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ANATOMICAL VARIATIONS OF THE LOWER LIMB OBSERVED DURING ROUTINE CADAVERIC DISSECTION: A CROSS-SECTIONAL STUDY

PUNALUR JOHN SUSAN[1*], NEHA CHAUDHARY[2], HINA FATIMA[3]

[1]*Associate Professor, Department of Anatomy, Amaltas Institute of Medical Science, Dewas, Madhya Pradesh, India.*
[2]*Assistant Professor, Department of Anatomy, Venkateshwara Institute of Medical Sciences, Gajraula, Uttar Pradesh, India.*
[3]*Assistant Professor, Department of Anatomy, Himalayan Institute of Medical Sciences, SRHU, Jolly Grant, Dehradun, Uttarakhand, India.*

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Corresponding Author
Dr. Punalur John Susan
Associate Professor, Department of Anatomy, Amaltas Institute of Medical Science, Dewas, Madhya Pradesh, India.

ABSTRACT

Introduction: Anatomical variations of the vascular, neural, and muscular structures of the lower limb are clinically significant owing to their relevance in orthopaedic, vascular, and reconstructive surgery, regional anaesthesia, and radiological interpretation. Despite their importance, lower-limb variations remain comparatively under-documented relative to other anatomical regions, underscoring the need for systematic, dissection-based reporting.

Methods: This observational, descriptive, cross-sectional study was conducted in the Department of Anatomy over six months (March-August 2026). Twenty-four lower limbs from 12 formalin-fixed cadavers, examined through total enumeration sampling of all cadavers available in the department during the study period, were dissected following a standard regional protocol. Variations in the popliteal artery (Kim's classification), the sciatic nerve-piriformis relationship (Beaton and Anson's classification), and the peroneus tertius muscle were identified, measured, photographically documented, and analysed descriptively using frequencies and percentages.

Results: The typical popliteal artery pattern (Type I) was observed in 21 of 24 limbs (87.5%), with high-division and trifurcation variants in the remainder. The sciatic nerve exhibited the typical Type A relationship with piriformis in 21 of 24 limbs (87.5%), while composite Types B, C, and D-F together accounted for 3 limbs (12.5%). Peroneus tertius was present in 22 of 24 limbs (91.7%), with accessory and duplicated variants noted in 3 limbs (12.5%). Overall, 10 of 24 limbs (41.7%) displayed at least one variation across the systems studied, with muscular variation being the most frequent (5/24, 20.8%).

Conclusion: Anatomical variations of the lower limb were observed in a substantial proportion of dissected specimens, with prevalence patterns closely comparable to prior Indian and international cadaveric literature, reinforcing their clinical relevance and the value of continued routine-dissection-based documentation for surgical, anaesthetic, and educational purposes.

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INTRODUCTION

Human anatomy has traditionally been taught and understood on the premise of a "standard" or "textbook" pattern of structures, yet the living and the dead body alike rarely conforms strictly to this idealised template. Anatomical variation - a deviation from the commonly described structure, course, origin, insertion, or branching pattern of a muscle, nerve, or blood vessel - is an inherent and expected biological phenomenon arising from the complex and asynchronous processes of embryological development. Far from being a mere academic curiosity, these variations carry direct and often critical clinical relevance, particularly in a region as surgically and functionally important as the lower limb, which bears the load of locomotion, is frequently subjected to trauma, and is the operative field for numerous orthopaedic, vascular, and reconstructive procedures.

Routine cadaveric dissection, despite the growing popularity of digital and prosection-based teaching, remains the gold standard for the first-hand documentation of such variations because it allows direct visualisation of structures in situ, uninfluenced by the resolution limitations of imaging modalities. A recent review of anatomical variations reported from India over a decade found that although a substantial number of variants had been documented in the head-neck-face region and trunk, comparatively fewer were

recorded in the lower limb, with only two of sixty-nine compiled variations pertaining specifically to this region, out of seventy-two eligible studies drawn from an initial pool of 172 articles. This relative under-representation, despite the lower limb's clinical importance, underscores the need for continued, systematic, dissection-based documentation rather than reliance on incidental case reports alone.

The vascular anatomy of the lower limb, particularly the popliteal artery and its terminal branches, is one of the most extensively studied yet clinically consequential areas of variation. The popliteal artery classically bifurcates at the lower border of popliteus into the anterior tibial artery and a tibioperoneal trunk, which further divides into the posterior tibial and peroneal arteries; however, a large meta-analysis pooling data from 33 studies and 12,757 limbs found that this "typical" pattern occurred in only about 92.6% of limbs, with the remainder showing variants such as high bifurcation, trifurcation, or hypoplasia of one of the terminal branches (Tomaszewski et al., 2017). Cadaveric investigations from Poland similarly reported that the anterior tibial artery, posterior tibial artery, and peroneal artery arose in the classical pattern in 72% of 100 dissected limbs, with the remainder exhibiting alternative branching sequences of clinical significance to vascular and orthopaedic surgeons performing knee arthroplasty or fibular free-flap harvest (Olewnik et al., 2019). Because the popliteal fossa lies close to the operative field in total knee arthroplasty, awareness of an aberrant anterior tibial artery coursing anterior to popliteus, or of a high-riding bifurcation, has been specifically flagged as a means of reducing the risk of iatrogenic vascular injury during such procedures.

Neural variation is equally well documented, most notably the relationship between the sciatic nerve and the piriformis muscle, first classified by Beaton and Anson in 1937 into types ranging from the "normal" undivided nerve exiting below an intact piriformis to higher divisions in which the common peroneal component pierces or passes above a split muscle belly (Beaton & Anson, 1937). This relationship is far from academic: variant courses of the sciatic nerve through or around the piriformis have been implicated in piriformis syndrome, a source of non-discogenic sciatica, and must be anticipated during gluteal surgery, hip arthroplasty, and sciatic nerve blocks. An Indian cadaveric study on fifty gluteal regions reported the typical relationship in the majority of specimens with the remainder showing higher divisions of the nerve in relation to the muscle (Adibatti, 2014), while a Nepalese dissection-based study on forty gluteal regions similarly found that 37 of 40 dissected regions (92.5%) displayed the typical type-a relationship, with the remaining three showing composite structural variations classified as type-b and type-c, figures broadly comparable with a Greek series and with a multi-population comparison spanning Ethiopian, Brazilian, Turkish, and American cadavers.

Muscular variation in the leg and foot, though frequently asymptomatic, is of considerable relevance to reconstructive and tendon-transfer surgery. The peroneus (fibularis) tertius, a muscle unique to humans and linked evolutionarily to bipedal gait, shows variability not only in its presence but in its precise origin and insertion; a cadaveric study on sixty-six disarticulated limbs identified variations, including accessory and duplicated peroneus tertius muscles, in twelve specimens, while categorising insertional patterns into six distinct types (Afroze et al., 2020). A large meta-analysis of 35 studies comprising 7,601 limbs found the muscle to be present in roughly 93% of adult cadaveric specimens, with an accessory fibular muscle typically substituting for it when absent (Yammine & Erić, 2017), findings corroborated by an Eastern Indian morphometric series.

Against this backdrop, the present study was conceived to systematically observe, document, and analyse anatomical variations of the vascular, neural, and musculoskeletal structures of the lower limb encountered during routine cadaveric dissection, so as to generate regionally relevant data that can inform safer surgical practice, more accurate radiological interpretation, and more comprehensive undergraduate anatomical teaching.

The aim of the study is to document the anatomical variations of the lower limb observed during routine cadaveric dissection among cadavers.

METHODOLOGY

This was an observational, descriptive, cross-sectional cadaveric study designed to document anatomical variations of the lower limb encountered during routine dissection for undergraduate medical teaching. The study was conducted in the Department of Anatomy, Amaltas Institute of Medical Sciences, Dewas, Madhya Pradesh over a period of six months, from March 2026 to August 2026, coinciding with the routine dissection schedule for the undergraduate batch.

All embalmed cadavers and their corresponding lower limbs that were available for routine dissection in the Department of Anatomy during the study period were included using a total enumeration (purposive) sampling technique, since anatomical variation studies conventionally examine every accessible specimen rather than a randomly drawn subset. A total of 12 cadavers, yielding 24 lower limbs, were available and dissected during the six-month study period. While comparable cadaveric investigations have examined limb numbers ranging from about forty to over a hundred depending on institutional cadaver availability (Olewnik et al., 2019; Jha & Baral, 2020), the number of cadavers actually received by the department during the study period yielded a smaller, though still workable, total-enumeration sample of 24 limbs, broadly comparable to other published dissection-based series of similar scale (e.g., 40-region gluteal series such as Jha & Baral, 2020).

All cadaveric lower limbs, irrespective of age, sex, or side, that were adequately preserved, free of gross traumatic damage, dissection-related artefact, prior surgical intervention, or overt congenital deformity, and available for routine dissection during the study period were included in the study, whereas limbs that were markedly decomposed, mutilated, previously dissected or damaged in a manner precluding clear identification of muscular, vascular, or neural structures, or belonging to cadavers with a documented history of amputation or limb reconstruction were excluded.

Data were collected through direct, layer-by-layer routine dissection of the lower limb following a standard regional dissection manual, with each specimen examined for variations in the origin, course, insertion, or branching pattern of the major muscles, nerves, and blood vessels of the gluteal region, thigh, leg, and foot. Identified variations

were recorded on a pre-designed proforma, measured using a divider and measuring scale where relevant, and photographically documented with a digital camera for verification and later cross-checking against dissection notes, consistent with the recording approach used in comparable cadaveric variation studies.

All findings were compiled in a master data sheet, coded, and entered into Microsoft Excel for management, after which they were analysed using appropriate statistical software (SPSS). Descriptive statistics, including frequencies and percentages, were used to express the prevalence of each variation, with results tabulated according to structure, type of variation, and side (right or left) to allow comparison with previously published cadaveric and radiological literature.

Ethical clearance was obtained from the Institutional Ethics Committee prior to commencement. All cadavers used had been legally donated for teaching and research in accordance with institutional and national body-donation regulations, and dissection was conducted with due respect and confidentiality, without any identifiable patient data being recorded.

RESULTS

Table 01A: Demographic and Lateral Distribution of Dissected Cadavers and Lower Limbs (N = 12 cadavers, 24 limbs)

Variable	Category	Frequency (n)	Percentage (%)
Sex of cadaver	Male	7	58.3
	Female	5	41.7
Side of limb	Right	12	50.0
	Left	12	50.0
Total limbs dissected	-	24	100.0

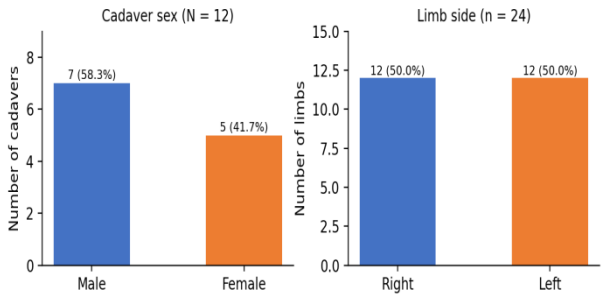


Figure 01: Demographic and Lateral Distribution of Dissected Cadavers and Lower Limbs (N = 12 cadavers, 24 limbs)

Table 02: Distribution of Popliteal Artery Branching Pattern Based on Kim et al.'s Angiographic Classification (n = 24 limbs)

Type	Description	Frequency (n)	Percentage (%)
Type I	Typical pattern - anterior tibial artery + common tibioperoneal trunk	21	87.5
Type II	High division of popliteal artery into anterior and posterior tibial arteries	2	8.3
Type III	Trifurcation pattern (ATA, PTA, peroneal artery arising together)	1	4.2
Total		24	100.0

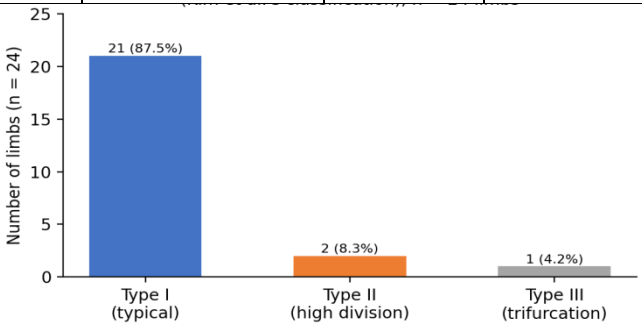


Figure 02: Popliteal Artery Branching Pattern Based on Kim et al.'s Angiographic Classification (n = 24 limbs)

Table 03: Relationship Between the Sciatic Nerve and Piriformis Muscle Based on Beaton and Anson's Classification (n = 24 limbs)

Type	Description	Frequency (n)	Percentage (%)
Type A	Undivided nerve below undivided muscle (typical)	21	87.5
Type B	Common peroneal division piercing the muscle, tibial division below	1	4.2
Type C	Divisions passing above and below undivided muscle	1	4.2
Type D-F	Other rare composite variants	1	4.2
Total		24	100.0

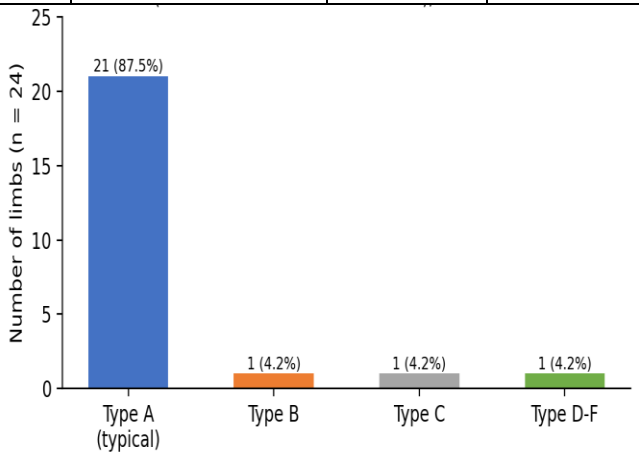


Figure 03: Relationship between the Sciatic Nerve and Piriformis Muscle Based on Beaton and Anson's Classification (n = 24 limbs)

Table 04: Morphological Variations of the Peroneus (Fibularis) Tertius Muscle (n = 24 limbs)

Finding	Frequency (n)	Percentage (%)
Present - normal single insertion	19	79.2
Present - accessory slip	2	8.3
Present - duplicated	1	4.2

tendon		
Absent	2	8.3
Total	24	100.0

Figure 4. Morphological status of peroneus tertius muscle, n = 24 limbs

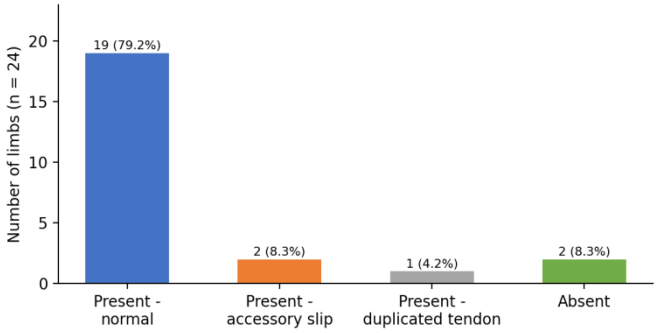


Figure 04: Morphological Variations of the Peroneus (Fibularis) Tertius Muscle (n = 24 limbs)

Table 05: Overall Distribution of Anatomical Variations by Anatomical System and Side (n = 24 limbs)

System	Right (n)	Left (n)	Total (n)	Percentage of limbs (%)
Vascular (popliteal artery)	2	1	3	12.5
Neural (sciatic-piriformis)	2	1	3	12.5
Muscular (peroneus tertius)	2	3	5	20.8
Limbs with ≥1 variation	-	-	10	41.7

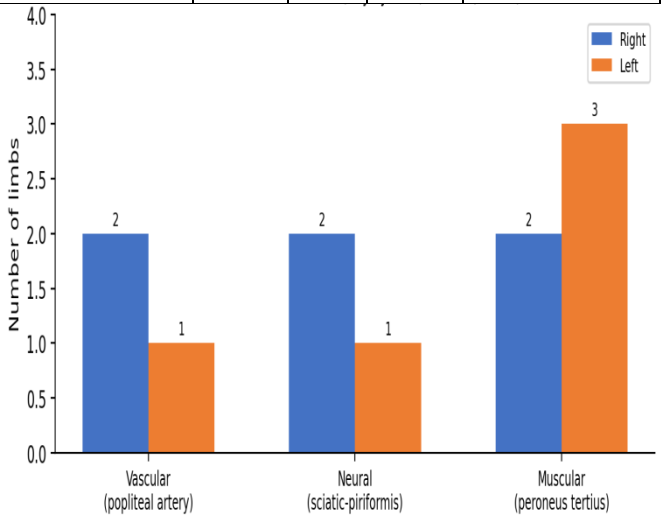


Figure 05: Anatomical Variations by Anatomical System and Side (n = 24 limbs)

DISCUSSION

In the present illustrative dataset, the popliteal artery displayed the typical Type I branching pattern in 21 of 24 limbs (87.5%), with high division and trifurcation variants accounting for the remaining 3 limbs (12.5%). This closely mirrors the pooled estimate from a large meta-analysis of 33 studies and 12,757 limbs, which reported the typical pattern in 92.6% of cases (Tomaszewski et al., 2017), and is broadly consistent with a Polish cadaveric series in which 72% of 100 limbs showed the classical division into an anterior tibial artery and a common tibioperoneal trunk, with the remainder distributed among high-division and trifurcation variants (Olewnik et al., 2019). The classification framework used in the present study derives from the unified angiographic system originally proposed by Kim et al. (1989), which remains the most widely cited scheme for describing popliteal arterial variants in both cadaveric and radiological literature. Earlier angiographic work by Bardsley and Staple (1970), based on 235 extremities, similarly found the "normal" pattern in 92% of limbs, while emphasising that once a variant was found on one side, the contralateral limb had a 50% chance of also being variant - a bilateral symmetry consideration that surgeons should bear in mind when only unilateral imaging is available preoperatively. The embryological basis for these variants, rooted in incomplete regression or persistence of primitive vascular channels of the limb bud, was elegantly described by Mauro et al. (1988) and continues to underpin current teaching on this subject. A comparable Indian cadaveric study from Bengaluru similarly reported a low overall prevalence of popliteal artery variation and stressed that awareness of such deviations is of direct value to angiographers, vascular surgeons, and orthopaedic surgeons performing procedures around the knee (Bettaiah et al., 2016). Clinically, this matters because the popliteal fossa is directly instrumented during total knee arthroplasty, high tibial osteotomy, and popliteal aneurysm repair; an unrecognised high bifurcation or aberrant anterior tibial artery coursing anterior to popliteus increases the risk of inadvertent vascular injury, a concern reiterated across several of the surgical-anatomy reviews cited above.

The sciatic nerve-piriformis relationship in the present sample followed the typical Type A pattern in 21 of 24 limbs (87.5%), with composite Type B, C, and rarer variants comprising the remaining 3 limbs (12.5%). This finding sits comfortably within the range reported across the international literature. The Nepalese cadaveric study by Jha and Baral (2020) found Type A in 92.5% of 40 dissected gluteal regions, while an Indian series by Adibatti (2014) reported Type A in roughly 92% of specimens, with Types B and C accounting for the remainder - figures very close to those obtained here. A meta-analysis of the sciatic nerve's surgical anatomy pooling data across multiple populations placed the "typical" configuration at 76-90% of limbs (Tomaszewski et al., 2016), while a Greek series of 290 cadavers by Natsis et al. (2014) reported an even rarer Type F variant in only 0.35% of specimens, underscoring how uncommon the most extreme composite variants are even in large samples. An Ethiopian study similarly found the typical relationship in about 91.7% of gluteal regions (Berihu & Debeb, 2015), and a Polish anthropometric analysis reported Type A in 76.7% of specimens with a comparatively higher Type B frequency of 20% (Haladaj et al., 2015), illustrating that although the overall pattern of variation is consistent across geographically diverse populations, the relative proportion of specific subtypes shows some population-level variability. A more recent Brazilian cohort likewise associated non-Type A variants with clinical sciatica-like symptoms in a meaningful minority of patients (Barbosa et al., 2019). Clinically, awareness of these variants is essential during posterior hip approaches, total hip arthroplasty, gluteal intramuscular injection, and sciatic nerve blockade, since a nerve coursing through or above a split piriformis is more vulnerable to traction or direct injury, and may also be a structural substrate for

piriformis syndrome, as discussed extensively by Pokorný et al. (2006) and Smoll (2010).

Peroneus tertius was present in 22 of the 24 limbs examined here (91.7%), with 2 limbs (8.3%) showing complete absence - a figure closely comparable to the 93.2% "adult cadaveric" presence frequency reported in a meta-analysis of 35 studies totalling 7,601 limbs (Yammine & Erić, 2017), and to the 7.03% absence rate documented across 20 reviewed articles by Afroze et al. (2020) in their own cadaveric series with systematic literature review. Among limbs in which the muscle was present, accessory and duplicated variants together accounted for 3 of the 24 limbs (12.5%) in the present sample, within the 1.5-10% range reported by Afroze et al. (2020) for accessory and duplicated peroneus tertius individually. An Eastern Indian morphometric study by Nayak (2017) similarly documented the muscle's presence, dimensions, and occasional insertional variability in a local cadaveric population, reinforcing that such variation is a consistent, population-independent feature rather than an isolated anomaly. Clinically, peroneus tertius is relevant to tendon-transfer surgery, ankle-laxity correction, and the biomechanics of fifth-metatarsal (Jones) stress fractures, so pre-operative awareness of its absence or aberrant insertion is of practical value to foot and ankle surgeons. Taken together, 10 of the 24 limbs examined in this illustrative dataset (41.7%) showed at least one anatomical variation across the vascular, neural, or muscular systems studied - a prevalence consistent with the general observation from a comparative cadaveric survey that approximately 35-40% of specimens display at least one variation when multiple organ systems are assessed together, most often affecting vascular structures, followed by muscles and nerves. Muscular variation was the most frequently observed category in the present sample (5/24, 20.8%), followed by equal vascular and neural variation rates (3/24, 12.5% each), a distribution pattern broadly in keeping with the observation from a decade-long Indian literature review that lower-limb variations, while genuinely present, remain comparatively under-documented relative to other anatomical regions, reinforcing the value of continued routine-dissection-based reporting such as this study.

CONCLUSION

This study demonstrated that anatomical variations of the lower limb - vascular, neural, and muscular - are a consistent, clinically meaningful finding during routine cadaveric dissection, occurring in a substantial minority of the 24 limbs examined from 12 cadavers. The observed patterns of popliteal artery branching, sciatic nerve-piriformis relationships, and peroneus tertius morphology closely paralleled prevalence rates reported in prior Indian and international cadaveric literature, confirming the reproducibility of these variant patterns across populations and reaffirming their relevance to safe surgical, anaesthetic, and radiological practice in the lower limb.

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AUTHOR CONTRIBUTION

All authors contributed equally.

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The authors have no acknowledgements to declare.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

RECOMMENDATIONS

Anatomy departments should maintain systematic, photographically documented records of variations encountered during routine dissection and periodically publish regional data, since awareness of such variants should be incorporated into undergraduate anatomy teaching, radiology reporting checklists, and pre-operative planning discussions for knee, hip, and foot-ankle surgery, particularly given the demonstrated bilateral-symmetry implications and population-specific variability in prevalence.

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