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MORPHOMETRIC AND MORPHOLOGIC EVALUATION OF ANTERIOR TIBIAL ARTERY*

ARTERIA TIBIALIS ANTERIOR'UN MORFOMETRİK VE MORFOLOJİK DEĞERLENDİRİLMESİ

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ABSTRACT

Objective: Previous studies related to the anatomy of the anterior tibial artery have focused mainly on morphology. The number of studies examining arterial morphometry is limited. Consequently, we aimed to examine the morphology and morphometry of this artery in detail.

Material and Method: The study was performed on 30 lower extremities injected with colored silicone. Morphological features of anterior tibial and popliteal arteries were assessed. The morphometrical evaluation included the tibiofibular trunk length, diameters of popliteal, anterior tibial, posterior tibial, fibular, dorsalis pedis arteries, and the vertical distances between the origin of the anterior tibial artery and the head of the fibula and tibial tuberosity.

Result: Five types of the anterior tibial artery were determined according to branching morphology, location, and course. The mean length of the tibiofibular trunk was 32.0±9.9 mm. Mean diameters of popliteal, anterior tibial, posterior tibial, fibular, and dorsalis pedis arteries were 5.8±1 mm, 4.1±0.6 mm, 3.5±0.6 mm, 3.7±0.7 mm and 2.8±0.4 mm, respectively. The mean vertical distance of the origin of the tibialis anterior artery to the head of the fibula and tibial tuberosity was 38±10.2 mm and 23.6±8.0 mm, respectively.

ÖZET

Amaç: Arteria (a.) tibialis anterior anatomisi ile ilgili yapılmış çalışmalar ağırlıklı olarak arter morfolojisine odaklanmıştır. Arterin morfometrisini inceleyen sınırlı sayıda çalışma bulunmaktadır. Bu doğrultuda, arter morfolojisi ve morfometrisini ayrıntılı olarak incelemeyi amaçladık.

Gereç ve Yöntem: Çalışma renkli silikon enjekte edilen 30 alt ekstremite üzerinde gerçekleştirildi. *A. tibialis* anterior'un ve a. poplitea'nın morfolojik özellikleri değerlendirildi. Truncus tibiofibularis'in uzunluğu, a. poplitea, a. tibialis anterior, a. tibialis posterior, a. fibularis ve a. dorsalis pedis'in çapları ile a. tibialis anterior'un orijin yerinin caput fibulae'ya ve tuberositas tibiae'ye vertikal uzaklığı morfometrik olarak incelendi.

Bulgular: *A. tibialis* anterior'un dallanma morfolojisi, yeri ve seyrine göre beş tipi belirlendi. Truncus tibiofibularis'in ortalama uzunluğu 32,0±9,9 mm idi. A. poplitea, a. tibialis anterior, a. tibialis posterior, a. fibularis ve a. dorsalis pedis'in ortalama çapları sırasıyla 5,8±1,0 mm, 4,1±0,6 mm, 3,5±0,6 mm, 3,7±0,7 mm ve 2,8±0,4 mm olarak bulundu. A. tibialis anterior'un orijin yerinin caput fibulae'ye vertikal uzaklığı ortalama 38±10,2 mm; tuberositas tibiae'ye mesafesi ise ortalama 23,6±8,0 mm olarak ölçüldü.

*This study is derived from the thesis entitled "Morphometric evaluation of anterior tibial artery" (Yök Thesis No: 541254). In addition, the Turkish and English abstracts of this study with less than 300 words were presented as a poster presentation at the 20th National Anatomy Congress on 27-31 August 2019 and received the "Best Cadaver-Based Clinical Anatomical Study" award.

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Conclusion: Knowledge regarding anterior tibial artery anatomy and popliteal artery branching variations are essential for endovascular interventions around the knee, infrapopliteal bypass procedures planned for peripheral arterial disease, and orthopedic operations involving the tibial plateau. We believe that our results will help orthopedic and vascular surgeons.

Keywords: Popliteal artery, anterior tibial artery, tibiofibular trunk, posterior tibial artery, fibular artery

Sonuç: A. tibialis anterior'un anatomisini ve a. poplitea'dan dallanma varyasyonlarını bilmek; diz çevresindeki endovasküler girişimler, periferik arter hastalığı için planlanan infrapopliteal bypass, ve tibial platoyu ilgilendiren ortopedik operasyonlar açısından oldukça önemlidir. Elde ettiğimiz sonuçların ortopedik ve vasküler cerrahlara yardımcı olacağı düşüncesindeyiz.

Anahtar Kelimeler: Arteria poplitea, arteria tibialis anterior, truncus tibiofibularis, arteria tibialis posterior, arteria fibularis

INTRODUCTION

The femoral artery passes through the adductor canal and reaches the popliteal fossa on the posterior aspect of the leg, and it is called the popliteal artery (PA). When the PA comes in line with the distal edge of the popliteus muscle, it branches into the anterior tibial artery (ATA) and the posterior tibial artery (PTA). PTA then gives off the fibular artery (FA) branch. ATA is initially located in the posterior (flexor) compartment of the leg. Passing between the two heads of the posterior tibial muscle, it reaches the oval opening in the upper part of the interosseous membrane of the leg, where it passes into the anterior (extensor) compartment of the leg. In the anterior compartment of the leg, the ATA passes just medial to the head of the fibula. Here it runs over the interosseous membrane and between the extensor muscles of the leg towards the ankle. It then passes under the inferior extensor retinaculum and becomes the dorsalis pedis artery (DPA). Some authors use the "tibiofibular trunk" (TFT) definition for the portion of the popliteal artery after giving the ATA and subsequently dividing into PTA and FA (1,2). There is no consensus on the use of this definition and it is not included in Terminologia Anatomica (3). However, in this study, the definition of TFT was used to be compatible with the current literature.

Although the PTA and FA injury rates are low, ATA accounts for one-third of vascular injuries (4). Injuries of ATA due to high-energy trauma, tibia fractures, and blunt traumas have been reported (4). In addition, it has been reported in the literature that ATA has iatrogenic injuries during procedures such as intramedullary nailing, tibial osteotomy, external fixation, and arthroscopic reduction.

There are various studies on the clinical significance and anatomy of the ATA, but these studies examined branching variations of ATA from the PA. In our study, we aimed to examine the course, morphometry, and morphology of ATA in detail.

MATERIAL and METHODS

The study was carried out between November 2017 and July 2018 at the Department of Anatomy of the Istanbul Faculty of Medicine. The cadavers with no signs of size difference, shape abnormality, trauma, burns, or surgical scars in the lower extremities were included in the study. Thus, the bilateral lower limbs of 15 cadavers were dissected for examination of the ATA. The cadavers were embalmed with a mixture of formaldehyde-phenol-glycerin-ethanol. The study was approved by the Ethics Committee of the Istanbul Faculty of Medicine (Date:13.10.2017, No: 16). Written consent was obtained from the donor-cadaver before death.

Colored silicone injection

To better follow the ATA and its branches during the dissection, the colored silicone injection method developed by Sanan et al. was modified and used (5). Pebeo brand 514/5 numbered red acrylic paint, Polisan brand synthetic thinner as diluent, Ottosil BS 15 mold silicone, and Ottosil BS Cat as catalyst were used in this mixture. Firstly, 50 ml of silicone and 4 ml of red acrylic paint were mixed with a wooden tongue depressor until the mixture was homogeneous in plastic containers of appropriate size. The silicone was diluted 1:1 with a synthetic thinner to increase its flowability. Next, the popliteal fossa was dissected, the PA was found, and a window was opened in its wall. Plastic cannulas were inserted into the opened window. The vessel was ligated to prevent the reflux of dye. A 3% catalyst was added to the prepared silicone-paint mixture and mixed homogeneously. The mixture was injected into the PA with a 100 cc syringe. The mixture was allowed to cure for at least 48 hours.

Dissection protocol

A vertical incision was made into the popliteal fossa. After the popliteal adipose tissue was removed, the common fibular nerve, tibial nerve, popliteal vein, and artery were identified. After the PA was separated from the adjacent anatomical structures by fine dissection, it was cannulated, and a colored silicone mixture was injected. After the mixture was cured, the PA was dissected distally. TFT, ATA, PTA, and FA were defined. In addition, a vertical skin incision was made in the anterior leg region from the tibial tuberosity to the inferior extensor retinaculum on the dorsum of the foot. The skin and crural fascia were released laterally and the anterior compartment muscles of the leg were defined. ATA was dissected from the interosseous membrane of the leg to the inferior extensor retinaculum level. And finally, DPA was identified distal to the retinaculum.

Morphometric evaluation

1. Leg length regarding the most protruding points of the head of the fibula and lateral malleolus,

2. Vertical distance from the origin of the ATA to the head of the fibula,

3. Diameter of PA before and after giving ATA,

4. Diameter of ATA, PTA, FA, and DPA at their origin point

5. TFT length,

6. The vertical distance between the tibial tuberosity and the point the ATA reaches the anterior leg compartment from the interosseous membrane of the leg was measured.

All measurements were made with a digital caliper (Mitutoyo Corporation, Kawasaki-shi, Kanagawa, Japan) with a measurement accuracy of 0.01 mm. The measurements were repeated twice by an experienced investigator and the mean values were used. If the difference between the two measurements was more than 10% the measurement was repeated.

Morphological evaluation

1. Branching morphologies of ATA, PTA, and FA from PA were recorded.

2. The leg region was divided into three parts, proximal, middle, and distal. The number of muscular branches in each part of ATA was recorded.

Statistical analysis

A priori power analysis was performed based on the findings of the study by Heidari et al. (6). Taking the study of 40 unilateral extremities as a reference, the minimum required sample size was estimated as n=26 unilateral extremities with a power of 0.80 and an alpha value of 0.05. Power analysis was performed under G*Power 3.1.9.4 (http://www.gpower.hhu.de/). Whether the obtained parametric values showed normal distribution or not was evaluated with Kolmogorov-Smirnov and Shapiro-Wilk tests. Descriptive statistics were made for the values showing normal distribution. The comparison of the number of branches according to the side and leg length was evaluated with the Kruskal Wallis test. PTA and AF diameters, as well as differences between both sex were compared with the ANOVA test. SPSS ver.21.0 (IBM Corp., Armonk, NY) software was used for the analysis, and $p<0.05$ was considered significant.

RESULTS

Eight cases were female, and seven were male, aged 52 to 79 years (mean 68.8±6.78). Morphometric values were found to have a normal distribution for the right and left sides. The mean values of the morphometric measurements are shown in Table 1.

When morphometric parameters were compared according to gender, only leg length was found to be statistically significantly longer in males ($p<0.001$). No significant difference was observed when the parameters were compared according to body sides. The comparison of morphometric measurement values according to gender and body sides and their statistical significance are shown in Table 2.

The mean number of muscular branches of ATA in the proximal, middle, and distal sections were found as 6, 5, and 5, respectively. There was no statistically significant difference between these values ($p=0.67$).

ATA was divided into five types according to branching morphology from PA, place of origin, and course.

Table 1: Measurement values of morphometric parameters

	Sample (n)	Mean±SD (mm)
Leg length	30	356.6±24.8
The vertical distance between the origin of ATA and the head of fibula	30	38.0±10.2
Diameter of the PA before giving ATA	30	5.8±1.0
Diameter of the PA after giving ATA	26*	4.8±0.8
Diameter of the ATA	30	4.1±0.6
Diameter of the PTA	30	3.5±0.6
Diameter of the FA	30	3.7±0.7
Diameter of the DPA	30	2.8±0.4
Length of the TFT	26*	32.0±9.9
The vertical distance between tibial tuberosity and ATA	30	23.6±8.0

* Since the TFT was not observed in cases with trifurcation, these parameters could not be measured
ATA: Anterior Tibial Artery, PA: Popliteal Artery, PTA: Posterior Tibial Artery, FA: Fibular Artery, DPA: Dorsalis Pedis Artery, TFT: Tibiofibular Trunk, n: Number, SD: Standard Deviation

Table 2: Comparison of morphometric parameters by sex and body sides

	Gender			Body sides		
	Male (mm)	Female (mm)	p value	Right (mm)	Left (mm)	p value
Leg length	378.6	337.3	**<0.01**	355.3	357.8	0.724
The vertical distance between the origin of ATA and head of the fibula	40.0	36.3	0.337	39.2	36.8	0.468
Diameter of the PA before giving ATA	6.1	5.5	0.100	5.7	5.8	0.468
Diameter of the PA after giving ATA	5.0	4.74	0.417	4.9	4.7	0.740
Diameter of the ATA	4.1	4.08	0.662	4.1	4.1	0.846
Diameter of the PTA	3.7	3.41	0.119	3.6	3.4	0.361
Diameter of the FA	3.84	3.60	0.428	3.7	3.6	0.468
Diameter of the DPA	3.0	2.71	0.073	2.9	2.7	0.225
Length of the TFT	31.2	32.6	0.269	34.5	29.6	0.901
The vertical distance between tibial tuberosity and ATA	27.3	20.9	0.053	21.5	25.6	0.950

ATA: Anterior Tibial Artery, PA: Popliteal Artery, PTA: Posterior Tibial Artery, FA: Fibular Artery, DPA: Dorsalis Pedis Artery, TFT: Tibiofibular Trunk

- **Type-1 (Classical pattern):** After the PA passes the lower edge or more distal of the popliteus muscle, it divides into ATA and TFT. TFT is divided into PTA and FA. This was the most common type and was found in 24 (80%) cases (Figure 1).
- **Type-2 (Anterior TFT):** PA is divided into PTA and TFT. TFT is then split into ATA and FA. This finding was found in 1 (3.3%) case (Figure 2).
- **Type-3 (Trifurcation):** It is the separation of ATA, FA, and PTA less than 5 millimeters apart. This pattern was found in 3 (10%) cases (Figure 3).
- **Type-4 (High division):** PA gives ATA proximal to the lower edge of the popliteus muscle. This type was observed in 1 (3.3%) case. And in this case, it was seen that ATA originated from the medial aspect of the PA (Figure 4).

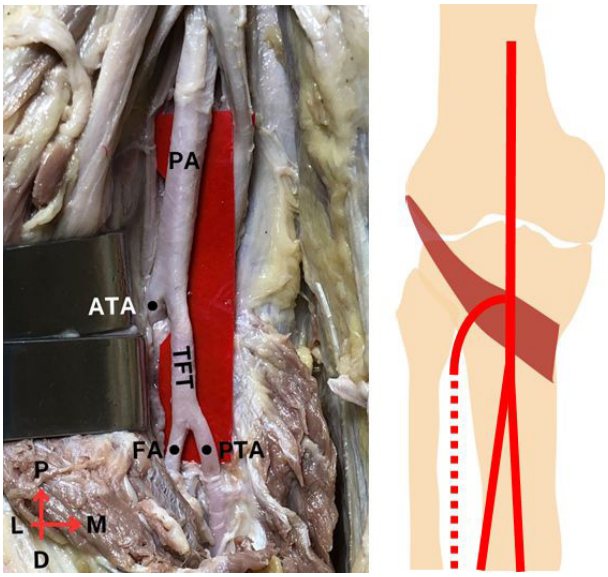

Figure 1: Type-1 (Classical pattern)
Posterior view of left leg
PA: Popliteal Artery, ATA: Anterior Tibial Artery, TFT: Tibiofibular Trunk, FA: Fibular artery, PTA: Posterior Tibial Artery, P: Proximal, D: Distal, L: Lateral, M: Medial

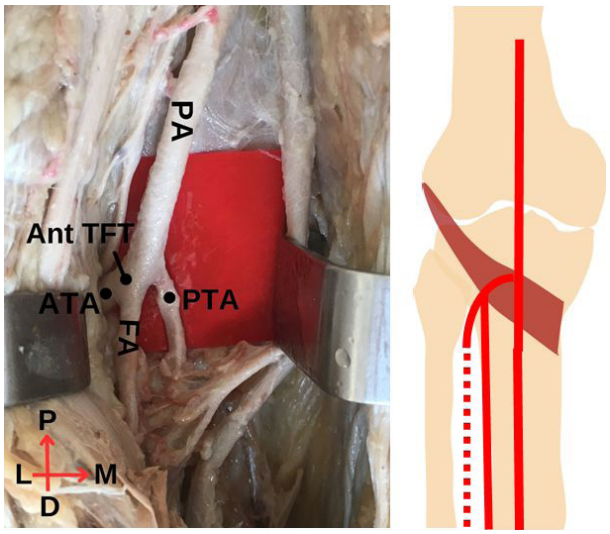

Figure 2: Type-2 (Anterior TFT)
Posterior view of left leg
PA: Popliteal Artery, PV: Popliteal Vein, ATA: Anterior Tibial Artery, FA: Fibular artery, PTA: Posterior Tibial Artery, P: Proximal, D: Distal, L: Lateral, M: Medial

- **Type-5 (Hypoplasia/Aplasia):** ATA is hypoplasic/aplasic. Hypoplasic ATA was found in one case (3.3%). In this case, it was observed that DPA originated from FA (Figure 5).

Accordingly, 24 (80%) of the 30 lower extremities showed branching in the general pattern, and 6 (20%) showed branching in other patterns. Of these six extremities, four were unilateral and one was bilateral. If ATA showed branching according to the classical pattern in one half of the body, the probability of anatomical variability on the other side was found to be 28.5%. And if there was anatomical variability in ATA branching morphology on one side of the body, the probability of variability on the other side was found to be 20%.

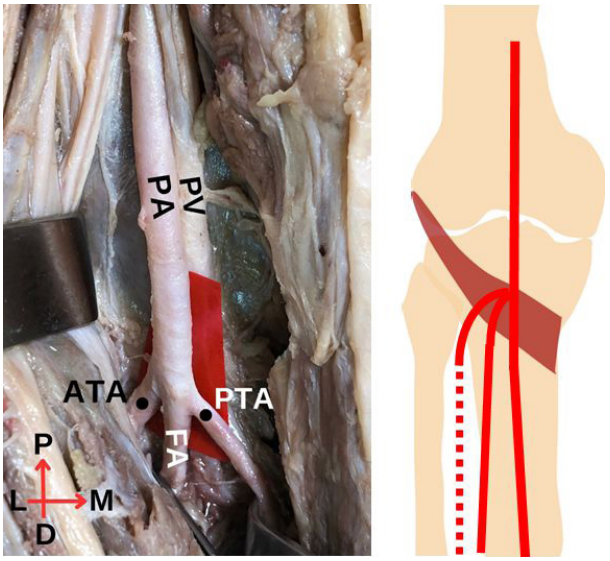

Figure 3: Type-3 (Trifurcation)
Posterior view of left leg
PA: Popliteal Artery, ATA: Anterior Tibial Artery, Ant TFT: Anterior Tibiofibular Trunk, FA: Fibular artery, PTA: Posterior Tibial Artery, P: Proximal, D: Distal, L: Lateral, M: Medial

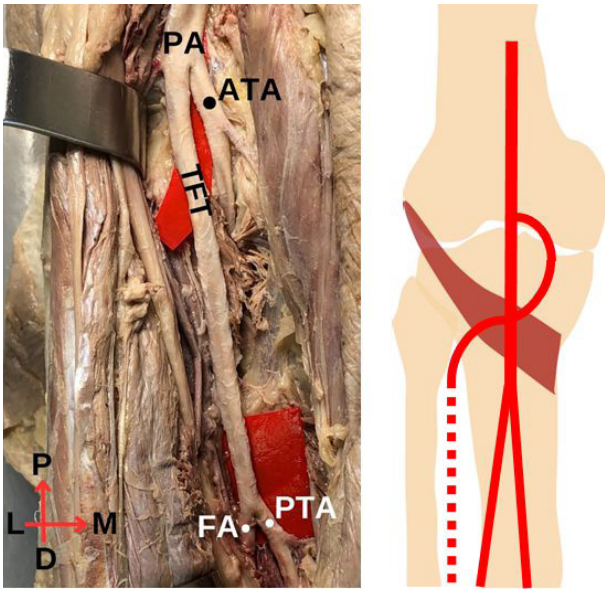

Figure 4: Type-4 (High division)
Posterior view of left leg
PA: Popliteal Artery, ATA: Anterior Tibial Artery, TFT: Tibiofibular Trunk, FA: Fibular artery, PTA: Posterior Tibial Artery, P: Proximal, D: Distal, L: Lateral, M: Medial

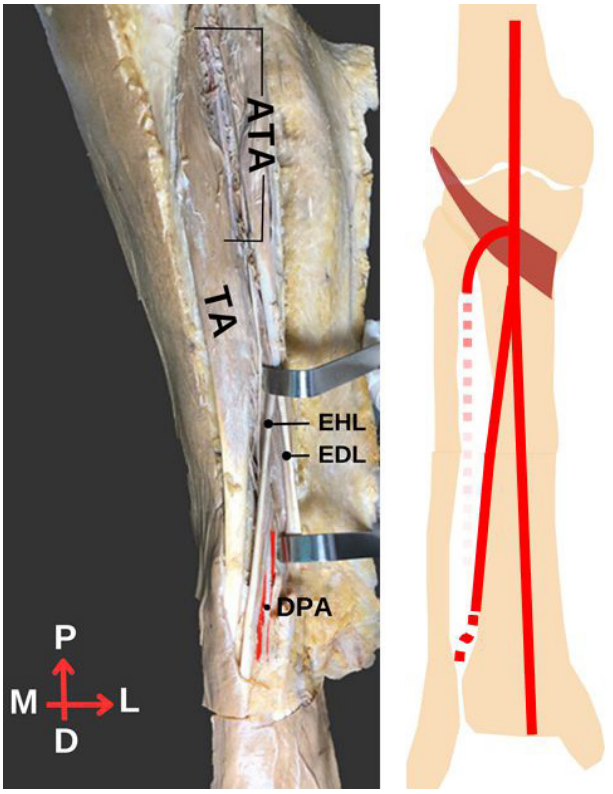

Figure 5: Type-5 (Hypoplasia/Aplasia)
Anterior (in cadaver image) and posterior (in schematic diagram) views of left leg
ATA: Anterior Tibial Artery, TA: Tibialis Anterior Muscle, EHL: Extensor Hallucis Longus Muscle, EDL: Extensor Digitorum Longus Muscle, DPA: Dorsalis Pedis Artery, P: Proximal, D: Distal, L: Lateral, M: Medial

DISCUSSION

To explain the branching variations of ATA, it is necessary to know the embryological development of the lower extremity arteries. The axial artery, which provides the arterial supply of the lower extremity, develops from the umbilical artery originating from the dorsal aorta. In the 11-12th stages of embryological development, the lower extremity bud is observed for the first time. At stages 13-16, the axial artery runs along the lower extremity bud. The axial artery develops in stages 16-17 and is called the ischiadic artery in the thigh, the poplitea profunda artery in the knee region, and the interosseous artery in the leg. The external iliac artery originates from the umbilical artery, runs distally, and extends towards the knee as the

femoral artery. A branch of the femoral artery, called ramus communicans superior, passes posteriorly and joins the ischiadic artery. In stage 18, a branch called poplitea superficialis emerges between the poplitea profunda and the interosseous arteries. Two new arteries arise from the poplitea superficialis, the tibialis posterior superficialis and the peroneal posterior superficialis. At this stage, an artery named ramus perforans cruris emerges from the interosseous artery, passes through the tibiofibular interspace, and forms the primitive ATA. At this time, there are three arteries in the leg. Also, the proximal portion of the ischiadic artery begins to regress at this stage and remains the inferior gluteal artery in adults. In stage 19, ATA develops as the distal part of the ramus perforans cruris. An artery called ramus communicans inferius arises from the peronea posterior superficialis artery. At this stage, there are five arteries in the leg (tibialis posterior superficialis, peronea posterior superficialis, ramus communicans inferior, interosseous, and anterior tibial arteries). In stage 20, the ramus communicans inferius fuses with the interosseous artery to form the adult peroneal (fibular) artery. At this stage, a connection called ramus communicans medius is formed between the peroneal artery and the deep popliteal. This branch eventually becomes the proximal part of ATA. With the regression of the popliteal profunda, interosseous, and peronea posterior superficialis arteries, the leg arteries take their adult form (7,8).

Variations of ATA can be explained by the deviation of these developmental steps. As a result of the lack of regression of the anterior part of the ischiadic artery, anterior TFT, which is the common root containing ATA and FA, occurs (9). The permanence of the distal portion of the ischiadic artery enables anastomosis with the popliteal artery, thus forming a trifurcation (1). Failure in the formation of the ramus communicans medius causes the anterior tibial artery to be of high origin (10).

Morphometry

In intramedullary nailing for tibial fractures requiring anatomical reduction and fixation, the locking holes are located close to the ATA and are therefore at risk of iatrogenic injury (6). For this reason, it is important to know the distances of ATA to adjacent bone structures in determining the position of the nailing holes in new surgical techniques. Heidari et al. found the mean distance between the ATA and the head of the fibula as 35.7±9.0 mm, and May et al. found this distance as 36.5±6.0 mm (6,11). In this study, this distance was 38±10.2 mm.

The most common peripheral artery aneurysm is seen in the PA (12). The diameter of the vessels should be determined in the diagnosis of the aneurysm and the selection of the treatment method (12). While the diameter of the PA in the study by Hölzle et al. was 5.5 mm on the right and 5.4 mm on the left, it was found as 5.8±1.0 mm in the current study (13). While Ozgur et al. found the diameters of ATA, PTA, and FA to be 6.1±1.1 mm, 4.5±0.9 mm, and 4.4±0.9 mm, respectively, in this study, these values were 4.1±0.6 mm, 3.5±0.6 mm, and 3.7±0.7 mm (14). In the literature, the diameter of the DPA ranges from 1.5 mm to 5.0 mm, and in this study, it was 2.8±0.4 mm (15).

Current anatomy sources state that ATA and PTA are the two terminal branches of AP, and AF is a sub-branch of PTA (7,16). However, Adachi expressed his thoughts on these branches as follows: "Although I use the term truncus peronaeo-tibialis posterior, my view is that the peronaeal artery, the continuation of the popliteal artery, is very variable and the tibialis posterior artery is considered as a lateral branch of the peroneal artery." (17). Therefore, this study compared FA and PTA diameters and found no statistically significant difference (p=0.452). In line with this information, the authors' knowledge that FA is a branch of PTA should be re-examined.

The importance of TTF length in the planning of the endovascular treatment of peripheral arterial diseases and the selection of appropriate equipment and the planning of infrapopliteal bypass operations was emphasized (18,19). The length of the TFT was determined by Ozgur et al. as 30.3±16.2 mm, Celtikci et al. as 30.5 mm, and Kim et al. as 39 mm (14,18,19). In the present study, this was found to be 32.0±9.9 mm. In addition, Celtikci et al. created two subclasses because there was a statistically significant difference between the right and left sides in cases with a general pattern (Type 1A) (18). They classified the cases with TTF longer than 3 cm as Type 1-A-L (Long) and those below as Type 1-A-S (Short). According to this classification, they found 363 (51.7%) cases as 1-A-L and 339 (48.3%) cases as 1-A-S. In the present study, 16 (66.6%) 1-A-L and 8 (33.3%) 1-A-S cases were found according to this subclassification. Similarly, the 1-A-L subtype was more common in both studies.

Morphology

Many classifications have been proposed for the branching morphology of the PA (17,19,20). The classification of Kim et al. is the most widely used today (19). In this study, three main categories and three subcategories for each of these were defined for the PA branching pattern. In this classification, In this classification, Category-1 is normal branching of PA, Category-2 is high-origin branching, and Category-3 is explains hypoplastic/aplastic arteries. Kim et al. reported that 92.2% of PA showed normal branching (19). This prevalence ranges from 72% to 96% (1,17). Similarly, it was found that 80% of the lower extremities examined in our study showed normal branching patterns.

The cases in which the first branch originating from the PA was PTA and then the common roots of ATA and FA were defined as anterior TFT. The incidence of this type varies

between 0.1% and 5%, and anterior TFT was found in one case (3.3%) in our study (21,22). Kim et al. defined the branching of ATA, PTA, and FA within 0.5 cm as trifurcation, and they found this type of branching in 12 cases (2%) (19). In this study, trifurcation was found in 3 cases (10%). The reason why this rate was higher in this study compared to other studies may be the number of samples.

The definition of high origin was used for the branches originating from the PA in the proximal of the lower end of the popliteus muscle in cadaver studies and in the proximal of the tibial plateau in angiographic studies (2,10,17,18,20,21). In this study, ATA separated from the PA proximal to the lower end of the popliteus muscle was found in one case (3.3%). In addition, in this case, it was observed that ATA emerged from the medial side of the PA, not from the lateral side as it should normally be. Kim et al. divided high-origin ATA into two subclasses, with the normal course and medial origin at the beginning, and this type was found in 4 cases (0.7%), and Celtikci et al. in 5 cases (0.6%) (18,19). In cases where the PA branches are hypoplastic/aplastic, the nutrition of the distal leg changes. In the case of hypoplastic/aplastic ATA, DPA originates from FA or PTA (13,19,23). In the present study, hypoplastic ATA was found in one case and it was observed that FA gave DPA.

Limitations

This study was designed as a preliminary study. It is planned to extend the study as a multi-center study to increase the sample size and add radiological data.

CONCLUSION

This study highlights ATA morphometry and variations in the hope that this information will be incorporated into future procedures and reduce avoidable complications. It was concluded that the branching pattern of the ATA differed from the classical pattern in 20% of the cases included in the study, with trifurcation being more common. In addition, no significant difference was found between the diameters of the FA and PTA. Therefore, we believe that the information that the FA is a branch of the PTA should be reconsidered and that it would be more appropriate to use the nomenclature "tibiofibular trunk" instead.

Ethics Committee Approval: This study was approved by Istanbul Faculty of Medicine Clinical Research Ethics Committee (Date: 13.10.2017, No: 16).

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