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**Circular frame fixation for calcaneal fractures risks injury to the medial neurovascular structures: A
cadaveric description**

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Keywords:

External Fixation; Calcaneus; Heel Fractures; Safe-Zone; Surgical Procedures; Ilizarov

Abstract

Aim: There is a risk of iatrogenic injury to the soft tissues of the calcaneus and this study assesses the risk of injury to these structures in circular frame calcaneal fracture fixation.

Materials and Methods: After olive tip wires were inserted, an L-shaped incision on the lateral and medial aspects of 5 formalin fixed cadaveric feet was performed to expose the underlying soft tissues. The calcaneus was divided into zones corresponding to high, medium and low risk using a grading system.

Results: Structures at high risk included the posterior tibial artery, posterior tibial vein and posterior tibial nerve on the medial aspect. Soft tissue structures on the lateral side that were shown to be at lower risk of injury were the small saphenous vein and the sural nerve and the tendons of fibularis longus and fibularis brevis.

Conclusion: The lateral surface of the calcaneus provides a lower risk area for external fixation. The risk of injury to significant soft tissues using a circular frame fixation approach has been shown to be greater on the medial aspect.

Clinical Relevance: This study highlights the relevant anatomical relations in circular frame fixation for calcaneal fractures to minimize damage to these structures.

Keywords:

External Fixation; Calcaneus; Heel Fractures; Safe-Zone; Surgical Procedures; Ilizarov

Introduction

The calcaneus is the most frequently fractured tarsal bone and accounts for about 2% of all fractures in the human body and 70% of these are displaced ¹. Extra-articular fractures account for the remaining 30% and include all fracture patterns that do not involve the posterior facet of the calcaneus ². Open reduction and internal fixation (ORIF), over the last decade, has been considered the 'gold standard' in the surgical treatment of physiologically young patients and leads to good outcomes ³.

There is a risk, however, of considerable early and delayed complications. Early complications often relate to surgical technique with infection and wound dehiscence remaining a feared outcome. There is a definite incidence of neurological injury with a 6% incidence of sural nerve insult ⁴.

Despite these concerns, there is a body of evidence which demonstrates good outcomes following fixation of fractures via an extensile lateral approach. Buckley ⁵ has noted significantly higher satisfaction scores in operatively managed patients who were not receiving Worker's Compensation, were women, or were patients younger than 29 years old. Since this landmark paper, there has been real interest in fixing calcaneal fractures. Griffin's group from Warwick describe less optimistic two year outcomes from a multi centre randomised controlled trial ⁶. They have noted no difference in outcome between those who have been managed conservatively and those who have proceeded to operative intervention.

Following the publication of this paper, there has been real controversy. Some trauma surgeons are of the opinion that fixation of calcaneal fracture is now not merited. Others, however, have come to the conclusion that perhaps alternative methods of fixation should be explored. There is a developing vogue in Europe for minimal access calcaneal osteosynthesis ⁷. Its long term results are yet to be described. The indications for this technique are still evolving.

Another alternative method of fixation for treating Sander's type II, III and IV calcaneal fractures involves circular frames. Percutaneous olive wires are used to aid in reduction of the fracture⁸. This treatment has been found to be effective in treating intra-articular fractures in small-scale studies with a decreased incidence of complications associated with more invasive techniques⁹⁻¹¹. It maintains extra-articular reductions just as effectively¹². Ilizarov surgery is not commonly performed by most orthopaedic surgeons which when combined with a steep learning curve and the, technical difficulty of such surgery has led to a lack of uptake in this technique. The clinical results of circular frame fixation of these fractures is promising, however^{13, 14}.

Despite these promising results, there remains a lack of reporting within the literature regarding the incidence of neurological and soft tissue injury¹⁵ following circular frame fixation. Some studies have attempted to divide the surfaces of the calcaneus into zones according to increasing risk of injury to neurovascular and tendinous structures¹⁶⁻²⁰ but have yet to come to a clear agreement. It has been suggested by Labronici et al. that vascular structures found superficially to the anteromedial surface of the calcaneus are at high risk of damage during wire fixation performed via the lateral aspect of the hindfoot²⁰.

The optimal point of entry of transcalcaneal wires is vital for reducing the risk of iatrogenic injury to neurovascular and tendon structures²¹. In this study, we aim to describe the incidence of injury to neurovascular and tendinous structures as well as describing the presence of high, medium and low risk zones within the calcaneus to help guide the insertion of fine olive tip wires in both a medial to lateral and a lateral to medial direction.

Materials and Methods

Five cadaveric ankle specimens were used in this investigation, three right feet and two left feet from 3 patients (two male and one female), that had been perfused and fixed in a solution containing methanol, phenol, formalin, glycerol, and phenoexetol. All cadaveric specimens were

obtained from adults >70 years of age without any prior trauma to the heel. Mean age of the subjects was 87 (range: 74-95). The selection of specimens was from the regular stock in the Laboratory of Human Anatomy, University of Glasgow. All specimens were from the body donor programme and conformed to the Anatomy Act 1984 and the Human Tissue (Scotland) Act 2006. Criteria for use included no specific disease or trauma related to the lower limb with no previous dissection in the calcaneal region. Due to the fixation method used, the specimens were all found to be in slight plantar flexion.

Two standard trans-osseous 1.8mm Smith & Nephew olive wires were placed through the calcanei, one directed from the medial aspect towards the anterolateral surface, and one directed in from the lateral aspect anteriorly to the anteromedial surface of the hindfoot. The crossed wires were positioned by the senior author. The wires were placed obliquely to maximise bony purchase and were placed from medial to lateral and lateral to medial to aid in fracture reduction particularly with regard to lateral calcaneal wall extrusion.

Easily palpable anatomic landmarks were recognised as the inferior tip of the lateral malleolus (A) and the superior tip of the posterior calcaneus palpable from the lateral aspect of the hindfoot (B). The base of the 5th metatarsal was also used as an additional reference point (C) on the lateral side. Medially, palpable landmarks were established as the inferior tip of the medial malleolus (D), the superior tip of the posterior calcaneus palpable from the medial hindfoot (E) and the most prominent part of the navicular tuberosity (F). These points are shown in Figure 1. The lateral to medial, and medial to lateral olive wire exit points were identified on each aspect of the foot and varied from specimen to specimen.

Dissection was initially performed medially via a L-shaped incision from 10cm superior to the tip of the medial malleolus to 10 cm anterior to the navicular tuberosity on the medial aspect. A similar incision was utilised on the lateral aspect extending from above the lateral malleolus to distal to the base of the 5th metatarsal. Gentle dissection of the soft tissue surrounding

neurovascular structures was necessary to maximise preservation of their true anatomical position.

On the lateral aspect the courses of the sural nerve, small saphenous vein, and tendons of fibularis longus and brevis were identified (Figure 1a). The courses of the posterior tibial artery, vein and branches of the posterior tibial nerve were identified medially as well as the tibialis posterior, flexor digitorum longus and flexor hallucis longus tendons (Figure 1b). These structures were assessed for their risk of iatrogenic injury from the wires. The medial wall of the calcaneus was obstructed by abductor hallucis and was excised to complete the dissection of the underlying structures. The great saphenous vein was removed with the cutaneous layer as its path ascends anteriorly to the medial malleolus, well away from the area being studied. Its tributaries were not considered in this study.

Using Clarke CM145 digital Vernier callipers, distances between each of the three anatomic landmarks on each side were established. Then, the distance from the protruding wires to the landmarks A and B laterally, and D and E medially. These lines were marked on the specimens using a ruler to allow the distance to the vulnerable structures outlined to be measured whilst maintaining the same trajectory towards the landmark.

A colour-coded scale was used to determine the risk of damage to the adjacent structures from each wire. Wires that were < 5 mm away were assigned to red, equivalent to high risk. Structures at moderate risk were assigned to amber and were 5 – 10 mm away. Distances >10 mm were considered to have low risk and assigned to the green colour denomination.

For each specimen the mean of four measurements were taken by two separate observers at different times. Combined mean distances were calculated from mean distances for all five specimens and then overall risk denominations were assigned. If on any specimen a structure was lacerated by an olive wire, it was deemed at high risk even if the combined mean distance was greater than 5 mm. Two observers were used, each taking two measurements per structure at

different times in an attempt to reduce inter and intra observer bias. All mean values included the standard deviation as an indication of the range.

Results

Mean distances including standard deviations from all five specimens were taken on the lateral and medial aspects for each structure. On the lateral aspect of specimen 4, the lateral to medial wire was closest to the small saphenous vein at 9.60 ± 1.31 mm away, towards the lateral malleolus. The sural nerve was also near at 14.39 ± 2.14 mm. The calcaneal branch of the sural nerve was 8.05 ± 1.58 mm along the line towards the superior part of the posterior calcaneus from the wire. The medial to lateral wire, which was more anterior, towards the lateral malleolus was closest to the small saphenous vein at 4.72 ± 1.22 mm in specimen 3. The sural nerve was also close to the wire along this line at 7.50 ± 0.98 mm in specimen 5 (Figure 2a). In specimen 3 only, the fibularis longus tendon was impaled by the wire as it passed from the medial aspect to the superficial lateral aspect. All anatomic structures were identified in each specimen apart from the small saphenous vein of specimen 1 which was unable to be recognised. The upper bound of the margin of error, at 95% confidence, was 13.17 mm for the lateral aspect measurements. Combined mean measurements were all greater than 10 mm away from the wires on the lateral aspect.

On the medial aspect of specimen 4, the posterior tibial artery was lacerated and was at close proximity in specimen 5 at 5.51 ± 2.04 mm away from the lateral to medial wire towards the medial malleolus. The posterior tibial vein was struck by the lateral to medial wire in specimen 5 (Figure 2b), and was near at 4.22 ± 0.97 mm in specimen 4. The medial to lateral wire did not hit any superficial structure on the medial aspect and the closest structure to the wire was the posterior tibial vein and in specimen 3 was particularly close at 4.97 ± 1.07 mm. The medial calcaneal nerve was the only structure found between the medial to lateral wire and the superior

part of the posterior calcaneus. The upper bound of the margin of error, at 95% confidence, was 10.48 mm for the medial aspect measurements.

The colour grading system using red, amber and green in this study was used to establish three zones corresponding to, high, moderate and low risk of injury respectively and is illustrated in Figure 3. The graphical model of the hindfoot plots the distances of each structure to scale. Red zones were made from circles around the soft tissues plotted along each measurement line with a radius of 5 mm. When a wire passed less than 5 mm from an anatomical structure it would be contained in this high risk zone. Overlapping amber circles around the soft tissues were plotted with a larger radius of 10 mm so that when the wire is between 5-10 mm away from the structure, it would be enclosed in this moderate risk zone. A green zone was proposed as a low risk area of greater than 10 mm from the structures of interest but marked conservatively to cover areas barren of the courses of the soft tissues.

On the lateral aspect, the lateral to medial and medial to lateral wires fell within the green, low risk zone. On the medial aspect however, both wires were found in high risk zones where the posterior tibial vein, posterior tibial artery, and tibial nerve branches were most at risk. The artery and vein were also punctured by the more anterior olive wire in two dissections. The low risk zone marked was smaller on the medial aspect covering only part of the posterior calcaneus. The larger low risk zone on the lateral aspect was found on the posteroinferior and posterior part of the calcaneus. The more anterior exiting wires on both aspects were the closest to structures on average.

Discussion

A firm understanding of the anatomy relating to calcaneal fracture fixation is fundamental to providing patients with the best possible outcome. Several studies have attempted to define an anatomical “safe zone” for placing external fixation wires using the distance of the neurovascular and tendinous structures to various anatomical landmarks as a means of describing this ^{18,19,21,22}. However, there is still limited data from cadaveric studies in the literature that define clear safe zones on the medial and lateral aspects of the calcaneus to minimise risk of iatrogenic injury to surrounding soft tissues.

In the study by Labronici et al. ²⁰, the calcaneus was divided into six areas, to try to replicate a fracture of the calcaneus that would be fixed using six 2 mm Kirshner wires. The three most medial and proximal zones of the calcaneus (IA, IB and IIA) presented the most significant risks of injury to arteries, veins and nerves. Notably, the likelihood of tendon injury was nil in all six zones they studied. In the total 53 calcanei dissected they noted that the paths of neurovascular branches were highly varied and thus made it difficult to predict the likelihood of lacerations to the neurovascular bundle and did not use these branches in their analysis of risk. Not all the landmarks used in Labronici’s investigation to create the zone boundaries are readily palpable. Our investigation used easily palpable anatomical landmarks on the calcaneus as their identification is more reproducible in preoperative planning.

Mekhail’s group ²¹ analysed 15 feet from cadavers after insertion of two Steinmann pins. They concluded that the safest zone for avoiding neurovascular structures is a point in the posteromedial region, located at three-quarters of the distance from the lower tip of the medial malleolus to the medial tubercle of the calcaneus. They concluded that anteromedial calcaneal pin placement is associated with soft tissue injury and that this is avoided with a posteromedially introduced pin. An overly posterior placement however, may lead to an avulsion fracture of the calcaneal tuberosity if traction is applied on the pin.

Santi and Botte¹⁹ assessed the lateral aspect for safe zones and found a large area on the posteroinferior aspect of the tuberosity where the peroneal tendons and sural nerve were consistently anterior to this area. The lateral calcaneal branches of the sural nerve that innervate the posterolateral hindfoot were the soft tissues most at risk of iatrogenic injury following pins placed in the lateral aspect of the calcaneus.

The results from this study demonstrate that the medial to lateral olive wire was safer than the lateral to medial olive wire. The medial to lateral olive wire lacerated peroneus longus in one specimen. The medial to lateral wire was greater than 5 mm away from all vulnerable structures. Medial structures namely the posterior tibial artery, vein and tibial nerve branches were more likely to be damaged by the lateral to medial olive wire. Olive wires exiting the medial surface of the calcaneus presented moderate to high risk of iatrogenic injury to the proximal medial neurovasculature. Lateral structures were considerably less at risk from the lateral to medial wire than medial structures with the small saphenous vein being the closest structure at 15.83 mm away on average.

The specimens used in this study were fixed with formaldehyde which meant the compressibility and elasticity of living tissue was altered which could offer some degree of protection against perforation upon insertion of a wire²³. The anatomical variation seen in our specimens may not be seen in other cadaveric specimens and thus may not fully represent the adult population.

Further studies would increase the sample size with use of either all female or male cadavers to give a more specific sample population since measurement differences are significantly larger in males than in females. Sexual morphology was not accounted for and is likely to be a reason for the high standard deviation in the combined mean distances, exacerbated by a small sample size. Slight plantar flexion was noted in the cadaveric feet due to fixation methods but it has been shown that there is only a weak correlation between the degree of flexion and difference in measurement distances¹⁷. Our specimens had no trauma to the calcaneus and thereby exhibited

normal calcaneal anatomy without fracture. In traumatic injuries, the local anatomy may be distorted and structures could be displaced resulting in some uncertainty as to where the soft tissues lie.

Given that the risk of injury to a vital nerve or artery of the hindfoot on the medial side has been shown to be greater than on the lateral side, careful consideration should be given to the use of circular frame fixation for calcaneal fractures due to the unacceptably high risk of iatrogenic injury shown in our study. There is perhaps a role for alternative fixation methods be that with ongoing plate fixation⁵, or minimal access calcaneal osteosynthesis or with a lateral only calcaneal external fixator.

Conclusion

This study examined the relative risk of injury to structures during the fixation of calcaneal fractures in circular frame calcaneal fracture fixation, presented as different safety areas for fine wire insertion on the calcaneus. The lateral calcaneus provides a greater area for safe percutaneous wire placement in comparison to the medial aspect of the calcaneus. The posterior tibial artery, posterior tibial vein and posterior tibial nerve were designated as high risk to iatrogenic injury after wire placement. The results of this study should facilitate the safe placement of external fixation wires when applied clinically. A larger scale prospective study is needed to confirm our findings and compare outcomes with other minimal access surgical approaches.

Conflict of interest

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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Figure 1. Detailed dissection of the heel of specimen 5 with olive wires inserted: **a.** Lateral view of the inferior tip of the lateral malleolus (A), the superior part of the posterior calcaneus (B), the base of the 5th metatarsal (C). The courses of the small saphenous vein (1), the sural nerve (2), fibularis longus (3), and fibularis brevis (4) are shown. **b.** Medial view of the inferior tip of the medial malleolus (D), the superior part of the calcaneus (E), the navicular tuberosity (F). The paths of the tibialis posterior (1), flexor digitorum longus (2), posterior tibial artery (3), posterior tibial vein (4), medial calcaneal branch of tibial nerve (5), lateral plantar nerve (6), and the flexor hallucis longus tendon (7), are shown.

Figure 2. Detailed dissection of the heel of specimen 5 from Figure 1 with measurement lines superimposed. **a.** Lateral measurements were taken along the blue lines from the lateral to medial wire, and along the red lines from the medial to lateral wire. **b.** Medial measurements were taken along the blue lines from the medial to lateral wire, and along the red lines from the lateral to medial wire.

Figure 3. Graphical representation (to scale) for the location of the sites of wire placement related to vulnerable soft tissue structures. Coloured areas show the different safety areas of wire placement according to high (red), moderate (amber) and low (green) risk. **a.** Lateral view showing risk zones for lateral structures. **b.** Medial view showing risk zones for medial structures.

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