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Implications of Dorsalis Pedis Artery Anatomical Variants for Dorsal Midfoot Surgery

Abstract

Background: The dorsalis pedis artery (DPA) usually branches into the arcuate artery (AA) from its lateral side which in turn crosses the bases of the lateral four metatarsals. The DPA then passes into the first interosseous space, where it divides into the first metatarsal artery and the deep plantar artery. In this study, we aimed to determine the extent of variation in the DPA and the distance between the AA and the tarsometatarsal (TMT) joint with the aim of reducing the risk of vascular complications arising from dorsal midfoot surgery.

Methods: In 29 fresh cadaveric feet, we examined the course of the DPA and the distance between the AA and the TMT joint on computed tomography images with barium sulfate contrast.

Results: The DPA was observed to have a standard course in 11 of the 29 cases (37.9%) but did not give rise to the AA and lateral tarsal artery or branches of the plantar arterial arch supplied the second to fourth metatarsal spaces in 10 of 29 cases (34.5%). The mean closest distance from the TMT joint to the AA at the second, third, and fourth metatarsal level in the sagittal plane was 11.4 mm, 14.6 mm, and 17.1 mm, respectively.

Conclusions: We found substantial variation in the arterial anatomy of the DPA system across the dorsal midfoot.

Clinical relevance statement: The risk of pseudoaneurysm and frank arterial disruption may be mitigated if the surgeon is aware of the variations of the course of the DPA when performing dorsal midfoot surgery.

level of evidence IV, cadaveric study

Key words: dorsalis pedis artery, arcuate artery, tarsometatarsal joint, midfoot, pseudoaneurysm

Introduction

The dorsalis pedis artery (DPA) is the main source of the blood supply to the dorsum of the foot. As a standard pattern, the DPA is a continuation of the anterior tibial artery at the talocrural joint just distal to the inferior extensor retinaculum, and gives medial tarsal artery and lateral tarsal artery (LTA), which crosses the navicular bone and passes in arched direction laterally, lying on the tarsal bones. Then, the DPA usually runs into the space between the first and second metatarsals and divides into the first dorsal metatarsal artery (DMA), the deep plantar artery, and the arcuate artery (AA). The AA usually crosses the base of the second, third, and fourth metatarsals almost transversely and gives off the second, third, and fourth DMAs. There are many reports of variations in the standard branching pattern of the DPA.[5,10,15,17,19,20,22]

The Lisfranc joint, also known as the tarsometatarsal (TMT) joint, can be fused in patients with osteoarthritis or injury. Marks et al. and Alberta et al. compared the use of plates and screws for fusion of the TMT joints during loading.[1,16] However, pseudoaneurysm in the foot has been reported as a complication following dorsal midfoot surgery,[9,12,24,27] although this is the low morbidity. Although a report by Amuti noted the distance of the DMA from the base of the metatarsal,[2] there has been limited research on anatomical variation of the DPA, including the course of the AA, that might help to prevent vascular complications during dorsal midfoot surgery.

In this fresh cadaveric study, we demonstrated variation in the DPA and in the distance from the AA to the TMT joint on enhanced computed tomography (CT) images. Awareness of this variation may help to avoid vascular complications during dorsal midfoot surgery.

Materials and Methods

The study was approved by our institutional review board and included 29 feet of 29 fresh cadavers (16 male, 13 female; 15 right, 14 left; mean age 78.9 years at the time of death). Fresh cadavers with a known history or signs of previous ankle trauma or surgery, congenital or developmental deformity, or inflammatory arthritis were excluded.

The vessels of whole bodies were flushed with warm normal saline solution through a plastic catheter placed in the external iliac artery. Next, barium sulfate suspension (Barytester®, Fushimi Pharmaceutical Co., Inc., Marugame, Japan) was injected into the external iliac artery under firm manual pressure. Enhanced multi-slice CT images (Somatom Emotion 16, Siemens Healthcare, Erlangen, Germany) of the lower extremities were obtained with the ankle in the neutral position, and reviewed.

As a non-standard pattern, we classified the DPA variation using the system reported by Luckrajh et al[15] which focused on the clinical relevant classification of the DPA course (Table 1).

Type 1: The DPA fails to give rise to the AA. The LTA or branches of the plantar arterial arch supply the second to fourth metatarsal spaces.

Type 2: The DPA gives rise to the first and second DMAs only. The third and fourth DMAs arise from the plantar arterial arch.

Type 3: The DPA gives rise to the first and second DMAs while the third and fourth DMAs arise from the LTA.

Type 4: The second, third, and fourth DMAs arise from a large LTA, while the DPA only gives rise to the first DMA.

Type 5: A proximal LTA and distal LTA are present and run obliquely and laterally to join and form a loop. The second, third, and fourth DMAs arise from this loop and the DPA gives rise to the first DMA.

Type 6: A U-shaped loop with a recurrent branch is observed. The proximal LTA and distal LTA course laterally to the level of the base of the fifth metatarsal where they join to form a loop and give rise to the second, third, and fourth DMAs. A recurrent branch joining the two LTAs is found proximally.

We confirmed the continuity of the AA, if present in a standard pattern, in the axial plane (Fig. 1a). The shortest distance of AA distal to the middle dorsal TMT joint was at the second, third, and fourth metatarsal levels in the sagittal plane (Fig. 1b). Representative one specimen was dissected to show the DPA with a standard course.

Inter- and intra-observer reliabilities were evaluated using the intra-class correlation coefficient (ICC). All measurements were made by two independent orthopedic surgeons to decide inter-observer reliability using the ICC. Each observer repeated the measurements after a 6-week interval to decide intra-observer reliability. An ICC > 0.80 was accounted to represent a reliable measurement. The values were averaged and are shown as the mean ± standard deviation.

Results

The DPA was observed to have a standard course in 11 cases (37.9%) (Fig. 2a).

Lateralization of the DPA was observed in 2 cases (6.9%) (Fig. 2b). The DPA arose from the peroneal artery and passed into the first intermetatarsal space in 1 case (3.4%) (Fig. 2c).

Regarding a non-standard pattern, the type 1 variant was identified in 10 cases (34.5%). In 6 (20.7%) of these cases, the plantar arterial arch supplied the second to fourth metatarsal spaces (Fig.3a); we classified this variant as type 1a. In 4 cases (13.8%), the plantar arterial arch supplied the second metatarsal spaces and the lateral plantar artery (LPA) supplied the third and fourth metatarsal spaces (Fig. 3b); this variant was classified as type 1b. The type 2 variant was identified in 2 cases (6.9%) (Fig. 3c), type 3 in 2 cases (6.9%) (Fig. 3d), type 4 in 2 cases (6.9%) (Fig. 3e), and type 5 in 1 case (3.4%) (Fig. 3f). Type 6 was not found in any specimen. The AA was observed to have a high origin in 1 case (3.4%) (Fig. 3g).

The mean closest distances of AA distal to the middle dorsal TMT joint at the second, third, and fourth metatarsal levels in the sagittal plane were 11.4 ± 3.5 mm (range 7.5–17.3), 14.6 ± 2.8 mm (range 11.7–19.4), and 17.1 ± 2.6 mm (range 10.6–20.3), respectively.

Discussion

As Table 2 showed a brief summary of this study, enhanced CT images of fresh cadaveric feet demonstrated variations in the course of the DPA and in the distance from the AA to the TMT joint, which has implications in terms of avoiding vascular complication during dorsal midfoot surgery.

As Fig. 4 showed, the DPA followed the standard course in 35% of specimens in the study reported by Sarrafian,[22] 36.4% in the study by Ntuli in,[17] and in 42.5% in the report by Luckrajh in.[15] The findings of our present study are similar to those reported by those authors but different to those of others. For example, Kulkarni found that the DPA followed the standard course in only 15.2% of cases,[13] which is lower than the rate in our study. In contrast, our prevalence rate was lower than previously reported rates of 52%,[20] 53.3%,[28] 54.7%,[19] 56%,[26] 65.6%,[4] 67.5%,[14] and 67.5%.[10] Moreover, three further studies have reported rates of 90%,[25] 96%,[23] and 98%[21]; however, these high rates for the standard anatomical course of the DPA are questionable because they are so far away from the findings of the majority of other researchers. Overall, their study found the arterial network of the foot to show the normal "textbook" anatomy, which is a very rare finding.

Lateral deviation of the DPA has been variously reported to occur at a rate of 4%,[3,26] 5%,[6,8,25] 6%,[13] and 7.5%.[14] These rates are again similar to the one found in our study. However, Luckrajh observed lateral deviation in the course of the DPA in 25% of cases.[15] DPA arising from peroneal artery has been observed at rates of 2%,[21] 5%,[17] 6.7%,[28] 7.5%,[14] and 8%.[26] These rates are consistent with our present findings.

Another study by Kulkarni found that the DPA arose from the peroneal artery in 12.1% of cases.[13] DPA lateralization and the origin of the DPA from peroneal artery may be a factor in the formation of pseudoaneurysms because the DPA gets to be close to the anterolateral portal. This result also indicates that recognition of the anatomical variation in the DPA is important to avoid pseudoaneurysm.

Regarding a non-standard pattern, in our study, the type 1 variant was found in 11 specimens (37.9%). Overall, this rate is similar to the rates of 32.5% reported by Luckrajh et al[15] and 40% reported by Vengadesan.[25] However, Rajeshwari et al. found the type 1 variant in only 16.6% of cases.[19] We identified a type 1 variant in 6 (20.7%) of our specimens in which the plantar arterial arch supplied the second, third and fourth metatarsal spaces; we classified these cases as type 1a. The same variant was identified in 1.6% of the cases reported by Chepte[5] and in 2% of those reported by Sadeesh, which they classified as type G.[20] Those rates are lower than the rate in our study. We also observed a type 1 variant which we classified as type 1b in 4 cases (13.8%) where the plantar arterial arch supplied the second metatarsal space and the LPA supplied the third and fourth metatarsal spaces. This variant was identified in 5% of cases in the study by Chepte[5] and in 6% of cases in the study by Sadeesh,[20] which they described as a type C variant. These rates are lower than the rate in our study. By contrast, Sarrafian identified the group C variant in 34% of cases.[22]

We identified the type 2 variant in 2 (6.9%) of our specimens, whereas Chepte reported a rate of 3.3% and Sadeesh reported a rate of 6% of their cases, and they identified this variant as type D.[5,20] Both Luckrajh and El-Saeed also reported that it occurred at a rate of approximately 10%.[6, 15] These all rates are in line with our findings. However, Rajeshwari reported a rate of 14.2%,[19] which is slightly higher.

The type 3 variant occurred in 2 (6.9%) of our cases; this result is similar to the rates of 5% reported by Luckrajh[15] and 6.6% (described as type B) by Chepte.[5] However, Rajeshwari et al. reported a rate of 2.3% in their specimens[19] and Sadeesh found a rate of 17% (classified as a type B variant).[20]

We identified the type 4 variant in 2 (6.9%) of our specimens. Similar rates of 5%,[14,15] 9.1%,[13] and approximately 10%[19,26] have been reported. However, Awari reported a much higher rate of 40%.[3] Type 5 was found in 1 (3.4%) of our specimens, which compares well with the rates of 2.3% reported by Rajeshwari[19] and 5% in the report by Luckrajh.[15] However, Sarrafian reported a much higher rate of 19% (as group B). [22] The type 6 variant was not found in any of our specimens but was observed in 2.5% of the cases reported by Luckrajh.[15] We found that the AA had a high origin in only 1 case (3.4%). AA with a high origin was found at rates of 1.6% in the study by Kaur,[11] 3.3% (as type E) in the report by Chepte,[5] and 4% (as type E) in the study by Sadeesh.[20] These rates are comparable with ours. EI-Saeed et al. reported a rate of 30%,[6] which is much higher and might reflect ethnic variation in foot and ankle anatomy.

Fishman[7] and Nunley[18] reported vascularized pedicle bone grafting for nonunion of the tarsal navicular, and the clinical outcomes appeared to be beneficial. They dissected the vessels going to the cuneiform, and the vascularized bone graft from the cuneiform was rotated on its pedicle into navicular nonunion site dorsally. Knowledge about a non-standard pattern of the DPA can help selection of the arteries for pedicle-based bone transfer to treat nonunion of the tarsal navicular.

Although the mean distance of the first, second, third, and fourth DMAs was measured in a study by Amuti,[2] we found that the AA, when present in a standard pattern, was 11.4 mm distal to the second metatarsal base and 14.6 mm distal to the third metatarsal base. These findings show that AA can be easily injured during the approach to the dorsal midfoot

Our study has limitations. First, the number of specimens included was small, but was inevitable due to the limited availability of fresh-frozen human cadavers in Japan. Second, the images analyzed in the study were acquired in the neutral ankle position, which needs to be borne in mind when interpreting our findings because vascular structures of the foot vary in anatomical location with movement of the ankle and most surgeries are performed with the ankle plantarflexed which may change the location of these arterial branches

Declaration of Conflicts of interest

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Figure and Table Legends

Fig. 1 Enhanced computed tomography images of a fresh cadaveric foot showing the AA (indicated by the arrow) in the axial plane (a) and the closest distance between the arcuate artery and the middle dorsal TMT joint in the sagittal plane (b). AA, arcuate artery

Fig. 2 Enhanced computed tomography images of fresh cadaveric feet showing the standard course of the DPA accompanied by a diagram (a) with arrows showing lateralization of the DPA (b) and the DPA arising from the peroneal artery (c). DPA, dorsalis pedis artery

Fig. 3 In type 1, The plantar arterial arch supplies (a) the second to fourth metatarsal spaces (type 1a) or (b) the second metatarsal spaces with the supply to the third and fourth metatarsal spaces provided by the lateral plantar artery (type 1b). In type 2, the DPA gives rise to the first and second DMAs only and the third and fourth DMAs arise from the plantar arterial arch (c). In type 3, the DPA gives rise to the first and second DMAs while the third and fourth DMAs arise from the LTA (d). In type 4, the second, third, and fourth DMAs arise from a LTA, while the DPA gives rise to the first DMA (e). In type 5, LTAs form a loop, from which the second, third and fourth DMAs arise, and the DPA gives rise to the first DMA (f). The AA has a high origin (g). AA, arcuate artery; DMA, dorsal metatarsal artery; DPA, dorsalis pedis artery; LTA, lateral tarsal artery

Fig. 4 A photograph and a diagram of dissected fresh cadaveric foot indicate the DPA with a standard course. AA, arcuate artery; DPA, dorsalis pedis artery

Table 1. Classification of the DPA with a non-standard course.[15]

 Table 2. A brief summary.

Figure 1

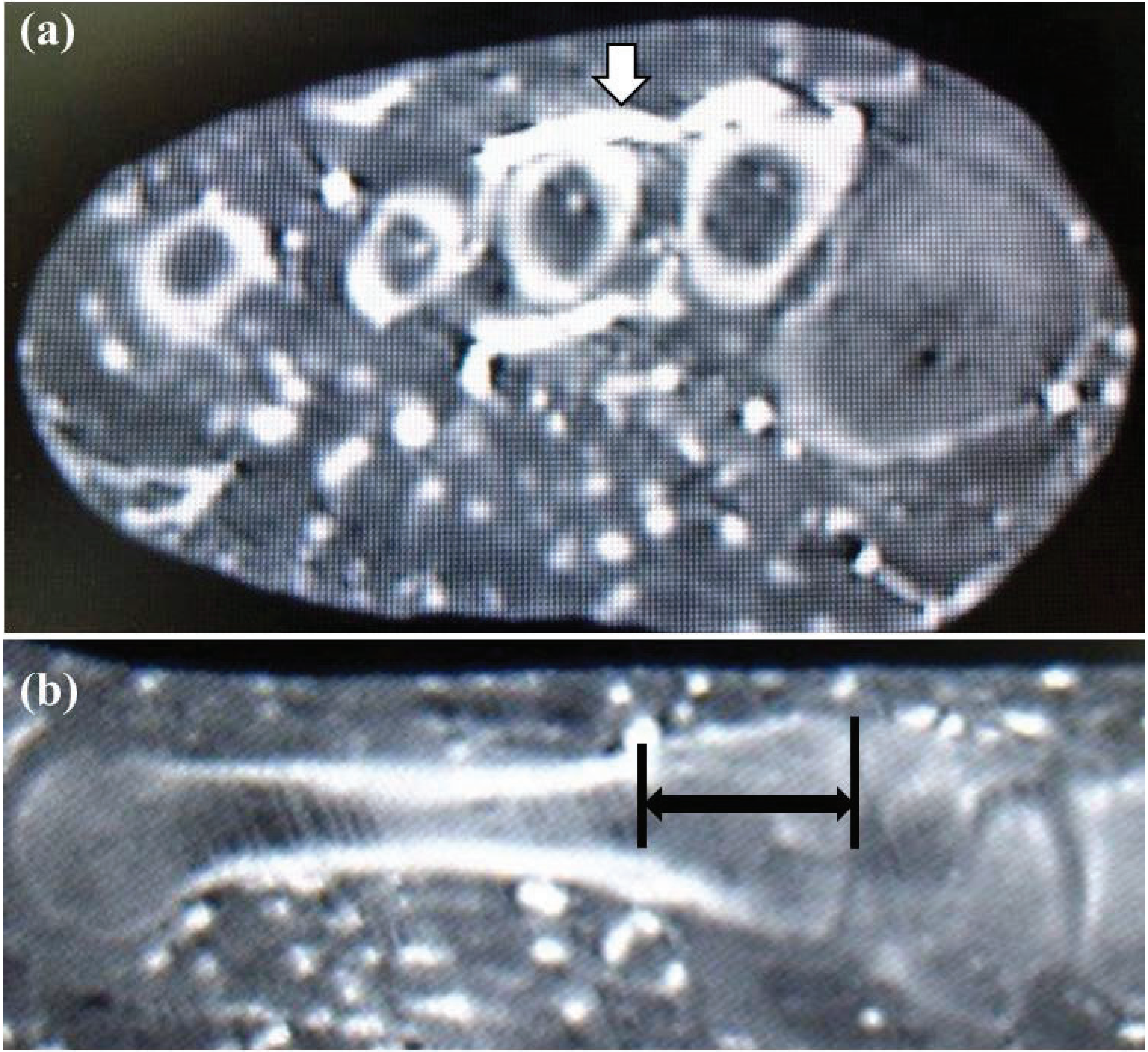


Figure 2

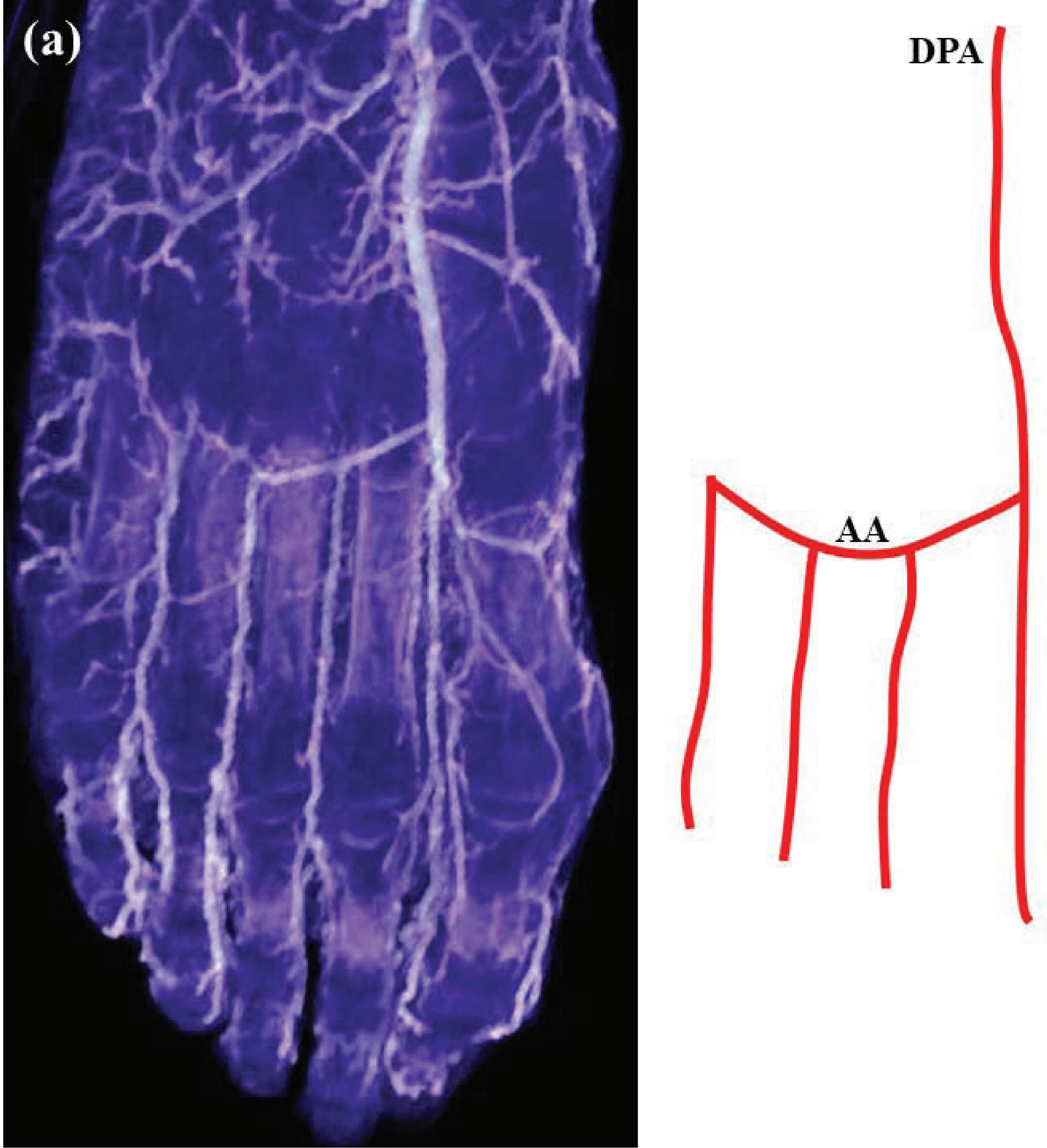
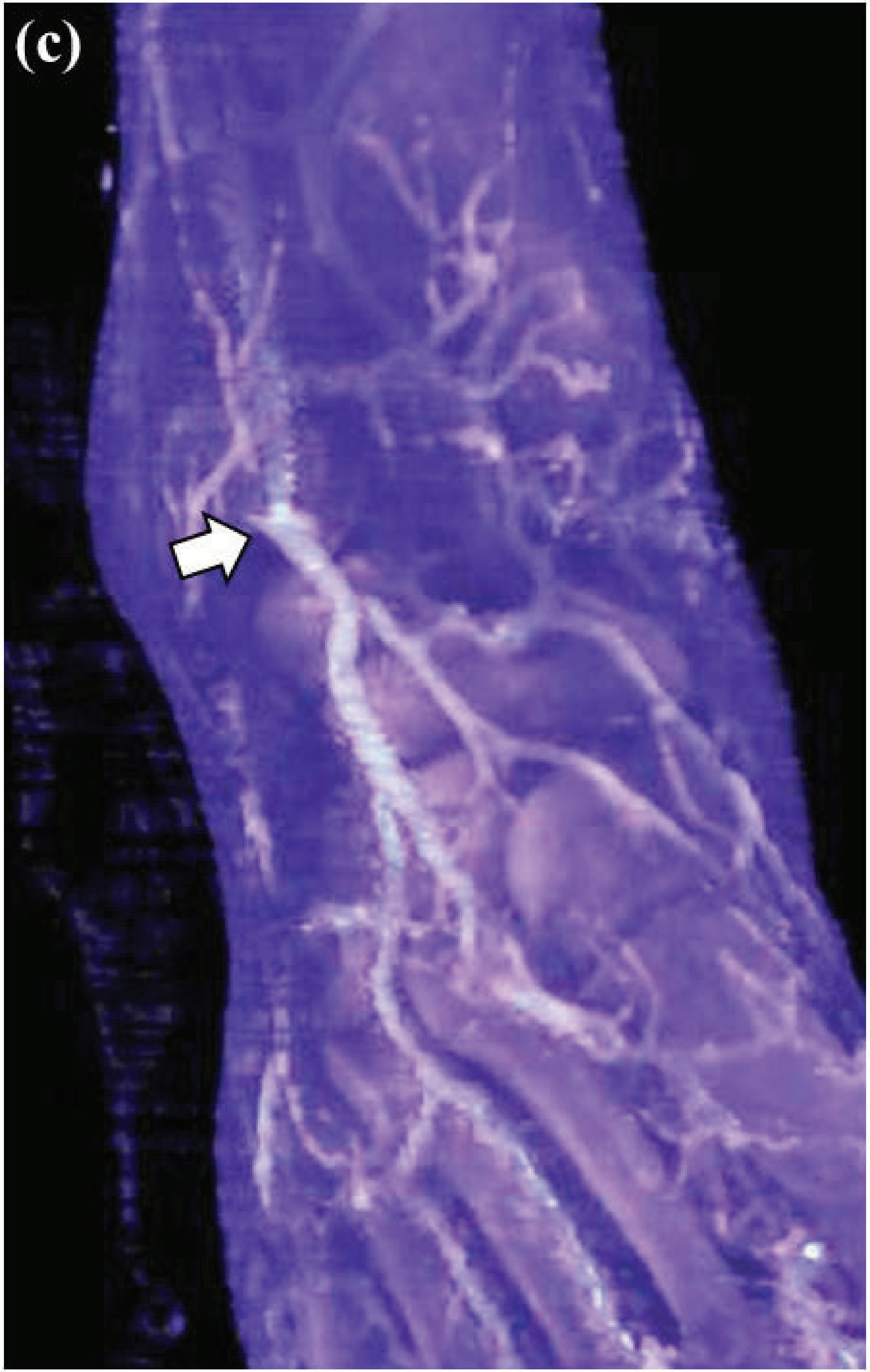


Figure 2

Figure 2



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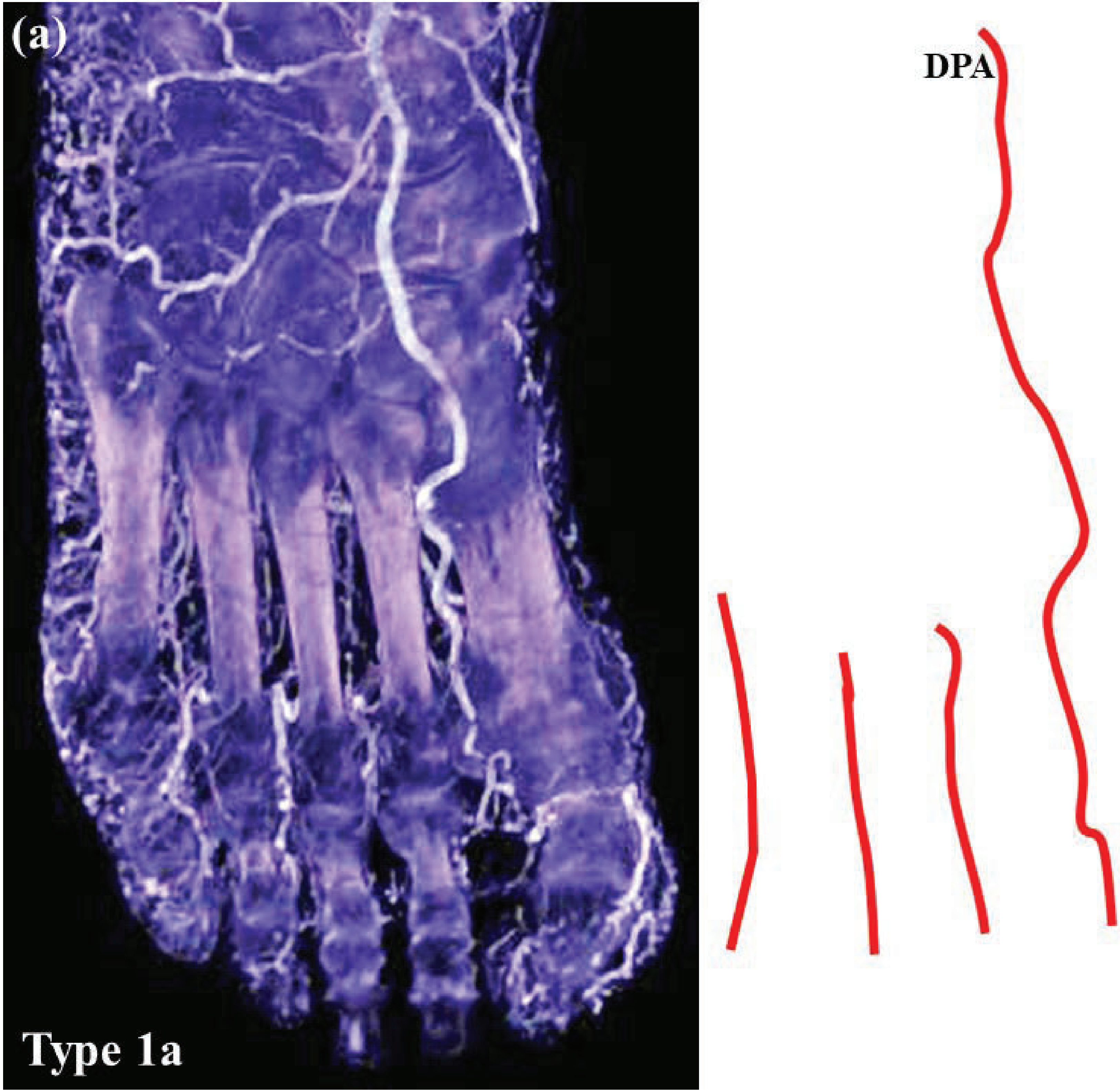

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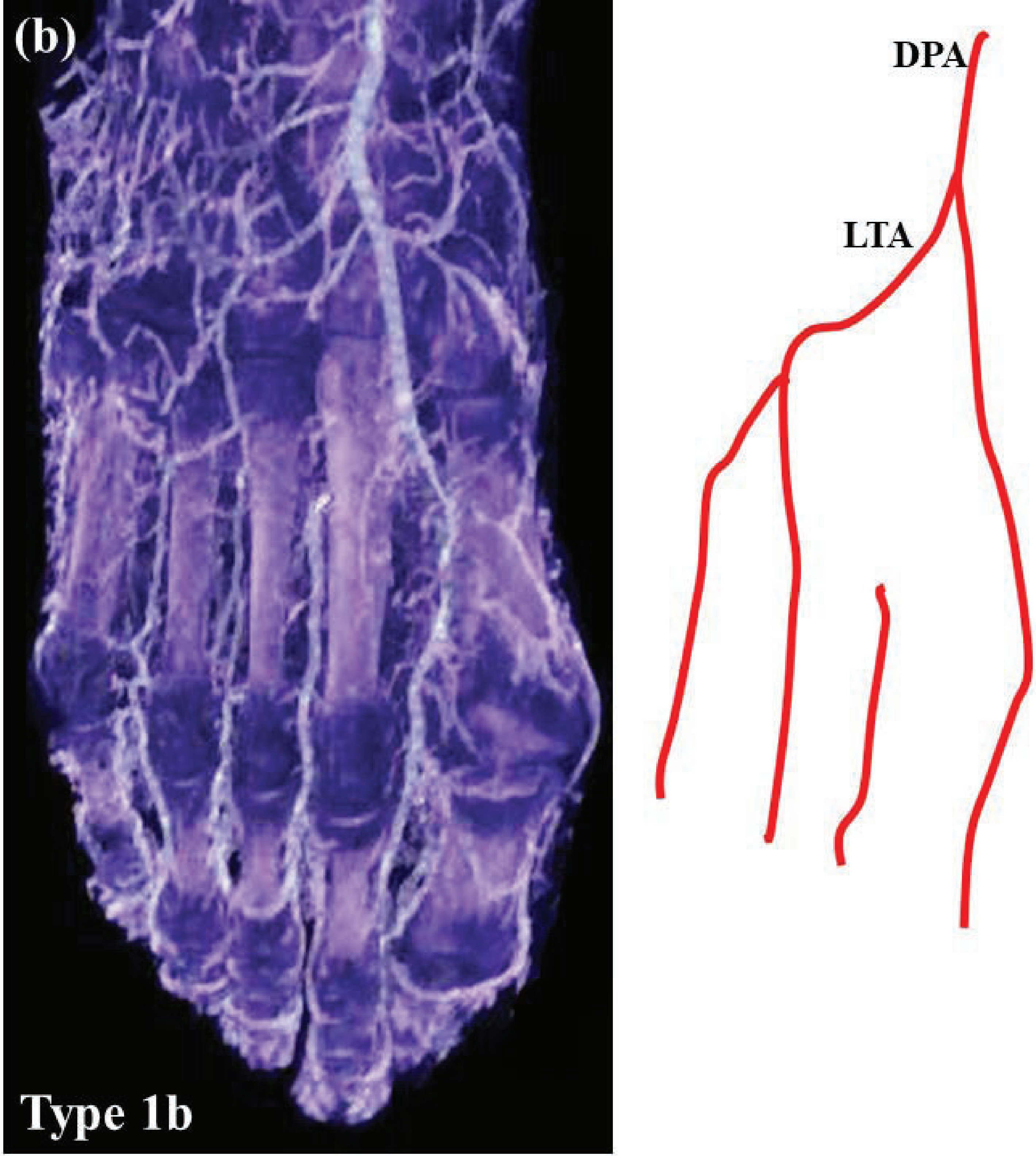

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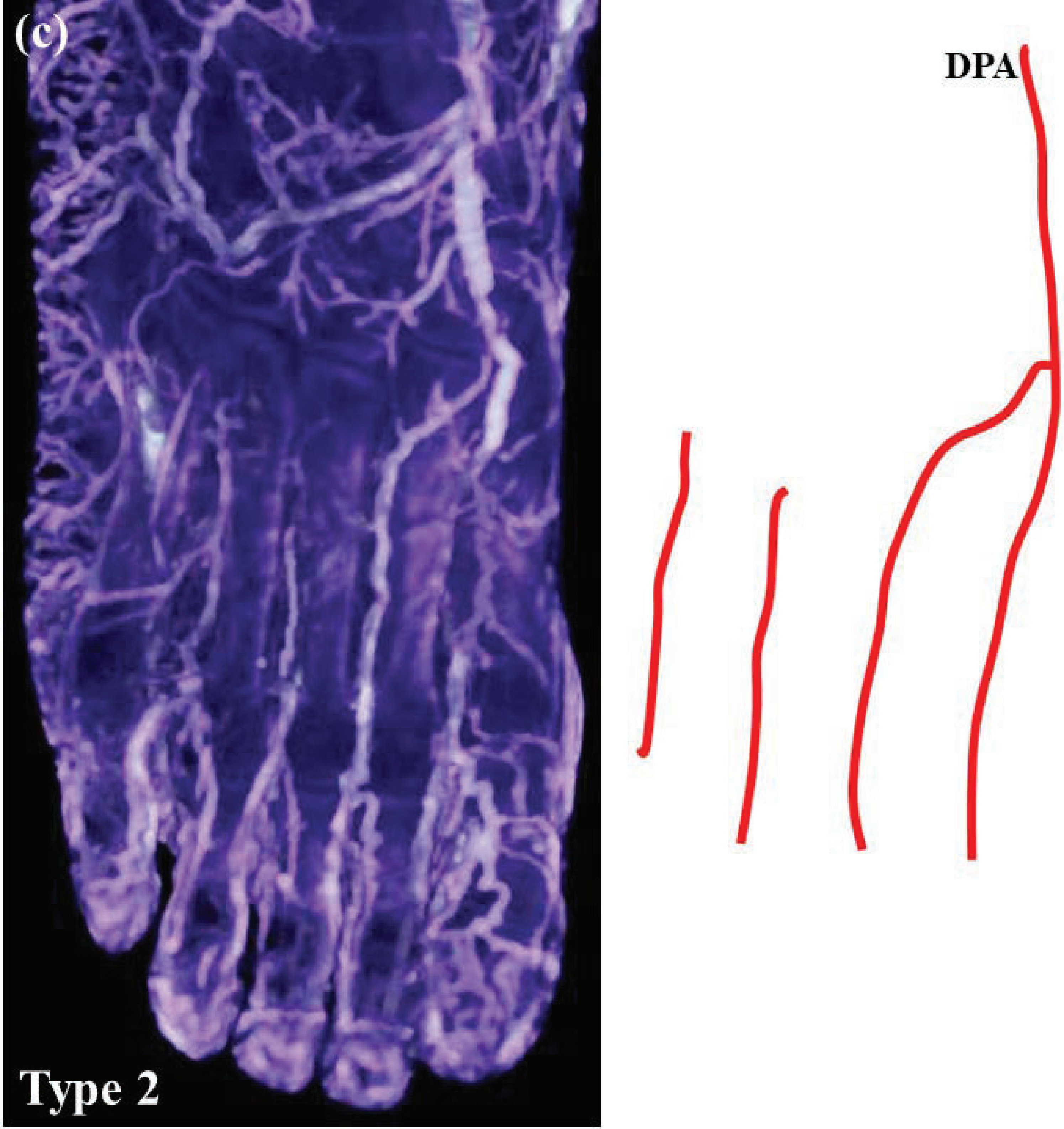

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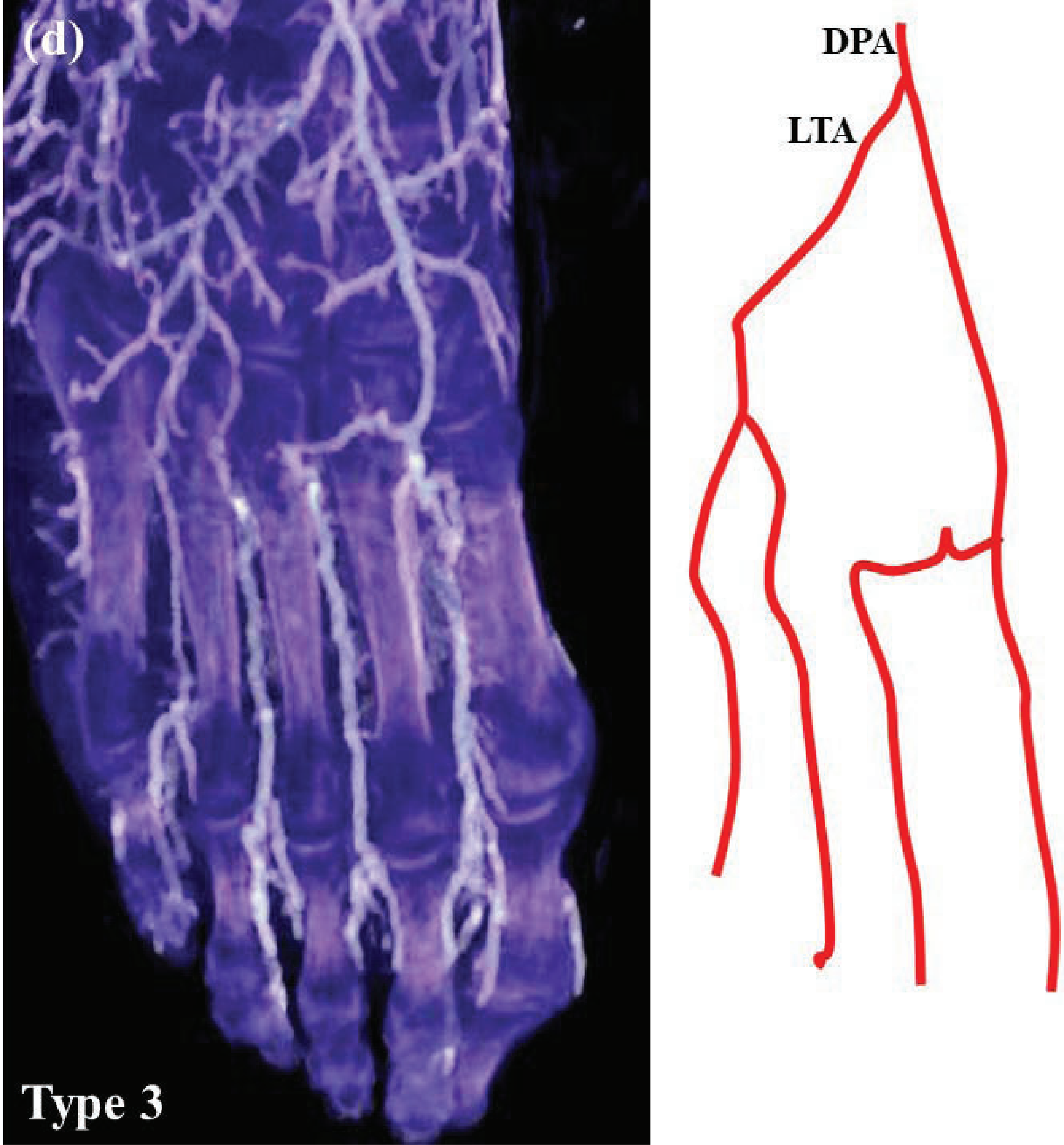

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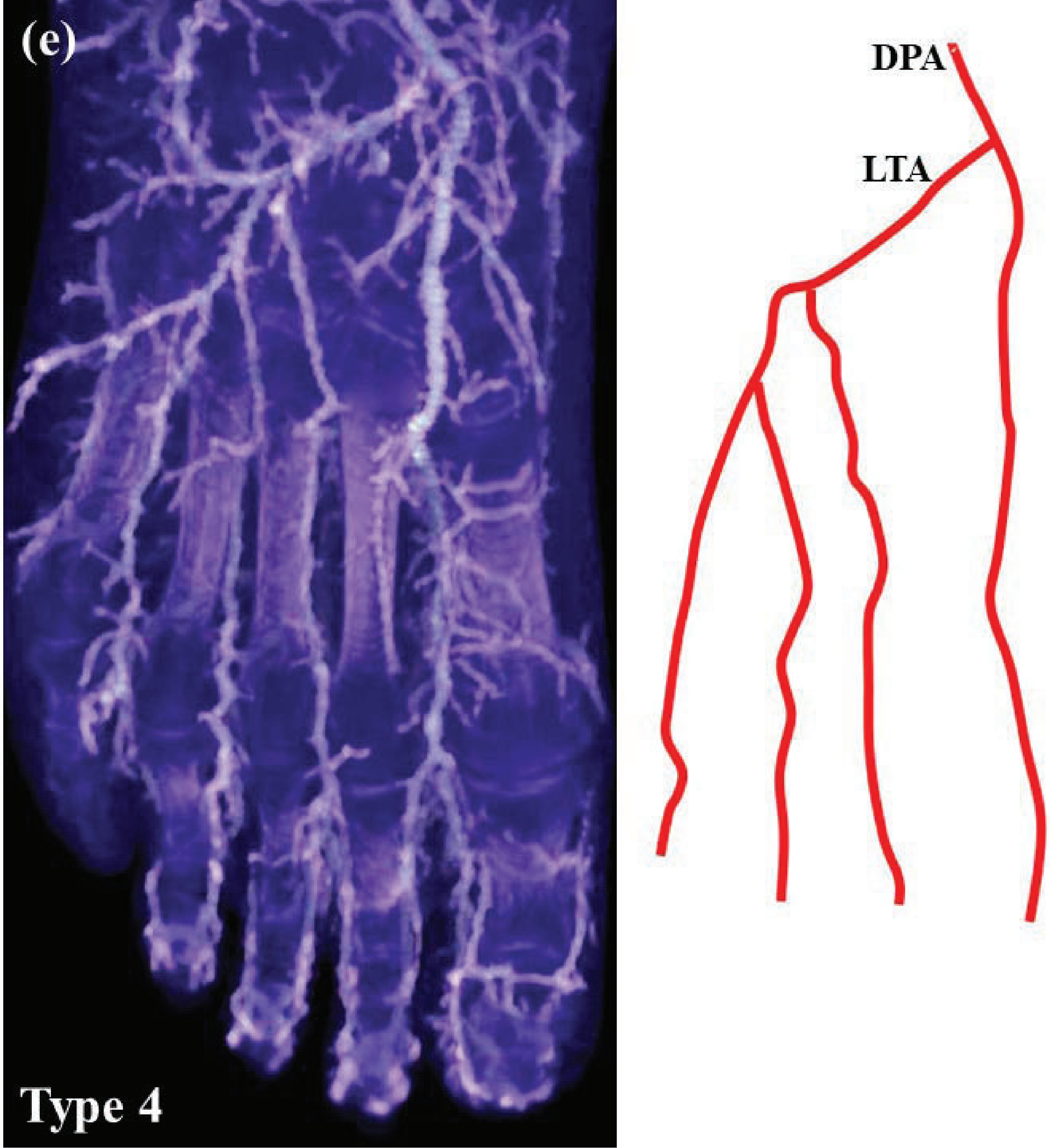

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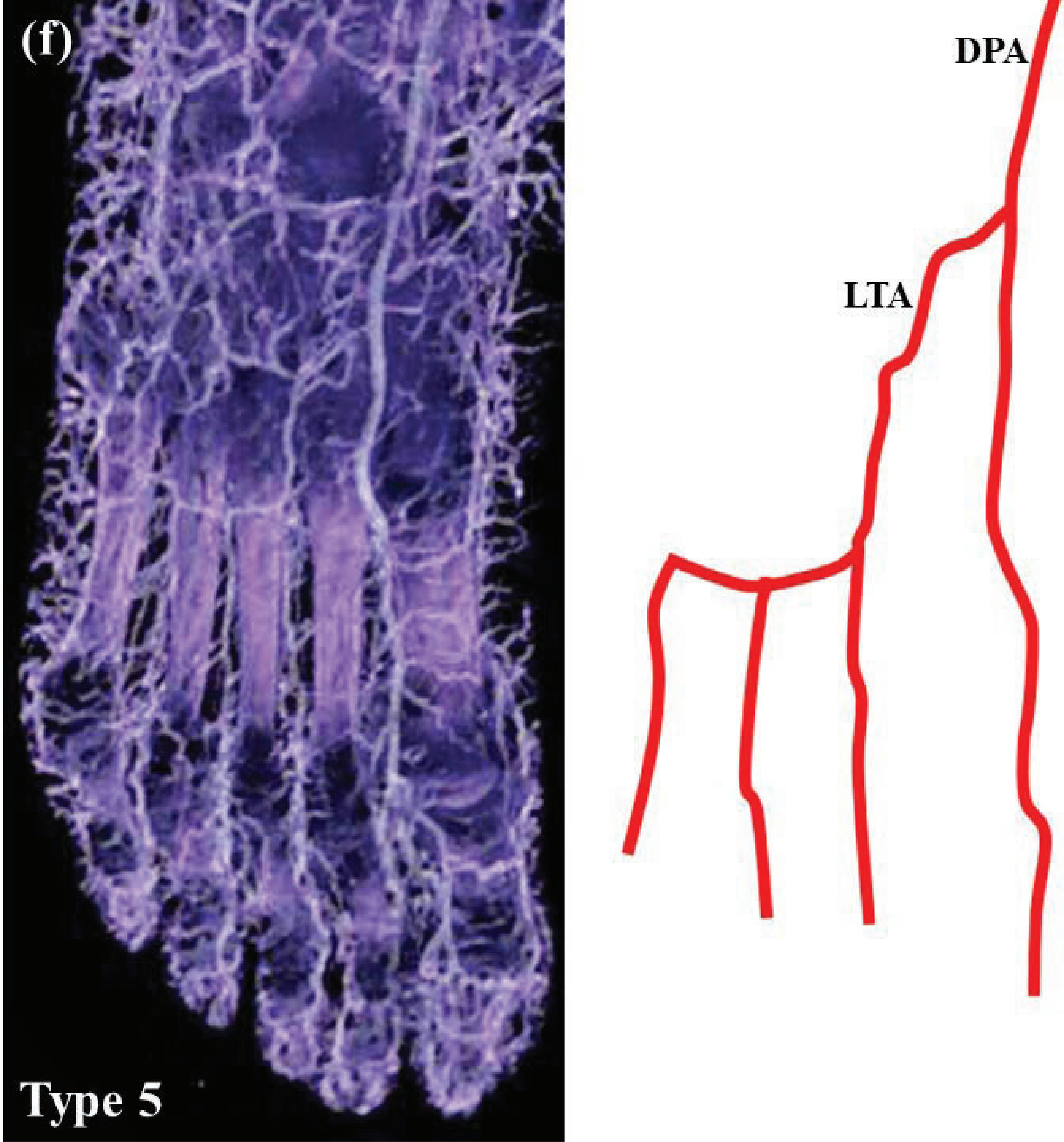

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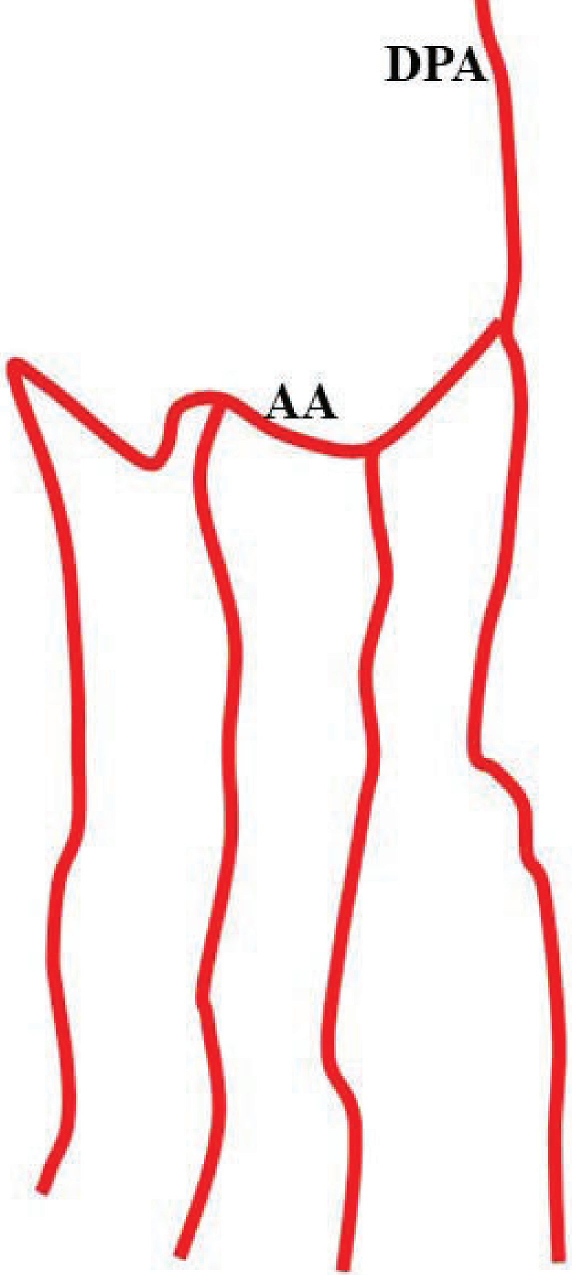

Figure 4

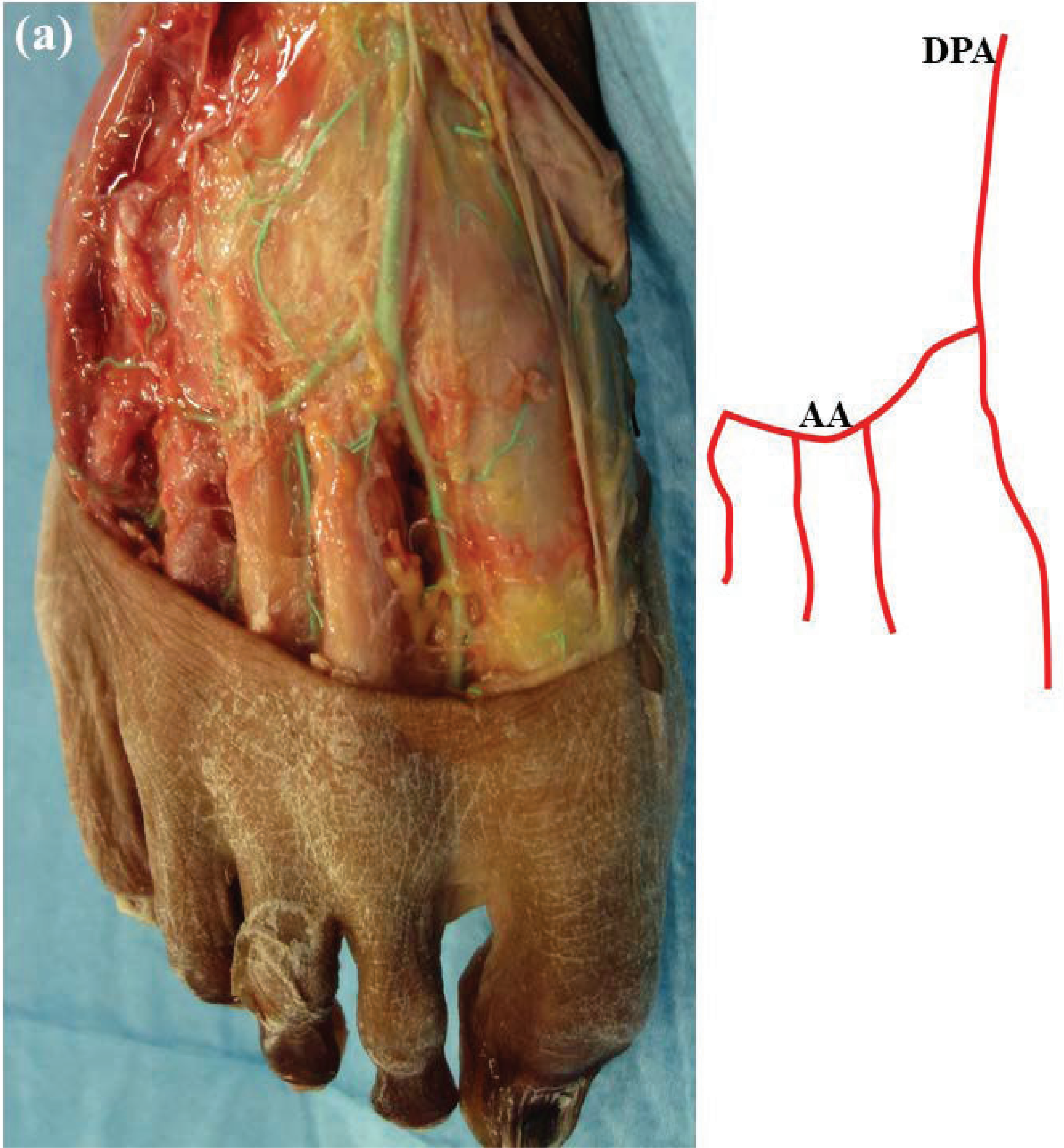

Table 1

Type 1:	The DPA fails to give rise to the AA. The LTA or branches of the plantar arterial arch supply the second to fourth metatarsal spaces.
Type 2:	The DPA gives rise to the first and second DMAs only. The third and fourth DMAs arise from the plantar arterial arch.
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Type 5:	A proximal LTA and distal LTA are present and run obliquely and laterally to join and form a loop. The second, third, and fourth DMAs arise from this loop and the DPA gives rise to the first DMA.
Type 6:	A U-shaped loop with a recurrent branch is observed. The proximal LTA and distal LTA course laterally to the level of the base of the fifth metatarsal where they join to form a loop and give rise to the second, third, and fourth DMAs. A recurrent branch joining the two LTAs is found proximally.

AA, arcuate artery; DMA, dorsal metatarsal artery; DPA, dorsalis pedis artery; LTA, lateral tarsal artery

Table 2

- Lateralization of the DPA was observed in 6.9%.
- The DPA was observed to have a standard course in 37.9%.
- The LTA or branches of the plantar arterial arch supplied the second to fourth metatarsal spaces in 34.5%.
- The distance from the TMT joint to the AA at the second, third and fourth metatarsal level was 11.4, 14.6 and 17.1 mm.

DPA; dorsalis pedis artery, LTA; lateral tarsal artery, TMT; tarsometatarsal, AA; arcuate artery