Morphology breakdown of femoral nerve- its branching pattern and association with adjacent structures in Jharkhand

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Abstract

Objectives: The study aims to explore morphological variations of the lateral femoral cutaneous nerve (LFCN) as well as its connections within the lumbar plexus, offering insights for clinical assessments and surgical considerations in lumbar spine approaches. The goal is to enhance understanding of LFCN anatomy, particularly its origin and intra-abdominal course, in diverse anatomical configurations.

Methods: The study employed detailed stratigraphic dissection techniques on 80 cadavers to investigate the morphological variations of the LFCN and its connections within the lumbar plexus. Cadaveric specimens were dissected to assess the origin of LFCN at different levels and potential differences in its course, providing valuable insights for clinical and surgical implications.

Results: The study revealed significant anatomical variability in the lateral femoral cutaneous nerve (LFCN) across specimens. The origin of LFCN, typically from L2-L3 lumbar roots, exhibited diverse patterns, with variations observed in 48.3% of cases. Notably, the L2 root dominated in 81.25% of instances, and origin solely from L2 root constituted 11.5% of specimens, higher than previously reported rates. Unusual patterns included LFCN starting from femoral nerve in 7.5 % of specimens, highlighting the intricate nature of lumbar plexus anatomy. These findings contribute to a nuanced understanding of LFCN variations and their clinical implications.

Conclusion: The study underscores the substantial morphological alterations of the lateral femoral cutaneous nerve, emphasizing the need for clinicians to be cognizant of diverse patterns in lumbar plexus anatomy. These findings have important implications for surgical interventions and neurologic assessments involving the lateral femoral cutaneous nerve.

Keywords: *Lateral Femoral Cutaneous Nerve, Lumbar Plexus Variations, Anatomic Variability, Neuroanatomy*

Introduction

The lateral femoral cutaneous nerve (LFCN) originates predominantly from the dorsal segments of the 2nd and 3rd lumbar nerves (L2 to L3). There are occasional variations where arises from 1st and 2nd lumbar nerves (L1 to L2) and in some cases, only from the 2nd lumbar nerve itself [1, 2]. This sensory nerve plays a crucial role in providing sensation to the abdominal wall lining and extending its reach to cover the thigh (both frontal and peripheral surfaces), reaching down to the knee [3, 4]. The trajectory of the LFCN can be subdivided into four categories starting from lumbar region, then inguinal and iliac region and finally ending in the femoral segments. The lumbar segment finds its place between the peripheral and inner portions of the lumbar plexus muscle [4]. It begins within the peripheral surface of this muscle, taking a diagonal descent around the pelvis and coursing over the iliac muscle. The LFCN, particularly in the inguinal portion, traverses through an anatomical structure termed the "aponeuroticofascial tunnel", positioned between the inguinal canal and the iliopubic tract [5]. Notably, the nerve location relative to the frontal superior spine of the iliac region and the groin ligament exhibits variability [6-10].

As the LFCN progresses into the femoral segment, it undergoes division into posterior and anterior branches. The anterior/frontal branch caters to sensation on the frontal and peripheral areas of the thigh, while the dorsal branch, piercing the fascia lata at a higher point than its frontal counterpart, supplies sensation to the parallel surface from the upper end of the femur to middle of the thigh [3]. The entirety of the nerve is enveloped by a comprehensive fascial canal that extends beyond its terminal branches, defining its anatomical course [11, 12].

Building on the intricate nature of peripheral nerves, these bundles comprise a mix of unmyelinated and myelinated, autonomic, and somatic fibres, forming fascicles. The internal neural topography, characterized by splitting, rejoining, and branching, holds crucial importance in understanding nerve lesion manifestations [13]. This complexity is particularly evident in cutaneous nerves, where fibres from various spinal nerves coexist, leading to variations in dermatome distribution and skin areas supplied by specific nerves. This variability is notable in the skin nerve distribution of the thigh, involving multiple nerves with diverse anatomical alterations. Consequently, patients may exhibit diverse clinical symptoms despite experiencing a similar nerve palsy [13]. Navigating these intricacies is vital for accurate clinical assessment and tailored treatment strategies.

De Ridder et al. demonstrated that deviations from the customary path of the lateral femoral cutaneous nerve are present in over a quarter of the test cohort (25 %), highlighting significant anatomical variability in both the femoral segment's relationships and the corresponding innervated skin territory [1, 6-10]. While variations in the intra-abdominal regions of the femoral nerve have been less explored, only a few studies have demonstrated these aspects and their connections with lumbar plexus branches.

In this study, our objective was to identify morphological variations in the intra-abdominal course of the LFCN, specifically focusing on remnants of unconventional nerve growth pathways. We aimed to establish associations between particular femoral nerve roots and distinct morphological variations. Additionally, we assessed the generalized position of this nerve within the lumbar plexus muscle, considering its distance to the frontal area of the spinal cord at every interspace within the lumbar level. This comprehensive examination aims to enhance our understanding of anatomical nuances and their implications for clinical signs associated with LFCN variations.

Methods

Dissections were performed on 80 cadavers, encompassing 160 nerves fixed in a 10 % formalin solution from Medinirai Medical College in Palamu, Jharkhand, India. The study sample included 44 men and 36 women, with a mean age of 68.1 years (between 47 to 85 yrs). Male cadavers had a mean age of 66.7 yrs (between 47 to 80 yrs), while female cadavers averaged 68.4 yrs (between 52 to 85 yrs).

Conforming to previously outlined anatomical dissection techniques, the research adhered to a meticulous protocol [14, 15]. Prior to each procedure, a comprehensive visual examination was conducted to eliminate specimens displaying signs of trauma, deformities, or indications of prior surgeries. The assessment commenced with a detailed inspection of the iliac, inguinal, and lumbar segments of the lateral femoral cutaneous nerve (LFCN), with a specific focus on morphological variations. Special attention was given to potential communications Amongst the LFCN and other branches of the lumbar plexus.

The relationship between the upper lumbar plexus and the psoas major muscle, inclusive of the LFCN, was examined following the approach outlined by Kepler et al [16]. Distance measurements from the space in the frontal area of the spine disc to the roots of the femoral nerve or the nerve itself were recorded at regular levels. In alignment with framework of Kepler et al., nerve-related appendages were deemed potentially susceptible in cadavers where the femoral nerve was situated within the anterior psoas. A pivotal stage involved exposing the lumbar plexus muscle through blunt dissection, extending to the intervertebral foramina, facilitating the excision of this muscle, encompassing roots, branches, and all intra-abdominal components of the femoral nerve.

The neuronal diameters were measured using a digital caliper and the protocols were adjusted as necessary in subsequent stages [17, 18]. Each lumbar plexus specimen was soaked for a fortnight in acetic acid (10 %), enabling the removal of the epineural sheath. Nerve dissection in a reverse direction was then carried out using microsurgical equipment under a high-resolution binocular loupe.

The protocol consisted of careful removal of superficial epineurium and muscles, followed by proper identification of nerve fascicles extending to specific lumbar plexus roots. The dissection included exposing muscles in the posterior abdominal wall, preventing harm to associated vessels and nerves. Fibers of the psoas major muscle were methodically detached, and the iliogenital nerve was traced on the frontal surface of the psoas to the lower back nerves. Precise removal of the psoas from lumbar vertebrae transverse processes revealed nerves and branches for examination.

Results/Outcomes of the study

Morphological Diversity in the origin of LFCN

In the course of this investigation, diverse origins of the LFCN from the lumbo-sacral plexus were scrutinized. Typically, this presented as a singular trunk starting from posterior segments of the ventral rami of the lumbo-sacral plexus. The predominant roots of origin were L2 and L3, as seen in 92 cases (57.7 % of LFCN specimens). Notably, in 76 cases (47.5 %), the L2 root exhibited dominance, while the L3or 3rd lumbar root was predominant in 16 specimens (10.2 %). An additional 15% of cases (24 instances) showcased the LFCN originating from the L1 and L2 roots, with the latter being dominant in all occurrences. Furthermore, in 18 cases (11.2 %), the LFCN had a sole origin from the L2 root (Table 1).

Table 1: LFCN Origin Variation

Origin	**T12, L1, L2**	**L1, L2**	**L2**	**L3**	**L2, L3**	**Femoral nerve**	**Absent**
Number of patients (%)	2.5 %	3.1 %	47.5 %	10.2 %	57.7 %	7.5 %	1.8 %

An intriguing revelation emerged from 12 cases (7.5 %), where the LFCN originated directly from the anterior crural nerve. This alteration in percentages was particularly noteworthy in 6 female specimens (bilaterally in two) and unilaterally in two male cadavers, where absence of LFCN was noted. Initial shared epineurium between nervus femoralis and the LFCN suggested a common origin, yet meticulous dissection unveiled the LFCN as a separate branch along the dorsolateral area of the nervus femoralis.

In instances of nervus femoralis origin, the roots of LFCN adhered to the standard pattern, starting from the L2-L3 lower back nerves. The prevalent observation involved this stemming from L2 lumbo-sacral root, with fascicles situated in the dorsal region of its cross-section. Additionally, a smaller fibre bundle from L3 joined the LFCN, situated in the posterior upper part of this root cross-section. Additionally, four cases featured an unusual lumbar plexus configuration with T12 contribution and intricate loop formations, shedding light on the complexity of peripheral nerve anatomy. These findings contribute a comprehensive understanding of LFCN anatomical variations and emphasize the intricate nature of peripheral nerve configurations.

Multiplicity Variations in LFCN Numbers

In 12 instances (7.5 %), the absence of LFCN was observed, with 4 specimens on the right side (both specimens being male), 4 on the left side (2 each in female and male cadavers), and bilateral absence in 2 male cadavers. Compensatory innervation occurred in 10 cases through branches of the nervus femoralis and in 2 cases through a branch of the iliofemoral nerve. Additionally, accessory LFCNs were noted in 4 cases, both arising from the nervus femoralis. The first case showed the main LFCN originating from lumbo-sacral nerves, L1 and L2, with diameters 2.2 mm and 0.80 mm for the main and accessory LFCNs, respectively. In the other case, the main LFCN originated from L2 - L3 nerves, with diameters of 1.88 mm for the main and 1.14 mm accessory LFCNs. The Descriptive Statistics of LFCN Nerve Root Width in Various Anatomic Origin Variations from the Lumbar Plexus is depicted in Table 2.

Table 2: Statistics: LFCN Nerve Root Width in Lumbar Plexus Variations

	Type of LFCN origin	**L1 to L2**		**L2**	**L2 to L3**		**L2 to L3**	
	Root	**L1**	**L2**	**L2**	**L2**	**L3**	**L2**	**L3**
Distance (mm)	Minimum	0.67	1.44	1.42	1.64	0.83	0.85	1.40
	Maximum	1.32	2.41	3.13	3.17	1.75	1.86	2.22
	Average	1.12	1.94	2.19	2.24	1.18	1.16	1.96

Morphological Deviations in the Intra-Abdominal Segment of the LFCN

Various morphological deviations were identified throughout the route of the LFCN in the genital region, spanning from the lateral edge of the hip flexor muscle to the groin ligament. The primary variances set encompassed scenarios in which communications were observed amongst nervus femoralis and LFCN, were all unilateral. In two specific cases involving the right half of a female specimen (constituting 1.25 % of the 160 nerve specimens), a connecting branch merging with the LFCN after originating from the femoral nerve, with fascicles of the L2 nerve. Herein, the LFCN originated from L1 - L2 nerves. The initial diameter of this nerve was 1.77 mm before getting the connecting branch from the nervus femoralis, and it increased to 2.07 mm after incorporation (connection diameter = 1.03 mm).

In 3.75 % of LFCN specimens (6 out of 160 nerves), a connecting branch fused with the femoral nerve after originating from the LFCN. This change in dimensions involved L2 originating nerves (4 cases) and L1 to L2 (2 cases) originating lumbar nerve roots, observed in two female cadavers (right half) and four male cadavers (two each on both the sides). Additional reunion after splitting of the nervus femoralis, entwining iliacus muscle fibres, were noted in these male cadavers. The diameters of the LFCN pre- and post-emitting the connecting branch with the nervus femoralis varied in each case. On the opposite sides, an absence of LFCN (in 2 male specimens) or a normal LFCN was noted.

Connecting Link Between the iliofemoral nerve and the LFCN

In two male cadavers, a connecting branch between the LFCN and iliofemoral nerve was identified. In-depth dissection of the lumbar nerve network from these specimens showed its origin from L1 lumbo-sacral nerve. This connecting segment merged with the LFCN, resulting in a communication diameter of 1.85 mm. Consequently, the diameter of the LFCN prior to losing this connecting branch with the iliofemoral nerve was identified to be 2.88 mm, while that after losing the branch was 3.30 mm. The iliofemoral nerve maintained a typical branching pattern in its subsequent route.

Elevated Division of the LFCN

In two female cadavers on the right side, a heightened splitting of LFCN into frontal and dorsal branches was identified. Conversely, in 2 male cadavers, the absent iliac branch of the iliofemoral nerve showed substitution with a branch of the LFCN. Notably, the femoral branch of the iliofemoral nerve followed a regular trajectory and territorial distribution, while the splitting of the LFCN as frontal and dorsal nerve segments was seen within the iliac segment. Additionally, the dorsal segment of the LFCN extended laterally to the frontal iliac crest.

Associations of the LFCN with the hip flexor Muscle Structure

Irrespective of the heterogeneity in LFCN morphology, the nerve roots consistently originating from the dorsal segments of the lumbo-sacral plexus were situated within the outer and inner layers of the hip flexor muscle. The average distance from the frontal intervertebral segment to the frontal border of the lumbo-sacral plexus was 29.4 mm (between 27.6 to 34.5 mm) in the L1 to L2 roots, 26.3 mm (between 24.7 to 32.8 mm) in L2 to L3 roots, and 26.8 mm (between 24.6 to 33.1 mm) in the L3 to L4 roots.

But, in 4 instances (2.5 %), systematic dissection showed LFCN within the outer layer of the anterior psoas muscle. Moreover, in two specimens (right side of female cadavers), the LFCN emerged on the frontal aspect of the muscle, running diagonally within the anterior psoas, starting from the L1 - L2 roots. Likewise, in another 2 cases (left side of female cadavers), the nerve starting from the L2 - L3 roots, emerged on the outer side of anterior psoas. Additionally, an abnormal union between the LFCN and iliofemoral nerve traversed the fronto-lateral surface of the psoas major in 2 cases (right side of male cadavers). These observations highlight unusual courses of the LFCN concerning the anterior psoas in 3.7 % of the cadavers.

Discussion

Comprehending cutaneous innervation and the dispersion of dermatomes holds paramount importance in nerve-related assessments during patient care. Recent progress in medical science and prognostic techniques underscores the necessity to bridge the disparities between traditional anatomical descriptions of sensory supply and the unconventional frameworks of impaired sensation witnessed in medical contexts [19, 20]. Anomaly is inherent in the dispersion of dermatomes, with regular dermatomal areas punctuated by inconsistent empty areas of overlapping nature [21]. Furthermore, anatomical changes manifests in the area of cutaneous nerves, where fibres from multiple spinal nerves contribute, resulting in broader cutaneous nerve areas compared to the sole supply by a single dermatome [22]. This variability emerges from the intricate interplay of diverse mechanisms governing axonal growth, pathfinding, and branching patterns [23, 24].

The typical origin of the LFCN involves the L2 to L3 lumbo-sacral roots; but, noted pervasiveness of anatomical heterogeneity in its origin reaches up to 48.3 % [3, 25]. Anloague and Huijbregts observed that the LFCN could receive segmental nerve supply from atypical levels besides L2 - L3 in 14.7 % of lower back plexuses [14]. While the LFCN commonly originates from L2 - L3, and infrequently from L1 - L2, our study aligns with these findings, revealing that in 15 % of cases, the LFCN arose from the L1 and L2 roots. Notably, L2 exhibited dominance in 81.25 % of cases, with the LFCN originating solely from L2 in 11.5 % of instances. Moreover, our study observed the LFCN arising from the nervus femoralis in 7.5 % of specimens, contrasting with the lower reported prevalence in previous studies [14, 26].

The absence of the LFCN, either unilaterally or bilaterally, may occur, and in such instances, it can be substituted by nerve segments from the iliofemoral or femoral nerves, the ilioinguinal nerve or anterior femoral cutaneous nerve [25]. Notably, in our study, among the cases lacking the LFCN, one instance saw replacement by a genitofemoral nerve branch, while in the remaining cases, branches from the femoral nerves took on this role. Conversely, we observed cases where an LFCN branch substituted the iliac branch of the iliofemoral nerve. Our findings align with report of Carai et al. on the LFCN being absent in 8.8 % of surgical cases for Roth's meralgia, with nerve splitting being a less common occurrence in our investigation (2.5 %) [7]. Various studies including the work carried out by Ashwini et al have reported pre-inguinal reunion and splitting of the nervus femoralis, akin to the current study [27-30].

The heterogenous morphological relations of the LFCN suggest that nerve fibres originating from distinct spinal nerves may get to the skin area in diverse manners. The level of LFCN origin holds clinical and diagnostic significance, particularly in cases of suspected LFCN nerve pain like Bernhardt-Roth syndrome, where clinical examination may reveal sensory loss in the dispersion of the LFCN, overlapping with the skin area distribution of L2 - L3 [3]. Moreover, participation of L1 root LFCN formation, nerve pain of the LFCN possibly resembles radiculopathy of the upper lumbo-sacral region [2]. Morphological anomalies of LFCN could be linked with various dispersions of the nerve in the groin, impacting clinical considerations [5]. For instance, work done by Park et al. and Shin et al. propose the utility of LFCN neural studies for the selective prognosis of radiculopathy of the upper lumbo-sacral region, plexopathy, and meralgia paresthetica [9, 31]. Nonetheless, the accuracy of such studies is compromised by the morphologic heterogeneity of nerve.

Furthermore, surgeons operating in this region must possess a comprehensive understanding of the lumbo-sacral plexus nerves' anatomy on the dorsal abdominal wall [28, 32, 33]. The morphological traits of both examined muscles concerning the surgical method for lateral transpsoas interbody fusion was elaborated by Kepler et al [16]. Accordingly, the neural structures are considered at risk when the lumbo-sacral plexus is lesser than 20 mm from the frontal inter-vertebral segment, proposing this as the least distance for accomplishing transpsoas interbody fusion without potential iatrogenic harm or nerve retraction. Their findings align closely with ours, indicating an average distance between the frontal intervertebral plane and the frontal border of the lumbo-sacral plexus at different spinal levels.

This study is limited by the intricate nerve structure, marked by fascicular redistribution as well as the mingling of diverse branch fibres through fascicular plexuses [13]. As such, relying on only intraneural fascicular dissection hinders precise determination of somatotropic nerve organization. While not aiming for an exhaustive assessment of LFCN somatotropic organization, our study contributes to a broader understanding of LFCN origin levels due to anatomic variations. We also explored fiber source levels from lumbo-sacral nerves in connections, which sometimes manifested as morphologic heterogeneity, amongst the LFCN and other nerves originating from the lumbo-sacral plexus.

Our study, relying on morphologic dissection methods (systematic dissection), provides an approximate estimate of the possibility of LFCN surgical damage. Future research should ascertain the actual vulnerability of iatrogenic harm to particular lumbar plexus branches in diverse surgical approaches, particularly using the hip flexor muscle corridor like lateral access. These analyses, conducted on frozen cadavers, can simulate surgical scenarios realistically, allowing subsequent anatomic verification of potential lumbar plexus damage. Nonetheless, our findings highlight unusual morphologic relationships involving the LFCN, its potential union with neighbouring nerves, and the hip flexor muscle as potential risk factors for nerve damage.

Conclusion

The current study focussing on the Morphology of formation of Femoral, nerve, its relation with neighbouring structures and its branching pattern in Jharkhand population, revealed substantial anatomical variations in its origin and intra-abdominal course. The common depiction of LFCN arising from the L2 to L3 lumbar roots was challenged, as diverse patterns emerged, including contributions from L1 and L2, L1, L2, and L3 roots, L3 alone, and direct origin from the femoral nerve. Unusual lumbar plexus configurations were also observed, emphasizing the complexity of peripheral nerve anatomy. These findings are vital for clinicians navigating potential LFCN neuropathies and for surgeons considering procedures involving the lumbar plexus. Overall, our study highlights the intricate nature of LFCN anatomy, contributing valuable insights for both clinical and surgical contexts.

Limitations

Limitations of this study include the inherent complexity of nerve structure, making precise determination of somatotropic nerve organization challenging. Additionally, the study's focus on anatomic dissection techniques allows an approximate estimation of the possibility of iatrogenic harm to specific lumbar plexus branches, calling for further research using frozen cadavers for realistic surgical simulation and verification.

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