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Mode of insertion of the abductor hallucis muscle in human feet and its arterial supply

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The abductor hallucis flap is commonly used as a pedicled flap (distally or proximally based) in the management of ankle, heel, and mid-foot lesions, where it is ideally used for closing defects. This study investigates the anatomical details of this muscle regarding its various forms of insertion and its arterial supply in 15 cadaveric feet. Four types of insertion could be distinguished: type A, insertion at the proximal phalanx of the big toe (46.7%); type B, insertion by two slips into the base of the proximal phalanx and the sesamoid bone (33.3%); type C, insertion at the sesamoid bone (6.7%); And type D, the insertion is divided into superficial tendinous and deep fleshy parts which are attached to the base of the proximal phalanx and to the metatarsophalangeal joint capsule of the big toe, respectively (13.3%). As regards the arterial supply, three patterns were noticed: pattern A (40%) where the medial plantar artery (MPA) is divided into superficial and deep branches that supplied the muscle; pattern B (53.3%) where the MPA failed to produce a deep branch but instead continued as the superficial branch supplying the two ends of the muscle; and pattern C (6.6%) where the MPA continued as a deep branch supplying the muscle. A superficial branch of MPA provided a branch to the abductor hallucis muscle from its proximal part. In two specimens (13.3%), the lateral plantar artery shared in the supply of the most proximal part of the muscle. These results can be useful in determining the appropriate flap design based on the abductor hallucis type of insertion and the pattern of its arterial supply in the patients. (Folia Morphol 2010; 69, 1: 54–61)

Key words: insertion of abductor hallucis, medial plantar artery

INTRODUCTION

A detailed anatomy of the abductor hallucis is of great importance in clinical application. A full anatomical description of this muscle is quite scarce in literature. The free tendon of the abductor hallucis muscle originates from the muscle's belly at about one or two fingers width proximal to the head of the first metatarsal bone. The abductor hallucis consists of three parts, i.e. belly, transitional area, and tendon, and is entirely enveloped in deep fascia. The abductor hallucis lies along the medial border of the foot where it covers the origins of plantar vessels and nerves. As the tendon of the abductor hallucis always traverses below the transverse axis of the first metatarsophalangeal joint, the abductor hallucis performs not only abduction but also plantar flexion of the first metatarsophalangeal joint, being active in the late stance and toe-off phases of gait, and is a dynamic stabilizer of the longitudinal arch [2, 3, 24].

Paediatric surgeons are interested in the anatomy of the abductor hallucis muscle to correct disorders of the foot [8, 13, 19]. One of the main activities in paediatrics is dealing with hallux valgus. In this case, the abductor hallucis muscle and its insertion is involved

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in the aetiology as well as in the therapy of this very common disorder of the foot [2, 6, 23]. Moreover, in plastic and reconstructive surgery, the abductor hallucis muscle is of increasing interest as it is used as a graft for flap surgery [10–12, 21].

The abductor hallucis muscle flap is used for deep defects that lie between the medial malleolus and the heel [7, 15]. A proximally based abductor hallucis flap constitutes an alternative for coverage of minor defects at the medial aspect of the calcaneal or plantar region. The medial plantar artery supplies both the proximal and distal pedicles of the abductor hallucis muscle and thus is suitable to be dissected for abductor hallucis muscle flap supply [4].

Treatment with abductor hallucis muscle as a pedicled flap (distally or proximally based) with or without conjoined regional fascio-cutaneous flaps offers a durable alternative to microsurgical free flaps for small to moderate defects over the weight-bearing area of the head of the first metatarsal and over the heel with the calcaneous bone, medial ankle, midfoot, and forefoot with exposed bone, tendon, or joint. These areas are difficult sites for reconstruction because these areas are predisposed to damage and chronic ulceration for various reasons [1, 20, 25].

To our knowledge, abductor hallucis muscle flap is not frequently used due to the lack of detailed anatomy in literature. The aim of this research is to study the anatomic basis of the abductor hallucis muscle flap by reporting its various forms of insertion and its arterial supply, which will provide the surgeon with more detailed, helpful information.

MATERIAL AND METHODS

The dissection study was undertaken on 15 embalmed cadaveric feet (six right and nine left) showing no signs of peripheral neurovascular or musculoskeletal disease, such as hallux valgus, pes planus, or pes cavus, to exclude possible muscle alteration associated with these clinical conditions.

Precise dissection of the abductor hallucis muscle was performed. A description of the insertion of the abductor hallucis muscle and its arterial supply were made. The posterior tibial artery was exposed through a vertical incision placed midway between the posterior margin of the medial malleolus and the medial margin of the Achilles tendon. A 16-gauge cannula was introduced caudally in the artery, and 50 mL of red latex were injected manually and slowly. Then the skin was incised along the margins of the foot and reflected together with the subcutaneous tissues. The abductor hallucis was cleaned. Its length from the proximal to its distal attachments, the width of the muscle belly at the distal end of the flexor retinaculum, and the ratio between the length of the tendon and that of the muscle were measured. Its various modes of termination (insertion) were studied.

To trace the complete course of the medial plantar artery and its branches, the abductor hallucis muscle was cut near its distal end and reflected to demonstrate the terminal end of the posterior tibial artery and its two terminal branches: the medial and lateral plantar arteries. These arteries were identified and dissected starting from their level of bifurcation from the posterior tibial artery.

All the branches of the medial plantar artery (MPA) up to the abductor hallucis muscle were dissected from their proximal origin to their points of entry into the muscle belly. The number of branches of the MPA supplying the abductor hallucis was counted and studied. The results were recorded, photographed, and tabulated.

RESULTS

The abductor hallucis muscle arises from the medial tubercle of the calcaneous, the flexor retinaculum, and the plantar aponeurosis. The abductor hallucis showed two types of morphology: straight and arciform (four and eleven specimens, respectively) (Figs. 1, 2). In the straight morphology, the muscle described a course parallel to the reference line traced from the calcaneal tuberosity to the head of the first metatarsal bone, whereas in the arciform morphology, the muscle described a curved course with the concavity directed downwards.

In analysis of the insertion of the abductor hallucis muscle, three different types of insertion can be identified:

— Type A — insertion at the proximal phalanx of the first toe without attachment to the sesamoid bone, seven specimens, 46.7% (Figs. 3–5). The tendon of the abductor hallucis muscle traverses the first metatarsophalangeal joint in

Figure 1. The left foot showing the straight shape of the abductor hallucis muscle (A).

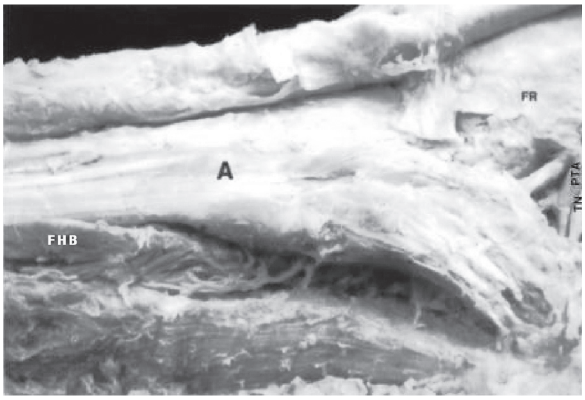


Figure 2. The right foot showing the arciform shape of the abductor hallucis muscle (A). Flexor retinaculum (FR), the flexor hallucis brevis (FHB), the posterior tibial artery (PTA), and the tibial nerve (TN).

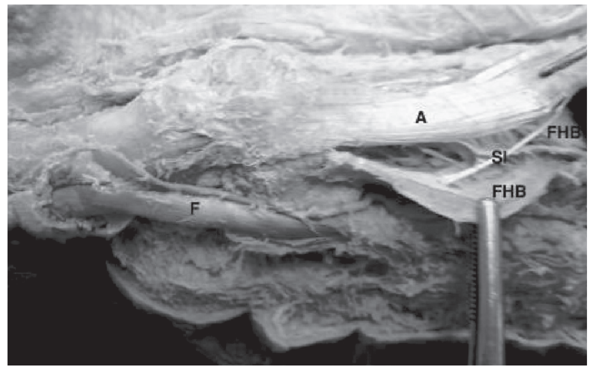


Figure 5. The right foot showing the splitting of the tendon of abductor hallucis (A) into medial and lateral slips attached to the proximal phalanx. Some fibres of the main tendon (SI) are given to the flexor hallucis brevis (FHB). Tendon of flexor hallucis longus (F); insertion type A.

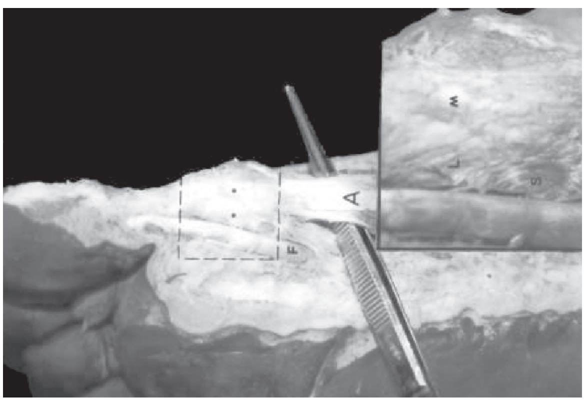


Figure 3. The right foot with magnification of the area bounded by the dotted square showing that the tendon of abductor hallucis (A) splits into two slips (*): medial (M) and lateral (L), which are attached to the plantar aspect of the proximal phalanx, and no fibres could be traced to the sesamoid bone (S). Tendon of flexor hallucis longus (F); insertion type A.

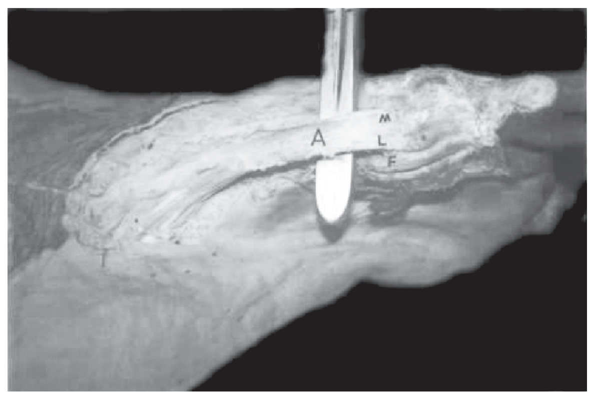


Figure 6. The left foot showing the insertion of abductor hallucis (A). Its medial slip (M) is inserted into the base of the proximal phalanx. The lateral slip (L) is attached to the sesamoid bone (*). It does not terminate at the sesamoid bone but further on spreads to the medial border of the proximal phalanx. Flexor hallucis longus (F); insertion type B.

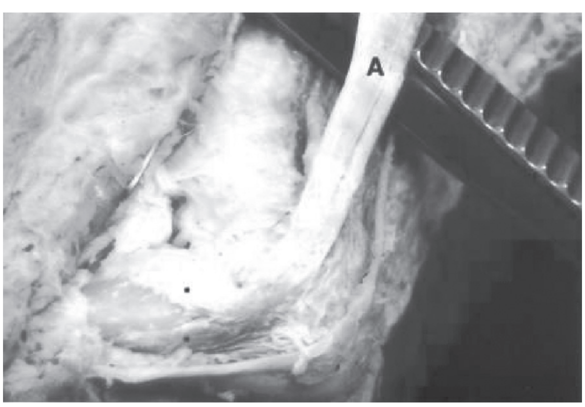


Figure 4. The right foot showing the splitting of the tendon of abductor hallucis (A) into medial and lateral slips (*) attached to the plantar aspect of the proximal phalanx; insertion type A.

a plantar direction crossing its transverse axis. In these three right and four left feet, the tendon splits into two slips which are attached to the plantar aspect of the proximal phalanx, whereas the sesamoid bone does not receive any fibres of the tendon. In one of these cases, some slips are given to the flexor hallucis brevis (Fig. 5).

— Type B — the medial slip of the tendon of abductor hallucis is inserted into the base of the proximal phalanx of the big toe. The lateral slip is attached to the sesamoid bone, five specimens, two right, and three left feet, 33.3% (Figs. 6, 7). In some specimens, the lateral fibres of the abductor hallucis do not terminate at the sesamoid bone but further on spread to the medial

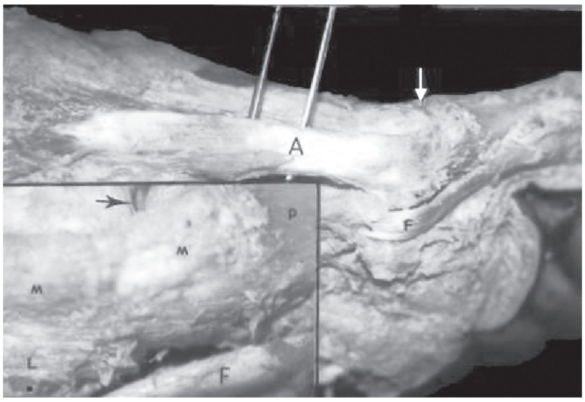


Figure 7. The left foot showing the insertional areas of abductor hallucis (A) magnified. The tendon of A is divided into 2 slips. A large medial slip (M) which passed distal to the opened metatarsophalangeal joint (arrow) to be attached to the proximal phalanx of the big toe (P). A smaller lateral slip (L) is attached to the sesamoid bone (*). Flexor hallucis longus (F); insertion type B.

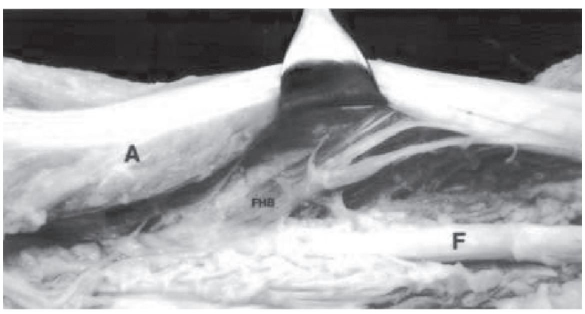


Figure 8. The left foot showing that the tendon of abductor hallucis (A) takes some slips from the flexor hallucis brevis (FHB). Flexor hallucis longus (F).

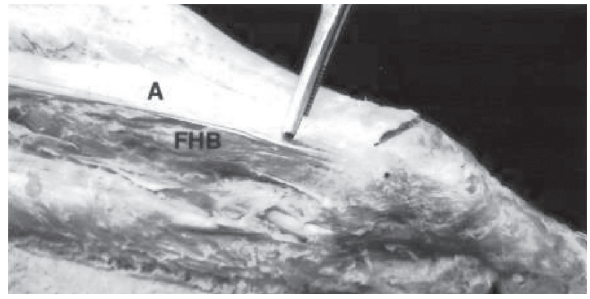


Figure 9. The left foot showing that the distal end of the flexor hallucis brevis (FHB) joined the abductor hallucis (A) tendon and fused with it. They are inserted into the sesamoid bone (*). The fibres of the tendon further spread to the proximal phalanx; insertion type C.

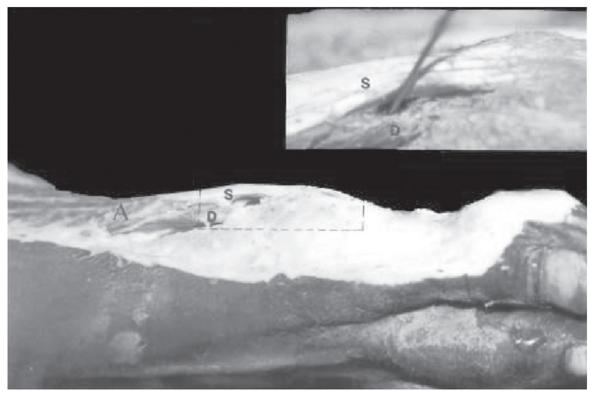


Figure 10. The right foot showing that the abductor hallucis (A) is partially divided into superficial tendinous (S) and deep fleshy parts (D). The tendinous part extended distal to the joint to be attached to the base of the proximal phalanx while the deep part is attached to the joint capsule; insertion type D.

border of the proximal phalanx (Fig. 6). In two specimens (13.3%), its tendon sometimes takes some slips from the flexor hallucis brevis (Fig. 8).

- Type C — insertion at the sesamoid bone, one left foot 6.7% (Fig. 9). The fibres of the tendon further spread to the proximal phalanx running in a dorsoplantar direction.
- Type D — close to the insertion, the abductor hallucis is partially divided into a superficial tendinous and deep fleshy parts in 2 specimens, one right and one left feet, 13.3% (Fig. 10). The tendinous part extends distal to the metatarsophangeal joint to be attached to the base of the proximal phalanx while the deep part is attached to the joint capsule.

The mean length of abductor hallucis was 14.29 ± ± 1.47 cm, and the mean width of the belly was 2.20 ± ± 0.43 cm. The mean value of the ratio between the length of the tendon and that of the abductor hallucis was 0.56 ± 0.07 cm (Table 1).

As regards the arterial supply, it was found that the main arterial supply of the abductor hallucis muscle is via branches from the smaller terminal branches of the posterior tibial artery. The medial plantar artery passes forward along the medial side of the foot with the medial plantar nerve lying on its lateral side. Proximally and distally, the MPA gives off minor branches (pedicles) to supply the proximal and distal portion of the abductor hallucis. The number of branches that supply this muscle ranged from 4 to 9 with a mean value of 7.06 ± 1.79 (Table 2).

The results of this research confirm the variability of the course of the MPA so as to allow the definition of three main patterns.

Pattern A (40%). In six specimens, the MPA was divided into two branches that passed deep to the muscle. The superficial branch supplied the proximal portion of the abductor hallucis. The deep branch gave small twigs to the distal part of the abductor hallucis (Fig. 11A, B).

Table 1. Characteristics of the abductor hallucis muscle (A)

Case	Side	(A) Shape	(A) Length [cm]	(A) Width [cm]	Tendon/muscle length ratio
1	Left	Arciform	15.5	2.2	0.67
2	Right	Arciform	15.5	2.0	0.51
3	Right	Arciform	14.5	2.6	0.56
4	Left	Straight	12.5	2.5	0.73
5	Right	Arciform	15.3	2.3	0.62
6	Left	Arciform	14.0	2.8	0.46
7	Left	Arciform	12.5	2.5	0.54
8	Left	Straight	14.0	1.9	0.51
9	Left	Arciform	12.5	1.5	0.53
10	Right	Arciform	16.0	2.0	0.60
11	Left	Straight	14.5	1.8	0.48
12	Right	Arciform	17.0	2.1	0.52
13	Left	Arciform	15.0	1.5	0.56
14	Right	Straight	13.5	2.6	0.58
15	Left	Arciform	12.0	2.8	0.53
Mean ± SD			14.29 ± 1.47	2.20 ± 0.43	0.56 ± 0.07

Table 2. Characteristics of branches of medial plantar artery

Case	Number of branches from SMPA to abductor hallucis		Number of branches from DMPA to abductor hallucis		Total number of branches to abductor hallucis
	Proximal	Distal	Proximal	Distal	
1	3	2	Absent	Absent	5
2	5	3	Absent	Absent	8
3	2	0	2	1	5
4	5	2	Absent	Absent	7
5	2	2	Absent	Absent	4
6	3	1	3	2	9
7	6	3	Absent	Absent	9
8	2	2	3	2	9
9	6	1	Absent	Absent	7
10	6	2	Absent	Absent	8
11	1	1	3	1	6
12	4	2	Absent	Absent	6
13	2	1	1	1	5
14	3	2	3	1	9
15	2	2	3	2	9
Mean ± SD	3.47 ± 1.73	1.73 ± 0.79	1.2 ± 1.42	0.67 ± 0.82	7.06 ± 1.79

SMPA — superficial branch of medial plantar artery; DMPA — deep branch of medial plantar artery

Pattern B (53.3%). In eight specimens, the MPA failed to produce a deep branch and instead continued along the lateral border of the abductor hallucis in the same manner as the superficial branch supplying the proximal and distal ends of the muscle (Figs. 12, 13).

Pattern C (6.7%). In one case, the MPA continued as a deep branch supplying the abductor hallucis. A superficial branch of the MPA provided branches to the proximal part of the abductor hallucis (Fig. 14).

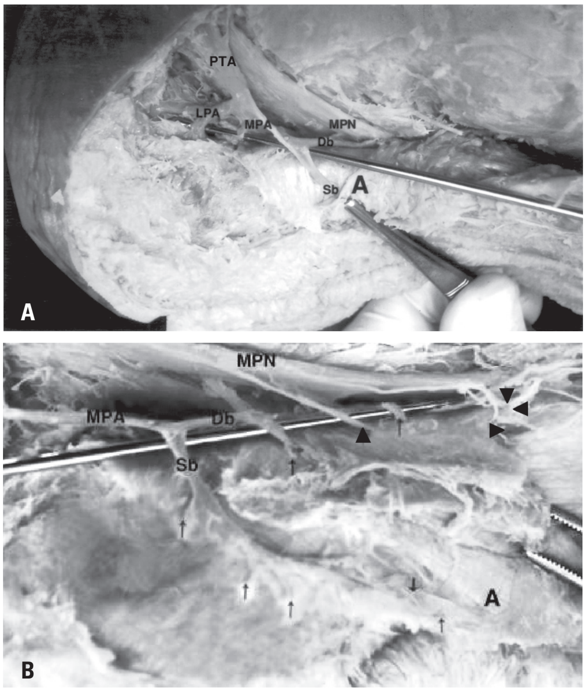


Figure 11. A. The left foot showing the posterior tibial artery (PTA), which is divided into medial plantar artery (MPA) and lateral plantar artery (LPA). The MPA further divided into superficial (Sb) and deep (Db) branches; MPN — medial plantar nerve; A — abductor hallucis (pattern A); **B**. A further dissection of the previous photograph showing the reflected inner aspect of the A. The MPA is divided into Sb and Db branches. The Sb and Db supplied it by multiple branches (black arrows). The MPN supplied the A by some branches (arrow heads) (pattern A).

Figure 12. The left foot showing the medial plantar artery running along the lateral border of the abductor hallucis (A) supplying its proximal part by multiple branches (black arrows). Its distal end also received a branch from it (black arrow) (pattern B).

In two specimens (13.3%), the lateral plantar artery gave calcaneal branches to the abductor hallucis at the proximal calcaneal end together with branches of the medial plantar artery demonstrating its double source of vascularity (Fig. 15A, B).

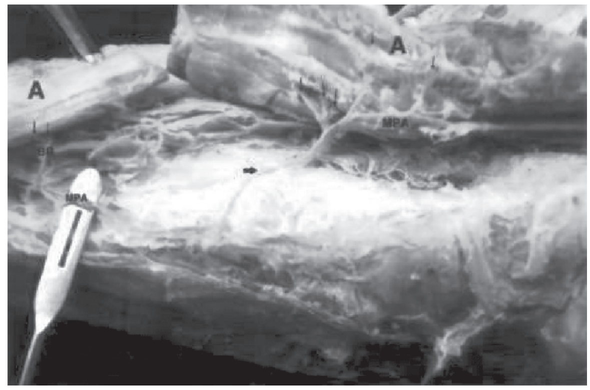


Figure 13. The left foot showing the abductor hallucis (A) reflected downwards. The medial plantar artery is running along its lateral border giving it multiple branches (black arrows). Its distal end also received branches from it (BR) (black arrow) (pattern B).

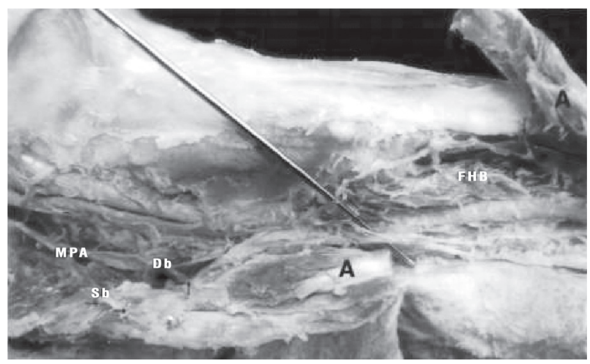
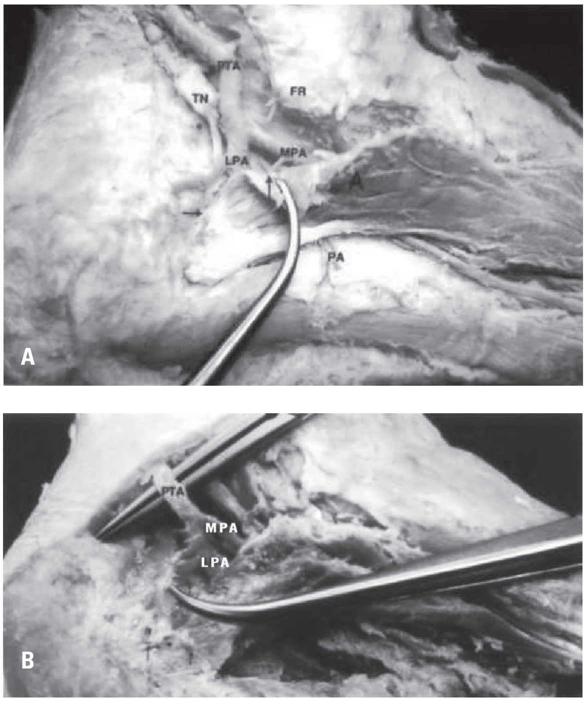


Figure 14. The left foot showing the reflected inner aspect of the abductor hallucis (A). The medial plantar artery (MPA) continued as deep branch (Db) on the deep surface supplying both the proximal and distal parts of A (black arrows). A superficial branch (Sb) provided smaller twigs (black arrows) to its proximal part; FHB — flexor hallucis brevis (pattern C).

DISCUSSION

Different opinions exist about the insertion of abductor hallucis. German textbooks report that the muscle inserts at the medial sesamoid bone and spreads to the medial side of the proximal phalanx of the first toe. In Anglo-American literature, the insertion is at the medial side of the capsule of the first metatarsophalangeal joint involving the medial sesamoid bone, and at the medial side of the proximal phalanx of the first toe. In French textbooks, this muscle was inserted in the medial sesamoid and the plantar tubercle at the base of the proximal phalanx [2].

This study reveals the insertion of the abductor hallucis muscle into the medial sesamoid bone and the base of the proximal phalanx of the first toe. The German textbooks summarize type B and C, which represent 33.3% and 6.7% of this study, respectively. How-



Figures 15. Two specimens of the left feet showing that the posterior tibial artery (PTA) is divided into medial plantar artery (MPA) and lateral plantar artery (LPA). The LPA supplied calcaneal branches to the abductor hallucis (A) at its proximal end (arrow). **A.** The MPA gave a proximal branch to it (arrow), demonstrating its double source of vascularity. **B.** LPA supplied the proximal part of the abductor hallucis by two branches (arrows); FR — flexor retinaculum; TN — tibial nerve; PA — plantar aponeurosis.

ever, they fail to mention type A in which the medial sesamoid is not involved in the insertion of the muscle.

The Anglo-American version describes an insertion of type B, which represents about 33.3% of cases in the current study. The French version just represents type C, which accounts for about 6.7% of this study. These differences may be based upon different geographical prevalence [2].

An insertion of type C with direct attachment to the medial sesamoid bone presumably would be the most predisposing type for hallux valgus, as Debrunner [5] stated.

In this work, the mean length of the abductor hallucis ranged from 12 to 17 cm with a mean of 14.29 ± ± 1.47 cm, the mean width of the belly ranged from 1.5 to 2.8 cm with a mean of 2.20 ± 0.43 cm. These results were in contrast to Hua et al. [9], who mentioned that its total length ranged from 11.2 to 15.2 cm with a mean of 13.4 ± 1.0 cm and its width ranged from 1.7 to 1.9 cm with a mean of 1.8 ± 0.1 cm.

Orbay et al. [18] and Michlits et al. [16] stated that the abductor hallucis receives its main blood supply from the medial plantar artery MPA. This observation is in agreement with this study. Schwabegger et al. [20] and Hua et al. [9] stated that the proximal and distal pedicles of this muscle are supplied only by the MPA. By carefully dissecting the pedicles to their origin, the investigators were able to get a suitable pedicle length that allowed a good range of motion of the flap. In the current research, it was observed that a proximal branch from the lateral plantar artery supplied the proximal part of the abductor hallucis in two specimens in addition to the branches of the MPA. Schwabegger et al. [22] demonstrated that the distally based abductor hallucis flap received its blood supply from both the dorsal arterial network and the deep plantar system through communicating branches with the MPA.

The medial plantar artery gives off 4 to 9 small branches with a mean of 7.06 ± 1.79 to the abductor hallucis muscle, in contrast to Hua et al. [9] who noticed that this artery gives off 5 to 10 small branches to this muscle with a mean of 6.9 ± 1.8.

Soft tissue coverage of the medial ankle and foot remains a difficult, challenging, and often frustrating problem for patients as well as surgeons. Abductor hallucis muscle is used frequently as a proximally based muscle flap in medial midfoot, heel, and ankle defects and was introduced for treatment of chronic ulcers or osteomyelitis of the foot and ankle region. It is also possible to use the abductor hallucis muscle as a distally based flap by reversing the direction of blood flow to reconstruct a large defect in the forefoot because abductor hallucis flap is a well-vascularised tissue. Special care should be taken not to injure the medial plantar nerve because it is functionally important [20, 22]. The anatomical findings of Michlits et al. [16] mentioned that the adaptation in pedicle preparation of the abductor hallucis allowed an increase in rotation of the flap and ease of handling that results in successful coverage of defects overlying the Achilles tendon.

Other investigators used a medial plantar flap with a functioning abductor hallucis for simultaneous reconstruction of the thenar skin and muscle defects. The medial plantar flap provides not only stable skin to the thenar area with sufficient thenar bulk but also satisfactory abduction of the thumb [10].

A detailed anatomy of the abductor hallucis is also useful for many operations such as sectioning of the abductor hallucis tendon for correction of metatarsus varus deformity or correction of varus deformity of a club foot [14]. Abductor hallucis lengthening can be performed in treatment of resistant and severe idiopathic fore-foot abduction deformity. Tenotomy of the abductor hallucis is also done for correction of a resistant metatarsus varus deformity. In early severe or resistant congenital metatarsus varus deformity, correction can be achieved either by division of the tendon with release of its capsular attachment or, in more severe deformity, by complete release of the abductor hallucis muscle from its extensive attachment to bone and soft tissue [17].

The abductor hallucis muscle flap, with the medial plantar artery and nerve as its pedicle, is also used to reanimate facial palsy and reconstruct lower facial paralysis. It has many unique advantages such as the appropriate size and shape of the muscle and adequate bulk, the closely parallel alignment and unvaried anatomy of the main vessels and nerve distribution to the muscle, the easy surgical isolation of the muscle, its long neurovascular pedicle, and lack of functional deficit after muscle removal. The nerve and muscle grafts can be performed by microneurovascular anastomosis in one surgical procedure [12]. The medial plantar vessels are anastomosed to the facial vessels and the medial plantar nerve to the buccal branch of the facial nerve [11]. Abductor hallucis transplantation is an ideal method to reconstruct functions of facial nerve and mimic muscles.

The results of the present study will be useful in determining the appropriate flap design based on the abductor hallucis type of insertion and the pattern of its arterial supply in the patient.

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