Diversity of Arterial Branches in the Crural and Foot Region as Correlated with the Relative Thickness of the Fibular and Posterior Tibial Arteries

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Objective: We studied how the course and branching of peripheral arteries are influenced by the diversity of the proximal arteries, taking examples in the leg and foot region.

Materials and methods: The arteries in the leg and foot was studied in 18 lower extremities of Japanese cadavers and their diversity was correlated with the relative thickness of fibular and posterior tibial artery.

Results: The posterior tibial artery was dominant in 8 cases (PTAD) and the fibular artery was dominant in 10 cases (FAD). The communicating branch between the two arteries was single in 7 cases and multiple in 11 cases. The perforating branch of the fibular artery was large in 4 cases, medium in 6 cases, and small in 8 cases. The large perforating branch was found in FAD group, and the small perforating branch was mainly found in PTAD group. The dorsalis pedis artery was formed mainly by the anterior tibial artery, but by the perforating branch in the cases of thick perforating branches. The anterior lateral malleolar artery was single in 10 cases and multiple in 8 cases. The number of dorsal roots of dorsal metatarsal arteries was 3.3 in the cases of thick perforating branch, 2.2 in medium perforating branch, and 0.6 in small perforating branch.

Conclusions: The formation of the dorsalis pedis artery and the number of dorsal roots of the dorsal metatarsal arteries were influenced by the thickness of the perforating branch and thus by the relative thickness of the fibular artery.

Keywords: fibular artery, posterior tibial artery, anterior tibial artery, dorsalis pedis artery, dorsal metatarsal artery

Introduction

The arteries manifest significant diversity in the dividing pattern and courses they take in the human body. Arterial diversity has been the concern of anatomists ever since the 19th centuries when Quain1) and Dubrueil2) published monographs on arterial variation. Adachi3) studied the arterial variation in the various parts of the body using Japanese cadavers and proposed a classification of variations in specific parts of the body. In the latter half of the 20th century, the arteries were visualized by medical imaging technique, and arterial variations were studied by radiologists. Based on 675 anatomical and radiological studies in the literature, Lippert and Pabst4) published a monumental monograph on arterial variation. Anatomical studies of arterial variation have the advantage of detailed analysis visualizing minute arterial branches, but are time-consuming and labor intensive making it difficult to do quantitative analysis of large numbers of examples. On the other hand, radiological studies facilitated the quantitative analysis of large numbers of examples, but were inadequate to observe minute arterial branches.

The arteries in the extremities constitute a single trunk in the proximal region, and divide into a few parallel arteries in the peripheral regions. The forearm contains the radial and ulnar arteries, whose relative dominance was known to be variable, and their relative dominance per se affected the variation of the superficial and deep palmar arch in the hand5). Recently Serita et al.6) studied the arterial variations distributing the muscles around the scapula, and clarified that the distribution...
pattern was influenced by the variation of branching pattern of the origin of supplying arteries.

The arteries of the leg are unique in possessing three major arteries in parallel, the anterior and posterior tibial arteries and the fibular artery. After the monumental study by Adachi, the studies of arterial variation in the leg were followed by Trotter who reported the branching pattern of the popliteal artery in American cadavers, and by Kim and Orron based on radiological observations. Recently Kropman summarized the branching patterns of popliteal artery based on 7,671 examples in four anatomical and eleven radiological studies in the literature. However, these studies focused on the branching patterns of the three major arteries from the popliteal artery, and did not clarify the relative dominance of these arteries and their relation to the variations in their peripheral arteries.

In the present study we reported the variations of the peripheral branches of three major arteries of the leg, and clarified their relation to the relative dominance of the three major arteries.

Materials and methods

In the present study, 18 lower extremities were examined from Japanese adult cadavers (11 right legs and 7 left legs; 6 males and 12 females; average age at the time of death, 82.8 years; range 60–107 years) dissected in the gross anatomy course at the Juntendo University School of Medicine in the years 2011–2013. Cadavers with significant arteriosclerosis or arteriostenosis were excluded. The popliteal arteries and its three tributaries as well as their peripheral branches were pursued in the leg and foot, and the anatomical findings were recorded by photographs and sketches. The images of the left side examples were reversed for the convenience of analysis.

Results

At the lower end of the popliteal fossa, the popliteal artery divided into the anterior and posterior tibial arteries in the middle of the popliteus muscle, with the latter sending off the fibular artery just below the lower end of the popliteus muscle. After entering the anterior compartment through the supreme portion of the crural interosseous membrane, the anterior tibial artery descended along the medial surface of the tibialis anterior muscle (Figure-1A, B). In the posterior compartment of leg, the fibular and posterior tibial arteries descended on the lateral and medial side of the region deeper to the soleus muscle, respectively (Figure-1C, D).

1. Arterial branches in the posterior compartment of the leg

The posterior tibial artery and the fibular artery were unequal in thickness, and in 8 cases the posterior tibial artery was relatively thick (PTAD; posterior tibial artery dominant) and in the other 10 cases the fibular artery was relatively thick (FAD; fibular artery dominant).

The posterior tibial artery and the fibular artery were connected by one or a few communicating branches predominantly at the level of the lower end of interosseous membrane of leg where the

Figure-1 Photographs and schematic drawings of the arteries in the right leg.

The posterior aspect (A, B) and the anterior aspect (C, D) are shown. The opening for the perforating branch at the lower end of the interosseous membrane was indicated by the arrowheads. Pp = popliteal artery, At = anterior tibial artery, Pt = posterior tibial artery, Fb = fibular artery, Pb = perforating branch of the fibular artery, Cb = communicating branch of the fibular artery, Al = anterior lateral malleolar artery, Dp = dorsalis pedis artery.
perforating branch of fibular artery penetrated it. The number of communication branches was one in seven cases (Figure-2A, C, E, J, K, M, P) and multiple in the other 11 cases (Figure-2B, D, F, G, H, I, L, N, O, Q, R), with a maximum of 4 from the posterior tibial artery and 6 from the fibular artery (Figure-2H).

The single and multiple communicating branches manifested differences in their level of distribution. The single communicating branch was always found in a dominant region around the level of the lower end of interosseous membrane of leg, whereas the multiple communicating branches were distributed in a wider range between the middle of the leg and the calcaneus. In the cases of multiple communicating branches, the highest one (in 3 cases the highest two; Figure-2I, L, O) was largest and the other communicating branches were significantly thinner (Figure-2B, D, F, G, H, N, Q, R). The level of the highest communicating branch was higher than the dominant region in 3 cases (Figure-2I, L, O), and in the dominant region in 8 cases (Figure-2B, D, F, G, H, N, Q, R). The lowest communicating branch was observed in the

Figure-2 Schematic drawings of the arterial branches in the lower half of the leg. The 18 cases were divided into the fibular artery dominant (10 cases; A-J) and the posterior tibial artery dominant (8 cases; K-R). The communicating branch was either single in 7 cases (A, C, E, J, K, M, P) or multiple in 11 cases (B, D, F, G, H, I, L, N, O, Q, R). In the cases of multiple communicating branches, the highest one (in 3 cases the highest two) was largest and the other communicating branches were significantly thinner. The level of highest communicating branch was higher than the dominant region in 3 cases (I, L, O), in the dominant region in 8 cases (B, D, F, G, H, N, Q, R). The lowest communicating branch was found in the dominant region in 3 cases (I, O, R) and at the level of calcaneus in 8 cases (B, D, F, G, H, L, N, Q). The single communicating branch was inclined in 3 cases (A, C, K) and horizontal in 4 cases (E, J, M, P), whereas among the multiple communicating branches the highest one (or two) was obviously inclined.
dominant region in 3 cases (Figure-2I, O, R) and at the level of calcaneus in 8 cases (Figure-2B, D, F–H, L, N, Q).

The single and multiple communicating branches also manifested differences in inclination. The single communicating branch was inclined in 3 cases (Figure-2A, C, K) and horizontal in 4 cases (Figure-2E, J, M, P), whereas among the multiple communicating branches the highest one (or two) was obviously inclined (Figure-2B, D, F, G, H, I, L, N, O, Q, R). The inclined communicating branch was connected at the proximal end to the thicker one and at the distal end to the thinner one of the two parallel arteries in the posterior compartment of leg in most cases (10 cases out of 11; Figure-2D, F–I, L, N, O, Q, R), an arrangement which would facilitate even circulation on both sides of the ankle region. The inclination was in the opposite direction in the other case in which the thicker fibular artery continued to a very thick perforating branch, and the tributaries to the posterior tarsal region were very thin. In this case the communicating branch may facilitate even circulation in the posterior tarsal region (Figure-2B).

Figure-3  Schematic drawings of the arterial branches in the anterior leg and dorsum of foot. The perforating branch of the fibular artery was large in 4 cases (A–D), medium in 6 cases (E–H, K, L) and small in 8 cases (I, J, M, N, O, P, Q, R). The anterior tibial artery transferred into the dorsalis pedis artery in 14 cases (E–R), the anterior tibial artery and the perforating branch of almost equal thickness jointed to become the dorsalis pedis artery in 1 case (C), and the perforating branch transferred into the dorsalis pedis artery in 3 cases (A, B, D). The anterior lateral malleolar artery was single in 10 cases arising either from the anterior tibial artery (G, K, M, N, P) or from the dorsalis pedis artery (A–E), and multiple in the other 8 cases with higher branches arising at the level up to the middle of the leg in 7 cases (F, H, I, L, O, Q, R) and without in the other case (J). The number of dorsal roots of dorsal metatarsal arteries was 4 in 3 cases (B, D, E), 3 in 3 cases (A, G, I), 2 in 4 cases (C, F, H, K), 1 in 2 cases (O, Q) and none in 6 cases (J, L, M, N, P, R).
2. Arterial branches in the anterior aspect of the leg

The anterior tibial artery passed through the proximal part of the interosseous membrane of leg, descended in the anterior compartment of leg to send off branches to the extensor muscles of the leg and around the ankle joint. The perforating branch of the fibular artery passed through the distal part of the interosseous membrane to enter the lowest part of the anterior compartment. Either the anterior tibial artery or the perforating branch of the fibular artery became the dorsalis pedis artery in the dorsum of foot (Figure-1).

3. Perforating branch of the fibular artery

The perforating branch of the fibular artery pierced the most distal part of the interosseous membrane in all the cases examined. The perforating branch was classified into three groups on the basis of thickness. The large thickness group had thickness comparable with the two main arteries in the posterior compartment (4 cases; Figure-3A-D), the medium thickness group had considerable thickness, but obviously smaller than these two arteries, (6 cases; Figure-3E-H, K, L), and the small thickness group included smallest ones which were barely detectable (8 cases; Figure-3I, J, M-R). The thickness of perforating artery was correlated with the relative thickness of the fibular and posterior tibial arteries. The large thickness perforating branch was found in the FAD group, and the small thickness perforating branch was mainly found in the PTAD group (Table-1).

4. Dorsalis pedis artery

In 14 cases among the 18 cases examined, the anterior tibial artery transferred into the dorsalis pedis artery either without participation of the perforating branch or with participation of a small twig of the perforating branch (Figure-4A). In one case among the 18 examined, the anterior tibial artery and the perforating branch of almost equal thickness anastomosed to become the dorsalis pedis artery (Figure-4B). In the other 3 cases, the perforating branch transferred into the dorsalis pedis artery with participation of a small twig of the anterior tibial artery (Figure-4C). In the 4 cases of the large thickness group, the perforating branch substantially contributed to the dorsalis pedis artery (Figure-3A-D), whereas in the 6 and 8 cases of the middle (Figure-3E-H, K, L) and small thickness group (Figure-3I, J, M-R), the anterior tibial artery transferred into the dorsalis pedis artery without substantial participation of the perforating branch.

5. Anterior lateral malleolar artery

The anterior lateral malleolar artery entering the lateral malleolar network arose either from the

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Table-1 Classification of the perforating branch

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<tr>
<th>Size of the perforating branch</th>
<th>FAD group</th>
<th>PTAD group</th>
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<tbody>
<tr>
<td>The large sized group</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>The middle sized group</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>The small sized group</td>
<td>2</td>
<td>6</td>
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Figure-4 Schematic drawings of the origin of dorsalis pedis artery. At = anterior tibial artery, Pb = perforating branch of the fibular artery, Dp = dorsalis pedis artery.

A. The dorsalis pedis artery was formed as continuation of the anterior tibial artery without substantial participation of the perforating branch (14/18).

B. The dorsalis pedis artery was formed by union of the anterior tibial artery and perforating branch with almost equal thickness (1/18).

C. The dorsalis pedis artery was formed by the perforating branch with participation of a small twig of the anterior tibial artery (3/18).
anterior tibial artery or from the perforating branch or from the dorsalis pedis artery in a wide range of the lower leg and dorsum of pedis. The number of anterior lateral malleolar arteries was also variable, being single in 10 cases (Figure-3A-E, G, K, M, N, P) and multiple in 8 cases (Figure-3F, H–J, L, O, Q, R). The single anterior lateral malleolar artery arose at the level of talocrural joint in 5 cases (Figure-3G, K, M, N, P; Figure-5A) and in the dorsum of pedis in 5 cases (Figure-3A-E; Figure-5B). In the cases with multiple anterior lateral malleolar arteries, the thickest branch of the artery was found at the level of talocrural joint, and the other thinner branches were found either from the anterior tibial artery in the region up to the middle of the leg in 7 cases (Figure-3F, H, I, L, O, Q, R; Figure-5C) or as continuation of perforating branch in the other one case (Figure-3J; Figure-5D).

6. Arterial distribution in the dorsum of foot

In the dorsum of foot, the dorsal metatarsal arteries in number were formed both by the metatarsal branches from the dorsalis pedis artery or from the arcuate artery and by the perforating branches from the deep plantar arch, a tributary of the posterior tibial artery. The number of metatarsal branches contributing to the dorsal metatarsal arteries was variable: 4 branches in 3 cases (Figure-3B, D, E), 3 branches in 3 cases (Figure-3A, G, I), 2 branches in 4 cases (Figure-3C, F, H, K), 1 branch in 2 cases (Figure-3O, Q) and no branch in 6 cases (Figure-3J, L–N, P, R). We found a correlation between the thickness of perforating branch and the number of metatarsal branches. In the large thickness group (Figure-3A–D) the number of metatarsal branches was 3.3 in average, in the middle thickness group (Figure-3E–H, K, L) it was 2.2 in average, and in the small thickness group (Figure-3I, J, M–R) it was 0.6 in average. The number of metatarsal branches was also correlated with the relative thickness of the fibular and posterior tibial artery, and 2.7 ± 1.3 (average ± SD) in the FAD group, and 0.5 ± 0.8 (average ± SD) in the PTAD group (Figure-3). The difference was significant by Mann–Whitney U test (P value < 0.05).

Discussion

In the present study on the peripheral arterial branches of the three arteries arising from the popliteal artery, we obtained novel findings in the four regions of the leg and foot: 1) communicating branches between the fibular and posterior tibial artery; 2) the dorsalis pedis artery formed by the anterior tibial artery and/or the perforating branch of the fibular artery; 3) the anterior lateral maleolar artery distributing to the lateral ankle region; and 4) dorsal metatarsal artery distributing to the dorsal surface of the second to fifth toes. The three arteries arising in the popliteal region were the object of investigation by means of cadaver dissection and medical imaging, and their branching patterns in the popliteal fossa, and their frequency of defect were reported. On the peripheral branches of the three arteries, Adachi, et al...
Wachsmuth and Huber provided some contributions after cadaver dissection.

1. Communicating branch between the fibular and posterior tibial artery

In the present study, we reported the number, localization, and inclination of the communicating branch for the first time. The anatomy of communicating branch was so far reported by Adachi, who claimed that the number and courses of the communicating arteries were so diverse that systematic analysis of the communicating branches was impossible. After the study by Adachi, no anatomical studies on the communicating branches were reported as far as we know.

We found that the number of communicating branches was either single (7/18, 38.9%) or multiple (11/18, 61.1%). General description of the communicating branches in the anatomy textbooks such as Gray’s Anatomy and Hollinshead state that the communicating branch is single, as defined in the Terminologia anatomica. The present study clarified that the communicating branch was not always single, but frequently multiple in number.

The localization of communicating branches was also diverse. General descriptions of the communicating branch state that the communication branch represented a branch of the fibular artery at the level of perforating branch at the lower end of leg. The present study revealed that the dominant region of the single communicating artery was found in the lower end of the leg, but multiple communicating branches were distributed in a wider region up to the middle of the leg and down to the calcaneus. In the cases of multiple communicating branches, either the highest branch was thickest (8/11) or the highest two branches were thickest (3/11). Further novel findings concerned the inclination of the communicating branch. The single communicating branch was either horizontal or slightly inclined, whereas the thickest one of the multiple communicating branches was considerably inclined. These facts fitted well with the hypothesis that the multiple communicating branches contributed to the equalization of the blood supply between the lateral and medial side of the leg more effectively than the single communicating branch.

2. Formation of the dorsalis pedis artery

The dorsalis pedis artery is usually considered to be a continuation of the anterior tibial artery, and is formed exceptionally by the perforating branch from the fibular artery. The present study revealed that the dorsalis pedis artery was formed by the perforating branch totally in 3 cases (Figure-3A, B, D) and partially in one case (Figure-3C) out of 18 cases. The frequency of formation by the communicating branch (totally 3/18; 16.7%, partially 1/18; 5.6%) was much higher than that reported in previous studies such as Huber (totally 5.0%, partially 0.5%) and Adachi (totally 7.1% and partially 0%).

It is noteworthy that the 4 cases (Figure-3A-D) with formation of dorsalis pedis artery by the perforating branch have thick perforating branches, and belong to the FAD group with relatively thick fibular arteries. This fact suggests that the relative thickness of the three major arteries from the popliteal artery determines in part the branching and course of the peripheral arteries in the leg and foot.

3. Anterior lateral malleolar artery

Descriptions of the anterior lateral malleolar artery in the textbooks and studies up to now were diverse and sometimes contradictory. It may arise either from the anterior tibial artery or from the dorsalis pedis artery. Adachi reported that it arose either from the superior to the talocrural joint (higher origin) in 4 cases, at the level of the joint (middle origin) in 16 cases and inferior to the joint (lower origin) in 32 cases. Lanz reported that it arose from the level of the talocrural joint or distally in 90-92%. In these textbooks and studies it was generally assumed that the anterior lateral malleolar artery was single in number.

The present study revealed for the first time that the anterior lateral malleolar artery was frequently multiple in number (8 cases out of 18; Figure-3F, H-J, L, O, Q, R). In cases of the single artery, it arose with middle or lower origin, whereas in the cases of multiple arteries, they arose either with higher or middle origin, and not with lower origin. The area of origin of the multiple anterior lateral malleolar arteries shifted more proximal compared with that of the single one (Figure-3F, H, I, L, O, Q, R).
4. Dorsal metatarsal artery

The dorsalis pedis artery continued to the arcuate artery traversing the proximal part of the metatarsal, and during this course the arteries sent off dorsal roots which joined the ventral roots of perforating branches from the deep plantar arch to establish the four metatarsal arteries. The two roots were not equivalent and either one root or the other was frequently the dominant one. Adachi\(^3\) classified the formation of the dorsal metatarsal arteries into dorsal-dominant, plantar-dominant and equivalent types, and reported the higher incidence of dorsal roots in the first dorsal metatarsal artery than the other arteries. According to the data by Adachi\(^3\), the number of dorsal roots was four in 21.3%, three in 19.6%, two in 10.4%, one in 39.1% and null in 9.6% of the cases, and the average number of dorsal roots was 2.04. The number of dorsal roots found in the present study was a little lower (1.72) than average, and the cases without dorsal roots of metatarsal arteries were more frequent (33.3%).

The present study revealed that the number of dorsal roots of dorsal metatarsal arteries were influenced by the thickness of perforating branch from the fibular artery. The average number of dorsal roots was 3.3 in the cases with large perforating branches (Figure-3A–D), 2.2 in the cases with middle-thickness perforating branches (Figure-3E–H, K, L), and 0.6 in the cases with small perforating branches (Figure-3I, J, M–R). The thickness of perforating branches was influenced by the relative thickness of fibular and posterior tibial arteries, as stated earlier. Thus one may expect that the number of dorsal roots was correlated with the relative thickness of fibular and posterior tibial artery. In fact, the average number of dorsal roots was 2.7 in FAD group, and 0.5 in PTAD group (Figure-6).

References

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