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**Monoaxial External Fixation of the Calcaneus: An Anatomical Study Assessing the Safety of  
Monoaxial Pin Insertion**

**Callum M Thomson<sup>a</sup>, Tom Esparon<sup>a</sup>, Paul M. Rea<sup>a</sup>, Bilal Jamal<sup>b</sup>**

<sup>a</sup> Laboratory of Human Anatomy, Thomson Building, School of Life Sciences, College of Medical,  
Veterinary and Life Sciences, University of Glasgow, UK

<sup>b</sup> Department of Orthopaedics, Glasgow Royal Infirmary, UK

**Authors:**

Callum M Thomson: BSc Anatomy Honours student at the University of Glasgow

Tom Esparon: BSc Anatomy Honours student at the University of Glasgow

Dr Paul M Rea: Senior University Teacher and Licensed Teacher of Anatomy at University of Glasgow

Mr Bilal Jamal: Specialty Trainee Orthopaedic Surgeon

**Address for correspondence:**

Dr Paul M. Rea

Laboratory of Human Anatomy

Thomson Building

School of Life Sciences

College of Medical, Veterinary and Life Sciences

University of Glasgow, UK

[+44] [0]141 330 4366

[Paul.Rea@glasgow.ac.uk](mailto:Paul.Rea@glasgow.ac.uk)

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## **Abstract**

The use of external fixation for intra-articular calcaneal fractures is increasing in popularity. Studies have shown fine wire and monoaxial external fixation to be a viable surgical alternative to more invasive methods of open reduction and internal fixation of the calcaneus. However, there is an absence of literature that quantifies the risk of pin insertion for monoaxial fixation.

This study aimed to determine the safety of inserting monoaxial pins within the calcaneus to house the Orthofix Calcaneal Mini-Fixator. Five formalin embalmed cadaveric ankle and lower leg specimens were inserted with six monoaxial pins. Careful dissection then revealed the presence of the tendons of peroneus longus and brevis, the sural nerve and the small saphenous vein in relation to these pins. Measurements from each pin to each of these structures were made as the structures transected lines drawn from each pin to two palpable bony landmarks: the inferior tip of the lateral malleolus and the posterosuperior calcaneus. In doing this, the risk posed by each pin could be evaluated. We found that two particular pins, those used to hold the articular surface of the subtalar joint in a reduced position, posed a larger risk of injury to surrounding structures than the remaining pins. These findings therefore suggest that monoaxial fixation of the calcaneus using a six pin approach is a relatively safe method of rectifying calcaneal fractures and thus may serve as a welcome alternative to other methods of calcaneal fixation.

## Introduction

Calcaneal fractures constitute 1-2% of all fractures [1]. By convention, due to improvements in computed tomography scanning and surgical techniques, open reduction and internal fixation (ORIF) has been used extensively to reconstruct displaced intra-articular calcaneal fractures [2,3,4].

Fine wire external fixation is one such method whereby the calcaneus can be effectively reduced without the need for open surgery [5]. As external fixation is respectful of the soft tissues, it does not rely on a delay to theatre to allow for soft tissue swelling to settle. It also permits almost immediate post-procedural weight bearing. Few complications occur with external fixation, such as minor infections at pin insertion sites [6]. As wires pass through the calcaneus percutaneously in external fixation, there is an indeterminate risk of damage to structures which traverse the calcaneus. To avoid this, there has been a variety of proposed safe zones within the calcaneus in the literature [7,8,9]. However, more emphasis has been placed on the medial side, perhaps as a consequence of a greater density of structures at risk. Of all the studies considered, a definite safe zone of the medial side of the calcaneus could not be identified, despite deploying several different techniques and taking variations in anatomy and gender into consideration. This may suggest that there is no medial safe zone that could eliminate the possibility of injury to neurovascular or tendinous structures.

A more contemporary method utilizing monoaxial external fixation involves placing pins, instead of wires, only into the lateral side avoiding penetration through the calcaneus to the medial side [10]. Despite there being a number of studies that have attempted to evaluate the results of fine wire external fixation of the calcaneus, there is a paucity of anatomical studies evaluating the safety of monoaxial fixation, and an absence of suggested safe zones for this approach.

The aim of this study was to determine which structures, if any, have been impinged by the pins and also to determine how close these pins are to structures of interest. By doing this, the safety of the Orthofix Calcaneal Mini-Fixator in rectifying intra-articular calcaneal fractures could be evaluated.

## **Materials and Methods**

Five formaldehyde embalmed ankle and lower leg cadaveric specimens were obtained from the regular stock in the Laboratory of Human Anatomy, University of Glasgow. All dissections were carried out under the Anatomy Act 1984 and the Human Tissue (Scotland) Act 2006. These specimens were from four different male individuals (four left specimens and one right specimen), with a mean age of 79 years (range 74-87). Six monoaxial pins were inserted into the lateral side of each of these specimens by an orthopaedic surgeon in line with the surgical technique for the Orthofix Calcaneal External Fixator [11]. In this study, these pins are numbered 1 to 6, from anterior to posterior. The middle pair of pins, pins 3 and 4, are used to hold the articular surface of the subtalar joint in a reduced position. The more anterior and posterior pins (pins 1, 2, 5 and 6) are used to maintain the length of the calcaneus and also serve to correct the varus angulation of the hindfoot following a fracture. However, when there is severe comminution of the anterior calcaneal apophysis, it may be necessary to insert pins 1 and 2 within the cuboid bone [11].

An incision was made down the midline anteriorly at the level approximately four finger breadths above the most inferior part of the lateral malleolus to the level of the base of the fifth metatarsal. This incision was continued laterally both proximally and distally to allow the skin to be carefully reflected to expose the area surrounding the pins. The subcutaneous fat was carefully removed so as not to damage any superficial structures. The sural nerve and small saphenous vein were first identified proximally and their course and distributions were revealed through blunt dissection. Care was taken not to disturb any soft tissue attachments of these structures to ensure their true anatomical positions were maintained. The tendons of peroneus brevis and peroneus longus muscles were then identified in close proximity to the lateral malleolus. Three easily palpable landmarks, the most inferior tip of the lateral malleolus, the posterosuperior tip of the calcaneus and the base of the fifth metatarsal were then revealed by dissection down to the level of bone. A photograph taken of one fully dissected specimen can be seen in figure 1.

All measurements were taken using Clarke CM145 digital Vernier calipers in millimetres and repeated four times by two independent observers at different times. These calipers are accurate to within  $\pm 0.03$  mm for measurements between 0 and 200.00 mm. The distances between each of the three bony landmarks were then measured. Lines were drawn with a marker pen from each pin to both the most inferior part of the lateral malleolus and the posterosuperior tip of the calcaneus. The total distances from each pin to each of these landmarks were measured. Measurements were then taken from each pin to the sural nerve, small saphenous vein and the tendons of peroneus brevis and peroneus longus as they transected each of the drawn lines. Some structures did not transect every line due to both anatomical variation and the absence of structures at particular portions of the calcaneus such as the tendons of peroneus longus and brevis which were only present within the anterior portion of the calcaneus.

The mean distances between all of the established palpable bony landmarks as well as the mean distances of each pin to structure measurement were calculated from the four independent measurements. The standard deviations between the four measurements of each distance were also calculated to assess inter/intra observer reliability. To combine data from all five specimens, an overall mean and standard deviation was calculated for each distance using the calculated mean distances from each specimen.

## **Results**

In four out of the five specimens, the tendon of the peroneus longus muscle was impinged by pin 3. A calcaneal branch of the sural nerve was also impinged in one specimen by pin 5. The remaining pins; 1, 2, 4 and 6 did not impinge any structures in any of the specimens. Both the smallest mean distances obtained from individual specimens and the smallest combined mean measurements from all five specimens are given in table 1. It can be seen from this table, that pins 3 and 4 were the closest pins to anatomical structures and that pin 6 was the furthest away. This suggests that pins 3

and 4 pose the highest risk of injury to vulnerable anatomical structures and pin 6 poses the least risk of damage.

Table 2 gives the mean measurements for each distance, which were calculated using four independent measurements from each specimen. A combined mean from all specimens as well as the 95% confidence interval and the standard deviation are also given for each distance. A traffic light labelling system is used to assess the 'danger' of each pin of damaging each structure. Red is used to highlight structures that were impinged in any of the five specimens. Amber is used when the mean distance from all specimens between a pin and a structure is greater than 0 mm but less than or equal to 20.0 mm. Finally, green highlights structures that were a mean distance of 20.1 mm or greater away from each pin respectively. In some cases, certain structures were not visibly present on lines between each pin and the inferior tip of the lateral malleolus and the posterosuperior calcaneus and are labelled as 'N/A' to show this. Larger standard deviations were observed in mean measurements from all specimens than those from individual specimens. This is likely to be due to variations between specimens, such as the individual's foot size. Large anatomical variation in the courses and distributions of structures, namely the sural nerve and the small saphenous vein may also have directly affected the increased spread of results for mean measurements. It can be deduced from table 2 that the pins which pose the greatest risk of neurological, vascular or tendinous damage are pins 3 and 4. There are no structures in relation to these pins that are highlighted as green, therefore all structures were present at a distance of 20.0 mm or less. This is to be expected however, as pins 3 and 4 are situated in the area of the calcaneus with the greatest density of structures vulnerable to damage. Pins which are placed both at the anterior and posterior margins of the calcaneus, pins 1 and 6, are the pins which were deemed to pose least risk of damage.

Figure 2 presents the combined results of the five specimens (as seen in table 2). Pins 3 and 4 are the closest pins to the subtalar joint and these are most closely related to structures that may well be injured.

## **Discussion**

This study aimed to determine the risk of impingement upon anatomical structures when placing pins for the Orthofix Calcaneal Mini-Fixator. This was achieved by finding the smallest distances from each of the six pins to surrounding neurological, vascular and tendinous structures as they transected straight lines connecting each pin to two palpable bony landmarks. The results of this current study show that in five specimens inserted with six monoaxial pins, the tendon of the peroneus longus muscle was impinged in four out of the five specimens and a calcaneal branch of the sural nerve in one of the specimens. In clinical practice, a small incision is made over the subtalar joint and the tendons of peroneus longus and brevis are retracted hence these tendons are not at risk [12]. The sural nerve is noticeably variable in its distribution [13,14,15]. Santi and Botte (1996) concluded in their study, which aimed to determine safe zones for wire insertion for external fixation, that the lateral calcaneal branches arising from the sural nerve were the structures most at risk of impingement by wires within the lateral calcaneus [7]. The calcaneal branches of the sural nerve supply exclusively sensory innervation to the lateral portion of the calcaneus and impingement of these branches would result in little clinical importance [16]. Painful neuroma formation does remain a possibility but this can be addressed surgically at a later sitting [17].

Percutaneous reduction and external fixation was used to treat 52 patients with closed articular displaced calcaneal fractures in a study by Magnan et al. (2006) [18]. For this study, the monoaxial Orthofix Mini-Fixator (series M300) was used. The authors reported an excellent Maryland foot score result in 26 out of 54 cases (48.1%). This score assesses pain, motion and stability, amongst other factors, of the foot post-operatively. Although a four-pin fixator was used in this study, no neurological, vascular or tendinous complications were reported.



A six pin Orthofix Calcaneal Mini-fixator was used in a study by Corina et al. (2014) [19]. This study aimed to demonstrate that use of the six pin Mini-fixator provides greater stability, better and more stable reduction and improved functional outcomes over the previous four pin series. Sixty-nine closed heel intra-articular displaced fractures were treated and an excellent score on the Maryland Foot Score was attained in 53.6% of interventions. There were no cases of hypoaesthesia of the sural nerve, however fifteen patients suffered algodystrophy. Whether this was caused by the initial trauma or as a consequence of surgery is unknown.

The use of fine wire or monoaxial external fixation has been shown to result in minimal wound complications in comparison to ORIF. Benirschke et al. (1993) reported that following ORIF of the calcaneus in 80 patients, 16% experienced wound complications and deep infection was observed in two patients [20]. A wound complication rate of 25% was found in a study by Folk et al. (1999) in which 190 calcaneal fractures were treated with ORIF [21]. In comparison, a study by McGarvey et al. (2006) found that in 31 patients with 33 Sanders types II, III and IV fractures treated with external fixation, there was only one deep infection in a diabetic smoker [6]. Smoking however, is widely considered to be a risk factor for wound complications following calcaneal ORIF [22]. Despite this deep infection requiring secondary surgery, a considerably lower second-surgery rate was obtained than has been reported after ORIF.

The results of our study in combination with the studies discussed above suggest that monoaxial external fixation of the calcaneus is a relatively safe method of reconstructing calcaneal fractures. The largest risk of damage to vulnerable structures appear to be via pins 3 and 4.

Several limitations of this study are recognised. The cadaveric specimens used were embalmed in formalin. Fresh frozen cadavers would have provided a superior life-like representation of tissue in comparison. No female specimens were used and so it was not possible in this study to determine variations in measurements between male and female subjects. Furthermore, only five specimens within a narrow age range were investigated, a study which included a greater number of subjects,

within a wider age range, would perhaps provide more reproducible results. Larger standard deviations were observed with mean measurements in comparison to individual specimen measurements. This is likely to be due to a large variance in foot size used for the study in conjunction with a small number of specimens investigated; this is a noted limitation of the study. Cadaveric specimens that had no prior or existing calcaneal trauma were used in this study however, in subjects with trauma involving the calcaneus, the anatomical location of structures such as the sural nerve and small saphenous vein may become distorted.

Additional study which further investigates the safety of monoaxial fixation of the calcaneus is advised. Studies which look at a greater number of both male and female specimens may be beneficial and help to delineate differences, if any, in anatomy between sexes. A study which perhaps investigates the safety of monoaxial pins inserted into specimens with existing trauma such as type II, III and IV Sander's type fractures of the calcaneus would help overcome the limitation of unpredictable anatomical variation that may occur after trauma, although it is understood that it may be difficult to obtain specimens to this specification.

Despite these limitations, our results show that pins 3 and 4 pose a much greater risk of damage than the remaining pins. The use of a small incision centred over the subtalar joint combined with appropriate dissection and retraction eliminates the risk of injury to these tendons. Monoaxial external fixation of the calcaneus using the Orthofix Calcaneal Mini-Fixator appears to be a safe method of fixation of the calcaneus.

## **Conclusions**

This study aimed to use cadaveric dissection to evaluate the risk of injury to anatomical structures with the use of monoaxial external fixation.

The tendon of peroneus longus and the calcaneal branches of the sural nerve appear to be most at risk of impingement by monoaxial pins when a six pin approach is employed. However, as the tendons of the peroneus longus and peroneus brevis are retracted during surgery, these structures

will not be injured. Pins 3 and 4 should be inserted under direct vision to avoid peroneal tendon injury.

The morphology of the calcaneal branches of the sural nerve were noticeably variable in the specimens studied. This therefore makes defining areas of the calcaneus which eliminate the risk of damage to these structures extremely difficult. Pin 5 can damage branches of the sural nerve but this is unlikely to be of great clinical significance given the limited distribution of these nerves.

## Figure legends

**Figure 1:** Photograph of one specimen showing the anatomical structures that were identified. The six monoaxial pins are also labelled, these are numbered in a clockwise fashion from pin 1 most anteriorly through to pin 6 most posteriorly. A = most inferior part of lateral malleolus; B = posterosuperior calcaneus.

**Figure 2:** Scaled representation showing mean measurements from all five specimens from each of the six-monoaxial pins to the sural nerve, small saphenous vein and the tendons of the peroneus longus and peroneus brevis muscles. Structures are shown in relation to these pins as they transect lines from each pin to two palpable bony landmarks; the inferior tip of the lateral malleolus and the posterosuperior calcaneus.

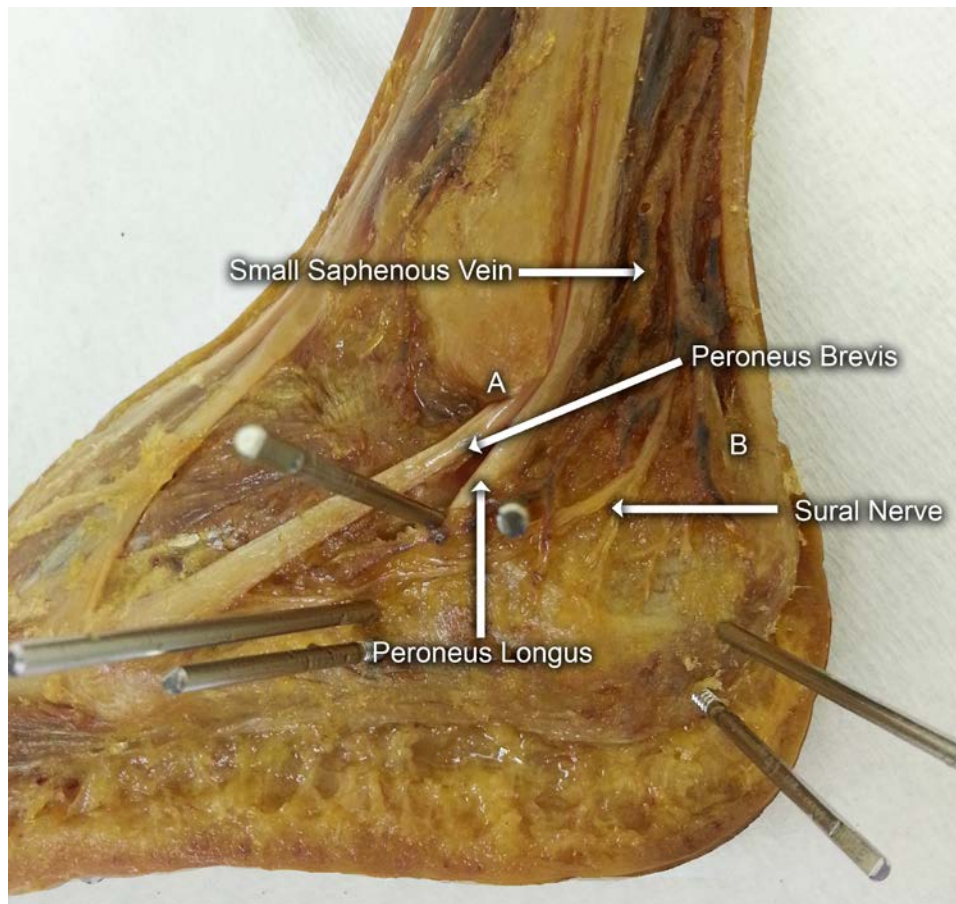


Figure 1: Photograph of one specimen showing the anatomical structures that were identified. The six monoaxial pins are also labelled, these are numbered in a clockwise fashion from pin 1 most anteriorly through to pin 6 most posteriorly. A = most inferior part of lateral malleolus; B = posterosuperior calcaneus.

Table 1: Summary of Smallest Distances Measured

| Pin | Smallest Mean Distances in any Specimen (structure: measurement $\pm$ S.D) (mm) | Smallest Mean Distances from all Specimens (structure: measurement $\pm$ S.D) (mm) |
|-----|---|--|
| 1   | TPL: 7.4 $\pm$ 0.9  | SN: 16.3 $\pm$ 3.4   |
| 2   | TPL: 3.2 $\pm$ 0.2  | SN: 8.3 $\pm$ 3.6  |
| 3   | SN: 1.6 $\pm$ 0.5   | SSV: 8.2 $\pm$ 1.6   |
| 4   | SSV: 2.1 $\pm$ 0.3  | SSV: 6.0 $\pm$ 3.7   |
| 5   | SSV: 8.6 $\pm$ 0.9  | SN: 33.0 $\pm$ 6.7   |
| 6   | SN: 11.7 $\pm$ 0.4  | SSV: 41.0 $\pm$ 4.0  |

TPL = tendon of the peroneus longus muscle; SN = sural nerve; SSV = small saphenous vein.



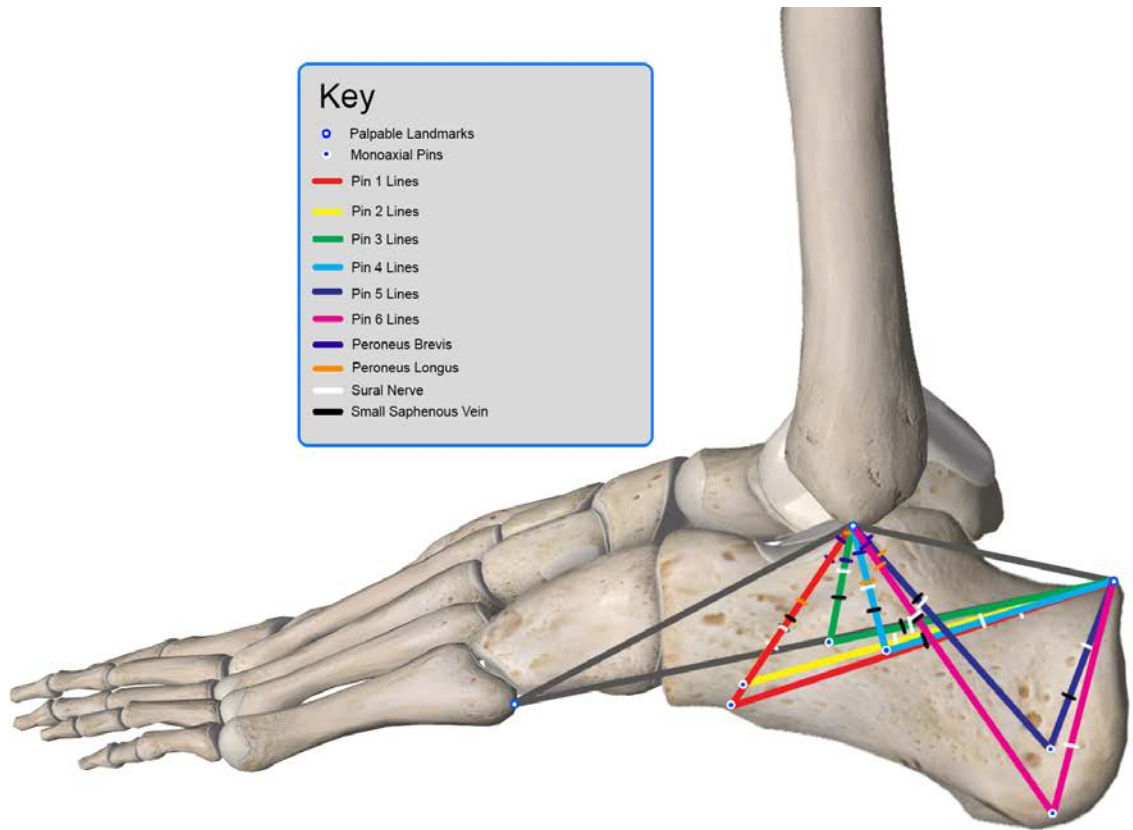


Figure 2: Scaled representation showing mean measurements from all five specimens from each of the six monoaxial pins to the sural nerve, small saphenous vein and the tendons of the peroneus longus and peroneus brevis muscles. Structures are shown in relation to these pins as they transect lines from each pin to two palpable bony landmarks; the inferior tip of the lateral malleolus and the posterosuperior calcaneus.



## References

- [1] Mitchell MJ, McKinley JC, Robinson CM. The epidemiology of calcaneal fractures. *Foot* 2009 Dec; 19(4): 197-200.
- [2] Al-Ashhab MEA. "ORIF" for displaced intra-articular calcaneal fractures in children. *Foot* 2015;25(2): 84–8.
- [3] De Boer AS, Van Lieshout EMM, Den Hartog D, Weerts B, Verhofstad MHJ, Schepers T. Functional outcome and patient satisfaction after displaced intra-articular calcaneal fractures: a comparison among open, percutaneous, and nonoperative treatment. *J Foot Ankle Surg.* 2015;54(3): 298–305.
- [4] Yu G, Zhao H, Yang Y, Zhou J, Li H. Open reduction and internal fixation of intra-articular calcaneal fractures in children. *Orthopedics* 2012;35(6): 874–9.
- [5] Zgonis T, Roukis TS, Polyzois VD. The use of Ilizarov technique and other types of external fixation for the treatment of intra-articular calcaneal fractures. *Clin Podiatr Med Surg.* 2006; 23(2): 343-53.
- [6] McGarvey WC, Burris MW, Clanton TO, Melissinos EG. Calcaneal fractures: indirect reduction and external fixation. *Foot Ankle Int.* 2006;27(7): 494–9.
- [7] Santi MD, Botte MJ. External fixation of the calcaneus and talus: an anatomical study for safe pin insertion. *J Orthop Trauma* 1996;10(7): 487–91.
- [8] Langdon IJ, Harling R, Atkins RM, Nicholson H. A cadaveric study of the medial relations of the calcaneum. *Foot Ankle Surg.* 2000;6(3):169–73.
- [9] Casey D, McConnell T, Parekh S, Tornetta P. Percutaneous pin placement in the medial calcaneus: is anywhere safe? *J Orthop Trauma* 2002;16(1): 26-9.

- [10] Rammelt S, Dürr C, Schneiders W, Zwipp H. Minimally invasive fixation of calcaneal fractures. *Oper Orthop Traumatol* 2012;24(4-5): 383–95.
- [11] Orthofix. Orthofix Calcaneal External Fixator [Internet]. [place unknown]. Orthofix; 2010 Aug [cited 2015 Dec 21]. 9 p. Available from:  
<http://web.orthofix.com/Products/Products/Calcaneal%20Minifixator/EF-0701-OPT-E0%20OT%20Calcaneal%20Fixator.pdf>.
- [12] Hoppenfeld S, Deboer P, Buckley R. *Surgical Exposures in Orthopaedics: The Anatomic Approach*. 4th rev. ed. USA: Lippincott Williams and Wilkins; 2012. 192 p.
- [13] Apaydin N, Bozkurt M, Loukas M, Vefali H, Tubbs RS, Esmer AF. Relationships of the sural nerve with the calcaneal tendon: an anatomical study with surgical and clinical implications. *Surg Radiol Anat* 2009;31(10): 775–80.
- [14] Kavyashree AN, Subhash LP, Asha KR, Bindu Rani MK. Anatomical variations in formation of sural nerve in adult Indian cadavers. *J Clin Diagn Res* 2013;7(9): 1838–41.
- [15] Seema SR. Study of sural nerve complex in human cadavers. *ISRN Anat*. 2013; Article ID 827276.
- [16] Aktan Ikiz ZA, Uçerler H, Bilge O. The anatomic features of the sural nerve with an emphasis on its clinical importance. *Foot Ankle Int* 2005;26(7): 560–7.
- [17] Plotkin D, Patel D, Roberto T. Heel neuroma: a case study. *J Foot Ankle Surg* 2009;48(3): 376–9.
- [18] Magnan B, Bortolazzi R, Marangon A, Marino M, Dall'Oca C, Bartolozzi P. External fixation for displaced intra-articular fractures of the calcaneum. *J Bone Joint Surg Br* 2006;88(11): 1474–9.

[19] Corina G, Mori C, Vicenti G, Galante VN, Conserva V, Speciale D, et al. Heel displaced intra-articular fractures treated with mini-calcaneal external fixator. *Injury* 2014;45 Suppl 6:S64–71.

[20] Benirschke SK, Sangeorzan BJ. Extensive intraarticular fractures of the foot. Surgical management of calcaneal fractures. *Clin Orthop Relat Res* 1993;292: 128–34.

[21] Folk JW, Starr AJ, Early JS. Early wound complications of operative treatment of calcaneus fractures: analysis of 190 fractures. *J Orthop Trauma* 1999;13(5): 369–72.

[22] Abidi NA, Dhawan S, Gruen GS, Vogt MT, Conti SF. Wound-healing risk factors after open reduction and internal fixation of calcaneal fractures. *Foot Ankle Int* 1998;19(12): 856–61.