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Chapter 2.3

The neurovascular anatomy of the lateral hindfoot in relation to incisions for a lateral approach of the ankle and the calcaneus.

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ABSTRACT

Background: Soft-tissue related complication rates following a lateral approach of the ankle are high and can result in neuropathic pain, wound necrosis or wound infections. Therefore this anatomy study aims to map both neural- and vascular safe zones, resulting in a safer approach of the lateral ankle.

Methods: In 10 embalmed and 10 fresh-frozen lower legs, the sural nerve and vascular anatomy was dissected. A novel method, Computer Assisted Surgical Anatomy Mapping (CASAM) was used to compare anatomy and compute both neural and vascular safe zones and relate them to different surgical approaches.

Results: Both the neural and vascular anatomy of the lateral hindfoot follow a relatively predictable pattern. The sural nerve is mainly at risk in an extended lateral approach or in an incision for the posterolateral portal in ankle arthroscopy. Damage to the main branch can easily be prevented moving the (proximal part of) the incision closer to the Achilles tendon. Damage to the distal sural nerve can be reduced when approaches to the fifth metatarsal are located inferior to the metatarsal head. In addition, the medial calcaneal branch of the postior tibial artery supplies a large part of the lower hindfoot and is easily damaged during an extended lateral approach, especially when the incision is placed further away from the sole of the foot. This results in impaired bloodflow to both the full-thickness skin-flap and the lateral-posterior calcaneus. The sinus tarsi approach is located in a neural safe zone and is situated in an area which is supplied by choke vessels of all three suppliying arteries: the anterior tibial, fibular and medial calcaneal branch of the posterior tibial artery. This may explain lower soft-tissue complication rates following this approach.

Conclusion: The neurovascular anatomy of the lateral hindfoot is relatively predictable and soft-tissue related complication rates can be further reduced by implementing effective changes to existing surgical approaches.

Clinical relevance: This study shows that the neurovascular anatomy of the lateral hindfoot is relatively predictable and soft-tissue related complication rates can be further reduced by implementing effective, anatomy based changes to existing guidelines on for instance the extended lateral approach of the calcaneus, the sinus tarsi approach, the approach to the fifth metatarsal and portal placement in ankle athroscopy.

INTRODUCTION

Research and innovation on surgical treatment of foot and ankle injuries has traditionally focused on mechanical aspects of the injury and primary repair techniques. Soft tissue complications such as wound necrosis, wound infection and neuropathic pain are major drawbacks of foot and ankle surgery. Fear for these complications has increased popularity of minimally invasive surgical techniques. However, it is not clear yet if small incisions are safer than large ones in this respect. Current gold-standard incisions for surgery in the lateral hindfoot are merely based on 'nervous safe zones' alone. Therefore the aim of this study is to combine anatomical data of multiple specimens and propose a combined neural and vascular safe-zone(s) for an optimal approach of the lateral side of the ankle and hindfoot.

Traditionally, surgical safe zones in foot and ankle surgery are implicitly seen as 'nervous safe zones'. These zones are anatomical areas in which little or no nerves are encountered during the surgical approach. Of the three sensory nerves running distally, the sural nerve is of particular interest. It innervates the lateral part of the foot. Especially in the lower leg the sural nerve has a variable course mostly located between both gastrocnemius muscles[1,2] whereas more distally it runs close to the Achilles tendon. The sural nerve is at risk for iatrogenic damage in both open and minimally invasive (postero-)lateral approaches for the surgical treatment of talar fractures, ruptured anatomic ankle ligaments, calcaneus fractures, malleolar fractures, percutaneous Achilles tendon repair and ankle arthroscopy[3-7]. Iatrogenic damage to the distal part of the sural nerve can lead to a wide spectrum of postoperative complaints varying from local skin numbness to sharp and invalidating or even causalgic pain[8,9]. Moreover, the sural nerve is considered to recover slower from injury than other cutaneous nerves and appears to have the highest possibility of developing painful neuromas interfering drastically with daily routine and quality of life[3].

Uncomplicated wound healing requires adequate vascularization of a surgical wound. Therefore 'vascular safe zones' are as important as 'nervous safe zones'. The use of watershed areas in ankle surgery in order to preserve perfusion of soft tissues, is relatively new. The main arteries supplying the lateral ankle are the fibular artery (FA), the anterior tibial artery (ATA) and the medial calcaneal branches of the posterior tibial artery (MCBPTA). Sparing these arteries becomes even more paramount in the already fragile soft tissues of a bruised foot after a high energy trauma. In such cases iatrogenic arterial damage may easily result in soft tissue ischemia leading to infection and necrosis of the lateral hindfoot. Especially in large surgical exposures, such as the extended lateral approach for the calcaneus, an optimal location of the skin incision is important to maintain adequate perfusion of soft tissue. Following open reduction and internal fixation of calcaneal fractures for instance, superficial necrosis has been reported to occur in up to 25%[10-12] of treated cases resulting in a high (permanent) morbidity rate.

First the anatomy of the sural nerve and the main arterial blood supply of the lateral ankle and hindfoot will be described. Then we will discuss the clinical implications to surgical approaches of the lateral ankle such as the extended lateral approach of the ankle (ELAC), the sinus tarsi approach (STA), and the minimally invasive longitudinal approach (MILA). Also implications to ankle arthroscopy, the lateral approach to the fifth metatarsal and the dorso-lateral approaches to the cuboid will be examined.

MATERIALS AND METHODS

The neurovascular anatomy of the lateral hindfoot was dissected in 10 embalmed and 10 fresh frozen unpaired lower legs from adult donors. None of the limbs showed macroscopic signs of disease or scarring. In the embalmed specimens the course of the sural nerve and its concurrent branches was dissected. These specimens had been flushed with AnubiFiX[13] to regain tissue and joint flexibility and were embalmed with a mixture of 6% formaldehyde and 5% phenol. In the fresh frozen specimens the arterial blood supply of the lateral ankle was dissected. After cannulation of the popliteal artery these specimens had been flushed with FillOpaQ[14]. FillOpaQ is a filling-agent having the viscosity close to that of water. It therefore is capable to even reach the smallest capillaries in the foot. Blue-green dye was added to the filler as it contrasts well to the color of fresh-frozen specimen. Once set, FilloPaQ stays slightly flexible (a rubber like rigidity is created) which allows for easy manipulation when dissecting. Dissection was performed using a magnifying glass (5 diopter) until nervous or arterial branches were too small for further dissection (<1mm).

Computer-Assisted Surgical Anatomy Mapping (CASAM)

The anatomy-mapping tool CASAM[1,15,16] was used to visualize and evaluate the complex and variable anatomy of each specimen and to visualize all dissected nerves and arteries in one image of a single ankle with average dimensions. First, each ankle was flexed in 90°, simulating the onset position for most lateral ankle

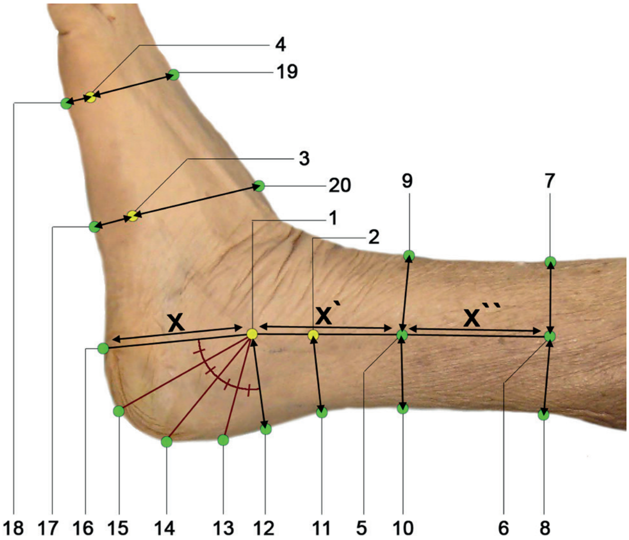

Figure 1. landmarks used for CASAM
Yellow: bony landmarks: The most distal (= malleolus tip; 1) and the most proximal part of the malleolus (malleolus top; 2), the tuberosity of the fifth metatarsal (3) and the fifth metatarsal head (4).
Green: non-bony landmarks: On the sole of the foot: The nearest point to the tip of the lateral malleolus (16), the nearest point to the tuberosity of the fifth metatarsal (17), the nearest point to the fifth metatarsal head (18). On the foot ridge: the nearest point to the fifth metatarsal head (19), the nearest point to the tuberosity of the fifth metatarsal (20). On the achilles tendon: the nearest point to the tip of the lateral malleolus (12), the nearest point to the top of the lateral malleolus (11).
The distance between landmark 1 and 16 (X) was used to create landmark 5 (X`) and 6 (X``) (in line with the tibia). Landmarks 7 and 8 are the nearest points on the posterior and anterior side of the leg to landmark 6. Landmarks 9 and 10 are the nearest points on the posterior and anterior side of the leg to landmark 5.
The angle between landmark 12 and 16 over landmark 1 was measured and divided into four segments (Red lines), thereby creating landmarks 13, 14 and 15 on the edge of the hindfoot.

surgeries. Then, osseous landmarks were identified and marked. Subsequently, non-osseous landmarks were deduced from the osseous landmarks to delineate the different shapes of the individual ankles (Figure 1). Each ankle was photographed, using a standardized protocol, with a Canon 350D camera (Canon USA, Lake Success, New York) with a Canon EF-S 18-55-mm lens (Canon USA). The average location of all osseous and nonosseous landmarks were calculated from each specimen. Then, with the use of Magic Morph 1.9510 software (EffectMatrix Software Studio)[17], each specimen in each original photograph was reshaped (warped) to match the calculated average shape. A thin plate spline was used as a warping algorithm. Since all warped specimens have an identical calculated average shape, the relative position of the anatomical structures of interest could be mapped and visualized in one averagely shaped ankle. Photoshop CS4 (Adobe Systems, San Jose, California)[18] was used to highlight relevant anatomy and make renditions. The following renditions were made:

- The sural nerve and its branches
- arterial blood supply of the lateral foot
  - o Anterior tibial artery (ATA)
  - o Medial calcaneal branches of the posterior tibial artery (MCBPTA)
  - o Fibular artery (FA)

Watershed area

The main branches of each supplying artery were defined both in each specimen and in each photographed ankle. Arteries of distribution were located and assigned to either one of the three supplying arteries. An area of 25 pixels (=5 times the width of the smaller branches) surrounding each artery was selected and colored. Areas of distribution of each artery were colored and their opacity was set to 40% (Figure 5 A-E). Overlapping areas were again selected and colored, describing the estimated angiosomes of each of the three main arteries supplying the lateral foot. The area in which all three angiosomes overlap was colored green.

RESULTS

Sural nerve

The dissected sural nerves of 10 specimens are visualized in an ankle with average dimensions (Figure 2). The main branch of the sural nerve runs a fairly predictable course. In five specimens the main branch of the sural nerve is a continuation of the medial branch of the sural nerve (originating from the tibial nerve) whereas in the other five specimens the medial branch conjoins with the lateral branch of the sural nerve (originating from the common peroneal nerve) just distal to the posterior inferior tibiofibular ligament. Between the lateral malleolus and the Achilles tendon the posterior border of the main branch is located at 58% of the distance between landmark 1 and 12, and 90% of the distance between landmark 2 and 11. Also, the distal border of the main branch is located at 50% of the distance between landmark 1 and 16. Anteriorly, the border of the main branch variation is located at 60% of the distance between landmark 5 and 10, and 40% of the distance between landmark 2 and 11. The main branches of all specimens run anterior and proximal to the tuberosity of the fifth metatarsal. In

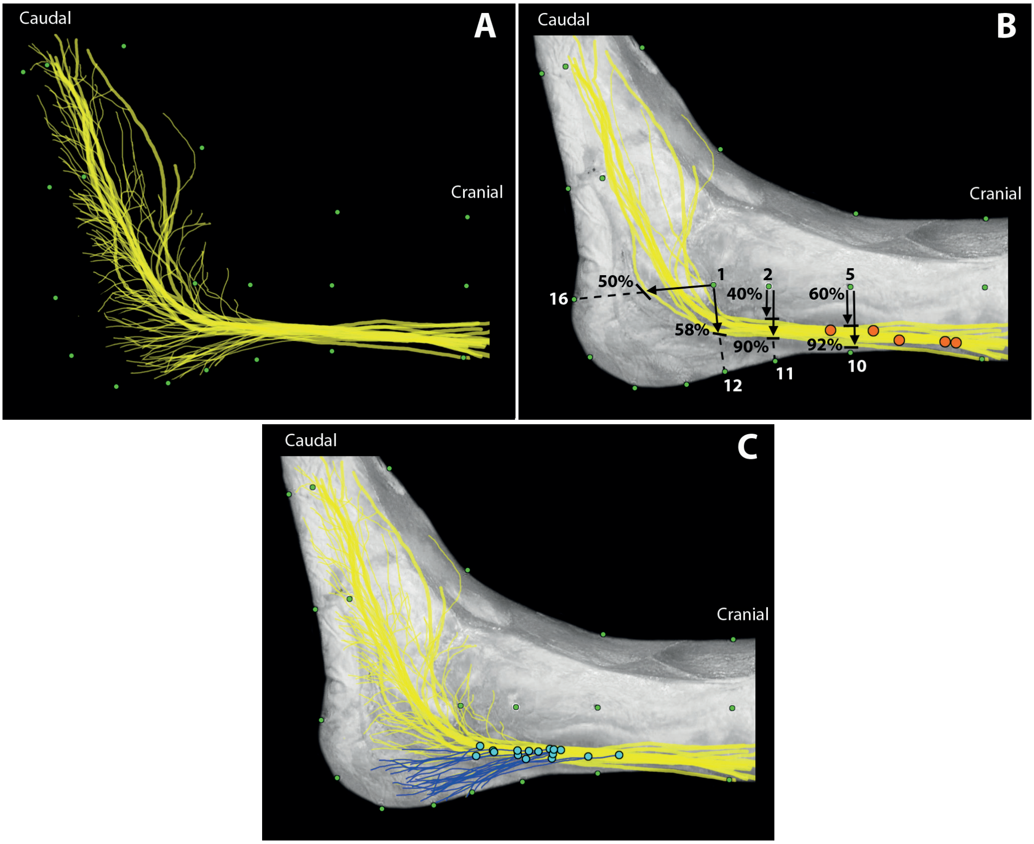

Figure 2. Anatomy of the sural nerve.
A. Variations of the ten dissected sural nerves. B. Orange dots: location where the lateral and medial branch of the sural nerve conjoin. Posterior edges of main branch variations: 92% (d 5-10), 90% (d 2-11), 58% (d1-12) and 50% (d 1-16). Anterior edges of main branch variations: 60% (d5-10) and 40% (d 2-11). All main branches of the sural nerve run anterior and proximal to the tuberosity of the fifth metatarsal. C. The calcaneal branch (blue) and the dorsal branch (purple).

six specimens the lateral calcaneal branch of the sural nerve (innervating the heel) consists of two separate branches and in three specimens only one branch is identified. Twelve of the sixteen origins of the lateral calcaneal branch originate proximal to the uppermost top of the lateral malleolus and in four specimens the origin of the lateral calcaneal branch is located posterior to the lateral malleolus. No origins are found more distal than the most distal tip of the lateral malleolus. In four specimens the sural nerve has a dorsal branch, splitting of the main branch just caudal to the lateral malleolus. This branch then runs to the dorsum of the foot either conjoining with the intermediate cutaneous branch (of the peroneal nerve) or completely replacing it.

Arterial blood supply

Medial calcaneal branches of the posterior tibial artery

A total of 15 medial calcaneal branches of the posterior tibial artery (MCBPTA) are present in nine specimens. In one specimen the medial calcaneal branch is not present. Four specimens contain only one medial calcaneal branch, whereas in another four two individual branches are present. In one specimen three individual branches were present. All branches originate from the lateral plantar artery, distal to its bifurcation from the posterior tibial artery (PTA) (Figure 3 A). In the specimen with three medial calcaneal branches, the most proximal branch runs off directly from the posterior tibial artery. The superficial, terminal branches supply arterial blood to a large area of the plantar part of the lateral ankle, ranging from the heel to as far as the fifth metatarsal head (Figure 3 B).

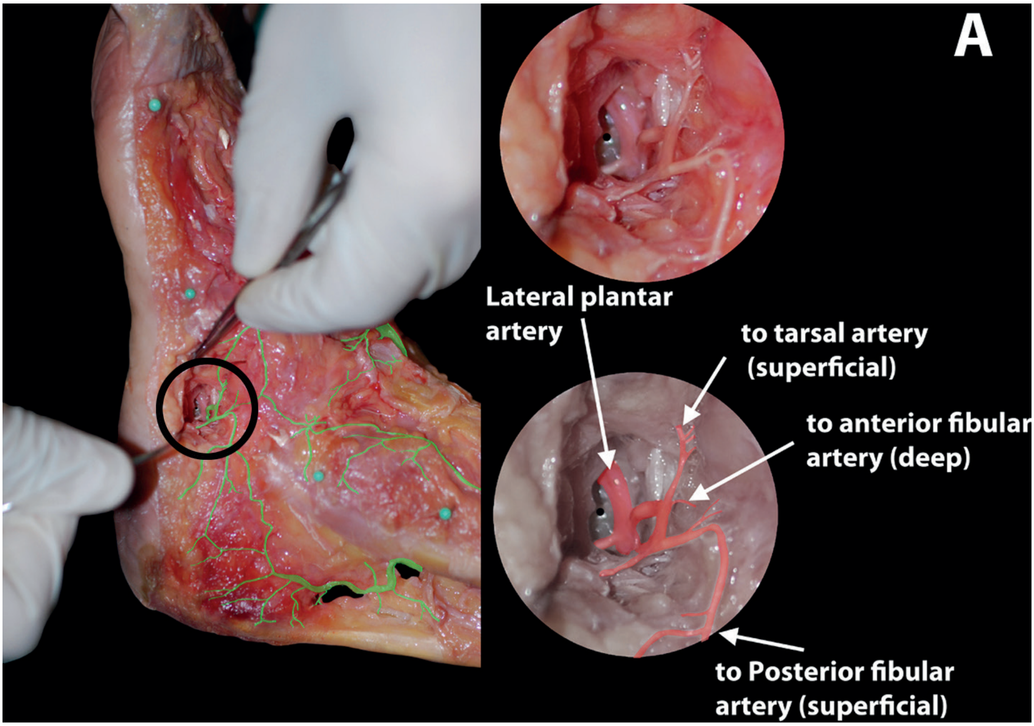

Figure 3 A. Medial calcaneal branch of the posterior tibial artery
A: Example of a dissected medial calcaneal branch of the posterior tibial artery, originating from the lateral plantar artery and connecting superficially with both the tarsal and posterior fibular artery. The connecting artery with the anterior fibular artery runs beneath the peroneal tendons.

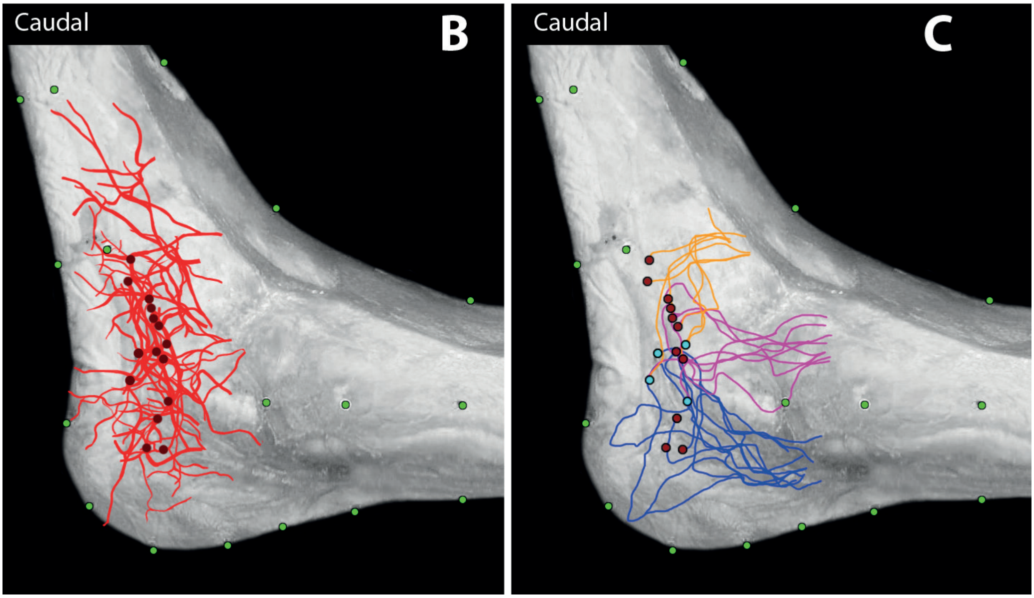

Figure 3B-C. Medial calcaneal branch of the posterior tibial artery
B: Terminal branches, highlighting the probable arterial supply area for the medial calcaneal branch. C: Blue dots: medial calcaneal branch, when only one branch is present. Red dots: medial calcaneal branch when more than one branch is present. Blue lines: connecting arteries that run superficially to the posterior fibular artery. Purple lines: connecting arteries that run posterior to the peroneal tendons to connect with the anterior fibular artery. Orange lines: superficial arteries connecting with the tarsal artery.

If only one medial calcaneal branch is present, it is located just anterior to the lateral process of the calcaneal tuberosity and it runs a transverse course close to the "roof" of the calcaneal bone (Figure 3 C, blue dots). If more than one medial calcaneal branch is present, the perforators are located along the lower ridge of the calcaneal bone and also run a transverse course close to the bone (Figure 3 C, red dots). The perforators then always communicate with each other superficially.

In seven specimens either one of the medial calcaneal branches communicates with the anterior fibular artery. The interlaying artery runs a deep course just beneath the tendons of peroneus longus and brevis muscles, and pierces the cruciate ligament just anterior to the lateral malleolus before it connects with the anterior fibular artery (Figure 3 C, purple lines). In seven specimens the medial calcaneal branch communicates with the posterior fibular artery through the superficial arteries running subcutaneous between the peroneal tendons and Achilles tendon (Figure 3 C, blue lines). In five specimens, either one of the medial calcaneal branches communicates superficially with the arteria tarsalis or the arteria arcuata (both continuations of the arteria dorsalis pedis). The interlaying artery always runs a subcutaneous course posterior and proximal to the tuberosity of fifth the metatarsal (Figure 3 C, orange lines).

Fibular artery

In all but one specimen the fibular artery (FA) consists of two main branches. The posterior branch is always present and dominant. Its proximal course is deep and posterior to the fibula whilst at the level of the lateral malleolus it runs closer to the Achilles tendon. At this level horizontal anastomoses to the PTA exist that run a course flush on the Achilles tendon. The posterior branch has no clear branching pattern but in four specimens a distinct calcaneal branch is identified that runs a course close to the calcaneus in the direction of the outermost part of the heel. The anterior branch runs a very superficial course just anterior to the fibula. On average two anastomoses between the anterior and posterior branch exist located over or just caudal to the lateral malleolus. The fibular arterial system connects to the anterior tibial artery (ATA) in all 10 specimens (Figure 4 A, purple and orange dots). In specimens in which no anterior branch of the fibular artery was present, the anterior tibial artery consists of two instead of one branch and there are two connections between the fibular artery and the ATA located caudal to the lateral malleolus (Figure 4 A, orange dots).

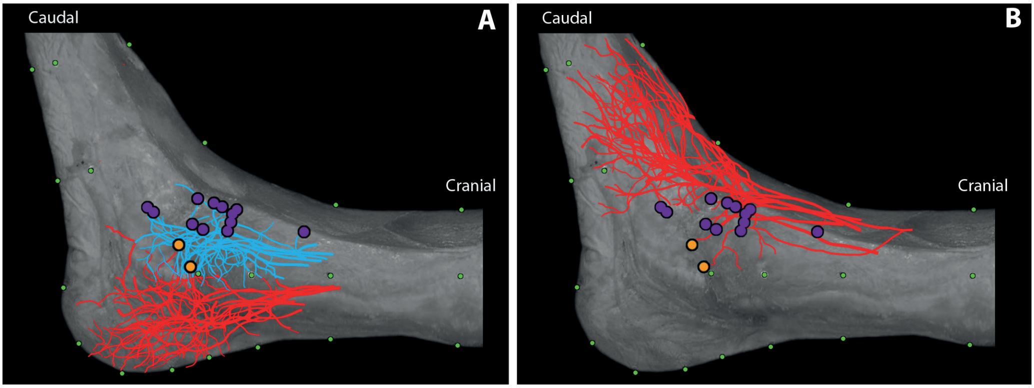

Figure 4. Fibular artery and anterior tibial artery
A: Fibular artery. Red: posterior branch. Blue: anterior branch. Purple dots: connections between the anterior branch and the ATA. Orange dots: connections between the posterior branch and the ATA (both in one specimen).
B: Anterior tibial artery. (a. dorsalis pedis).

Anterior tibial artery

The branches of the ATA mainly supply the dorsolateral side of the foot and the soft tissues caudal to the head of the fifth metatarsal (Figure 4 B). The ATA is the dominant branch and always runs a course anterior to the tibia. Most of the arterial branches are located deep to the extensor tendons, giving off multiple perforating superficial branches. Connections with the fibular artery are generally situated deep, close to the bone, whilst connections with the MCBPTA are found superficially, in the subcutaneous fat.

In one specimen in which the anterior branch of the fibular artery was not present, the ATA consists of two main branches of which one runs a course perpendicular to the fibula supplying the soft tissue caudal and anterior to the lateral malleolus, thus completely taking over the area of distribution of the anterior branch of the fibular artery.

Watershed area of the lateral foot

The areas of distribution between all three supplying arteries showed much overlap. Especially in the area inferior-anterior to the lateral malleolus many connections between either three of the supplying arteries exist. In previous classical texts such an area is suggested to be a watershed area, in which surgical approaches should be avoided as bloodflow, and thus optimal wound healing, cannot be guaranteed. In the present study, in which meticulous and specific dissection and mapping techniques were used, the anatomical data suggests that in fact no real or full watershed area exists. Instead a system of multiple small and sometimes deeply situated branches exists through which a patent blood flow can be guaranteed in case of damage to other branches of this system. In other words: a complex system of anastomoses exists which can compensate for (surgical) trauma if constituent main branches are spared.

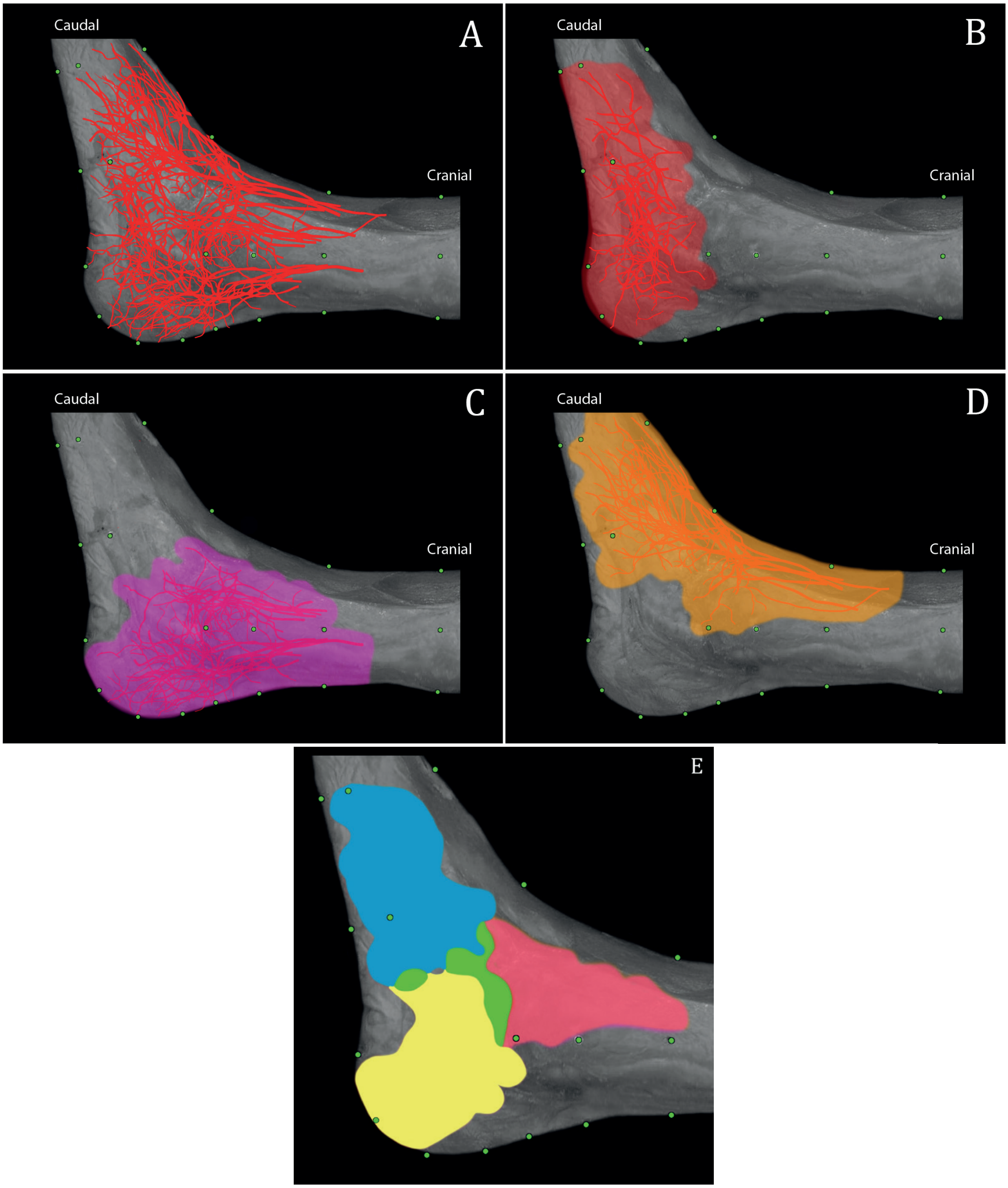

Figure 5. Angiosomes of the lateral foot
A: Dissected arteries (N=10) up to 1mm. B: Medial calcaneal artery of the posterior tibial artery. C: Fibular artery. D: Anterior tibial artery. E: Approximation of the watershed areas of the lateral hindfoot. Pink area: between ATA and fibular artery. Yellow area: between MCBPTA and the fibular artery. Blue area: between MCBPTA and the ATA. Green area: overlap between the angiosomes of all three arteries.

DISCUSSION AND CLINICAL IMPLICATIONS

Iatrogenic injury to branches of the neural and arterial structures of the lateral ankle is common. A detailed description of the relative course of these structures is important to redefine clinical guidelines and minimize the risk of iatrogenic damage.

Both the main trunk of the sural nerve as well as its two main branches, the calcaneal branch and the dorsal branch, show a relatively predictable course and distribution pattern. Our findings, although much more detailed and visualized in an average specimen, are in accordance to previous reports on sural nerve anatomy[5,19]. Although this study revealed that the exact location of arteries in the lateral hindfoot showed much variation, the general irrigation zones (angiosomes) and the anatomy of the three main supplying arteries are more or less uniform. The concept of angiosomes, dividing the body into three-dimensional blocks of tissue supplied by specific arterio-venous roots, has first been described by Taylor et al[20]. Attinger et al.[21,22] further developed this concept in relation to treatment algorithms for the diabetic foot and lower extremity artherosceloritic disease. In essence each angiosome is irrigated via one main arterio-venous bundle that perforates various anatomical layers and has tangential connections to neighbouring angiosomes either via reduced caliber "choke vessels" or normal sized true anastomoses.

In contrast to previous reports[20,21,22] this study shows that the role of subcalcaneal perforators of the PTA (MCBPA`s) are important for adequate perfusion of the lateral hindfoot. Previously described watershed areas (areas located between the angiosomes in which mostly small caliber "choke vessels" are located) proved to be located differently mainly because the MCBPA was not integrated in these models. Extensive surgical procedures through incisions in formerly defined watershed areas are prone for complications such as wound dehiscence, infection and necrosis. These incisions should be avoided as the vascular blood supply is easily compromised. Conversely, in the center of all three watershed areas, the area anterior and inferior to the lateral malleolus, our study identified a zone which is perfused by all three main supplying arteries in nine of the ten dissected specimens. Incisions in this area might be less prone to soft-tissue complications since soft tissues have multiple good caliber alternatives of perfusion.

Our anatomical observations can be applied to several standard surgical approaches to the laterale side of the ankle and hindfoot.

Extended lateral approach of the calcaneus (ELAC)

The classic exposure of the calcaneus is the angulated incision from the base of the 5th metatarsal, running parallel to the sole of the foot to the dorsal end of the calcaneus and sharply turning 80-90 degrees cranially. Depending on the exact location of the vertical part of the incision the sural nerve might be at risk[4,8,23,24], especially since skin and subcutis are mobilized as a thick soft-tissue flap in ELAC[23,25]. Sural nerve damage is seen in up to 10% of patients and an iatrogenic sural nerve lesion can lead to invalidating pain[8,9].

When an incision is drawn exactly conform the gold standard (Figure 6 A), the main branch of the sural nerve is at risk of transection in 10% of the dissected specimens. An incision line with the vertical limb running slightly posterior towards the Achilles tendon, as described by Eastwood and Atkins et al.[23], can reduce the risk of such iatrogenic sural nerve damage[5].

Especially in more extended approaches of the hindfoot complications such as necrosis are associated with the localization of the skin incision. Due to the high energetic etiology of calcaneal fractures, soft tissue is already damaged and extensively bruised and any further iatrogenic damage to arteries results in the high necrosis rates reported after calcaneal surgery. The PTA perforators are not only at a high risk for transection during the initial incision for an extended lateral approach, but especially when the full/thickness skin flap is dissected as the perforators run perpendicular to the dissection plane. Furthermore, since the perforators run almost flush to the roof of the calcaneus they are prone for injury during the initial trauma or osteosyntheses using the lateral side of the calcaneus. Figure 6 (B-D) shows an ELAC: Damage to MCBPTA`s and FA will compromise the arterial blood supply to the lateral calcaneus invariably (orange area in Figure 6 E). As a consequence the only remaining arterial inflow is through the very small arteries in subcutaneous tissue of the heel (Figure 6 D and E). In fresh calcaneus fractures flow in these subcutaneous arteries can be seriously compromised due to extensive swelling and soft tissue damage as a result of the high impact trauma and will be further compromised by a surgical exposure of the calcaneus. This study shows that it is beneficial to have the incision for an ELAC as close to the sole of the foot as possible to avoid damage to the MCBPTA`s (both during incision and dissection of the full-thickness flap) and to keep the subcutaneous flow to the heel as short as possible. Since no anastomoses exist anymore, postoperative pressure to the sole of the foot and heel should be avoided and swelling should be reduced as much as possible to prevent additional ischemia.

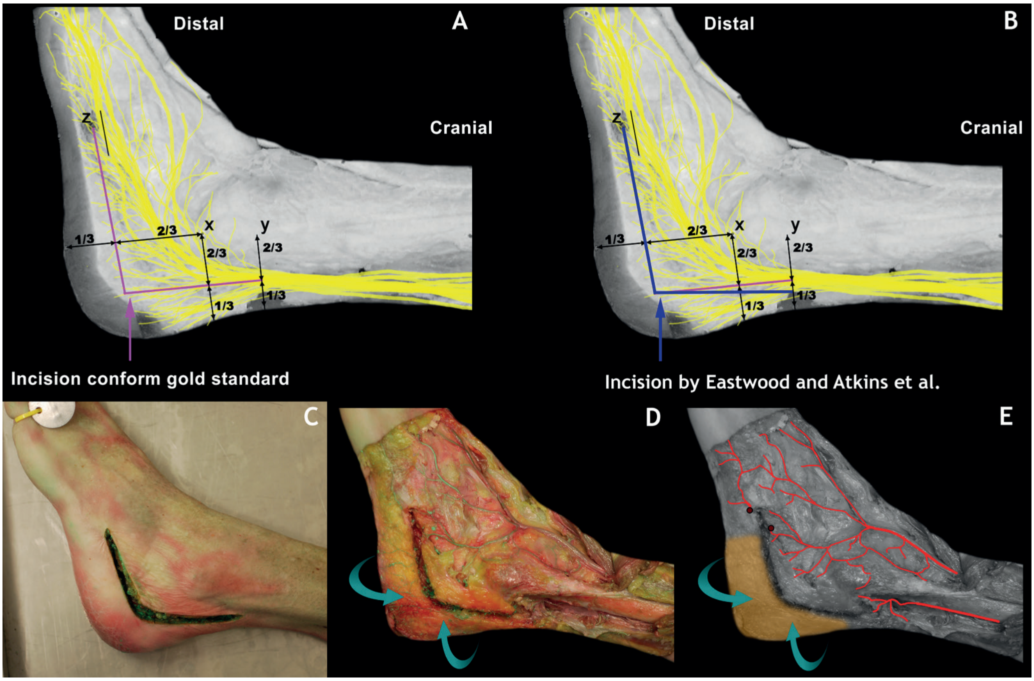

Figure 6. Gold standard Extended Lateral Approach of the Calcaneus (ELAC)
A) X: distal tip lateral malleolus. Y: top of lateral malleolus Z: tuberosity of the 5th metatarsal. Purple line: ELAC conform gold standard.
B) Blue line: an incision as described by Eastwood and Atkins et al. will reduce main branch sural nerve damage since the angle of the proximal incision is aimed at eh posterior Achilles tendon and the average angle between the proximal and distal incision is 120 degrees (instead of the conventional 80-90 degrees).
C), D) and E) Especially ELAC incisions that are placed further away from the sole of the foot will have a higher risk to damage the MCBPTA`s and FA, which further compromises the arterial blood supply to the lateral calcaneus (colored area in figure C) and consequently the only remaining arterial inflow is through the very small arteries in the subcutaneous tissue of the heel and sole of the foot (turquoise arrows in fig D and E).

Sinus tarsi approach (STA)

The sinus tarsi approach has recently gained popularity in calcaneus surgery since it provides a good surgical exposure and is more tissue sparing. Results of STA have shown to be similar or favorable when compared to the gold-standard and soft-tissue related complication rates after STA are lower when compared to ELAC and range from 0-15%[26]. In STA the dorsal branch of the SN, which is present in 40% of the specimen, needs to be transected (Figure 2 C). This may in theory lead to more neuroma formation in a generally sensitive area (the instep of the foot). The main branch of the SN should not be at risk in STA as long as the proximal incision starts just inferior from the distal tip of the malleolus and then runs towards a point approximately 15 mm cranial to the tuberosity of the fifth metatarsal bone. The major part of the STA is located in a watershed area, in which is traditionally incisions should not be located. However this area of the lateral hindfoot is perfused by all three major supplying lower leg arteries (Figure 5.E, green area): PTA, ATA and FA in nine of the ten dissected specimens. The high amount of choke vessels in this area gives plenty of opportunity for alternative arterial perfusion of the soft tissues after surgery and might therefore contribute to lower rates of soft-tissue complications.

Minimally invasive longitudinal approach (MILA)

Zhang et al. first described MILA, a longitudinal incision located at the posterior calcaneus. First results of this approach of calcaneal fractures of Sanders type II and III show lower soft tissue related complication rates when compared to STA[27]. Besides the minimal invasive nature of this approach the low complication rates can be explained using the data of this anatomical study. The largest part of the incision is located outside of the posterior watershed area and the incision line runs perpendicular to branches of the FA. The posterior skin is perfused by anastomoses located just deep to the Achilles tendon and the superficial “choke vessels” are not those of the foot sole and therefore not injured by the initial trauma.

Other approaches

Ankle arthroscopy is frequently performed through stab incisions not exceeding 1 cm in length. The sural nerve is at risk of iatrogenic damage from such a stab incison to create the posterolateral portal. Damage to the main branch of the SN can be avoided if the skin is incised close to the Achilles tendon and immediately a deep course towards the postero-lateral ankle is followed. Damage to the calcaneal branch of the SN cannot be reduced by changing the incision location. However, a blunt dissection through a slightly larger incision can easily reduce the risk of damaging this branch. In the lateral approach to the 5th metatarsal an incision inferior to the MT5 (closer to the sole of the foot) minimizes the risk of damaging the main branch of the SN and avoid any chance of damaging the dorsal branches of the SN. A dorsolateral approach to the cuboid should follow the same guidelines as a sinus tarsi approach to the calcaneus; An incision on a virtual line between the inferior tip of the lateral malleolus to a point 15 mm dorsal to the tuberosity of the fifth metatarsal, can avoid damage to the main branch of the sural nerve. The dorsal branch of the SN, if present, will likely be damaged by a dorsolateral approach of the cuboid.

CONCLUSION

The neurovascular anatomy of the lateral hindfoot is relatively predictable and common soft tissue complications due to iatrogenic neurovascular damage following ankle and calcaneal surgery can be further minimized by using personalized ‘tailor made’ incisions, choosing the most fitting approach for each patient.

REFERENCES

1) Kerver AL, Leliveld MS, den Hartog D, Verhofstad MH, Kleinrensink GJ. The surgical anatomy of the infrapatellar branch of the saphenous nerve in relation to incisions for anteromedial knee surgery. J Bone Joint Surg Am. 2013 Dec 4;95(23):2119-25. doi: 10.2106/JBJS.L.01297. Review. PubMed PMID: 24306699.
2) Balcı Hİ, Polat G, Dikmen G, Atalar A, Kapıcıoğlu M, Aşık M. Safety of posterior ankle arthroscopy portals in different ankle positions: a cadaveric study. Knee Surg Sports Traumatol Arthrosc. 2016 Jul;24(7):2119-23. doi: 10.1007/s00167-014-3475-6. Epub 2014 Dec 13. PubMed PMID: 25502830.
3) Bai L, Han YN, Zhang WT, Huang W, Zhang HL. Natural history of sensory nerve recovery after cutaneous nerve injury following foot and ankle surgery. Neural Regen Res. 2015 Jan;10(1):99-103. doi: 10.4103/1673-5374.150713. PubMed PMID: 25788928; PubMed Central PMCID: PMC4357126.
4) Sanders R, Fortin P, DiPasquale T, Walling A. Operative treatment in 120 displaced intraarticular calcaneal fractures. Results using a prognostic computed tomography scan classification. Clin Orthop Relat Res. 1993 May;(290):87-95. PubMed PMID: 8472475.
5) Eastwood DM, Irgau I, Atkins RM. The distal course of the sural nerve and its significance for incisions around the lateral hindfoot. Foot Ankle. 1992 May;13(4):199-202. PubMed PMID: 1634152.
6) Baumhauer JF, O'Brien T. Surgical Considerations in the Treatment of Ankle Instability. J Athl Train. 2002 Dec;37(4):458-462. PubMed PMID: 12937567; PubMed Central PMCID: PMC164377.
7) Jowett AJ, Sheikh FT, Carare RO, Goodwin MI. Location of the sural nerve during posterolateral approach to the ankle. Foot Ankle Int. 2010 Oct;31(10):880-3. doi: 10.3113/FAI.2010.0880. PubMed PMID: 20964966.
8) Harvey EJ, Grujic L, Early JS, Benirschke SK, Sangeorzan BJ. Morbidity associated with ORIF of intra-articular calcaneus fractures using a lateral approach. Foot Ankle Int. 2001 Nov;22(11):868-73. PubMed PMID: 11722137.
9) Ebskov L, Rasmussen PB, Erichsen M. [Isolated lesions to the sural nerve. Causes, claims review procedure and compensation]. Ugeskr Laeger. 2008 Sep 8;170(37):2885-7. Danish. PubMed PMID: 18796285.
10) Rammelt S, Amlang M, Barthel S, Zwipp H. Minimally-invasive treatment of calcaneal fractures. Injury. 2004 Sep;35 Suppl 2:SB55-63. Review. PubMed PMID: 15315879.
11) Zwipp H, Rammelt S, Barthel S. Calcaneal fractures--open reduction and internal fixation (ORIF). Injury. 2004 Sep;35 Suppl 2:SB46-54. PubMed PMID: 15315878.
12) Folk JW, Starr AJ, Early JS. Early wound complications of operative treatment of calcaneus fractures: analysis of 190 fractures. J Orthop Trauma. 1999 Jun-Jul;13(5):369-72. PubMed PMID: 10406705.
13) http://www.anubifix.com/?action=pagina&id=310&title=Over%20AnubiFIX
14) http://www.anubifix.com/?id=311&id2=35
15) Kerver AL, Leliveld MS, den Hartog D, Verhofstad MH, Kleinrensink GJ. The surgical anatomy of the infrapatellar branch of the saphenous nerve in relation to incisions for anteromedial knee surgery. J Bone Joint Surg Am. 2013 Dec 4;95(23):2119-25. doi: 10.2106/JBJS.L.01297. Review. PubMed PMID: 24306699.
16) Kerver AL, Carati L, Eilers PH, Langezaal AC, Kleinrensink GJ, Walbeehm ET. An anatomical study of the ECRL and ECRB: feasibility of developing a preoperative test for evaluating the strength of the individual wrist

extensors. J Plast Reconstr Aesthet Surg. 2013 Apr;66(4):543-50. doi: 10.1016/j.bjps.2012.12.015. Epub 2013 Jan 29. PubMed PMID: 23369737.

17) EffectMatrix Software Studio. Magic Morph 1.95. "http://www.effectmatrix.com/morphing/".
18) Adobe Corp. Adobe Photoshop CS-4. 40) "http://www.adobe.com/nl/products/photoshop/photoshop/".
19) Geng X, Xu J, Ma X, Wang X, Huang J, Zhang C, Wang C, Muhammad H. Anatomy of the sural nerve with an emphasis on the incision for medial displacement calcaneal osteotomy. J Foot Ankle Surg. 2015 May-Jun;54(3):341-4. doi: 10.1053/j.jfas.2014.07.008. Epub 2014 Sep 8. PubMed PMID: 25201235.
20) Taylor GI, Palmer JH. The vascular territories (angiosomes) of the body: experimental study and clinical applications. Br J Plast Surg. 1987 Mar;40(2):113-41. PubMed PMID: 3567445.
21) Attinger CE, Evans KK, Bulan E, Blume P, Cooper P. Angiosomes of the foot and ankle and clinical implications for limb salvage: reconstruction, incisions, and revascularization. Plast Reconstr Surg. 2006 Jun;117(7 Suppl):261S-293S. Review. PubMed PMID: 16799395.
22) Taylor GI, Pan WR. Angiosomes of the leg: anatomic study and clinical implications. Plast Reconstr Surg. 1998 Sep;102(3):599-616; discussion 617-8. PubMed PMID: 9727424.
23) Eastwood DM, Langkamer VG, Atkins RM. Intra-articular fractures of the calcaneum. Part II: Open reduction and internal fixation by the extended lateral transcalcaneal approach. J Bone Joint Surg Br. 1993 Mar;75(2):189-95. PubMed PMID: 8444935.
24) Paley D, Hall H. Intra-articular fractures of the calcaneus. A critical analysis of results and prognostic factors. J Bone Joint Surg Am. 1993 Mar;75(3):342-54. PubMed PMID: 8444912.
25) Ishikawa K, Kyutoku S, Takeuchi E. Free lateral calcaneal flap. Ann Plast Surg. 1993 Feb;30(2):167-70. PubMed PMID: 8489183.
26) Schepers T. The sinus tarsi approach in displaced intra-articular calcaneal fractures: a systematic review. Int Orthop. 2011 May;35(5):697-703. doi: 10.1007/s00264-011-1223-9. Epub 2011 Feb 19. Review. PubMed PMID: 21336854; PubMed Central PMCID: PMC3080500.
27) Zhang T, Su Y, Chen W, Zhang Q, Wu Z, Zhang Y. Displaced intra-articular calcaneal fractures treated in a minimally invasive fashion: longitudinal approach versus sinus tarsi approach. J Bone Joint Surg Am. 2014 Feb 19;96(4):302-9. doi: 10.2106/JBJS.L.01215. PubMed PMID: 24553886.


2