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Lumbar plexus — review

Nicol Zielinska[1], Marta Pośnik[2], Izabella Kaczmarczyk[2], Ilona Klejbor[3], George Triantafyllou[4], Eva Maranillo[5], Łukasz Olewnik[1], Janusz Moryś[6]

[1]Department of Clinical Anatomy, Masovian Academy in Plock, Płock, Poland
[2]Department of Anatomical Dissection and Donation, Medical University of Lodz, Łódź, Poland
[3]Department of Anatomy, Institute of Medical Sciences, Jan Kochanowski University, Kielce, Poland
[4]Department of Anatomy, School of Medicine, Faculty of Health Sciences, National and Kapodistrian University of Athens, Athens, Greece
[5]Department of Human Anatomy and Embryology, Complutense University of Madrid, Madrid, Spain
[6]Department of Human Anatomy and Physiology, Pomeranian University in Slupsk, Słupsk, Poland

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The lumbar plexus is a collection of nerves, and it originates from the anterior rami of the T_{12}–L_5 laterally to the intervertebral foramina. It gives off 6 peripheral nerves, and in the available literature there are a lot of descriptions of each nerve and its possible morphological variations. In some cases, the occurrence of accessory nerve or absence of whole nerve is observed. In other cases, morphological variations regarding the origin, course, or division into more branches are also noticed. Such variations may be associated with some clinical aspects. Understanding the anatomical variations of the lumbar plexus's nerves is essential for procedures involving the lower abdomen, regional anaesthesia, and managing nerve entrapment syndromes.

The main aim of this review is to present condensed information on the lumbar plexus based on the available literature. A further aim is to compare the classification systems and the results of previous studies in adults and foetuses. This manuscript also includes information on the most common clinical implications associated with anatomical variations of the individual nerves of the lumbar plexus. (Folia Morphol 2025; 84, 1: 1–21)

Keywords: lumbar plexus, iliohypogastric nerve, ilioinguinal nerve, lateral femoral cutaneous nerve, obturator nerve, genitofemoral nerve, femoral nerve, anatomy, embryology, anatomical variations, clinical significance

INTRODUCTION

The lumbar plexus (LP) is a collection of nerves, and it originates from the anterior rami of the T_{12}–L_5 laterally to the intervertebral foramina. The LP exists bilaterally and allows nerves to combine with different levels. The LP gives off 6 peripheral nerves, and 4 of them are passing posterior to the psoas major muscle (PM) and next laterally to it. This group includes the iliohypogastric nerve (IHN), the ilioinguinal nerve (INN), the lateral cutaneous femoral nerve (LFCN), and the femoral nerve (FN) (Fig. 1). There is also the genitofemoral nerve (GFN), which courses on the anterior surface of the PM and is divided into 2 branches (the genital and the femoral branch), and the obturator nerve (ON), emerging from the PM's medial border, near edge of the pelvic inlet [15, 50].

Address for correspondence: Łukasz Olewnik, MD, PhD, Department of Clinical Anatomy, Masovian Academy in Plock, Plac Dąbrowskiego 2, 09–402 Płock, Poland; e-mail: lukaszolewnik@gmail.com

Based on the results of available studies, nerves of LP are characterised by different morphological variations. For example, the cutaneous branch of the IHN may be absent, and in such instances its function might be taken over by the GFN [6, 61]. On the other hand, the same nerve may give off some accessory communicating branches to the subcostal nerve, INN, FFN, or LFCN [38]. Another variation is an absence of the INN, and when the nerve is completely absent, its distribution might be taken over by the genital branch of the GFN, and the IHN might supply its territory [44]. The INN might also be replaced by the femoral branches of the GFN [6]. In addition to variants characterised by the absence of whole nerve or the presence of additional structure, morphological variations regarding the origin, course, or division into more branches were also observed. For example, the ON in most cases originates from the L_2–L_4 nerve roots. However, there are also other variants like ON formed by L_1–L_4, L_2–L_5, L_3–L_4, or L_3–L_5 [49].

It is worth mentioning that anatomical variations may be associated with some clinical aspects. Understanding the anatomical variations of the LP's nerves is essential for procedures involving the lower abdomen, regional anaesthesia, and managing nerve entrapment syndromes, as well as during graft harvesting. For example, the LFCN may leave the pelvis in different ways. In most cases the LFCN travels medially to the anterior superior iliac spine (ASIS), but in some cases it is located laterally. Such a position increases the risk of iatrogenic injury during bone graft harvesting. Such a procedure is performed commonly in reconstructive orthopaedic surgery [86].

The main aim of this review is to present condensed information on LP based on the available literature. A further aim is to compare the classification systems and the results of previous studies in both adults and foetuses. This manuscript also includes information on the most common clinical implications associated with anatomical variations of the individual nerves of the LP.

EMBRYOLOGY

Around the third week of pregnancy, the lumbar spine starts developing. This process is initiated by the notochord, which secretes growth factors. These factors encourage the ectoderm to transform into a neuroectoderm. Neurons are created from neuroblasts derived from neural precursor cell [71].

Additionally, the paraxial mesoderm divides into pairs of somites on either side of the neural tube by the end of the third week. A dermomyotome and a sclerotome develop from each somite. At this stage, each myotome is attached to a single spinal nerve, and the myotomes responsible for the creation of limb muscles migrate in the direction of the limb buds [71].

The sclerotome divides into cranial and caudal cell clusters. Neural tube neurons enter these clusters and innervate particular dermatomes and myotomes. The cranially placed clusters of the adjacent sclerotome fuse with the caudally located cell clusters to form the vertebral body. The interverbal disc forms in between each cluster of cells. The vertebral arch is formed when sclerotome cells travel around the neural tube and fuse dorsally at the same time [71].

The main reason for the anatomical variations of the nerves from the LP seems to be notable differences in their formation and in the migratory routes [71].

ILIOHYPOGASTRIC NERVE

Classical anatomical description and innervation range

According to the classical textbook definition, the IHN arises from the ventral ramus of the L_1 spinal nerve root of the LP, along with the INN [15, 50, 79]. The IHN emerges from the upper lateral border of the PM and passes inferolaterally, posterior to the lower pole of the kidneys, and in front of the quadratus lumborum muscle (QL) [15, 50, 79]. While the IHN runs to the anterior abdominal wall, it pierces the transversus abdominis muscle (TA) posteriorly, just above the iliac crest, and continues anteriorly between the TA and the internal abdominal oblique muscle (IA) [15, 50, 79]. When the IHN passes between the TA and IA, it divides into 2 branches: a lateral cutaneous branch (that pierces both the IA and external abdominal oblique muscle [EA] superior to the iliac crest and supplies posterolateral aspects of the gluteal skin) and an anterior cutaneous branch (that continues anteriorly between the IA and TA, innervates them, pierces the IA medially to the ASIS, and passes through the EA above the superficial inguinal ring to supply the skin superior to the pubic area) [15, 50, 79] (Fig. 1).

In scientific literature, terminating branches of the IHN may be described slightly differently. The terminal branches may be introduced as an abdominal

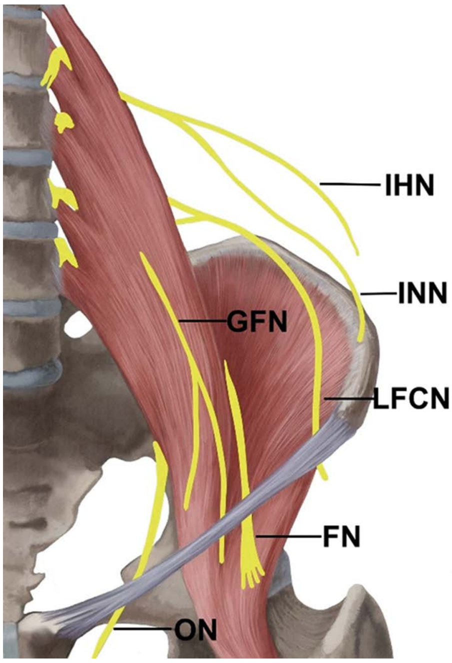

Figure 1. Schematic presentation of nerves arising from the lumbar plexus. FN — femoral nerve; GFN — genitofemoral nerve; IHN — iliohypogastric nerve; INN — ilioinguinal nerve; LFCN — lateral femoral cutaneous nerve; ON — obturator nerve.

and a genital branch, which arise while the IHN is positioned between the TA and IA. In the positions described in the literature it is also mentioned that, at the lateral summit of the iliac crest, the IHN gives off its only collateral branch, a lateral cutaneous branch, which is distributed in the skin of the posterior gluteal region [16, 46]. The abdominal (muscular) branch travels along the lateral abdominal wall, positioned between the TA and IA. As it approaches the outer opening of the inguinal canal, it penetrates the IA and continues its path between the IA and EA, eventually reaching the rectus abdominis muscle's sheath. Behind the rectus abdominis muscle, the abdominal branch splits into lateral and medial cutaneous branches, which provide sensory innervation to the suprapubic area. Along its route between the abdominal muscles, the abdominal branch of the IHN forms connections with abdominal branches from both the INN and subcostal nerves, emitting several branches that innervate the lower part of the lateral abdominal muscles [72, 83]. The genital (sensory) branch of the IHN accompanies the abdominal branch, traveling between the TA and IA. At the level of the ASIS, it pierces the IA and runs parallel to and above the inguinal ligament. In the inguinal region, this branch continues along the aponeurosis of the EA, situated anterior to the IA. Approximately 2–4 cm above the subcutaneous opening of the inguinal canal, the genital branch becomes subcutaneous and provides sensory innervation to the skin of the pubic area [72, 83].

The iliohypogastric nerve has both sensory and motor functions. As mentioned, the nerve supplies sensory fibres to the EA, IA, and TA [15, 50, 79]. The IHN also supplies the suprapubic region's skin and the gluteal region's posterolateral aspect [15, 50, 79]. As for its motor function, the IHN also supplies motor fibres to the TA and IA [15, 50, 79]. Moreover, the IHN also innervates the conjoint tendon formed from the common aponeurosis of the TA and IA [15, 50, 79].

Morphological variation

In cadaveric studies, the reported absence of the IHN ranges from 0 to 34.35% [45], and the cutaneous branch of the IHN is absent in 10% of cases [42]. In such instances, its function might be taken over by the GFN [6, 61].

The origin of the IHN varies greatly. It typically arises from the L1 nerve root, sometimes with additional input from T_{12} [24, 31, 61]. In some cases, the IHN may originate solely from T_{12} or receive a contribution from T_{11} [6, 45]. The IHN may originate together with the INN and subcostal nerve via a common trunk [6, 45].

When it comes to the IHN variation, the nerve may produce accessory communicating branches to the subcostal nerve, INN, GFN, or to the LFCN [38]. In the case of a common trunk between the IHN and subcostal nerves, they may separate around the TA origin or between the TA and IA [43].

Regarding the IHN branching pattern, 2 types may be distinguished regarding the relationship between the IHN and INN: Type I — where the IHN emerges from the outer border of the PM, united with the common trunk with the INN, and Type II — classical type — where the IHN and INN emerge from the PM border separately [45]. The prevalence of both those types varies greatly between studies. For example, Moreno-Egea [52] reported Type II in 78% of cases, whereas Geh et al. [23] found Type II in 47% of cases (Tab. 1).

However, Klaassen et al. [38] also proposed a classification of the IHN spinal nerve origin and distinguished 4 types (Fig. 2, Tab. 2).

During the IHN course, the position of the nerve on the anterior surface of the QL shows little to no

Table 1. Variation of the iliohypogastric nerve branching patterns (based on Manolakos et al. [45]).

Study (year)	Number of IHN and INN studied	Type I [%]	Type II [%]
Moreno-Egea (2021) [52]	100	22	78
Reinpold et al. (2015) [68]	60	18	82
Geh et al. (2015) [23]	43	53	47
Gandhi et al. (2013) [22]	60	11.7	88.3
Klaassen et al. (2011) [38]	200	20	80
Ndiaye et al. (2010) [55, 56]	100	14	86
Rahn et al. (2010) [67]	36	50	50
Anloague and Huijbregts (2009) [5]	38	5.8	94.2
Peschaud et al. (2006) [62]	40	7.5	92.5
Mandelkow and Loeweneck (1988) [43]	42	30	70
Papadopoulos and Katritsis (1981) [58]	348	46.83	53.17

IHN — iliohypogastric nerve; INN — the ilioinguinal nerve.

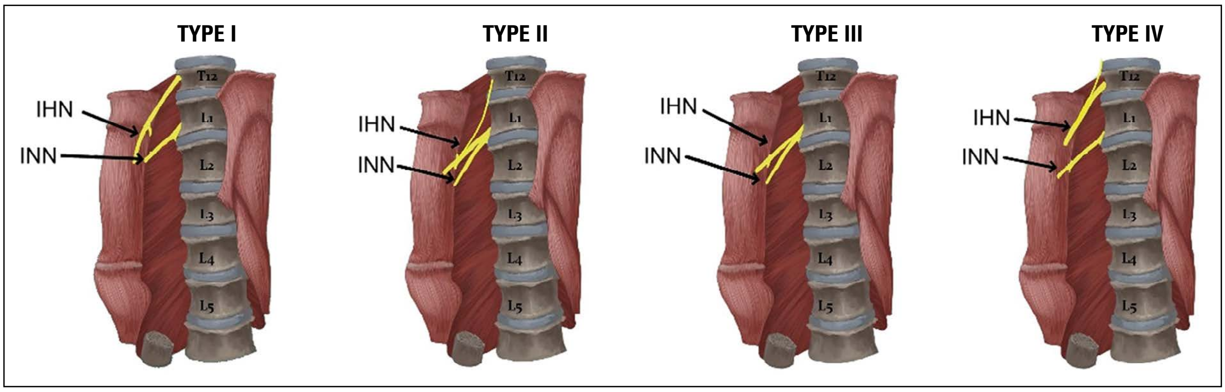

Figure 2. Schematic presentation of the iliohypogastric nerve origin proposed by Klaassen et al. [38]. IHN — iliohypogastric nerve; INN — ilioinguinal nerve; TYPE I — IHN origin from the T_{12}; TYPE II — IHN origin from T_{12} and L_1 conjointly.

variability. Further, the IHN enters the abdominal wall, by penetrating the TA aponeurosis, above the iliac crest and lateral from the ASIS. The mean distance from the penetration of the TA to the ASIS varies greatly. Klaassen et al. [38] reported 2.8 ± 1.3 (range: 1.1–5.5) medial, 1.4 ± 1.2 (range: 0.6–5.1) inferior, based on examination of 200 specimens; Whiteside et al. [93] reported 2.1 ± 1.8 (range: –1.6 to 5.0) medial, 0.9 ± 2.8 (range: –5.4 to 5.5) inferior, based on 13 specimen; and Reinpold et al. [68] reported 6.9 ± 3.1 (range: 2.0–12.3) dorsal, based on 56 specimen.

The IHN consistently lies above the supracostal plane, maintaining an average distance of 4 cm [22, 88]. Within the lateral intermuscular space, it travels alongside the INN for a distance of 5.6 to 9.0 cm (average: 7.2 ± 3 cm). This pathway consistently runs 2 cm below the ASIS [45].

When it comes to the relationship between the IHN and the inguinal canal, the mean distance between those structures was measured as 2.7 cm. Wijsmuller et al. [94] demonstrated that in 89% of cases, the IHN penetrated the IA at an average distance of 2.4 cm above the internal ring. However, in 11% of cases, the nerve pierced the IA approximately midway and above the spermatic cord [94].

Table 2. Classification of the iliohypogastric nerve proposed by Klaassen et al. [38].

Type	Description	Prevalence [%]
I	Origin from the T_{12}	7
II	Origin from T_{12} and L_1 conjointly	14
III	Origin from the L_1	10
IV	Origin from T_{11} and T_{12}	6

Salama et al. [72] reported that the genital branch of the IHN was absent in 12% of cases. When present, it typically terminates at the deep surface of the fascia of the EA and then splits into 2 branches. In 95% of cases, the superior terminal (pubic) branch exits the inguinal canal through a separate opening, distinct from the superficial orifice, to innervate the pubic region. In the remaining 5% of cases, the inferior terminal branch exits either through the superficial orifice or a small, separate opening, providing sensory innervation to the femoral and scrotal regions [72]. Furthermore, in 60% of cases, the distal portions of the IHN and INN merge, forming a single genital branch [1, 51, 72]. According to Klaassen et al. [38], the mean distance of the termination of the IHN is 4 ± 1.3 cm (range: 2.0–12.6 cm) lateral; according to Whiteside et al. [93] 3.7 ± 2.7 cm (range: 1.0–10.6 cm) lateral; and according to Rahn et al. [67] 3.8 cm (range: 1.3–5.7 cm) lateral to the midline.

Clinical significance

Understanding the anatomical variations of the IHN is essential for procedures involving the lower abdomen, regional anaesthesia, and managing nerve entrapment syndromes. The branches of the IHN have a significant relationship with surgical techniques performed in the lower abdominal region. Cardosi et al. [14] conducted a study on postoperative neuropathies after major pelvic surgeries such as radial hysterectomy, pelvic lymphadenectomy, lateral extended endopelvic resection, and total pelvic exenteration. The study identified 24 postoperative neuropathies, 5 of which regarded either the IHN or INN. According to Mandelkow and Loeweneck [43], IHN damage is probable during the pararectal incision, lower medial incision, and especially during the oblique lumbar incision. Injury to the IHN can lead to paresis of the abdominal muscles and a loss of sensation along the iliac crest and in the area above the pubic symphysis. As previously described, the IHN presents significant anatomical variability; therefore, to avoid postoperative complications, knowledge of its variation remains crucial.

Additionally, it is important to highlight that the IHN/INN block, an effective and easy-to-perform analgesia procedure during various inguinal surgical procedures, has a 10–25% failure rate [73]. A lack of understanding of the anatomy and anatomical variations of the described nerves causes such high value. Van Schoor et al. [73] performed a cadaveric study on 25 infant and neonatal cadavers and proposed an insertion point closer to the ASIS, approximately 2.5 mm (range: 1.0–4.9) from the ASIS on a line drawn between the ipsilateral ASIS and the umbilicus.

ILIOINGUINAL NERVE

Classical anatomical description and innervation range

The INN is a continuation of the anterior ramus of the spinal nerve L_1. Upon its origin, it passes posterior to the PM and emerges to the anterior surface of the QL. Therefore, the INN continues downwards obliquely, across the QL surface, passing also over the anterior surface of the IM. At the iliac crest level, the INN pierces the TA. After that, the nerve passes through the IA and enters the inguinal canal, where it is located superficially to the spermatic cord. The INN exits the inguinal canal through the superficial inguinal ring and gives off its terminal branches: anterior scrotal or anterior labial nerves that supply the skin in the genital region [50, 79] (Fig. 1).

When it comes to the structures innervated by the INN, during its course over the posterior abdominal wall, the INN gives off multiple motor branches that supply the TA and IA. The INN's terminal branches, the anterior labial or scrotal nerves, innervate the skin of the anterior 1/3 of the labium major and the root of the clitoris in females, and the skin of the anterior 1/3 of the scrotum and the root of the penis in males. Also, the INN innervates the skin of the proximal medial thigh [50, 79].

Morphological variation

In cadaveric studies, the reported absence of the INN ranges from 0 to 35% [44]. When the nerve is completely absent, its distribution might be taken over by the genital branch of the GFN, and the IHN might supply its territory. The INN might also be replaced by the femoral branches of the GFN [6].

When it comes to the INN origin, it presents significant variability. It is known that the INN is mostly derived from the L1, with occasional contribution from T_{12} to L_2. According to the meta-analysis performed by Manolakos et al. [44], the INN rises solely from L_1 with reported rates of 65–100%, from L_1–L_2 with reported rates of 0–22.5%, and from T_{12}–L_1 with reported rates of 0–14%. It is important to note that sometimes the INN might derive from L_2 and L_3 roots. Based on the INN's origin, Klaassen et al. [38] prepared the classification of the INN (Fig. 3, Tab. 3).

When it comes to the branching patterns of the INN, they are analogous to the IHN. Two types were

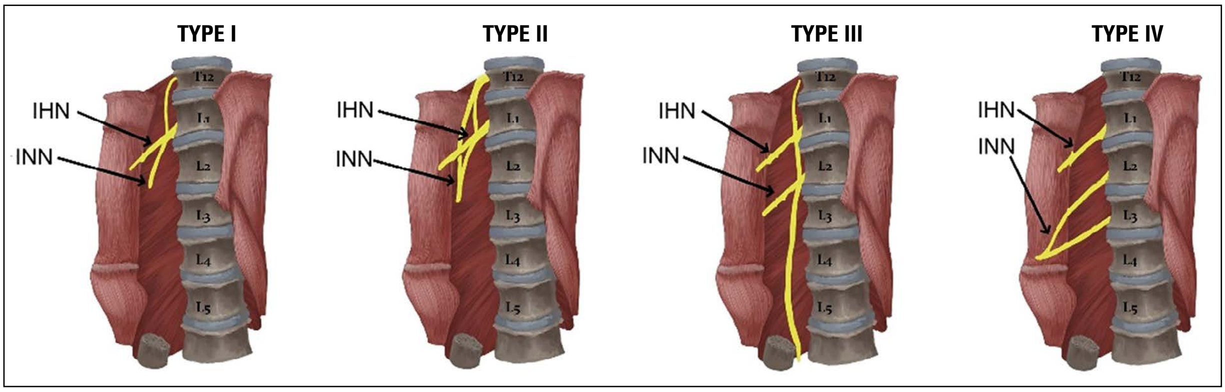

Figure 3. Classification of the ilioinguinal nerve by Klaassen et al. [38]. IHN — iliohypogastric nerve; INN — ilioinguinal nerve; TYPE I — INN origin from the L_1; TYPE II — INN origin from T_{12} and L1 conjointly; TYPE III — INN origin from the L_1 and L_2; TYPE IV — IHN origin from L_2 and L_3.

Table 3. Classification of the ilioinguinal nerve by Klaassen et al. [38].

Type	Description	Prevalence [%]
I	Origin from L1	65
II	Origin from T12 and L1	14
III	Origin from L1 and L2	11
IV	Origin from L2 and L3	10

distinguished: Type I — where the INN emerges from the outer border of the PM united with a common trunk with the IHN; and Type II — most common — where the INN emerges from the PM as a separate structure (Tab. 1).

During the INN course, the position of the nerve on the anterior surface of the QL shows little to no variability. Similarly, to the IHN, the topographical variability of the INN increases from the dorsal to the ventral side. The nerve's position concerning the posterior superior iliac spine varies significantly. As noted by Reinpold et al. [68], in approximately 50% of cases, the nerve is located up to 5.0 cm laterally and up to 1.6 cm medially from the posterior superior iliac spine. As reported by Moreno-Egea [52], the INN typically passes through the TA approximately 1.2 cm cranial and medial to the posterior superior iliac spine.

During its course, the INN lies 5–6 mm deep to the TA fascia, exits the retroperitoneal space, and enters the abdominal wall [44]. The mean distance of TA penetration to the ASIS varies between studies. Rahn et al. [67] reported 2.5 cm (range 1.1–5.1) medially 2.4 cm (range 0–5.3) inferior, Pescaud et al. [62] reported 2.8 ± 1.2 cm (range 2.5–3.2) medially, Avsar et al. [62] reported 4.84 cm (3–6.4) (right) 3.37 cm (2–5) (left), and Mandelkow and Loeweneck [43] — 3.08 ± 1.18 cm medially. Between the TA and the EA, the INN follows a common course with the IHN at a mean distance 7.2 ± 3 cm (range 5.6–9 cm). This course was always 2 cm below the ASIS [62].

Regarding the relationship between the INN and inguinal canal, in a more recent study on this subject, Ndiaye et al. [55] observed that the INN emerged from the IA at an average distance of 1 ± 0.8 cm from the inguinal ligament, with this distance being less than 2 cm in 34% of cases. In 50% of the cases, the nerve followed a course parallel to the inguinal ligament. In 28.72% of cases, the INN initially ran parallel to the ligament but gradually converged with it before reaching the outer orifice of the inguinal canal. In a subsequent study, Ndiaye et al. also found that the INN was located posterior to the inguinal ligament in 18% of cases, formed a common trunk with the IHN in 14% of cases, and appeared as a single trunk in half of the cases [55, 56].

Mandelkow and Loeweneck [43] reported that after a short course in the inguinal canal, the INN runs medially to the spermatic cord at the superficial inguinal ring. In 10% of the specimens, it passes lateral to the spermatic cord or the round ligament. In the rest of the cases (18%), the INN perforates the deep fascia of the EA 1–2 cm above the superficial inguinal ring [43].

Ndiaye et al. [55] reported that in 78.7% of cases, the INN travels in front of the spermatic cord towards the superficial inguinal ring. In 2.12% of cases, the nerve prematurely perforates the fascia without connecting to the spermatic cord. However, the anatomy commonly described in textbooks is only found in 60% of specimens [44]. Mandelkow and Loeweneck [43] observed that in 72% of cases, the INN passes medially to the spermatic cord. The nerve may also traverse through or lie posterior to the cremaster muscle. Occasionally, the fibres of the INN are so fine that they are difficult to detect [44].

When it comes to the termination of the INN, Akita et al. [1] reported that 90.7% of INN supplied sensory distribution to the pubic symphysis, the anterior surface of the scrotum in men, the labia majora in women, and the superomedial area of the thigh. However, in 13% of these cases, the GN also contributed to the innervation. Mandelkow and Loeweneck [43] found an additional GN contribution in 18% of cases, and interestingly, Ndiaye et al. found the classical innervation type only in 2.12%.

Ndiaye et al. [55, 56] analysed the terminal distribution of the INN. They found that in 50% of cases, the INN formed a single trunk, terminating in the scrotal region (85.1%), pubic region (8.5%), or femoral region (6.4%). In the remaining half of the specimens, the nerve split prematurely in the inguinal region into collateral and terminal branches, which were distributed to the scrotal, pubic, or femoral areas [55, 56]. Overall, 16 different patterns of INN division were documented [44]. Most of them originated above the superficial inguinal ring, in 31.6% of cases the terminal and collateral branches perforated the EA aponeurosis, and in 5.4% anastomosis with the branches of the IHN was found [55].

Interestingly, in an older study, Salema et al. [72] found the terminal division in 88% of cases, the separation was the rule and the upper pubic branch in 95% of cases, and a lower branch distributed to the femoral or scrotal regions.

As noted earlier, the genital branches of the INN and IHN can either remain separate or merge to form a common trunk. In 60% of instances, the distal segments of these two nerves join to create a single genital branch [1, 51, 72]. Genital branches are often (12%) absent; however, when they are present they terminate at the deep surface of the fascia of the EA. Occasionally, the anterior branch of the IHN is replaced by the INN just before its exit from the superficial inguinal ring [44].

Clinical significance

Like the IHN, the morphological variations of the INN are significant when it comes to lower abdomen operations, regional anaesthesia, and nerve entrapment syndromes [44]. The INN, just like the IHN, might be destroyed during radial hysterectomy, pelvic lymphadenectomy, lateral extended endopelvic resection, or total pelvic exenteration. The reported INN injury after Pfannenstiel incision is 3.2%, and the reported incidence of INN entrapment after laparoscopic hernia repairs is 1.1% [41, 80]. INN injury might manifest itself as the absence of cremaster reflex or lancinating and burping pain in the anterior scrotum or labia major [44].

As previously mentioned, the reported IHN/INN blockade failure is estimated as 10–25% [73]. Knowledge of morphological variation of INN and IHN is crucial to preventing postoperative nerve injuries and the formation of painful neuromas, which may result after needle misposition.

It is also important to highlight that the reported absence of the INN varies from 0 to 35%, and when the INN is absent, the GN's genital branch might contribute to the innervation. Such a possibility is important to remember when the INN is not found under the EA aponeurosis, and therefore special attention is required during the approach of the cremaster muscles and the dissection of the herniated sac [44].

Additionally, possible inter-nervous connections, anastomoses between nerves, variation of the position of the origin, and whether the nerve originates as a single structure or together with the IHN may result in sensory overlap or provoke chronic spontaneous neuropathies and failures and complications regarding their blockades. The intricate branching patterns of the INN can alter the clinical presentation of its lesions, potentially expanding the area affected by neuralgia and affecting the precision of nerve blocks [38, 44].

LATERAL FEMORAL CUTANEOUS NERVE

Classical anatomical description and innervation range

The lateral femoral cutaneous nerve (LFCN) originates from the dorsal branches of the L_2 and L_3 ventral rami. The nerve emerges from the lateral edge of the PM and travels diagonally across the IM and runs downwards to the ASIS. This is where the LFCN innervates the parietal peritoneum. The left LFCN passes behind the lower section of the descending colon and the right LFCN courses posterolaterally relative to the caecum. Both nerves pass behind or pierce the inguinal ligament, then pass alongside or anterior to the sartorius muscle into the thigh and divide into anterior and posterior branches (Fig. 1) [50, 79].

The anterior branch becomes superficial below the ASIS and provides innervation to the skin of the anterior and lateral sides of the thigh. This innervation extends to the knee level and at its termination forms connections with the anterior division of the FN and the infrapatellar branch of the saphenous nerve. All the described branches combine to form the infrapatellar plexus [50, 79].

The posterior branch penetrates the *fascia lata* superior to the position of the anterior branch and splits to provide innervation to the skin of the lateral side of the thigh. Posterior branch innervation extends from the greater trochanter to the middle of the thigh. Moreover, the posterior branch might also supply sensation to the skin of the gluteal region [50, 79].

Morphological variation

Lateral femoral cutaneous nerve; variation was examined on many levels in adults [27, 95] and foetuses [20, 30, 69]. Studies have been conducted on its origin, ways of exiting the pelvis, the number of its main trunks and branches, the angle between the nerve and the IM, and the placement of the LFCN in relation to other structures, as well as the geographical background and the distance between the LFCN and ASIS [95].

Haładaj et al. [27] investigated variation of LFCN origin. According to the authors, the LFCN arises most commonly from L_2 and L_3 — such a pattern was observed in 58.75% of cases. The authors observed that when the LFCN originated from both L_2 and L_3, one of these origins dominated, mostly the L_2 root. In 15% of cases, the authors observed an origin from either L_1 or L_2. In 11.25% LFCN originated solely from the L_2, and in 7.5% the nerve originated from the FN. Haładaj et al. [27] found the LFCN to be absent in 7.5% of cases.

As previously mentioned, variation of the LFCN concerning the location at which the nerve leaves the pelvis was also examined. Murata et al. [54] provided information about the position of the LFCN and how it is related to the ASIS. Moreover, the point at which the nerve decussates over the iliac crest, or whether it travels under the inguinal ligament without crossing the iliac crest, was considered. The authors distinguished 4 types (Tab. 4) [54].

Murata et al. [54] proposed a second classification based on where the LFCN intersects the IM. They identified 2 types: in Type 1, the nerve crosses the IM 5 cm behind the ASIS. Type 2 was further divided, with 8.9% of cases crossing within 3 cm of the iliac crest, and in Type 2', the crossing occurs more than 3 cm from the iliac crest in 91.1% of cases [54].

Aszmann et al. [9] studied the course of the LFCN in relation to the soft tissues and bony landmarks as it left the pelvis, and they distinguished 5 types (Tab. 5).

The distance between the ASIS and LFCN was measured by Kosiyatrakul et al. [39]. According to the authors, the LFCN passed medially to the ASIS in 58.3% of the cases, at the ASIS level in 22.9% of cases, and lateral to the ASIS in 18.8% of cases. In this study, the LFCN was mainly situated 2.1–3.9 cm beneath the crest and 2–5 cm lateral to the ASIS. In the study by Surucu et al. [82] the LFCN was located 1.52 cm medially to the ASIS, and Mischkowski et al. [48] presented similar results. Interestingly, Hospodar et al. [29], on the other hand, found the LFCN passing only medial to the ASIS. Lee et al. [40] provided quantitative

Table 4. Types of lateral femoral cutaneous nerve concerning its relationship to the anterior superior iliac crest, suggested by Murata et al. [54].

Type	Relationship with the anterior superior iliac crest	Prevalence [%]
A	More than 2 cm to the ASIS	2
B	Within 2 cm from the ASIS	10.8
C	At the ASIS level	28.7
D	Under the IL, anterior to the ASIS	58.5

ASIS — anterior superior iliac spine; IL — inguinal ligament.

Table 5. Types of exit of the lateral femoral cutaneous nerve from the pelvis and their incidence by Aszmann et al. [9].

Type	The point of exit from the pelvis	Prevalence [%]
A	Posterior to the ASIS, across the iliac crest	4
B	Anterior to the ASIS, superficial to the origin of the sartorius muscle and within the substance of the IL	27
C	Medial to the ASIS, ensheathed in the tendinous emergence of the sartorius muscle	23
D	Medial to the emergence of the sartorius muscle, in the interval between the sartorius muscle and the fascia of the iliopsoas muscle, deep to the IL	26
E	The most medial, embedded in the loose connective tissue deep to the IL, overlying the thin fascia of the iliopsoas muscle, assisting the femoral branch of the genitofemoral nerve	20

ASIS — anterior superior iliac spine; IL — inguinal ligament.

data about distances from the ASIS, the lateral margin of the FA, and the lateral tip of the pubic tubercle. In 90.3% of cases the LFCN passed under the IL medially to the tip of the ASIS and laterally to the FA, the distance from the LFCN to the medial tip of the ASIS ranged from 4.3 to 40.2 mm (mean 8.89 mm), the medial tip of the ASIS was 55.4 mm from the lateral margin of the FA, and the lateral tip of the pubic tubercle was 57.5 mm away from it. In 80.6% of cases the LFCN was found within 2 cm of the medial tip of the ASIS, and in 10% of cases the LFCN was lateral to the ASIS [40].

The variability in the branching pattern of the LFCN was studied by several authors, who focused on the number of branches and their percentage incidence (Tab. 6).

The angle between the LFCN and the inguinal ligament was also examined. Grothaus et al. [26] investigated the LFCN as it branched into 3 rami and measured their angles. The range for the first branch was from 20 to 90 degrees, for the second branch from 30 to 90 degrees, and for the third from 60 to 90 degrees. For all the branches, the average value was around 61–70 degrees.

Lee et al. [40] also studied the angle between the IL and the LFCN as the nerve enters the femoral region of the thigh. The value ranged from 68.08 to 111.08 degrees (mean 83.38 degrees).

Grothaus et al. [26] also studied the relationship between the LFCN and the sartorius muscle. The authors measured the distance from the ASIS to where the LFCN crosses the sartorius muscle measured along the inguinal ligament. The average distance from the ASIS to where the nerve intersected the lateral edge of the sartorius muscle was 12 mm, with a range of 1 to 36 mm. The branches crossed the lateral border of the sartorius muscle at distances varying from 2.2 to 11.3 cm below the ASIS. Specifically, the mean distances for the first, second, and third branches were 54 mm, 60 mm, and 63 mm below the ASIS, respectively [26].

Clinical significance

Morphological variations of the LFCN are of great clinical significance. Aszmann et al. [9] stated that in 59% of cases, the LFCN was covered by an aponeurotic expansion of the sartorius muscle. However, there are also suggestions that the nerve has its own canal that isolates it from the sartorius muscle, *musculus tensor fasciae latae*, and other more superficial layers. Since the LFCN canal was described recently, clinicians should maintain additional awareness, because not only the nerve may have a different course, but also a different branching pattern, and therefore it might be easier to injure it, especially during procedures of the sartorius muscle or treatment of an inguinal hernia [9].

It is important to highlight that LFCN variability may interfere with hip arthroplasty. According to reports, 81% of patients suffer from neuropraxia in the region innervated by the LFCN after hip arthroplasty using an anterior approach — a method used to decrease the chance of dislocation [13, 25]. To prevent a loss of sensation in the femoral region of the thigh, the precise location of the LFCN should be known [57].

Another procedure that may cause iatrogenic injury of the LFCN is a revisional total hip arthroplasty (THA) using the direct anterior approach (DAA) [84]. Different types of incisions used during this procedure might cause nerve palsy, which would manifest itself as a sensation of numbness, severe pain, or burning sensation in the anterior region of the thigh [84].

It is also important to highlight that ASIS is used as a bony landmark to measure different possible

Table 6. Percentage occurrences of numbers of branches documented in the literature based on Włudyka et al. [95].

Studies	Number of examined specimen	Number of branches and their prevalence			
		1	2	3	4
Sürücü et al. (1997) [82]	44	11.4%	84%	2.3%	2.3%
Dias Filho et al. (2003) [17]	52	–	66%	34%	–
Doklamyai et al. (2008) [19]	85	75.3%	21.2%	2.3%	1.2%
Ropars et al. (2009) [70]	34	–	94.1%	5.9%	–
Zhang et al. (2010) [98]	20	–	100%	–	–

placements of the ways the LFCN may leave the pelvis. Even though in most cases the LFCN travels medially to the ASIS, in some cases it is located laterally [86]. Such a position increases the risk of iatrogenic injury during bone graft harvesting. Such a procedure is performed commonly in reconstructive orthopaedic surgery [18]. When preparing for this procedure, it is essential to consider the different paths of the LFCN to avoid iatrogenic injury, which could potentially lead to meralgia paraesthetica [95].

GENITOFEMORAL NERVE

Classical anatomical description and innervation range

The GFN is a nerve that arises from the L_1 and L_2 nerve roots (Fig. 1). It courses on the anterior surface of the PM and is divided into 2 branches: the genital and the femoral. The genital branch goes downward on the PM's surface and then enters the deep inguinal ring and goes into the inguinal canal. This branch is responsible for motor innervation of the cremaster muscle (in men), causing muscle contraction in response to touch on the medial part of the thigh — this is the cremasteric reflex. The genital branch also provides sensory innervation of the scrotal skin (in men), mons pubis, and labia majora (in women). In turn, the femoral branch courses beneath the inguinal ligament and it goes in the lateral muscular compartment sensory innervating the superior part of the anterior and medial skin of the thigh [1–3].

Morphological variation

Variations of this nerve seems to be common. Anloague and Huijbregts [5] carried out a study the results of which show that the GFN was morphologically variable in 47.1% of studied cases. The most common variation was a high division into femoral and genital parts, without penetrating the PM, and this muscle was located between the femoral and genital branches (26.5% of studied cases). The second variant (20.6%) was represented by division into the femoral and genital branches, but this division was located at the upper part of the PM (not in the middle of this muscle, as in the standard anatomical variant) [5].

Sim and Webb [75] also observed anatomical variations in the GFN. In 8% of studied LP, the GFN divided into terminal branches before emerging from the PM. During this study, the level of GFN's emergence from the PM was also assessed, and it turned out that the most common level was L_3 (48%) and L_3–L_4 (18%). Other levels of emergence were L_4 (15%), L_2–L_3 (7%), and L_4–L_5 (3%). Moreover, in most cases (91%), the GFN was created by L_1 and L_2 nerve roots. Only in 9% was it formed by a single L_1 nerve root [75]. Yasar et al. [97]carried out a study among human foetuses, and the results were similar. In most cases (90%), the GFN's origin was standard (L_1–L_2); however, there were also cases when the GFN originated only from the L_2 spinal nerve (10%).

In the study carried out by Benes et al. [11], the GFN's exit from the PM was standard only in 50% of cases. In 48.1% the GFN left this muscle already divided into 2 branches: the femoral and genital. An interesting but very rare variation (0.4%) is a femoral branch of the GFN arising from a common trunk with the INN nerve. Another rare variation is the femoral branch arising from the LFCN (0.4%). In some cases, the GFN's femoral branch may also arise from the FN (1.2%) (Tab. 7, Fig. 4).

Iwanaga et al. [32] also checked the GFN's course. In most cases (75%) this structure was standard and had a common trunk. In 25% there was no common trunk, and the GFN had 2 separate branches: medial (genital) and lateral (femoral). Each of them had the appropriate number of its own branches; the medial branch gave off from 1 to 3 branches, and the lateral branch, from 1 to 4 branches. The most common number of own branches from the medial and lateral branch was 1–2, which occurred in 75% of all cases. In 33.3%, 1 or 2 branches (from either the medial or lateral branch) terminated as femoral or genital branches. In 4.2%, one branch from the medial (genital) branch terminated as a femoral branch, and one

Table 7. Proportions of the individual variations of the genitofemoral nerve [11].

Type	Right	Left	Total
Standard	48.2%	52.1%	50%
Exiting the PM as two separate branches	49.6%	46.2%	48.1%
Origin of the femoral branch from the FN	2%	0.8%	1.2%
Origin of the femoral branch from the LFCN	0%	0.8%	0.4%
Origin of the femoral branch from the INN	0.7%	0%	0.4%

FN — femoral nerve; INN — the ilioinguinal nerve; LFCN — the lateral cutaneous femoral nerve; PM — psoas major muscle.

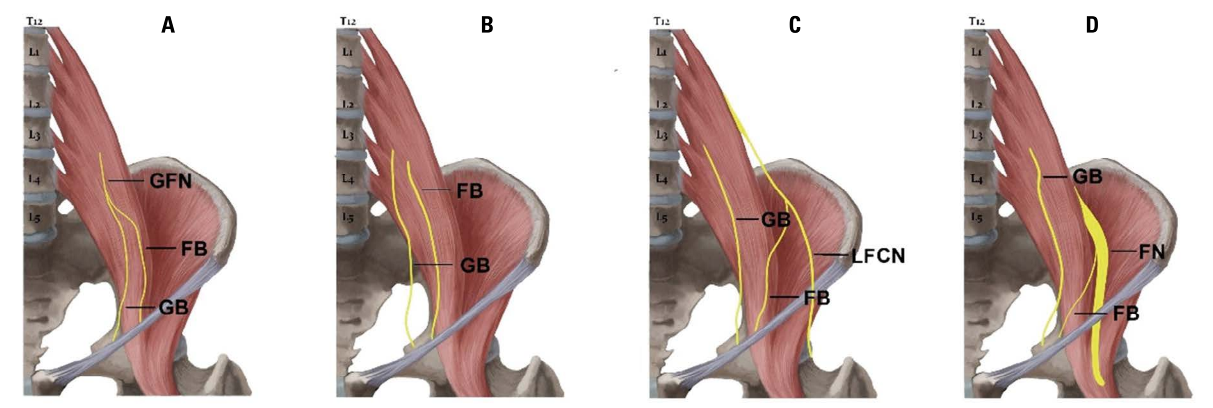

Figure 4. Variations of the genitofemoral nerve anatomy based on study carried out by Benes et al. [11]. FB — femoral branch of the genitofemoral nerve; FN — femoral nerve; GB — genital branch of the genitofemoral nerve; GFN — genitofemoral nerve; LFCN — lateral femoral cutaneous nerve; TYPE A — usual appearance of the genitofemoral nerve; TYPE B — femoral and genital branches of the genitofemoral nerve exiting the psoas major muscle separately; TYPE C — origin of the femoral branch of the genitofemoral nerve from a common trunk with the lateral femoral cutaneous nerve; TYPE D — origin of the femoral branch of the genitofemoral nerve from the femoral nerve.

branch from the lateral (femoral) branch terminated as a genital branch. It was termed partial reversed type. Another variation (4.2%) was characterised by a medial branch ending as a femoral branch, not a genital branch, and the lateral branch ended as a genital, not femoral branch, and this type was called complete-reversed type. In 4.2% there was no genital branch (the medial terminated as the femoral branch). In 4.2% there was no femoral branch (the lateral branch terminated as the genital one) [32].

Geh et al. [23] created a classification system of GFN's variations (Fig. 5). The Type 1 branching pattern was the most common, occurring in 50% of specimens and characterised by division into femoral and genital branches after exiting the PM. Type II was represented by a single GFN without splitting into a genital and femoral branch; it occurred in 30% of studied specimens. The rarest type (20%) was Type 3, in which the GFN emerged from the PM as 2 or more branches. The point of emergence was also assessed and divided into 3 categories. In the first one (10%), the proximal nerve emergence occurred when it was located superior to the L2 transverse process. The most common was the middle one (70%), which was when the GFN emerged between the L_2 transverse process and iliac crest, while the distal one (20%) was when the nerve emergence was inferior to the iliac crest (Tab. 8).

In another study [66] the branching patterns of the GFN and INN were assessed, and a new classification system was created. Four types of cutaneous branching patterns were identified. Type A, the most common type (43.7%), was characterised by GFN's domination in the scrotal/labial and the ventromedial thigh region, and the INN was not responsible for sensory innervation of these regions. In turn, in Type B, which was observed in 28.1% of studied cases, the dominant nerve was the INN, and the GFN was not responsible for sensory innervation, but it shares a branch with the 10INN and gave off branches to the cremaster muscle in the inguinal canal. The GFN was a dominant nerve in Type C (20.3%); however, unlike Type A, the INN represented sensory innervation to the mons pubis and inguinal crease, and the anteroproximal part of the penis or labia majora roots. In Type D (7.8%), cutaneous branches emerged from both the GFN and the INN, and the INN was also responsible for innervation to the mons pubis and inguinal crease, and the anteroproximal part of the penis or labia majora roots. What is interesting, the type of cutaneous branching pattern was bilaterally symmetric in 40.6% [66].

Wijsmuller et al. [94] studied the course of the genital branch of the GFN and its relationship with the inguinal canal. It transpired that in most cases (94%) the genital branch passed downward laterocaudally to the inguinal canal, through the deep inguinal ring. Only 6% of studied cases were represented by GFN's genital branch coursing through the inguinal canal a few millimetres caudal to the deep inguinal ring [94].

In another study [68] the relationship of the GFN and INN and IHN were assessed. It was shown that in 100% of cases, both the femoral and genital

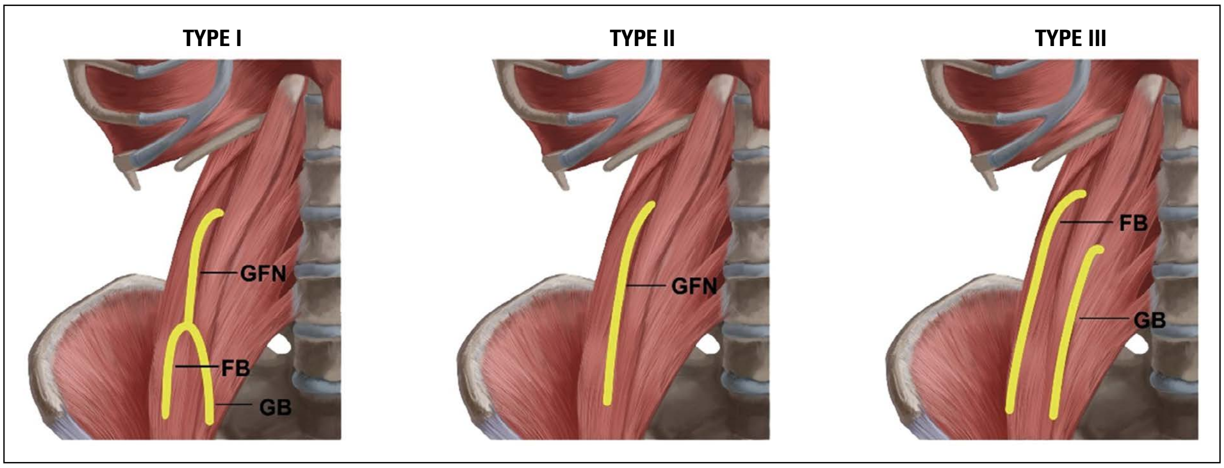

Figure 5. Classification system of the genitofemoral nerve created by Geh et al. [23]. FB — femoral branch of the genitofemoral nerve; GB — genital branch of the genitofemoral nerve; GFN — genitofemoral nerve; TYPE I — division into femoral and genital branches after exiting the psoas major muscle; TYPE II — a single genitofemoral nerve without splitting into genital and femoral branch; TYPE III — the genitofemoral nerve emerged from the psoas major muscle as 2 or more branches.

Table 8. Frequency (%) of GFN variations classified by Geh et al. [23].

GFN exit point	Type			Total
	Type 1	Type 2	Type 3	
Proximal	7.5%	0%	2.5%	10
Middle	40%	22.5%	7.5%	70
Distal	2.5%	7.5%	10%	20
Total	50%	30%	20%	100%

GFN — the genitofemoral nerve.

branches of the GFN were located medial to the INN and IHN.

Clinical significance

Knowledge about the GFN's anatomy and possible anatomical variations is important, for example, for inguinal region invasive procedures like open inguinal hernia repair or laparoscopic inguinal hernia repair. This nerve may be suffer iatrogenic damage from other surgical procedures like caesarean section, appendectomy, lymph node biopsy, vasectomy, and hysterectomy [71].

Alfieri et al. [3] confirmed that the risk of chronic inguinal pain (as a result of post-surgery neuropathy) increased with the increasing number of GFN branches undetected before surgery. However, the misdiagnosis of genitofemoral neuralgia as ilioinguinal neuropathy also occurs. So, to avoid such situations, selective nerve block may be used, and when the INN nerve block causes relief of the patient's symptoms, it means that the diagnosis is ilioinguinal neuralgia. In the other hand, when the symptoms are not relieved, it means that the GFN is the main reason for the chronic pain [81].

As mentioned above, the GFN may vary in its division into the genital and femoral branches. Sometimes additional branches from these structures are observed. The GFN may be formed by different nerve roots, and its relationship with the PM and iliacus muscle may also be variable. High morphological variability is the reason that, in some cases, the invasive procedures may have side effects such as nerve damage. Knowledge about the standard course of the GFN and its possible anatomical variations may decrease the number of side effects or prevent the duration of operation from being extended.

FEMORAL NERVE

Classical anatomical description and innervation range

The FN is the largest nerve of the LP. It arises from the dorsal divisions of the ventral rami of the L_2–L_4 nerve roots (Fig. 1). It courses laterally to the lateral border of the PM and goes downward to the muscular space located under the inguinal ligament. Then it enters the femoral triangle, coursing lateral to the femoral artery. Then the FN separates into anterior and posterior divisions (separated by the lateral femoral circumflex artery). The FN has 4 major branches: cutaneous, muscular, vascular (to the femoral artery and its branches), and articular (to the hip and knee joints). Cutaneous branches are responsible for innervation of the anterior and medial part of the thigh skin. Among cutaneous branches, the intermediate femoral cutaneous nerve, medial femoral cutaneous nerve (from anterior division), and saphenous nerve (from posterior division) should be mentioned. Muscular branches are responsible for innervation of the pectineus muscle (before division to the anterior and posterior parts of the FN), sartorius muscle (anterior division), and rectus femoris, vastus medialis, vastus literalism vastus intermedius, and articular genus muscle (posterior division) [1–3].

Morphological variation

The course of the FN is not always the same. Sometimes this nerve is characterised by some morphological variations. The nerve might be divided into numerous slips by additional muscular components of the iliopsoas muscle complex [63–65]. In a study carried out by Anloague and Huijbregts [5] the FN was found to vary in 35.3% of studied cases. In all variations, the FN bifurcated into 2 or 3 branches, and the PM passed between these slips. In one specimen, there was an additional connection between the medial and lateral slips. In another case, the FN bifurcated also into medial and lateral segments, but the lateral segment coursed posterior to the PM, exited along the lateral border, and then rejoined the medial segment, without an additional structure connecting these 2 structures [5].

Kirchmair et al. [37] found that the FN was divided into 2 branches in 14.8% of cases, and into 3 branches in 6.6% of studied specimens. Among cases of FN with some division, 84.6% branches reunited proximally to the inguinal ligament [37].

Parker et al. [59] also found an interesting case of an FN divided into 3 slips. This nerve was traversed by the psoas quartus muscle, which coursed through the FN and divided it into a medial part (smaller one) and a lateral part (larger one). The division for the third part was caused by iliacus minor muscle [59]. Khalid et al. [36] described a case in which the FN was also pierced by a muscle band, in this case the psoas tertius muscle, and after division, the medial and lateral branches reunited. In another study [91], the prevalence of muscular bands from the PM or iliacus muscle, piercing or covering the FN, was 7.9%.

Wong et al. [96] found and interesting case of an accessory muscle that caused the FN to bifurcate into 4 separate branches. This FN's origin was standard, and it was formed from L_2–L_4. After that, (at the level of L5) the mentioned division was observed. The most medial branch was responsible for innervation the psoas quartus muscle and iliacus muscle. The second and the third ones were divided by an aberrant muscle innervating it, and they distally reunited. The last branch (located laterally) coursed independently under the inguinal ligament, and this branch was responsible for cutaneous innervation of the lateral part of the thigh region [96].

Spratt et al. [77] carried out a study on the PM and iliacus, and it turned out that in 2.2% of cases, these muscles spilt the FN. Similar variation was found by Jelev et al. [34] bilaterally. On the right side, the main part of the FN was located behind the accessory PM, and bifurcation was observed there. These 2 nerves were passing downward, and after that they fused with each other again. On the left side, in the place where the FN should be found, only 2 small nerve fascicles were observed. The main part of the FN passed through the iliacus muscle. Nerve fascicles arising from the FN were also observed, as well as over the superficial part of the iliacus muscle connected with the FN [77]. In the available literature, there is also a variation characterised by a single accessory slip of the iliacus muscle piercing the FN [10, 60].

In a study carried out by Sim and Webb [75], the FN was formed in all cases by L_2–L_4 nerve roots. However, the level of emergence of the FN from PM was variable, and the most common were L_5 (32%) and L_4–L_5 (27%). Other levels were as follows, with frequencies: L4 (20%), L_5–S_1 (13%), and S_1 (7%) (Tab. 9). Interestingly, in this study, the LFCN arising directly from the FN was also observed (10%) [75].

Archana et al. [7] conducted another study in which 94% of the FN's origin was standard (L_2–L_4). The remaining 6% of studied FN arose from dorsal divisions of the ventral rami of L_1–L_3. Additionally, in 4%, the FN passed behind the PM.

The branching pattern of the FN in the iliac fossa was also studied [8]. The results showed different variations; for example, an abnormally long L_2 nerve root (3.1%) found bilaterally in a male cadaver, which was 92 mm on the right side and 85 mm long on the left side (the mean length of all specimens was 34 mm). Also, high division of the FN (3.1%), the LFCN arising directly from the FN (6.3%), single nerve to the pectineus muscle originating in the iliac fossa (4.7%), and division of the FN by an accessory band of the iliacus muscle (3.1%) or PM (4.7%) [8]. As mentioned above, the LFCN directly arising from the

FN was observed not only in this study but also in the study by Sim and Webb [75] (in 10%). Dias Filho et al. [17] found such a case in 2% of studied LP. In the available literature, there are also descriptions of the accessory LFCN arising directly from the FN above the inguinal ligament [90].

Benes et al. [11] also described variation connected with the FN, for example, LFCN (0.4%), INN (1.5%) or femoral branch of GFN (1.2%) directly arising from this nerve [11]. In the same study, they found that 82.3% of FN was standard. The group of observed variations includes: low formation outside of the PM (3.8%), small accessory FN coursing independently through the muscular space under the inguinal ligament (12.3%), and high branching within the pelvic cavity (1.5%) [11] (Tab. 10).

An interesting variation was described by Sripriya and Sivashanmugam [78]. During ultrasound femoral triangle scanning, the FN was not observed in the standard location but was seen to be winding around an abnormal band of iliacus muscle or PM [78].

In the available literature there are also studies carried out on human foetuses. For example, Jakubowicz [33] checked the correlation between course of FN and components of the iliopsoas muscle. In 2.5% of studied specimens, a separate muscular band of the PM coursed between the trunks of the FN. The other 2.5% of studied LP was represented by the iliacus muscle passing between the trunks of the FN [33]. Yasar et al. [97] also carried out a study among human foetuses. The results showed that the FN was the thickest nerve of the LP.

Table 9. Level of emergence of the femoral nerve (FN) from psoas major by Sim and Webb [75].

Level of emergence of the FN	Frequency
L_4	20%
L_4–L_5	27%
L_5	32%
L_5–S_1	13%
S_1	7%
S_1–S_2	2%

Table 10. Proportions of the individual variations of the femoral nerve (FN) by Benes et al. [11].

Type	Right	Left	Total
Standard	79.4 %	85.7 %	82.3 %
Accessory FN	14.9 %	9.2 %	12.3 %
Low formation	3.5 %	4.2 %	3.8 %
High branching	2.1 %	0.8 %	1.5 %

Clinical significance

The FN and its anatomical variations may be associated with some clinical implications. The fact that the FN is covered by the iliac fascia, and the PM and iliacus muscle also, makes the FN predisposed to neuropathy, especially due to haematoma or abscess formed in the mentioned muscles as a result of anticoagulant therapy, vessel catheterisation, or psoas abscess [21].

Anatomical variations, like LFCN arising directly from the FN, are significant, especially during LFCN blocks, due to the possibility of simultaneous blockade of the FN and, consequently, the structures innervated by it [74].

Knowledge about other morphological variants of the FN are necessary during anaesthesia for the anterior thigh region, knee joint, and medial part of the foot. Such anaesthesia is used during orthopaedic and plastic surgeries [53].

Surgical and anaesthetic interventions in these regions predispose to injuries of the plexus. It may be observed as meralgia paraesthetica, groin pain, testicular pain, and limb weakness. This is the reason why knowledge about standard course of the FN, and its possible anatomical variations, may decrease the number of femoral neuropathies caused by invasive surgical procedures [7].

In a study carried out by Archana et al. [7], in most cases the FN emerged from the lateral border of the PM. However, 2 cases emerging from behind the PM were also found. Such variation may increase the risk of nerve compression because of PM abscess, haematoma, retroperitoneal tumours, or retroperitoneal haemorrhage [7].

Summing up, knowledge about the standard course of the FN and its possible anatomical variations may be necessary for clinicians, especially for anaesthesiologists, orthopaedics, and plastic surgeons.

OBTURATOR NERVE

Classical anatomical description and innervation range

The ON arises from the ventral divisions of the L_2–L_4 in the LP (Fig. 1). It emerges from the PM's medial border, near edge of the pelvic inlet. It goes downward behind the common iliac arteries. After that, it passes lateral to the internal iliac vessels. Then it enters the lesser pelvis and goes through the obturator foramen to the thigh region where there is a division into an anterior and a posterior branch. The ON sensory innervates the medial part of the thigh and gives off muscular branches to the adductor muscles of the lower limb (external obturator m., adductor longus m., adductor brevis m., adductor magnus m., and gracilis muscle). Sometimes, the ON also takes part in innervation of the pectineus muscle m. [1–3].

Morphological variation

Variations of this nerve seem to be uncommon. Anloague and Huijbregts [5] carried out a study in which there was no anatomical variation of the course of the ON. However, the accessory ON was found in 8.8% of studied cases. It was a small structure arising from the L_3 and L_4 level, coursing along the medial border of the PM. What is interesting is that this accessory nerve passes above the superior ramus of the pubic bone (not through the obturator foramen). Its function is innervation of the pectineus muscle and the hip joint [5].

Benes et al. [11] also carried out a study of the ON. They found that in all cases this nerve did not present any variations at its point of emergence from the PM. On the other hand, morphological variations were observed in the ON's division into anterior and posterior branches, because in 40.4% of studied cases it was a high division before passing through the obturator canal. Moreover, the accessory ON was also observed, and it was found in 9.2% of cases (Tab. 11, Fig. 6).

The accessory ON was also observed by other scientists. For example, Webber [92] found this variation in 8% of studied LP. Akkaya et al. [2] found accessory ON in 12.5% of cases. Sim and Webb [75] found it in 12% of specimens. A higher frequency was observed by Horwitz [28]. On the other hand, there are also studies in which the accessory ON was not found [12, 87]. Yasar et al. [97] carried out a study on human foetuses, and accessory ON was present in 20% of studied cases. There were no other variations associated with the ON [97]. Katritsis et al. [35] found the accessory ON in 13.2% of studied LP. The origin of this nerve was also assessed, and it turned out that the most common type (63.6%) was the accessory

Table 11. Proportions of the individual variations of the obturator nerve (ON) by Benes et al. [11].

Type	Right	Left	Total
Standard	43.3%	58.8%	50.4%
High division	44.7%	35.3%	40.4%
Accessory ON	12.1%	5.9%	9.2%

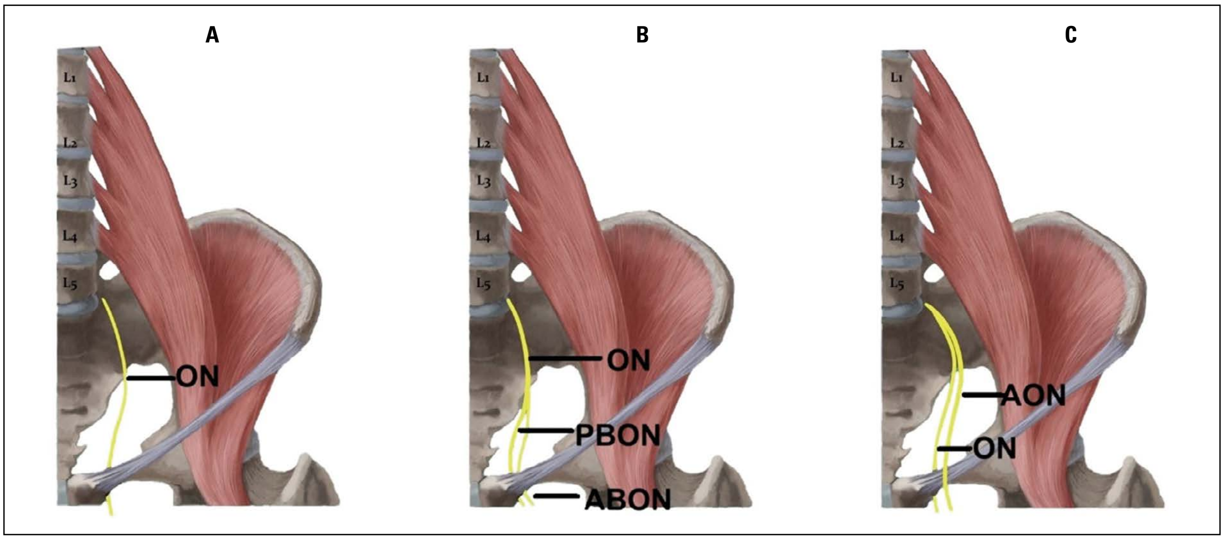

Figure 6. Variations of the obturator nerve anatomy based on study carried out by Benes et al. [11]. ABON — anterior branch of the obturator nerve; AON — accessory obturator nerve; ON — obturator nerve; PBON — posterior branch of the obturator nerve; TYPE A — usual appearance of the obturator nerve; TYPE B — high division of the obturator nerve; TYPE C — accessory obturator nerve in addition to the proper obturator nerve.

ON originating from the anterior primary divisions of L_3–L_4. In 10.6% of cases this accessory structure was formed by L_2–L_4 nerve roots, in 7.5% by L_2–L_3, and in 6.1% only by the L_3 nerve root. In 12.1% the accessory ON arose directly from the ON [35] (Tab. 12).

Level of the ON's emergence of the LP nerves from the PM was also assessed, and it was shown to be variable. The most common level was L_5–S_1 (60%). Other levels with their frequency were as follows: S1 (22%), L_5 (15%), L_4–L_5 (2%), and S_2 (2%) [75].

As mentioned above, in most cases, the ON is formed by L_2–L_4 nerve roots, and in a study carried out by Sim and Webb [75] it was observed in 97%. In 3%, the L_2 nerve root did not take part in forming this nerve, and the ON was created only by the L_3–L_4 nerve roots. These results were confirmed by a study carried out on Ethiopian cadavers by Berhanu et al. [12]. In 88.1% the ON had its origin from the L_2–L_4 spinal nerves. 11.9% originated only from the L_3–L_4 nerve roots. Tshabalala [87] found a standard origin (L_2–L_4) in 80%, and 20% originated from L_3–L_4. Anandhi et al. [4] also confirmed this, reporting that that the L_2–L_4 variant is predominant and the L_1–L_3 variant is present in only 2% of cases. Miura et al. [49] also found that the ON originated from L_2–L_4 in most cases (76%). Other variants were formed by L_1–L_4 (11%), L_2–L_5 (5%), L_3–L_4 (4%), and L_3–L_5 (4%) [49]. What is interesting is that the results of Horwitz's study [28] showed that only 10% of ON had a standard origin, and the most common was ON formed by L_3–L_4 nerve roots (77%). In this study, there were also ON with T_{12}–L_5 origins [28]. A comparison of various studies for variations in origin of the ON is shown in Table 13.

Berhanu et al. [12] also assessed other characteristics of ON. For example, the ON may be variable because of a different place of bifurcation to the anterior and posterior branches. The most common location of it is within the obturator canal (44.8%); however, it may also take place in the extrapelvic region (44.8%) or intrapelvic region (23.9%) [12]. In the anterior branch, morphological variations are also observed, especially in the number of muscular subdivisions. In this study, the most common (65.7%) was an anterior branch divided into 3 subdivisions (to adductor longus muscle muscle, adductor brevis muscle, and gracilis muscle). Subdivision into 4 branches (additionally to the pectineus muscle) was rarer (25.4%), and the rarest type was subdivision into 2 muscular branches (only to the adductor longus muscle and gracilis muscles) [12].

The ON's posterior branch is also variable, so the most common (65.7%) subdivision is represented by 2 muscular branches (to the obturator externus muscle and adductor magnus muscle). In other cases (34.3%), the posterior branch was divided into 3 (the additional branch was to the adductor brevis muscle) [12].

Mazurek et al. [47] described an interesting case of a junction between the ON and saphenous nerve. As mentioned above, the ON in the thigh region is divided into anterior and posterior branches. In this case, the anterior one gave off 4 branches at the same level: the 3 motor nerves to the adductor longus muscle, the gracilis muscle, the adductor brevis muscle branch, and one cutaneous branch with an atypical course. This variation coursed downwards, then bent laterally towards the saphenous nerve and

Table 12. Level of origin of the accessory obturator nerve (ON) by Katritsis et al. [35].

Level of origin of the accessory obturator nerve	Frequency
L_2–L_3	7.5%
L_2–L_4	10.6%
L_3	6.1%
L_3–L_4	63.6%
Accessory nerve arising directly from the ON	12.1%

Table 13. Comparison of various studies for variations in origin of the obturator nerve.

	T_{12}–L_5	L_1–L_3	L_1–L_4	L_2–L_4	L_2–L_5	L_3–L_4	L_3–L_5
Horwitz (1939) [28]	13%	–	–	10%	–	77%	–
Miura et al. (1994) [49]	–	–	11 %	76%	5 %	4%	4%
Anloague and Huijbregts (2009) [5]	–	–	–	100%	–	–	–
Tshabalala (2015) [87]	–	–	–	80%	–	20%	–
Anandhi et al. (2018) [4]		2%		98%	–	–	–
Berhanu et al. (2020) [12]	–	–	–	88.1%	–	11.9%	–

descended under the intermuscular septum along with the associated femoral vessels. This cutaneous branch ended in 2 separate branches: the first one to the knee joint (the articular branch) and the second one connecting with the saphenous nerve [47].

Clinical significance

Knowledge about anatomical variations of the ON is necessary, especially for anaesthetists. When surgical procedures are performed at the hip joint region, the proximal part of the thigh, or the medial thigh region, and also in the region of the knee joint, effective blocking of the ON is necessary [12]. Variations in division to the anterior and posterior branch, or the presence of an accessory junction, branches, or accessory ON, and different levels of emergence the ON from the PM or different level of nerve roots forming the ON may cause difficulties during anaesthesia or surgery, increase the number of side effects, or prolong the course of surgery [12].

It is worth mentioning that the presence of the accessory ON could negatively influence the effectiveness of an ON block, so during surgical procedures, when the accessory ON occurs, this nerve should be also blocked [89].

In the other hand, some variants of the ON may predispose to obturator neuropathy. It is a pathology characterised by sensory alteration in medial thigh, like sensory loss, paraesthesia, or pain [85].

Sorenson et al. [76] carried out a study in which the results showed that the most common symptom associated with obturator neuropathy (42.1%) was medial thigh or groin pain. In 15.8% of patients, weakness of the muscles supplied by the ON occurred, and 6% of patients complained of sensory loss. In 44.7% of studied cases, the neuropathy occurred immediately after a well-defined moment — surgical procedure (36.8%) or trauma (7.9%). It turned out that the most common surgery was total hip arthroplasty [76].

The results of this study confirmed that knowledge about the standard course of the ON and its possible anatomical variations may decrease number of obturator neuropathies caused by invasive surgical procedures.

CONCLUSIONS

Based on the results of available studies, the nerves of the LP are characterised by different morphological variations. Anatomical variations are very common and may be associated with some clinical aspects. Understanding the anatomical variations of the LP's nerves is essential for procedures involving the lower abdomen and thigh, graft harvesting, regional anaesthesia, and managing nerve entrapment syndromes.

ARTICLE INFORMATION AND DECLARATIONS

Author contributions

Nicol Zielinska — project development, data collection and management, data analysis, and manuscript writing. Marta Pośnik — data analysis and manuscript editing. Izabella Kaczmarczyk — data analysis and manuscript editing. Ilona Klejbor — data analysis and manuscript editing. George Triantafyllou — data analysis and manuscript editing. Eva Maranillo — data analysis and manuscript editing. Łukasz Olewnik — data collection, data analysis, and manuscript editing. Janusz Moryś — data collection, data analysis, and manuscript editing.

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Conflict of interest

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