Investigation of popliteal artery branching patterns in magnetic resonance angiography examinations:
Experience of Kayseri Education and Research Hospital

Alt ekstremite manyetik rezonans anjiyografi incelemelerinde popliteal arter dallanma paternlerinin araştırılması:
Kayseri Eğitim ve Araştırma Hastanesi merkezi deneyimi

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ABSTRACT

Objective: This study was designed to evaluate variations in popliteal artery (PA) distal branching observed in lower extremity magnetic resonance angiography (MRA) images.

Methods: A total of 576 lower extremity MRA examinations that were performed consecutively between 2008 and 2012 in a single hospital were retrospectively evaluated. In all, 767 lower extremity images of 425 patients were included in the study and 151 examinations that were inappropriate were excluded. A bilateral evaluation was conducted of 342 lower extremities, and 83 lower extremities were evaluated unilaterally. The anatomical variations in the PA branching patterns were classified and assessed, and the results were evaluated with other studies that have examined PA distal branching variations with digital subtraction angiography and computed tomography angiography.

Results: The most frequently seen pattern was type IA (normal pattern), detected in 613 (80%) extremities. Variations in PA branching were depicted in 154 (20%) extremities and 733 (95.6%) limbs had a normal level of PA branching. Type II variations, with a high division of the PA (at or above the level of the tibial plateau), were seen in 34 (4.4%) extremities. Type III variations were observed in 87 (11.4%) extremities. Of the 342 bilaterally evaluated patients, 251 (73%) had a bilaterally symmetrical pattern. Type IA was the most frequently encountered bilaterally symmetrical pattern.

Conclusion: MRA examination can be used as an alternative to digital subtraction angiography for the evaluation of PA branching patterns.
Femoral artery is the main nutrient artery supplying the lower extremity. After passing through the adductor channel, it continues as popliteal artery (PA) in the popliteal fossa. PA is divided into three branches distal to the popliteal fossa. In this branching, variations depending on the level, and order of branching, and presence of aplasia, and hypoplasia of distal branches stemming from the embryological development of the arterial system of the lower extremities are seen.\[1\]

Knowing the variations of the distal branching of the popliteal artery is important in surgical and endovascular treatment of extremity-threatening ischemia secondary to atherosclerosis, in the use of free fibula flap, in knee trauma and surgery, and in evaluations of thrombotic processes.\[2–6\]

Digital subtraction angiography (DSA) is the gold standard for imaging of the arterial system of lower extremities and distal branches of PA\[6\]. This invasive, costly, and long-lasting method uses ionizing radiation and requires at least four hours of observation after the procedure. In addition, specially trained personnel and special units are required for this procedure. It is important to develop easily accessible, and applicable noninvasive low-cost investigations with shorter processing time, and lesser complications that will be alternative to DSA examination. For this purpose, noninvasive imaging methods such as Doppler ultrasonography (US), computed tomography angiography (CTA), magnetic resonance angiography (MRA) are used with increasing frequency in daily practice.

US examination is user-dependent and does not provide angiographic images as cross-sectional imaging modalities such as CTA, and MRA. Besides interpretation of US examination becomes more difficult in the presence of increased subcutaneous fatty tissue and edema. CTA examination has a high spatial resolution but uses ionizing radiation and nephrotoxic iodine contrast agent. MRA examination is cheaper than DSA examination, it does not use ionizing radiation, and contrast agents with gadolinium are utilized.\[7\] In this study, we investigated the frequency of PA distal branching patterns detected in MRA examinations of lower extremities and evaluated its results with those of DSA and BTA tests in which frequencies of PA distal branching patterns were also investigated.

**METHODS**

Lower extremity MRA images of consecutive 576 patients performed in the radiology unit of our hospital between the years 2008, and 2012 using 1.5 T MR (magnetic resonance) devices (Signa HDxt and Signa excite, GE Healthcare, USA) were retrospectively evaluated over image archiving and communication systems (Picture Archiving and Communication System®, PACS). MRA examinations were performed by delivering 0.3 cc/kg contrast agent at a time using dynamic table movement technique and body coil. Three separate scout images of abdominal aorta-iliac arteries, thigh region, calf region-distal part of lower extremities in 3 planes for each region were acquired, and fast-spin TOF angiographic sequences were obtained to guide endovascular processes.

Arterial phase contrast-enhanced 3D T1-weighted FSPGR sequence images were obtained by taking these guiding images into consideration. Contrast-enhanced 3D MRI images were obtained by removing the images used for guidance from the contrast-enhanced examination images and only the acquired 3D-MIP images were combined. Frequently used imaging parameters were as follows; TR: 3.78–4.45 msec, TE: 1.34 msec, NEX: 1, FA: 30°, FOV: 460 mm, section thickness: 2.8 mm, matrix: 352x192–352x352. The mean duration of the examination was 20 minutes. Contrast-enhanced MRA examinations were not repeated in any patient.

A total of 151 patients were excluded from the study, including 98 patients with severe atherosclerosis, and proximal occlusion, and 49 cases with venous contamination, and 4 cases with occlusion in one and venous contamination in the other lower extremity.

Venous contamination was detected in 119 (10.3%) of 1152 extremities which precluded examination. Regardless of the patient’s clinical information and diagnosis, MRA examinations covered vascular structures which preserved their arterial integrity from PA to ankle. In this study MRA images of a total of 767 (381 right, and 386 left) lower extremities belonging to 425 cases were examined. The vascular structure of the lower extremities was evaluated bilaterally in 342, and unilaterally in 83 cases. Anatomical variations in PA branching patterns were classified according to the system used by Kim et al.\[2\] According to this classification, the level of type I branching is the lower edge of the popliteus muscle and is divided into three subtypes in order of branching (Fig. 1a).
In Type IA (normal) branching, PA firstly gives rise laterally to anterior tibial artery (ATA) branch at the level of the lower edge of the popliteus muscle. ATA passes over the anterior aspect of the leg and ankle and continues as arteria dorsalis pedis on the back of the foot. After branching of ATA, the tibioperoneal root is divided into two branches medially as posterior tibial artery (PTA) and centrally as fibular artery (FA) extending distally.

In the leg FA ends in after giving branches to the muscle fibers proximal to the ankle. PT courses on the medial posterior aspect of the ankle and forms the arch of the foot with ATA distal part of the foot (Fig. 1b). In type IB, there is no true tibioperoneal root, the origins of all three branches are close to each other within a distance of 5 mm (Fig. 1c). In type IC, PTA is the first branch separated medially, and FA and ATA come out of the common root, extending together to the ankle (Fig. 1d).

Branching at the level of tibial plateau or higher is classified as type II (Fig. 2a). Type IIA with branching of PTA and FA from the tibioperoneal root where the first branch is high-division ATA which divides into two smaller branches. In Type IIA1, high-division ATA shows a normal course laterally (Fig. 2b). In Type IIA2, high-origin ATA leads first medial and then lateral course (Fig. 2c). In Type IIB, PTA is the first branch with high division ATA and FA arise from a common root (Fig. 2d). In type IIC, the first branch is high-division FA’ (Fig. 2a).

In type I and type II, ATA and PTA form the foot arch in the distal part of the foot supply nutrients to the foot, and FA sends branches to the muscles proximal to the ankle and ends at these levels. In type III variation, the branching level and sequence are normal, ATA and/or PTA are aplasic-hypoplasic and FA which replaces the aplasic-hypoplasic artery forms the foot arch distally, (Fig. 3a).

In Type IIIA, PTA is aplasic-hypoplasic, and distally FA, supplies blood to perfusion area of the aplastic-hypoplasic PTA, forms the foot arch with ATA (Fig. 3b). In Type IIIB, ATA is aplasic-hypoplasic, and distally FA provides the blood circulation of the area normally perfused by aplastic-hypoplasic ATA and forms the foot arch with PTA (Fig. 3c). In Type IIIC, ATA and PTA are aplasic-hypoplasic, and FA provides the blood circulation of the foot in place of aplasic-hypoplasic arteries (Fig. 3d).

RESULTS

The branching patterns and their frequencies detected in magnetic resonance angiography examinations are
Investigation of popliteal artery branching patterns

The frequencies of popliteal artery distal branching variations we detected in magnetic resonance angiograms

<table>
<thead>
<tr>
<th>Branching patterns</th>
<th>Number of extremities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type IA</td>
<td>613 80</td>
</tr>
<tr>
<td>Type IB</td>
<td>28 3.6</td>
</tr>
<tr>
<td>Type IC</td>
<td>5 0.65</td>
</tr>
<tr>
<td>Type IIA1</td>
<td>14 1.8</td>
</tr>
<tr>
<td>Type IIA2</td>
<td>6 0.8</td>
</tr>
<tr>
<td>Type IIB</td>
<td>13 1.7</td>
</tr>
<tr>
<td>Type IIC</td>
<td>0 0</td>
</tr>
<tr>
<td>Type IID</td>
<td>1 0.1</td>
</tr>
<tr>
<td>Type IIIA</td>
<td>51 6.7</td>
</tr>
<tr>
<td>Type IIIB</td>
<td>31 4</td>
</tr>
<tr>
<td>Type IIIC</td>
<td>5 0.65</td>
</tr>
<tr>
<td>Total</td>
<td>767 100</td>
</tr>
</tbody>
</table>

Table 1. The frequencies of popliteal artery distal branching variations we detected in magnetic resonance angiograms

shown in Table 1. Type IA (normal pattern) was the most common branching pattern, and detected in 613 (80%) lower extremities. In 154 (20%) lower extremities PA branching variation patterns were observed. The most frequent variation was type IIIA detected in 51 (6.7%) and the second most common variation was type IIIB seen in 31 (4%) lower extremities. PA branching of 733 (95.6%) lower extremities was at its normal level (just below the popliteus muscle: type I, III).

Type I variation where branching level was just inferior to the popliteus muscle was present in 646 (84.2%) lower extremities. In type IA (normal pattern) where ATA was laterally divided as the first branch, was detected in 613 (80%) lower extremities. Type IB in which all three branches were separated together within a distance of 5 mm was detected in 28 (3.6%) lower extremities. Type IC in which PTA showed branching medially as the first branch, was detected in 5 (0.65%) lower extremities.

Type II high-division variations were detected in 34 (4.4%) lower extremities where popliteal artery branching was at or above tibial plateau.

Types IIA1, and IIA2 where ATA was the first branch of high-division were seen in 14 (1.8%), and 6 (0.8%) lower extremities, respectively. Type IIB where the first branch of high division PTA was detected in 13 (1.7%) lower extremities.

In our study, we did not encounter a rarely seen type IIC pattern in which FA is the first branch of high-division. In our study, in accordance with the assessment of Mavili et al. [4] the variation in which all three branches are of high-division, and ATA leads first a medial and then a lateral course was considered as the variant type IID (Fig. 4a, b).

Type III variation where popliteal artery branching was at its normal (inferior to the popliteus muscle) level, but with aplasic-hypoplastic distal branches was detected in 87 (11.4%) lower extremities. We also observed type IIIA (n=51; 6.7%), type IIIB (n=31; 4%), and type IIIC (n=5; 0.65%) branching patterns in indicated number of lower extremities.

Of the cases who underwent bilateral assessments, 251 (73%) cases (233 type IA, 7 type IIIB, 6 type IIIA, 3 type IIB, 1 type IIA1, 1 type IIA2) had the same branching variation bilaterally. In 23.3% of the cases the same bilateral variations were detected.

**DISCUSSION**

It is important that clinicians and radiologists know the clinical effects of distal branching patterns of popliteal artery.
Klecker et al.\textsuperscript{[5]} indicated that ATA should be watched out in the variation of high-division ATA coursing between the anterior popliteus muscle and the tibial cortex in knee surgery. In their study, they described this important variation as aberrant ATA for knee surgeries such as high tibial osteotomy, total knee arthroplasty, and lateral meniscus repair. They retrospectively detected this variation in 23 (2.1\%) cases out of 1116 routine knee MRI examinations.\textsuperscript{[5]} However they did not take into account the variation of the ATA extending inferiorly from the posterior aspect of high-division popliteus muscle. In DSA examinations, anteroposterior projection can not detect whether the ATA is in the front of or behind the popliteus muscle, but suspicion may arise indicating that the high-division ATA coursing medially may further run in front of the popliteus muscle. The relationship between ATA and popliteus muscle may be revealed in cross-sectional images such as MRA and CTA. In our study, we did not consider the location of ATA (whether coursing in front or behind the popliteus muscle) in the evaluation of high-division ATA type IIA variation.

Popliteal artery variations are important for open surgery and endovascular interventions in the treatment of critical lower extremity ischemia. Ovcharenko et al.\textsuperscript{[3]} retrospectively evaluated PA branching patterns in angiographies in 248 peripheral angioplasty studies in which endovascular treatment with primary revascularization was applied for critical cases of lower extremity ischemia. They also investigated the effects of PA variations on invasive procedures. In this study, they identified variations in 31 (12.5\%) cases including 17 type III (6.8\%), variations, and stated that these variations caused technical problems during angioplasty and subsequently led to complications.

Although 14 of 31 variant cases were detected by angiography, 7 of 17 cases could be identified after complications occurred. Complications occurred during searching for PTA or forced perforation of the hypoplastic-aplastic artery. In the literature, it was reported that 27.5\%–50\% of cases with variations had bilateral variation of the same type. Careful examination of the arterial system of the other lower extremity may be problem solving in problematic angioplasty procedures.\textsuperscript{[3]} In our study, 23.3\% of the patients with variations had bilateral variations of the same type. The frequency of popliteal artery branching patterns has been evaluated in studies performed using DSA and CTA.\textsuperscript{[2-4,8-11]}

Variations are detected in 7.8\%–17.6\%, of the lower extremities undergoing digital subtraction angiographic examinations.\textsuperscript{[2-4,8-9]} Kim et al.\textsuperscript{[3]} detected type IA in 92.2\%, and variations in 7.8\% of the lower extremities examined. Most frequently they detected type IIA1 (3\%), type IB (2\%), type IIIA (3.8\%), and type III (5.6\%) variations. Day and Orme\textsuperscript{[8]} found type IA in 90.7\%, and variations in 9.3\% of the lower extremities subjected to DSA examinations, and they most frequently observed type IIA (4.5\%) and type IB (3.2\%), type III (1\%) branching patterns. In their DSA study, Mavili et al.\textsuperscript{[11]} found type IA branching pattern in 82.4\% and variations in 17.6\% of the lower extremities examined. In this study, most frequently type IB (5.4\%) and type IIIA (3.7\%) patterns, and type III variation (6.1\%) were detected.

In a BTA study Calisir et al.\textsuperscript{[10]} detected type IA in 87\%) and variations in 13\% of 636 extremities. In this study, type IB (4.2\%) was the most common variation. In their CTA study Yanik et al.\textsuperscript{[11]} found type IA pattern in 83.6\% and variations in 16.4\% of 126 lower extremities. In this study, type IC and type IIA2 were the most frequently detected variations with the same frequency (4.4\%).

Type IIIC variation is also known as arteria peronea magna (APM). The most feared complication of free fibula flap surgery is the presence of variation of APM in FA to be used as a flap. In the APM variation, since FA is the dominant nutrient artery of the foot, pedal ischemia is induced when FA is included in the fibula flap. Rossen and Sign have proposed preoperative MRA examination to rule out the presence of APM variation so as to avoid postoperative pedal ischemia. Although in some studies any complications related to the presence of APM variation after free fibula flap surgery have not been reported, other studies have found clinical examinations insufficient to determine the risk of postoperative ischemia of the foot. Many surgeons use preoperative vascular imaging as a precaution to determine vascular patency and exclude vascular anomalies before the use of free fibula flaps, an MRA is an imaging modality chosen in most centers.

Rossen and Sign reported the incidence of APM in the community as 0.2–8.3\%.\textsuperscript{[12]} In our study, we also detected APM in 5 cases (0.65\%).

In their study realized using 3 T MR device, Lohan et al.\textsuperscript{[6]} evaluated the effect of MRA examination on surgical planning of facial reconstruction with free fibular flap to be performed in 29 patients in terms of
the atherosclerotic disease, and congenital anomalies. MRA findings changed the surgical approach in 16 of 29 patients and a different flap donor site was selected in the contralateral lower extremity in 13 of 16 patients (because of the presence of an atherosclerotic disease in 7, and participation of FA in pedal perfusion in 6 patients) after MRA examination. Mandibular defect was reconstructed using fibula flap in 27 patients with MRA findings and in 2 patients latissimus dorsi-serratus anterior muscle flap was used instead of fibula flap.

Fibula flaps were not used in one of these patients because of type IIIB variation in both legs and presence of serious bilateral atherosclerosis in the second case. Type III variations, including APM, may not be detected by pulse examination and may not induce claudication. Preoperative imaging is required to prevent postoperative ischemia of the foot. In this study, distal branching variations of PA were classified in 58 extremities and type IA variation was detected in 81%, type IB in 17%, type IIB in 6.9%, type IIIA in 3.4%, type IIB in 6.9% of the them. In their study using 3 T MRI, Sandhu et al.\textsuperscript{13} compared time-resolved MRA and bolus-chase MRA examinations to evaluate septocutaneous perforators of FA and PA branching patterns in 53 legs of 27 patients who would undergo fibula flap reconstruction, and they could not find any significant difference between the two modalities. They stated that they performed assessments with MRA in each patient who had fibula flap reconstruction in their own centers. In this study, type IA variations was detected in 53 (79.2%) extremities with the same frequencies. Thanks to time-resolved MRA examinations, they were able to detect the branching patterns in 2 extremities that could not be detected by bolus-chase MRA examinations.

In mobile table and bolus-chase MRA technique, images in arterial phase were obtained from different regions by contrast material injection and table movement. However, image acquisition may lag behind contrast agent movement. In this case, especially distal arterial structures cannot be evaluated due to venous contamination.\textsuperscript{14} Accelerated arteriovenous transit time, such as seen in arteriovenous malformation, and presence of an abnormal tissue such as cellulitis with altered circulation may cause venous contamination.\textsuperscript{15}

In the time-resolved contrast-enhanced MRA examination, venous contamination is not a problem since contrast enhancement is visualized separately in the arterial and venous phases with multiple sequential rapid images obtained from the same site after contrast agent injection, and also hemodynamic information may be obtained in the presence of high-flow lesions such as arteriovenous fistula and collateral circulation.\textsuperscript{14} Ho et al.\textsuperscript{15} found that venous contamination was detected in 5 of 20 patients in their study using the mobile table and bolus-chase MRA technique. Sandhu et al.\textsuperscript{14} detected venous contamination in 52.9% of the cases in their bolus-chase contrast MRA examination performed following low-dose contrast-enhanced MRA examination. This high rate may be related to the time-resolved MRA examinations performed before the bolus-chase MRA and the patient population that were mostly evaluated for fibula-free flap reconstruction. In our study, we detected venous contamination in 10.3% of the cases.

In this study, where we investigated the frequency of PA variations using MRA, we detected type IA in 80% and variations in 20% of lower extremities. Type IIIA (6.7%) and type IIB (4%) were the most common variations we detected. In our study, the frequency of variation and the type III variation were slightly higher compared to other studies performed with DSA and CTA, but comparable to those in which PA branching patterns were evaluated in MRA examinations.\textsuperscript{2-4,6,8-11,13} In studies performed Type IIC pattern was quite rare, and we also did not observe type IIC pattern in our study. In addition, in our study, we obtained MRA images similar to those classified by Mavili et al.\textsuperscript{4} as type IID in a DSA study.

The limitations of our study was that we did not evaluate MRA images obtained from the our cases by comparing simultaneously with gold standard DSA images.

The limitations of MRA examination are that the MRA shooting protocols are complex, and expensive because of the advanced technologies used. Besides this latest technology is not available everywhere. The examination is very sensitive to movement artifacts, and the patient must remain motionless for the duration of the examination. Patients with claustrophobia can not tolerate the examination, patients carrying appliances as surgical clips use during bypass surgery, cardiac pacemaker or defibrillator, and patients at risk for nephrogenic systemic fibrosis (NSF) are not eligible for MRA. NSF has been described in recent years and it is thought to develop in patients with renal failure who underwent contrast-enhanced MRI examination.\textsuperscript{16} Kidney disease may exist prior
to gadolinium injection or onset simultaneously with gadolinium injection.

Cases of NSF not related to contrast agent injection have been also reported.[17] Previously, it was thought to be just a skin disease, but later on with the detection of connective tissue involvement in NSF including skin, internal organs and muscle, its systemic nature has been recognized.[18] Most of these patients have comorbid conditions that present an increased risk for NSF. These comorbid conditions include metabolic acidosis, vasculopathy, high-dose erythropoietin treatment, immunosuppression, increased calcium, iron, phosphate levels, major surgery and infection.[16] The clinical picture of NSF may vary from patient to patient, even in the same patient at different periods.

The disease has acute phase symptoms as fever, hypotension, anemia, and also chronic phase manifestations as skin lesions, joint contracture, and restriction of movement. It can be seen as a thin plaque on the leg or it can cause severe contracture and death.[17] Patients with NSF risk should be monitored and identified with interclinical collaboration to avoid contrast-enhanced MR imaging in risky groups.

In conclusion, lower extremity MRA examination is an imaging modality that may be an alternative to other invasive and cross-sectional imaging modalities in the evaluation of PA variations.

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REFERENCES

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