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Structural and morphometric evaluation of the lumbar plexus and its branches: Focus on lumbar nerve roots

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ABSTRACT

Background: Variations in Lumbar plexus anatomy can affect surgical and anaesthetic outcomes. Despite the documented general anatomy, detailed morphometric measurements of lumbar nerve roots and branches remain limited, especially in the Indian population. Understanding these morphometric characteristics is crucial for nerve reconstruction, identification of nerve pathologies, and radiological interpretation. **Aims and Objectives:** This study aims to provide a detailed morphometric analysis of the lumbar plexus and to establish statistical correlations between measurements while examining branching patterns. **Materials and Methods:** This cadaveric study included 100 specimens used for routine undergraduate dissection in the anatomy department. **Results:** The ventral rami of L1-L4 spinal nerves were present in all dissected lumbar plexuses. One specimen showed a T12 contribution, and four specimens received L5 contributions. The genital and femoral branches were seen as separate branches piercing the psoas major in 43% of specimens. The accessory obturator nerve (ON) was observed in 16% of specimens. The lateral femoral cutaneous nerve originated from the femoral nerve (FN) in 6% of cases. Statistically, the thickness of L3 and L4 roots was found to be positively correlated, independent of L1. A significant negative correlation was found between the femoral and ONs and the L3 and L4 roots. The ilioinguinal nerve had the longest course, whereas the FN had the shortest. The thickest nerve was the FN, and the thinnest was the ilioinguinal nerve. **Conclusion:** Morphometric knowledge can be useful during procedures, such as lumbar plexus blocks, estimating nerve root compression risks, selecting donor nerves for grafts, and planning nerve rehabilitation.

Key words: Lumbar plexus; Posterior abdominal wall; Psoas major

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INTRODUCTION

The Lumbar plexus, a network of nerves in the posterior abdominal wall formed by the ventral rami of the first three and most of the fourth lumbar nerves, with contributions from the 12th thoracic nerve, shows significant anatomical variations in its formation, branching patterns, and relationship with surrounding structures.[1] These variations can affect the success of surgical outcomes and anaesthetic interventions. While the general anatomy of the lumbar plexus has been documented, there remains a gap in the literature regarding detailed morphometric measurements involving statistical analysis, particularly in the Indian population. The thickness and length of the lumbar nerve roots and their relationship to branches have not been thoroughly investigated, and the statistical correlations between root and branch thickness remain undocumented. Understanding these morphometric characteristics is essential for medical applications, including peripheral nerve reconstruction, regional

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anaesthesia, and interpretation of radiological scans for neuropathy diagnosis. This knowledge helps radiologists visualize nerve roots and identify pathologies, such as nerve compression and demyelination. For surgeons, understanding these relationships is crucial for anticipating anatomical variations during procedures, such as lumbar plexus blocks, estimating nerve root compression risks, selecting donor nerves for grafts, and planning nerve rehabilitation. This study addresses this knowledge gap by providing a detailed morphometric analysis of the lumbar plexus, focusing on root and branch thickness and length. In addition, it seeks to establish statistical correlations among measurements while examining the branching pattern of the plexus. These findings will provide insights into existing knowledge and potentially improve surgical and anesthetic outcomes.

Aims and objectives

This study aims to provide a detailed morphometric analysis of the lumbar plexus and to establish statistical correlations between the measurements. This study also aims to examine the branching patterns of the plexus.

MATERIALS AND METHODS

The approval of the institutional ethical board was obtained from the Government Medical College Institutional Ethics Committee, Kozhikode (February 04, 2013). This study is a descriptive study conducted at the Department of Anatomy, Government Medical College, Kozhikode, Kerala. Considering a 55% prevalence of variation using a 95% confidence level and 20% relative precision, the sample size was calculated as seventy-nine. A total of 100 specimens from 50 embalmed cadavers aged 50–80 years with normal lumbosacral regions were included in this study. Sex was not considered because of the limited number of female cadavers. Specimens with surgical scars or injured specimens were excluded.

A midline incision was made in the posterior lumbar region to expose the skin and thoracolumbar fascia. To improve access, the posterior spinal parts were removed. Upon exposure of the spinal cord, the dura was incised longitudinally. The point where the first four lumbar roots pierced the duramater was noted, and the thickness of nerve roots was measured with a digital vernier caliper. Dissection was performed anteriorly, keeping the psoas major muscle intact in its original location, and the relationship between the psoas major and the lumbar plexus was observed. The genitofemoral (GF) nerve was identified on the anterior surface of the psoas major. The points of emergence of the ilioinguinal, iliohypogastric, lateral femoral cutaneous, and femoral nerves (FN) from the lateral border of the psoas major, as well as the obturator nerve (ON) from the medial border, were documented. These nerves were traced through the psoas major to its origin. Photographs were used to document and systematically examine the origin and variations of branching patterns. Both the anterior rami of the lumbar nerves and the psoas major were then removed from the transverse processes of the lumbar vertebrae. A twine and scale were used to measure the length of nerves at designated locations, and the results were recorded. The genito FN was traced to its division into genital and femoral branches. The ilioinguinal nerve was traced till its entry into the inguinal canal. The iliohypogastric nerve was traced to its division into anterior and lateral branches. The lateral femoral cutaneous nerve (LFCN) and the FN are traced to the point where they pass below the inguinal ligament. The ON was traced till the point of entrance onto the obturator foramen. The thickness of the three nerves was measured with a vernier caliper at the L4 level. Parameters were recorded and photographed.

Statistical analysis

In addition to descriptive statistics, correlation analysis using Pearson's correlation coefficient (r), hypothesis testing using P-value, scatter plot analysis, and multiple regression analysis were performed. The statistical results were interpreted and documented.

RESULTS

Roots forming the lumbar plexus

In 100% of the dissected specimens, the ventral rami of the 1^{st}–4^{th} (L1-L4) spinal nerves were consistent with the formation of the lumbar plexus. In one specimen, the lumbar plexus showed a contribution from T12, and four specimens received contributions from L5 (Figure 1).

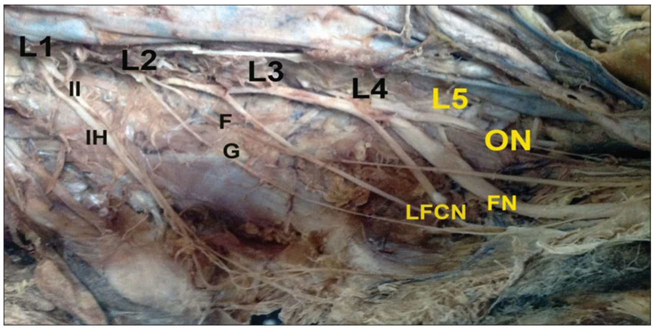

Figure 1: Lumbar plexus showing post fixation (L1, L2, L3, L4, L5-First, second, third, fourth and fifth lumbar roots respectively, IH-Iliohypogastric nerve, II-Ilioinguinal nerve, g and f: Genital and femoral branches of genitofemoral nerve, LFCN: Lateral Femoral Cutaneous nerve, FN: Femoral nerve, ON: Obturator nerve)

Relationship between the lumbar plexus and the psoas major

The lumbar plexus was situated within the psoas major in 100% of the specimens in the posterior third of the muscle. When the iliohypogastric, ilioinguinal, lateral femoral cutaneous, and FNs emerged from the posterolateral border of the psoas muscle, the GF nerve pierced the anterior surface of the muscle, and the ON emerged from the medial border. Instead of the GF nerve, its genital and femoral branches were seen separately piercing the psoas major in 43% of specimens.

Bilateral variation in branching pattern of the lumbar plexus

A symmetrical bilateral arrangement of the lumbar plexus was observed in 38% of the dissected cadavers. Conversely, 62% of cadavers exhibited differences in the arrangement of the lumbar plexus on both sides. A binomial test showed that the results were not statistically significant (P=0.119). These findings suggest that although asymmetry was more frequently observed, the difference did not reach statistical significance.

Thickness of lumbar nerve roots

The thickness of the first four lumbar roots that contributed to the lumbar plexus was measured at the point where they punctured the duramater. A digital Vernier caliper with a precision 0.1 mm was used for the measurement. The first lumbar root (L1) was the thinnest, and the fourth (L4) was the thickest. The thickness of the lumbar roots gradually increased from the upper to the lower segments (Table 1).

To look for any relationship between the roots thickness, Pearson correlation coefficient (r) and probability (P) values were calculated. For L3 and L4 roots, values of 0.52 and <0.001 were found, respectively, indicating a strong positive relationship between L3 and L4 root thickness. The scatter plot also confirms the positive linear relation (Chart I). A moderate correlation between L2 and L3 thickness was found with r=0.34 and P=0.001. A weak positive relationship existed between the L2 and L4 roots (r=0.28, P=0.005), but a very weak correlation was found between L1 and all other roots. The L1 root thickness appears to be independent of the other roots. The clinical implication is that surgeons can expect thicker L4 roots when L3 is thick; however, L1 thickness cannot be predicted from other roots.

Table 1: Thickness of lumbar roots (in mm)

Root	Minimum	Maximum	Mean
L1	3.20	4.07	3.72 mm (SD=0.18)
L2	4.22	4.88	4.55 mm (SD=0.16)
L3	5.00	5.96	5.32 mm (SD=0.16)
L4	5.35	6.00	5.71 mm (SD=0.16)

SD: Standard deviation

Table 2: Length and thickness of typical branches of the lumbar plexus in the posterior abdominal wall

Nerve	Length in cm	Thickness in mm
Iliohypogastric nerve	12.63	1.82
Ilioinguinal nerve	18.84	1.22
Genitofemoral nerve	11.19	1.40
Lateral femoral cutaneous nerve	12.02	1.76
Femoral nerve	11.16	2.86
Obturator nerve	12.20	2.5

The L1 root, through the iliohypogastric and ilioinguinal nerves, possesses substantial sensory supply compared to the L3 and L4 roots, which exhibit greater motor functions through the femoral and ONs. Motor axons enter limbs before sensory axons.[1] During development, these lower roots contribute to the growth and function of lower limb muscles, requiring coordination among them. The lack of correlation between L1 and the lower roots may stem from its distinct pathway and sensory supply, making it less likely to coordinate with the lower lumbar roots. This understanding could help surgeons anticipate a thicker L3 root in patients with a thick L4 root but not in those with a thick L1 root.

Length and thickness of typical branches of the lumbar plexus in the posterior abdominal wall

The length of the six typical branches of the lumbar plexus was measured from the point of origin to the point at which the nerve ends its course in the posterior abdominal wall. Measurements were taken using a twine-and-measuring scale, and the thickness of the three nerves was measured using a Vernier caliper at the L4 level.

Comparing the length of the nerves in the posterior abdominal wall (Table 2), the ilioinguinal nerve had the longest course, whereas the FN had the shortest. The thicknesses of the six typical nerves were measured using a digital Vernier calliper in millimetres at the level of the L4 vertebra. The thickest nerve was the FN, and the thinnest was the ilioinguinal nerve. Statistical studies did not indicate any relationship between the length and thickness of these nerves.

Origin and branching pattern of lumbar plexus

The different lumbar roots contributing to the formation of the typical branches of the lumbar plexus in this study are depicted in Table 3.

Some interesting observations found in the origin and branching pattern in the study include

1. An additional branch, the accessory ON (aON), was observed in 16 of the 100 specimens (16%). The

Table 3: Origin of typical branches of the lumbar plexus

Nerves	T12-L1	L1	L1-L2	L2	L2-L3	L2-L4	L2-L5	Absent	Total
Iliohypogastric	1	96	0	0	0	0	0	3	100
Ilioinguinal	0	99	1	0	0	0	0	0	100
Genitofemoral	0	0	98	1	1	0	0	0	100
Lateral femoral cutaneous nerve	0	0	92	8	0	0	0	0	100
Femoral nerve	0	0	0	0	0	96	4	0	100
Obturator nerve	0	0	0	1	0	99	0	0	100

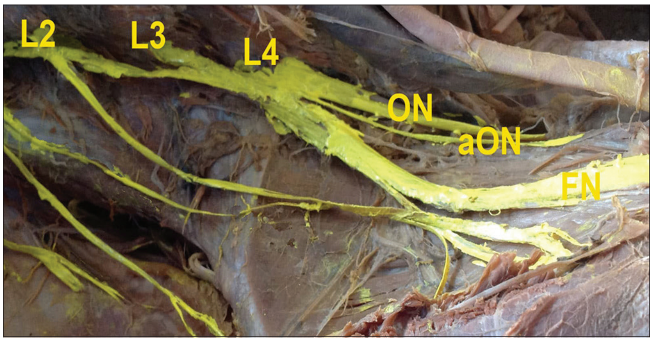

Figure 2: Lumbar plexus showing presence of accessory obturator nerve (L2, L3, L4-Second, third and fourth lumbar roots respectively, FN: femoral nerve, ON: Obturator nerve, aON: Accessory obturator nerve

nerve was seen to arise from the ventral divisions of the L3-L4 spinal nerves (Figure 2)

2. In 9% of specimens, the ilioinguinal and iliohypogastric nerves were found to arise as a common trunk from L1, subsequently dividing into individual nerves
3. The GF nerve was observed as a short stem of 2 cm originating from the L2-L3 vertebrae, which subsequently bifurcated into the genital and femoral branches in one specimen. In 43% of specimens, the genital and femoral branches of GF nerve were seen separately piercing the psoas major. In one specimen with high bifurcation, the Iliohypogastric nerve was absent (Figure 3)
4. In 6% of the cases, the LFCN originates from the FN rather than directly branching from the lumbar plexus (Figure 4)
5. In one of the specimens, some fibres from L2 coursed through the LFCN before joining L3 and L4 to form the FN, thus forming a communication between both the femoral and LFCN
6. In four specimens, the FN bifurcated into two branches, which subsequently rejoined before the nerve traversed beneath the inguinal ligament, encapsulating some fibres of the psoas major muscle.

Statistical analysis of the relationship between branch thickness and the thickness of their contributing roots

Statistical analysis revealed a significant correlation between the thickness of roots and branches, particularly in relation to the femoral and ONs.

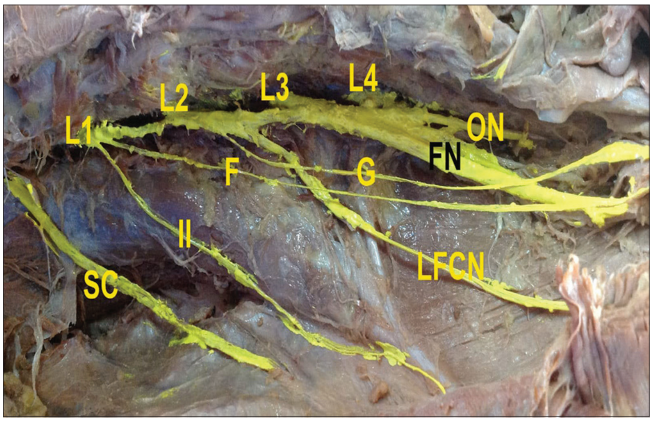

Figure 3: Lumbar plexus showing absence of iliohypogastric nerve (L1, L2, L3, L4-first, second, third and fourth lumbar roots respectively, SC: Subcostal nerve, II-Ilioinguinal nerve, (g and f) genital and femoral branches of genitofemoral nerve, LFCN: Lateral femoral cutaneous nerve, FN: Femoral nerve, ON: Obturator nerve)

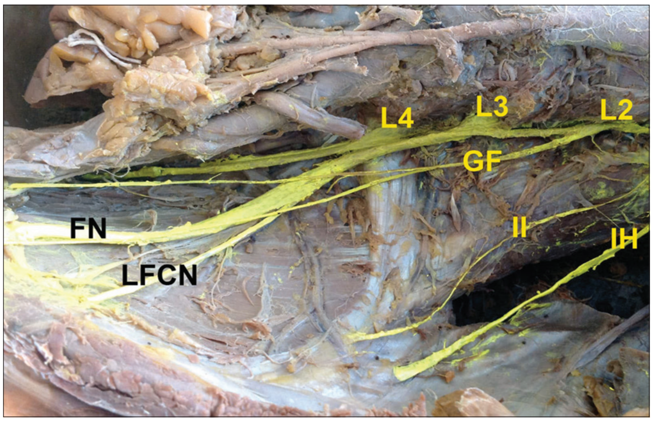

Figure 4: Lateral femoral cutaneous nerve arising as branch of femoral nerve (L2, L3, L4-Second, third and fourth lumbar roots respectively, IH: Iliohypogastric nerve, II: Ilioinguinal nerve, GF: Genitofemoral nerve, LFCN: Lateral femoral cutaneous nerve, FN: Femoral nerve)

Statistically significant negative correlations exist between L3, L4 roots and the FN, with correlation coefficients of −0.24 and −0.31 and P-values of 0.02 and 0.002, respectively. L4 showed a stronger negative correlation than L3. The L2 roots showed no correlation (P=0.31). Multiple regression analysis of L2, L3, and L4 revealed that these roots accounted for 13% of FN variability, with L3 and L4 as significant predictors. This indicates that a thicker L4 and L3 root relates to a thinner FN, independent of the L2 thickness.

The study identified significant negative correlations between the ON and L3 and L4 roots, with correlation coefficients (r) of −0.21 and −0.28, and P=0.04 and 0.006, respectively. This indicates that thicker L4 roots are correlated with thinner ONs. The L2 roots showed a non-significant correlation (P=0.44). Multiple regression analysis of the L2, L3, and L4 roots revealed that they accounted for 9% of the ON variability. Surgeons may consider L3 and L4 root sizes when evaluating femoral and ON variability, although other factors may have a greater influence. The observed correlations in nerve root thickness may be underpinned by embryological developments.

Embryological evidence has shown that nerve roots compete for Schwann cells and growth factors during development.[2] So L3/L4 axons can potentially diverge early to innervate the larger muscles of the lower limb, making the femoral and ONs thinner. A thin nerve does not necessarily mean a reduced axonal count; it may result from myelination, and studies suggest that nerve thickness reflects both axon count and myelination, which may vary inversely if roots allocate axons differentially.[3] The thickness of the different spinal components within these branches can be compared to identify which components primarily contribute and contribute less to the lower limb.[4]

Statistical analyses of the relationship between thickness of various branches

The thicknesses of various nerves within the lumbar plexus were analyzed for potential intercorrelations. For the iliohypogastric and ilioinguinal branches, a weak negative linear relationship was identified (r=−0.01), indicating that as the thickness of one nerve increased, that of the other showed a slight decrease. The scatter plot showed a weak negative trend. The P=(0.06) exceeded the significance threshold (0.05), indicating no statistically significant relationship between these nerves. The weak negative correlation (r=−0.21) likely stems from random variations or unmeasured factors.

For the obturator and FN s, an r value of 0.34 indicated a weak to moderate positive relationship, confirmed by a scatter plot. The P=(0.001) was below the significance threshold (α=0.05), showing statistical significance. So, when the FN is thick, surgeons can anticipate a slightly thick ON. Regression analysis showed that femoral thickness accounted for only 12% of obturator thickness variability.

Our statistical analysis reveals critical correlations between the thickness of lumbar roots and their branches, underscoring the morphometric variability's potential impact on surgical outcomes.

DISCUSSION

This study identified the lumbar plexus within the psoas major in all specimens. Our findings provide the detailed anatomical and morphometric analysis aimed for, revealing significant variations in the lumbar plexus. Contributions from L1, L2, L3, and L4 roots were observed across all 100 specimens, whereas the L5 contribution was found in four specimens. T12 contribution is found to be 1%, which has been substantiated by many other authors.[5-8] Understanding these atypical nerve patterns is crucial for preventing nerve damage during lower spine procedures and ensuring effective anaesthesia. The GF nerve frequently appears as separate genital and femoral branches, piercing the psoas major in 43% of cases. This prevalence exceeds the findings of Paul and Shastri[9] (13.3%) and Mahajan et al.[10] (20%). This discrepancy may stem from our larger sample size and meticulous dissection approach, which allows plexus access from the anterior and posterior views.

An aON from the L3-L4 ventral divisions was found in 16% of cases. While higher than in previous studies, this was less than that reported by Yasar et al.,[11] whose study included 30 fetal specimens. This nerve follows the medial border of the psoas major and innervates the pectineus muscle. Its identification is vital to prevent injury during hernia repair and hip surgeries, and to avoid incomplete adductor blockade.

The LFCN originated from the FN in 6% of cases. Gandhi et al.,[12] found this in 11.6% of cases, terming the anterior external femoral cutaneous nerve. Traditional nerve blocks may fail if branching occurs distally. Communication between the femoral and LFCN was found in one specimen. In four specimens, the FN split into rejoining slips before passing beneath the inguinal ligament, enclosing the psoas major fibers. This variation increases the risk of nerve injury during retroperitoneal and lateral approaches. Preoperative radiological screening is recommended.

The lumbar roots showed a progressive increase in thickness from L1 to L4. Similar findings have been documented by Izci et al.,[13] and Matejcik.[14] The present study found that the ilioinguinal nerve had the longest course in the posterior abdominal wall, whereas Izci et al.,[13] identified the iliohypogastric nerve as the longest. This discrepancy may be due to differences in methodology or racial variations such as pelvic dimensions. Iczi et al.,[13] does not describe the roots or nerve branching, making it difficult to conclude if they included measurement of common nerve trunks. The FN was found to be the shortest among all the authors.

In the current study, the ilioinguinal nerve was identified as the thinnest branch of the lumbar plexus, and the FN was the thickest, corroborating the findings of Izci et al.[13] Conversely, Gandhi et al.,[12] reported that the iliohypogastric nerve is the thinnest branch. Their study did not mention the measurement site, making it difficult to compare thickness with the present study, where it was measured at the L4 level.

Although the literature documents morphometric measurements of the roots and branches of the lumbar plexus, statistical analysis of these data is rare. To the best of our knowledge, no statistical analysis data have been published on the relationship between the thickness of roots and branches or among the thickness of branches. The Indian literature documents morphometric data, such as measurements from these nerves to the adjoining bony points, including the center of the anterior superior iliac spine, iliac crest, inguinal ligament, and supracristal plane. However, documentation of the length of nerves from the origin to specific landmarks, as well as the thickness of nerves at specific landmarks, is lacking.

Our study represents an inaugural report of these data within the context of the Indian literature. Through statistical analysis, we determined that an increase in the thickness of L4 roots was associated with a reduction in the thickness of the femoral and ONs, independent of L2. Furthermore, our study identified a positive correlation between the thickness of the obturator and FNs, indicating a slight increase in the thickness of the ON when the FN thickness increased and vice versa. Although standard textbooks suggest an inverse relationship between the thickness of the ilioinguinal and iliohypogastric nerves, where a thicker iliohypogastric nerve may correspond to a thinner ilioinguinal nerve, our findings revealed a weak negative correlation between these variables that was not statistically significant. Identifying the nerve roots, looking for axonal loss and demyelination, and signs of compression are vital to radiologists who can utilize this knowledge to diagnose and assess the severity of nerve pathologies such as demyelinating polyneuropathy and disc herniation.[15]

Limitations of the study

The sample contained less age diversity and a limited female population, which limits the statistical analysis with respect to age and sex.

CONCLUSION

Variations in the lumbar plexus were diverse. The FN is the thickest nerve, and the ilioinguinal nerve is the thinnest. The thickness of the femoral and ONs is inversely related to the thickness of the L3 and L4 roots, irrespective of L1. This knowledge can be useful during procedures like lumbar plexus blocks, estimating nerve root compression risks, selecting donor nerves for grafts, and planning nerve rehabilitation.

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Authors' Contributions:
SSV- Review of literature, prepared first draft of manuscript, implementation of study protocol, data collection, data analysis; **SAK**- Manuscript preparation and submission of article, Review of literature, concept, design, manuscript editing, and manuscript revision; **STR**- Concept, design, manuscript editing, and manuscript revision.

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