Anatomic bases of medical, radiologic and surgical techniques

Applied anatomy of the V-shaped fibular osteomyocutaneous flap in reconstruction of the hindfoot

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Abstract

Abstract To establish the applied anatomy of the V-shaped fibular osteomyocutaneous flap pedicled on the peroneal vessels, cadaver dissections were made in 60 lower limbs and 40 calcanei were examined to sum up the features of calcaneal biomechanics on the stability of the foot and the blood supply of the fibular osteomyocutaneous flap. There were four anastomoses and large communicating branches between the lower segment of the peroneal artery and the anterior and posterior tibial arteries. The flap was well supplied by a retrograde circulation through these anastomoses. A suitable length of pedicle was 20 cm. In the sagittal section of the calcaneus passing through the center of the articular surface for the cuboid bone, the arrangement of the trabeculae formed a triangular zone. The V-shaped flap corresponds nicely with the calculated lines of stress evoked by the weight of the body. The procedure may provide a new method for hindfoot reconstruction. This flap meets the criteria outlined for composite tissue reconstruction of defects of the extremities and biomechanics of the hindfoot, especially for calcaneal and cuboid defects.

Anatomie du lambeau ostéo-myo-cutané fibulaire en V. Application à la reconstruction de l'arrière-pied

Résumé : Dans le but de préciser l'anatomie appliquée du lambeau ostéo-myo-cutané fibulaire en V pédiculé sur les vaisseaux fibulaires, nous avons réalisé des dissections cadavériques sur 60 membres inférieurs et 40 calcanéus pour récapituler les caractéristiques biomécaniques du calcanéus sur la stabilité du pied et la vascularisation du lambeau ostéo-myo-cutané fibulaire. Il existait 4 anastomoses et de grosses branches communicantes entre le segment distal de l'artère fibulaire et les artères tibiales antérieure et postérieure. Le lambeau était bien vascularisé par une circulation rétrograde issue de ces anastomoses. La longueur utilisable du pédicule était de 20 cm. Sur les coupes sagittales de calcanéus passant par le centre de la surface articulaire pour l'os cuboïde, les trabécules de l'os spongieux formaient une zone triangulaire. Le lambeau en V s'adapte bien aux lignes de forces calculées correspondant à la transmission du poids du corps. La technique décrite ajoute une nouvelle méthode pour la reconstruction de l'arrière-pied. Ce lambeau possède les critères requis pour une reconstruction tissulaire composite des pertes de substance des extrémités et la biomécanique de l'arrière-pied, spécialement pour les pertes de substance du calcanéus et du cuboïde.

Many reports have been published on the successful transfer of vascularized bone grafts in the treatment of extensive bone defects and intractable congenital anomalies using microsurgical techniques. In the lower limb, the use of the free fibular graft for filling the defect has expanded since its introduction by Taylor [12]. Defects in various areas of the body and limbs may be repaired by this procedure. Yoshimura [17] reported monitoring the circulation of the grafted fibula Wei's [15] intention was to raise an osteoseptocutaneous flap Masquelet [6] and Valenti [14] applied the lateral supramalleolar flap to skin defects of the foot, ankle and lower third of the leg. Minami [7, 8]designed this flap for anterior spinal fusion and described the reverse-flow vascularized fibular graft based on the peroneal a. (PA) and v. and their branches. Cai [1], Wu [16] and Tang [11] successfully repaired heel defects using reverse transfer of the composite island flap from the lateral lower leg. However, a large, systematic and detailed investigation of the clinico-anatomic problems of the calcaneus and the lower segment of the PA has not been performed and no data are available on the distal anastomoses of the PA with the anterior tibial a. (ATA) and/or posterior tibial a. (PTA), especially in the region of the ankle and foot.

The aim of the present study was to investigate the surgical anatomy at the lower segment of the PA and the arrangement and orientation of trabecular patterns within the calcaneus, in the hope of providing an anatomic and biomechanical basis for hindfoot reconstruction.

Material and methods

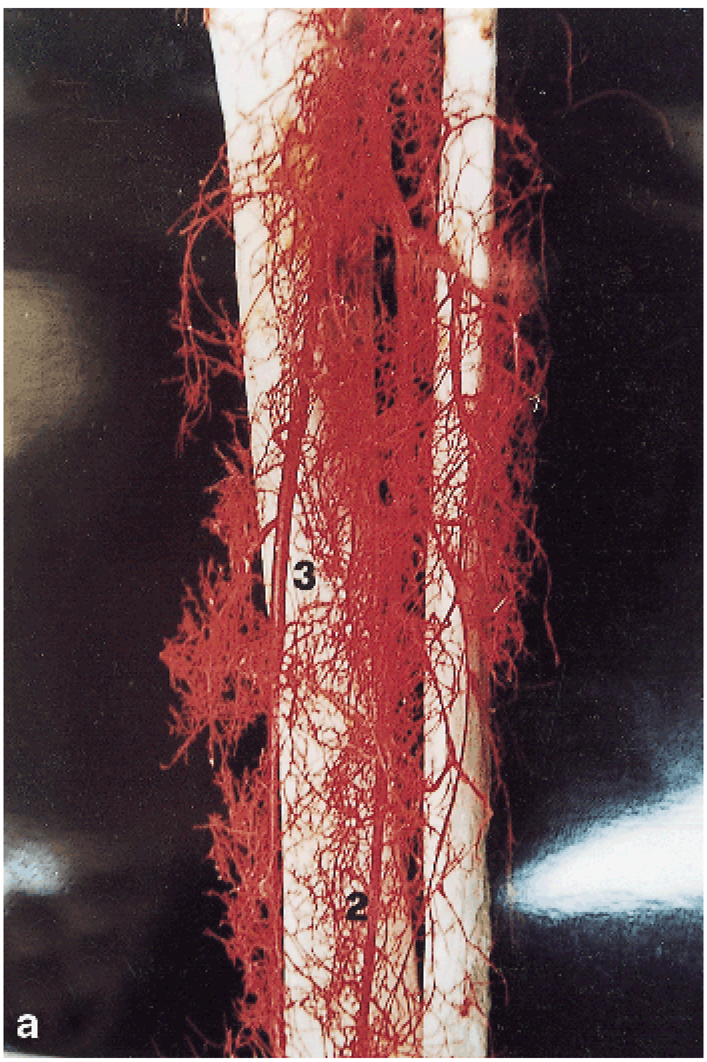
In twenty adult cadavers (40 sides), colored latex was injected into the femoral a. before dissection. Selective injection of the dorsalis pedis a. was made in 5 cases (10 sides). The PTA was cannulated where it gave rise to the PA and black ink, mixed with 95% alcohol (21), was injected into the artery in 3 cases (6 sides). After ligature of the ATA above the superior extensor retinaculum and catheterization of the dorsalis pedis a., ink was injected in 2 cases (4 sides). The dissections were done within 72h after injection to reduce leakage of ink.

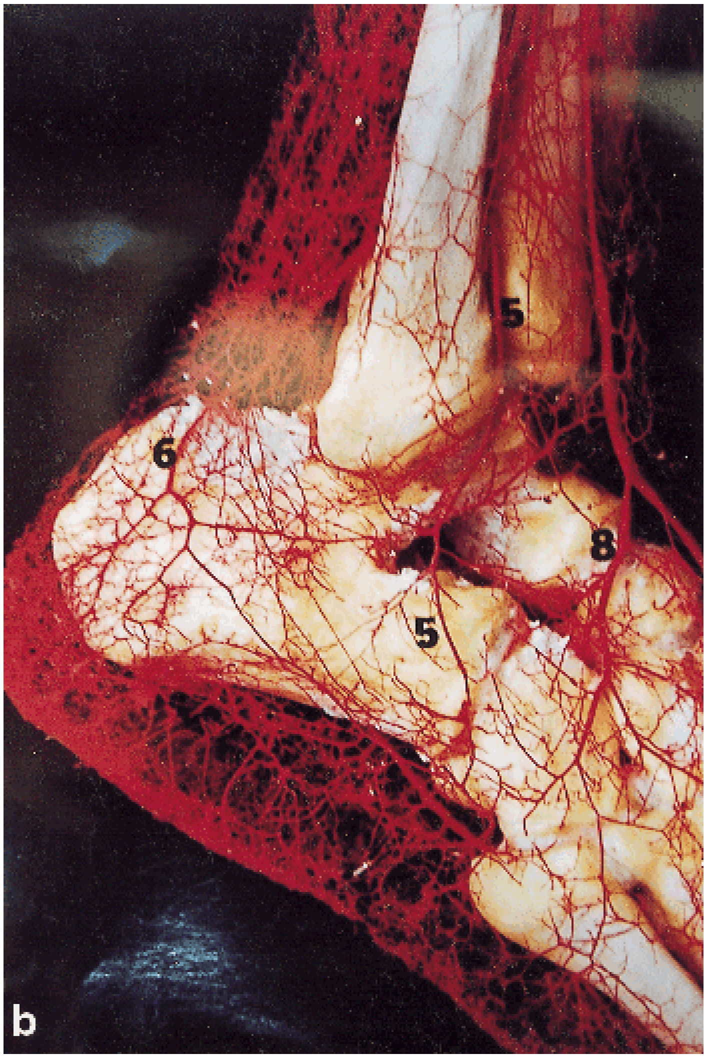
Forty dry human calcanei were measured and four frozen feet and ten dry calcanei were sectioned using a high-speed electric saw. Two sagittal planes separated the bone into three fragments, passing through the center of the articular surface for the cuboid bone and the center of the anterior articular surface for the talus, to analyze the internal architecture. Ten casts of arteries of the leg and foot were observed.

Results

Vascular anatomy

Several branches coming from the PA supplied the fibula and the skin on the lateral side of the leg. The PA is a terminal branch of the PTA (Fig. 1a), arising 3 cm on average below the mid-point of the lower border of the popliteus m., but it arose from the ATA or popliteal a. in 8.3%.

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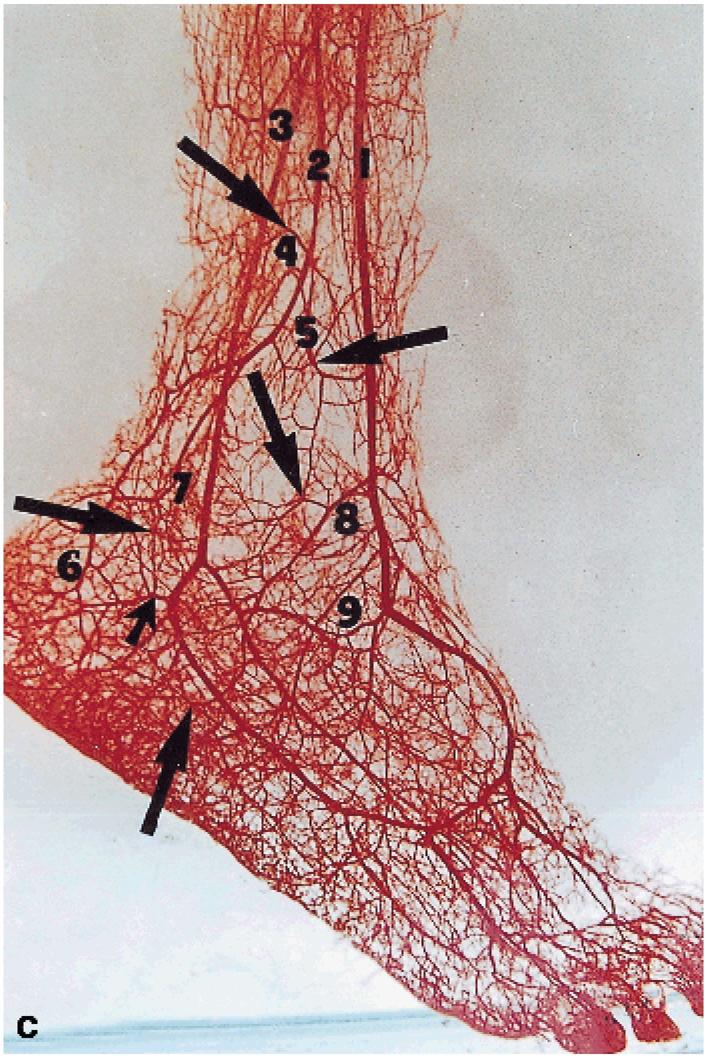
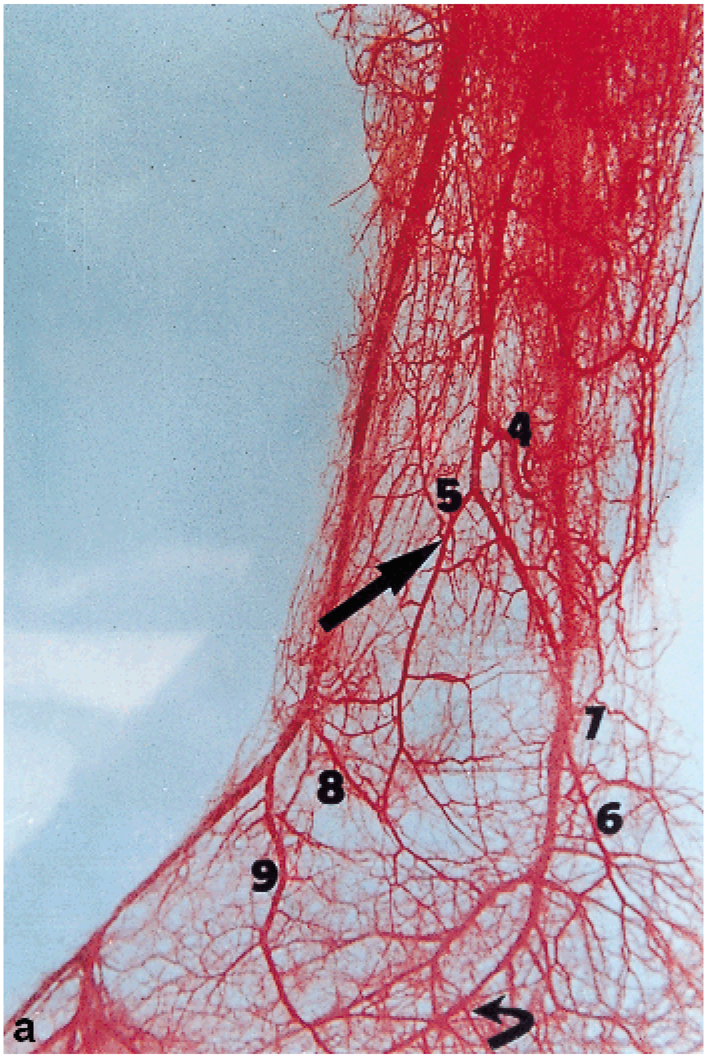


Fig. 1a-c Blood supply of the fibula and arteries of the ankle. Arterial anastomoses are clearly visible (*arrow*). *1*, ATA *2*, PA *3*, PTA *4*, communicating branch *5*, perforating branch *6*, lateral calcaneal branch *7*, posterior malleolar branch *8*, anterior malleolar branch *9*, lateral tarsal a. *short arrow*, calcaneal branch of the lateral plantar a.

The PA average outer diameter was 2.04 ± 0.4 mm, which may be larger than the continuation of the PTA. It derived from the lateral aspect of that vessel in the upper part of the leg and passed laterally across the surface of the tibialis posterior m. to lie between the interosseous membrane and the fibula under cover of or within the flexor hallucis longus m. It gave off muscular branches to the flexor hallucis longus, posterior tibialis and peroneal mm., a nutrient artery and about 9 arcuate aa. to the fibula. The arcuate aa. were relatively small, with an average outer diameter of 1.0 mm. These arteries mostly came from the PA and anastomosed with each other, forming a profuse peroneal network on the surface of the fibula, especially at its middle two-fourths (Fig. 1a).

The lower segment of the artery, its lower fourth, usually gave off 4 branches (Table 1) (Figs. 1b, 1c, 2a) to anastomose with the ATA, PTA and lateral tarsal a. (LTA). Four anastomoses were identified.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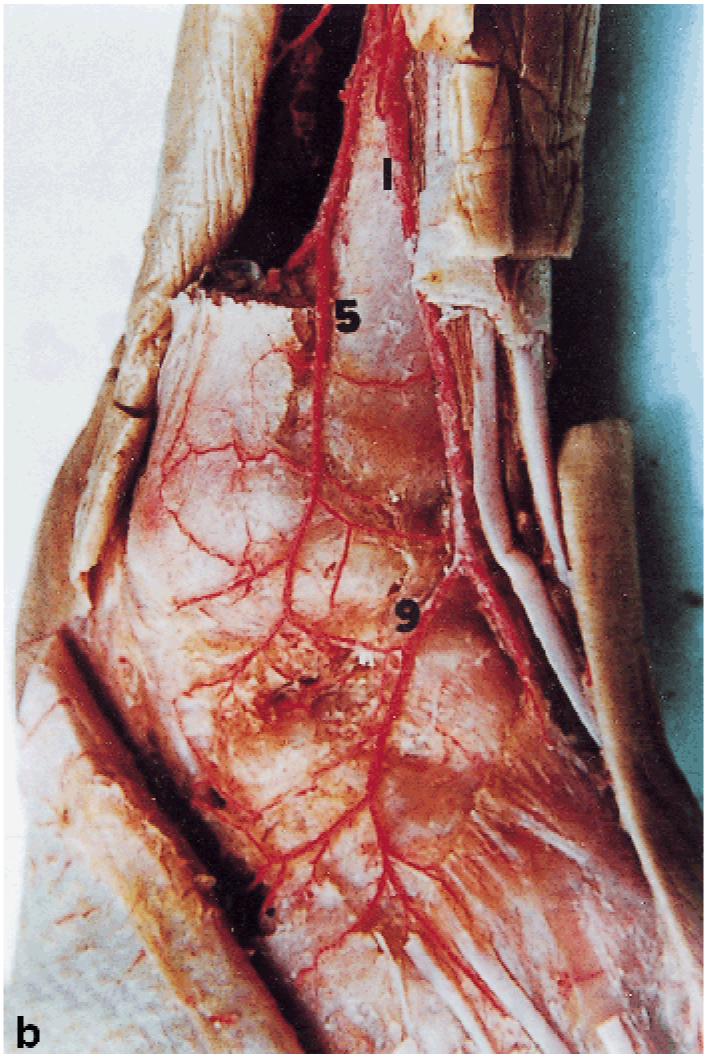
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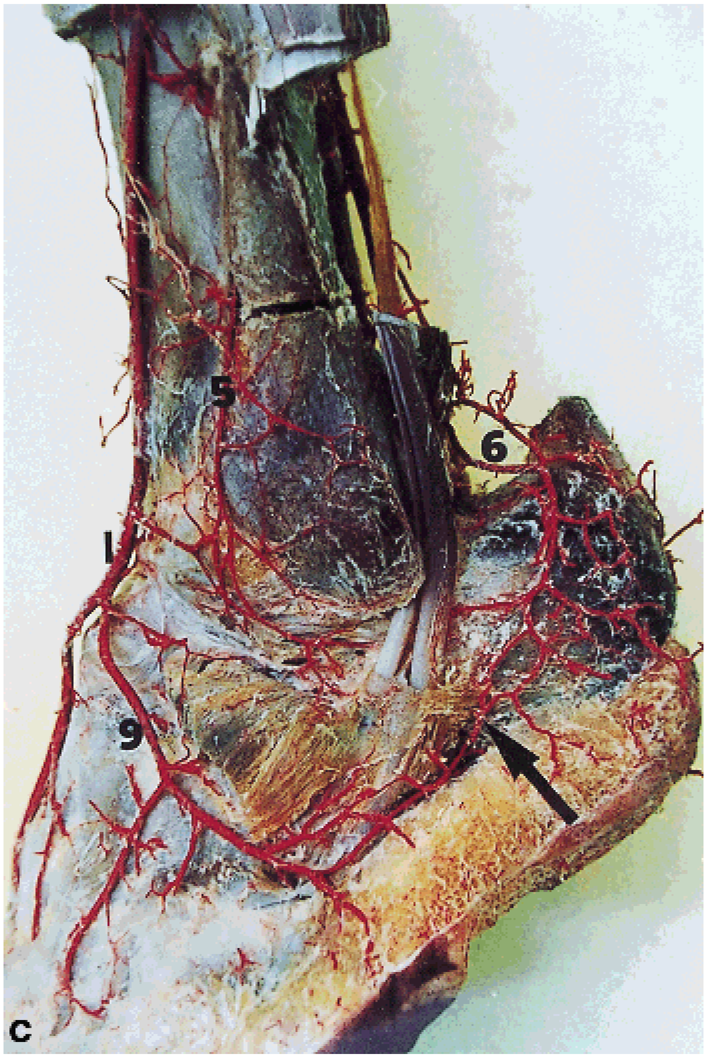


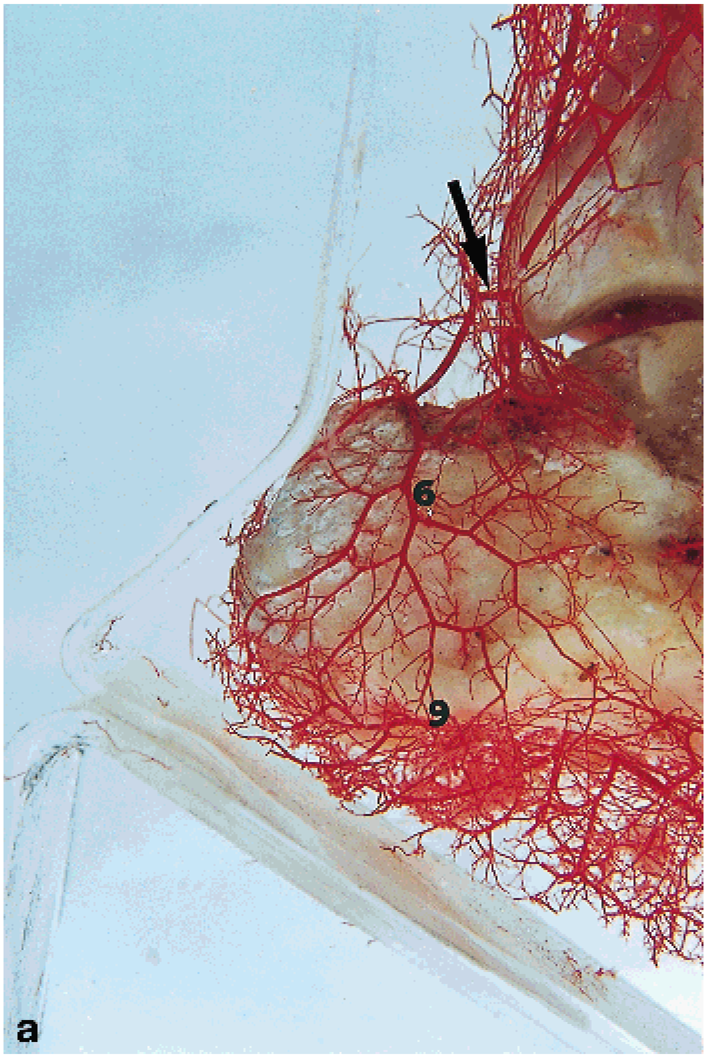
Fig. 2a -c Perforating branch, lateral tarsal a. and lateral calcaneal branch. *4*, communicating branch *5*, perforating branch *6*, lateral calcaneal branch *7*, posterior malleolar branch *8*, anterior malleolar branch *9*, lateral tarsal a.

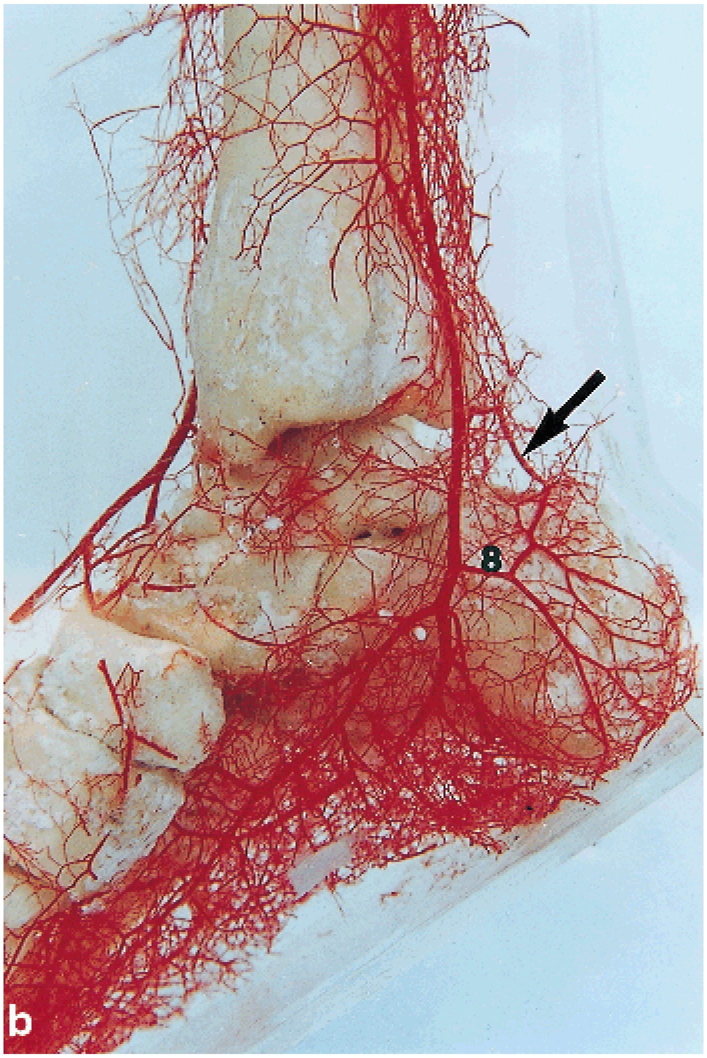
Name	Per cent	Caliber (mm)	Anastomoses with
Perforating branch	93.3	1.07 ± 0.2	ATA & LTA
Communicating branch	96.7	1.27 ± 0.3	PTA
Posterior malleolar branch	81.5	1.17 ± 0.3	PTA
Lateral calcaneal branch	90.0	1.25 ± 0.2	PTA & LTA

Table 1. Branches of the lower segment of the peroneal a.

The first anastomosis was the perforating branch arising from the PA 4.4 ± 0.9 cm above the lateral malleolus. It proceeded anteriorly and downward between the fibula and tibia through the lower part of the interosseous membrane to the front of the leg, and divided into ascending and descending branches (Fig. 2A, long arrow). The descending branch gave off many secondary branches to the lateral malleolus and its final branch anastomosed with the anterior malleolar branch in 93.3%, with the LTA in 75%, and/or with the ATA in 66.7%, where the vessel was 0.8 mm, 0.8 mm and 1.0 mm in diameter respectively (Figs. 1c, 2) at the lateral aspect of the dorsum of the foot.

The PA gave off a lateral calcaneal branch 4.9 ± 1.1 cm above the lateral malleolus, which emerged from the posterior edge of the lateral malleolus and coursed downward along the lateral aspect of the calcaneus. Finally, it anastomosed with the LTA in 90% (82% was reported by Lutz [5]) and/or calcaneal branch of the lateral plantar a. in 95%, where the vessel was 0.8 mm and 0.6 mm in diameter respectively (Figs. 1b, 1c, 2a curved arrow, 2c long arrow, 3a). The communicating branch joined with the PTA in 96.7%, where the vessel was 1.2 mm in diameter (Figs. 1c, 2a, 3c). The posterior malleolar branch was connected to the PTA and calcaneal branch of the PTA in 81.5%, where the vessel was 0.8 mm in diameter (Figs. 1c, 3b, 3c).

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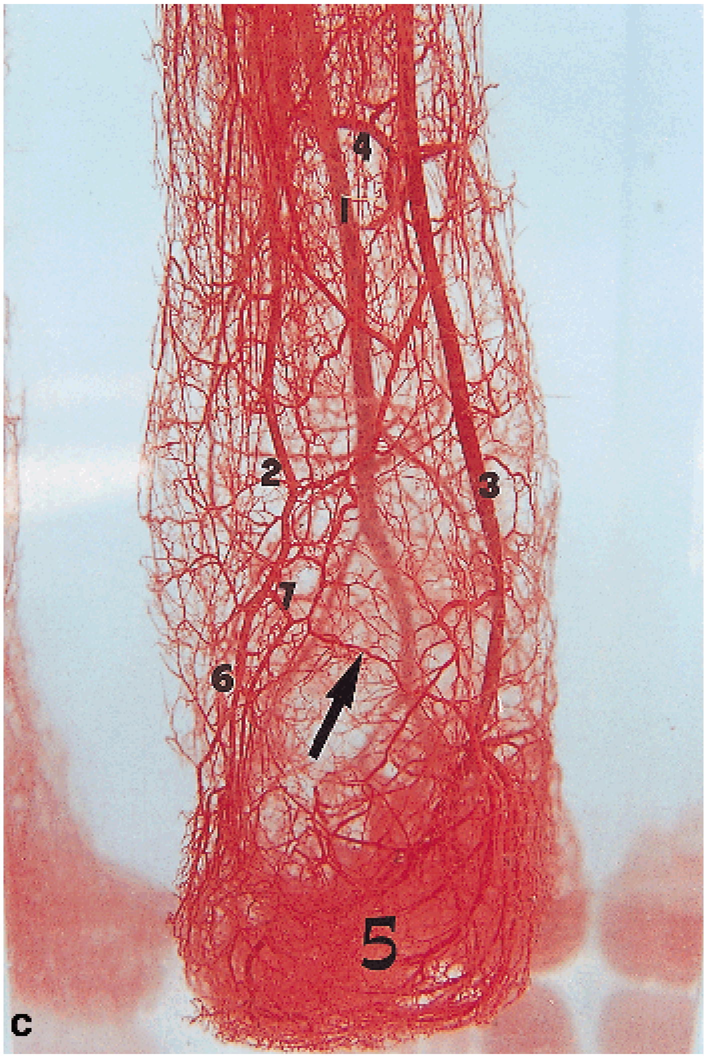

Fig. 3a -c Arterial supply of the calcaneus. **a.** lateral view lateral calcaneal branch anastomoses with calcaneal branch of the lateral plantar a. **b.** medial view calcaneal branch of the PTA anastomoses with posterior malleolar branch (*arrow*). **c.** posterior view calcaneal branch of the of the PTA anastomoses with posterior malleolar branch (*arrow*). *1*, ATA *2*, PA *3*, PTA *4*, communicating branch *5*, arterial network of the calcaneus *6*, lateral calcaneal branch *7*, posterior malleolar branch *8*, calcaneal branch of the PTA *9*, calcaneal branch of the lateral plantar a.

The PA was absent in 5%. In such cases the fibula and the skin on the lateral side of the leg were supplied by the ATA and/or PTA.

There are 2 sets of veins in the flap 1- a superficial vein, the small saphenous v., was about 3.0 mm in diameter and 2- two deep veins, the peroneal vv., were about 3.2 mm in diameter. They ran on both sides of the peroneal a. and collected on their way venous branches accompanying the parallel arteries. They emptied into the posterior tibial v. The cutaneous nerve was the lateral sural cutaneous n.

Calcaneus

The length from the tuberosity (A) to the articular surface for the cuboid bone (B), was 6.97 ± 0.5 cm that from the tuberosity (A) to the posterior articular surface for the talus (C) was 5.11 ± 0.4 cm (Fig. 4). The width of body cross-sections was 2.88 ± 0.2 cm and its thickness was 4.06 ± 0.3 cm.

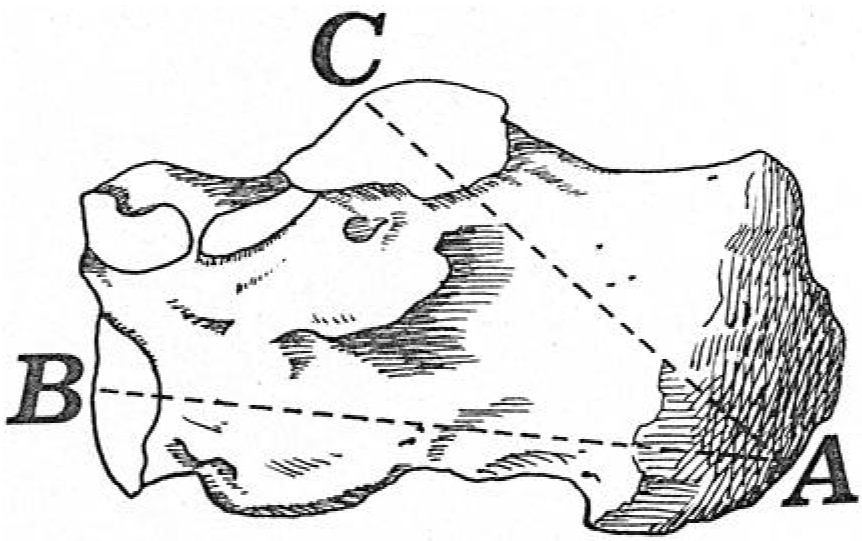

Fig. 4 Medial view of the calcaneus

The different calcaneal sections differed in internal structure. In the sagittal section passing through the center of the anterior articular surface for the talus, fanlike trabeculae fanned out from the posterior articular surface for the talus to the tuberosity (Fig. 5a). In the sagittal section passing through the center of the articular surface for the cuboid bone, the arrangement of the trabeculae formed a triangular zone. Trabecular systems extended from the subtalar surface toward the distal heel and anteriorly toward the calcaneocuboid joint. Trabeculae also extended along the inferior surface of the calcaneus (Fig. 5b, c).

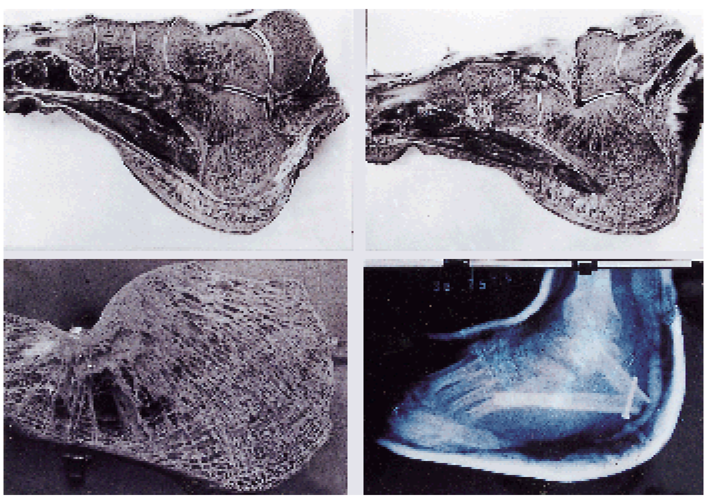

Fig. 5 Calcaneal sagittal sections

Discussion

Vascular basis of the flap

This study demonstrated that the fibula and the skin and muscles on the lateral side of the leg may be elevated and still obtain good perfusion by retrograde blood flow through anastomoses of the PA with the ATA and PTA.

The PA average diameter at its origin was 2.04 mm, although 3.7 mm was reported by Chen[2].There are on average 8.6 branches that penetrate the posterior intermuscular septum and widely anastomose with each other, forming a profuse peroneal network on the surface of the fibula and in the muscles and subcutaneous tissue. The flap is well supplied by a retrograde circulation through these anastomoses.

As the fibular osteomyocutaneous flap is raised, the deep veins are denervated, venous pressure of these veins is increased after ligation of their proximal ends, and the veins are kept filled by blood from the leg. All these factors facilitate reverse flow through the valves and so the venae comitantes should provide sufficient drainage. This resembles the retrograde flow of the radial forearm flap and the anterolateral thigh flap [10, 13].

Biomechanics of the calcaneus

Bone density is not the unique factor conditioning bone strength, the microscopic pattern of the trabecular network also plays an important role. The resistance of bone tissue is influenced not only by bone density parameters but also by bone architecture parameters, such as the microarchitecture and anisotropy of trabecular bone.

This study underlines the importance of triangular trabecular organization of cancellous bone on calcaneal biomechanics. We showed that the 3 (anterior, posterior and inferior) trabeculae secure horizontal and vertical stability of the subtalar joint (Fig. 5b, c). The triangular architecture of the calcaneus resembles a roof frame where the talus is fixed to the vertex of the triangle this is fundamental to obtain a rigid and stable triangle. This resembles what Giddings and Sabry described [4, 9]. The trabeculae of the cancellous substance are not arranged randomly, but in a regular pattern, also in accordance with the functions of the calcaneus. Since this bone experience two types of force, pressure and muscle traction, the trabeculae are arranged along the lines of the compression and stretching forces. Conforming to the different direction of these forces, the different parts differ in structure.

The forces exerted upon the arch of the foot are large, for they are the sum of the weight on the leg and the pull of the triceps surae m. In running, the strain on the arch obviously increases markedly because of the impact of the weight upon the ball of the foot.

Design of the V-shaped composite fibular graft

In accordance with the biomechanics of the calcaneus, to bear gravity and form the arch of the foot, we devised a V-shaped fibular osteomyocutaneous flap for reconstructing the hindfoot (Fig. 6). According to the length of the calcaneus (AB + AC) (Fig. 4) the middle part of the fibula is substituted. Its proximal end is "b" and distal end "c", with ab = AB (Fig. 4) then a wedge is cut at "a" (Fig. 6b), and finally a V-shaped fibular flap is extracted (Fig. 6c, d). The angle at " a" is 45°. The PA and the arcuate aa. must not be accidentally injured when fashioning the V-shaped fibular flap.

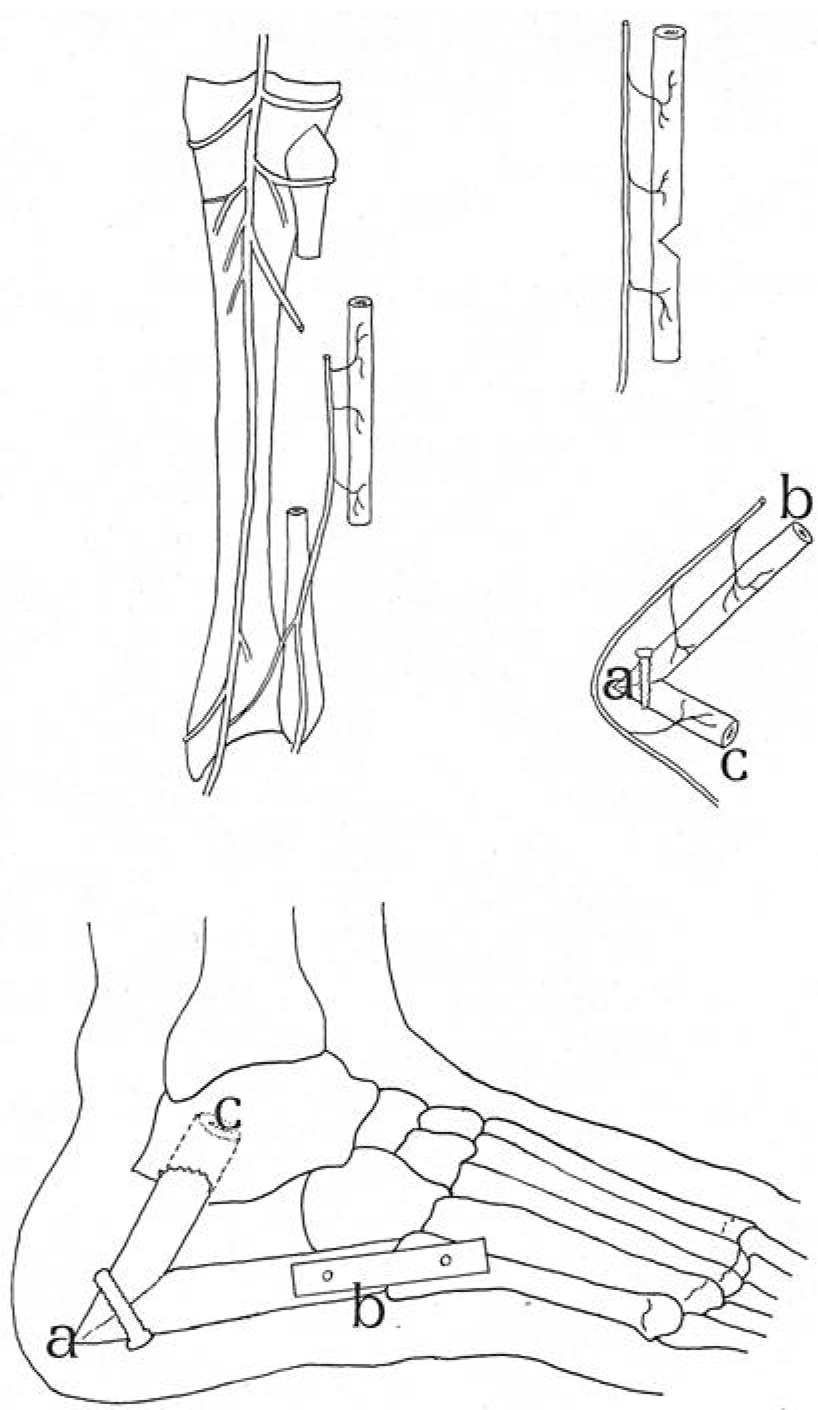

Fig. 6 Design of the V-shaped fibular graft

Technique of flap elevation

Withthe anterior and posterior skin, peronei and flexor hallucis longus mm. attached to the fibula, an osteomyocutaneous flap can be elevated. The surgical approach requires the patient to be in a prone position, allowing a posterior longitudinal incision in the leg. The procedure may be similar to that described by Dennis [3]. A groove between the peroneal and soleus mm. is clearly visible when the evertors and abductors contract. Through a longitudinal incision along this groove, the vascular pedicle covered by the soleus m. is then clearly visible. It is very important for the surgeon to locate the PA and its branches to the fibula and skin. At the middle third of the leg the osteonutrient arterial branches frequently arise from the PA the nutrient a. of the fibula arises from the PA at a level 7.9 cm below its origin (Fig. 1a). Exposure of the distal portion of the PA is accomplished by separating the peroneus brevis and flexor hallucis longus mm. The PA is then visualized when the fibular attachments of the flexor hallucis longus are divided. The size of the skin flap may be about 20 cm x 12 cm, the largest skin flap being 32 cm x 15 cm [2]. The distal mobility of the flap, with the pivot of rotation at about 6 cm above the lateral malleolus, was 20 cm. This was farther increased to 25 cm when the pedicle was dissected with the periosteum of the tibia down as far as the lateral malleolus. There the vessels are 1.6 mm in diameter. There are still 3 to 5 twigs below this point. The pivot of rotation allows application to the forefoot.

It is important to anastomose the lateral sural cutaneous n. to the plantar n. or lateral calcaneal n. to provide sensory recovery, which is essential to achieve stability in the shoe and to prevent trophic skin ulceration.

The fibular osteomyocutaneous flap offers an easy dissection. The donor site is within the same tourniquet field, and the available length of straight cortical bone, the large skin flap, and the good diameter of the vascular pedicle promote expediency and safety. This flap meets the criteria outlined for composite tissue reconstruction of defects of the extremities and biomechanics of the hindfoot. It is wise to fuse the distal tibiofibular joint when harvesting the fibula in a skeletally mature individual.

Ascertainment of the safe level and of the PA with the aid of a Doppler probe before operation is advisable. Usually these flow determinations locate two to five points, which are marked on the skin. If the PA or its anastomosis with the PTA and ATA is absent, this flap cannot be harvested.

Acknowledgments We thank Professor Xu Dachuan who introduced us to the study of clinical anatomy.

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