**Title**

The Minimally Invasive Calcaneal Osteotomy: Does the Shannon Burr Endanger Neurovascular Structures? A Cadaveric Study.

**Abstract**

Calcaneal osteotomies are used to correct hindfoot alignment. Traditional open procedures are plagued with complications. Various minimally invasive techniques have been described, but are laborious and time-consuming. A percutaneous technique using a side cutting ‘Shannon’ burr offers a simple and reliable alternative, but there is little evidence to address safety concerns. The aim of this study was to quantify the risk posed to medial and lateral neurovascular structures by this technique. The study was performed at the anatomy department, University of Sussex using 13 fresh frozen below knee cadaveric specimens during a training session held by WG Healthcare UK Ltd (Letchworth, Herts). The participants were eleven consultant orthopaedic surgeons, inexperienced in minimally invasive surgery and two demonstrators. Each performed a chevron calcaneal osteotomy using a Shannon burr via a lateral percutaneous approach under fluoroscopic guidance. The authors subsequently dissected the specimens to identify the neurovascular structures, describe their anatomic relations and proximity to the burr and note any damage incurred. There was no evidence of significant neurovascular injury. Two very small proximal branches of the sural nerve were transected, the nerve itself passing safely 9-21mm anterosuperior to the entry point. The medial neurovascular bundle crossed the path of the osteotomy in six specimens, but was protected by the medial head of Quadratus Plantae. In summary, the Shannon burr for calcaneal osteotomy has the potential to minimise surgical morbidity and maximise surgical efficiency without compromise to safety in all patients with normal anatomy of the Quadratus Plantae muscle.

**Level of Clinical Evidence: 5**

**Keywords**

calcaneal nerve, calcaneus, flatfoot deformity, sural nerve, tibial nerve, vascular system injuries, quadratus plantae

**Introduction**

 A minimally invasive surgical procedure is any procedure less invasive than the traditional open surgery. Its aim is to achieve outcomes similar to that of an open procedure but through a smaller incision, thus minimising soft tissue disruption and surgical morbidity. Over the last two decades there has been a considerable shift towards minimally invasive procedures, with arthroscopic procedures replacing open techniques in a number of surgical disciplines.

 In foot and ankle surgery, a calcaneal osteotomy is used to treat a variety of pathology in which hindfoot alignment requires adjustment (1-3). Two popular approaches are the extended lateral incision(4) (or modifications thereof) and an oblique incision from the superior border of the calcaneus posterior to the calcaneal peroneal tubercle to the inferior extent of the proposed osteotomy (5). Extensile incisions in the hindfoot however, are plagued by wound healing problems, with Lamm *et al* reporting an incidence of 5% wound complications requiring surgical debridement in 20 Dwyer osteotomies (2). A number of authors have modified their surgical technique to address this issue. DiDomenico *et al* (6) described a percutaneous osteotomy using a Gigli saw inserted into a subperiosteal tunnel that looped up and over the calcaneus via four stab incisions. Their cadaveric study of 20 limbs revealed no neurovascular damage. Tennant *et al* (7) published the outcomes of a variant of this procedure in 25 patients where they passed a suture through the subperiosteal tunnel under arthroscopic guidance prior to “shuttling” a Gigli saw along the track. None of the patients suffered vascular injury, but one had persistent numbness in the sural nerve distribution.

 In the United Kingdom and France, a technique for percutaneous osteotomy has been developed by Redfern (8) and Vernois (9) using a modification of the Shannon burr (high torque, low speed 3mm Shannon burr, WG Health Care Catalogue no: MI007) with end and side cutting performance. Currently its use is restricted to consultants who have been specially trained. Whilst the benefits of this technique are already recognised in forefoot reconstruction (10), there has been more caution in its use in hindfoot surgery. In our unit, we have found the Shannon burr to be a safe, effective and timesaving device for minimally invasive calcaneal osteotomy. A commonly voiced concern however, which has not been addressed in the literature thus far, is whether this technique puts neurovascular structures at risk.

 Our study aimed to quantify the risk to medial and lateral neurovascular structures when a Shannon burr was used for percutaneous chevron calcaneal osteotomy, using fresh frozen cadaveric specimens in a ‘high risk’ situation where the majority of surgeons were novices to the technique.

 **Patients/ Materials and Methods**

 This study was performed at the anatomy department, University of Sussex, Brighton. Cadaveric images used were taken with permission, under the auspices of the Human Tissue Authority licence held by Brighton and Sussex Medical School. There were 13 fresh frozen below knee cadaveric specimens obtained for this study. The study was performed during a training session by WG Healthcare UK Ltd (Letchworth, Herts). The participants were eleven consultant orthopaedic surgeons, inexperienced in minimally invasive (MI) surgery and two experienced demonstrators. After a demonstration by an experienced MI surgeon, each surgeon performed an MI chevron calcaneal osteotomy, with guidance from facilitators in a 2:1 ratio. Fluoroscopy was available throughout the procedures.

*Surgical Technique*

 The entry point was marked prior to incision, being ascertained by obtaining a lateral radiograph of a Kirschner-wire (K-wire) placed over the lateral aspect of the calcaneus in the desired position of the chevron osteotomy, taking care to avoid the subtalar joint, insertion of the plantar fascia and Achilles tendon. A 1cm longitudinal skin incision was made at the entry point, and artery forceps were used for blunt dissection to the calcaneus. A curved periosteal elevator was used for periosteal elevation on the superior and inferior aspects of the calcaneal body.

 Using an artery forceps to protect the soft tissues, a 3x20mm Shannon burr (WG Healthcare Ltd, Letchworth, Herts) was inserted into the entry point, ensuring it was perpendicular to the skin. All threads of the burr were inserted into the bone through both cortices. Cuts were then made via the lateral entry point in the following order: dorsal cut lateral cortex, dorsal cut medial cortex, plantar cut lateral cortex, plantar cut medial cortex. All cuts were performed by a lever action of the wrist, with the entry point acting as a fulcrum. Fluoroscopy was essential to ensure correct position of cuts (**Fig.1**).

*Dissection*

 A minimum data set was collected from the participating surgeons: their prior MI surgical experience and their dominant hand. Following the procedure, a lateral calcaneal radiograph was obtained, demonstrating the position of the osteotomy. The medial and lateral aspects of the heel were dissected by two authors who had not participated in the training, and the neurovascular structures examined for damage. Anatomical variation was noted including the presence or absence of a medial head of Quadratus Plantae, and the position and number of medial and lateral calcaneal nerve branches.

 The same dissection steps for a lateral and medial approach were used for each specimen. A skin flap was raised on the deep fascia. On the lateral side, the short saphenous vein and its branches were identified, enabling localisation of the sural nerve (SN) and its variable branches as they emerged 10cm proximal to the insertion of the Achilles tendon on its lateral border (11). The course of the SN was followed and its anatomy noted. For the purpose of radiograph measurement calibration, on the lateral side the distance between the highest point of the calcaneal tuberosity and the highest point of the osteotomy was measured with callipers accurate to 0.1mm, using burrs to mark each position. Secondly, one burr was inserted into the entry point. From this point, the minimum distance to the SN and closest lateral calcaneal branch were measured.

 On the medial side, superficial dissection revealed a number of long saphenous vein tributaries, which were divided to enable access to deeper tissues. The medial flexor retinaculum was incised to allow dissection of the tendons of tibialis posterior, flexor digitorum longus, and flexor hallucis longus; the posterior tibial artery (PTA), medial plantar artery (MPA), and lateral plantar artery (LPA); the tibial nerve (TN), medial plantar nerve (MPN), lateral plantar nerve (LPN); and the medial calcaneal nerve (MCN). A burr was inserted through the entry point, and another through the upper and lowermost point of the osteotomy. Unlike the lateral side, the medial structures were theoretically at risk throughout the whole length of the osteotomy due to their exposure to the tip of the burr. Therefore, the minimum distance of any part of the osteotomy from the closest tibial nerve or artery and the closest medial calcaneal branch was measured. All data was analysed using SPSS Inc. 20.0 (IBM, New York 10504-1722).

**Results**

 Seven left and six right feet were dissected following completion of calcaneal osteotomy. Thirteen different surgeons performed the osteotomies. Nine were using an MI burr for the first time, two for the second or third. The final two surgeons were demonstrators, pioneers of MI foot surgery in Europe, each with an experience exceeding 200 surgeries. All but one surgeon was right handed. The lateral entry point was consistently within a 20 x 8mm ellipse in the centre of the lateral wall of the calcaneal tuberosity. The position of the osteotomy on the medial side was less consistent and spread over a large area of the calcaneal tuberosity (**Fig.2**). In four cases the proximally directed osteotomy was in direct line with the posterior tibial artery and/or tibial nerve if the burr had been advanced excessively through the osteotomy (**Fig.3**).

 Dissection of the lateral neurovascular structures demonstrated that the short saphenous vein was consistently superficial and anterior to the sural nerve. The number of lateral calcaneal nerve branches (branches of the sural nerve) varied between 1 and 5, the most common being 2 which occurred in 7 specimens. In nine feet there was a very small primary lateral calcaneal branch (i.e. first branch from the sural nerve), which arose very proximally as the sural nerve left its posterior position and moved anteroinferiorly across the lateral aspect of the foot (**Table**). The minimum distance from the burr entry point to the sural nerve was 9mm, with a mean of 14.3mm (range 9-21mm). In all cases, the entry point was within 8mm of the closest lateral calcaneal branch (mean 3.4mm, range 0-8mm) (**Fig.2**). We were unable to analyse accurately the vascular structures on the lateral side. The only neurological damage identified was transection of a primary lateral calcaneal nerve branch in two specimens (**Fig.4**). This was unrelated to the experience of the surgeon. A second or third undamaged branch was present in both specimens.

 Medially, there was no evidence of damage to any neurovascular structure. In all 13 specimens the tibial nerve branched into medial and lateral plantar nerves proximal to the medial malleolar-calcaneal axis. The medial calcaneal nerve branch(es) arose from the tibial nerve proximal to the superior border of the calcaneum, singly or in duplicate (**Table**). The medial head of Quadratus Plantae was present in 12 of 13 feet, with a broad insertion on the medial wall of the calcaneum. This muscle had an important function as a spacer between the osteotomised medial calcaneal wall and the posterior tibial neurovascular bundle, and had not been breached in any of our specimens. In all specimens the path of the osteotomy was within 13mm of the tibial nerve, crossing it in four specimens (mean 5.5mm, range 0-13mm), and within 11mm of the closest medial calcaneal nerve branch (mean 2.9mm, range 0-11mm), crossing it in six specimens. None were damaged in any specimen. Similarly, the path of the osteotomy crossed the tibial artery in two feet, without injury (**Fig.3**).

**Discussion**

 The neurovascular anatomy of the hindfoot has been studied extensively in relation to the use of calcaneal pin fixation. Some studies have attempted to quantify medial and lateral safe zones for the calcaneal pin placement, however there are a number of disagreements between these studies (12-17). Mekhail (13) recommended a posteromedial pin entry point, ¾ of the distance between the palpable tip of the medial malleolus and the most inferior and posterior point of the calcaneus. With the pin inserted transversely, the minimum distance from any major neurovascular structure to a pin was 1.2cm medially and 1.3cm laterally. They did report however, a close relation to the lateral calcaneal nerve. Casey (14) described a ‘safe zone’ in relation to three bony prominences (posterior to 1/3 of the distance from the posteroinferior calcaneus to the medial malleolus and posterior to a point halfway between the posteroinferior calcaneus and the navicular tuberosity). Anterior to this area, the medial calcaneal and lateral plantar nerves were at significant risk of injury from a calcaneal pin. Santi (16) however, emphasized that even within this ‘safe’ zone were terminal branches of the medial calcaneal nerve. This concern was echoed by Gamie (17), who accused previous studies of ignoring anatomical variations of the medial calcaneal nerve, missing areas at risk, or producing cumbersome lines difficult to reproduce in clinical practice.

 Anatomical studies of the neurovascular structures in relation to calcaneal osteotomies have raised even greater concerns of possible damage. Green *et al* (5), in an anatomical study of 22 cadaveric specimens operated via an extended lateral approach found that an average of four neurovascular structures crossed the oblique calcaneal osteotomy site (range 2 to 6), usually branches of the lateral plantar nerve or the posterior tibial artery. DiDomenico *et al* (6) described the relations of medial structures in relation to a percutaneous medial displacement sliding calcaneal osteotomy, demonstrating several structures to be at risk. These included the lateral plantar nerve and its branches and the posterior tibial artery and its branches as they crossed the osteotomy. The most alarming data was from a cadaveric series of ten scarf-type calcaneal osteotomies performed via an extended lateral approach. The medial or lateral plantar nerve was transected in three cases, and both structures transected in a fourth. The posterior tibial artery crossed the osteotomy in eight cases, being elongated in one specimen, but never transected. In the remaining two specimens, this vessel was only 3mm from the osteotomy (18).

 In clinical practice, a traditional open calcaneal osteotomy is not without risk. Niki *et al* (3) published the outcome of 25 patients undergoing calcaneal osteotomy for pes planus reconstruction. There were two superficial wound infections, both treated successfully with oral antibiotics and local wound care. Four patients (16%) complained of reduced sensation lateral to the scar. In the literature, major neurovascular damage appears to be rare. There is a single case report of lateral plantar artery pseudoaneurysm after calcaneal osteotomy (22) and two case reports of tibial nerve palsy following a lateralising calcaneal osteotomy, which was attributed to compression from the tensioned inferior flexor retinaculum (23). Ray *et al* (24) analysed 36 calcaneal osteotomies and found a complication rate of 22%. There was 1 non-union, 2 patients suffered sural nerve damage, 2 patients developed symptoms relating to prominent screws, 2 patients had a wound breakdown and 1 had a superficial infection. It is unsurprising that surgeons have evolved percutaneous techniques to reduce soft tissue disruption and therefore reduce patient morbidity.

 In our study we have described the anatomy of ‘at risk’ structures and then quantified the actual damage incurred by these structures when a Shannon burr was used to perform a minimally invasive chevron-type calcaneal osteotomy via a lateral portal. This study was performed in a training situation where the majority of the surgeons were novices to the techniques. Despite this, the lateral entry point of the osteotomy was consistent in its position. The medial osteotomy exit point was variable, and illustrated the learning curve common to all operative procedures (**Fig.2**).

 On the lateral side, we found considerable anatomical variability of the sural nerve and its branches, which varied in number with 1 to 5 branches being identified in different specimens (**Table**). This matches the findings of Lawrence *et al* (21) *that* the sural nerve gave off an average of three branches (range 1-5) that continued to the lateral heel. Its main body was consistent in its course, passing a minimum of 9mm anterosuperiorly to the osteotomy entry point in all cases. The lateral calcaneal branches were multiple, arising sequentially from the nerve (or its branches) after it crossed the superior border of the calcaneus. Distinct from these branches, we observed a ‘primary calcaneal branch’ in 70% of specimens, approximately 0.5mm in diameter, which arose much more proximally and had a long posterior course (**Fig.4**). Transection of these nerves accounted for the only incidents of neurovascular damage from the burr, occurring in 2 specimens at the entry point. In each case at least one other calcaneal branch remained undamaged in the immediate area. Potentially, even this degree of damage was avoidable by using an artery forceps to protect the soft tissues, and inserting all threads of the burr through the lateral cortex prior to performing the wrist lever action for the osteotomy. A formal open procedure to perform a calcaneal osteotomy would be very likely to sacrifice the majority of these small branches.

 In 4 of 13 specimens in our study, the posterior tibial nerve crossed the path of the osteotomy. In two of those four specimens, the posterior tibial artery also crossed the osteotomy. The relative position of the posterior tibial artery to the nerve was constant, approximately 5mm anterosuperior. This study revealed the degree of protection to medial neurovascular structures by the medial head of the Quadratus Plantae (or *flexor accessorius*) along its broad attachment to the medial surface of the calcaneus (**Fig.3**). Its presence is particularly important when using the Shannon burr, which has been designed to rapidly halt its progression on contact with soft tissue, thereby protecting the overlying neurovascular structures. A recent cadaveric study of 50 specimens described anatomical variations of the muscle (25). It arose from a medial and lateral head in the vast majority of feet (80%), a medial head only in 10%, a lateral head only in 8%, but was altogether absent in one specimen (2%). This is in keeping with our study, in which one of 13 specimens lacked the medial head of this muscle. Ultrasonography could be used to ensure that patients selected for this surgery belong to the 90% of the population who possess a medial head of Quadratus Plantae.

 This study was limited by the lack of a ‘traditional open procedure’ control group, necessary for statistical evaluation. The small sample size could have introduced bias, and prevented the authors from making comparison between the surgical outcomes of experienced and novice MI surgeons.

 In conclusion, a percutaneous chevron osteotomy performed using a Shannon burr may result in minor damage to small branches of the sural nerve, but the medial neurovascular bundle is protected by the medial head of Quadratus Plantae. These results could be used in developing randomised controlled trials to make a formal comparison between minimally invasive and open techniques.

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**References**

1. Hix J, Kim C, Mendicino RW, Saltrick K, Catanzariti AR. Calcaneal osteotomies for the treatment of adult-acquired flatfoot. Clin Podiatr Med Surg 24:699-719, 2007.

2. Lamm BM, Geshaff MG, Salton HL, Dupuis TW, Zeni F. Preoperative planning and intraoperative technique for accurate realignment of the Dwyer calcaneal osteotomy. J Foot Ankle Surg 51:743-748, 2012.

3. Niki H, Hirano T, Okada H, Beppu M. Outcome of medial displacement calcaneal osteotomy for correction of adult-acquired flatfoot. Foot Ankle Int 33:940-946, 2012.

4. Freeman BJ, Duff S, Allen PE, Nicholson HD, Atkins RM. The extended lateral approach to the hindfoot. Anatomical basis and surgical implications. J Bone Joint Surg [Br] 80:139-142, 1998.

5. Greene DL, Thompson MC, Gesink DS, Graves SC. Anatomic study of the medial neurovascular structures in relation to calcaneal osteotomy. Foot Ankle Int 22:569-571, 2001.

6. DiDomenico LA, Anain J, Wargo-Dorsey M. Assessment of medial and lateral neurovascular structures after percutaneous posterior calcaneal displacement osteotomy: a cadaver study. J Foot Ankle Surg 50:668-671, 2011.

7. Tennant JN, Velikovic A, Phisitkul P. Technique tip: Percutaneous endoscopically-assisted calcaneal slide osteotomy. Iowa Ortho J 33:191-195, 2013.

8. Walker R, Redfern D. Minimally invasive hallux valgus correction: The MICA technique. J Bone Joint Surg [Br] 94-B(SUPP XXII):38, 2012.

9. Vernois J. The treatment of the hallux valgus with a percutaneous chevron osteotomy. J Bone Joint Surg [Br] 93-B(SUPP IV):482, 2011.

10. Perera AM, Beddard L, Marudunayagam A. A case-controlled study of minimally invasive vs. open hallux valgus surgery. Bone Joint J 96-B(SUPP XIII), 2014.

11. Webb J, Moorjani N, Radford M. Anatomy of the sural nerve and its relation to the achilles tendon. Foot Ankle Int 21:475-477, 2000.

12. Langdon IJ, Harling R, Atkins RM, Nicholson H. A cadaveric study of the medial relations of the calcaneum. J Foot Ankle Surg 6:169-173, 2000.

13. Mekhail AO, Ebraheim NA, Heck BE, Yeasting RA. Anatomic considerations for safe placement of calcaneal pins. Clin Orth Rel Res 332:254-259, 1996.

14. Casey D, McConnell T, Parekh S, Tornetta P. Percutaneous pin placement in the medial calcaneus: is anywhere safe? J Orthop Trauma 16:26-29, 2002.

15. Mereau T, Beck D, Seligson D. Surgical tip: calcaneal pin placement: anatomic considerations. Foot Ankle Int 26:270-271, 2005.

16. Santi MD, Botte MJ. External fixation of the calcaneus and talus: an anatomical study for safe pin insertion. J Orthop Trauma 10:487-491.

17. Gamie Z, Donnelly L, Tsiridis E. The ‘‘safe zone’’ in medial percutaneous calcaneal pin placement. Clin Anat 22:523-529, 2009.

18. Vermeulen K, Neven E, Vandeputte G, Van Glabbeek F, Somville J. Relationship of the scarf valgus-inducing osteotomy of the calcaneus to the medial neurovascular structures. Foot Ankle Int 32:540-544, 2011.

19. Davis TJ, Schon LC. Branches of the tibial nerve: anatomic variations. Foot Ankle Int 16:21-29, 1995.

20. Bilge O, Ozer MA, Govsa F. Neurovascular branching in the tarsal tunnel. Neuroanatomy 2:39-41, 2003.

21. Lawrence SJ, Botte MJ. The sural nerve in the foot and ankle: an anatomic study with clinical and surgical implications. Foot Ankle Int 15:490-494, 1994.

22. Ptaszek AJ, Aminian A, Schneider JR, Milos S. Lateral plantar artery pseudoaneurysm after calcaneal osteotomy: a case report. Foot Ankle Int 27:141-143, 2006.

23. Krause FG, Pohl MJ, Penner MJ, Younger AS. Tibial nerve palsy associated with lateralizing calcaneal osteotomy: case reviews and technical tip. Foot Ankle Int 30:258-261, 2009.

24. Ray R, Jameson S, Kumar S. Complications of calcaneal osteotomy. J Bone Joint Surg [Br] 92-B(SUPP IV):590, 2010.

25. Hur M, Kim J, Woo J, Choi B, Kim H, Lee K. An anatomic study of the Quadratus Plantae in relation to tendinous slips of the Flexor Hallucis Longus for gait analysis. Clin Anat 24:768-773, 2011.

**Tables**

Table - Summary of anatomical variation encountered in 13 below-knee cadaveric specimens.

|  |  |  |  |
| --- | --- | --- | --- |
| Variant | Medial head of PQ present | No. of med calc nerve branches | No. of lat calc nerve branches |
| 1 | 2 | 1 | 2 | 3 | 4 | 5 |
| Freq. of occurrence | 12 | 5 | 8 | 2 (1)\* | 7 (4)\* | 3 (3)\* | 0 | 1 (0)\* |

\* represents subgroup of specimens with a very proximal ‘primary’ lateral calcaneal nerve branch.

PQ pronator quadratus, med calc medial calcaneal, lat calc lateral calcaneal, freq frequency

**Figures**

**Figure 1** – Lateral calcaneal radiograph demonstrating the appropriate position of the osteotomy entry point (black ring) and of the dorsal (outline arrow) and plantar (block arrow) cuts for a chevron osteotomy.

**Figure 2**- Calibrated composite diagram of the entry point for the osteotomies performed on the lateral calcaneal wall (upper diagram) and the complete osteotomy trajectory on the medial calcaneal wall (lower picture), with overlaid detail of the neurological structures. This information was obtained from the post-procedural lateral radiographs, and calibrated by measuring the distance between the superior border of the osteotomy the Achilles tendon insertion and secondly from the osteotomy entry point to the superior border of the osteotomy. The position of the medial and lateral neurological structures (indicated in yellow) in comparison to the entry point (green ring) and osteotomy position (indicated in red) illustrates the variability of both the anatomy and the osteotomies performed.

**Figure 3** – Photograph taken of the medial hindfoot dissection in one specimen. The proximity of the medial calcaneal nerve to the Shannon burr trajectory is illustrated by pushing the burr through the quadratus plantae muscle (this is done for illustrative purposes and the quadratus plantae was not breached in any specimen examined).

**Figure 4** – Photograph taken of the lateral hindfoot dissection of the sural nerve and its branches in one specimen. The burr marks the osteotomy entry point. The forceps indicate the damaged ‘primary calcaneal branch’ of the sural nerve.