VIA MEDICA

ORIGINAL ARTICLE

Folia Morphol.
Vol. 78, No. 1, pp. 71–78
DOI: 10.5603/FM.a2018.0052

ISSN 0015–5659
journals.viamedica.pl

Branching patterns of the foetal popliteal artery

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[Received: 14 February 2018; Accepted: 10 June 2018]

Background: *The objective of the study is to evaluate the popliteal artery topography and the origin variability of its branches in human foetuses at the gestational age of from 4 to 9 months. The basis for the analysis are direct observations of classic anatomic dissections of the popliteal fossa. Possible dimorphic and bilateral differences, as well as the gestational age variability at the foetal period, were considered. A typology of popliteal artery branches will be made on the basis of the studies.*

Materials and methods: *The research material of this study comprises 231 foetuses (including 116 males and 115 females). The foetuses were divided into five 28-day age classes. The vessels of the lower extremity were injected with LBSK 5545 latex through the femoral artery. The bilateral dissection of the popliteal artery along with its branches was performed. No visible malformations were found in the research material, and the foetuses came from spontaneous abortions and premature births.*

Results and Conclusions: *Ten per cent of the cases featured the variations of popliteal artery terminal branches. Three most commonly seen variations are the trifurcation, anterior tibial-peroneal trunk, and high terminal division of the popliteal artery. The most common course of the superior muscular branches is that there are two large branches which are distributed from the popliteal artery at the height of the knee joint cavity and they do not distribute cutaneous branches. Sural branches are also present as two large vessels without cutaneous branches. The genicular anastomosis branches that run on their own are a typical topographic system of these branches.* (Folia Morphol 2019; 78, 1: 71–78)

Key words: popliteal artery branches, popliteal artery topography, human foetuses

INTRODUCTION

Knowledge of the development at embryonic and foetal periods that determine the anatomical variability of the cardiovascular system is of extreme significance to anatomists, surgeons and radiologists [3, 7, 25]. The variability of the course and the occurrence of popliteal artery variations may have clinical implications for vascular transplants, indications for direct surgical intervention, percutaneous transluminal angioplasty (PTA) or embolectomy. It is significant for clinicians to distinguish between an artery blockage or artery injury and the occurrence of artery variations, which is a result of being aware of possible variations of the artery. Lack of such knowledge leads to the development of complications during vascular surgeries [14].

The objective of the study is to evaluate the popliteal artery topography and the origin variability of

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its branches in human foetuses at the gestational age of from 4 to 9 months. The basis for the analysis are direct observations of classic anatomic dissections of the popliteal fossa. Possible dimorphic and bilateral differences, as well as the gestational age variability at the foetal period, were considered. A typology of popliteal artery branches will be made on the basis of the studies.

MATERIALS AND METHODS

The research material of this study comprises 231 foetuses (including 116 males and 115 females) at the gestational age from 84 to 224 days, stored in formalin solution. The material comes from the collection of the Department and Division of Normal Anatomy of Wroclaw Medical University. Study has the Local Bioethics Commission acceptance. The foetuses were divided into five 28-day age classes. The vessels of the lower extremity were injected with LBSK 5545 latex through the femoral artery. The bilateral dissection of the popliteal artery along with its branches was performed. No visible malformations were found in the research material, and the foetuses came from spontaneous abortions and premature births. The list of the gestational age of the foetuses is shown in Table 1.

The gestation age of the foetuses was evaluated on the basis of the last menstruation of the mother and verified by means of the method suggested by Gworys [8] where 4 of 16 characteristics were relevant to determine age — body weight and length, circumference of head and chest.

For the evaluation of popliteal artery topography varieties and popliteal artery branches, both Adachi [2] and Lippert and Pabst [16] typologies were considered, including the Kim et al. modification [14]. Both Adachi [2] and Lippert and Pabst [16], as well as other authors dealing with the anatomy of the popliteal artery, placed their emphasis on the last portion of the popliteal artery, that is on the observation of the variability of its terminal division. We could not find the detailed description of the artery course in the available source literature. The analysis of the collected dissectional material (462 lower extremities) allowed us to evaluate the origin level and symmetry of the artery branches. It enabled us to determine the artery course in relation to the knee joint, walls of the popliteal fossa, popliteal fascia and in relation to other components of the neurovascular bundle. The variability of the popliteal artery terminal division was also analysed.

Table 1. Sample sizes in successive gestational age classes

Male	Gestational age [month]	Female
20	4	22
21	5	23
22	6	23
22	7	19
20	8	19
11	9	9
116	Σ	115

Based on the analytics platform Statistica 10, the evaluation of bilateral differences was made by means of the Wilcoxon signed-rank test. The significance evaluation of dimorphic and gestational age differences was made using the Kruskal-Wallis test.

RESULTS

It was found that the beginning of the popliteal artery is determined by the adductor hiatus in all 462 cases. It is a transition from the femoral artery to the popliteal artery. It was found that the diameter of the hiatus varied. However, regardless of the width of the adductor hiatus a typical course of the artery in the popliteal fossa is as follows: it is slightly covered by the terminal insertion of the semimembranosus muscle in the proximal part of the popliteal fossa. The artery runs between both heads of the gastrocnemius muscle, and, on the sagittal side, under the plantaris muscle. The artery runs along the popliteal surface of the femur, then along the posterior wall of the articular capsule of the knee joint, and along the oblique popliteal ligament in the further part of the popliteal fossa. Along with the artery, the popliteal vein runs through the adductor hiatus. The vein lies more superficially than the artery, and it covers the artery incompletely. The covering degree varies individually. Both vessels are covered by the same vascular sheath. From the sheath, the tibial nerve runs superficially, which moves along the entire length of the popliteal fossa from the medial side of the sheath to the lateral side. In the distal angle of the popliteal fossa, the popliteal artery is divided into the anterior and posterior tibial arteries.

An unusual course of the popliteal artery at the foetal state was found in 30 extremities altogether, including 18 males and 12 females. We distinguished two types of the artery course: type I — the typical course, i.e. the artery is covered by a homonymous

Table 2. Typology of the popliteal artery course at the foetal period

Male				Gestation age [month]	Female			
Right side type		Left side type			Right side type		Left side type	
I	II	I	II		I	II	I	II
20	0	20	0	4	21	1	22	0
19	2	20	1	5	22	1	22	1
20	2	19	3	6	23	0	21	2
21	1	20	2	7	17	2	18	1
17	3	18	2	8	17	2	18	1
11	0	9	2	9	8	1	9	0
108	8	106	10	Σ	108	7	110	5

Table 3. Typology of the superior muscular branches in the foetuses

Male						Gestation age [month]	Female					
Right side type			Left side type				Right side type			Left side type		
I	II	III	I	II	III		I	II	III	I	II	III
8	8	4	9	8	3	4	10	9	3	11	11	2
10	8	3	8	9	4	5	10	11	2	11	9	3
8	9	5	9	10	3	6	8	12	3	9	12	2
6	11	5	7	11	4	7	6	9	4	5	10	4
6	10	4	5	13	2	8	5	9	5	5	10	4
2	6	3	2	5	4	9	2	5	2	1	5	3
40	52	24	40	56	20	Σ	41	55	19	42	57	18

vein, and lies slightly medially from it; type II — the artery lies laterally from the popliteal vein. Within those two types there was found 10 cases (6 male, 4 female) where the artery was covered by the medial head of the gastrocnemius muscle through most of the course. In 3 cases (1 male, 2 female) there was observed another rare phenomenon — the artery bifurcates in the proximal part of the popliteal fossa to merge in the distal part forming a kind of loop.

In conclusion, it should be noted that the typical course of the popliteal artery was seen in 93.5% of the foetuses. Type II (inverted situation) was seen in 6.5% of the foetuses (Table 2). The statistical testing did not show any statistically significant dimorphic and bilateral differences, or differences in relation to the gestation age of the foetuses.

Branches of the popliteal artery can be divided into muscular branches, articular branches, genicular anastomosis branches, and terminal branches.

Superior muscular branches that run to the posterior femoral muscles and sural arteries supply gastrocnemius, soleus and plantaris muscles. Three types of superior muscular branches in the foetuses were distinguished: type I — no superior muscular branches, type II — which features two branches, and type III — with three branches.

The only statistically significant differences were observed between the age classes in both sexes in both lower extremities. With the gestation age of the foetuses, the percentage of type II increases from 25% on average at the gestation age of 4 months to over 50% at the gestation age of 9 months; at the same time, the percentage of type I, where no branches were determined, decreases to several per cent (Table 3).

Sural arteries are two large branches, which are distributed from the popliteal artery at the height of the knee joint cavity. In type I there are no sural arteries, in type II they do not distribute cutaneous branches, and type III features cutaneous branches that run to the skin located on the posterior surface of the crus.

Sural arteries were found to have a very steady and typical course without cutaneous branches (57–

Table 4. Typology of the sural branches of the popliteal artery in the foetuses

Male						Gestation age [month]	Female					
Right side type			Left side type				Right side type			Left side type		
I	II	III	I	II	III		I	II	III	I	II	III
5	13	2	5	12	3	4	6	14	2	6	13	3
5	13	3	5	13	3	5	6	14	3	6	14	3
4	13	5	4	12	6	6	4	14	5	5	13	5
3	13	6	4	12	6	7	3	12	4	3	13	3
3	12	5	2	12	6	8	2	13	4	2	13	4
1	5	5	0	5	6	9	0	5	4	1	4	4
21	69	26	20	66	30	Σ	21	72	22	23	70	22

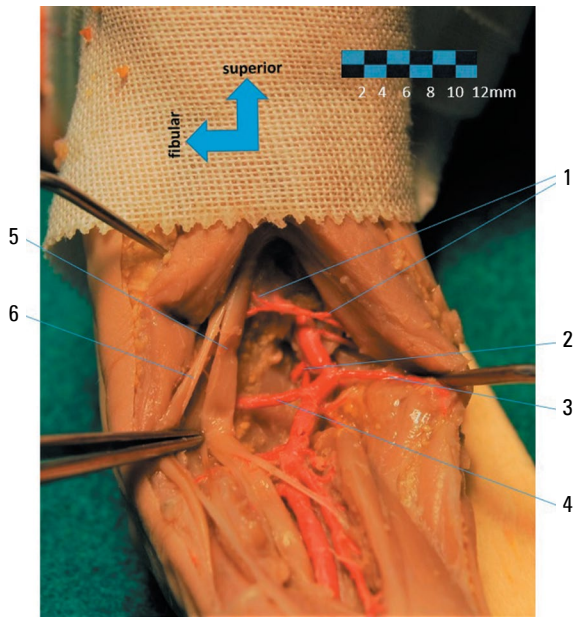

Figure 1. Foetal popliteal artery with two middle genicular arteries; 1 — muscular branches; 2 — middle genicular arteries; 3 — medial inferior genicular artery; 4 — lateral inferior genicular artery; 5 — tibial nerve; 6 — fibular nerve.

62%). The occurrence of cutaneous branches was only found in 10–20% of the cases — type III (Table 4). The statistical analysis performed by means of the Kruskal-Wallis test did not show any statistically significant differences.

The articular branch is the middle genicular artery. Three types were distinguished: type I — where middle genicular artery hypoplasia can be observed, type II — where there is only one artery, and type III — there are two middle genicular arteries (Fig. 1).

Regardless of the gestation age, sex, and side of the body of the foetus, an even number of middle genicular arteries was found in individual cases. The percentage of type II (one middle genicular artery) increases statistically significantly at the foetal period: from 75% in female foetuses at the gestation age of 4 months on the left side to 91% in male foetuses at the gestation age of 9 months on the right side, and, simultaneously, the percentage of the foetuses without the middle genicular artery decreases (Table 5).

Genicular anastomosis branches are four genicular arteries: medial superior, medial inferior, lateral superior, and lateral inferior. Type I was distinguished as the unassisted origin of all four genicular anastomosis branches from the popliteal artery trunk. Type II featured the same beginning of the medial superior genicular artery with another branch. Type III was the same beginning of the lateral superior genicular artery with another branch. Type IV was distinguished as the same beginning of inferior genicular arteries with another branch (Table 6).

A typical topographic system of these branches is genicular anastomosis branches running on their own (type I). Having observed the course of superior genicular arteries, it should be noted that the medial superior genicular artery anastomoses with other branches in comparison to the analogous lateral artery. The medial artery mainly anastomoses with the descending genicular artery (130 cases, i.e. 93.5%), and in individual cases it anastomoses with the middle genicular artery or one of the sural arteries. The course variations of both interior genicular arteries occurred extremely rarely, i.e. in 2.8% of the foetuses. Sex, bilateral and age class differences are not statistically significant.

On the basis of the analysis of our own foetal material we distinguished six types of the terminal division. Type I was characterised by a low division (below the popliteus muscle) into the anterior tibial artery and posterior tibial artery, which results in

Table 5. Typology of the middle genicular artery in the foetuses

Male						Gestation age [month]	Female					
Right side type			Left side type				Right side type			Left side type		
I	II	III	I	II	III		I	II	III	I	II	III
6	14	0	7	12	1	4	7	14	1	7	15	0
4	15	2	5	15	1	5	7	16	0	6	16	1
4	16	2	4	17	1	6	5	16	2	6	16	1
4	18	0	5	17	0	7	3	15	1	3	14	2
2	17	1	2	16	2	8	2	16	1	2	17	0
0	10	1	0	9	2	9	1	8	0	0	7	2
20	90	6	23	86	7	Σ	25	85	5	24	85	6

Table 6. Typology of genicular anastomosis branches at the foetal period

Male								Gestation age [month]	Female							
Right side type				Left side type					Right side type				Left side type			
I	II	III	IV	I	II	III	IV		I	II	III	IV	I	II	III	IV
9	6	4	1	10	6	4	0	4	11	6	4	1	10	7	4	1
10	7	4	0	9	7	5	0	5	10	8	4	1	11	7	5	0
11	7	4	0	10	7	4	1	6	11	7	6	0	10	8	4	1
12	6	4	0	10	6	5	1	7	10	6	2	1	9	5	3	2
9	5	5	1	9	6	3	2	8	9	7	3	0	10	6	3	0
7	2	2	0	6	3	2	0	9	6	2	1	0	6	2	1	0
58	33	23	2	54	35	23	4	Σ	57	36	20	3	56	35	20	4

a short posterior tibial-peroneal trunk. Type II featured the trifurcation of the popliteal artery into the two tibial arteries and the peroneal artery. Type III featured the anterior tibial-peroneal trunk, where the posterior tibial artery is distributed on their own as a first branch, while the peroneal artery is distributed from the initial division of the anterior tibial artery. Type IV was the terminal division of the popliteal artery is located high, i.e. where the popliteus muscle lies. Type V was posterior tibial artery hypoplasia. Type VI was anterior tibial artery hypoplasia.

The observation of the terminal branch topography of the popliteal artery does not show any statistically significant differences in terms of sex and the side of the body. However, there are statistically significant differences regarding the occurrence of the distinguished types of the artery terminal division and the artery variability with the gestation age of the foetus. Type I is the most represented one, the occurrence of which varies from 80% to 82% in the youngest foetuses; it increases to 89% at the gestation age of 9 months — it even increases to 91% in the male foetuses on the right side (the difference is statistically significant at $p = 0.05$). The mean occurrence of type II (*trifurcation)* varies from 3.5% and 7% and it does not show any focused changes in relation to the gestation age of the foetuses. The remaining types of the branches of the popliteal artery occur in single cases irrespective of the gestation age of the foetuses (Tables 7, 8).

DISCUSSION

The difference in the course topography of the popliteal artery and its branches are a consequence of the processes that take place at the embryonic period. Most of the varieties involved persistent primary segmental arteries or lower extremity artery aplasia or hypoplasia in some divisions [17]. The embryonic period has a major impact on the development of lower extremity vascularisation. The arteries of the lower extremity develop as a result of the sprouting angiogenesis of the sciatic artery and femoral artery, which takes place when the embryo is 9 mm. These arteries directly come from the internal iliac artery and the external iliac artery, respectively. The sciatic artery is often referred as to the axial artery because it is the

Table 7. Typology of the terminal branches of the popliteal artery in the male foetuses

Right side type						Gestation age	Left side type					
I	II	III	IV	V	VI		I	II	III	IV	V	VI
16	2	1	0	0	1	4	16	0	2	0	1	1
17	1	1	0	1	1	5	17	1	2	0	1	0
20	1	0	0	1	0	6	17	2	0	0	1	1
20	1	1	0	0	0	7	21	0	1	1	0	0
18	1	0	1	0	0	8	18	1	1	0	0	0
10	0	0	1	0	0	9	10	0	0	1	0	0
101	6	3	2	2	2	Σ	99	4	6	2	3	2

Table 8. Typology of the terminal branches of the popliteal artery in the female foetuses

Right side type						Gestation age	Left side type					
I	II	III	IV	V	VI		I	II	III	IV	V	VI
18	2	1	0	1	0	4	18	1	1	0	1	1
19	1	1	0	1	1	5	19	2	1	0	0	1
20	2	1	0	0	0	6	20	2	0	0	1	0
17	1	0	0	1	0	7	17	1	0	1	0	0
17	1	0	1	0	0	8	17	1	1	0	0	0
8	0	0	1	0	0	9	8	1	0	0	0	0
99	7	3	2	3	1	Σ	99	8	3	1	2	2

main vessel of the free part of the lower extremity at early phases of the embryonic period. When the embryo is 11 mm, the sciatic artery begins to be affected by atrophy in some divisions. When the embryo is 14 mm, the femoral artery, its posterior bundle — the saphenous artery — to be exact, assumes a leading role in the vascularisation of the extremity. Progressing sciatic artery regression requires the artery to be anastomosed with the femoral artery at the level of the adductor canal, while the same trunk becomes the preferred way of the blood flow. The initial division of the saphenous artery, the part of the sciatic artery above the anastomosis, and the distal part of sciatic artery lose their importance and gradually disappear. Three arteries — the inferior gluteal artery, popliteal artery, and peroneal artery — are the remnants of the sciatic artery regression. The terminal vascular relations in the area of the lower extremity are formed when the embryo is 45 mm.

Superior and inferior genicular arteries, as well as the middle genicular artery, are formed from the superior bundle of the sciatic artery, from which the popliteal artery is developed; therefore, their individual variability is relatively low and in our research material is only shown in single cases. We observed that the percentage of the occurrence of two superior muscular branches increases from 25% on average at the gestation age of 4 months to over 50% at the gestation age of 9 months; simultaneously, the occurrence of other configurations decreases. The middle genicular artery demonstrates the statistically significant variability: at the foetal period, its occurrence increases statistically significantly from 75% in the female foetuses at the gestation age of 4 months on the left side to 91% in the male foetuses at the gestation age of 9 months on the right side. We observed the rare phenomenon such as presence of two genicular arteries which was also stated by other authors [22]. The posterior tibial artery develops from the femoral artery, and as a result of the sciatic trunk regression, the posterior tibial artery is distributed from the popliteal artery.

The high individual variability of the popliteal artery terminal branches results from the variability of sciatic artery atrophy and its degree of the anastomosis with the femoral artery.

Therefore, the trifurcation of the popliteal artery into the two tibial arteries and the peroneal artery is a result of the remaining distal part of the sciatic artery, which makes the anastomosis with the popliteal

artery possible [9]. This variation involves from 3.5% to 7% of the studied foetuses and is not associated with their gestation age.

The anterior tibial-peroneal trunk is a result of the lack of anterior sciatic artery bundle regression. It was found in 3 female foetuses and 6 male foetuses in our foetal material.

The high division of the popliteal artery results from the variability of sciatic artery medial division regression. It occurred in 3 cases in the foetuses of both sexes at the gestation age of 7, 8, and 9 months.

Anterior or posterior tibial artery hypoplasia was found in 6 foetuses of both sexes in the research material. Abdelwahab and Zwass [1] observed absence of both tibial arteries, although in our studies we did not notice such phenomenon.

Based on the studies carried out, a typical model for the course of the popliteal artery and its branches at the human foetal period may be demonstrated.

The artery that runs through the popliteal fossa medially is covered by a homonymous vein, which lies slightly laterally from it [4]. This course occurs at the foetal period in 89.8% of the foetuses throughout the entire foetal period. Most often (45–50%), two superior muscular branches occurred that ran to the flexor muscles of the thigh. This combination was found to increase slowly with the gestation age of the foetuses, while at the same time the number of foetuses that did not have these muscular branches decreased with the gestation age of the foetuses. Sural arteries demonstrate a very steady and typical course in 57–62% of the cases, vascularising the calf as a result. They do not distribute cutaneous branches. The percentage of the occurrence of one middle genicular artery increases statistically significantly at the foetal period: from 75% in the female foetuses at the gestation age of 4 months on the left side to 91% in the male foetuses at the gestation age of 9 months on the right side. Simultaneously, the percentage of the cases without the middle genicular artery decreases. The genicular anastomosis branches that run on their own are a typical topographic system of these branches, which occurred in the foetuses at a frequency of nearly 50%. Sex, bilateral and age differences are not statistically significant. The terminal branch topography of the popliteal artery does not show any statistically significant differences in terms of sex and the side of the body. However, there are statistically significant differences regarding the occurrence of the distinguished types of the artery terminal division and the artery variability with the gestation age of the foetus. Type I was the most common, which is characterised by a low division (below the popliteus muscle) into the anterior tibial artery and posterior tibial artery, which results in a short posterior tibial-peroneal trunk. The percentage of this configuration in the youngest foetuses varies from 80% to 82%, to reach 89% at the gestation age of 9 months — and even 91% in the male foetuses on the right side (the difference is statistically significant at $p = 0.05$). Mavili et al. [18] and Ozgur et al. [20], Szpinda [23] on the basis of their research, also stated that such a model of popliteal artery division is most commonly found in the following cases. The second most common terminal division of popliteal artery is trifurcation (type II).

The topography and variability of the termination branches of the popliteal artery are described in detail. The typology of the artery and its branches was initiated by Quain [21], and was further developed by Adachi [2], Trotter [24], Keen [10], Morris [19], Bardsley and Staple [5], Lippert and Pabst [16], and Kim et al. [14]. Kropman et al. [15] made a comparative analysis of the earlier studies, both anatomical and radiological. Despite numerous literature reports the comparison of our own research results with the results of other authors' research is impossible due to the lack of such research on foetal material. Therefore, the comparative analysis was performed in relation to adult material. It concerns the topography of the popliteal artery terminal branches only. The results are shown in Table 9.

The comparison indicates that the terminal stabilisation of the arterial system takes place throughout the entire foetal period. The early foetal period (the gestation age of 4 and 5 months) is characterised by a statistically significantly higher variability of the artery topography in comparison to later foetus periods. The perinatal period features a relative stabilisation of the lower appendage artery course, and the terminal topographic relations are similar to those dominant in the postnatal period.

Ten per cent of the cases featured the variations of popliteal artery terminal branches. Similar situation was observed in the studies of Kil and Jung [13] and Kelly et al. [11]. Three most commonly seen variations are the trifurcation, anterior tibial-peroneal trunk, and high terminal division of the popliteal artery. Khandelwal et al. [12] noticed only typical model of branching of popliteal artery. Knowledge of the topographical variations in relation to the branches

Table 9. The comparison of the occurrence of type I popliteal artery terminal branches

Author	Source	Extremities examined		Per cent
Quain (1844)	Dissection	258		90.3
Adachi (1928)	Dissection	770		96.0
Trotter (1940)	Dissection	1168		93.4
Keen (1961)	Dissection	280		90.7
Morris (1960)	Angiography	246		88.6
Bardsley (1970)	Angiography	235		92.8
Lippert (1985)	Dissection	282		90.0
Mauro (1988)	Angiography	343		88.0
Kim (1989)	Angiography	605		92.6
Szpinda (2006)	Angiography	152		87.5
Our own material (foetuses)	Dissection	4–6 months	131	80.0
		7–9 months	331	90.9

of the popliteal artery makes surgery planning easier and reduces the probability of causing significant and unexpected injuries to the artery [6, 18].

Acknowledgements

The authors wish to express their gratitude to all those who donated their bodies to medical science.

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