MAK HILL Publications Research Journal of Medical Sciences

Research Article
doi: 10.36478/makrjms.2024.12.695.701

OPEN ACCESS

Key Words
Variations in branching pattern, popliteal artery, genicular artery, anatomical variations, anatomy

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Received: 10 October 2024
Accepted: 15 November 2024
Published: 31 December 2024

Citation: Dr. S. Maya, Dr. Geetha Jayachandran and Dr. M. Shefna, 2024. Branching Patterns and Anatomical Variations of the Popliteal Artery: A Descriptive Study. Res. J. Med. Sci., 18: 695-701, doi: 10.36478/makrjms.2024.12.695.701

Branching Patterns and Anatomical Variations of the Popliteal Artery: A Descriptive Study

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ABSTRACT
Understanding the anatomical variations in the branching pattern of the popliteal artery is crucial for surgical and diagnostic procedures involving the lower limb. This descriptive study aimed to examine the branching pattern and termination of the popliteal artery in 70 lower limbs from embalmed cadavers at Government Medical College Thiruvananthapuram and Alappuzha. Cadaveric dissection followed standard anatomical protocols, documenting variations in the origin, termination and branching patterns, with specific assessment of genicular and peroneal arteries. Statistical analysis was performed on recorded data. The study found that 34.3% of the examined limbs exhibited variations, including trifurcation and genicular artery differences. Notably, 11.4% showed a trifurcation pattern, while 2.9% had a high division of the popliteal artery. These findings emphasize the importance of recognizing such variations in clinical settings, particularly for radiologists, vascular surgeons and orthopedic surgeons, to enhance diagnostic accuracy, improve surgical outcomes and minimize complications in lower limb procedures. Further research is recommended to explore the clinical implications of these anatomical variations.

INTRODUCTION

The popliteal artery, a continuation of the femoral artery, begins at the tendinous opening in the adductor magnus muscle and serves as the primary conduit for blood flow to the leg and foot[1]. This artery travels laterally from the adductor magnus to the femoral intercondylar fossa, positioning itself as the deepest neurovascular structure within the popliteal fossa. Upon passing under the fibrous arch of the soleus muscle, the artery divides into its terminal branches, the anterior tibial artery and the posterior peroneotibial trunk and gives off muscular, cutaneous and genicular branches[2]. The popliteal artery is particularly vulnerable at the adductor magnus hiatus and the fascia associated with the soleus muscle, where it is prone to traction injuries during knee traumas and dislocations[3]. The genicular branches, along with contributions from other arteries, form a crucial anastomosis around the knee joint[4,5]. This anatomical positioning makes the artery susceptible to damage during orthopedic procedures such as arthroscopy and total knee arthroplasty, where instruments may come close to the posterior capsule of the knee[6]. Injuries to the popliteal artery can result in severe complications, including limb disability or life-threatening hemorrhage[7,8]. Given the potential for anatomical variations in the popliteal artery and its branches, understanding these variations is critical for surgeons performing procedures like femorodistal bypass grafting[9], revascularization of the lower limb, and treatment of popliteal entrapment syndrome. This cadaveric study aims to provide detailed insights into the branching patterns of the popliteal artery, including the origin and course of the artery, the mode and level of termination, variations in the genicular arteries[10] and the source and level of origin of the peroneal artery[11,12]. This information is valuable for radiologists, vascular surgeons, orthopedic surgeons and anatomists for enhancing diagnostic, interventional and educational practices[13,14].

MATERIALS AND METHODS

This descriptive study examined the branching patterns of the popliteal artery in 70 dissected adult human cadaveric lower limbs at the anatomy departments of Government Medical College Alappuzha and Government Medical College Thiruvananthapuram. The study spanned two years (2015-2018). The sample size was calculated using a formula n=(Z_(1-∝/2)^2 pq)/d^2, where 'p' is the prevalence and was obtained from a study by Reena Singla[15], which indicated an 85% prevalence of normal popliteal artery branching patterns. We included all embalmed lower limbs available at these institutions, excluding specimens with pathological lesions, traumatic lesions, or surgical scars. Cadavers used in the study were obtained either through donation with consent or from authorized police officers in the case of unknown and unclaimed bodies. Ethical approval was secured for the study. The dissection process followed Cunningham's Manual of Practical Anatomy, beginning with a horizontal incision made at the posterior aspect of the cadaveric lower limb at the lower border of the gluteal region at the upper one-third of the thigh. A vertical incision was made extending downwards from the middle of the first incision up to the heel. The skin and fascia were reflected. In the thigh region hamstring muscles were identified and detached to expose the adductor magnus muscle and adductor hiatus was identified. Popliteal fossa is exposed by lifting the tendons of muscles semimembranosis, semitendinosis and gracilis muscles from their distal attachments. Both the heads of the gastrocnemius muscle detached along with plantaris muscle. The Soleus muscle was separated from its attachment to tibia and turned downwards. The Popliteus muscle was cleared. The popliteal artery traced downwards from the level of adductor magnus to the level of lower border of popliteus muscle carefully by clearing the fascia and fat. Bifurcation of popliteal artery at the lower border of popliteus muscle was noted. Posterior tibial artery was further traced downwards to note the level of origin of peroneal artery. During dissection special care was taken to preserve the genicular branches and other significant vascular structures. Any variations in the branching patterns were documented and numbered. For visual clarity, arteries were painted red, veins blue, and nerves yellow, using fine brushes and oil colours. Photographs of the specimens were captured using a Canon 16-megapixel digital camera. The dissection tools included blunt and toothed forceps, scalpel blades and scissors, while painting tools comprised fabric colours and brushes.

RESULTS AND DISCUSSIONS

The present study was conducted on 70 formalin-fixed lower limbs from adult human cadavers in the departments of anatomy at Government Medical Colleges in Thiruvananthapuram and Alappuzha, with approval from the Institutional Ethics Committee. All specimens were selected according to specific inclusion and exclusion criteria and dissected following the Cunningham's Manual of Practical Anatomy. The study focused on describing the origin, termination and branching patterns of the popliteal artery, as well as variations in the genicular and peroneal arteries. It was observed that 85.7% of the specimens were from male cadavers and 14.3% were from female cadavers. There were equal numbers of right and left limbs. The popliteal artery was found to originate normally from the hiatus of the adductor magnus muscle in all specimens. The termination of the artery was observed at the lower border of the popliteus muscle in 97.1% of cases, which is considered the normal anatomical

position. However, a high division, where the artery terminated above the popliteus muscle, was observed in 2.9% of limbs and in both limbs of a single male cadaver. So, both limbs of a male cadaver had high division of the popliteal artery. (See Table 1). The mode of termination of the popliteal artery varied among the specimens. While 61% of limbs showed the typical bifurcation into the anterior tibial artery and posterior peroneotibial trunk, 11.4% exhibited a trifurcation pattern, where the artery divided into three branches: anterior tibial, posterior tibial and peroneal arteries. Additionally, in 1.4% of limbs, the artery terminated into the anterior peroneotibial trunk and posterior tibial artery. Notably, these variations were more prevalent in male cadavers, with 13.3% displaying trifurcation, while female limbs did not exhibit this variation (See Table 2). Genicular artery variations were also significant. The superior genicular artery, typically presenting as superior medial and superior lateral branches, showed a normal pattern in 87.1% of limbs(See Fig. 1-3).

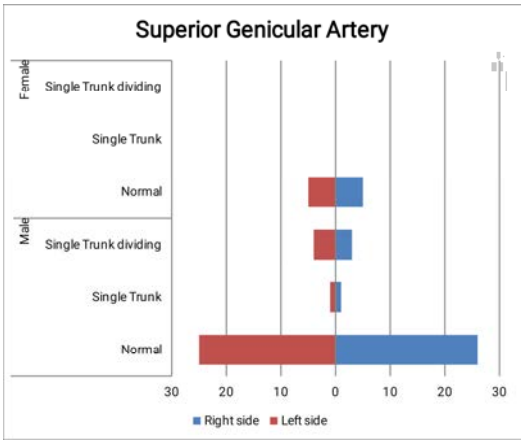

Fig. 1: Component Bar Diagram Showing Comparison of Gender Wise and Side Wise Distribution of Variations in Superior Genicular Artery

Fig. 2: Showing Superior Genicular Artery Emerging as a Single Trunk and Dividing

Fig. 3: Specimen Showing Superior Medial Genicular Artery, Superior Lateral Genicular Artery was Absent. Normal Middle and Inferior Genicular Arteries Can be Seen

In some cases, a single trunk was observed (2.9%) and in 10% of limbs, a single trunk divided into medial and lateral branches. These variations were predominantly found in male cadavers (See Table 3). The middle genicular artery was absent in 4.3% of limbs, all from male cadavers (See Fig. 4). The inferior genicular artery exhibited the highest variability, with 84.3% showing a normal presentation, 11.4% as a single trunk, 2.9% as a single trunk dividing and 1.4% where the artery was absent (See Fig. 5).

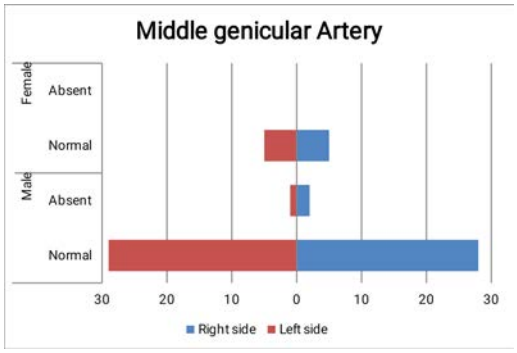

Fig. 4: Component Bar Diagram Showing Comparison of Gender Wise and Side Wise Distribution of Middle Genicular Artery

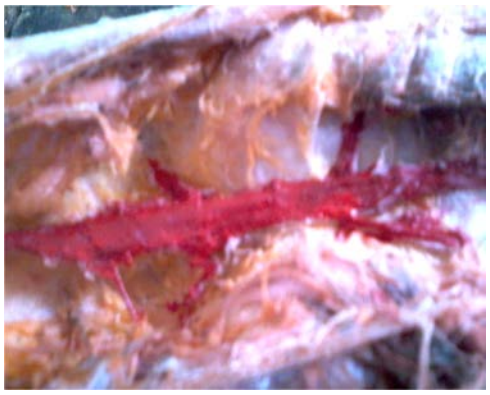

Fig. 5: Absence of Middle Genicular Arteries with Normal Superior and Inferior Genicular Arteries

Table 1: Comparison of Side-Wise and Gender-Wise Distribution of Variations in the Level of Termination of Popliteal Artery

Popliteal artery termination level	Male						Female					
	Right side		Left side		Total		Right side		Left side		Total	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Below Popliteus	29	96.7	29	96.7	58	96.7	5	100	5	100	10	100
Above Popliteus	1	3.3	1	3.3	2	3.3	0	0	0	0	0	0
Total	30	100	30	100	60	100	5	100	5	100	10	100

Table 2: Comparison of Side Wise and Gender-Wise Distribution of Variation in Mode of Termination of Popliteal Artery

Popliteal artery mode of termination	Male						Female					
	Right side		Left side		Total		Right side		Left side		Total	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Normal	25	83.3	27	90	52	86.7	5	100	4	80	9	90
Anteriorperoneotibial trunk and posterior tibial trunk	0	0	0	0	0	0	0	0	1	20	1	10
Trifurcation	5	16.7	3	10	8	13.3	0	0	0	0	0	0
Total	30	100	30	100	60	100	5	100	5	100	10	100

Table 3: Comparison of Side-Wise and Gender-Wise Distribution of Variations of Superior Genicular Artery

Superior Genicular Artery	Male						Female					
	Right side		Left side		Total		Right side		Left side		Total	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Normal	26	86.7	25	83.3	51	85	5	100	5	100	10	100
Single Trunk	1	3.3	1	3.3	2	3.3	0	0	0	0	0	0
Single Trunk dividing	3	10	4	13.3	7	11.7	0	0	0	0	0	0
Total	30	100	30	100	60	100	5	100	5	100	10	100

Table 4: Comparison of Side-Wise and Gender-Wise Distribution of the Variations in the Level of Origin of Peroneal Artery

Peroneal artery level of origin	Male						Female					
	Right side		Left side		Total		Right side		Left side		Total	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Normal	24	80	26	86.7	50	83.3	5	100	5	100	10	100
Low level	1	3.3	1	3.3	2	3.3	0	0	0	0	0	0
Just below popliteus	5	16.7	3	10	8	13.3	0	0	0	0	0	0
Total	30	100	30	100	60	100	5	100	5	100	10	100

Table 5: Comparison of Side Wise and Gender Wise Distribution of Variations in Source of Origin of Peroneal Artery

Peroneal artery source of origin	Male						Female					
	Right side		Left side		Total		Right side		Left side		Total	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Posterior tibial artery	25	83.3	27	90	52	86.7	5	100	4	80	9	90
Anterior tibial artery	0	0	0	0	0	0	0	0	1	20	1	10
Separate single trunk	5	16.7	3	10	8	13.3	0	0	0	0	0	0
Total	30	100	30	100	60	100	5	100	5	100	10	100

Role (Concepts, Design, Definition of intellectual content, investigation, manuscript writing, etc.)	Contributor 1	Contributor 2	Contributor 3	Contributor 4
Concept	Yes	Yes	Yes	Yes
Design	Yes	Yes	Yes	Yes
Definition of intellectual content, Review of literature	Yes		Yes	Yes
Investigation	Yes	Yes	Yes	
Data entry and Data analysis	Yes	Yes		Yes
Manuscript writing	Yes	Yes	Yes	Yes

Further analysis of the peroneal artery revealed that it had a normal level of origin in 85.7% of limbs. In 11.4%, the artery originated at the level of the lower border of the popliteus muscle, while a low origin, at about 5.7 cm from the bifurcation, was noted in 2.9% of cases (See Table 4). The source of origin of the peroneal artery also varied, with 61% originating from the posterior tibial artery, 11.4% as a separate trunk and in one instance, from the anterior tibial artery. These variations were primarily observed in male cadavers (See Table 5). The study found that 34.3% of the examined limbs exhibited variations in the branching pattern of the popliteal artery. This was observed more frequently in male cadavers (35%) compared to female cadavers (30%). Among male cadavers, 40% of right limbs and 30% of left limbs displayed variations, while among female cadavers, 20% of right limbs and 40% of left limbs showed variations. In summary, the study highlighted significant variations in the branching pattern of the popliteal artery in 24 lower limbs. Bilaterally variant popliteal artery was seen in 6 cadavers, with four lower limbs showing same

variations on both sides. The variations were more in its genicular branches. These findings emphasize the importance of considering anatomical variations in clinical settings, especially given the increasing frequency of knee surgeries and to have an angiographic evaluation of the leg prior to these procedures. The results suggest that further studies with larger sample sizes are warranted to better understand the implications of these anatomical variations.

Variations in the branching pattern of the popliteal artery have been documented since the 18th century. The first detailed study was by Quain[16], followed by subsequent descriptions by T.P. Anderson Stuart[9] and H.D. Senior[17], who linked popliteal artery embryology with adult anatomical variants[18]. Adachi created the first classification of these variations in 1928[19], refined by Lippert and Pabst[20]. The most widely accepted classification, by Kim[21], relies on radiological studies[22]. Numerous studies have since investigated the incidence of these variations, with findings often varying[23]. The adult vascular anatomy of the lower limb is established by the third month of gestation, with variations resulting from the persistence, degeneration, or abnormal fusion of embryonic vessels[15,24,25]. Our study, conducted on embalmed cadavers from Government Medical Colleges in Thiruvananthapuram and Alappuzha (2015-2018), sought to correlate these variations with embryo genesis and assess the incidence and types of branching variations of the popliteal artery[26-28]. Anomalous branching patterns may arise due to embryo logical defects, racial differences, or acquired factors and detailed knowledge of these variations is crucial for vascular and endo vascular surgery to avoid iatrogenic injuries[29-31]. In our study, all specimens exhibited a normal origin of the popliteal artery from the adductor magnus hiatus, continuing from the femoral artery[32-34]. No variations in the origin were noted, consistent with previous reports[35,36]. However, variations in the termination of the popliteal artery were observed, particularly high bifurcation above the popliteus muscle in 2.9% of limbs. This finding aligns with similar incidences reported by Adachi[37], Trotter[38] and Keen[39], among others. Notably, we observed trifurcation of the artery into the anterior tibial, posterior tibial and peroneal arteries in 11.4% of limbs, a higher incidence than previously reported, where rates ranged from 0.4-5%[20,40]. Additionally, the variation where the peroneal artery emerges from the anterior tibial artery was found in 1.4% of cases, similar to the incidences reported by Adachi[41] and Kim[21]. Variations in genicular arteries were present in 27% of limbs, predominantly in male cadavers[42-49]. These variations included single trunks and the absence of the middle genicular artery, which may have been compensated by the superior genicular artery. Overall, our study found that 34.3% of limbs exhibited branching variations, a higher percentage compared to earlier studies by Adachi[41], Quain[16], Keen[39] and others, which generally reported incidences below 10%[15]. This higher incidence in our study could be attributed to the increased frequency of genicular artery variations and trifurcation observed. The findings highlight the clinical significance of understanding these anatomical variations, particularly in surgical planning and management. The study's limitations include the lack of statistical comparison of gender-based variations and right-left preferences. Future research should focus on these aspects to further understand the genetic and embryo logical factors influencing these variations.

CONCLUSIONS

This study reveals a higher incidence of variation in the branching pattern of popliteal artery compared to previous reports, with significant variations in genicular arteries and trifurcation patterns. These findings underscore the importance for radiologists, vascular surgeons and orthopedic specialists to be aware of these anatomical variations. Understanding these variations is crucial for accurate diagnosis and effective management of knee joint procedures, endo vascular interventions and orthopedic surgeries, potentially mitigating complications and improving patient outcomes.

Ethics Approval and Consent to Participate: The cadavers used in this study were sourced through voluntary donation with consent or from authorized police officers in the case of unclaimed bodies. Prior approval was obtained from the Head of the Department of Anatomy at the respective institutions. Additionally, ethical clearance was granted by the Institutional Ethics Committee of Government Medical College, Thiruvananthapuram, Kerala, India.

List of Abbreviations: No abbreviations used.

Data Availability: The data supporting the findings of this study are available from the corresponding author upon reasonable request. Due to ethical considerations and institutional regulations, access to cadaveric study data is restricted. No publicly available repository has been used for data deposition.

Conflicts of Interest: The authors declare no financial or personal relationships that could influence this research. There are no affiliations, consultancies, stock ownerships, or paid expert roles linked to this study. No non-financial relationships, collaborations, or technological developments affect its objectivity. This study is presented transparently, adhering to ethical standards, with no conflicts of interest.

Funding Statement: This research received no financial support or funding from any organization or grant.

Authors' Contributions: All authors have contributed equally to this article at every stage, including conceptualization, data collection, analysis and manuscript preparation. Each author has actively participated in the research process, ensuring accuracy, consistency and critical evaluation of the findings. The drafting and revision of the manuscript were carried out collaboratively, with all authors providing intellectual input and reviewing the content thoroughly. All authors have read and approved the final version of the manuscript, confirming its integrity and validity.

ACKNOWLEDGMENTS

We extend our sincere appreciation to the faculty members of the Department of Anatomy at Government Medical College, Thiruvananthapuram and Alappuzha for their invaluable guidance and support throughout this research. Special thanks to the concerned departments for granting permission and facilitating the study. We also acknowledge Dr. Ashwin Raj KK, Assistant Professor, Department of Community Medicine, MES Medical College, Perinthalmanna, Kerala, for his assistance in resolving statistical queries. Additionally, we are grateful for the support provided during the cadaveric dissections, which significantly contributed to the success of this study.

Supplementary Materials: No supplementary materials are available for this study.

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