



Research paper

Variations of the popliteal artery in human fetuses: Preliminary study

Anna Żurada¹, Jerzy Gielecki², Marcelina Łopińska² , Katarzyna Polak-Boroń² ,
Michał Ciucias²

¹ Individual Specialist Medical Practice, Olsztyn, Poland

² Department of Anatomy, School of Medicine, Collegium Medicum, University of Warmia and Mazury in Olsztyn, Poland

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ABSTRACT

Introduction: This paper provides an in-depth analysis of the anatomical and morphometrical attributes of the popliteal artery (PA) in human fetuses. Additionally, it showcases significant interindividual variation in branching patterns, which are of great clinical importance in the context of vascular surgery and interventional radiology.

Aim: The purpose of this research was to systematically examine and categorize the anatomical and morphometrical diversities observed in the PA among a 166 sample of human fetuses at various gestational stages, spanning from 16 to 30 weeks of pregnancy.

Material and methods: The latex was injected into the 166 PA within the fetal specimens to visually analyze their anatomical features, and high-resolution digital images were captured at 24-bit color depth for detailed analysis.

Results and discussion: The PAs were systematically classified into three distinct categories, further subcategorized into specific types. The classification system employed was based on the framework established initially by Lippert and Pabst, with modifications by Kim. The results of the analysis revealed the following distribution: Category I – it was mainly detected in the majority of specimens, comprising 144 cases (86.7%) of the sample population, and represented the most common anatomical configuration; Category II – it was found in 19 specimens (11.4%) of the total sample population (this category represented a less common anatomical variation within the PA); Category III – the rarest anatomical configuration observed in only 3 specimens (1.8%) from the sample population.

Conclusions: The frequent occurrence of short tibiofibular trunks in PA may be due to incidental lesions or postnatal developmental changes, highlighting the need for further research.

1. INTRODUCTION

Understanding anatomical variations in the popliteal fossa and specifically the popliteal artery (PA) holds paramount significance in surgical procedures, including vascular grafting, transluminal angioplasty, embolectomy, and angiography during arterial injury diagnosis.^{1,2} In addition, the length and course of the PA and its branches are essential for treatment selection. Anatomic variations affect surgical approach, dissection techniques, and the choice of an appropriate arterial graft site.³ In femoropopliteal grafting, proper anastomotic site selection is essential to prevent complications such as backflow, graft thrombosis, rupture, and extravasation.⁴⁻⁶

The femoral artery (FeA) becomes the PA as it passes through the adductor hiatus and enters the popliteal fossa.⁷ Inside the popliteal fossa, the PA passes superficially (posteriorly) to the popliteus muscle and branches into the anterior tibial artery (ATA) and posterior tibial artery (PTA). This division appears near the lower border of the popliteus muscle, deep into the fibrous arch of the soleus muscle. ATA runs over the upper border of the interosseous membrane entering the anterior compartment of the leg. Due to the fact that the main branch of PTA is the fibular artery (FA), the proximal part of the PTA is often called the tibio-fibular trunk (TFT). However, this term has not yet made its way into the Terminologia Anatomica and officially it is still referred to as PTA.⁷

In addition to the conventional course and division of the PA, frequently encountered anatomical variations are noteworthy. This study utilized the classification system for PA variations initially proposed by Lippert and Pabst in 1985⁸ and subsequently modified by Kim in 1989⁵. Understanding the PA's developmental and anatomical variations and its multifaceted role in lower limb blood supply is pivotal for the optimal management of vascular diseases and the preservation of limb function.

2. AIM

The objective of this study was to perform a morphological analysis and systematically categorize anatomical variations within PA observed in human fetuses spanning gestational ages from 16 to 30 weeks.

3. MATERIAL AND METHODS

The study was performed on 87 human fetuses that were spontaneously aborted (48 female, 39 male) aged from 16 to 30 weeks of gestation. The fetal age was established by measuring the length of the humeral and femoral bones using ultrasound. The fetal arteries were filled with latex and preserved in 4% formalin and then dissected using a surgical microscope. The dissected arteries were digitalized in 24-bit digital pictures. For approximation and scaling of the microscopic picture (2272 × 1704 pixels), the AnalySIS software (Olympus) was used. Custom-generated MORPHO-04

software was used for the morphometrical analysis.⁹ A 166 PAs were analyzed, however, in the case of 8 fetuses only one PA (5 left and 3 right) was taken into analysis, the other side PA was rejected due to the fact of significant limb damage or insufficient latex filling.

For the classification of a variation, the average diameter of the PA and the length of TFT were measured. Classification of variations applied here was proposed by Kim (1989)⁵ and it is based on the PA division level, as well as the order and course of its branches (Figure 1). The PAs, which end at the lower border of the popliteus muscle, were included in Category I, while Category II was used for PAs ending near the upper border of the popliteus muscle. Category

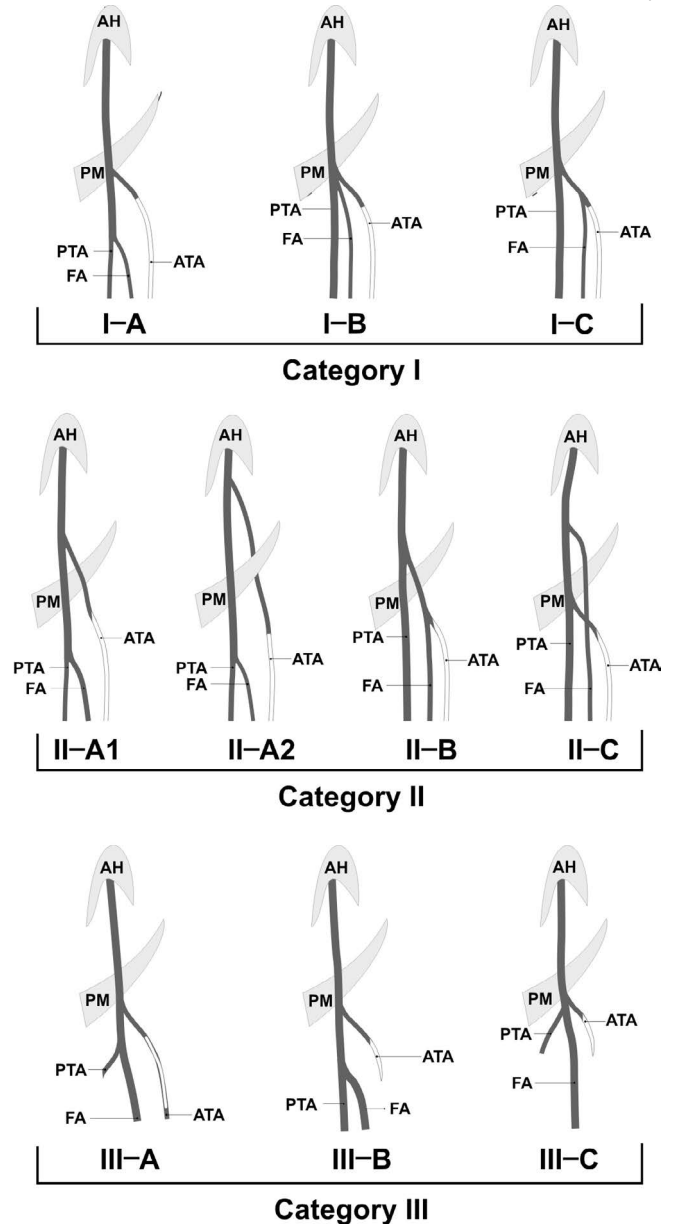


Figure 1. The classification of PA variation was proposed by Lippert and Pabst and modified by Kim et al. Comments: PM – popliteus muscle, PTA – posterior tibial artery, ATA – anterior tibial artery, FA – fibular artery, AH – adductor hiatus.

III incorporates all specimens where one or two terminal branches of the PA are aplastic or hypoplastic (Figure 1).

Category I is categorized into 3 distinct types:

- Type IA – Typically, PA bifurcates at the lower edge of the popliteus muscle (PM), forming two branches: PTA and the ATA. The FA arises from the PTA, and this initial portion of the PTA is referred to as the posterior TFT.
- Type IB – This type involves trifurcation, characterized by the simultaneous division of the PA into 3 terminal branches: the ATA, PTA, and the FA.
- Type IC – In this classification, the FA branches from the ATA, and that's why the initial section of ATA is called anterior TFT.

Category II is further categorized into 3 distinct types, with 2 subtypes identified within Type A:

- Type II A1 – In this subtype, the ATA branches from the PA near the upper border of the PM, and it courses posteriorly to the PM.

- Type II A2 – Similar to Type II A1, the ATA branches from the PA near the upper border of the PM, but it takes an anterior course in relation to the PM.

- Type IIB – This type is characterized by the origin of the PTA as the first branch at the level of the upper border of the PM.

- Type IIC: The FA arises at the level of the upper border of the PM.

Category III encompasses situations where one or two terminal branches of the PA exhibit hypoplasia. Within this category, three specific types are identified:

- Type IIIA: Characterized by hypoplasia of the PTA alongside the presence of a large FA.

- Type IIIB: Marked by hypoplasia of the ATA accompanied by a large FA.

- Type IIIC: In this subtype, both the ATA and PTA exhibit hypoplasia, while the FA remains notably enlarged.

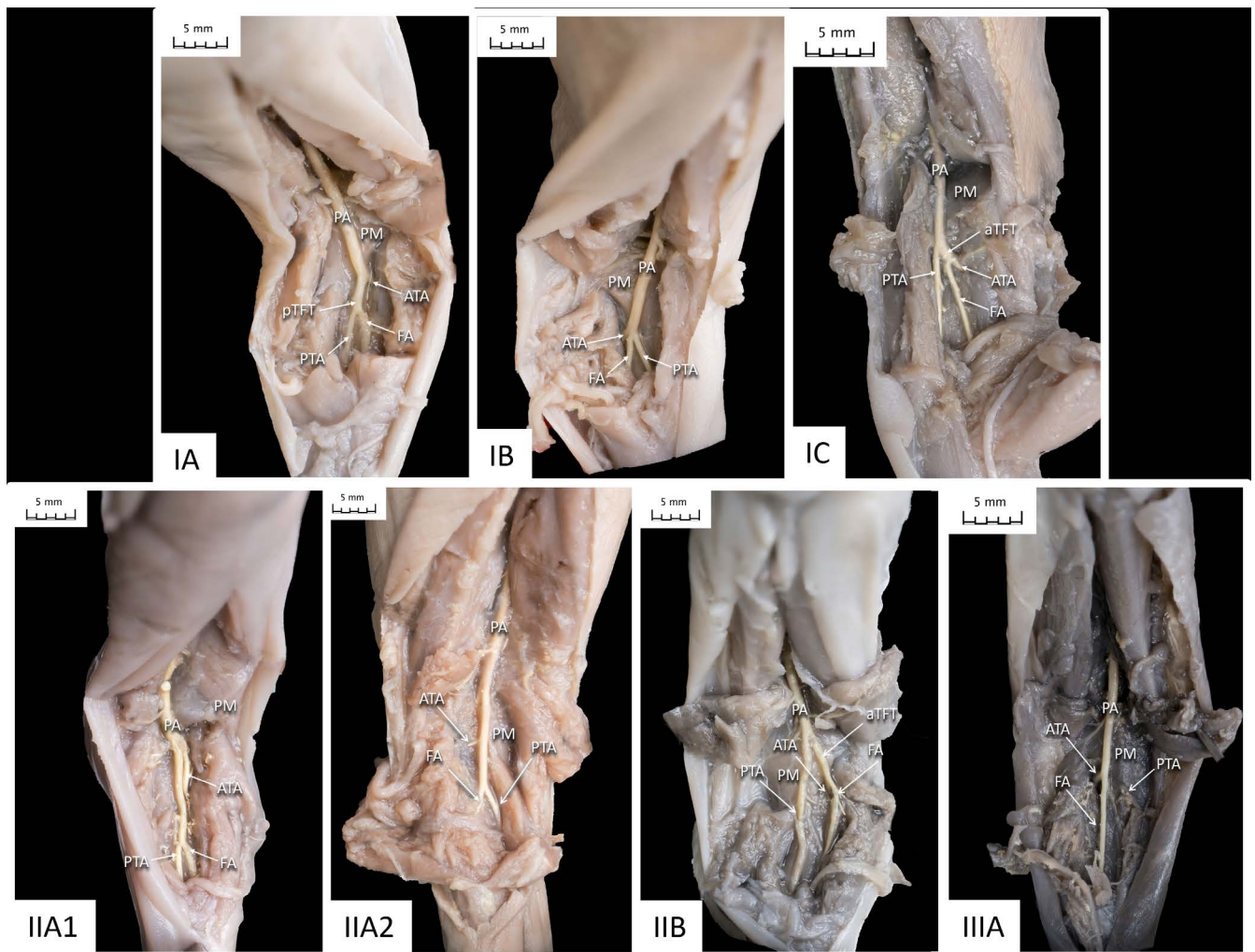


Figure 2. Course and branching patterns of the PA variation within the fetal population, categorized according to the adapted Lippert and Pabst system, as modified by Kim. Posterior View. This figure offering a visual and topographical representation of the anatomical structures and their relationships in the popliteal fossa. Comments: PA – popliteal artery; PM – popliteus muscle; ATA – anterior tibial artery; PTA – posterior tibial artery; TFT – tibio-fibular trunk; aTFT – anterior TFT; pTFT – posterior TFT; FA – fibular artery.

4. RESULTS

Based on the provided data, the distribution of PA variations was as follows:

- Category I was identified in 144 specimens, constituting 86.7% of the total;
- Category II was observed in 19 specimens, representing 11.4% of the sample population;
- Category III was the least common, found in only 3 specimens, making up 1.8% of the cases.

These findings provide insight into the prevalence of different anatomical variations within the fetal population, categorized according to the adapted Lippert and Pabst system, as modified by Kim.

Type IA was identified in 126 (75.9%) analyzed PTAs, which exhibited a visible posterior TFT (pTFT) with a length exceeding the average diameter of the PA. In 8 cases, a very short pTFT (shorter than the average PA diameter) was observed. The presence of a pTFT, regardless of its length, was noted in 80.72% of the examined specimens (Figure 2).

Among the 166 specimens examined, in 17 cases (10.24%) the type IB was observed, where the length of TFT did not surpass the average diameter of the tibial artery. Within these 17 cases, a true trifurcation of the PA, with 3 branches but without a pTFT, was observed in 4 cases (2.4%). In 8 of these cases, a pTFT was present, while in the remaining 5 cases, an anterior TFT (aTFT) was observed. The length of the TFT exceeded the average diameter of the PA in only 1 instance (0.6%). However, despite its length, type IC with an aTFT was observed in 6 cases (3.6%).

In all examined specimens within Category II, the FA divides from the PTA near the lower border of the PM (Figure 2). Within Type IIA, 2 distinct subtypes were identified, primarily differentiated by the course of the ATA in relation to the PM. Subtype 1 was observed in 6 out of 166 cases, accounting for 3.6%, whereas subtype 2, where the ATA passes anteriorly to the PM, was identified in 7 out of 166 cases, constituting 4.2%. Type IIB was observed in 6 out of 166 cases, accounting for 3.6%.

In 3 out of 166 cases, representing 1.8% of the total cases type IIIA was found.

5. DISCUSSION

Numerous previous publications describe PA variability mainly in adults. Adachi (1928)¹⁰ analyzed adult specimens and defined trifurcation if the common trunk following the origin of the first branch was less than or equal to 0.5 cm in length, finding 0.8% cases of trifurcation. Kim (1989)⁵ and Arayapithak (2023)¹¹ estimated a 2% frequency applying Adachi's rule but they analyzed angiograms. It is noteworthy that gender plays a significant role in branching variation.¹¹

Morris (1960)¹² proposed a broader criterion for trifurcation, encompassing cases where the TFT is shorter than 1 cm (5.8%). This more practical classification may be preferable for vascular surgeons, although Adachi's criteria are anatomi-

cally precise.⁵ The constant length criterion for TFT could not be applied due to varying fetal ages. Adachi and Morris assumed lengths (0.5 cm and 1 cm, respectively) comparable to the average PA diameter in adults. This study's classification exceeds Adachi's but doesn't broaden Morris's criteria. Among 166 examined limbs in 13 cases (7.8%), the TFT was shorter than the average diameter of the PA. In 8 of these cases the FA branches from the PTA (pTFT), and in 5 cases from the ATA (aTFT). Organism growth leads to changes in arterial supply preferences. It's essential to recognize that arterial segments don't exhibit uniform growth rates across developmental stages (fetal, infancy, or childhood), and the diameter-to-length ratio isn't constant. Also, no evidence was found that at every stage the ratio between the volume and the length of a vessel remains constant (and the diameter increases in direct correlation to the length of the vessel). Therefore, predictions could not be made of how many arteries with a short but visible TFT would be described as variations IA or IC after the completion of development. If we consider the analysis solely based on the presence or absence of the TFT, the current study would describe the following distribution: 134 cases (80.7%) of the usual branching type of PA, 4 cases (2.4%) of trifurcation and 6 cases (3.6%) with aTFT. Regarding the high PA division (Type II) in the current study, it was observed in 19 out of 166 examined limbs, constituting 11.45% of cases. Comparatively, Bardsley and Staple (1970)¹³ reported a 5.9% frequency, Lippert and Pabst (1985)⁸ found 5%, Kim (1989)⁵ noted 4.7%, Mauro (1988)³ reported 3.2%, and Adachi (1928)¹⁰ had a lower occurrence at 0.8%. The first branch at the same level as the popliteus muscle could be the ATA (Type IIA), the PTA (Type IIB), or the FA (Type IIC), with variations in the course of the ATA, including posterior (Type IIA1) or anterior (Type IIA2) to the PM. That independent branching of the FA over the knee joint was described by Kim (1989)⁵ in a single case found among 605 examined limbs (0.16%). During Adachi's (1928)¹⁰ dissections of adults, 0.9% type IIA1 variations and 1% type IIA2 variations were observed, while Lippert and Pabst (1985)⁸ found 3% type IIA1 variations and 1% type IIA2 variations. According to Bardsley and Staple (1970)¹³, the determination of whether a high ATA passes superficially or deep to the PM is not possible on an anteroposterior arteriogram. In such cases, the course of the ATA can only be evaluated using the lateral projection due to anteroposterior arteriograms' limitations. Mauro (1988)³ and Kim (1989)⁵ based their research on sketches by Adachi and concluded that the initial medial course of ATA, which then travels laterally, apparently crossing the TFT indicates that ATA goes deep to the PM (Type IIA1). However, only Kim (1989)⁵ attempted to evaluate such arteriograms and found type IIA1 incidence of 3%, and type IIA2 of 0.7%. In these findings, the type IIA2 variation was found in 7 limbs (4.2%) out of 166. Only in 3 of them, the ATA took an initially medial swing. In 4 other cases, the artery was directed laterally.

Within the category III, Kim included the PAs, where one terminal branches was aplastic or hypoplastic, which was related to the alteration of the foot's arterial supply

source. Strongly involuted PTA (type IIIA) joins either the communicating branch of the FA or FA directly. Thus, the extension of the PA is an enlarged FA, which is also the source of supply for the lateral plantar artery and the medial plantar artery. According to Adachi (1928)¹⁰, such variations appear in 8.5% of Europeans. Lippert and Pabst (1985)⁸ noticed 5% of such cases, Kim (1989)⁵ 3.8%, and Bardsley and Staple (1970)¹³ 0.9%. In the classical vascular pattern, the perforating branch of the FA anastomoses to the anterior lateral malleolar artery and takes part in the creation of the lateral malleolar network and the calcaneal anastomosis. In the case of a hypoplastic ATA (Type IIIB), the perforating branch of the FA can potentially replace the dorsalis pedis artery.¹⁴ The frequency of such variation differs in presented reports from 1.6% (Kim 1989)⁵ to 7.1% (Adachi 1928).¹⁰ In extremely rare cases (Type IIIC) both the AT and PTA may be hypoplastic, with the FA supplying the entire foot. Senior (1919)¹⁵ described it as the saphena (peronea) magna artery. Kim (1989)⁵ found only 1 such case among 495 examined extremities (0.2%). In this research, only 4 cases of hypoplastic PTA (2.4%) were found. These variations in Category III contribute to the understanding of alterations in foot arterial supply sources.

6. CONCLUSIONS

- (1) The abundance of PAs featuring abbreviated TFT and a frequent occurrence of bifurcation at the upper margin of the PM may be ascribed to population-specific idiosyncrasies or, alternatively, postnatal developmental changes in body proportions.
- (2) This investigation underscores the absence of empirical support for the constancy of the diameter-to-length ratio in arterial vessels throughout the entirety of the developmental period.
- (3) Further research is imperative to comprehensively elucidate the growth dynamics of the PA and its branch segments at various stages of development.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Ethics

Using the fetuses collection for the research received a positive opinion from the Local Ethics Committee for Scientific Research in Bydgoszcz (approval number 61/98).

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