for the most prevalent calcaneal fracture classification systems. Although useful in this study as an evaluation tool, the Bernstein classification and the scoring system for outcome-correlation have not yet been shown to produce valid information and, as such, could threaten the validity of our conclusions. To develop a validated classification system for calcaneal fractures, a 3-phase construction process would be required as postulated by Audige et al.[69] The development process would entail reliability testing for inter-rater and intra-rater agreement, construct validity testing, and factor analysis. Because none of the classifications that we identified in the literature has been shown, by means of reliability testing, to produce valid information, this probably explains why we measured only moderate interobserver reliability and poor correlation between the classification systems and treatment and outcome.

In conclusion, a large number of classification systems exist for calcaneal fractures, and interobserver reliability is, at best, only moderate for most prevalent classifications. Moreover, the most prevalent classifications show no direct correlation with treatment; however, they do tend to correlate with outcome. In effect, none of the classification systems available at present meet all of the criteria required for an ideal classification system.

Considering the numerous classifications that exist in the literature at present, those by Crosby and Sanders appear to be the most prevalent and best suited for clinical practice and for research purposes. These systems of classification of calcaneal fractures showed moderate interobserver agreement amongst surgeons, and they displayed an acceptable correlation with outcome.

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Chapter 5

Radiographic evaluation of calcaneal fractures; To measure or not to measure

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ABSTRACT

Objective

The aim of this study was to correlate the functional outcome after treatment for displaced intra-articular calcaneal fracture with plain radiography.

Design The design was a prognostic study of a retrospective cohort with concurrent follow-up.

Patients

A total of 33 patients with a unilateral calcaneal fracture and a minimum follow-up of 13 months participated. Patients filled in three disease-specific questionnaires, graded their satisfaction, and the indication for an arthrodesis was noted. Standardised radiographs were made of the previously injured side and the normal (control) side. Different angles and distances were measured on these radiographs and compared with values described in the literature. The differences in values in angles and distances between the injured and uninjured (control) foot were correlated with the outcome of the questionnaires, and the indication for an arthrodesis.

Results

None of the angles correlated with the disease-specific outcome scores. Of the angles only the tibiotalar angle correlated with the VAS (r=0.35, p=0.045) and only the absolute foot height correlated with the indication for an arthrodesis (odds=0.70, CI=0.50–0.99).

Conclusions

In this study the radiographic evaluation correlated poorly with the final outcome. Measurements on plain radiographs seem not to be useful in determining outcome after intra-articular calcaneal fractures.

INTRODUCTION

The evaluation of calcaneal fractures and determination of the effect of treatment traditionally relies on three pillars, consisting of standardised questionnaires, physical examination and the use of radiographs in various projections. The standard lateral and axial views and the axial according to Harris (posterior oblique image) are well known. Less well known are the oblique views by Brodén[1], Isherwood[2], and Anthonsen[3]. These have proved useful in visualising the extent of the fracture lines in the posterior facet after trauma, but almost all have been replaced by computed tomography (CT) in the last two decades.[4] After the implementation of CT scanning the usefulness of the standard radiographic projections was questioned, for example the need for an axial view.[5] Besides the different plain radiographic projections, various angles and distances were determined in the lateral and axial view. The value of radiography at follow-up has been a point of discussion for some time. As early as 1955 Maxfield and McDermott[6] concluded that the anatomy as seen radiographically did not correlate well with functional results and the point of view that radiography is of limited value in the evaluation of outcome is shared by several authors.[7-9] In contrast, the plain radiograph is more readily available and reduces the risks of radiation significantly. The present study was conducted to investigate the usefulness of plain radiography in determining the outcome of treatment compared with different disease-specific outcome scores in the follow-up of patients with an intra-articular calcaneal fracture.

MATERIAL AND METHODS

Patients with a unilateral intra-articular calcaneal fracture treated between 1998 and 2004 were informed about the study, following approval of the Internal Reviewing Board (IRB). Excluded prior to the study were patients who had deceased (n=2), emigrated (n=4), no known address (n=5), a bilateral fracture (n=9) or who had an arthrodesis performed (n=5). All patients were treated using the percutaneous distraction technique by Forgon and Zadravecz[10], which was introduced in our institute in 1998, and had a minimum follow-up of at least 13 months.

Outcome measurement

At follow-up patients were invited to the outpatient clinic and were asked to complete the Maryland Foot Score (MFS), the Creighton-Nebraska score (CN) and the American Orthopaedic Foot and Ankle Society Hindfoot score (AOFAS) questionnaires.[11-13] The MFS, CN and AOFAS scores are disease-specific outcome scores consisting of 9, 7 and 10 individual items respectively and have a range of 0 points minimum and 100 points maximum each.

In addition to the three different outcome scores, patient satisfaction was assessed on a single question Visual Analogue Scale (VAS) analysed on a scale of 100 millimetres (mm). Zero millimetres represented the worst possible outcome and 100 mm was scored if patient satisfaction was excellent. The single question VAS is part of the multiple question VAS as proposed by Hildebrand et al., who found good correlation between the VAS and the disease-specific outcome score by Rowe as well as with the Short Form-36.[14] The range of motion of both ankles and subtalar joints was measured as part of the different outcome scores.

Radiographic technique

Plain radiographs were taken of both feet in exactly the same fashion: a weight-bearing lateral view and an axial view. The film focus distance (FFD) was 105 cm in all cases. All distances from foot to camera and all settings were kept the same. In these radiographs different angles and distances were measured with a hand-held goniometer by two independent observers (TS, AG), and each set of two values was averaged. Any measurement discrepancy of more than 5° was settled by consensus. The angles were compared with reference values as mentioned in the literature.

The angles measured were: Böhler's tuber angle, Gissane's crucial angle, the calcaneal inclination angle, the talar declination angle, the tibiotalar, the talocalcaneal and the tibiocalcaneal angle (Figure 1). The distances measured were: the calcaneal width, the calcaneal facet height, the absolute foot height and the calcaneal length (Figure 1). In contrast to the angles above there are no reference values for length, height and width measurements. These have to be compared with the contralateral healthy side.

All angles and distances measured are shown in Figure 1.

Böhler's tuber joint angle by (Angle A) is measured using the highest points of the calcaneal tuberosity, the subtalar joint and the anterior process and is taken as a relative measurement of the degree of compression and deformity in calcaneal fractures.

The *crucial angle*, as described by Gissane (Angle B), is the angle formed by the posterior facet and the line from the calcaneal sulcus to the tip of the anterior process of the calcaneus.

The *calcaneal inclination* or calcaneal pitch angle (Angle C) is formed by the line connecting the most inferior part of the tuberosity of the calcaneus to the most distal and inferior part of the calcaneus along the calcaneocuboid joint (calcaneal axis) and the plane of support, which is defined by the line connecting the most inferior part of the calcaneal tuberosity with the most inferior part point of the fifth metatarsal head.[15-17]

The *lateral talocalcaneal angle* is formed by the calcaneal axis and the collum tali axis (Angle D). This angle is a measure of the hindfoot alignment. The angle decreases when there is varus angulation of the hindfoot or when the foot is in dorsiflexion. The talocalcaneal angle increases with valgus or plantar flexion.[18] There are two ways of measuring this angle (depending on which line is to be chosen as the calcaneal axis). Some authors use the centre line of the calcaneus as axis.[16,19] Others use the line formed by the most inferior part of the calcaneal tuberosity and the most inferior point of the calcaneocuboid joint.[15,17] The latter is less likely to be affected by inter-observer variability, because of the use of fixed points, and was used in the current study.

The *tibiotalar angle* (Angle E) on the lateral radiograph is formed by the axis of the tibia and the axis of the talus.

The *tibiocalcaneal angle* (Angle F) is formed by the axis of the tibia and the axis of the calcaneus. The angle increases with plantar flexion and subsequently decreases with dorsal flexion of the foot.[18]

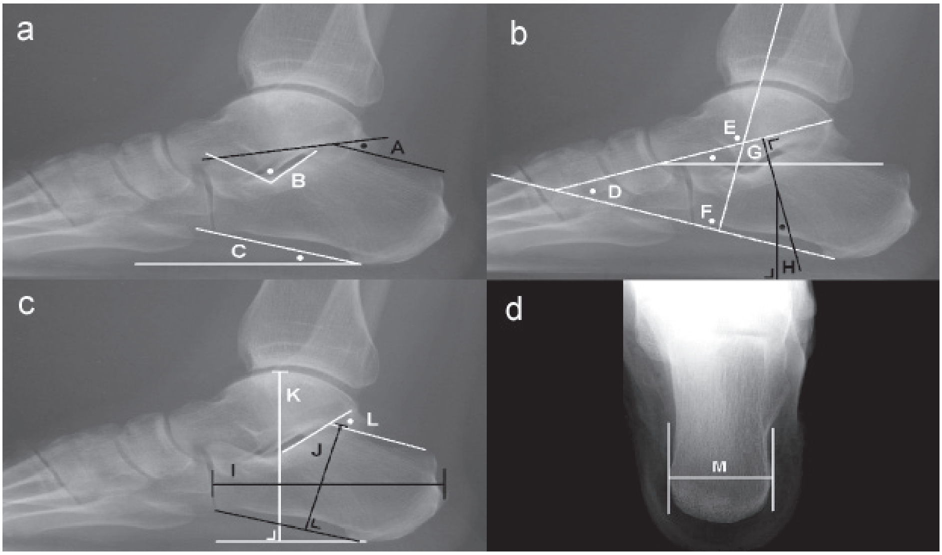

Figure 1. Graphical representation of measurement of different angles and distances (for explanation see Material and methods). a–c Weight-bearing lateral view. A Böhler's angle; B Gissane's angle; C calcaneal inclination angle; D talocalcaneal angle; E tibiotalar angle; F tibiocalcaneal angle; G talarhorizontal angle; H talar declination angle; I length of calcaneus; J calcaneal facet height; K absolute foot height; L facet inclination angle. d Axial view. M width of calcaneus

The *talar declination angle* (Angle H) is formed by the intersection of perpendicular lines drawn from the axis of the collum tali, which bisects the head and neck of the talus, and the plane of support. This line is essentially the same as the horizontal angle of the talus (Angle G), as described by Vanderwilde, and quantifies the anterior tibiotalar impingement according to Quill.[18]

The *posterior facet inclination* (Angle L), as described by Sarrafian, is the angle formed by the two intersecting lines drawn along the surface of the posterior facet and along the upper surface of the calcaneal tuberosity.

The *length* of the calcaneus (Distance I) is measured on the lateral view from the most posterior point of the tuberositas to the calcaneocuboid joint.

The *height* of the posterior facet (Distance J), as described by Leung et al., is measured by a line perpendicular on the calcaneal axis to the highest point of the posterior facet.[20]

The *absolute foot height* or talocalcaneal height (Distance K) is measured from the plane of support to the upper point of the talus.[19]

The *width* of the calcaneus (Distance M) is measured on the axial view, as described by Böhler, or on the Harris-Beath projection.[20-22]

Statistical analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) version 11.0 (SPSS, Chicago, IL, USA). The Spearman rank correlation coefficient was used for the correlation of ordinally scaled data.

For the dichotomous outcome variable “indication for an arthrodesis (yes/no response)” the odds ratio, including the 95% confident interval (CI), was calculated. Within-patient difference between the injured and the uninjured side were tested using the Wilcoxon signed rank test. Correlations were considered statistically significant with a p value of ≤0.05. An independent statistician performed all analyses.

RESULTS

A total of 33 patients was available at follow-up. The average follow-up was 29 months (range 13–75 months). The average age at trauma was 46 years (range 18–65 years), 76% were male. The right foot was injured in 16 patients and the left foot in 17. Four patients (12%) had an indication for a secondary arthrodesis because of disabling residual pain during follow-up. These patients filled in the questionnaires and had the standardised radiographs taken prior to the operation. The mean outcome scores were: AOFAS 85 points, MFS 80 points and CN 78 points out of 100 points each, and the VAS reached 7 out of 10 points.

Radiographic data

Böhler’s angle According to Böhler, the angle normally ranges from 25 to 40°.[21] One study reported an average angle of 30±6° in 120 patients with a normal radiograph.[23] In this study the average angle measured 16° on the injured side, compared with an average of 32° on the uninjured side.

Gissane’s angle Gissane’s angle varies between 120 and 145° in the literature.[24] In the present study the mean angle was 113° on the uninjured side, and 108° on the injured side.

Facet inclination In the literature, the posterior facet inclination angle measures an average of 65°, with a range of 55–75°.[25] It measured 54° on the injured side and 66 on the uninjured side in the study group.

Tibiotalar angle Vanderwilde found a quite constant mean tibiotalar angle of about 110° on the non-weight-bearing lateral view.[18] Our population showed a normal tibiotalar angle of 105° versus 103 on the injured side.

Talar declination angle Values vary slightly in the literature between 19 and 25°.[15] In the present study it measured 16° on the injured side compared with 20° on the uninjured side.

Calcaneal inclination angle The angle varied between 20 and 30°, according to Bryant et al.[15] In the current study the uninjured side measured 23° and on the injured side 21°.

Talocalcaneal angle The normal range varies between 35 and 50° and between 25 and 45° in the literature.[17,26] However, an even larger range, from 15 to 60°, is mentioned.[18] In our population of unilateral fractures the angle on the uninjured side measured 43° versus 37° on the injured side.

Tibiocalcaneal angle It ranged from 60 to 75° on the nonweight-bearing lateral X-ray in the literature.[18] There was a slight increase in the angle after trauma in this series from 62° on the uninjured side to 65° on the injured side.

Width Width increased from 40 mm on the uninjured side to 46 mm on the injured side.

Facet height On the uninjured normal side it measured 50 mm, whereas it was 47 mm on the injured side.

Absolute foot height The normal value was 81 mm and on the injured side it was 77 mm.

Length The length measured 82 mm on both sides.

All differences in angles between the injured side at follow-up and the uninjured side were significant, except for that of the tibiotalar angle (Table 1). Of the distances measured all differences between the injured and uninjured side were statistically significant, except for the length of the calcaneus (Table 2). When correlating the angle and distance differences with the outcome scores and the VAS, only the tibiotalar angle correlated significantly with the VAS (r=0.35, p=0.045).

When correlating the angles and distances with the indication for an arthrodesis, only a significant correlation with the decrease in absolute foot height was found (odds=0.70, CI=0.50–0.99). The AOFAS, MFS, CN and VAS were significantly related to the indication for an arthrodesis (odds=0.91 [CI=0.83–0.99], 0.93 [CI=0.87–0.99], 0.93 [CI=0.87–0.99], and 0.14 [CI=0.023–0.825] respectively).

Table 1. Differences in calcaneal angles between injured and uninjured feet

Angle	Reference	Uninjured	Injured	p-value
Böhler (degree)	25-40	32 (25 - 40)	16 (-10 - 40)	< 0.001
Gissane (degree)	120-145	108 (90 - 125)	113 (80 - 140)	0.023
Facet inclination (degree)	55-75	66 (51 - 80)	54 (15 - 75)	< 0.001
Tibiotalar (degree)	110	105 (94 - 128)	103 (92 - 110)	0.101
Talar declination (degree)	19-25	20 (15 - 28)	16 (10 - 26)	< 0.001
Calcaneal inclination (degree)	20-30	23 (12 - 33)	21 (13 -29)	0.028
Talocalcaneal (degree)	25-45	43 (32 - 58)	37 (23 -57)	< 0.001
Tibiocalcaneal (degree)	60-75	62 (45 - 81)	65 (35 - 80)	0.011

Normal values as mentioned in the literature on various plain radiographic angles, compared with the mean normal values of uninjured feet and mean follow-up values of injured feet in 33 patients in this study (range). A p value<0.05 indicates a significant difference in angles between the injured and uninjured feet using the Wilcoxon signed rank test.

Table 2. Differences in calcaneal distances between injured and uninjured feet

Size	Uninjured	Injured	p-value
Width (mm)	40 (35 - 46)	46 (37 - 56)	< 0.001
Facet height (mm)	50 (43 - 56)	47 (38 - 58)	0.001
Absolute foot height (mm)	81 (67 - 92)	77 (65 - 90)	< 0.001
Length (mm)	82 (71 - 93)	82 (71 - 92)	0.701

Normal values of various distances as measured on the lateral and axial plain radiographs and mean values of injured feet as measured in 33 patients (range) with a unilateral calcaneal fracture. A p value<0.05 indicates a significant difference in distance between the injured and uninjured feet using the Wilcoxon signed rank test.

DISCUSSION

In this study, only two correlations were found between the measurements on the standardised radiographs and the outcome scores. The tibiotalar angles correlated significantly with the VAS and the absolute foot height correlated significantly with the indication for a secondary arthrodesis. All other angles and distances showed no significant correlation with the outcome. The outcome scores, which consist of clinical items and measurements at physical examination, did correlate significantly with the indication for an arthrodesis. The correlation coefficient between the tibiotalar angle and the VAS was 0.35, indicating a weak correlation, which possibly occurred by chance because of multiple testing.

Weight-bearing radiographs provide a reflection of the structural and functional aspects of the foot, and are therefore frequently used in the pre- and postoperative assessment of conditions of the foot.[15] Bryant showed in his study that repeated measurements on weight-bearing foot radiographs taken on two different occasions have a strong correlation, indicating that weight-bearing foot radiographs can be reliably reproduced.[27] Another study showed that measurements are not significantly affected by slightly different central ray centring points.[23] Three precautions have to be taken into account when making these radiographs: the normal side must be used for comparison; true lateral projections must be used; and the X-ray cassette must be placed on the same side of the foot every time.[28] Several other authors concur that comparison with radiographs of the uninjured side is helpful, especially to determine the normal value for the different angles, like that of Böhler.[29-32]

Böhler's angle and Gissane's angle, as measured on the lateral radiograph of the calcaneus, are the most frequently assessed angles in the evaluation of calcaneal fractures. They can give some idea of the severity of the injury, but cannot clearly delineate the location and extent of the lesion.[11] Many authors use different reference values, as mentioned above. Several studies found correlations with the outcome and measurements of Böhler's angle, usually with extremes of Böhler's angle or when division of Böhler's angle into three groups was applied ("less than zero degrees", "zero to 15°" and "16° or higher").[33-36] Frequently, there is no correlation between the angle and functional results of treatment.[9,11,37,38] Correlations between the crucial angle, as described by Gissane, and the final outcome were never found.[11,20,37]

The angles and distances measured in the current study give an adequate comparison of bone anatomy between the two feet, but do not take into account the condition of the posterior facet. Earlier studies graded osteoarthritis and the postoperative step-off in the posterior talocalcaneal facet, but their correlation with outcome is unclear.[20,35] The grading of osteoarthritis and postoperative step-off is difficult and most likely prone to interobserver variability. Second, Letournel stated that plain radiographs are not successful in the assessment of the posterior facet at follow-up.[8] This is in concordance with earlier findings. In their study of freshly amputated lower extremities, in which the bony landmarks were marked with lead wires, Shereff and Johnson showed that only the central third of the posterior subtalar joint could be visualised on the lateral projection and the axial view showed only the anterior third.[39] To overcome this problem various radiographic angles were defined; each showing a different part of the articulating surfaces of the calcaneus.[1-3,22] Still, the tarsal bones superimpose and the articular surfaces can be extremely difficult to assess.[40] Also, the problem of reproducing the highly specialised projections makes evaluating the calcaneus, especially after a fracture, difficult and time-consuming.[2]

In 1975, Soeur and Remy stated that the use of CT scanning had not been proven useful and was not recommended.[31] CT became increasingly available in the early 1980s and was used to visualise hindfoot pathology, especially calcaneal fractures. This brought about important change in the understanding of complex intraarticular calcaneal fractures.[4] Nowadays, fast multislice CT scanning with multiplanar reconstructions, is considered the preoperative imaging modality of choice. Only a few retrospective studies show a correlation between the condition of the posterior facet, as seen on CT, before and after surgical treatment and final outcome.[13,41] However, it remains unclear whether or not it is also a more appropriate tool for assessment at follow-up.[42]

CONCLUSION

Of the traditional three pillars on which the evaluation of outcome after treatment of intra-articular calcaneal fractures rests, outcome scores, physical examination and plain radiography, the latter appears to give very little information concerning the outcome of treatment. It is useful in determining fracture healing, alignment and the restoration of anatomy as aimed for by operation. For the actual measurement of outcome physical and clinical evaluations remain the most important tools. The role of CT assessment at follow-up has to be further investigated.

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Chapter 6

Clinical outcome scoring of calcaneal fracture treatment

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ABSTRACT

Objectives

Outcome reporting of intra-articular calcaneal fractures is inconsistent. This study aimed to identify the most cited outcome scores in the literature and to analyze their reliability and validity.

Methods

A systematic literature search identified 34 different outcome scores. The most cited outcome score was the American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot score, followed by the Maryland Foot Score (MFS) and the Creighton-Nebraska score (CN). Reliability (internal consistency) and validity (content, construct, and criterion) were determined for the 3 outcome scoring systems.

Results

Internal consistency (Cronbach's alpha, reliability) was similar for the Maryland Foot Score ($\alpha = 0.82$) and American Orthopaedic Foot and Ankle Society hindfoot score ($\alpha = 0.78$), but lower for the Creighton-Nebraska ($\alpha = 0.61$). Floor and ceiling effects were good for all 3 scores. The individual items within these outcome scores showing best content validity were pain, return to work, subtalar range of motion, walking distance, ankle range of motion, and gait abnormalities or limping. Construct validity was good for all individual items except sagittal motion, stability at physical exam, and shoe size. The 3 outcome scores showed high correlation with patient satisfaction as measured with a visual analogue scale (VAS, criterion validity) and indication for an arthrodesis.

Conclusion

In conclusion, pending consensus, we would recommend choosing between the widely accepted, reliable and valid AOFAS hindfoot and the Maryland Foot Score as the scoring systems of choice.

INTRODUCTION

Outcome reporting in randomized controlled trials and meta-analysis of intra-articular calcaneal fractures is inconsistent. A variety of different outcome scores are used by different research groups.[1-3] Consensus on one outcome scoring system for the assessment of outcome in displaced intra-articular calcaneal fractures would aid in the comparison of results of multiple studies with comparable methodologies, and combining different smaller prospective trials into a meta-analysis.[4,5] Patient-based outcome scores can be divided into 2 groups. The first group consists of the generic instruments such as the Short Form 36, Visual Analogue Scales, and other quality-of-life scores, which look at a wide variety of general health issues.[6,7] The second group consists of disease-specific instruments, which focus on patient perception of one specific condition, for example calcaneal fractures.[6]

Prior to implementation, scoring systems should be tested for reliability (eg, internal consistency, test-retest, intraobserver and inter-observer agreement), validity (eg, content, construct, and criterion), and responsiveness.[8,9]

Few scoring systems in foot and ankle surgery have been tested for reliability and validity after they were developed.[8] The aim of this study was first to identify widely accepted outcome scores used in intra-articular calcaneal fractures in the literature and their individual items. The reliability (internal consistency) and validity (content, construct, and criterion) of 3 most cited outcome scoring systems was then determined in a cohort of patients with a displaced intra-articular calcaneal fracture.

PATIENTS AND METHODS

Literature Search

A literature search was conducted in the electronic databases of Embase, Cochrane Library, and PubMed using the following search-terms and Boolean operators: "calcaneus" OR "os calcis" OR "calcaneum" OR "calcaneal" AND "fracture" up to December 2006. Articles were requested at the university medical (Internet) library and were reviewed by two authors (T.S. and M.J.H.). An article was found eligible when it concerned the treatment of patients with intra-articular calcaneal fractures. Additionally, a comprehensive search of reference lists of published articles and review articles was conducted to find additional studies. The applied outcome scoring systems were extracted from all these articles. In determining reliability and validity we restricted the next analysis to the 3 most frequently cited widely accepted outcome scores.

Patients

After exclusion of patients (25%) who had died (n = 2), emigrated (n = 4), had an unknown address (n = 5), and those who already had a secondary arthrodesis performed (n = 5), a total of 48 patients with 59 displaced intraarticular fractures of the posterior facet of the calcaneus were surgically treated in our level-1 trauma center from January 1999 to December 2004. Patients who responded for clinical interview and examination, after acknowledging understanding of the Institutional Review Board (IRB) agreement and granting informed consent to participation in clinical research, had a mean follow-up of 34 months (range 13 to 75 months). The median age was 49±13 years at trauma, and 72% were male. According to the Sanders classification[10] there were 23 type II, 18 type III, and 18 type IV fractures. The percutaneous reduction and fixation, modified from Forgon and Zadravecz[11], was the only surgical approach for displaced intra-articular calcaneal fractures used in our hospital. This technique relies on the principle of a triangular distracting force between the talar neck, the calcaneal tuber and the cuboid, followed by percutaneous screw fixation. All of the patients were asked to complete the American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot score, the Maryland Foot Score (MFS), and the Creighton-Nebraska score (CN), each of which have a range of 0 to 100 points. Patients with bilateral fractures were instructed to report on the side with the least satisfactory result.[11] In addition to the 3 different outcome scores, patient satisfaction with the overall outcome was assessed with a single-question 100-mm visual analogue scale (VAS).[12] Zero mm represented no satisfaction at all, and 100 mm was scored if patient satisfaction was excellent. To our knowledge, there is no consensus or gold standard scoring system used to assess foot and ankle surgery, to date. Correlations between foot-ankle–related outcome scores and the more generic health Medical Outcome Study Short Form-36 show moderate coefficients.[13,14] We therefore chose to use the single-question VAS to measure overall patient satisfaction with treatment results, which has been shown to convey a moderate correlation with the SF-36 and a good correlation with the disease-specific outcome (Rowe) score in patients with a calcaneal fracture.[12,15]

Statistical Analysis

The statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) version 12.0 (SPSS, Chicago, IL). Correlations were considered statistically significant if the *P* value was 0.05 or less.

Reliability

To determine the reliability of the 3 outcome scoring systems, the internal consistency, represented by Cronbach's alpha, was calculated.[9] Cronbach's alpha indicates the extent to which a set of test items measure a single variable like outcome. A Cronbach's alpha of 0.70 to 0.80 is regarded as satisfactory. For clinical application, values up to 0.95 are desirable.[16] Another aspect of reliability is whether the scoring system measures the full range of the disease or complaints.[17] The incidence of minimum (floor; zero points) and maximum (ceiling; 100 points) scores was calculated for all of the used outcome scores. A score with low floor and ceiling effect, below 10%, can differentiate better between patients at the high and low ends of the outcome scoring system.[17]

Validity

Content validity determines if the domain of interest is comprehensively sampled by the items, or questions, in the instrument (ie, scoring system).[18] Two means of determining content validity exist: piloting the instrument with representative respondents, and item selection by expert panels.[19] Therefore, the outcome scores were broken down into their individual items to determine the frequency with which these items were used. The individual items comprising the available outcome scores cited in the literature were selected by expert panels. The most frequently used items were expected to have the largest content validity.

The following 4 items, determined at physical examination, were added because we felt that they were clinically important: the range of motion of the ankle and subtalar joint, heel width (mm) measured from the plantar side at the level of both malleoli, calf circumflex 15 cm beneath the knee joint (in mm), and the ability to walk on heels and toes (yes or no).

Construct validity shows whether the items and outcome score measure what they should measure. All individual scoring items in the 3 most frequently used outcome scores, as well as additional frequently used individual items, were correlated with the total result of the 3 scoring systems and the VAS. The Spearman rank correlation coefficient was used for this "item versus total score correlation."

Criterion validity is the correlation between the developed score and an accepted validated score.[17] The total scores of the scoring systems were correlated with patient satisfaction (VAS) as a measure of criterion validity. The "indication for an arthrodesis" was used as an alternative measure of criterion validity. This indication was defined as a persisting, deteriorating limitation in daily activities due to pain at the level of the subtalar joint, with a positive, pain-relieving effect of a lidocaine injection into the subtalar joint.[20,21] Patients who had already undergone a secondary arthrodesis were deliberately excluded before the study, because of the low reliability of retrospective assessment of the clinical status before the secondary arthrodesis with an outcome scoring system.[22] The odds ratio per unit of the total score with the 95% confidence interval (CI) was calculated for the dichotomous outcome variable "indication for an arthrodesis (yes/no response)." This correlation provides information on the predictive value of the entire score in predicting the secondary arthrodesis. The Spearman rank correlation coefficient was used for testing relationships between the VAS and the total score of the 3 scoring systems and also for the correlation between the 3 scoring systems. To determine paired differences between the 3 most cited scoring systems, the Wilcoxon signed rank test was used.

RESULTS

Literature Search

Of 195 studies related to calcaneal fracture, a total of 34 outcome scoring systems were identified (Table 1). The 3 most frequently cited outcome scores were the AOFAS, the MFS, and the CN score.[10,23,24] A total of 49 different subjective and physical exam items were extracted from 26 outcome scores, yielding a median of 6.5 items per outcome scoring system.

Reliability

The Cronbach's alpha coefficient, as a measure of the internal consistency, was 0.78 for the AOFAS, 0.82 for the MFS, and 0.61 for the CN score. The ceiling score was encountered in 8%

for the AOFAS and the CN scores, 0% for the MFS, and 13% for the VAS. The floor effect was seen in 0% for the disease-specific scores and in 2% for the VAS.

Table 1. Outcome scoring systems used in the literature to determine outcome after treatment for calcaneal fracture

Outcome score	(First) author	Year	Citation
Allan criteria[25]	Allan	1955	2
Maxfield-McDermott criteria[26]	Maxfield	1955	3
Lindsay-Dewar criteria[27]	Lindsay	1958	2
Rowe outcome score[15]	Rowe	1963	7
Nade-Monahan questionnaire[28]	Nade	1973	1
Mignot criteria[11]	Mignot	1975	2
Fayt criteria[29]	Fayt	1978	1
Modified Mazur ankle score[30]	Mazur	1979	3
Noble-McQuillan criteria[31]	Noble	1979	1
Grenoble score[32]	Champetier	1979	1
Mestdagh score[33]	Mestdagh	1984	2
Myerson scoring system[20]	Myerson	1986	1
SO.F.C.O.T. criteria[32]	Simon	1988	4
Zwipp score[34]	Zwipp	1989	9
Creighton-Nebraska[23]	Crosby	1990	19
Bradley disability score[35]	Bradley	1990	1
Melcher-score[36]	Melcher	1991	2
Iowa Calcaneal Score[37]	March	1992	2
Buckley outcome score[38]	Buckley	1992	3
Maryland Foot Score[10]	Sanders	1992	29
Parmar outcome criteria[39]	Parmar	1993	1
Paley-Hall score[40]	Paley	1993	6
Letournel outcome criteria[41]	Letournel	1993	1
Fernandez outcome criteria[42]	Fernandez	1993	1
AOFAS hindfoot score[24]	Kitaoka	1994	51
Modified Merle D'Aubigné hip score[43]	Kundel	1996	10
Calcaneal fracture scoring system[37]	Kerr	1996	12
Functional Outcome Assessment[44]	Thordarson	1996	3
Musculoskeletal Functional Assessment[45]	Martin	1996	1
Oral Analogue Scale (OAS)[46]	Morin	1998	1
Strømsøe rating system[47]	Strømsøe	1998	1
Hannover Scoring System (HSS)[48]	Thermann	1999	2
Mod. Hannover Questionnaire (HQ)[48]	Thermann	1999	2
Kiel Calcaneus Score[49]	Schwall	2000	1

Overview of disease-specific outcome scores developed or used for the evaluation of calcaneal fractures, summarized by year of publication. The first author and citation frequency are mentioned.

Validity

Six items showed good content validity. These items (Figure 1) were pain (encountered in 21 scoring systems), return to work (n = 13), subtalar range of motion (n = 13), walking distance (n = 12), ankle range of motion (n = 10), and gait abnormalities or limping (n = 10). Five of these 6 items are used in the AOFAS and MFS scores, and 4 in the CN score.

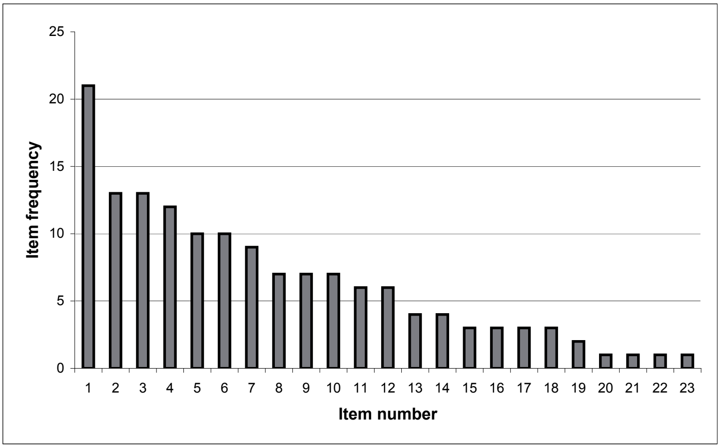

Figure 1. Individual items ranked by frequency with which they were used
The item numbers in this figure correlate with the rank numbers in Table 2, first column.

Table 2. Correlation between individual items and total outcome scores

	Score items (Rank number)	Total outcome score: AOFAS	MFS	CN	VAS
Subjective	Pain (1)	0.90*	0.77*	0.73*	0.61*
	Pain activity (8)	0.90*	0.77*	0.73*	0.61*
	Pain rest (15)	0.50*	0.37*	0.48*	0.31‡
	Activity limitations (11)	0.83*	0.81*	0.70*	0.70*
	Walking distance (4)	0.65*	0.54*	0.60*	0.54*
	Walking surface (9)	0.60*	0.64*	0.57*	0.48*
	Gait abnormality (5)	0.73*	0.77*	0.65*	0.58*
	Climb stairs (17)	ns	0.34‡	0.37*	0.39*
	Cosmesis (23)	0.45*	0.55*	0.37‡	0.34*
	Stability objectively (20)	ns	ns	ns	ns
	Stability subjectively (21)	0.52*	0.61*	0.58*	0.44*
	Shoe type (7)	0.29‡	0.51*	0.30‡	ns
	Shoe size (22)	ns	ns	ns	ns
	Support/aids (12)	0.37*	0.40*	0.40*	0.38*
	Return to work (2)	0.96*	0.56*	0.76*	0.60*
	Swelling (13)	0.46*	0.65*	0.55*	0.62*
Objective	Calf circumference (19)	ns	ns	ns	ns
	Walk on toes (10)	0.45‡	0.42‡	0.36‡	0.41‡
	Walk on heels (16)	ns	ns	ns	ns
	Heel width (18)	ns	ns	ns	ns
	Hindfoot motion (3)	0.40*	ns	0.42*	0.36‡
	Sagittal motion (6)	ns	ns	ns	ns
	Alignment (14)	0.36‡	0.30‡	0.30‡	0.36‡

For item-total score correlations and item-VAS the Spearman rank correlation coefficient is presented. The rank numbers between brackets in the first column correspond with figure 1. VAS, Visual Analogue Scale for patient satisfaction; AOFAS, American Orthopaedic Foot and Ankle Society Hindfoot Score; MFS, Maryland Foot Score; CN, Creighton-Nebraska score; ns, not significant; *, significant at the $p < 0.001$ level; ‡, significant at the $p < 0.05$ level.

A total of 16 items showed construct validity by correlating with all outcome scores and with the VAS. The AOFAS score and the MFS correlated significantly with 16 (70%) items, the CN with a total of 17 (74%) items, and the VAS with 16 (70%) items (Table 2). Items showing no correlation with any of the outcome scores were sagittal plane range of ankle motion, stability at physical exam, shoe size, walking on heels, heel width, and calf diameter. There was a statistically significant correlation between the total scores with the Spearman rank test: between MFS and AOFAS ($r = 0.84$, $P = 0.001$), between CN and AOFAS ($r = 0.84$, $P = 0.001$), and between MFS and CN ($r = 0.79$, $P = 0.001$). The Wilcoxon signed ranks test showed a significantly better outcome measured with the AOFAS score than the MFS ($P = 0.001$) and the CN ($P = 0.001$) scores. The MFS resulted in significantly better outcome than the CN score ($P = 0.027$) per patient. As a measure of criterion validity, all total outcome scores correlated significantly with overall patient satisfaction as measured on the VAS (AOFAS $r = 0.75$, MFS $r = 0.72$, CN $r = 0.76$, $P = 0.001$ in all cases). All total scores also correlated significantly with the indication for an arthrodesis (odds ratio AOFAS = 0.93 [CI: 0.87– 0.99], $P = 0.02$; odds ratio MFS = 0.94 [CI: 0.89–0.99], $P = 0.02$; odds ratio CN = 0.94 [CI: 0.89–0.99], $P = 0.03$).

DISCUSSION

The literature search performed in this study showed a large amount of variation in existing calcaneal fracture outcome scoring systems. None of the available outcome scoring systems was applied in approximately 70% of the articles reviewed. The AOFAS score was cited most frequently and appears to be the most widely accepted scoring system. Even though citation frequency does not necessarily reflect clinical relevance, broad acceptance of a single outcome score would facilitate comparison of multiple studies.[50]

Our search represents a first comprehensive analysis of outcome scoring systems specifically used in determining outcomes associated with calcaneal fractures, identifying 34 outcome scores. A restricted meta-analysis on outcome rating scales in general foot and ankle surgery showed 49 scoring systems, of which 18 were cited more than once.[8] The AOFAS hindfoot score was also the most frequently applied scoring scale. No scoring system in the current literature was identified as being reliable, valid, or responsive.[8] An earlier attempt to identify a rational scoring system combined the 4 most important individual items (pain at rest, pain with activity, return to work, ambulation, and walking aids) of 6 outcome scores (Rowe, CN, Buckley, March, Paley, MFS) into a multiple regression model and found that their Kerr-Atkins score correlated equally good with outcome with only 4 items, suggesting that not all scoring items contribute equally in predicting outcome.[37]

The internal consistency (reliability) of the AOFAS score and the MFS were similarly satisfactory and both scoring systems correlated well with individual subjective and objective patient outcome characteristics. The CN score showed lower internal consistency and appeared to be less suitable as an outcome score for calcaneal fractures. All 3 scores showed good floor and ceiling effects (reliability).

The individual items showing best content validity were pain, return to work, subtalar range of motion, walking distance, ankle range of motion, and gait abnormalities or limping. Most of the individual items correlated with the outcome (construct validity). The AOFAS, MFS, and CN scoring systems had similarly good correlations with patient satisfaction (VAS) and the indication for an arthrodesis (criterion validity). In terms of test-retest reliability, previous research has shown good intra- and interobserver agreement of the AOFAS hindfoot score.[51]

Per patient, the total AOFAS score was significantly higher than the MFS, which scored significantly higher than the CN. This was due to the different weighting of the outcome score items per scoring system. Patients frequently scored low on the important CN item "return to work," which was more heavily weighted in the total CN score compared to the AOFAS score item "activity limitations."

The AOFAS score could therefore underrate the value of returning to a previous level of activity or occupation. In contrast, the internal consistency of the CN score was lower than the internal consistency of the AOFAS score and the MFS.

Other studies have compared the SF-36 with the AOFAS score showing moderate correlations, indicating that a good disease-specific status does not always correlate with good generic health.[13,14] Therefore, the SF-36 might not be the proper score to compare disease-specific scores for calcaneal fractures with. Hildebrand et al.[12] found a significant association between scoring systems and patient satisfaction (VAS) with the overall result. The VAS as designed by Hildebrand et al to determine overall result (satisfaction), showed significant correlation with the SF-36 and the disease-specific outcome score by Rowe with good correlation coefficients (0.7 and 0.8, respectively) in patients treated by open reduction and internal fixation versus patients treated conservatively.[12] The good correlation between the outcome scoring systems and the indication for an arthrodesis suggests that "the indication for an arthrodesis" is a valid clinical end point.

In this study, the calculations for the 3 most frequently applied outcome scoring systems were performed for a cohort of patients that were all treated with the same treatment modality, ie, by percutaneous reduction and fixation. In this way, a more homogeneous group was established. Although this might be considered a limitation, there are no indications that the operative technique used had affected the reliability and validity of the used outcome scoring systems. Both the ceiling and the floor effects showed the use of the entire range of the outcome scores, indicating that all levels of outcome were included in the study.

In summary, the AOFAS hindfoot score is the most applied and cited score of 34 outcome-scoring systems used in calcaneal fractures, followed by the MFS and the CN score. Reliability as measured by the internal consistency was good for the AOFAS score and the MFS. All 3 scores measured the full range of complaints. Six of 23 individual items showed good content validity and 16 items showed good construct validity. In conclusion, during consensus discussion for clinical outcome reporting of intra-articular calcaneal fractures, we would recommend choosing between the widely accepted, reliable and valid AOFAS hindfoot score and the MFS as the scoring systems of choice.

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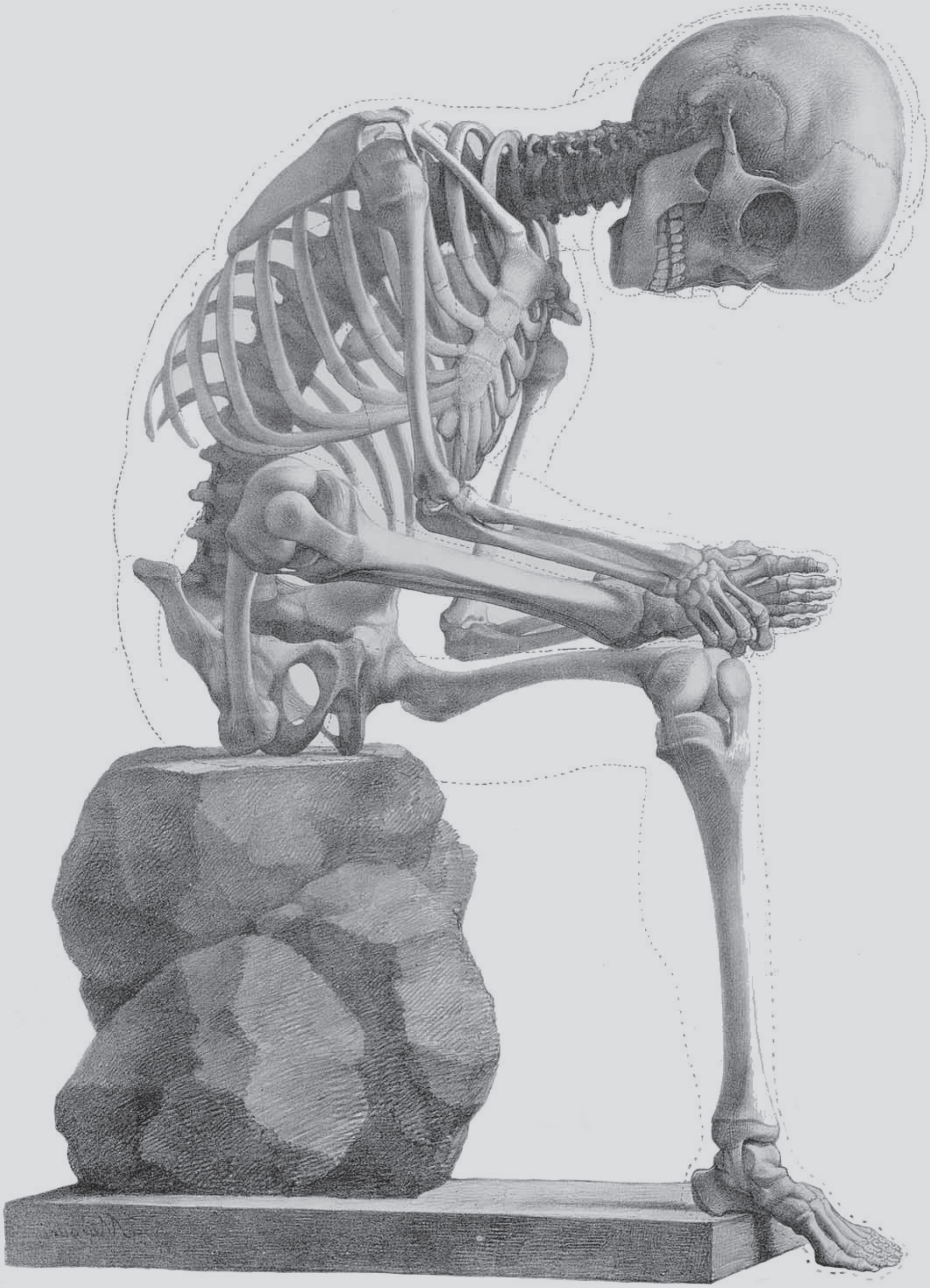
Part 3

Percutaneous treatment of intra-articular calcaneal fractures



Chapter 7

Treatment of displaced intra-articular calcaneal fractures by ligamentotaxis; Current concepts review

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ABSTRACT

Objective

A large variety of therapeutic modalities for calcaneal fractures have been described in the literature. No single treatment modality for displaced intra-articular calcaneal fractures has proven superior over the other. This review describes and compares the different percutaneous distractional approaches for intra-articular calcaneal fractures. The history, technique, anatomical and fracture considerations, limitations and the results of different distractional approaches reported in the literature are reviewed.

Method

Literature review on different percutaneous distractional approaches for displaced intra-articular calcaneal fractures.

Results

Eight studies in which application of a distraction technique was used for the treatment of calcaneal fractures were identified. Because of the use of different classification, techniques, and outcome scoring systems, a meta-analysis was not possible. A literature review reveals overall fair to poor result in 10 to 29% of patients. Ten up to 26% of patients is unable to return to work after percutaneous treatment of their fracture. A secondary arthrodesis has to be performed in 2 to 15% of the cases. Infectious complications occur in 2 to 15%. Some loss of reduction is reported in 4 to 67%.

Conclusion

Percutaneous distractional reduction and fixation appears to be a save technique with overall good results and an acceptable complication rate, compared with other treatment modalities for displaced intra-articular calcaneal fractures. A meta-analysis, based on Cochrane Library criteria, is not possible, because of a lack of level 1 and 2 trials on this subject.

INTRODUCTION

For many centuries the treatment of calcaneal fractures has been non-operative and included bandaging and elevation of the foot. The earliest published surgical attempts to reduce displaced fragments of a fractured calcaneus was by means of a pulley device, described by Clark in 1855.[1-3] The first open reduction took place in a open fracture by Bell in 1882[4] and the first open reduction and internal fixation (ORIF) by a lateral approach was performed by Morestin in 1902.[5]

In 1895 the radiographic visualization of fractures was introduced and many different treatment modalities, approaches and salvage procedures have been published since that time.[4] The minimal invasive techniques for the treatment of intra-articular calcaneal fractures have evolved from 1855 to present, but gained less popularity compared with ORIF. Minimal invasive surgery of calcaneal fractures can be divided into percutaneous reduction of fragments by Kirschner-wire leveraging[5-8], application of external fixators[9-11], and percutaneous distraction of displaced fragments, thus applying the principle of ligamentotaxis with subsequent percutaneous screw fixation.[12,13]

This literature review deals with the treatment of displaced intra-articular calcaneal fractures (DIACF) by percutaneous distraction and screw fixation. The history of different distractional approaches reported in the literature is described, including a technical description, the anatomical and fracture considerations, their limitations, and the clinical outcome obtained.

HISTORY

The first skeletal traction applied for the reduction of a displaced calcaneal fracture was reported by Clark in 1855.[1] He described a pulley system, but did not elaborate on this method further. Since then, several techniques and traction-devices were developed and applied in the treatment of DIACFs. In the early decades of the twentieth century the distraction methods were applied and were the most widely accepted treatment modality for displaced intra-articular calcaneal fractures.[14]

The different distraction techniques can be divided into single-, two- and three-point distraction, using the number of inserted pins as points of skeletal distraction as common denominator.

Single-point distraction

Various authors described different single-point distraction techniques (Figure 1). Some used the distraction as the only treatment [4,15], while others used it to assist the reduction by additional interventions.[4,15-21]

Two-point (linear) distraction

In 1929 Böhler described the technique of closed reduction with a wooden wedge in the footsole, lateral clamp compression and traction on the calcaneus with countertraction

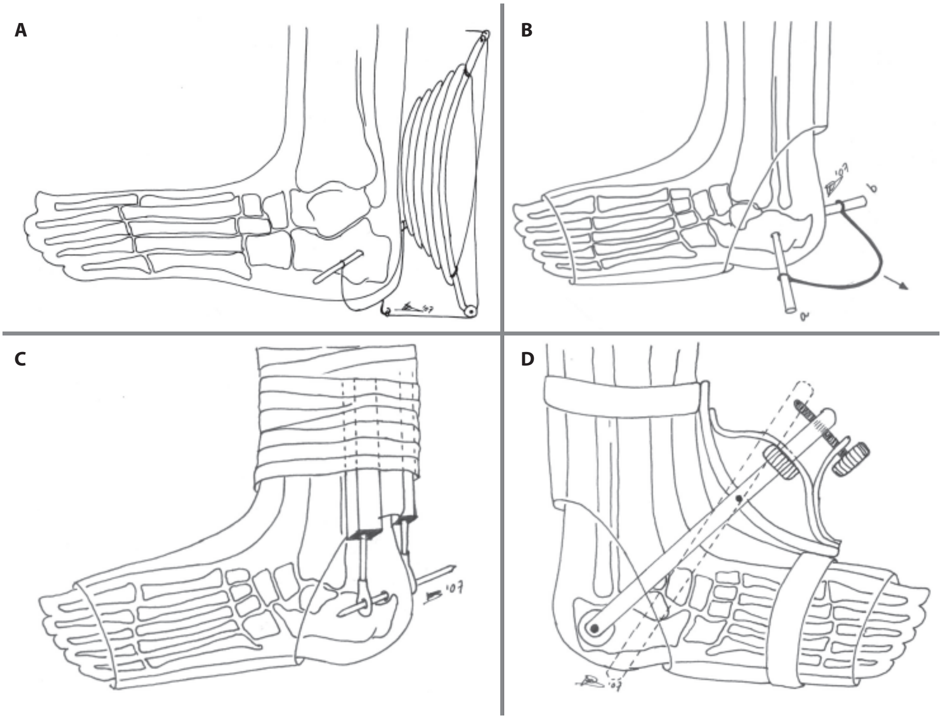

Figure 1. Single-point distraction techniques by Foldes [4] (1920; panel A), Kaess [4] (1922; panel B), Gillette [17] (1930; Panel C), and Carabba [16] (1936; panel D)

on the tibia.[22,23] Böhler changed this treatment strategy for calcaneal fractures repeatedly, and stopped using the transfixational pin through the tibia because of infectious complications.[4,13,22-24] Several authors applied the method used by Böhler completely or with (minor) modifications using specially designed traction-devices (Figure 2).[4,14,25-30]

Three-point (triangular) distraction

Three-point distraction was first introduced by McBride (1944)[31], followed by others.[32,33] These triangular distraction methods were combined and formed the technique described by Forgon and Zadravecz (1983).[34,35] This is currently one of the most frequently applied distraction techniques.[36-38] The three-point distraction approaches used nowadays differ in the direction of applied traction (Figure 3).[31-33,36-39]

BIOMECHANICAL CONSIDERATIONS

The subtalar joint is surrounded by a strong joint capsule and numerous ligaments, which stabilize the subtalar and ankle joint. The ligaments used in ligamentotaxis between the ankle joint, talus, and calcaneus are the calcaneofibular, the tibiocalcaneal ligament of the deltoid ligament, the talocalcaneal interosseous ligament, cervical and the anterior, lateral, posterior, and medial talocalcaneal ligaments. The plantar and dorsal calcaneonavicular liga-

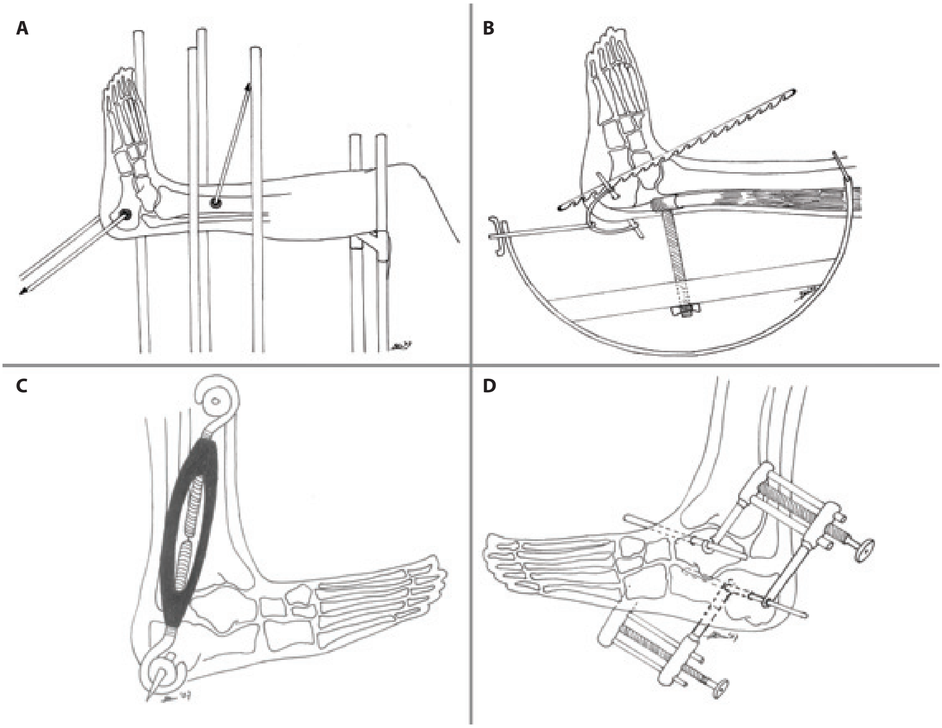

Figure 2. Two-point distraction techniques by Böhler[23] (1929; panel A), Conn[27] (1935; panel B), Olson[28] (1939; panel C), and Fröhlich[30] (1999; panel D)

ment and the calcaneonavicular portion of the bifurcate ligament are situated between the calcaneus and the navicular bone. The cuboid and calcaneus are connected by the dorsal calcaneocuboid ligament, the short and long plantar ligament, and the calcaneocuboid portion of the bifurcate ligament.

Ligamentotaxis, the indirect reposition of displaced osseous fragments through distraction on the ligaments attached to these fragments, restores the height of the posterior talocalcaneal joint and reduces the varus/valgus malalignment as well as the width of the calcaneal tuberosity. The lateral joint-fragment usually remains depressed, because the fracture lines run laterally to the interosseous ligament.[40,41] This fragment needs to be lifted upwards using Kirschner-wire leveraging or a bone-punch inserted plantarly via the primary fracture line to restore the joint congruence.[15]

It has been suggested that only Sanders type II DIACFs would benefit from distractional surgery, but the same has been said for severely comminuted calcaneal fractures, as anatomical reposition would be impossible even when using ORIF.[13,32] The main benefit of percutaneous reduction and fixation is the protective nature of the technique towards the soft tissues. Only small stab incisions are made in the skin and the fracture hematoma is left in place, thus enhancing fracture healing.[42]

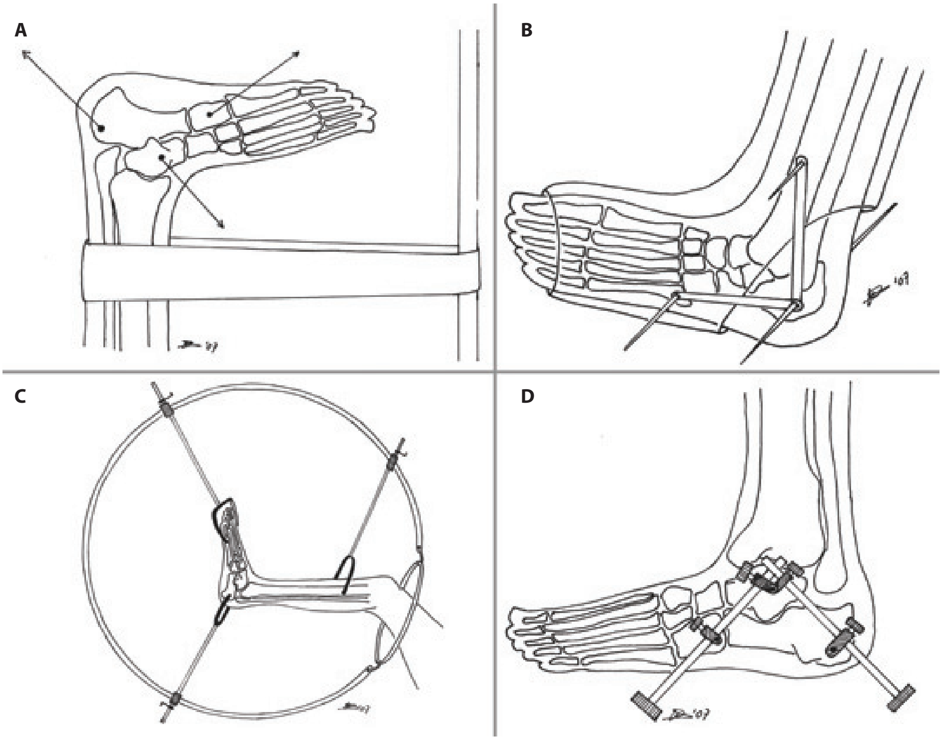

Figure 3. Three-point distraction techniques by Gill[32] (1944; panel A), McBride[31] (1944; panel B), Harris[33] (1946; panel C), and Forgon-Zadravecz[34] (1983; panel D)

TECHNIQUE

Depending upon the distraction technique used, one to three Kirschner wires or Steinmann pins are inserted. The universal location, which is always used, is through the calcaneal tuberosity. Additional insertion sites are, depending on the applied technique: the tibia, the talar trochlea, the cuboid, or the metatarsal bones. A distracting force is exerted from one distraction point or between two or three distraction points to reproduce the opposite force produced by the impact that caused the fracture. This procedure restores the arch of the foot and realigns the hindfoot, thereby restoring height and width, and reducing varus of the calcaneus.

Additional operative procedures to achieve reduction of fragments and to restore calcaneal anatomy include the Böhler press or clamp to reduce calcaneal widening and subsequent occurrence of impingement beneath the lateral malleolus.[23,25-27,29] Kirschner wires are used for additional leveraging of depressed fragments, especially the lateral joint fragment.[15,19-21,34,43] A bone punch to unlock and lift up these fragments is preferred by others.[15,37,38] Percutaneous insertion of bone graft has been used, but no additional benefit was reported.[15]

In order to improve the rate of anatomical fracture reduction, and therefore the overall outcome, several improvements have recently been implemented. The mobile C-arm system SIREMOBIL Iso-C3D enables intraoperative three-dimensional reconstructions of fracture reduction of the joint-surfaces. This was shown to be of value in ORIF of calcaneal fractures.[44] The same holds true for the intra-operative mobile CT-scanning.[45] The use of peroperative subtalar arthroscopy has been applied to obtain anatomic restoration of the posterior talocalcaneal joint, with a positive effect on outcome in retrospective series.[46-50]

LIMITATIONS AND COMPLICATIONS

Several concerns regarding the effectiveness of distraction techniques have been reported.[29,51,52] These include poor results in general, non-anatomical reduction, infectious complications, and loss of reduction.

Poor results in general

Bankart reported clinically poor results using Böhler's technique, probably because of the three months immobilization in plaster, which resulted in a stiff ankle joint.[51] His opinion was shared by others.[52] Currently functional aftertreatment is applied shortly after surgery and outcome appears to be more favorable.[15,30,34,38]

Non-anatomical reduction

No universal treatment or surgical approach exists that can be applied to treat all fractures of the calcaneus.[24] The question remains whether adequate reduction of displaced intra-articular calcaneal fractures is even possible by closed methods.[29] Assessing the reduction on plain radiographs, by measuring the tuber-joint angle by Böhler, does not ensure a proper restoration of the posterior talocalcaneal facet.[27,52,53] As the percutaneous reduction of fractures is indirect, perfect anatomical restoration of the posterior facet anatomy and longitudinal arch of the foot should not be expected.[12,27,54] These effects might be amplified by the decrease in viability of the cartilage.[55]

Infectious complications

The minimally invasive techniques were developed to protect the soft-tissues[12,13,42], but infectious complications do occur in patients treated percutaneously.[38] The later distraction techniques use screws situated subcutaneously rather than transosseous pins, which has resulted in a lower complication rate.[34]

Loss of reduction

Percutaneously placed screws might provide a less rigid fixation of fracture fragments compared with plating, as collapse or loss of the obtained reduction has been reported after percutaneous reduction and subsequent fixation.[15,37,38] One study showed a similar strength of plating versus percutaneous screw fixation in Sanders type 2B fractures.[56]

LITERATURE REVIEW

A literature search was conducted in the electronic databases of Embase, Cochrane Library and PubMed using the following search-terms and Boolean operators: ('calcaneus' OR 'os calcis' OR 'calcaneum' OR 'calcaneal') AND 'fracture' AND ('percutaneous' OR 'minimally invasive') up to November 2008. Manuscripts were reviewed by both authors. Manuscripts were considered eligible if treatment of displaced intra-articular calcaneal fractures by traction was used. In addition, the reference lists of these manuscripts were checked to find additional studies. Studies from 1990 and forward were selected, as these made better use of outcome scoring systems and computed tomography (CT) classifications.

In total, two review articles were identified[12,13], and eight retrospective case series were included.[15,18,21,30,36-39] The level of evidence, as suggested by the Cochrane Collaboration, was level IV (non-randomised series of patients compared with previous or historical controls) for cohort studies.

Considerable differences were found in these eight studies (Table 1).[15,18,21,30,36-39] There is a large variety in the number of treated fractures (15-265 fractures), amount of open fractures, the type of classification used, the severity of the fractures, the average duration of follow-up (12-68 months), and the outcome scoring applied. This makes the comparison of this data in a systematic review impossible.

Table 2 shows an overview of data on outcome and complications as mentioned in the eight studies included. A fair to poor result was seen in 10 to 39% of patients; 26% on average. Ten up to 26% of patients with a calcaneal fracture were unable to return to work. Considering complications encountered; a secondary arthrodesis was performed in 2 to 15%, infections occurred in 2 to 30%, and a loss of reduction was reported in 4 to 67%.[15,21,30,36-39]

To date, no randomized trial comparing the percutaneous distractional technique with ORIF or conservative treatment of intra-articular calcaneal fractures has been reported. In one study, two retrospective series of open and percutaneously treated patients were compared. This study revealed a favorable outcome and low complication rate for the percutaneously treated group.[30]

CONCLUSION

The percutaneous approach with the use of distractional force is the oldest operative treatment for intra-articular calcaneal fractures. A total of eight studies were identified in the literature. Because of large differences in these studies, and the lack of randomized trials in which the percutaneous techniques are evaluated, a meta-analysis was impossible. However, overall treatment outcome was good in most studies. One study showed improved outcome in percutaneously treated patients compared to patients treated with ORIF.

Table 1. Demographics for eight available studies concerning percutaneous distraction techniques

Study (Evidence level)	Trauma	Classification	Surgical treatment	np/nf	Age (years)	Male (%)	FU (months)	Outcome
Walde (2008) [21] Level IV	85% Fall 15% MVA	Sanders 16% Type II 57% Type III 27% Type IV	1-point distraction (tuberosity + K-wire leveraging)	63/67	46 (18-82)	72	68 (24-120)	Zwipp 61% (Very) Good 39% Fair-Poor
Schepers (2007) [38] Level IV	84% Fall 16% MVA	Sanders 38% Type II 28% Type III 28% Type IV	3-point distraction (tuberosity-cuboid, tuberosity- talus + bone-punch)	50/61	46 (16-65)	72	35 (13-75)	AOFAS 36% Excellent 36% Good 28% Fair-Poor
Stulik (2006) [15] Level IV	96% Fall 4% Other	Sanders 61% Type II 30% Type III 9% Type IV	1-point distraction (tuberosity + K-wire leveraging or bone-punch)	176/205	44 (13-67)	85	43 (25-87)	CN 16% Excellent 56% Good 28% Fair-Poor
McGarvey (2006) [18] Level IV	32% Fall 48% MVA 20% other	Sanders 32% Type II 26% Type III 29% Type IV	1-point distraction (tuberosity + bone-punch) External fixation	31/33	42 (19-64)	77	25 (6-55)	AOFAS 66 points (42-92)
Frohlich (1999) [30] Level III	N.S.	N.S.	2-point distraction (talus-tuberosity)	N.S. /94	N.S.	N.S.	N.S.	Mod Merle d'Aubigne 79% Good to excellent
Van Loon (1997) [37] Level IV	73% Fall 7% MVA 20% Other	Crosby-Fitzgibbons 93% Type II 7% Type III	Forgon-Zadravecz 3-point distraction (talus-cuboid, tuberosity- talus)	15/15	44 (21-67)	73	14 (6-26)	CN 27% Excellent 47% Good 26% Fair-Poor
Kuner (1995) [36] Level IV	N.S..	N.S.	3-point distraction (MT1-tuberosity, tibia-tuberosity)	-/45	N.S.	N.S.	N.S.	Merle d'Aubigne 71% Good to excellent
Forgon (1993) [39] Level IV	N.S..	Own classification 30% Type I 40% Type II 30% Type III	3-point distraction (talus-cuboid, tuberosity-talus)	-/265	41	N.S.	12	Own Score 43% Excellent 47% Good 10% Fair-Poor

MVA, motor vehicle accident; np, number of patients; nf, number of fractures; FU, follow-up; CN, Creighton-Nebraska outcome score; AOFAS, American Orthopaedic Foot Ankle Society hindfoot score; N.S., not specified.

Table 2. Outcome and complication rates after treatment of displaced intra-articular calcaneal fractures with percutaneous distraction techniques

Study	Fair/poor result (%)	Unable to work (%)	Loss of reduction (%)	Infection (%)	Arthrodesis (%)
Walde (2008) [21]	39	N.S.	1	13	N.S.
Schepers (2007) [38]	28	10	30	15	15
Stulik (2006) [15]	28	26	4.5	8.7	N.S.
McGarvey (2006) [18]	N.S.	N.S.	N.S.	30	N.S.
Frohlich (1999) [30]	21	N.S.	N.S.	2.1	2.1
Van Loon (1997) [37]	26	N.S.	67	13	N.S.
Kuner (1995) [36]	29	N.S.	N.S.	N.S.	N.S.
Forgon (1993) [39]	10	N.S.	4.1	3.7	N.S.

N.S., not specified.

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Chapter 8

Percutaneous reduction and fixation of intra-articular calcaneal fractures

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ABSTRACT

Objective

Percutaneous reduction by distraction and subsequent percutaneous screw fixation to restore calcaneal and posterior talocalcaneal facet anatomy. The aim of this technique is to improve functional outcome and to diminish the rate of secondary posttraumatic arthrosis compared to conservative treatment and, secondly, to reduce infectious complications compared to open reduction and internal fixation (ORIF).

Indications

Sanders type II–IV displaced intraarticular calcaneal fractures.

Contraindications

Isolated centrally depressed fragment.

Patients who are expected to be noncompliant.

Surgical Technique

Four distractors (Synthes®) are positioned, two on each side of the foot, between the tuberosity of the calcaneus and talus and between the tuberosity and cuboid. A distracting force is given over all four distractors. A blunt drifter is then introduced from the plantar side to unlock and push up any remaining depressed parts of the subtalar joint surface of the calcaneus. The reduction is fixated with two or three screws inserted percutaneously.

Postoperative Management

Directly postoperatively, full active range of motion exercises of the ankle joint can start, with the foot elevated in the 1st postoperative week. Stitches are removed after 14 days. Implant removal is necessary in 50–60% of patients.

Results

Between 1999 and 2004, 59 patients with 71 fractures were treated by percutaneous skeletal triangular distraction and percutaneous fixation. A total of 50 patients with 61 fractures and a minimum follow-up of 1 year were available for follow-up. According to the American Orthopaedic Foot and Ankle Society Hindfoot Score, 72% had a good to excellent result. A secondary subtalar arthrodesis was performed in five patients and planned in four (total 15%). Böhler's angle increased by about 20° postoperatively. Sagittal motion was 90% and subtalar motion 70% compared to the healthy foot.

INTRODUCTORY REMARKS

One of the earliest descriptions of minimally invasive treatment of calcaneal fractures through ligamentotaxis was by Clark in 1855, who described a pulley system to realign the arch of the foot.[1] Restoring calcaneal anatomy by distraction was further developed by Böhler in the late 1920s, and for some time percutaneous repair by traction with or without subsequent screw fixation was the most accepted treatment for intraarticular calcaneal fractures.[2] Later, open reduction through an extended lateral approach and rigid internal fixation with plate osteosynthesis (ORIF) became the standard operative treatment of displaced intraarticular calcaneal fractures. The most feared disadvantage of ORIF is the occurrence of wound complications with infection rates in the literature ranging from 0.4% to 27%.[3-5] Higher percentages of soft-tissue complications are mentioned, but these do not differentiate between wound dehiscence, superficial and deep infections.[4] In the largest randomized controlled trial, 5% deep and 17% superficial wound infections were seen.[6] The soft tissues, damaged by the trauma, determine outcome[7] and infectious complications of treatment are costly.[8] Therefore, special care has to be given to the tissue envelope surrounding the calcaneus. For this reason minimally invasive procedures, with or without guidance of arthroscopy or perioperative (three-dimensional) CT scanning, are re-emerging.[9-12] The three-point distraction technique as described by Forgon & Zadravecz has been used, with minor modifications, at our institute since 1998.[13-15]

SURGICAL PRINCIPLES AND OBJECTIVE

Percutaneous treatment by skeletal distraction and screw fixation of displaced intraarticular fractures of the calcaneus, with functional postoperative after-treatment, in order to reduce the secondary trauma and subsequent complication rates to the soft tissues as seen in the open reduction and fixation techniques.

ADVANTAGES

- Applicable to all types of displaced intraarticular calcaneal fractures, also to severely comminuted fractures.
- Additional damage of soft tissues is avoided; only small stab-wound incisions are necessary.
- Applicable in patients with compromised soft tissues and/or comorbidity like diabetes.
- Distraction pins are not left in place lowering the risk of infectious complications.
- Shorter learning curve in comparison to ORIF.

DISADVANTAGES

- Indirect reduction of subtalar joint with the image intensifier may not result in an exact anatomic reduction.
- Percutaneous screw fixation is less rigid than plate osteosynthesis. Slight flattening of Böhler's angle may occur postoperatively.
- Patients are, like with ORIF, not allowed to bear weight for 12 weeks.

INDICATIONS

- All displaced intraarticular calcaneal fractures, Sanders type II–IV.

CONTRAINDICATIONS

- Centrally depressed fractures are not manageable by traction alone.
- Patients who are expected to be noncompliant.
- Fractures older than 7 days, because of progressive stiffening of the soft tissues, the capsula and ligaments in particular.

PATIENT INFORMATION

- On average < 10% wound complications, with usually a mild presentation.
- Small percentage (10–15%) of neurapraxia, lateral dorsal cutaneous nerve (continuation of the sural nerve), with temporary numbness on the lateral side of the foot.
- Non-weight bearing for 12 weeks.
- Intensive physiotherapy.
- Recovery time after surgery may be up to 1 year.
- Chance of osteoarthritis with persistent pain at rest and during walking, with indication for secondary arthrodesis in 10–15%.

PREOPERATIVE WORK UP

- Clinical evaluation of soft tissues, function, vascular status, and sensibility.
- Conventional radiographs (lateral and axial), CT scan with reconstructions in the sagittal, axial and (semi)coronal plane.
- Routine preoperative laboratory tests.
- Rest, cryotherapy, compressive dressings, and elevation are administered in case of significant edema. Foot pumps can be used to reduce swelling more rapidly.

- Perioperative single-dose antibiotic prophylaxis (e.g., cephalosporin), following local hospital protocol.

SURGICAL INSTRUMENTS AND IMPLANTS

- Two orthogonally placed fluoroscopes (axial and sagittal).
- Three 3-mm Kirschner wires, 15–20 cm in length.
- Four distractors (custom-made by Synthes).
- Two or three threaded guide wires and 6.5-mm cannulated cancellous bone screws.

ANAESTHESIA AND POSITIONING (FIGURE 1)

- Spinal or general anaesthesia.
- Prone position with affected foot slightly elevated for sagittal fluoroscopy.
- Two sterile-draped C-arms positioned at the end of the table, with the monitor beside the operating table, next to anaesthesiologist's equipment.
- No tourniquet is needed.

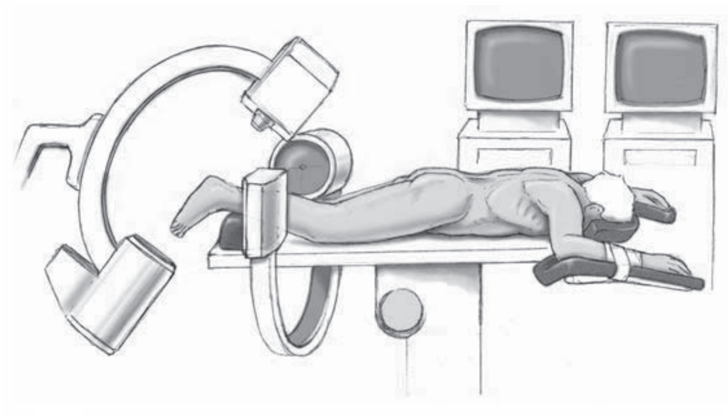

Figure 1. Patient in prone position, with the affected foot elevated.
Two fluoroscopes in sagittal and axial direction placed before sterile draping of the C-arms.

SURGICAL TECHNIQUE (FIGURES 2 TO 6)

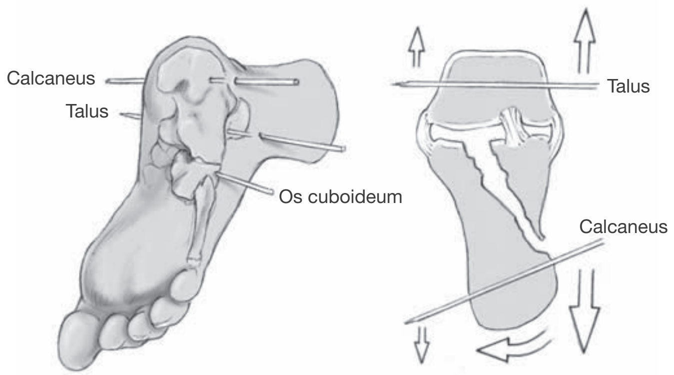

Figure 2. Three 3-mm Kirschner wires are inserted from the lateral side through the calcaneal tuberosity, the cuboid and the talar neck. The direction of the Kirschner wires has to be chosen on the basis of the tuberosity's displacement. If, for example, the heel is in varus position, the Kirschner wires are inserted converging from lateral to medial to correct varus of the heel pulling the tuberosity in a neutral position when distraction is applied.

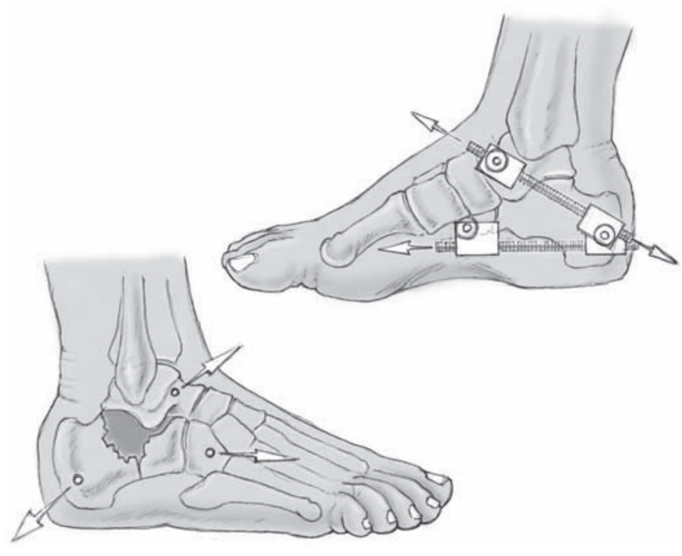

Figure 3. Two distractors are mounted on each side of the foot and winded apart to restore calcaneal height and length; in this case between the tuberosity of the calcaneus and talus and between the tuberosity and cuboid to obtain both height and length, comparable to the orientation used by McBride[16] and Kuner et al.[17]

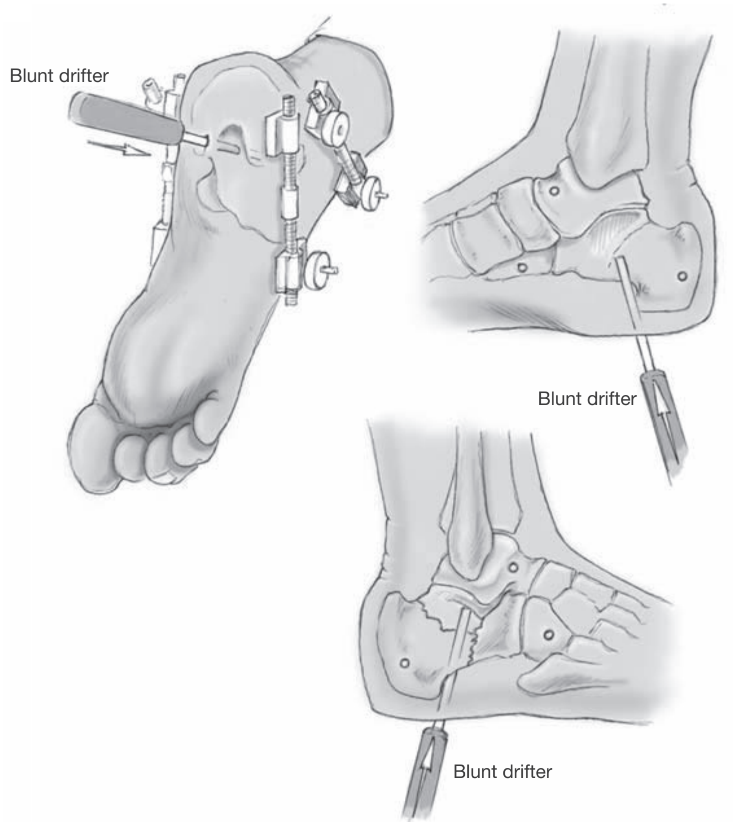

Figure 4. Insertion of a blunt drifter (punch) to unlock the depressed part of the posterior talocalcaneal facet in order to restore joint congruence.

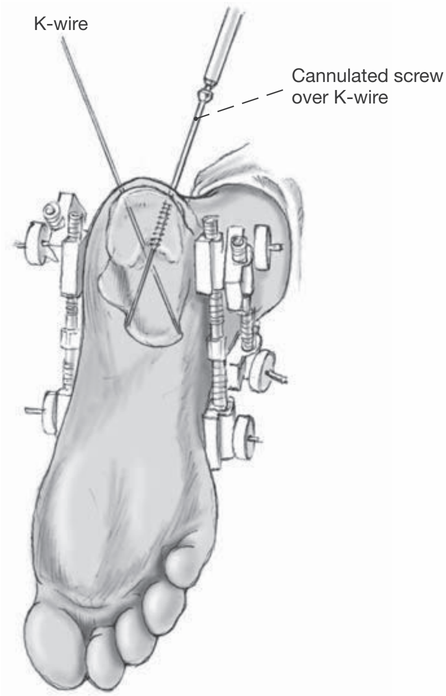

Figure 5. When acceptable reduction is obtained, two crossing 3-mm Kirschner wires are inserted from the calcaneal tuberosity toward the cuboid and navicular bone. These are then replaced by cannulated cancellous screws crossing each other. Care is given that they are not drilled into the adjacent bones. A third cannulated screw is inserted from the lateral side and guided into the sustentaculum, to reduce width.
This transversely placed screw maintains the correction of width, obtained by the percutaneous distraction. If used in combination with a washer, this screw provides additional reduction of the lateral wall and any fracture lines in the subtalar joint.

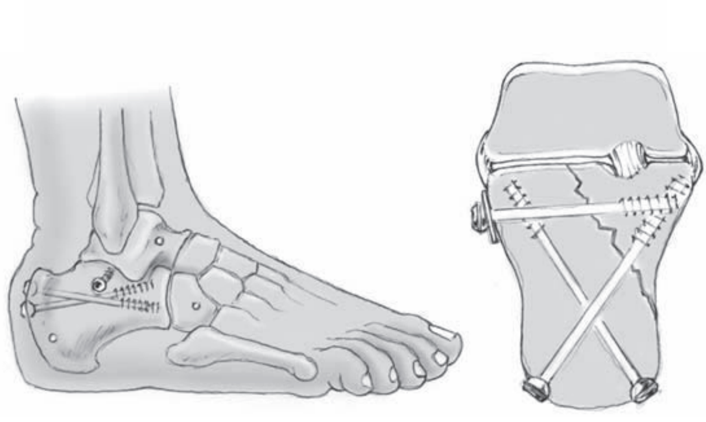

Figure 6. Final result in lateral and axial view after dismounting the external distractors.

SPECIAL CONSIDERATIONS

- In fractures with severe height loss, the distractors can be mounted from talus to calcaneus and talus to cuboid on both sides of the foot according to Forgon & Zadravecz.[13,14]
- Instead of a blunt drifter from plantar, a Kirschner wire inserted into the lateral fragment can be used as lever to lift up the fragment.
- Two-point distraction, e.g., by Sanatmetal (Hungary) and I.T.S. (Austria), between talus and calcaneal tuberosity is an option, especially in less comminuted fractures.[18]
- If, during the operation, a small unstable fragment of the posterior talocalcaneal joint cannot be bridged or supported by the cannulated screws and recollapses, it can be temporarily fixated by a transarticular Kirschner wire.[19,20] This, however, delays functional aftertreatment.[21]
- Direction of screw placement depends on the fracture line(s).
- Intraoperative use of CT scanning or subtalar arthroscopy might be considered to verify anatomic reduction of the subtalar joint.[9,11,12,22]

POSTOPERATIVE MANAGEMENT

- Directly postoperatively, full active range of motion exercises of the ankle joint can start, with the foot elevated in the 1st postoperative week.
- Adequate analgesics are mandatory.
- The physiotherapist can assist in the exercises, and the teaching of walking with crutches.
- Conventional radiographic control images are obtained postoperatively.
- The next radiographic check will be at 6 weeks and at 3 months.
- Stitches are removed after 14 days.
- Implant removal is necessary in 50–60% of patients. Complaints in terms of shoe wearing are mostly caused by distal migration of the two screw heads, which is due to a slight collapse of the posterior facet at follow-up. Removal of the cannulated screws can be considered after approximately 6 months. If a transarticular Kirschner wire was used, it is removed after 6–8 weeks.
- After 12 weeks, and following assessment of healing on control radiographs, patients are allowed to start weight bearing.

ERRORS, HAZARDS, COMPLICATIONS

- Secondary collapse of fragments: direction of the screws has to be chosen correctly to bridge large fragments and to support posterior facet fragments. As the extent of secondary collapse is usually minor, this needs no further treatment. In case of severe collapse, causing subtalar joint incongruency, an open revision should be considered.

- Injury to the lateral dorsal cutaneous nerve, the continuation of the sural nerve: this complication occurs in approximately 10%, and gives a temporary numbness on the lateral side of the foot, which requires no treatment.
- Peroneal tendon impingement or fibular abutment: if initial correction of the calcaneal width was insufficient, a secondary excision of the lateral wall exostosis can be performed.
- Intraarticular screw placement: this requires removal of the hardware prior to weight bearing mobilization.
- Surgical site infection: may be treated with antibiotics with or without wound debridement.

RESULTS

Between 1999 and 2004, 59 patients with 71 fractures were treated at our institute by percutaneous skeletal triangular distraction[15] (for examples see Figures 7 to 9). A total of 50 patients with 61 fractures and a minimum follow-up of 1 year were available at a mean follow-up of 35 ± 20 months. 72% were male, mean age was 46 ± 12 years. According to the Essex-Lopresti classification, 38% of the injuries were joint-depression fractures, 15% tongue-type, 44% comminuted, and 3% unknown fractures. The Sanders classification showed type II in 38%, type III in 28%, type IV in 28%, and an unknown type in 6%. There were five open fractures.

According to the American Orthopaedic Foot and Ankle Society Hindfoot Score[23,24], 72% of all patients had a good (80–89 points) or excellent (90–100 points) result; the mean score was 83 ± 14 points. Nine patients developed wound complications: seven superficial infections, one osteomyelitis, and one pin tract infection. Five patients already underwent, and four patients were scheduled for, secondary arthrodesis (total nine out of 61 feet). Böhler's angle increased from –2° (± 16°) to 19° (± 10°) postoperatively. In 32 patients, the healthy side measured 31° (± 5°) on average. At follow-up, the average Böhler's angle was 14° (± 12°), a collapse of 5°. Sagittal motion was 90% and subtalar motion 70% compared to the healthy foot. Previous studies with this treatment modality show comparable results.

Forgon showed, in a large population of 265 patients with a calcaneal fracture, a good to excellent result in 90%. The complications included wound healing disturbances in 3.7% and loss of reduction in 6.1%. No comments were made on the need for a secondary arthrodesis.[13] Fröhlich et al. treated 94 patients percutaneously with a modified Forgon-Zadravecz technique using a two-point distractor by Sanatmetal and reported a good to excellent result in 80%, with wound healing complications in 2.1% and the need for a secondary arthrodesis in another 2.1%.[18] In conclusion, percutaneous reduction by skeletal distraction and screw fixation can be considered a useful treatment modality, especially in severely comminuted fractures, expected wound complications in open fractures and patients with diabetes or peripheral vascular occlusive disease. The outcome from larger series, showing improved anatomic reduction with the use of intraoperative scanning or arthroscopy, might answer the question, if minimally invasive calcaneal repair is as effective as ORIF.

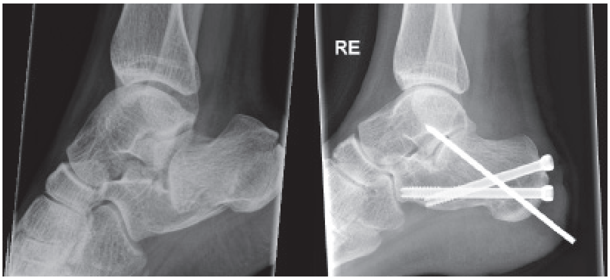

Figure 7. Case 1: a 32-year-old female patient was transferred to our hospital with an Essex-Lopresti tongue-type and Sanders type IIB fracture of her right calcaneus after jumping from a second-story window. After 4 days a percutaneous reduction by distraction with screw fixation was performed. An additional transarticular Kirschner wire was inserted to prevent the reduced subtalar joint from secondary collapse. The follow-up period is now 1 month, the transarticular Kirschner wire will be removed after 6–8 weeks.

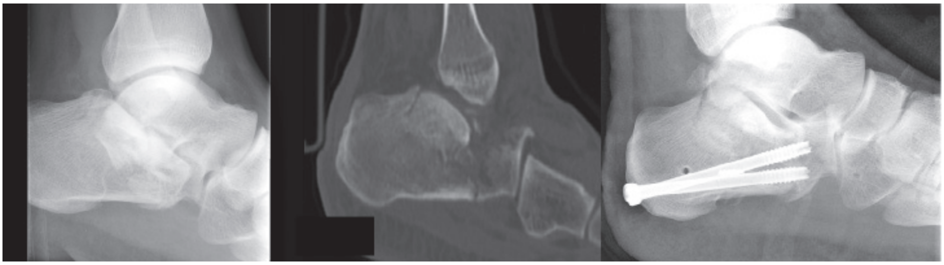

Figure 8. Case 2: a 24-year-old male patient fell from 2 m landing on his right foot. He sustained an Essex-Lopresti joint-depression and Sanders IIIAC type fracture, with luxation of the subtalar joint. The luxation and fracture were operated on the same day. After a follow-up of 19 months the patient has minor complaints of stiffness, but no complaints of pain.

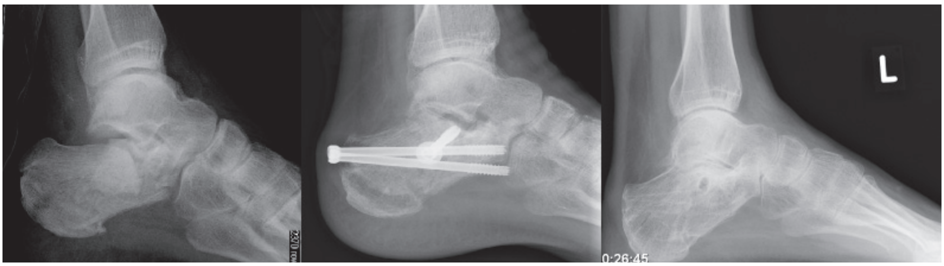

Figure 9. Case 3: a 43-year-old male patient fell from 3 m sustaining a bilateral calcaneal fracture. On the left, the fracture was classified as an Essex-Lopresti tongue-type and a Sanders type IIC. The operation appeared radiologically successful at 3 and 12 months, but the patient remained painful and a secondary subtalar arthrodesis was performed after 14 months.

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Chapter 9

Percutaneous treatment of displaced intra-articular calcaneal fractures

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ABSTRACT

Background

The outcome after displaced intra-articular calcaneal fractures is influenced by the condition of the surrounding soft tissues. To avoid secondary soft tissue complications after surgical treatment, several less-invasive procedures for reduction and fixation have been introduced. The percutaneous technique according to Forgon and Zadravecz is suitable for all types of displaced intra-articular calcaneal fractures and was therefore introduced in our clinic. The aim of this study was to evaluate the long-term outcome of percutaneous treatment according to Forgon and Zadravecz in patients with displaced intra-articular calcaneal fractures.

Methods

A cohort of patients with displaced intra-articular calcaneal fractures treated with percutaneous surgery was retrospectively defined. Clinical outcome was evaluated by standardized physical examination, radiographs, three published outcome scores, and a visual analogue scale of patient satisfaction.

Results

Fifty patients with 61 calcaneal fractures were included. After a mean follow-up period of 35 months, the mean values of the Maryland foot score, the Creighton-Nebraska score, and the American Orthopaedic Foot and Ankle Society score were 79, 76, and 83 points out of 100, respectively. The average visual analogue scale was 7.2 points out of 10. The average range of motion of the ankle joint was 90% of normal and subtalar joint movements were almost 70% compared with the healthy side or normal values. Superficial wound complications occurred in seven cases (11%) and deep infections in two (3%). A secondary arthrodesis of the subtalar joint was performed in five patients and was scheduled in four patients (15%).

Conclusions

Compared with the outcome of historic controls from randomized trials and meta-analyses, this study indicates favourable results for the percutaneous technique compared with the open technique. Despite similar rates of postoperative infection and secondary arthrodesis, the total outcome scores and preserved subtalar motion are overall good to excellent.

INTRODUCTION

Owing to their complexity and the diverse treatment options, displaced intra-articular calcaneal fractures remain a therapeutic challenge. The clinical evidence supporting operative treatment for selected patient groups is limited, whereas long-term complications and adverse outcomes are frequently documented.[1-3] One of the adverse effects of operative treatment is secondary damage to soft tissues after extensive surgical procedures. To avoid soft tissue complications, several less-invasive procedures have been introduced. The most frequently used minimally invasive technique for the tongue-type fracture was proposed by Westhues in 1935, modified by Gissane, and propagated by Essex-Lopresti.[4] In 1983 Forgon and Zadravecz introduced a new minimally invasive technique using an external distractor applied percutaneously, followed by percutaneous fixation.[5,6] This technique applies the principle of distraction–reduction (ligamentotaxis) of the fracture fragments and is suitable for all types of intra-articular fractures.[7] The aim of this study was to evaluate the long-term outcome of percutaneous treatment according to Forgon and Zadravecz in patients with displaced intraarticular calcaneal fractures.

PATIENTS AND METHODS

Patient selection

A study cohort was retrospectively defined to include all patients with displaced intra-articular calcaneal fractures treated according to Forgon and Zadravecz[5,6] over a 5-year period at our institution. Approval for the study was obtained from the Institutional Reviewing Board (IRB). Patients who died (n = 2), had a spinal cord lesion (n = 1), moved to a foreign country (n = 4), or whose addresses were unknown (n = 5) were excluded. After a follow-up period of at least 12 months (mean 35 months, range 13–75 months), patients were interviewed after informed consent was given and were evaluated for their functional outcome. Patients who had undergone secondary subtalar arthrodesis in the follow-up period were considered to have had a poor outcome for the primary surgery.

Surgical procedure

Surgical treatment according to the technique described by Forgon and Zadravecz[5,6] with three minor modifications was carried out by three staff trauma surgeons. The patient was placed in the prone position and received spinal analgesia and antibiotic prophylaxis prior to the operation. Two fluoroscopes were installed to provide imaging in two orthogonal planes. Three 3-mm Kirschner wires were inserted from the lateral side through the calcaneal tuberosity, the cuboid, and the talar neck. The first modification concerned the placement of the distractors. These were positioned on both sides of the foot between the tuberosity of the calcaneus and talus and between the tuberosity and cuboid. Zadravecz et al. placed the latter between the cuboid and talus (Figure 1). Through the distracting force generated between the three pins, the tuber angle of Böhler can be restored. The second modification concerned the insertion of a blunt drifter introduced from the plantar side to unlock and push up any remaining depressed parts of the subtalar joint surface of the calcaneus; Forgon and colleagues used pin leveraging from the lateral side to manipulate these fragments. The third modification was the discarding of the Böhler bone press to reduce the width of the fractured calcaneus. When an acceptable reduction was achieved, two Kirschner wires or two cancellous screws were inserted from the posterior aspect of the tuberosity. If necessary, a third screw was inserted from the lateral side of the calcaneus toward the sustentaculum tali to reduce bulging of the lateral wall. Postoperatively, patients remained non-weight-bearing for 3 months.

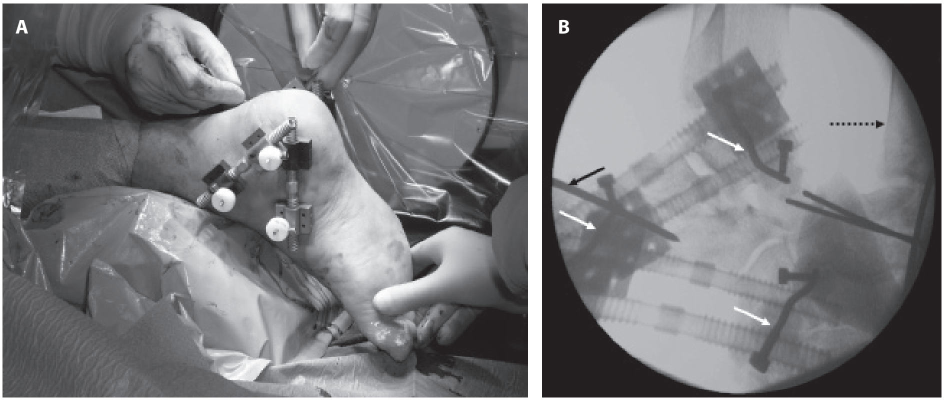

Figure 1. a Medial and lateral distractor in place during percutaneous surgery.
b Fluoroscopic image showing the distractor and the osseous structures of the foot. The white arrows show the three Kirschner wires for distraction in the calcaneal tuberositas, the talus, and the cuboid. The black solid arrow shows a Kirschner wire inserted posteriorly for fixation. The black dotted arrow shows the contralateral foot in which the calcaneal fracture has already been distracted and fixated with two Kirschner wires

Functional outcome

Patients completed three questionnaires: the Maryland foot score (MFS), the Creighton-Nebraska (CN) score, and the American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot score.[8-10] A modified visual analogue scale (VAS) was used to measure patient satisfaction on a scale of 1–10. Patients with a bilateral fracture completed the questionnaire for the foot with the most complaints and functional disability.[6] For the purposes of comparison, the AOFAS scores were divided into the same groups used for the MFS: a score of 90–100 was graded as an excellent result; 75–89 as good; 50–74 as fair, and less than 49 points was graded as a failure.[11,12] This differed slightly from the CN score, in which an excellent score is 90–100; good is 80–89; fair is 65–79, and poor is a score of less than 64 points.[8]

Physical examination

Physical assessments (walking ability on heels and toes, heel width, calf circumference, stability and alignment of the heel) were performed in the outpatient clinic by the investigator (TS). The ranges of motion of the ankle and the subtalar joint were measured according to the Association for Osteosynthesis (AO) neutral zero method. The subtalar range of motion was measured with patients sitting on their knees to measure only the subtalar joint motion.[13]

In patients with unilateral fractures, these measurements were compared with the values of the uninjured foot and ankle. In patients with bilateral fractures, standard normal values according to McMaster were used (inversion of 25° and 5° of eversion).[14] The mean normal sagittal (flexion and extension) range of motion of the ankle joint was set at 60°.[13]

Radiographic data

The preoperative radiographs and computed tomography (CT) scans were classified according to the classifications of Essex-Lopresti and Sanders, respectively, the latter without the use of subclasses.[10,15] Immediately after the operation, radiographs in the lateral and axial plane were obtained to show the status of fracture reduction. At the time of inclusion in this study additional weight-bearing lateral, axial, and 45° inverted foot (Anthonson) views of the calcaneocuboid joint were obtained for both feet. The angles of Böhler and Gissane on preoperative and immediate postoperative radiographs were compared with the follow-up values and with normal values in patients with a unilateral fracture.[15,16] The length, height, and width of the calcaneus were measured on the radiographs. The Zwipp score was used, in which the osteoarthrosis of the ankle joint, subtalar joint, and the calcaneocuboid joint, together with the difference in the Böhler's angle were scored.[17,18] A radiographic score of less than 6 points was considered a poor result, 7–8 points fair, 9–10 a good result, and 11–12 points an excellent result.[17,18] All radiographs were evaluated together with a radiologist.

RESULTS

A total of 59 patients with 71 fractures were considered for analysis. Nine patients refused to participate (Figure 2). The remaining 50 patients, with a total of 61 fractures, showed a mean time from trauma to operation of 5 days (range 0–17 days) and a mean hospital stay of 8 days (range 1–77 days). The trauma mechanism was a traffic accident in 8 patients and a fall from height in 42 patients. In the latter group, 16 patients fell from stairs or a ladder and 5 had attempted suicide. A total of 60 additional injuries were found in 46% of the patients, of which ten patients had vertebral fractures. The patient demographics and fracture characteristics are shown in Table 1. Forty-two patients were seen at the outpatient clinic; eight did not attend but completed the questionnaire at home.

Infectious complications

The complications, related to the fractured calcaneus or the operation, were collected from medical records and the visits to the outpatient clinic. Infectious complications occurred in 9 of 61 (15%) feet that had undergone an operation. Seven patients had a superficial wound infection that was treated conservatively with antibiotics or operatively by removal of hardware. Two patients developed a deep infection: one osteomyelitis and one pin tract infection. One patient had an impingement of the peroneal tendon.

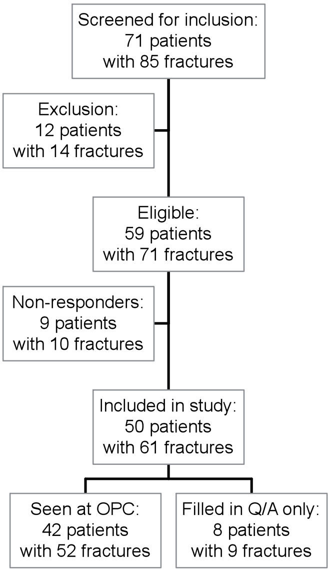

Figure 2. Flowchart showing the process of inclusion of patients in the study. *OPC*, outpatient clinic; Q/A, questionnaires

Table 1. Patient demographics and fracture characteristics of 50 patients with 61 fractures

Characteristic	**n = 50 patients with 61 fractures (%)**	
Gender	Male	36 (72)
	Female	14 (28)
Age (years)	46 (range 16-65)	
Fracture side	Right	21 (42)
	Left	18 (36)
	Bilateral	11 (22)
Soft tissue	Closed	57 (93)
	Open	4 (7)
Essex-Lopresti classification	Joint-depression	23 (38)
	Tongue-type	9 (15)
	Comminuted	27 (44)
	Unknown	2 (3)
Sanders classification	Type II	23 (38)
	Type III	17 (28)
	Type IV	17 (28)
	Unknown	4 (6)
Calcaneocuboid joint involvement	Yes	27 (44)
	No	29 (48)
	Unknown	5 (8)

Outcome

A total of five calcaneal fractures in five patients had been treated with a secondary (triple) arthrodesis and four patients had the procedure planned (total 9/61 feet; 15%) because of disabling residual pain. The five patients who had already undergone arthrodesis did not complete the questionnaire and were considered to have had a poor result from the primary treatment. The functional outcomes are presented in Table 2. A good to excellent result was found in 42% to 72% of patients, depending on the outcome score used. Patient satisfaction, as represented by the VAS, was on average 7.2 (range 0–10). Five patients (two who had already retired) did not reach the level of activity they enjoyed prior to the accident and were not working at the time of the follow-up. The other patients (90%) were able to work. Eighty-two percent of patients were able to wear normal shoes.

Table 2. Outcome according to four scoring systems after percutaneous treatment of intra-articular calcaneal fractures

Score	Average ± SD	Excellent (%)	Good (%)	Fair (%)	Poor/Failure (%)
	n = 45	n = 50			
AOFAS	83 ± 15	36	36	16	12
MFS	79 ± 16	28	32	24	16
CN	76 ± 17	18	24	28	30
VAS	7.2 ± 2	-	-	-	-

Outcome as measured by the scoring systems in percentages of 45 patients without an arthrodesis, using four different scores. Grouped outcome in which the patients with an arthrodesis were considered having a poor result of primary treatment.
AOFAS: American Orthopaedic Foot and Ankle Society score, CN: Creighton Nebraska score, MFS: Maryland Foot Score, VAS: Visual Analogue Scale, SD: standard deviation.

Physical examination

The average sagittal range of motion of the ankle joint (plantar plus dorsiflexion) was 53° (range 25°–75°, *n* = 37), which represents 88% of the normal range of motion.

The average range of motion of the subtalar joint was 20° (range 5°–40°), 67% of the normal value. There was an increase in heel width of almost 6% and a decrease in calf circumference of 5%. All feet showed a normal level of stability, and of the 61 fractured feet, three had a slight malalignment.

Radiographic evaluation

The results of the radiographic examination of the investigated feet at three different points in time are presented in Table 3. The Zwipp score for osteoarthritis was 8 points on average. A total of four patients scored 6 points or less, meaning a poor radiologic outcome.

Table 3. Radiographic data at follow-up

Parameters	Trauma (n = 61)	Post-operatively (n = 61)	Follow-up (n=37)	Healthy side (n = 32)
Böhler angle in degrees (±SD)	-2 (16)	19 (10)	14 (12)	31 (5)
Gissane angle in degrees (±SD)	116 (18)	114 (12)	113 (15)	109 (9)
Height in mm (±SD)	-	-	47 (5)	50 (3)
Length in mm (±SD)	-	-	82 (5)	83 (5)
Width in mm (±SD)	-	-	46 (5)	40 (3)

Radiological follow-up data at time of the trauma, direct post-operatively and after a mean follow-up of 35 months. All measurements were compared in patients with unilateral fractures without an arthrodesis. SD: standard deviation.

DISCUSSION

Various percutaneous and minimally invasive techniques have been introduced because of the skin and wound complications associated with open surgical techniques for the treatment of intra-articular calcaneal fractures. Forgon and Zadravecz combined several less invasive techniques for percutaneous reduction and fixation through the use of an external distractor.[4-6,19] In this study, the outcome of the percutaneous treatment according to Forgon and Zadravecz of patients with a displaced intra-articular calcaneal fracture was evaluated over the long term. Patients in this study achieved a good to excellent result in 42% to 72% of cases, according to the use of three different outcome scores. The range of motion of the ankle joint was nearly normal, and the range of motion of the subtalar joint was approximately 70% compared with the uninjured side. A limitation of this study is the absence of a control group treated with a different method. In the level-1 setting where the study was conducted, no other technique was implemented, thus removing the possibility of a concurrent control group. Migrants, the homeless, and patients receiving psychiatric treatment were mostly lost to follow-up; however, their fracture characteristics and patient characteristics were not significantly different from the patients analyzed. Murnaghan showed an equivalent level of patients lost to follow-up, however they found that the attenders and nonattenders in a calcaneal fracture trial constituted two significantly different groups. It is therefore not prudent to extrapolate the results of this study to all patients who were treated in the study period; this constitutes a second limitation.[20]

The largest published series of patients treated with the percutaneous distractor method comprised 265 cases and presented good to excellent results in approximately 85% of patients.[21] Differences in study parameters and outcome scores make it difficult to compare the results as presented by Forgon and Zadravecz and those of this study. The functional results presented in this study appear to be slightly less favorable than those reported for open reduction and internal fixation (ORIF) groups in the literature, but appear to be better than those for conservatively treated patients.[10,19,22,23]

The infection and wound complication rates in this study appear similar to those of ORIF and the infections that occurred at the insertion site of the traction pins were not severe. Historically complication rates as high as 30%–40% have been reported for ORIF. Reports from the last 5 to 10 years show a superficial skin infection or wound dehiscence rate of about 10%. Deep infections such as osteomyelitis occur at a lower rate.[24,25] The largest prospective, randomized multicenter study of Buckley et al. in 2002 showed a superficial infection and wound complication rate of 17% and a deep infection rate of 5% for ORIF.[2]

With a 15% arthrodesis rate, our study results appear more favorable than those for conservatively treated patients, but less favorable than for open reduced and fixated fractures.[2] Buckley et al. showed that the need for arthrodesis was 4% in the ORIF group versus 20% in the conservatively treated group.[2] Many studies point out restrictions at the subtalar joint for both surgically and conservatively treated fractures. The average range of motion is approximately halved compared with the uninjured foot.[26] The more favorable results presented in this study are supported by the findings of other authors.[27] The percutaneous approach minimizes secondary trauma to the soft tissues, which may lead to less scar tissue formation around the ankle and subtalar joint and may thus lead to less stiffness of the joint.[19]

In conclusion, this study confirms that the function of the calcaneus and subtalar joint can be restored by percutaneous reduction and fixation in patients with a displaced intra-articular calcaneal fracture. Despite similar infectious complication rates and higher secondary arthrodesis rates compared with open procedures, the good outcome scores and the preservation of the subtalar range of motion at 3-year follow-up indicate little benefit of open procedures, as reported in the literature, over percutaneous reduction and fixation.

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Chapter 10

Plantar pressure analysis after percutaneous treatment of displaced intra-articular calcaneal fractures

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ABSTRACT

Introduction

Clinical results for the treatment of displaced intra-articular calcaneal fractures are mainly expressed using disease-specific outcome scores, physical examination and radiographs. We hypothesized that plantar pressure and foot position analysis is a valuable tool in assessing foot function in patients with a unilateral displaced intra-articular calcaneal fracture treated percutaneously.

Patients and methods

With a follow-up of at least one year, 21 patients with a unilateral displaced intra-articular calcaneal fracture treated percutaneously participated in the study. The pedobarographic measurements in the injured foot were compared with the contralateral control foot. Correlations between the ratios (injured/control) of plantar pressure and foot position variables and outcome scores, the physical exam items ratios, the fracture classification and the radiological parameters were calculated.

Results

Statistically significant differences between the injured and the control foot were found for the weight distribution ($p = 0.002$), total contact time ($p < 0.001$), and the maximum pressure under the first metatarsal ($p = 0.02$) after a median follow-up of 18 months. Of all correlations calculated, only the heel time ratio correlated statistically significant with the heel width ratio ($p = 0.004$).

Conclusion

Significant differences in plantar pressure distribution between the injured and uninjured foot were found, indicating that plantar pressure analysis and foot position analysis is an objective test to assess deviations in foot function. Plantar pressure data revealed limited correlation with outcome scores. Therefore, plantar pressure analysis should not be used instead of but in addition to established outcome scores.

INTRODUCTION

Various modalities exist for the treatment of displaced intra-articular calcaneal fractures. Methods include standard open reduction and internal fixation (ORIF)[1], conservative management[1], three-point distraction according to Forgon and Zadravecz[2], percutaneous reduction according to Essex-Lopresti[3], manual reduction[4] and primary arthrodesis.[5] The percutaneous distraction technique according to Forgon and Zadravecz has been applied at our institute since 1998, with minor modification.[2,6]

Clinical results of treatment of displaced intra-articular calcaneal fractures have mainly been documented using disease-specific outcome scores. Infrequently, pressure distribution analyses have been used to analyze functional results after ORIF,[7,8] closed and semi-open treatment[9] and conservative treatment.[10,11] The studies comparing operative and conservative treatment showed improved results after surgical treatment.[12-14] Patients showed a better compensated walking pattern,[14] improved functional results, and reported fewer subjective complaints compared with patients treated conservatively.[12]

The aim of the current study was to assess the value of plantar pressure and foot position as a measure of outcome in patients with a unilateral displaced intra-articular calcaneal fracture treated according to a percutaneous distraction technique. The second aim was to determine the clinical relevance of pedobarographic analysis by studying whether plantar pressure pattern and foot position correlated with established outcome measurements such as disease specific questionnaires, fracture classification, radiographic data and physical exam data.

PATIENTS AND METHODS

Patients

Twenty-one patients (median age, 51yr; 25th to 75th percentiles, 46 to 55; weight, 80 kg; 25th to 75th percentiles, 70 to 89; height, 1.71 m; 25th to 75th percentile, 168 to 180; 67% male) with a unilateral displaced intra-articular calcaneal fracture treated by the percutaneous distraction technique according to Forgon and Zadravecz participated in this study after signing informed consent. The study was approved by the local ethical committee. These patients were a selected group from a larger cohort, after excluding patients because of migration or unknown address (n = 9), demise (n = 2), spinal cord lesion (n = 1), bilateral calcaneal fractures and additional ipsi- and contralateral lower extremity fractures (n= 11), prior to this study.[6] The left foot was injured in 10 cases and the right in 11. The median follow-up time was 18 months (25th to 75th percentile 16 to 26). Trauma mechanism was a fall from height (n = 10), a fall from the stairs or a ladder (n = 9), or a motor vehicle accident (n = 2). Considering the Essex-Lopresti[1] conventional radiographic classification there were 3 tongue type, 12 joint depression type and 6 comminuted type fractures. The Sanders[1,15] CT-classification showed 9 type II, 5 type III and 5 type IV fractures. For two patients the classification could not be determined as the CT-scans were not available.

Outcome was determined using three disease-specific outcome scores, and satisfaction with overall treatment was determined using a Visual Analogue Scale (VAS; range 0-10)[16], American Orthopaedic Foot and Ankle Society (AOFAS) Hindfoot Score [17], Maryland Foot Score (MFS)[15], and Creighton-Nebraska Score (CN)[18].

The physical exam was conducted by one independent observer with the patient in kneeling position with the ankle and foot freely movable. The range of motion (ROM) of the ankle and subtalar joint were measured using goniometry. The heelwidth (mm) was measured from the plantar side of the foot, at the level of both malleoli using sliding calipers. Standardized weight-bearing lateral radiographs were evaluated by one observer (TS) and an independent radiologist using goniometry; mean values were calculated from both observers. From the lateral radiograph, the angles of Böhler and Gissane were measured.

Dynamic pedobarographic analysis

In determining which plantar pressure and foot position variables have been investigated earlier, the literature (Pubmed) was reviewed for previous use of plantar pressure and foot position analyses after calcaneal fractures, up to May 2007, using the following search-terms and Boolean operators: ('calcaneus' OR 'os calcis' OR 'calcaneum' OR 'calcaneal') AND 'fracture' AND ('gait' OR 'plantar pressure'). This search identified thirteen studies; 9 used a platform as measuring device and 4 used insoles (Table 1). The number of items used per study ranges from 1 to 11. In total 24 different items were analyzed, of which 7 were determined only once. The most frequently used parameters were the Centre of Pressure (COP) and the pressure under different areas of the foot, which were both determined in 8 studies.

All plantar pressure distribution analyses were performed at a specialized center for foot, ankle and gait abnormalities. A plantar pressure plate (Footscan®, RSscan International, dimensions (L x W x H): 2 m x 0.4 m x 0.02 m, 16.384 sensors, 2 sensors per square cm, 100 Hz) was embedded in a 5 m long walking track. Subjects were unaware of the exact position of the pressure plate within this platform. Patients were asked to walk at a free-walking velocity on this platform. The following items were determined: the weight distribution between the injured and uninjured foot while standing, the maximum distance-change (delta x) in medial-lateral direction from the centre of pressure line (Δx COP; Figure 1A) to the foot axis, total contact time, load time percentage (percentage of loading, compared with unloading, during one single step), heel time, the total contact area, the degrees of abduction relative to the walking direction,[8,19,20] and the maximum pressure (Pmax) beneath the medial heel (H1), lateral heel (H2), metatarsals (M1 to M5) and the hallux (T1) (Figure 1B). The medial-lateral foot ratio ((H1+M1+M2)/(H2+M3+M4+M5)) was calculated. Five recordings were made for each patient. The lowest and highest scores for every item were deleted, the three remaining were averaged. Two investigators (AS, EL) measured all plantar pressure and foot position variables in duplicate to determine intra-observer variability and inter-observer agreement.

Statistical analysis

The statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) version 12.0 (SPSS, Chicago, IL, USA). The Kolmogorov-Smirnov test was used to test

Table1. Overview of plantar pressure and foot position items used in the literature

	Articles → / Parameters ↓	Mittlmeier (1993) [19]	Kitaoka (1994) [11]	Rosenbaum (1995) [20]	Mittlmeier (1996) [21]	Siegmeth (1996) [12]	Toth (1997) [13]	Catani (1999) [14]	Kinner (2002) [8]	Dudkiewicz (2002) [7]	Follak (2003) [9]	Davies (2003) [22]	Bozkurt (2004) [10]	Contreras (2004) [23]	**Total**
General	platform (P) or insoles (S)	P	P	P	P	P	P	P	S	S	S	P	P	S	
	number of patients	45	16	14	12	20	171	14	20	22	30	12	21	22	
	treatment	O	C	M	M	M	M	M	O	M	M	O	C	O	
	follow-up (months)	23	72	48	?	59	50	18	24	60	62	45	38	>15	
	Healthy controls	N	Y	Y	Y	Y	N	Y	N	N	N	N	N	N	
Temporal and distance factors	heel width								+			+			2
	mid-foot width								+						1
	effective foot length										+				1
	cadence (strides/min.)		+		+										2
	velocity (m/min)	+	+	+	+			+							5
	step/stride length	+	+	+	+			+							5
	% single-limb support		+												1
	% double-limb support		+		+										2
	time of heel/initial contact	+	+						+			+			4
	time of fore-foot contact	+	+						+						3
	stance-phase/complete contact		+	+					+		+				4
	time of contact other areas	+		+		+	+								4
	time of final contact		+												1
	time to peak pressures/forces		+												1
	contact area			+										+	2
Load and pressure distribution	total sole load			+							+				2
	foot-ground reaction forces		+					+				+	+		4
	maximum heel impact force						+		+						2
	max. fore-foot impact force								+						1
	average overlap integral										+				1
	pressure in different sub-areas	+		+		+	+			+	+	+		+	8
	centre of pressure line (COP)	+			+	+		+	+	+		+		+	8
	zones of max. impact						+		+						2
	vertical impulse difference	+		+	+	+									4
	Total number of parameters	8	11	8	6	4	4	4	9	2	5	5	1	3	

Treatment: C = conservative, O = operative, M = mixed

for normality of the data. The Levene's test was applied to assess homogeneity of variance between data of injured and control feet. Since most items did not show normal distribution or equal variance, all items were regarded as non-parametric for the statistical analysis. Therefore median numbers and the 25th to 75th percentile are provided.

The intraclass correlation coefficient (ICC) was determined as an index of reliability to measure repeatability (intra-observer reliability) and reproducibility (inter-observer reliability) of the pedobarographic analysis. These were graded according to Landis and Koch [21]: 0, poor;

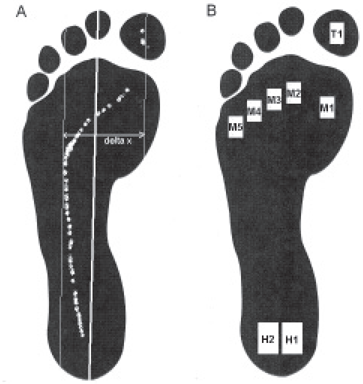

Figure 1. Graphical representation of pedobarographic analysis method.
A, Graphical representation of measurement method of the delta x COP, which is the maximum distance-change in medial and lateral direction during one single step of the center of pressure line (dotted line), from the reference line that runs from the center of the heel towards the second metatarsal head (straight line). The ratio of changes in the delta x of the injured / uninjured foot was calculated.
B, The different areas under the medial heel (H1), lateral heel (H2), metatarsals (M1 to M5) and the hallux (T1) where maximum pressure (Pmax) was measured.

0.01 to 0.2, slight; 0.21 to 0.4, fair; 0.41 to 0.6, moderate; 0.61 to 0.8, substantial; and 0.81 to 1.0, almost perfect agreement.

The Wilcoxon signed ranks test was used to assess whether plantar pressure and foot position variables differed between the injured and uninjured foot. For all items the ratio of injured versus unaffected foot was calculated. The Spearman rank test was applied to correlate these ratios to the disease-specific outcome scores, the VAS, and data from the physical exam. The radiological data and the fracture classification were correlated with the Footscan data of the injured foot. The Bonferroni correction was applied to correct for multiple comparisons; meaning that the significance level of p = 0.05 was divided by the number of correlations determined.

RESULTS

Patients

The median AOFAS was 88 points (25^{th} to 75^{th} percentile, 82 to 98). For the MFS this was 89 (25^{th} to 75^{th} percentile, 78 to 94), and the CN was 83 (25^{th} to 75^{th} percentile, 73 to 94). The median VAS score was 8 (25^{th} to 75^{th} percentile, 7 to -9). Determined from the physical exam the median ratio (injured/uninjured) of the ROM of the ankle joint in sagittal direction was 0.90 (25^{th} to 75^{th} percentile, 0.82 to 1.00) and the median ratio of the subtalar joint in the in- and eversion plane was 0.76 (25^{th} to 75^{th} percentile, 0.50 to 0.92). The median ratio for the heelwidth was 1.06 (25^{th} to 75^{th} percentile, 1.03 to 1.09). The median ratio of Böhlers angle of the injured foot at follow up versus that of the control foot was 0.57 (25^{th} to 75^{th} percentile, 0.30 to 0.82), for the Gissanes angle this was 1.04 (25^{th} to 75^{th} percentile, 0.99 to 1.08).

Pedobarographic analysis

The results of the plantar pressure and foot position variables analysis are shown in Table 2. Patients generally put more weight on the control foot than on the injured foot while standing. The injured foot had a statistically significantly reduced total contact time and higher maximum pressure under the first metatarsal compared with the control foot. None of the other items analyzed showed statistical difference between both feet.

Table 2. Plantar pressure data for the injured and the control foot

		Injured		Control		
		Median	25 - 75%	Median	25 - 75%	p Value
Static	Weight distribution (%)	45.0	[39.1 - 50.0]	55.0	[50.0 - 61.0]	0.002*
Dynamic	Max. Δx COP (mm)	41.0	[31.5 - 50.1]	38.8	[27.2 - 46.7]	0.13
Dynamic Force	Total contact time (msec)	791	[719 - 861]	853	[752 - 900]	<0.001*
	Load time (%)	65.6	[42.4 - 74.9]	61.5	[47.7 - 74.9]	0.66
	Heel time (msec)	520	[419 - 608]	543	[443 - 621]	0.08
	Contact surface (cm2)	123.0	[109.6 - 130.8]	119.5	[104.4 - 127.9]	0.41
Dynamic Pressure	Pmax H1 (N/cm2)	22.7	[20.1 - 28.8]	22.0	[20.1 - 28.8]	0.26
	Pmax H2 (N/cm2)	21.5	[17.1 - 29.4]	23.5	[20.1 - 29.5]	0.16
	Pmax M1 (N/cm2)	17.3	[11.9 - 21.3]	16.4	[13.2 - 27.2]	0.02*
	Pmax M2 (N/cm2)	28.1	[21.8 - 36.7]	28.0	[22.4 - 36.9]	0.82
	Pmax M3 (N/cm2)	28.5	[19.3 - 34.7]	25.6	[21.7 - 37.0]	0.43
	Pmax M4 (N/cm2)	20.7	[14.0 - 24.7]	20.0	[15.5 - 23.9]	0.88
	Pmax M5 (N/cm2)	15.2	[9.3 - 24.8]	14.1	[11.1 - 19.2]	0.32
	Pmax T1 (N/cm2)	13.0	[5.8 - 24.4]	19.9	[11.4 - 27.4]	0.29
	Medial/lateral[1]	0.9	[0.8 - 0.9]	0.8	[0.7 - 1.0]	0.59
	Degrees of abduction	8.1	[3.1 - 13.8]	11.4	[7.2 - 15.3]	0.15

Data are given as median with the 25th to 75th percentile.

* significant at the 0.05 level (2-tailed; Wilcoxon Signed Rank test).

[1] Medial/lateral ratio calculated as ((H1+M1+M2)/(H2+M3+M4+M5)) as described in material and methods. Max. Δx COP, maximum deviation of the centre of pressure line; Pmax, maximum pressure beneath a specific area beneath the foot.

To determine the accuracy of the measurements, the repeatability and the reproducibility were determined for all plantar pressure and foot position variables. The intra-observer reliability ranged from 0.83-1.00 for the first observer (AS) and from 0.96 to 1.00 for the second observer (EL). The inter-observer reliability ranged from 0.95 to 1.00.

To determine whether plantar pressure and foot position variables associated with clinical and outcome parameters, all pedobarographic pattern items were correlated with outcome scores, physical exam data and radiological data. Although several trends were observed, only the association between heel time (ratio injured/control) and heel width (ratio injured/control) were statistically significant after applying the Bonferroni correction: ($R_s = 0.60$, $p = 0.004$). The correlations with the outcome scores and VAS are shown in Table 3. None of the plantar pressure and foot position variables correlated statistically significant with commonly used outcome scores. However, there were trends for an inverse correlation of the percent load time with the VAS ($R_s = -0.47$, $p < 0.03$).

Although not statistically significant upon Bonferroni correction, the heel time ratio tended to associate with the ROM ratio in the sagittal plane ($R_s = 0.49$, $p = 0.02$).

Table 3. Correlation of Footscan data with the disease-specific outcome scores and VAS

		MFS	CN	AOFAS	VAS
Static	Weight distribution (%)	-0.06	0.18	-0.03	-0.01
Dynamic	Max. Δx COP (mm)	-0.20	0.02	-0.13	0.05
Dynamic Force	Total contact time (msec)	0.23	0.39	0.23	0.16
	Load time (%)	-0.18	-0.39	-0.39	-0.47
	Heel time (msec)	-0.07	0.04	-0.03	0.07
	Contact surface (cm2)	-0.08	0.08	0.06	-0.10
Dynamic Pressure	Pmax H1 (N/cm2)	-0.04	0.00	0.05	-0.24
	Pmax H2 (N/cm2)	0.05	0.15	0.06	0.19
	Pmax M1 (N/cm2)	0.01	0.06	-0.16	-0.23
	Pmax M2 (N/cm2)	0.20	0.18	0.09	-0.14
	Pmax M3 (N/cm2)	0.27	0.29	0.17	0.14
	Pmax M4 (N/cm2)	0.28	0.41	0.42	0.49
	Pmax M5 (N/cm2)	-0.06	0.14	0.11	0.25
	Pmax T1 (N/cm2)	0.38	0.52	0.41	0.35
	Medial/lateral[1]	-0.06	-0.14	-0.18	-0.43
	Degrees of abduction	-0.09	0.11	0.14	0.12

Correlation coefficients as determined using the Spearman Rank Correlation are given. Max. Δx COP, maximum deviation of the centre of pressure line; Pmax, maximum pressure under a specific area of the foot; MFS, Maryland Foot Score; CN, Creighton-Nebraska Score; AOFAS, American Orthopaedic Foot and Ankle Society Hindfoot Score; VAS, Visual Analogue Score.

[1] Medial/lateral ratio calculated as ((H1+M1+M2)/(H2+M3+M4+M5)) as described in material and methods.

P-values < 0.0125 (Bonferroni correction) are considered statistically significant.

DISCUSSION

The current study was conducted to establish pedobarographic deviations after percutaneous repair of displaced intra-articular calcaneal fractures and to correlate these data with standardized questionnaires, physical exam and radiographs. Data revealed changes in foot form and in the physiology of walking after an intra-articular calcaneal fracture. This is in concordance with findings from other studies.[9,11,13,14,20,22] Since treatment modalities, dynamic pressure and footscan equipment, items analyzed, and outcome scoring systems applied vary between studies, extrapolating data from one study to another is difficult.

At our institution the percutaneous technique was used as sole treatment for intra-articular calcaneal fractures. Only patients with a unilateral intra-articular calcaneal fracture treated percutaneously were included, justifying the use of the contralateral foot as an internal control.

Of all items used by others, the COP has been applied most. Four out of 8 studies reported a lateral shift of the COP line after calcaneal fracture.[8,14,22,23] However, as it was frequently not specified how this was calculated, subjectivity cannot be ruled out. In the current study a reproducible and quantitative method was chosen to determine the Max Δx COP. This method revealed no statistically significant difference between the injured and control foot, indicating equal stability of both feet in contrast to the study by Davies et al, who measured only the lateral deviation from the reference line.[23] An explanation for this difference might be the good subtalar movements in this study, which has shown correlation with lateralization of the centre of pressure line.[20,23]

A load shift to the lateral side for the injured foot reflecting reduced mobility of the subtalar joint was suggested in three studies.[8,20,22] The higher Pmax under M1 of the injured side as found in our study, however, suggests a medial rather than a lateral shift. Analyzing the Pmax ratio of medial/lateral areas revealed a trend towards lateralization of the injured foot; however this difference was not statistically significant because of the low power. In the study by Rosenbaum the lateral load shift was visualized by a significant increase in peak pressure at the level of the 5th metatarsal and a decrease under the head of the first metatarsal. This lateralization was not seen in other areas of the foot.[20] In their study only fourteen patients were included, of which two-third was treated operatively and one-third conservatively.

The current study indicated that patients bear weight on their injured foot significantly less while standing, and put more pressure on the first metatarsal of the injured foot than on the contralateral uninjured side. Since the heel time of the injured foot equals that of the control foot, these data imply that patients avoid walking on the injured heel. This could either be the consequence of existing physical complaints, or because of fear of physical complaints. This finding is in agreement with that of Rosenbaum.[20] As opposed to our study, Follak and Merk showed a trend in increased loading of the injured foot during standing, due to a greater loading of the forefoot.[9] It cannot be ruled out that this difference might be attributed to a difference in follow up time between their study (5 years) and the current study (1.5 year). Unfortunately the current study has insufficient power to assess if a correlation with follow up time exists. Moreover, Follak included patients treated with closed (n=15) and semi-open (n=15) repositioning of fragments, whereas in our study all patients are treated with the same treatment modality.

In our population the total contact time was statistically significantly shorter for the injured foot compared with the control foot. As the power for this item was low (17%), the meaning of this finding might be questioned. Increased contact phases were found by Siegmeth *et al.*[12] and Toth *et al.*[13], who also used pressure plates in their studies. The latter group reported a statistically significantly increased contact time of the injured midfoot. As opposed to these findings, studies by Follak[9] and Kinner[8] revealed equal total contact times and stance phase for both the injured and the control foot. In these two studies insoles were used instead of pressure plates. The interpretation of these results is complicated by a large variety in patient numbers (range, 20 to 171) and follow up time (24 to 72 months).

Of all correlations calculated, only heel time ratio correlated statistically significantly with heel width ratio. Other trends were identified, but lost statistical significance after correction for multiple testing. This means that pedobarographic analysis cannot be used as a replacement of routinely performed tests. The near perfect reproducibility and repeatability of our analyses indicate the high accuracy of the plantar pressure analyses performed. Therefore, determining plantar pressure and foot position variables may be a valuable addition to the panel of tests and outcome scores too assess differences between the injured and uninjured feet.[8,9]

It cannot be ruled out that for some items analyzed a limited power might have compromised the study results. A sample size of 325 patients would be required in order to reach sufficient power for all items (data not shown). Due to the low incidence of unilateral displaced intra-articular fractures, and the strict inclusion criteria, this was not feasible.

Dynamic pedobarography and gait analysis are objective measurements of foot function after intra-articular calcaneal fractures[8,19,23] and have been shown to correlate inconsistently with different outcome scoring systems, radiological parameters and physical exam.[19,23,24] It is said to be superior to radiographic analysis in assessing functional outcome[19], and will find increasing use in the evaluation and assessment of musculoskeletal function after reconstructive or corrective surgery.[9] The near perfect reproducibility and repeatability indicate the high accuracy of the pedobarographic analyses as described here supports the latter. This implies that, although correlation with outcome or radiology is poor, pedobarographic pattern analysis represents a reliable addition to the panel of tests and analyses performed at present.

CONCLUSION

Percutaneous treatment of displaced intra-articular calcaneal fractures according to Forgon and Zadravecz yields satisfying results on average. Patients had high scores on the different outcome scores but there were few statistically significant differences between the injured and the control foot during walking on plantar pressure and foot position variables.

Most of the plantar pressure and foot position variables analyzed did not correlate with the disease-specific questionnaires, physical exam and standardized radiographs, rendering the place of pedobarographic analysis in determining outcome after a displaced intra-articular calcaneal fracture unclear.

Pedobarography may represent a valuable addition to the currently applied tests such as radiographic and physical exams to assess the functional recovery, but large variation exists in methods and measured parameters. More uniformity is required to compare results of different studies and treatments, to enhance insight in this disabling injury.

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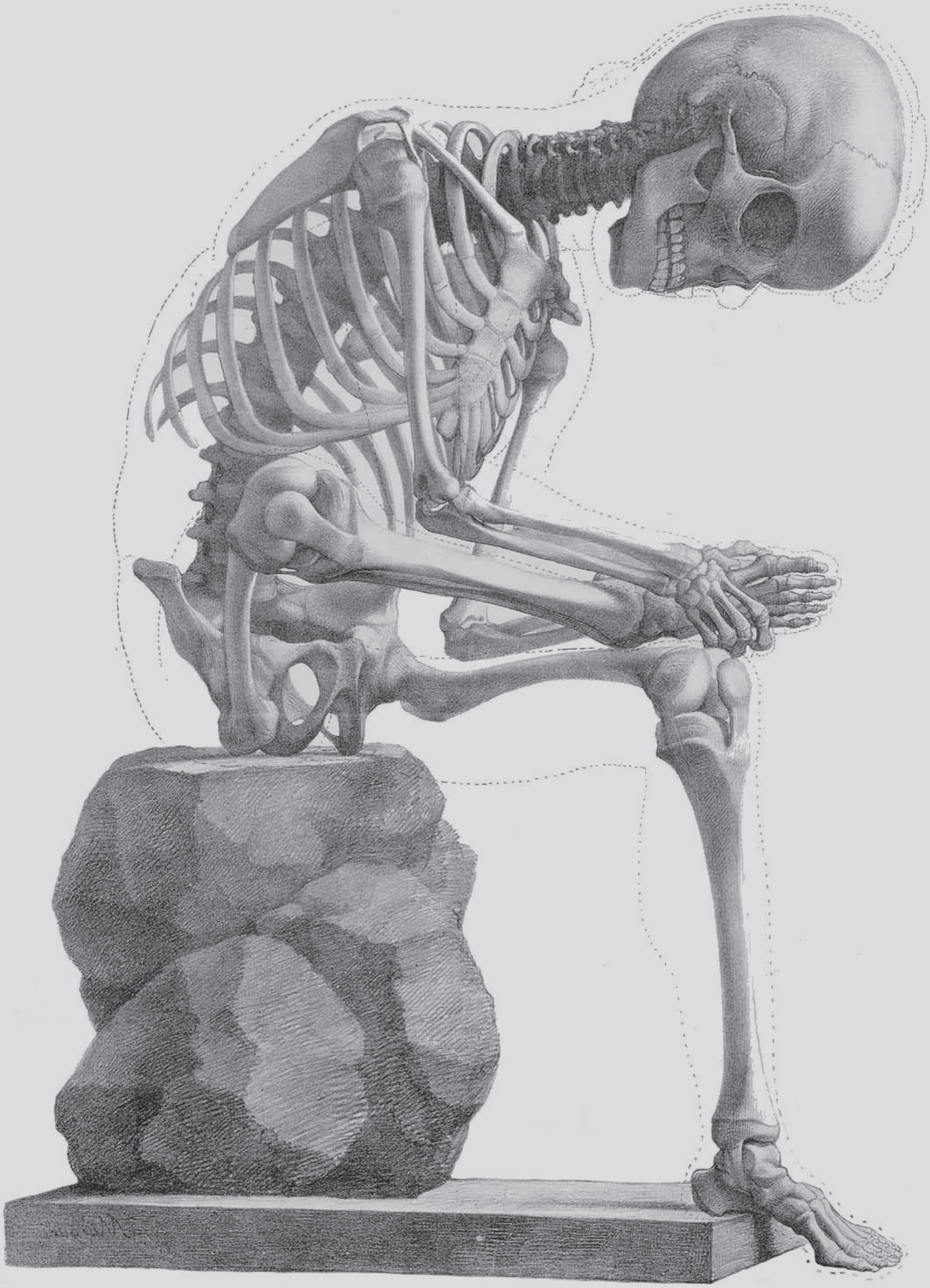
Part 4

Management of delayed complications



Chapter 11

Subtalar versus triple arthrodesis after intra-articular calcaneal fractures

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ABSTRACT

Objectives

Depending upon initial treatment between 2 and 30 percent of patients with a displaced intra-articular calcaneal fracture require a secondary arthrodesis. The aim of this study was to investigate the effect of a subtalar versus a triple arthrodesis on functional outcome.

Methods

A total of 33 patients with 37 secondary arthrodeses (17 subtalar and 20 triple) with a median follow-up of 116 months were asked to complete questionnaires regarding the disease-specific functional outcome (Maryland Foot Score, MFS), quality of life (SF-36) and overall satisfaction with the treatment (Visual Analogue Scale, VAS).

Results

Patient groups were comparable considering median age at fracture, initial treatment (conservative and operative), time to arthrodesis, median follow-up, and post-arthrodesis radiographic angles. The MFS score was similar after subtalar versus triple arthodesis (59 versus 56 points; p = 0.79). No statistically significant difference was found between both groups for the SF-36 (84 versus 83 points; p = 0.67) and the VAS (five versus six; p = 0.21). Smoking was statistically significantly associated with a non-union ($X^2 = 6.60$, p = 0.017).

Conclusions

The current study implies no significant difference in functional outcome between an in situ subtalar and triple arthrodesis as salvage technique for symptomatic arthrosis after an intra-articular calcaneal fracture. Smoking is a risk factor for non-union.

INTRODUCTION

Considerable research has been published on the treatment of displaced intra-articular calcaneal fractures. Although open reduction and internal fixation (ORIF) is currently used by most surgeons, approximately half of all patients is managed conservatively or percutaneously.[1] Assessing outcome by means of quality of life scores such as Short-Form-36 (SF-36) or visual analogue scale (VAS) revealed no apparent benefit in functional outcome of operative treatment over conservative treatment.[2] However, the need for a secondary arthrodesis is approximately 21-30% after initial conservative treatment versus 2-5% after operative treatment.[2-4] Currently there is insufficient evidence whether patients requiring a late subtalar arthrodesis after initial operative treatment do better than those initially treated conservatively.[5]

The late sequelae after an intra-articular calcaneal fracture are notorious and include, among others, incongruence and painful arthritis of the posterior talocalcaneal and calcaneocuboid joint, arthrofibrosis and a stiff subtalar joint, lateral impingement of the peroneal tendons and fibular abutment, impaired dorsiflexion of the ankle joint and tibiotalar impingement, broadening of the calcaneus and loss of height, hindfoot varus or valgus deformity, subluxation in the Chopart joint, pes planus, neuropathies, and a painful heel pad.[4,6,7] The dilemma of the painful old calcaneal fracture[8] has brought upon various different salvage procedures. These are based upon the four main indications for an arthrodesis: 1) to achieve correction of the deformity, 2) to relieve pain, 3) to stabilize the joints, and 4) to improve functional outcome.[9-12] Discussion remains whether these deformities should be managed by subtalar in-situ, triple, or bone-block distraction arthrodesis. Moreover, it remains unclear whether a secondary arthrodesis will result in improved outcome after initial operative treatment, compared with initial conservative treatment.

The objective of this study was to compare the outcome as measured by disease specific outcome and generic quality of life scores after a secondary in-situ subtalar versus triple arthrodesis for painful posttraumatic arthritis and malunion following an intra-articular calcaneal fracture, which were initially treated either conservatively or operatively.

PATIENTS AND METHODS

At our institution both the trauma and the orthopaedic surgeons provide the fracture-care in trauma patients. Initial treatment for calcaneal fractures by the trauma surgeons is usually operative (percutaneous or ORIF), whereas orthopaedic surgeons prefer conservative treatment. The conservative and ORIF methods are common treatment modalities and are performed following standard procedures, as described in the literature.[2,3,13] The percutaneous treatment had been performed following the technique described by Forgon and Zadravecz, with modifications as described before.[14] In short, this method is based upon distraction of the fracture and realignment of the hindfoot, restoring height, width, varus/valgus malalignment, and gross incongruence at the subtalar joint, by ligamentotaxis and subsequent percutaneous screw fixation.[14]

The decision to perform a subtalar or triple arthrodesis as salvage procedure is based upon patient history, physical examination, pre-operative radiographs and preference of the surgeon. Several patients were referred after various different treatment modalities or failed subtalar arthrodesis after an intra-articular calcaneal fracture.

Patient selection

All electronic operation records between 1990 and 2005 were searched for subtalar or triple arthrodesis using the appropriate operation codes. These records were subsequently searched manually for the indication to operate in order to select only the patients with an arthrodesis performed for the painful sequelae after an intra-articular calcaneal fracture. A minimum follow-up of two years was used, providing sufficient time for the arthrodesis to heal and for patients to adapt to the new situation.

Operative technique

In all subtalar and triple arthrodeses a lateral approach was used in one of two ways: a curved Ollier incision over the sinus tarsi or a longitudinal incision starting 1 cm caudal to the tip of the distal fibula towards the base of the fourth metatarsal. An additional medial incision, to approach the talonavicular joint, was used in four occasions when a triple arthrodesis was performed. The technique used for the in-situ fusion equals the method as described previously.[15-17] The need for bone grafting and internal fixation was determined during operation. A decompression of the lateral calcaneal wall was not performed routinely, but only in case in which a lateral impingement was evident after realignment of the hindfoot (N=3).[18] After-treatment consisted of 4 to 6 weeks of non-weight bearing below-knee plaster followed by 4 to 6 weeks weight bearing in a below-knee cast.

Pseudarthrosis and complications

The numbers of infections and nonunions at the arthrodesis site were determined by reviewing the charts and radiographs of all patients.

Radiological evaluation

Böhlers angle and the crucial angle by Gissane were determined in the pre-operative radiographs of all patients. In the pre-arthrodesis and post-arthrodesis radiographs the following angles were measured: the calcaneal inclination, the talar declination, and the talocalcaneal angle. Angles were determined as described before.[19] Pre-arthrodesis CT-scans or axial radiographs were used to classify the malunion according to the classification by Stephens and Sanders.[20,21] This classification consists of three malunion types. In type 1 there is bulging of the lateral wall without subtalar arthrosis. Type 2 shows lateral wall exostosis and an incongruent joint with subtalar arthrosis, without varus malalignment. Type 3 is characterized by lateral wall exostosis, subtalar arthrosis and more than 10 degrees of hindfoot varus.[21]

Clinical evaluation

Clinical evaluation was by postal questionnaire and by reviewing all charts after approval of the local Medical Ethics Committee. All eligible patients were sent a set of questionnaires, which included the SF-36, a single question VAS and the Maryland Foot Score (MFS)[22]. The MFS comprises of 100 point, and allows for objective assessment of the foot and ankle with respect to pain, function, cosmetics and range of motion. The MFS was previously shown to be reliable and valid in determining outcome after intra-articular calcaneal fractures.[23] The SF-36 consists of 36 items that assess health-related quality of life by means of eight health domains: physical functioning (PF); role limitations due to physical health (RP); bodily pain (BP); social functioning (SF); vitality energy or fatigue (VT); general health perceptions (GH); role limitations due to emotional problems (RE); and general mental health (MH). The PF, RP, and BP scales reflect the physical elements of health; the SF, RE, and MH represent psychological aspects; and VT and GH indicate the subjective perception of health. Scores ranging from 0 to 100 points are derived for each domain, with lower scores indicating poorer function. These scores were converted to a norm-based score and compared with the norms for the general population of the United States (1998). In the US population each scale was scored to have the same average (50 points) and the same standard deviation (10 points).

In addition to the retrieved data from the medical charts, patients were asked for their weight and length (from this data the BMI was calculated) and smoking behaviour as these might affect union-rates and outcome.

Statistical analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) version 12.0.1 (SPSS, Chicago, IL, USA). Functional outcome after subtalar arthrodesis versus triple arthrodesis was assessed using the non-parametric Mann-Whitney U test. In addition, the influence of smoking on the rate of nonunions was investigated using a Chi-square analysis. Associations were considered statistically significant with a p-value of < 0.05.

RESULTS

A total of 56 patients with in total 61 arthrodeses, either in situ subtalar or in situ triple, were identified during the first screening. All patients suffered from pain and restrictions in daily activities, which did not subside with conservative measures. Fourteen patients were left out for further analysis, as these had moved and their current address could not be retrieved. From the 42 sent questionnaires a total of 33 patients responded. The median age at trauma was 39 years (range 19-74) and 23 were male. In these patients 37 arthrodeses were performed (16 right sided, 13 left sided, and four bilateral). Twenty-four fractures were initially treated conservatively, and 13 patients were treated operatively (six ORIF, seven percutaneous). The median time between injury and arthrodesis was 29 months (range 9-456). There were 27 in-situ subtalar arthrodeses performed and ten triple arthrodeses performed as initial salvage procedure. Ten feet, that initially underwent a subtalar arthrodesis, were completed to a triple arthrodesis, which in seven of these feet was because of a non-union at the subtalar joint and progressive arthrosis at the Chopart joint, and in three feet only because of progressive arthrosis. Thus, at follow-up there were 17 subtalar and 20 triple arthrodeses.

An in-situ arthrodesis was performed in all cases, e.g. no bone-block distraction or sliding-osteotomy arthrodeses were performed. In 19 cases no internal fixation was used, whereas others were internally stabilized using staples (N=9) or cannulated screws (N=9). Bone graft was harvested from the iliac crest in eight feet or from the proximal tibia in nine feet. Local bone graft was used in eight cases; in 12 cases no bone graft was used.

Pseudarthrosis and complications

A nonunion was seen in one or more joints in 14 feet. In one out of ten initial triple arthrodeses a non-union occurred of the talonavicular and the talocalcaneal joint. In 13 out of 27 initial subtalar arthrodeses a non-union of the talocalcaneal joint occurred. In the total population of 56 patients with 61 arthrodeses a total of 18 non-unions occurred (30%). Revision surgery was performed in these cases, and three of these underwent a second revision surgery due to a persistent non-union. Three superficial infections and one osteomyelitis were seen in four feet. Screws or staples were removed in nine feet.

Radiological results

Median preoperative Böhlers and Gissanes angle for the entire group was 5 degrees (P_{25}-P_{75}, -15-17) and 112 degrees (P_{25}-P_{75}, 105-125), respectively. Preoperative talocalcaneal, calcaneal inclination and talar declination angles were 19 (14-23), 20 (16-24), and 8 (5-13) degrees, respectively. Most feet had some degree of varus (median 5 degrees, P_{25}-P_{75}, 0-14). The old calcaneal fractures were classified according to Stephens as two type 1, 29 type 2, three type 3, and 17 unknown). Postoperatively the talocalcaneal, calcaneal inclination and talar declination angles were 19 (14-25), 21 (18-25) and 8 (4-12) degrees respectively. On average feet were in neutral position, except for three feet that were still in 5 degrees or more varus. There were 24% missing values because of absence of radiographs or specific views. In Table 1 the pre- and postoperative data are presented according to the arthrodesis end-situation. No statistically significant differences between the two groups were noted.

Clinical results and correlations with outcome

Patients with both end-situations were comparable for sex, age at fracture, initial treatment, time to arthrodesis, follow-up and post-operative radiological angles (Table 1). There was no statistically significant difference in outcome, as measured by the MFS, SF-36 and VAS, between patients with a subtalar or triple arthrodesis ($p = 0.79$, 0.67, and 0.21, respectively; see Table 1).

In the group of responders with a non-union (N=9) seven patients were smokers (78%), whereas only five out of 19 patients without a non-union (26%) were smokers ($p = 0.017$). In the entire group of patients (N = 56 patients, with 61 arthrodeses) the correlation between smoking and the occurrence of a non-union was significant as well ($p = 0.021$).

Table 1.	Data of patients with a subtalar or triple arthrodesis at follow-up			
Parameters	Total	Subtalar	Triple	p
Patients/feet (n)	33/37	16/17	17/20	-
Male (n)	23	10	13	0.46[a]
Median age at fracture (year)[1]	39 (32-45)	43 (31-54)	36 (32-44)	0.44[b]
Initial treatment (C/O/P)	24/6/7	10/3/4	14/3/3	0.48[a]
Time to arthrodesis (months)[1]	29 (19-55)	27 (12-33)	42 (23-62)	0.69[b]
Median follow-up (months)[1]	116 (52-156)	110 (45-146)	127 (80-159)	0.16[b]
Post-arthrodesis angles (degree)[1]				
Talocalcaneal	20 (16-27)	20 (14-28)	20 (16-26)	0.85[b]
Calcaneal inclination	21 (18-24)	22 (18-26)	20 (18-24)	0.69[b]
Talar declination	8 (6-12)	9 (7-13)	8 (6-11)	0.58[b]
Varus/valgus	0 (0-3)	0 (0-4)	0 (-4-2)	0.29[b]
Missing values (%)	24	21	25	0.43[a]
Post-arthrodesis BMI[1]	27.1 (25.6-29.3)	27.4 (24.6-28.3)	27.1 (25.7-31.1)	0.72[b]
Outcome scores[1]				
MFS	56 (44-70)	59 (39-77)	56 (46-69)	0.79[b]
SF-36 (Total)	83 (72-97)	84 (69-99)	83 (72-93)	0.67[b]
SF-36 (PSC)	33 (26-46)	33 (26-47)	33 (25-42)	0.56[b]
SF-36 (MSC)	52 (39-56)	52 (38-57)	52 (39-56)	0.97[b]
Post-VAS	6 (4-7)	5 (4-8)	6 (5-7)	0.21[b]

C, initial conservative treatment; O, initial treatment using ORIF; P, initial percutaneous treatment; BMI, Body Mass Index; MFS, Maryland Foot Score; PSC, Physical Score Component; MSC, Mental Score Component; VAS, Visual Analogue Scale.
[1]Data are presented as median with the P_{25} and P_{75} between brackets.
Data were analysed using the [a]Chi2 and [b]Mann-Whitney U-test. P-values below 0.05 were considered statistically significant.

DISCUSSION

The aim of this study was to compare the functional outcome of an in-situ subtalar or triple arthrodesis for the painful sequelae of an intra-articular calcaneal fracture treated either conservatively or by means of osteosynthesis (ORIF or by percutaneous fixation using screws or K-wires) with a minimum follow-up of two years. No apparent statistically significant correlation between the type of arthrodesis and functional outcome was found, using a disease-specific outcome score (MFS), a generic quality of life scale (SF-36), and patient satisfaction (VAS) as outcome measures. The overall results of the questionnaires as returned by thirty-three patients were fair (56 points on the MFS). By breaking up the SF-36 into the physical health component and the mental health component clearly showed that the physical part of the SF-36 was affected far more than the mental component by deviating from the norm-based score of 50.[24] Patients still experience much nuisance from the previously fractured calcaneus.

A secondary triple arthrodesis after an intra-articular calcaneal fracture has not been described frequently in the literature. Over 500 cases of in situ subtalar arthrodeses performed after failed treatment of intra-articular calcaneal fractures were identified in numerous studies (Table 2), in contrast only 14 cases of secondary triple arthrodesis in three studies were found as salvage technique after calcaneal fractures (Table 3).

The results in this study compare negatively to the literature as summarised in Table 2. One study applying the MFS found an average score of 86 in 19 patients.[21] And with the use of the American Orthopaedic Foot and Ankle Society Hindfoot score (maximum of 94 points) an outcome score between 63 and 83 points has previously been found. All other studies classify patients into excellent, good or satisfactory groups, making comparisons slightly more difficult. Some studies reporting on the results of arthrodeses present mixed populations with acquired flat feet (e.g. tibial tendon dysfunction), subtalar dislocations, non-traumatic arthritis, and after calcaneal fractures. The results of arthrodeses after calcaneal fractures have been reported to be lower as compared to the arthrodesis for other causes.[17,25]

The fair results might be attributed to several factors. A rather high rate of non-union was found in this study, which might be partially explained by the high percentage of patients that smoked and a relatively high rate of revision surgeries of previously failed subtalar arthrodeses. A correlation of impaired healing of the arthrodesis and smoking has been demonstrated in other studies[25-27], as well as the correlation with revision surgery.[25] It has been demonstrated that the amount of avascular subchondral bone at the subtalar joint correlates with the occurrence of a non-union.[25] At our institute no per-operative data exist concerning the condition of the subtalar joint during the procedure.

There might have been a negative selection bias, in which more patients with persistent complaints returned the questionnaire. In addition, the operative technique might have been imperative in some cases. For example, the resection of the lateral wall[17,20,21,28-32] was not performed routinely at our institute (N = 2). There was no delineated treatment protocol.[30] In addition, a rather large variety of type of bone-grafting and fixation had been used in the current study. To what extent these factors contributed to less favourable results remains speculative.

Discussion has risen if the initial treatment modality influences the functional outcome after an arthrodesis. Regardless of the type of arthrodesis, current data revealed no statistically significant difference in the overall median MFS, VAS and SF-36 after initial conservative treatment (55, 6, and 83, respectively) versus initial operative treatment (64, 5, and 87, respectively; data not shown). However, statistical power was insufficient to make a definitive statement. Thermann found an AOFAS score of 69 points in the initially operated group (n = 17) versus 65 in the conservative group (n = 23), suggesting a trend towards improved functional outcome after subtalar arthrodesis with initial operative regime.[5] Others found no correlation with the initial treatment and the arthrodesis at follow-up.[32,33]

The 24% missing values in the radiological evaluation was due to a difference in the follow-up protocol for the trauma and orthopaedic surgeons. A lateral image of the hindfoot was made in all cases, an anteroposterior image of the ankle was made by the orthopaedic surgeons and an axial image of the calcaneus by the trauma surgeons only.

Table 2. Overview of the literature of in-situ subtalar arthrodesis

Author (year)	Patients (n) [calcaneal #]	Average time between fracture and arthrodesis (range)	Follow-up since arthrodesis (range)	Union rate (%)	AOFAS/other scoring system (range)	Return to work (%)
Conn (1935)[38]	39 [39]	-	-	-	50-66% G	-
Kalamchi (1977)[39]	6 [6]	Range 6-12m	Range 1.5-3.5y	100	100% S	50
Johansson (1982)[37]	21 [23]	av2.2y (1-5)	4.3y (2-9)	100	96% G+S	95
Russotti (1988)	45 [17]	28m	48m	98	71% S	93
Mann (1988)[40]	9 [5]	-	42m (23-103)	100	89% G+E	-
Myerson (1993)[41]	15 [15]	22m (10-49)	31m (26-41)	100	77 (45-91)	87
Stephens (1996)[21]	19 [19]	35m (2-194)	31m (12-54)	100	86* (84% G+E)	-
Dahm (1998)[18]	24 [19]	4y (0.3-33)	4y (2-6)	96	68% G+E	88
Mann (1998)[17]	44 [12]	3.5y (1-13)	60m (24-177)	100	83	-
Sammarco (1998)[16]	45 [13]	-	22.6m	93	82% S	-
Chandler (1999)[32]	18 [19]	32m (8-156)	27m (12-62)	100	71	67
Thermann (1999)[5]	40 [40]	3.5y (0.25-20)	5.2y (2-11)	98	65/69**	-
Easley (2000)[25]	152 [?]	17m (4-126)	51m (24-130)	85	70	-
Flemister (2000)[42]	49 [49]	28m	50m	96	75	61-71
Kolodziej (2001)[43]	9 [9]	25m (6-60)	37m 12-56)	100	63 (39-94)	83
Savva (2007)[28]	17 [17]	41m (7-288)	79m (48-94)	-	78 (48-94)	94
Davies (2007)[15]	96 [±67]	-	-	94	71% G***	-

This table shows the results from several studies concerning in situ subtalar arthrodeses. The number of patients and the number of calcaneal fractures are given, the time between the injury and the arthrodeses; as well as the duration of follow-up and the main findings at follow-up. E, excellent; G, good; S, satisfactory; y, years; m, months.
* MFS, ** scores for conservatively and operatively treated patients respectively, *** Angus-Cowell score.

Table 3. Overview of the literature of secondary in-situ triple arthrodesis

Author (year)	Patients (n) [calcaneal #]	Average time between fracture and arthrodesis (range)	Follow-up since arthrodesis (range)	Union rate (%)	AOFAS/other scoring system (range)	Return to work (%)
Conn (1935)[38]	6 [6]	-	-	-	83% G	-
Myerson (1993)[41]	5 [5]	33m (19-50)	34m (26-44)	-	51 (40-65)*	80
Kolodziej (2001)[43]	3 [3]	18m (5-36)	88m (63-112)	100	72 (50-94)	100

E, excellent; G, good; S, satisfactory; y, years; m, months. *Modified AOFAS This table shows the results from several studies concerning in situ triple arthrodeses. The number of patients and the number of calcaneal fractures are given, the time between the injury and the arthrodeses; as well as the duration of follow-up and the main findings at follow-up.

Several authors have pointed out the importance of performing a triple arthrodesis after failed treatment of displaced intra-articular calcaneal fractures, e.g. Conn[34], Harris[35], and Bankart[36]. And the need for a comparative study of subtalar versus triple arthrodesis was already stressed by Jahss in 1982.[37] Despite the limitations of this study it is the first to compare the in-situ subtalar and triple arthrodesis after an intra-articular calcaneal fracture. The data of the current study imply no statistically significant difference in functional outcome between secondary in-situ subtalar or tripe arthrodesis as therapy for symptomatic arthrosis after an intra-articular calcaneal fracture. Moreover, current data confirmed that smoking is a risk factor for non-union, as shown previously.[25-27] A standardised treatment-protocol (including the surgical technique and follow-up strategy) might improve outcome and would enable the comparison of different techniques.

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Chapter 12

Calcaneal nonunion: Three cases and a review of the literature

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ABSTRACT

The long-term follow-up of intra-articular calcaneal fractures is often accompanied by complications. Frequently occurring are arthrosis, arthrofibrosis of the subtalar joint, and malunion. Uncommon is the calcaneal nonunion. A total of three cases is presented in this report, including a review of the literature. The occurrence of a nonunion appears to be more common after conservative treatment, but the pathophysiology remains unclear, however smoking may play a role.

INTRODUCTION

During long-term follow-up after intra-articular calcaneal fractures complications frequently occur. In clinical practice, arthrosis and arthrofibrosis of the subtalar joint, malunion and nonunion are encountered.[1,2] Nonunion is only rarely found, and studies concerning complications after intra-articular calcaneal fractures do not describe this complication.[3,4] In only five studies, including nine patients, reports on nonunion are made.[5-9] Three patients with a pseudarthrosis after an intra-articular fracture of the calcaneus are presented in the current study.

CASES

Case 1:

A male adult (age 49) fell from a height of two meters fracturing his left calcaneus. According to the Essex-Lopresti classification he sustained a joint-depression type, and a type IIA fracture according to the Sanders classification. There was no injury to the soft tissues. After six days the fracture was operated on, using percutaneous reduction and fixation according to the technique of Forgon and Zadravecz.[10] Post-operative treatment consisted of active range of motion exercises and three months non-weight bearing. Initial recovery was uncomplicated. Two years after the trauma, the patient however returned to our outpatient department with complaints of painful walking, and unable to work. A computed tomography (CT) scan showed a pseudarthrosis of the calcaneus and talocalcaneal joint surface incongruence (Figure 1). An injection of 10cc lidocain in the subtalar joint temporarily reduced pain. A subtalar joint arthrodesis was performed, fusing the talus and calcaneus with the use of bone graft gained from the iliac crest. After 1 year the arthrodesis has fully consolidated, the patient is pain free, but has currently not yet returned to work.

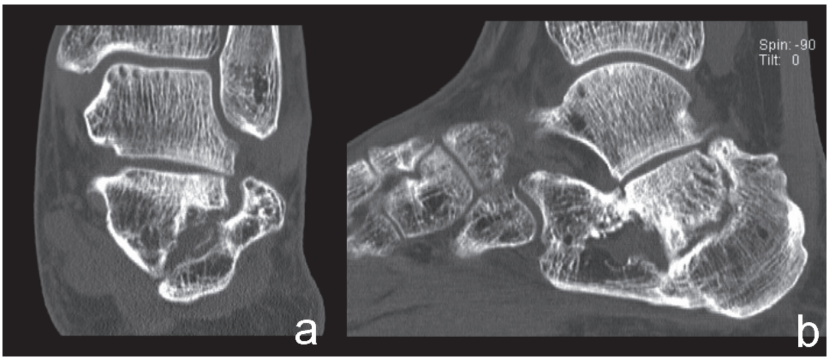

Figure 1. a, Case 1: Axial CT-scan image twenty-two months after percutaneous reduction and fixation showing nonunion; b, Sagittal view.

Chapter 12

Case 2:

A female patient, aged 53, sustained a fracture of the right calcaneus after a fall from the stairs (Essex-Lopresti joint depression type, Sanders type IIB). As patient was seen three weeks after the trauma, the initial treatment was conservatively, consisting of one week of plaster-of-Paris and three months non-weight bearing with active range of motion exercises. Two months later the patient was unable to bear weight at the fractured side due to pain. A CT showed a delayed union of the calcaneus (Figure 2). Peroperatively, 6 months after trauma, there was a nonunion of the fracture, without apparent signs of arthrosis of the talocalcaneal joint surface. Because of the smoking habits and diabetes in this patient, as independent causes of high wound complication rates, an early subtalar arthrodesis with bone graft harvested from the tibial tuberosity was performed instead of a correcting osteotomy. Three months after the salvage operation the arthrodesis had consolidated, the patient is walking pain free.

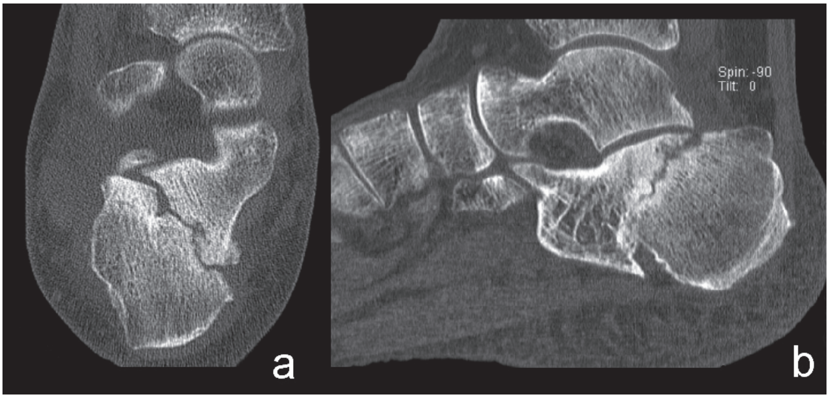

Figure 2. a, Case 2: Semi-coronal CT-scan image 5 months after conservative treatment showing delayed union; b, Sagittal view.

Case 3:

A male adult, of 39 years old, sustained a bilateral calcaneal fracture after jumping of a first storey balcony. The radiographs showed a comminuted intra-articular calcaneal fracture according to the Essex-Lopresti classification at both sides and Sanders type IIC and IIIAC fractures on the left and right foot, respectively. Initial treatment was conservative, consisting of 1 week of plaster-of-Paris and 3 months non-weight bearing with active range of motion exercises. Thirteen months later the patient returned to the outpatient department with complaints of pain at the left heel. Additional radiographs and CT showed a nonunion of the fracture of the left calcaneus (Figure 3). A subtalar arthrodesis was performed, with bone graft from the tibial tuberosity. Two cannulated screws were inserted from the tuberosity of the calcaneus, bridging the primary fracture line. The after treatment was complicated with a superficial infection, which could be treated adequately with intravenous antibiotics. Six months after the secondary fusion the patient was able to walk pain free.

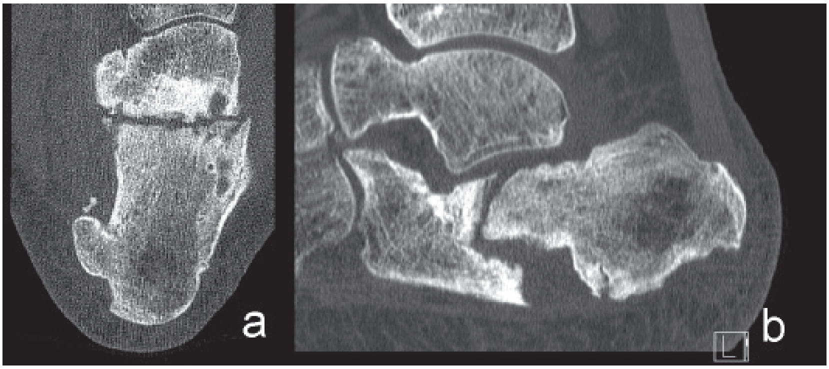

Figure 3. a, Case 3: Semi-coronal CT-scan image 13 months after conservative treatment showing nonunion; b, Sagittal view.

DISCUSSION

Improper healing after an intra-articular calcaneal fracture carries a high morbidity. Three groups: A, malunion; B, nonunion; and C, osteonecrosis, were suggested by Zwipp.[8] These groups are further divided according to the presence of joint incongruence, varus/valgus, loss of height, translation of bones and luxation. Treatment of these complications after intra-articular calcaneal fractures depends upon to the presence of these conditions.[8]

The first written report on calcaneal fracture nonunion was by Thomas in 1993. He presented a 36 year old female patient, treated non-operatively, who developed a calcaneal nonunion after six months.[7] A correction of the displaced fragment was performed and stabilized using plate osteosynthesis and bone graft. The patient was able to fully bear weight twelve weeks after this procedure.

Gehr described a 38 year old male patient with an intra-articular, comminuted fracture of the calcaneus.[5] This fracture was treated with open reduction and internal plate osteosynthesis. After removal of the plate at 18 months the patient returned to the clinic with local swelling and pain during walking. A nonunion was seen and a correction osteotomy was performed with bone graft and screw fixation. The fracture showed healing at eight weeks.

Karakurt et al. presented one 42-year old male patients with a nonunion of the calcaneus after conservative treatment.[6] The patient sustained a comminuted, open calcaneal fracture which was treated in plastercast for six months. Eight months after trauma the patient was unable to walk without crutches because of severe pain of the heel. After removing fibrotic tissue the calcaneus was filled with bone graft. Eight months after the operation patient was able to walk and work without pain.

Zwipp and Rammelt reported two patients with a nonunion of the calcaneus.[8] A 61 year old female patient with a Sanders IIC fracture with a luxation of the tuberosity fragment, treated conservatively. An arthrodesis of the subtalar and calcaneocuboid joint was performed six months after trauma. Postoperatively the American Orthopaedic Foot and Ankle Society hindfoot score improved significantly, compared with pre-operative values. The second patient was a 45 year old female polytrauma patient. After percutaneous reduction and fixation she was diagnosed with a nonunion one year after the trauma, for which a subtalar joint arthrodesis was performed. No data on outcome was provided in this case.

From cases described in literature and in the current report no similarities that could indicate a risk factor of nonunion could be found. There are no apparent similarities besides the nonunion (Table 1). There might be a trend of nonunion occurring after conservative treatment, suggesting that less rigid or no fixation may play a role in causing fracture nonunion in the calcaneus. However Howard et al. saw no cases of nonunion in a group of 164 intra-articular calcaneal fractures treated nonoperative.[4] Patient age varied between 36 and 61, both sexes were affected equally often and initial treatment differed between patients. Karakurt suggested that smoking could be the cause of the nonunion.[6] All patients in this report were smokers. For tibial fractures strong evidence exists for delayed fracture healing in smokers.[11] And a significant lower union-rate was seen after subtalar arthrodesis in smokers versus non-smokers.[12] Assous et al. however saw no difference in fracture healing between smokers and non-smokers in a small series of intra-articular calcaneal fractures treated operatively.[13]

In contrast to the infrequent occurrence of the calcaneal nonunion, stated by the case reports above, Thermann et al. describe an in incidence of 10% nonunion (n=4/40) in a group of patients receiving a subtalar arthrodesis for persisting invalidating pain after an intra-articular calcaneal fracture.[9] In these four patients the nonunion coincided with painful subtalar posttraumatic arthrosis, delineating the indication for a subtalar arthrodesis, instead of a correction osteotomy with internal fixation.[9]

Calcaneal nonunion has been reported on infrequently in the literature, but given the number of patients seen by Thermann, and our own series, suggests that the incidence might be higher than expected.

Table 1. Summary of patients presented in the literature after a calcaneal nonunion

Study	Gender	Age	Initial treatment	Salvage procedure	Follow-up (months)*
Thomas (1993)	Female	36	Conservative	Osteotomy, plate, bone graft	3
Thermann (1999)	-	-	-	Subtalar arthrodesis	62
Gehr (2000)	Male	38	ORIF	Osteotomy, screws, bone graft	2
Karakurt (2004)	Male	42	Conservative	Bone graft	8
Zwipp (2006)	Female	61	Conservative	Subtalar arthrodesis, calcaneocuboid joint fusion	-
	Female	45	Percutaneous	Subtalar arthrodesis	-
Current study	Male	49	Percutaneous	Subtalar arthrodesis	14
	Female	53	Conservative	Subtalar arthrodesis	3
	Male	39	Conservative	Subtalar arthrodesis	6

*The follow-up period after the salvage procedure is given.

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Summary, conclusions and future considerations

Since Bankart stated in 1942 that "The results of the treatment of crush fractures of the os calcis are rotten[1]" much has changed. Substantial research has been done, and the outcome appears more favorable than half a century ago. Treatment protocols for patient selection, choice of treatment modality, surgical approach to acute fractures and salvage procedures, and after-treatment have lowered complication rates and increased patient satisfaction.

This thesis covers three aspects of calcaneal fracture treatment: 1) classification systems, radiographic evaluation, and outcome scoring, 2) the surgical treatment; including outcome and complications, and 3) the after-treatment and management of failed primary treatment.

PART 1: CURRENT TREATMENT OF INTRA-ARTICULAR CALCANEAL FRACTURES

Chapter Two provides an overview of the current literature concerning all elements in the treatment process of intra-articular calcaneal fractures. A complete understanding of the complex anatomy and trauma mechanism, and interpreting various forms of diagnostic tools are important elements in the management of intra-articular calcaneal fractures. Selecting the appropriate treatment modality for the right fracture and the right patient is paramount. After decennia of research there is still no clear treatment strategy. Despite a higher risk of infectious complications, there appears to be a trend towards improved functional results after operative treatment, with an earlier return to work and a reduced need for a secondary arthrodesis. The best results are seen in high volume centres, as the learning curve (35-50 fractures) is completed earlier. There is a need for more consensus in classifying fractures and the use of outcome scoring systems.

In an attempt to describe the management of calcaneal fracture in the Netherlands (**Chapter Three**), for future research purposes, and to estimate the magnitude of the problem a national survey was conducted. The overall response rate was approximately 70 percent. The data from this survey shows that fracture classification was applied by 29% of the respondents. Treatment was mainly with ORIF (46%), conservative (39%) and percutaneous (10%), with a non-weight-bearing period of 9 weeks (SD 2 weeks). Only 7% of the respondents reported the use of an outcome score. And the total socio-economic cost of displaced intra-articular calcaneal fractures in the Netherlands was estimated to be €21.5–30.7 million.

PART 2: UNIFORMITY IN TREATMENT OF INTRA-ARTICULAR CALCANEAL FRACTURES

In the literature a large variety of treatment strategies is described, without uniformity concerning pre-, per-, and postoperative management as stressed by several authors worldwide.

The second part of this thesis was therefore meant to create more uniformity in the diagnostic care surrounding intra-articular calcaneal fractures.

First, three widely used radiological classification systems (the classifications of Essex-Lopresti, Crosby and Sanders) were tested for interobserver agreement and variability (**Chapter Four**). From these, the Sanders and Crosby classifications had comparable moderate interobserver variability among surgeons and radiologists and we therefore recommend using either one of these for the evaluation of intra-articular calcaneal fractures.

Secondly, the standard radiographic evaluation of intra-articular calcaneal fractures was investigated. The evaluation of outcome after a calcaneal fracture relies traditionally on three pillars: standardised questionnaires, physical examination and the use of radiographs in various projections. There is substantial controversy concerning the use of radiographic assessment as outcome measure, because each projection only shows a small part of the calcaneus and especially of the subtalar joint. A total of twelve different angles and anatomical distances were measured in patients after a unilateral intra-articular calcaneal fracture, after which these were correlated with the outcome (**Chapter Five**). There was no statistically significant correlation of radiologic findings with disease-specific outcome scores, patient satisfaction or the need for an arthrodesis. From these data it was concluded that measurements on plain radiographs might not be as useful in determining outcome after intra-articular calcaneal fractures as previously reported.

And thirdly, an overview of all outcome scoring systems used in the literature for the evaluation of treatment of intra-articular calcaneal fractures was made (**Chapter Six**). The three most frequently used outcome scores were the American Orthopaedic Foot Ankle Society (AOFAS) Hindfoot score, the Maryland Foot Score (MFS), and the Creighton-Nebraska score (CN). The AOFAS hindfoot score is the most applied and cited score of 34 outcome scoring systems used in calcaneal fractures, followed by the MFS and the CN score. Reliability as measured by the internal consistency was good for the AOFAS score and the MFS. All 3 scores measured the full range of complaints. From this study we recommend using the widely accepted, reliable and valid AOFAS hindfoot or the Maryland Foot Score as the scoring systems of choice.

PART 3: PERCUTANEOUS TREATMENT OF INTRA-ARTICULAR CALCANEAL FRACTURES

A review of the literature was performed to identify all studies published since 1990 in which a percutaneous form of surgery was performed on displaced intra-articular calcaneal fractures. The combined data is presented in **Chapter Seven** and shows overall good to excellent result in 71 to 90% of patients. Ten up to 26% of patients is unable to return to work after percutaneous treatment of their fracture. A secondary arthrodesis had to be performed in 2 to 15% of cases. Infectious complications occurred in 2 to 15% and some loss of reduction was reported in 4 to 67%.

Percutaneous reduction and subsequent fixation is the oldest form of operative treatment for displaced intra-articular calcaneal fractures (**Chapter Eight**). The technique of percutaneous reduction and fixation of displaced intra-articular calcaneal fractures according to

Forgon and Zadravecz (University Clinics of Pècs, Hungary), which forms the basis of this thesis, is described in detail. This minimal invasive treatment enables special care to the soft tissue envelope surrounding the calcaneus, while restoring anatomy (width, height and varus deformity) and reducing large defects in the posterior subtalar joint. This technique enables surgeons to restore foot function, the arch of the foot and overall shape (height and width), but at a lower rate of wound complications.

Chapter Nine shows the results of a retrospective series of 50 patients with 61 intra-articular calcaneal fractures treated percutaneously. With an average follow-up of 35 months the mean scores for the Maryland Foot Score (MFS), Creighton-Nebraska (CN) and American Orthopaedic Foot Ankle Score (AOFAS) were 79, 76 and 83 respectively, indicating a good to excellent result in most patients. Subtalar joint motion was 70%, which compares favorable to the literature on conservative and open operative treatment.

A less frequently applied form of outcome measurement is plantar pressure and foot position analysis (**Chapter Ten**). Twenty-one patients with a unilateral calcaneal fracture, treated with percutaneous reduction and fixation, were investigated with plantar pressure analysis. Correlations were determined between the ratios (injured/control) of plantar pressure and foot position variables and outcome scores, the physical examination items ratios, the fracture classification and the radiological. Patients put significantly more weight on the control foot than on the injured foot while standing. The injured foot had a significantly reduced total contact time and higher maximum pressure under the first metatarsal compared with the control foot. Limited correlations with outcome scoring systems were identified, suggesting that plantar pressure analysis should not be used instead of but in addition to established outcome scores.

PART 4: MANAGEMENT OF DELAYED COMPLICATIONS

Depending on the initial treatment modality between 2 to 30 percent of patients suffer from persistent complaints after a displaced intra-articular calcaneal fracture. These complaints are mainly caused by subtalar arthrosis. Different salvage techniques exist, but the most frequently applied is the secondary arthrodesis. In **Chapter Eleven** a total of 33 patients with 37 secondary arthrodeses (17 subtalar and 20 triple) with a median follow-up of 116 months were asked to complete questionnaires regarding the disease-specific functional outcome (Maryland Foot Score, MFS), quality of life (SF-36) and overall satisfaction with the treatment (Visual Analogue Scale, VAS). The results of this study showed no significant difference in functional outcome between an in situ subtalar and triple arthrodesis as salvage technique for symptomatic arthrosis after an intra-articular calcaneal fracture. Smoking was found to be a risk factor for non-union at the arthrodesis site.

A rare delayed complication of intra-articular calcaneal fractures is a nonunion at the fracture site. **Chapter Twelve** shows three cases and an overview of the literature in which a nonunion was treated, mostly by a secondary subtalar arthrodesis.

CONCLUSIONS

1. More uniformity can be obtained obtained in the evaluation of displaced intra-articular calcaneal fractures, considering classification systems, radiographic evaluation and outcome scoring.
2. Minimal invasive surgery, according to Forgon and Zadravecz, for displaced intra-articular calcaneal fractures provides overall good to excellent result in 71 to 90% of patients.
3. In case of persistent complaints a subtalar arthrodesis provides equal results compared to a triple arthrodesis.

FUTURE CONSIDERATIONS

Three recommendations to improve percutaneous reduction and internal fixation of displaced intra-articular calcaneal fractures, which may contribute to enhanced outcome, provided faster recovery, and a reduction in socio-economic burden, are proposed below.

1. Tailor-made treatment

No universal treatment or surgical approach exists that can be applied to treat all fractures of the calcaneus.[2] The choice of treatment should be based upon patient and fracture characteristics. The type of fracture, the degree of displacement, and incongruence at the subtalar joint are important indicators, but the physical and mental status of the patient should also be taken into account. The condition of the soft-tissues like open fractures[3-7], concomitant conditions like diabetes[8], and smoking habits[9,10] all contribute to increased wound complications and delayed fracture healing.

Additional prospective studies, preferably randomized controlled trials, are required in order to develop an evidence-based clinical guideline for intra-articular calcaneal fractures. This will enable surgeons to determine which patient and which fracture may benefit from conservative, open surgical or percutaneous treatment. The Closed Reduction versus ORIF versus Non-Operative Study for displaced intra-articular calcaneal fractures (CRONOS) has been developed to improve insight on this subject.

2. Surgeon and hospital volume

The learning curve for open reduction and fixation of intra-articular calcaneal fractures, is estimated to be 35-50 fractures.[11] According to a national survey among 70% of the Dutch hospitals, this learning curve will take more than five years to complete in most hospitals; 25 of 187 responding orthopaedic and trauma surgery departments (13%) treat more than 10 intra-articular calcaneal fractures per year; which, combined, represents less than 50% of all calcaneal fractures.[12] These 25 departments include the eleven level-1 trauma centers; which jointly treat 25% of all calcaneal fractures in the Netherlands.

In a meta-analysis, Poeze et al. have shown that the number of complications (infection and need for secondary arthrodesis) increases significantly when treating less than one calcaneal fracture with ORIF per month.[13] A complicated course of treatment might negatively affect rehabilitation time and patient outcome. Moreover, treatment of infections and secondary arthrodesis will lead to higher costs.[14]

Similar effects have also been demonstrated for other medical specialties. In Orthopaedic surgery, Urology, Gynaecology, Surgical oncology, and Thoracic surgery, hospital- and/or surgeon-volume effects have previously been identified, which improve outcome and survival and diminishes complication rates in complex surgical procedures.[15-19] In a few studies on complex foot and ankle surgery, including calcaneal fractures, this effect has been noted as well.[11,13,20]

Based on the above, a surgeon-volume of at least ten calcaneal fractures treated with ORIF or PRIF per year after a learning curve of approximately 35-50 patients, as indicated by Sanders et al. [11] seems preferable.

3. Improvements in operative treatment

Surgical techniques and instruments are continuously being improved; however the implication of such improvements is known to be delayed. Some of these recent improvements could be especially useful in percutaneous reduction and internal fixation. The improvements listed below have already been implemented in a clinical setting in dedicated centres for foot and ankle surgery.

a. The use of intra-operative scanning

Good to excellent functional outcome is determined by an exact anatomical restoration of the subtalar joint.[11,21,22] The currently used 2D-fluoroscopes provide a limited view of the subtalar joint, which makes it difficult to determine the accuracy of percutaneous reduction and fixation of fracture fragments. The mobile C-arm system SIREMOBIL Iso-C3D enables intra-operative three-dimensional reconstructions of fracture reduction of the joint-surfaces in intra-articular fractures.[23-26] This was shown to be of value in ORIF of calcaneal fractures.[27,28] The same holds true for intra-operative mobile CT-scanning.[29] A second benefit from intra-operative scanning is the early detection of inadequately placed screws that penetrate the subtalar joint.[21] In percutaneous reduction and fixation of intra-articular calcaneal fractures the incorrect placement of screws might be solved by computer guided screw insertion.[30]

b. The use of intra-operative arthroscopy

There is an increasing interest in arthroscopy of the foot and ankle, not only as diagnostic tool but also as therapeutic modality.[31-39] Arthroscopy has proven to be a valuable tool in patients with calcaneofibular impingement after calcaneal fractures[40,41], during removal of hardware[42], in performing subtalar[43-46] or triple arthrodesis[33,47], and in releasing of subtalar stiffness caused by arthrofibrosis.[42,48,49] Besides these examples subtalar arthroscopy has shown positive an effect on functional outcome in the treatment of intra-articular calcaneal fractures by aiding in a anatomical correction of the posterior talocalcaneal joint during open or percutaneous reduction the use of intra-operative.[42,50-52] *c. Improving stability*

One of the main nuisances reported by patients who sustained an intra-articular calcaneal fracture is the extended non-weight bearing time, which can last up to twelve weeks.[11,53] Diminishing this period should receive attention in future technical improvements as this might improve patient satisfaction and shorten the rehabilitation time. The benefit of angle-stable plating has been investigated, and shows, mainly in cadaver testing, less secondary dislocation of fracture fragments.[54,55] Several clinical studies have now shown that augmentation of the calcaneus with injectable calcium-phosphate bone cement can significantly reduce the time of non-weight bearing; from twelve to three weeks.[56-59] This will be especially beneficial in the rehabilitation after bilateral calcaneal fractures.[56-59] Whether these changes in care lead to improved outcome is yet to be seen.

d. Primary arthrodesis

Being dissatisfied with the results of the treatment modalities, several authors turned to primary or early arthrodesis of the subtalar joint after an intra-articular fracture of the calcaneus.[60-66] One of the earliest descriptions of this technique is by Van Stockum in 1912.[62] Others extended the fusion and recommended an early triple arthrodesis.[1,67] After the somewhat disappointing results from primary arthrodesis as delineated by Lindsay and Dewar the primary fusion became less popular.[62] Secondly the improved results from open reduction and internal fixation lowered the need for an arthrodesis. However, for the Sanders type IV fractures the pendulum might swing back towards primary subtalar arthrodesis after near-anatomical reconstruction of the calcaneus.[68,69] Several studies already revealed overall good outcome, with mean AOFAS scores between 75 and 88 for severely comminuted fractures treated with primary arthrodesis.[70-72] Recently, minimal invasive primary subtalar arthrodesis osteosynthesis was introduced.[73] Using an external two-point distraction apparatus, restoration of height, width and alignment can be obtained. Via a small posterolateral incision as described by Gallie in 1943 the destroyed posterior talocalcaneal joint can be further denuded of cartilage, after which the nail is inserted in the tuberosity of the calcaneus.[64,74] Two, angle-stable, tubero-talar screws are than inserted, with or without bone-grafting, completing the subtalar arthrodesis, and early ambulation is started. Clinical (randomized) studies proving superior results after primary arthrodesis in Sanders type IV fractures are pending.

Samenvatting en conclusies

Sinds Bankart (Orthopedisch Chirurg; 1879-1951) in 1942 zijn zorgen uitsprak over de resultaten van de behandeling van ernstige hielbeenbreuken (calcaneusfracturen), waarbij de breuk doorloopt in een van de belangrijkste delen van het onderste spronggewricht, is er veel veranderd. Diverse onderzoeken naar dit type breuk zijn verricht en de resultaten lijken beter dan een halve eeuw geleden. Het opstellen van behandelrichtlijnen voor verschillende patiënten en verschillende breuktypen en een betere behandeling van blijvende klachten heeft het aantal complicaties verlaagd en heeft geleid tot betere patiënttevredenheid.

Dit proefschift behandelt drie aspecten van de behandeling van hielbeenbreuken:
1. het diagnostische proces: de classificatie systemen, radiologische evaluatie en de uitkomst scores;
2. de chirurgische behandeling, inclusief de resultaten en complicaties; en
3. de nabehandeling en het management van blijvende klachten.

Deel 1: Hielbeenbreuken; de huidige stand van zaken

In **Hoofdstuk Twee** wordt een samenvatting van de huidige literatuur gegeven waarin alle aspecten van de behandeling van hielbeenbreuken de revue passeren. Belangrijke elementen in de behandeling van hielbeenbreuken zijn een goed inzicht in de complexe anatomie, begrip van het ongevalsmechanisme, en het juist interpreteren van verschillende diagnostische onderzoeken. Het selecteren van de beste behandeling voor de juiste breuk en de juiste patiënt staat hierbij centraal. Na vele tientallen jaren is er nog steeds geen eenduidig behandelplan voor alle verschillende breuktypen. Ondanks een hoger infectiegevaar lijkt er een trend te ontstaan voor betere functionele resulaten na een operatieve behandeling, met een snellere terugkeer naar werk en een afname van blijvende klachten. De beste resultaten worden behaald in ziekenhuizen met een groot aanbod van patiënten met een hielbeenbreuk, aangezien de leercurve van de operatieve behandeling van 35 tot 50 patiënten daar sneller behaald wordt. Tevens is er een duidelijke noodzaak om tot een overeenstemming te komen met betrekking tot het gebruik van classificatiesystemen en uitkomstscores.

Om de behandeling van hielbeenbreuken in Nederland in kaart te brengen en toekomstig onderzoek te vergemakkelijken is een enquête verstuurd naar alle vakgroepen Traumatologie en Orthopedie binnen Nederland (**Hoofdstuk Drie**). De gemiddelde respons bedroeg circa 70 procent. De respondenten van de enquête zagen per jaar zo'n 910 hielbeenbreuken. De enquête laat zien dat 29% van de respondenten een classificatiesysteem gebruikt. De behandeling van eerste keus is een open operatie met inwendige fixatie via een ruime incisie aan de buitenzijde van de voet (ORIF; 46%). De conservatieve behandeling en de percutane operatieve behandeling (minimaal invasief via kleine steekgaatjes van minder dan 1 cm) zijn respectievelijk in 39 en 10 procent gebruikt. De periode dat patiënten niet op de aangedane zijde mogen staan was gemiddeld 9 weken Slechts 7% van de respondenten gaf aan een uitkomstscore te gebruiken om de resultaten van de behandeling vast te stellen. De totale socio-economische kosten van verplaatste intra-articulaire, waarbij de breuk doorloopt in het onderste spronggewricht, hielbeenbreuken werden geraamd op €21,5 tot 30,7 miljoen.

Deel 2: Eenheid in de behandeling van hielbeenbreuken

In de literatuur wordt een grote verscheidenheid aan behandelingen beschreven. Er bestaat een gebrek aan eenheid in de pre-, per-, en postoperatieve behandeling. Het tweede deel van dit proefschrift is derhalve bedoeld om meer uniformiteit te creëren in het diagnostische proces rondom de behandeling van hielbeenbreuken.

Allereerst werden drie frequent gebruikte radiologische classificatiesystemen voor intra-articulaire hielbeenbreuken (Essex-Lopresti, Crosby and Sanders) getest op de gelijkgestemdheid tussen verschillende medisch specialisten (**Hoofdstuk Vier**). De classificaties Sanders en Crosby hadden een vergelijkbare gemiddelde interobserver variabiliteit tussen Chirurgen en Radiologen. Derhalve is de aanbeveling om een van deze twee classificatiesystemen te gebruiken in de evaluatie van hielbeenbreuken.

Als tweede hebben we de standaard radiologische evaluatie van hielbeenbreuken onderzocht. Het vaststellen van het resultaat van de behandeling na een hielbeenbreuk gebeurt meestal op drie manieren, nl. Middels gevalideerde vragenlijsten, lichamelijk onderzoek en beoordeling van röntgenfoto's. Met betrekking tot de laatste bestaat onenigheid over de bruikbaarheid in het vaststellen van de uitkomst, aangezien de verschillende röntgenfoto's vaak maar een beperkt deel van het hielbeen tonen. Twaalf verschillende hoeken en lengtes werden gemeten op gestandaardiseerde röntgenfoto's van patiënten met een enkelzijdige breuk van het hielbeen, waarna deze vergeleken werden met de behandeluitkomst (**Hoofdstuk Vijf**). Hierbij werd geen statistisch belangrijke overeenkomst gevonden tussen röntgenfoto's en uitkomst, gemeten middels drie verschillende ziekte-specifieke vragenlijsten, patiënttevredenheid en de noodzaak tot een operatieve verstijving van het onderste spronggewricht. De conclusie van dit onderzoek is dat standaard röntgenfoto's minder bruikbaar zijn in het vaststellen van de resultaten van een behandeling, in tegenstelling tot wat eerder in de literatuur vermeld is.

Als derde werd een overzicht gemaakt van alle uitkomstscoresystemen, welke in de literatuur gebruikt worden voor het vaststellen van het behandelresultaat van hielbeenbreuken (**Hoofdstuk Zes**). De drie meest gebruikte uitkomst-scoresystemen waren de American Orthopaedic Foot Ankle Society (AOFAS) Hindfoot score, de Maryland Foot Score (MFS), en de Creighton-Nebraska score (CN). The AOFAS score was de meest frequent gebruikte score van de in totaal 34 uitkomstscoresystemen. De betrouwbaarheid was het best voor de AOFAS score en de MFS score. Alle drie de meest gebruikte scores meten het volledige uitkomstspectrum. Naar aanleiding van deze studie adviseren wij dat de meest gebruikte AOFAS score en MFS score het best gebruikt kunnen worden voor het meten van de resultaten na de behandeling van hielbeenbreuken.

Deel 3: Percutane behandeling van hielbeenbreuken

Een samenvatting van de gezamelijke resultaten van alle studies (vanaf 1980) waarin de percutane (minimaal invasieve) behandeling voor verplaatste intra-articulaire hielbeenbreuken gebruikt is, wordt beschreven in **Hoofdstuk Zeven**. De gecombineerde resultaten laten een goed tot excellent resultaat zien in 71% tot 90% van de patiënten. Tien tot 26% van de patiënten is niet in staat om na een hielbeenbreuk terug te keren naar hun oude werk. Bij 2% tot 15% van de patiënten is het nodig om in een latere fase het onderste spronggewricht vast te zetten. Wondontsteking wordt gezien in 2% tot 15 % en (gering) verlies van herstel wordt gemeld in 4 % tot 67% van de patiënten.

Percutane repositie en fixatie is de oudst beschreven operatieve techniek voor hielbeenbreuken (**Hoofdstuk Acht**). De minimaal invasieve techniek, zoals beschreven door Forgon en Zadravecz uit Hongarije, welke de basis vormt van dit proefschrift, wordt in detail beschreven. Met deze percutane behandeling kan extra aandacht besteed worden aan de kwetsbare weke delen rondom het hielbeen, terwijl een herstel van de anatomie van het hielbeen (hoogte, breedte, en stand) en onderste sprongewricht goed mogelijk is. Deze operatieve methode biedt chirurgen de mogelijkheid om voetfunctie, -boog en -vorm te herstellen, met een lagere kans op wondcomplicaties in vergelijking met de klassieke open operatieve methode.

Hoofdstuk Negen toont de resultaten van 50 patiënten met 61 hielbeenbreuken, welke percutaan behandeld zijn. Met een gemiddelde duur tussen operatie en deelname aan het onderzoek van 35 maanden waren de gemiddelde scores voor de Maryland Foot Score (MFS), Creighton-Nebraska (CN) and American Orthopaedic Foot Ankle Score (AOFAS) respectievelijk 79, 76 and 83 punten,van een totaal van 100 punten, hetgeen een goed tot excellent resultaat voor de meeste patiënten betekende. De beweeglijkheid in het onderste spronggewricht bedroeg 70% van normaal, wat beter is dan het gemiddelde in de literatuur voor andere behandelopties.

Een weinig frequent toegepaste methode om de resultaten van een behandeling voor hielbeenbreuken te meten is voetdrukmeting (**Hoofdstuk Tien**). De resultaten van eenentwintig patiënten met een enkelzijdige, percutaan behandelde hielbeenbreuk werden middels voetdrukmetingen geanalyseerd. Overeenkomsten tussen deze metingen en ziektespecifieke vragenlijsten werden onderzocht. Patiënten zetten meer gewicht op de niet-aangedane zijde in vergelijking tot de kant alwaar de hielbeenbreuk zat. De aangedane zijde had een significant kortere 'totale contacttijd' met de grond. Tevens verschoof de druk onder de aangedane voet meer naar de grote teen. Er werd geen duidelijke correlatie tussen de voetdrukmetingen en de ziektespecifieke vragenlijsten gevonden, hetgeen suggereert dat voetdrukmetingen alleen te weinig zeggen over de resultaten van de behandeling van een hielbeenbreuk.

Deel 4: De behandeling van late complicaties

Afhankelijk van het type initiële behandeling (operatief of conservatief) houdt 2% tot 30% van de patiënten na een hielbeenbreuk blijvende klachten. Deze klachten houden veelal verband met gewrichtsslijtage van het onderste sprongewricht. Voor deze blijvende klachten bestaan verschillende behandelopties, maar de meest gebruikte is de operatieve verstijving (vastzetten) van het onderste sprongewricht. In **Hoofdstuk Elf** worden de resulaten beschreven van patiënten met blijvende klachten na een hielbeenbreuk waarbij het onderste sprongewricht is vastgezet volgens twee verschillende methoden: beperkt vastzetten versus uitgebreid vastzetten. Bij de eerste methode wordt het hielbeen vastgezet aan het sprongbeen, bij de tweede methode worden hiernaast ook enkele middenvoetsbeenderen vastgezet. Met een gemiddelde duur tussen operatie en deelname aan dit onderzoek van bijna tien jaar werden er geen significante verschillen gevonden tussen beide groepen, middels een ziektespecifieke score (MFS), een kwaliteit van leven score (SF-36) en patiënttevredenheid. Tevens werd geconstateerd dat roken een risicofactor is voor het falen van het operatief vastzetten van de verschillende botten van de voet.

Een zeldzame complicatie van hielbeenbreuken is het niet vastgroeien van de breuk zelf. In **Hoofdstuk Twaalf** worden drie patiënten besproken waarbij de breuk niet geheeld is. Tevens wordt een overzicht van de literatuur gegeven van deze zeldzame aandoening en de behandeling ervan.

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Now this is not the end.
It is not even the beginning of the end.
But it is, perhaps, the end of the beginning.
Sir Winston Churchill
(Speech in November 1942)

List of publications

1. A.M. van Alphen, **T. Schepers**, C. Luo, C.I. De Zeeuw. Motor performance and motor learning in Lurcher mice. Ann N Y Acad Sci 2002;978:413-424
2. T. van Ginhoven, **T. Schepers**, H. Obertop, C.H. van Eijck. Delayed closure of complex duodenal injuries by a Foley balloon catheter duodenostomy. Dig Surg 2006;23(3):150-153
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13. **T. Schepers**, E.M.M. van Lieshout, A.Z. Ginai, P.G.H. Mulder, M.J. Heetveld, P. Patka. Calcaneal fracture classification; A comparative study. J Foot Ankle Surg 2009;48(2):156-162
14. **T. Schepers**, P. Patka. Treatment of displaced intra-articular calcaneal fractures by ligamentotaxis; current concepts review. Arch Orthop Trauma Surg. 2009 Jun 19 [Epub ahead of print]
15. **T. Schepers**, B.C.T. Kieboom, J.H.J.M. Bessems, L.M.M. Vogels, E.M.M. van Lieshout, P. Patka. Subtalar versus triple arthrodeses after intra-articular calcaneal fractures. Submitted
16. **T. Schepers**, H.A. Berendsen, I.H. Oei, J. Koning. Flexor tenotomy for ulcers of the toes. J Foot Ankle Surg. Accepted for publication
17. **T. Schepers**, M. Willemsen, M.R. de Vries, M. Van der Elst. Demographics of forefoot injuries part 1: Metatarsal fractures. Submitted
18. **T. Schepers**, M. Willemsen, M.R. de Vries, M. Van der Elst. Demographics of forefoot injuries part 2: Toe fractures. Submitted

Curriculum Vitae

The author of this thesis was born on January 6th 1976 in Uden, the Netherlands.

After graduating from high school at the Kruisheren Kollege in Uden, he studied Biology for the period of one year at the University of Utrecht.

In 1994 he started his medical training at the Erasmus University in Rotterdam, which he completed in 2000. In this period, he participated in a research project at the Department of Neuroscience (Prof.dr. C.I. de Zeeuw).

After 3 months of travelling the inlands of Tanzania with two close friends, he started his rotations (internship), of which the latter part was followed at the department of surgery at the MCRZ hospital location St-Clara (Prof.dr. J.F. Lange) in Rotterdam.

In 2003 he received his degree in medicine and started working at the Erasmus MC (formally known as Dijkzigt Hospital Rotterdam); first at the Emergency Department (Dr. T. Tadros) and subsequently at the surgical ward (Prof.dr. H.J. Bonjer, Prof.dr. J. Jeekel). During this time the basis for this thesis was laid.

In 2005 he started his surgical training at the Erasmus MC (Prof.dr. J.N.M. IJzermans, Prof.dr. H.O. Obertop, Prof.dr. J.J.B. van Lanschot). From 2008, this training is continued at the Reinier de Graaf Gasthuis in Delft (Dr. L.P.S. Stassen, Dr. M. van der Elst).

PhD Portfolio

Name PhD student: T. Schepers Erasmus MC Department: Surgery-Traumatology Research School: Erasmus MC	PhD period: 2005-2009 Promotor(s): Prof. Dr. P. Patka Supervisor: Dr. M.J. Heetveld	
1. PhD training		
	Year	Workload (Hours/ECTS)
General academic skills		
Research skills		
• Cochrane Evidence Based Surgery course	2005	1 ECT
In-depth courses		
• ANIOS Surgery	2003-2005	
• AIOS Surgery	2005-2009	
• Foot-Ankle anatomy course	2008	1 ECT
• Foot-Ankle arthrodesis course	2009	1 ECT
Presentations		
• Presentations calcaneal RCT at various hospitals	2007-2009	2 ECT
• National Conference		
• Traumadagen	2004&2006	1 ECT
• Chirurgendagen	2007&2008	1 ECT
• ZWOT	2007	1 ECT
• Traumanacht	2007	1 ECT
• Stafdag Chirurgie	2006&2007	1 ECT
• LVO	2008	1 ECT
• Wetenschapsdag Erasmus MC	2005	1 ECT
• International Conference		
• EATES	2004	1 ECT
• ESSR	2007	1 ECT
International conferences		
• Smith-Nephew Zurich Fracture Course	2009	1 ECT
• Biomet Fracture Course	2009	1 ECT
Seminars and workshops		
• ACLS course	2003&2008	1 ECT
• AO fracture course	2006	1 ECT
• AIOD fracture course	2007	1 ECT
• Fix ex course	2007	1 ECT
• Fracture exposure course	2007	1 ECT
Didactic skills		
• Supervising research students and data-manager	2007-present	2 ECT
• LISA anatomy Foot-ankle course	2009	1 ECT
2. Teaching activities		
Lecturing		
• Teaching	2005-present	5 ECT