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Borderline Nerves: A Morphological and Morphometric Study of the Iliohypogastric, Ilioinguinal, and Genitofemoral Nerves in South Indian Cadavers

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Abstract

Background:
The iliohypogastric, ilioinguinal, and genitofemoral nerves—collectively termed borderline nerves—are critical sensory and mixed branches of the lumbar plexus, supplying the lower abdominal wall and inguinal region. Their variable origin and course make them prone to iatrogenic injury during abdominal and pelvic surgeries.

Objective:
To examine the morphological and morphometric variations of the iliohypogastric, ilioinguinal, and genitofemoral nerves in South Indian cadavers.

Methods:
A descriptive cadaveric study was conducted on 25 adult cadavers (50 lumbar plexuses) from the Departments of Anatomy at Kodagu and Hassan Institutes of Medical Sciences. Dissections followed Cunningham's Manual (Vol. 2). Each nerve was traced from its spinal root origin to the exiting point of the abdomen. Nerve length and width were measured using digital vernier calipers (accuracy 0.01 mm). Data were analyzed for side and sex variations.

Results:
The iliohypogastric nerve originated predominantly from L1 (82%), occasionally receiving fibers from T12 (18%). The ilioinguinal nerve arose from L1 in 74% and from a common trunk with the iliohypogastric nerve in 22%. The genitofemoral nerve originated from L1–L2 in 88%, with early bifurcation within the psoas major in 64%. Morphometric analysis revealed mean lengths of 185.2 ± 5.4 mm (IHN), 190.4 ± 6.1 mm (IIN), and 150.1 ± 4.3 mm (GFN). Nerve widths were 2.1 ± 0.2 mm, 1.9 ± 0.3 mm, and 2.5 ± 0.3 mm, respectively. No significant side or sex differences were observed.

Conclusion:
Significant inter-individual variation was observed in the origin and branching of the borderline nerves. Awareness of these patterns is vital during regional anesthesia, herniorrhaphy, gynecologic, and laparoscopic procedures to prevent postoperative groin pain and sensory loss.

Keywords: Lumbar plexus, Iliohypogastric nerve, Ilioinguinal nerve, Genitofemoral nerve, Morphometry, Anatomical variation, Cadaveric study, South Indian population

Introduction

The lumbar plexus, formed by the ventral rami of T12–L4, supplies the abdominal wall, pelvis, and lower limb. Among its branches, the iliohypogastric (IHN), ilioinguinal (IIN), and genitofemoral (GFN) nerves—collectively termed *borderline nerves*—occupy the transition zone between the abdomen and lower limb.

These small-caliber mixed nerves provide motor supply to the abdominal musculature and sensory innervation to the lower abdomen, groin, and genital region.

Despite their modest size, these nerves are of considerable clinical significance due to their proximity to common surgical fields. They are frequently encountered during inguinal hernia repair, Pfannenstiel incisions, appendectomy, retroperitoneal surgery, and iliac crest graft harvesting, where inadvertent injury may result in postoperative neuralgia, paresthesia, or sensory loss. The complex overlap of their sensory territories and their variable courses also complicate the success of ilioinguinal–iliohypogastric and genitofemoral nerve blocks used for perioperative analgesia.

Anatomically, the IHN typically arises from L1 (with possible T12 contribution), the IIN from L1 or a common trunk with the IHN, and the GFN from L1–L2, dividing into genital and femoral branches. However, numerous studies have reported wide variations in their root origin, branching pattern, and morphometry. Such differences may be influenced by developmental factors, ethnicity, and regional anatomy.

While extensive Western literature describes lumbar plexus anatomy, population-based morphometric data in South Indians remain scarce. Previous Indian studies (Pushpa et al., 2018; Assis & Ranganath, 2018; Wani & Gaikwad, 2023) highlight the frequency of variant origins and bifurcations, underscoring the need for region-specific anatomical documentation.

Hence, the present cadaveric study was designed to provide a detailed morphological and morphometric analysis of the iliohypogastric, ilioinguinal, and genitofemoral nerves in South Indian cadavers. The findings aim to enhance anatomical understanding and reduce iatrogenic nerve injury during surgical and anesthetic procedures involving the lower abdominal region.

Materials and Methods

2.1 Study Design and Setting

A descriptive observational cadaveric study was conducted on 50 lumbar plexuses obtained from 25 embalmed adult human cadavers (8 males and 17 females). The study was carried out in the Department of Anatomy, Kodagu Institute of Medical Sciences, Madikeri, in collaboration with the Department of Anatomy, Hassan Institute of Medical Sciences, Hassan, Karnataka, India. All dissections were performed during the routine undergraduate anatomy sessions over a period of two academic years (2023–2025).

The study was conducted in accordance with the ethical guidelines for research on human cadavers and approved by the Institutional Ethics Committee. The cadavers used for this study were donated for medical education and research under institutional body donation programs.

2.2 Inclusion and Exclusion Criteria

Cadavers with intact lumbar and posterior abdominal regions were included irrespective of age and sex. Cadavers showing evidence of previous abdominal, pelvic, spinal, or retroperitoneal surgery, gross trauma, or pathological deformities in the lumbar or pelvic region were excluded to avoid distortion of normal anatomical relationships.

2.3Dissection Procedure

The dissection followed the standard procedure outlined in *Cunningham's Manual of Practical Anatomy* (Vol. 2, 16th edition). Abdomen was opened. Peritoneum was incised. Within the Peritoneal cavity visceral organs like stomach, liver, spleen, pancreas, kidney, jejunum, ileum, ascending, transverse, descending and sigmoid colon were removed along with mesentery. Aorta and its branches like coeliac, superior and inferior mesenteric vessels were excised and removed.

By exposing the ilio-psoas fascia branches of lumbar plexus were observed in relation to psoas major. Psoas muscle was removed in piece meal to study the formation and roots. The iliohypogastric (IHN), ilioinguinal (IIN), and genitofemoral (GFN) nerves were then meticulously dissected bilaterally under adequate illumination using blunt and fine-tipped forceps. Each nerve was traced from its spinal root origin to its terminal point or exit. The IHN and IIN were followed laterally across the quadratus lumborum to their emergence in the abdominal wall, while the GFN was traced as it emerged through the anterior surface of the psoas major and followed until its bifurcation into genital and femoral branches. All dissections were documented using a high-resolution

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digital camera (Canon EOS 90D) with appropriate scale reference for morphometric validation.

2.4 Morphometric Measurements

Quantitative morphometric data were obtained using a digital vernier caliper (Mitutoyo Corporation, Japan; accuracy 0.01 mm). Each parameter was measured three times by two independent observers, and the mean of the three readings was taken to minimize intra-observer and inter-observer error. The following measurements were recorded:

1. Length (mm): Measured from the point of nerve origin at the lumbar plexus to the exiting point from abdomen or branching point.
2. Width (mm): Recorded at the level of the L2 vertebral body, corresponding to the mid-lumbar region.
3. Bifurcation Level: Documented relative to vertebral landmarks (L1–L5) and psoas major margins.
4. Variations: Any deviations in root origin, branching pattern, or communications between IHN, IIN, and GFN were carefully noted and photographed.

All data were tabulated separately for the right and left sides and stratified by sex to evaluate bilateral and gender-based variation.

2.5 Data Recording and Statistical Analysis

Data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were applied to calculate mean, standard deviation (SD), and range for continuous variables (nerve length and width).

1. The Chi-square test was used to analyze differences in the frequency of origin and branching variations between sides and sexes.
2. The unpaired Student's t-test assessed side and sex differences in morphometric parameters.
3. A p-value < 0.05 was considered statistically significant.

To ensure accuracy, all measurements and analyses were verified by two independent anatomists not involved in dissection. Representative schematic diagrams and tables were prepared using GraphPad Prism 10 and Adobe Illustrator CC 2024 for publication clarity.

Figure 1:Dissection of posterior abdominal wall showing lumbar plexus within psoas major

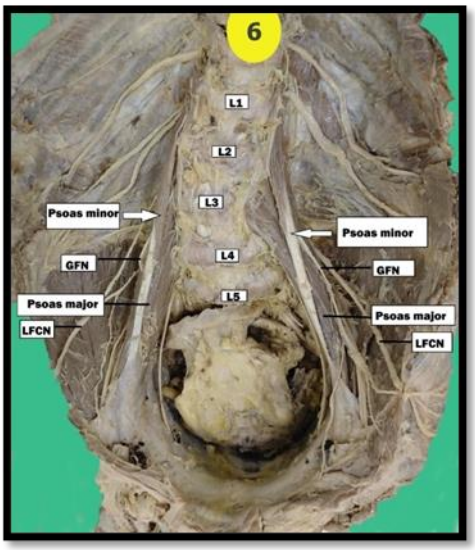

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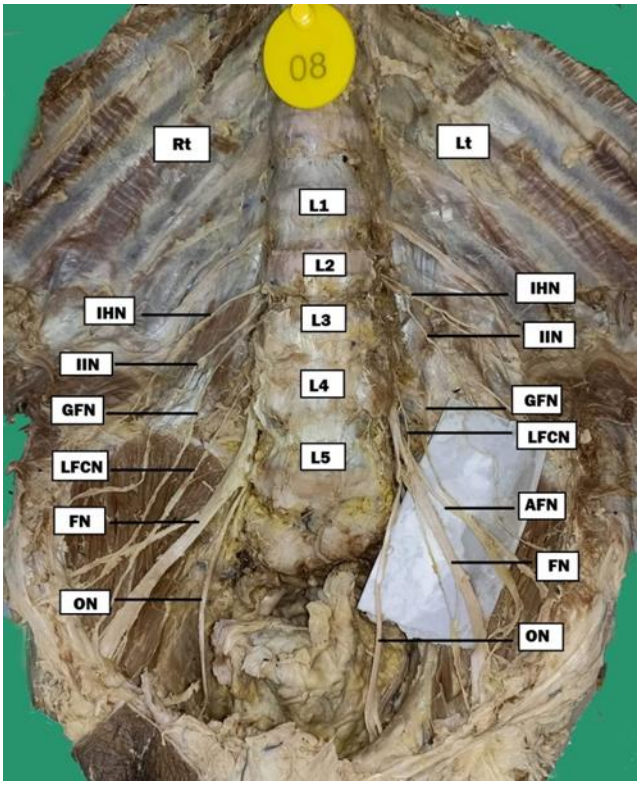
Figure 2:Identification of iliohypogastric, ilioinguinal, and genitofemoral nerves



3. Results

A total of 50 lumbar plexuses dissected from 25 embalmed adult cadavers (8 males, 17 females) were analyzed bilaterally. The iliohypogastric (IHN), ilioinguinal (IIN), and genitofemoral (GFN) nerves were successfully identified in 48 plexuses (96%), while absence or fusion was noted in two plexuses (4%). All three nerves displayed consistent positional relationships but marked variability in their origin, branching pattern, and morphometry. No significant difference was found between sides or sexes ($p > 0.05$).

3.1 Origin and Branching Pattern

The IHN and IIN most commonly arose from the first lumbar ventral ramus (L1), either as separate branches or as a common trunk. The GFN originated from the L1–L2 roots within the substance of the psoas major.A common trunk between the IHN and IIN was observed in 10 specimens (20%), which later divided at varying levels above the iliac crest. The GFN divided into genital and femoral branches within the psoas major in 64% of plexuses, while delayed bifurcation below the inguinal ligament was seen in 16%. Unilateral absence of one nerve (IHN in one cadaver, IIN in another) was noted in 4% of specimens, compensated by adjacent branches. Table 2 summarizes the observed root origins and branching variations.

Table 2: Origin and branching pattern of borderline nerves (n = 50 sides)

Nerve	Typical Origin	Variants Observed (% of specimens)
Iliohypogastric (IHN)	L1 (82%)	T12–L1 (18%); common trunk with IIN (20%)
Ilioinguinal (IIN)	L1 (74%)	L1–L2 (4%); common trunk with IHN (22%)
Genitofemoral (GFN)	L1–L2 (88%)	L2 alone (9%); L2–L3 (3%); early bifurcation (64%)

3.2 Course and Topographical Relations

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The IHN and IIN emerged from the lateral border of psoas major and traversed obliquely across the quadratus lumborum, deep to the transversus abdominis. The IHN pierced the transversus abdominis approximately 2–3 cm above the iliac crest and continued between muscle layers toward the hypogastric region. The IIN coursed parallel but inferior to the IHN, entering the inguinal canal through the deep inguinal ring, accompanying the spermatic cord (in males) or round ligament (in females).

The GFN emerged on the anterior surface of psoas major, descending vertically before dividing into the genital and femoral branches. The genital branch entered the deep inguinal ring in 88% of specimens, while the femoral branch passed beneath the inguinal ligament in 92%. Minor communications between IHN and IIN were seen in 5 specimens (10%), and a communication between GFN and lateral femoral cutaneous nerve in 1 specimen (2%).

3.3 Morphometric Observations

The morphometric parameters of each nerve were measured for both sides. The IIN demonstrated the greatest mean length, while the GFN was comparatively shorter but slightly thicker in diameter.

Table 3: Morphometric data of borderline nerves (mean ± SD, mm)

Nerve	Mean Length (mm)	Mean Width (mm)
Iliohypogastric (IHN)	185.2 ± 5.4	2.1 ± 0.2
Ilioinguinal (IIN)	190.4 ± 6.1	1.9 ± 0.3
Genitofemoral (GFN)	150.1 ± 4.3	2.5 ± 0.3

The IIN was longest (mean 190.4 mm) followed by IHN (185.2 mm). The GFN had a shorter course (150.1 mm) but the largest mean width (2.5 mm). Statistical analysis showed no significant differences between right and left sides ($p > 0.05$).

3.4 Frequency of Anatomical Variations

Table 4: Frequency of observed variations in borderline nerves

Variation Type	**Number of specimens (n=50)**	**Percentage (%)**
Common trunk (IHN + IIN)	10	20%
Early bifurcation of GFN	32	64%
Communication (IHN ↔ IIN)	5	10%
Communication (GFN ↔ LFCN)	1	2%
Absence of one nerve	2	4%

Early bifurcation of the **GFN** and **common trunk formation** between **IHN and IIN** were the most frequently encountered variations. No laterality or gender bias was observed.

3.5 Graphical Analysis

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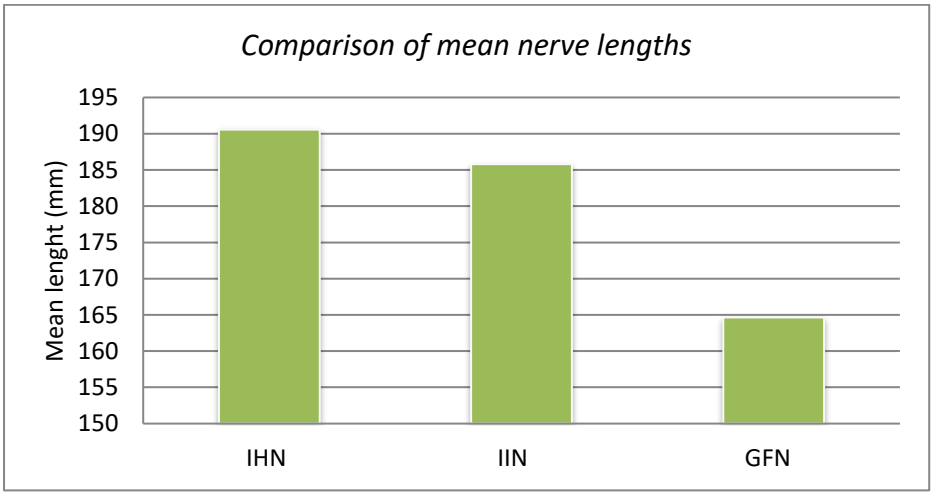
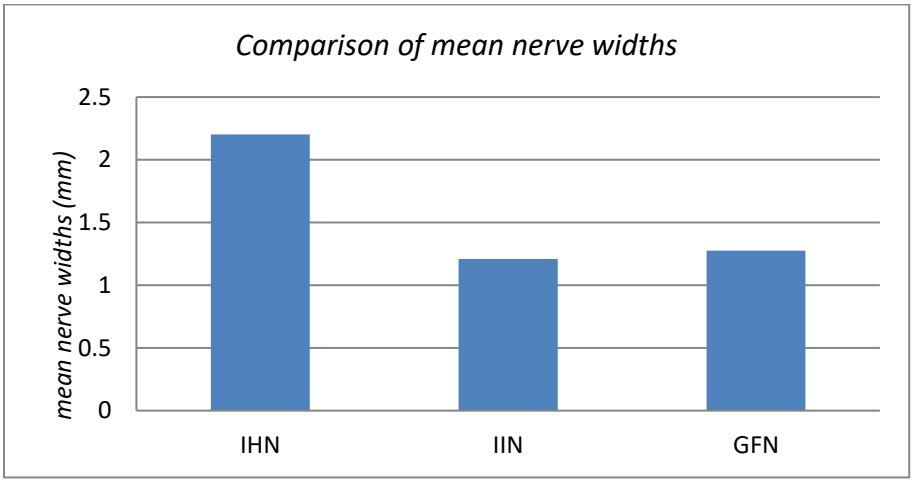
Figure 3:Comparison of mean nerve lengths (mm)



The ilioinguinal nerve showed the greatest mean length, followed by the iliohypogastric and genitofemoral nerves.

Figure 1:Comparison of mean nerve widths (mm)



The genitofemoral nerve had the greatest mean width, while the ilioinguinal nerve was narrowest.

3.6 Representative Dissection Findings

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Figure 5:Common trunk of iliohypogastric and ilioinguinal nerves arising from L1.

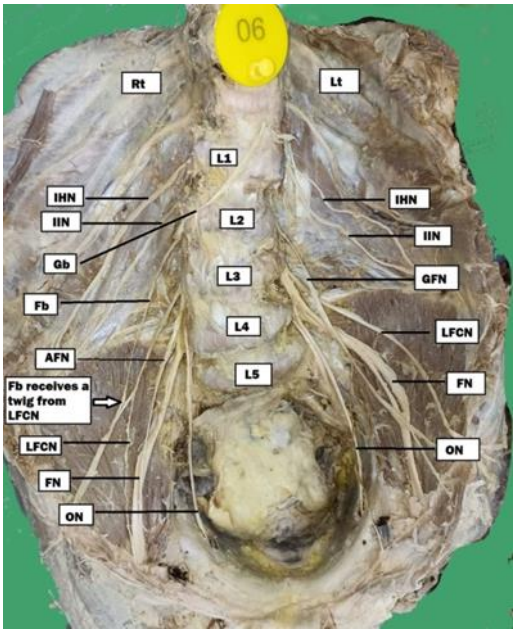
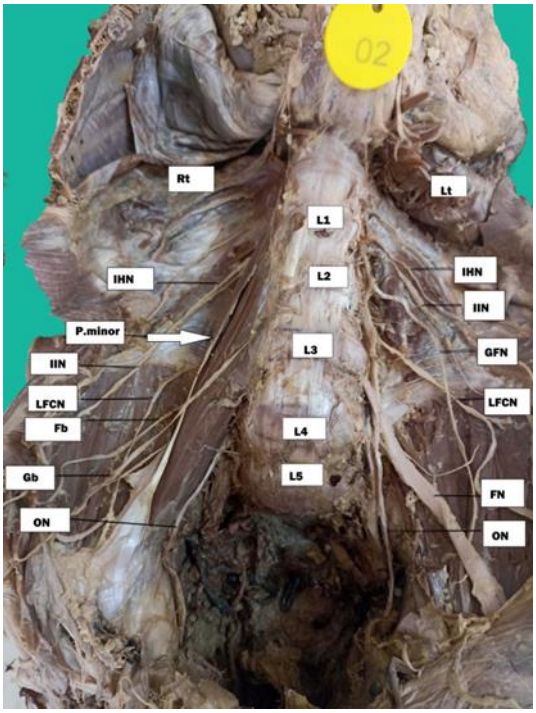


Figure 6:Early bifurcation of genitofemoral nerve on anterior surface of psoas major



Statistical analysis revealed no significant differences in the mean length or width of the iliohypogastric (IHN), ilioinguinal (IIN), and genitofemoral (GFN) nerves between the right and left sides or between sexes ($p > 0.05$). Among the observed variations, common trunk formation between the IHN and IIN and early bifurcation of the GFN were the most frequent, while minor intercommunications occurred in approximately 12% of plexuses without a consistent pattern. Overall, the IHN and IIN predominantly originated from the L1 spinal root, occasionally sharing a common trunk (20%), whereas the GFN most commonly arose from L1–L2, exhibiting early division in 64% of cases. The morphometric

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parameters remained largely symmetrical across sides and sexes, indicating a high degree of consistency. Despite this, notable anatomical variations were encountered frequently, highlighting their clinical relevance during regional nerve blocks, hernia repairs, and lower abdominal surgical procedures, where inadvertent nerve injury or entrapment can result in postoperative neuralgia or sensory deficits.

Discussion

This study provides a detailed morphological and morphometric analysis of the iliohypogastric (IHN), ilioinguinal (IIN), and genitofemoral (GFN) nerves—collectively referred to as *borderline nerves*—in South Indian cadavers. Although small, these nerves are clinically significant due to their close relation to the surgical field in the lower abdomen and pelvis, where inadvertent injury can result in persistent neuralgia or sensory deficits.

4.1 Nerve Origin and Variation

In the present series, both the IHN and IIN predominantly arose from L1, either independently or from a common trunk, while the GFN originated from L1–L2. A common IHN–IIN trunk was observed in 20% of plexuses, similar to the 18–25% reported in South Indian populations by Pushpa et al. (2018) and Anitha et al. (2019), but higher than Western reports (10–15%; Kumar et al., 2008; Assis & Ranganath, 2018).The GFN showed early bifurcation within the psoas major in 64%, comparable to prior findings by Assis & Ranganath (2018). These results highlight both the high variability of the upper lumbar plexus and the influence of ethnic and developmental factors on root formation.

4.2 Morphometry

Morphometric assessment revealed that the IIN was the longest (mean 190.4 mm), followed by the IHN (185.2 mm), while the GFN was shorter (150.1 mm) but thicker (2.5 mm). These measurements closely align with values reported in South Indian studies (Pushpa et al., 2018; Wani & Gaikwad, 2023). The greater thickness of the GFN reflects its mixed sensory and motor composition.
No significant differences were noted between sides or sexes, consistent with Radhakrishnan et al. (2024), suggesting morphometric symmetry across individuals. However, the observed variability in trunk formation and branching underscores a dynamic pattern of segmental overlap within the upper lumbar plexus.

4.3 Developmental Basis

The variations noted likely stem from segmental rearrangement during embryogenesis. The lumbar plexus develops through the convergence of ventral primary rami, and minor deviations in fiber migration can result in common trunks or abnormal branching. This embryological mechanism, described by Bolk (1937) and Bergman et al. (1988), explains the frequent IHN–IIN fusions and variable GFN bifurcation levels.

4.4 Clinical and Surgical Relevance

Understanding the detailed anatomy of these nerves is critical for surgeons and anesthesiologists. The IHN and IIN are particularly vulnerable during inguinal hernia repairs, Pfannenstiel incisions, appendectomies, and iliac crest bone graft harvesting, where inadvertent injury can lead to chronic groin pain, paresthesia, or sensory loss. Likewise, the genital branch of the GFN, which frequently bifurcates early, is at risk during retroperitoneal and laparoscopic procedures. Injury may manifest as postoperative orchialgia or labial numbness. Knowledge of morphometry and branching patterns enhances the precision of ultrasound-guided ilioinguinal–iliohypogastric and genitofemoral blocks and helps in the diagnosis and management of groin neuralgia syndromes.

Correlation with Imaging and Literature

Recent imaging-based studies using ultrasound and MRI confirm similar variability in the borderline nerves. Radhakrishnan et al. (2024) demonstrated interethnic differences in GFN branching using 3D MRI, correlating well with the present findings. The consistency between cadaveric and imaging data strengthens the anatomical validity of these observations and supports the need for region-specific anatomical databases to guide surgical and anesthetic practice.

The present study was limited by its sample size of 25 cadavers and the lack of detailed demographic information such as age and occupation, factors that could potentially influence nerve morphology and dimensions. Future research incorporating larger and more diverse populations, along with

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histomorphometric and imaging-based analyses, is recommended to provide a more comprehensive understanding of lumbar plexus variability. Despite these limitations, the findings demonstrated that the iliohypogastric (IHN) and ilioinguinal (IIN) nerves predominantly originated from L1, sharing a common trunk in 20% of specimens, while the genitofemoral nerve (GFN) most often arose from L1–L2 and exhibited early bifurcation in 64%. No significant side or sex differences were observed in the morphometric parameters. The frequent occurrence of variations and intercommunications among these nerves underscores the importance of detailed anatomical knowledge in preventing iatrogenic injury during lower abdominal and pelvic surgeries and in improving the accuracy of regional anesthesia techniques.

Conclusion

The present cadaveric study provides a detailed morphological and morphometric insight into the iliohypogastric (IHN), ilioinguinal (IIN), and genitofemoral (GFN) nerves—collectively referred to as the *borderline nerves* of the lumbar plexus. These nerves exhibited considerable variability in root origin, branching pattern, and course, though their overall morphometric characteristics remained symmetrical across sides and sexes. The IHN and IIN primarily originated from the L1 spinal root, often sharing a common trunk (20%), while the GFN most frequently arose from L1–L2, showing early bifurcation within the psoas major in 64% of cases.

Such variations, though anatomically subtle, have significant clinical and surgical implications. Understanding their topography is crucial in minimizing iatrogenic nerve injuries during abdominal wall and pelvic surgeries and in improving the precision of ultrasound-guided regional nerve blocks. The findings from this South Indian population add valuable regional data to the anatomical literature and reinforce the need for awareness of population-specific patterns in both surgical anatomy and anesthetic practice.

Further large-scale studies incorporating imaging correlation, histomorphometry, and functional mapping are recommended to strengthen the anatomical database and enhance the safety of procedures involving the lower abdominal and inguinal regions.

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