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Anatomic variations of popliteal artery: Evaluation with 128-section CT-angiography in 1261 lower limbs☆

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KEYWORDS
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Variation;
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Tibial artery

Abstract
Purpose: The purpose of this study was to evaluate the variations in popliteal artery branching in a large population on computed tomography angiography (CTA) using a 128-section configuration.
Materials and methods: A total of 652 patients (532 men, 120 women) with a mean age of 61.7 ± 18.1 (SD) years (range: 11—93 years) who had CTA of the lower limbs with a total of 1261 lower limbs (bilateral limbs in 609 patients, unilateral limb in 43 patients) were retrospectively included. CTA images were reviewed for popliteal artery branching and possible variations.
Results: The usual pattern of popliteal artery branching was observed in 1118 limbs (88.7%) (type IA) whereas branching variations without the usual pattern were found in 143 limbs (11.3%). Forty limbs (3.2%) were categorized as type I with non-classical patterns. Forty limbs (3.2%) showed type II high-level bifurcation and 63 limbs (4.9%) showed type III aplasia or hypoplasia. The type IIC pattern was not observed. Importantly, one single case considered as hypoplasia of the peroneal artery and another case identified with a long tibioperoneal artery were categorized into new subgroups.

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Conclusions: Recognizing and evaluating variations in popliteal artery branches is important in terms of vascular surgery approaches and interventional vascular procedures. CTA is an effective screening method to show the vascular frame of lower extremities and variations of popliteal artery. Our study allowed identifying two new branching patterns of the popliteal artery not previously described in the literature.

Popliteal artery variations are not rare [1,2]. The identification of normal branching patterns and variations of popliteal artery is important when evaluating patients with peripheral vascular diseases and most importantly for planning the most appropriate therapeutic approach [3]. Surgical and radiological interventional procedures in the knee region are frequent. Therefore, identifying the branching patterns of the popliteal artery is of major importance. Popliteal artery variations may increase the risk for complications in the femoropopliteal and tibial reconstructions, total knee replacements, and orthopedic surgeries including proximal tibial osteotomies and distal femur reconstructions [4]. It is also necessary to recognize the variations of this artery in radiological interventions, such as diagnostic angiography, transluminal angioplasty, transluminal stent implementation, and embolectomy, which involve the popliteal artery and tibial branches [1].

Three studies have evaluated popliteal arterial variations in 1000 or more limbs using angiography [1,3,5]. Other angiographic and cadaveric studies have been performed on smaller patient groups. Digital subtraction angiography (DSA) is considered as the gold standard in evaluating the peripheral vascular system. However, with progress in multidetector-row technology, computed tomography angiography (CTA) is now quite useful in evaluating the peripheral arterial system with high sensitivity and specificity [6,7]. To date, two English-language studies have evaluated popliteal arterial variations on CTA using multidetector-row technology [8,9]. Both studies were performed using 64-section CTA.

The purpose of this retrospective study was to evaluate the variations of popliteal artery branching on CTA using a 128-section configuration in a large population.

Materials and methods

From April 2010 through December 2014, lower extremity CTA results of 671 patients who had atherosclerotic arterial disease and posttraumatic or postoperative vascular laceration were retrospectively reviewed. A total of 1342 lower extremities were evaluated. Eighty-one limbs in 62 patients (bilateral limbs in 19 patients, unilateral limb in 43 patients) were excluded due to severe stenosis, occlusion, artifact, and amputation. Consequently, the study population consisted of 652 patients. There were 532 men (81.7%) and 120 women (18.3%) with a mean age of 61.7 ± 18.1 (SD) years, (range: 11—93 years) representing a total of 1261 lower limbs (bilateral lower limbs in 609 patients, unilateral lower limb in 43 patients). This retrospective study was conducted with the approval of the ethics committee.

Imaging protocol

All CTA examinations were performed with a 128-section MDCT scanner (Definition AS, Siemens Medical Solution, Forchheim, Germany). The patients were placed in a supine position with their feet entering the gantry first. Scanning was started in the renal arteries and then extended up to the toes. The imaging parameters were as follows: 120 kV, reference tube current 200 mAs (tube current range: 180—240 mAs), gantry rotation time 0.3 sec, pitch value 0.8, collimation 128 × 0.6 mm, reconstruction section thickness 0.6 mm, 512 × 512 matrix size, and table speed 100 mm/sec. In all examinations, Ultravist 370® (Iopromid, Bayer Schering Healthcare, Berlin, Germany) and Omnipaque 350® (Iohexol GE Healthcare, Milwaukee, WI, USA) were used. Contrast agent and saline flush were administered by automatic injection (Medrad®, Stellant®, Bayer HealthCare LLC., Whippany, NJ, USA) using an 18- to 20-G needle at an average rate of 4—5 mL/sec. Average scanning time was 14 sec, and the amount of contrast agent used ranged between 100 and 120 mL. In all patients, a 50-mL saline flush was used with the same physiological speed (4—5 mL/sec). To account for the time delay in the administration of contrast agent to each patient, the starting time of the scanning bolus tracking method (Care Bolus®, Siemens Medical Solution) was used. An attenuation threshold value of 200-Hounsfield unit was adopted by using 10—15 mm^2 round region of interest (ROI) in the abdominal aorta lumen at the infrarenal level. A medium soft-tissue deconvolution algorithm (B20 kernel) was routinely used in image reconstruction.

Imaging analysis

All CTA data were registered in an image archiving and communication system. CTA transverse source images were post-processed using a workstation (Osirix MD, Pixmeo). Transverse images were used to define the origin of arteries. In addition to transverse images, data were examined using maximum intensity projection (MIP), in multiplanar reformatted (MPR) sections, and in sagittal and coronal planes. At the same time, three-dimensional volume rendered (3DVR) images were obtained and further examined.

Two radiologists (D.H, Ç.A.O.) who have 8 years of experience in CTA each, reviewed all CTA examinations. The inferior border of the popliteus muscle, which is an

anatomically distinct point, was used as a reference. The branching (or not) of the popliteal artery was evaluated between two reference points (popliteus muscle and tibial plateau). When necessary, a senior radiologist (D.B.) with 15 years of experience in CTA was consulted for expert and consensus opinion.

In the normal anatomical course, the popliteal artery passes the popliteal fossa by way of the sequel of the femoral artery; it then branches into the anterior tibial artery (AT) and tibioperoneal trunk. The tibioperoneal trunk divides into the posterior tibial artery (PT) and peroneal artery (PR) lower branches. The branching of popliteal artery was categorized into 10 groups according to the classification by Kim et al. as follows (Fig. 1) [2]. In type I branching pattern, the popliteal artery branches from its normal position below the tibial plateau. The type I pattern is divided into three subtypes. The division of the anterior tibial artery is the first branch, and the division of the peroneal artery and posterior tibial artery in the form of the posterior tibioperoneal trunk is assigned as type IA (Fig. 2a), a pattern that is commonly seen. The division of AT, PR, and PT without a tibioperoneal trunk is assigned as type IB (Fig. 2b). AT, PT, and PR arise within 5 mm of each other. The division of PT as the first branch and the division of AT and PR branches as the anterior tibioperonel trunk are assigned as type IC (Fig. 2c). Popliteal branching above the normal level (i.e. above the tibial plateau) is assigned as type II; which in turn has four subgroups. The division of the anterior tibial artery over the knee and then following the normal course is assigned as type IIA1 (Fig. 3a). The division of the anterior tibial artery over the knee, and then going inward and subsequently continuing in the normal location, is referred to as type IIA2 (Fig. 3b). The division of the posterior tibial artery above the knee as the first branch and the division of AT and PR branches as the anterior tibioperoneal trunk is assigned as type IIB (Fig. 3c). The division of the peroneal artery above the knee as the first branch and division of AT and PR branches in the form of the tibiperoneal trunk is referred to as type IIC. The type III pattern, which is characterized by a change in the distal blood supply along with hypoplastic or aplastic branching, includes three subgroups. The replacement of the hypoplastic posterior tibial artery with the distal peroneal artery is identified as type IIIA (Fig. 4a), the replacement of the foot arch artery with the peroneal artery due to the hypoplastic anterior tibial artery is assigned as type IIIB (Fig. 4b), and the replacement of the distal PT and the foot arch dorsal artery with the peroneal artery since both AT and PT are hypoplasic is identified as type IIIC (Fig. 4c).

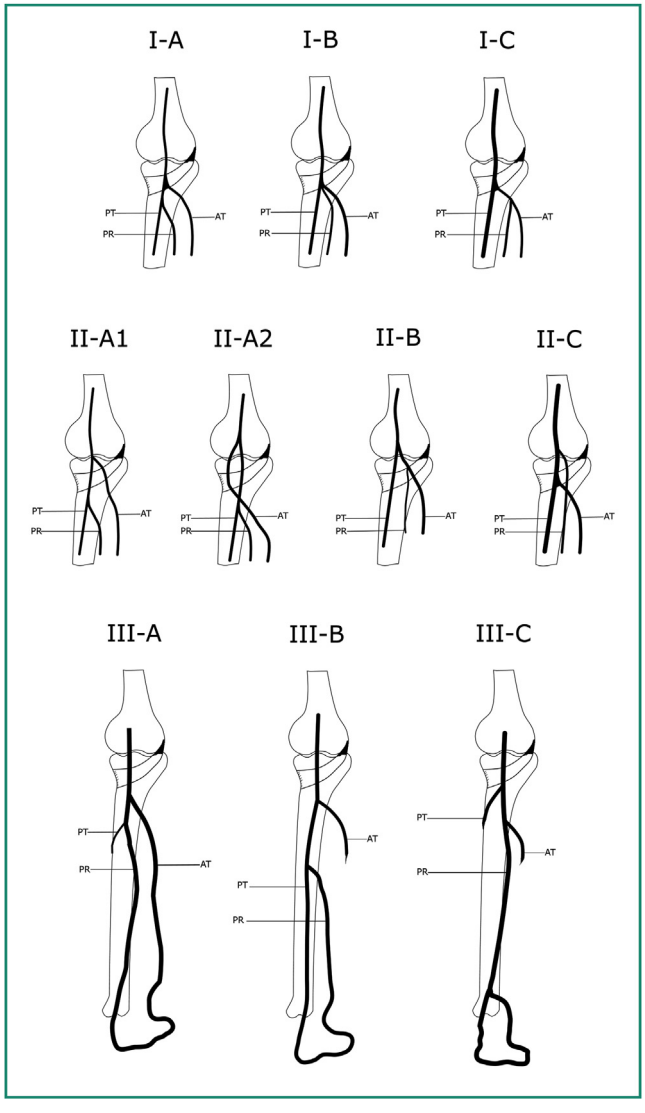

Figure 1. Diagrams show classification of popliteal artery branching variations. AT: anterior tibial artery; PT: posterior tibial artery; PR: peroneal artery.

Statistical analysis

Statistical analyses were performed using SPSS 18 (SPSS, Chicago, IL, USA) software. Variations were given in percentages. Chi^2 (χ^2) test was used to determine whether the variations observed were related to the patients' gender and whether variations resulted from the examined limbs being the right or left limb.

Results

A total of 1261 lower limbs were evaluated, of which 1118 had the usual popliteal artery variations (88.7%). In the other 143 lower limbs, 10 branching patterns were observed (11.3%; 68 right, 75 left). Forty lower limbs (3.2%) were assigned to the group type I non-classical patterns. Forty lower limbs (3.2%) showed type II patterns with bifurcation at a higher point and 63 lower limbs (4.9%) were assigned to the type III pattern with aplasia or hypoplasia (Table 1). In terms of frequency, 45 lower limbs (3.5%) were hypoplastic or aplasic and trifurcation in which three major arteries divide from the same root (type IB) were found in 32 extremities (2.5%). AT with origin at a higher point (type IIA1) was found in 28 extremities (2.2%), and hypoplastic or aplasic AT (type IIIB) was found in 16 extremities. PT with high origin (type IIB) was found in 7 extremities (0.6%), and anterior tibiperoneal trunk variation (type IC) was found in 7 extremities (0.6%). Type IIA2 pattern was found in 5 extremities (0.4%). Hypoplastic or aplasic AT and PT (type IIIC) was found in one extremity (0.1%). The peroneal artery

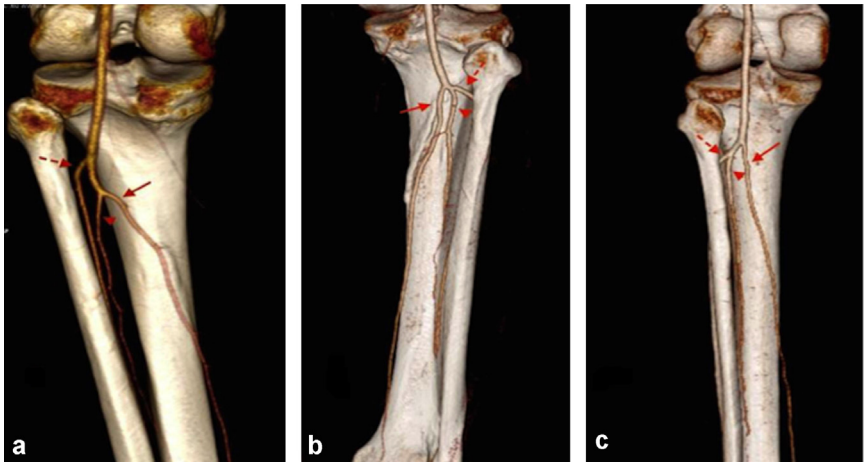

Figure 2. Type I subpatterns shown by three-dimensional volume rendered CT angiography images: a: usual type IA and AT as the first branch in a 42-year-old man. Posterior tibial artery and peroneal artery are seen to arise from a common root.; b: type IB pattern in a 48-year-old woman. The branches divide directly from popliteal artery without forming a common branch (trifurcation); c: type IC pattern in a 60-year-old man where posterior tibial artery is the first branch and anterior tibial artery and peroneal artery arise from the common root together. AT: anterior tibial artery (dashed arrow); PT: posterior tibial artery (flat arrow); PR: peroneal artery (arrowhead).

type with high origin (type IIC) was not found in our cohort. However, we identified two cases that did not fall into any of the categories described by Kim et al. [2]. One of these was a hypoplastic peroneal artery in which the PR occluded immediately after branching (Fig. 5a). In the other case, the posterior tibioperoneal trunk was considerably longer (110 mm) than normal (Fig. 5b). TP and PR divided from the tibioperoneal trunk in the medial cruris. The variations detected from the findings are shown in Table 1.

Furthermore, 623 patients showed the usual pattern in at least one lower extremity. Variation outside the usual pattern in one extremity was observed in 97 patients and in both extremities was observed in 23 patients. In total, variations were identified in 143 extremities (11.3%) of 120 patients. In 19 patients (15.8%), the same variation was found in both extremities, and in four patients (0.3%), different variations were observed in both extremities (Table 2).

When using the tibial plateau and popliteus muscle as a reference (Fig. 5c), no differences were identified. In the region between those reference points, early branching of the popliteal artery was not observed. No significant differences in branching patterns were found between men and women ($P = 0.41$) or between right and left lower limbs ($P = 0.54$).

Discussion

DSA is still the gold standard because of its high spatial resolution and reliability in monitoring the peripheral arterial tree. However, due to possible complications of this technique (occurring at a rate of 4%—9%), such as hematoma, anaphylaxis, arterial damage, and renal insufficiency, as well as disadvantages such as cost and patient discomfort,

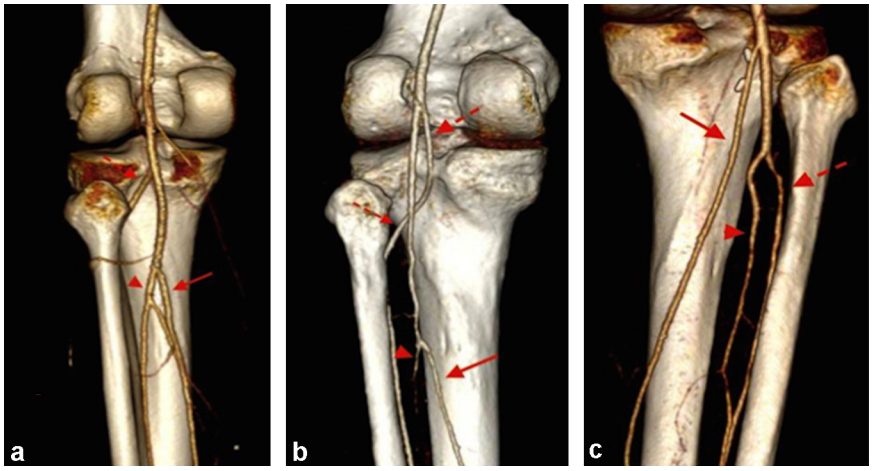

Figure 3. Three-dimensional volume rendered images show different type II subpatterns: a: type IIA1 pattern with high branching and normal course of the anterior tibial artery in a 74-year-old man; b: type IIA2 pattern with high branching and anterior tibial artery that first moves inward and then outward in a 61-year-old man; c: type IIB pattern with a high branching posterior tibial artery in a 49-year-old man. AT: anterior tibial artery (dashed arrow); PT: posterior tibial artery (flat arrow); PR: peroneal artery (arrowhead).

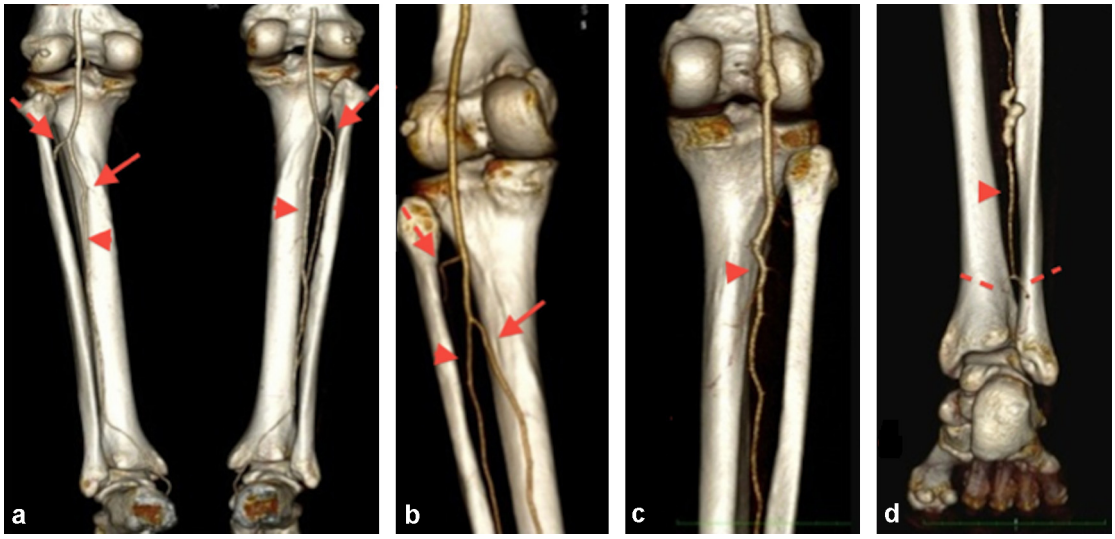

Figure 4. Three-dimensional volume rendered images showing the type III pattern: a: type IIIA pattern with hypoplasic posterior tibial artery (flat arrow) and aplasic posterior tibial artery in extremities of a 43-year-old woman; b: type IIIB pattern with hypoplasic AT (dashed arrow) in a 52-year-old woman; c: type IIIC pattern with aplasic anterior tibial artery and posterior tibial artery in a 35-year-old woman. The peroneal artery only can be observed in proximal section; d: type IIIC pattern. CTA shows only the peroneal artery and its branches in the ankle (dashed line). AT: anterior tibial artery (dashed arrow); PT: posterior tibial artery (flat arrow); PR: peroneal artery (arrowhead).

non-invasive methods such as color Doppler ultrasonography (CDUS), CTA, and MRA are now in demand [10]. DSA shows lower accuracy with diseases such as diabetes, where the prevalence of calcific plaque is high [10]. Assessment by CDUS is limited in obese patients with heavy calcification [9]. MR angiography is now routinely used in imaging peripherial arteries [11]. The advantages of MR angiography are that it does not use nephrotoxic iodinated contrast agents or ionizing radiation. Non-contrast-enhanced MR angiography techniques have been developed for patients with heavy renal insufficiency and who are at risk for nephrogenic systemic fibrosis [12]. Like non-contrast MR angiography, it is inappropriate for patients who are claustrophobic or who have metal implants such as pacemakers along with long examination times, which are among the main disadvantages [12].

CTA has several advantages that include short examination time, thin sections, three-dimenasional images, high spatial resolution, and the ability to detect blood vessel pathologies such as mural calcification [13]. Several studies

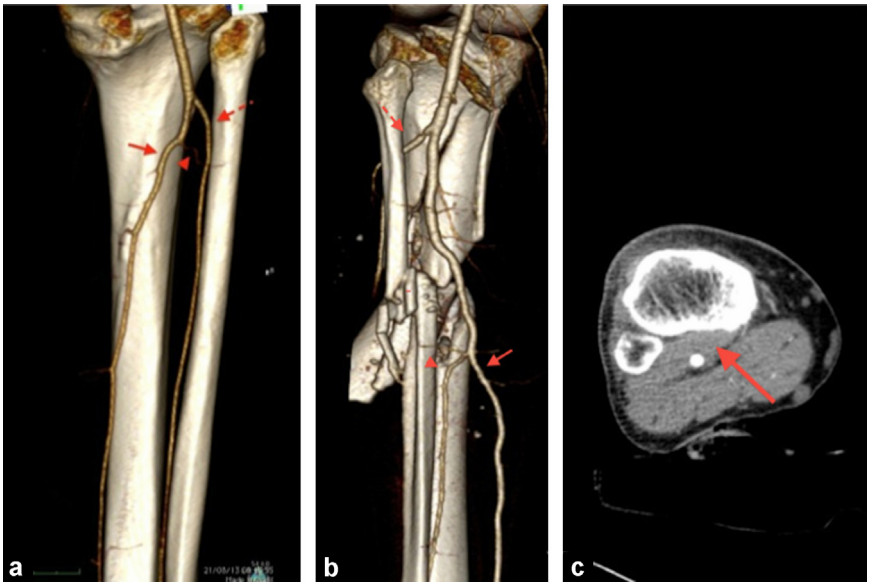

Figure 5. CT angiography images in different patients show patterns of variations distinct from the classification by Kim et al. [2]. Presentation of the anatomical reference point of the popliteus muscle: a: hypoplasic peroneal artery (arrow head) in a 42-year-old man; b: anterior tibial artery with normal branching, a long tibioperoneal root and division of posterior tibial artery and peroneal artery at cruris middle section in a 54-year-old man: c: popliteus muscle in the transverse plane (long arrow) in a 54-year-old man. AT: anterior tibial artery (dashed arrow); PT: posterior tibial artery (flat arrow); PR: peroneal artery (arrow head).

Table 1 Branching pattern findings of popliteal artery in the study.

Branching pattern		Number of extremity (%)
Type I		
A- Usual pattern		1118 (88.7%)
B- Trifurcation		32 (2.5%)
C- Anterior tibioperoneal trunk		7 (0.6%)
D- Long tibioperoneal trunk[a]		1 (0.1%)
	Total	1158 (91.9%)
Type II		
A1- AT arises at or above popliteus muscle Medial course of AT		28 (2.2%)
A2- AT arises at or above popliteus muscle Medial course of AT		5 (0.4%)
B- PT arises at or above popliteus muscle		7 (0.6%)
C- PR arises at or above popliteus muscle		0 (0.0%)
	Total	40 (3.2%)
Type III		
A- Hypoplastic—aplastic PT		45 (3.5%)
B- Hypoplastic—aplastic AT		16 (1.2%)
C - Hypoplastic—aplastic PT and AT		1 (0.1%)
D - Hypoplastic-aplastic PR[a]		1 (0.1%)
	Total	63 (4.9%)

AT: anterior tibial artery; PT: posterior tibial artery; PR: peroneal artery.
[a] Different subtypes from the classification made by Kim et al.

have evaluated the branching patterns of the popliteal artery. To our knowledge, the current study included the largest number of patients and extremities (1261) after a study by Pirker et al. [5] (with a total of 2000 extremities) amongst several other published studies involving both cadavers and DSA [1—3,14]. The literature contains two studies using 64 section CT: a study by Yanık et al. [8] that included 126 extremities and Çalışır et al. [9] that included 742 extremities.

In our study, the frequency of variational branching pattern observed with CTA was 11.3%, which is similar to variations of 6.5%—17.6% reported from other studies with larger groups [1—3,5,14]. These variations are important in evaluating the extremity arterial structure and clinical implementations by vascular surgeons and interventional radiologists. Knowing the type II patterns that display high branching between the popliteus muscle and the posterior tibial cortex is important in orthopedic interventions [8,15]. If a patient shows a type III pattern, it might be necessary to change the extremity angioplasty technique in balloon catheter angioplasty [16]. Morphological increases may be found in the classification of severity of stenosis and occlusion. This can, in turn, affect the treatment plan and angioplasty technique used [16]. Revisions might also be required in planning the lower extremity fibular free flap in patients showing type III pattern [8,17]. Kim et al. [2] offered a new classification of a popliteal artery branching pattern by modifying the Lippert's system [2,18]. Their classification includes three types and three subtypes, each of which is divided into two groups. Kim et al. [2] specified that a combined classification system would be better for surgeons in terms of clinical availability [2]. Our findings are similar to those of Kim et al. [2]. The type I pattern was the most frequently seen branching pattern in our study, which has been widely corroborated by many other studies. The branching frequency of the popliteal artery from the normal level was 91.9%. Type IA was the most commonly encountered pattern within type I, at a frequency of 88.7%, followed by type IB. In most studies, type IB was the second most viewed pattern in this group [1—3,8,9,14]. In large literature serials, the type IB pattern is reported to be found slightly more frequently than type IC. Our study showed similar results: 2.6% (type IB) versus 0.6% (type IC). Interestingly, Pirker et al. found no type IB pattern in a series of 2000 lower limbs [5]. In our study, we found only one case in which the popliteal artery displayed branching in the inferior popliteus muscle. However, this case showed a very long tibioperoneal trunk (110 mm). Cadaver studies have found tibiopeoneal trunk lengths of 30.3 ± 16.2 mm and 2—5 cm [19,20]. Existing literature has not defined a long tibioperoneal trunk in DSA and MDCT angiography studies. Thus, we have classified this as a different subtype in type I (type ID).

The frequency with which the popliteal artery displays a high-level branching (type II) has been defined in previous studies as ranging from 1.6% to 7.8% [1—3,5,8,9,14]. In our study, this frequency was 3.2%. In this group, the most frequently found pattern was type IIA, similar to the published literature. However, as also shown by Kil and Jung [1], we did not come across the type IIC pattern (Table 3), a variation that was reported by Kim et al. [2] and Day and Orme [3] at a rather low frequency of less than 0.2%.

The frequency of type III branching pattern has been reported to be between 1% and 7.6% in DSA and cadaver

Table 2 Number of patient for whom both lower extremities were evaluated together.

	Right lower extremity			Total
	Usual pattern	Variations	Excluded	
Usual pattern	495	43	18	556
Left variations	47	23	5	75
Excluded	20	2	18	40
Total	562	68	41	671

Table 3 Comparison between DSA studies made over 500 extremities and MDCT angiographic studies in popliteal artery variations.

		I (%)			II (%)			III (%)		
	Extremity (*n*)	A	B	C	A	B	C	A	B	C
DSA										
Pirker	2000	93.6	—	1.0	2.6	1.2	—	1.3	0.4	—
Kim et al.	605	92.2	2.0	1.2	3.7	0.8	0.2	3.8	1.6	0.2
Day and Orme	1037	90.7	3.2	0.3	4.5	1.1	0.2	0.8	0.1	0.1
Kil and Jung	1242	89.2	1.5	0.1	1.2	0.4	—	5.1	1.7	0.8
Mavili et al.	535	82.4	5.4	0.4	3.9	1.5	—0.2 (D)	3.7	2.2	0.2
MDCT angiography[a]										
Yanık et al.	126	83.6	0.8	4.4	5.2	2.6	—	3.4	—	—
Çalışır et al.	742	87	4.2	0.2	3.6	1.4	—	2.7	0.9	—

D: different subtypes from the classification made by Kim et al.
[a] Indicates that MDCT angiography was performed with a 64-section CT scanner.

studies [1—3,5]. In two studies performed using MDCT angiography, the rates were 3.4% [8] and 3.6% [9]. In our study, we detected at least one aplasic/hypoplasic infrapopliteal artery variation similar to DSA and cadaver studies, but slightly more than what has been reported in the MDCT angiographical studies (4.9%). In this group, we encountered mostly the type IIIA pattern, similar to the literature. Large DSA studies [1—3,14] have encountered the type IIIC pattern, but at a lower frequency, similar to our study (0.1—0.8%). MDCT angiographic studies have not shown the type IIIC pattern. In this group, we observed that the peroneal artery hypoplasia that was occluded immediately after outlet; unlike the data reported by Kim et al. [2]. We did not consider this to be an artifact of stenosis. The outlet of the peroneal artery was rather thin, and we have assigned this observation as meriting a new subtype of type III, i.e., type IIID.

In studies using 64-section CTA, Yanık et al. [8] reported that they did not observe type IIB, IIC, or IIIC patterns while Çalışır et al. [9] reported that they did not observe any type IIC or IIIC patterns. In our study, the only pattern that was not observed was the type IIC. This may be related to the differences in the number of patients examined in these studies. Of note, in both studies [8,9], the tibial plateau was used as reference point for the classification of popliteal artery branching while in anatomical cadaver studies, the popliteus muscle was used as the reference muscle [18,19,21]. As the popliteus muscle cannot be determined in DSA studies, the top edge of the tibial plateau is specified as the reference point. We also used the popliteus muscle as a real reference point as it is very easy to identify this muscle with MDCT. However, in our study, we did not identify the popliteal artery branches in the section between two reference points (superior border of the tibial plateau and inferior border of the popliteus muscle). In MDCT studies, it is possible to use real anatomical reference points.

Compared to the previous studies, our study appears to closely corroborate the data reported by Kim et al. [2]. The three most frequently encountered variations, following the usual patterns were (in order): hypoplasic or aplasic PT (type IIIA), AT with high origin (type IIA), and trifurcation (type IB) patterns. In the existing literature, these variations were encountered most frequently, although the alignment differed. We determined that a long tibioperoneal trunk in one case and hypoplasic PR in another case, which differed from the classification made by Kim et al. [2] and other previous studies. These patterns could be added to the classification by Kim et al. [2] as types ID and IIID, respectively. Similarly, Mavili et al. [14] encountered a trifurcation artery with a high location and abnormal course of AT in one patient. Taking their study and ours into consideration, additional variation types should be added to the classification by Kim et al. [2].

Our study has some limitations. Although the sample size is quite large, the study was conducted in one center. The CTA findings were not correlated with any other radiological examinations or surgical findings. The patients were examined by two radiologists and in some cases, a more experienced radiologist was consulted. Eighty-one limbs from patients with artifacts, vascular occlusion, or lower extremity surgery as well as those to whom iodinated contrast agents could not be given were excluded from the study. This exclusion may also have affected the results.

In conclusion, great diversity can be observed in popliteal artery branching patterns. Recognizing these anatomical differences is of importance in terms of surgical and vascular interventional implementations to be applied to lower extremities. 128-section CTA is useful in detecting these anatomical differences. In our study, we identified two new branching patterns of the popliteal artery not previously described in the literature. We propose to add them as types ID and IIID to the classification by Kim et al. [2].

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Disclosure of interest

The authors declare that they have no competing interest.

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