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Anatomy of the Lateral Lumbar Approach: Studies of the Psoas Muscle and Lumbar Plexus

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The minimally invasive lateral retroperitoneal transpsoas approach for lumbar interbody fusion (extreme lateral interbody fusion [XLIF®, NuVasive®, Inc., San Diego, CA]) is used to treat common spinal disorders, including degenerative disc disease, spondylolisthesis, traumatic injuries, and spinal deformity.[1-4] The XLIF approach provides anterior column access to the disc space from L1 to L5 without the need for an access surgeon. Access is achieved using a 90 degree off-midline surgical pathway passing through the retroperitoneal cavity and traversing the psoas muscle, while preventing injury to the nerves of the lumbar plexus. A thorough understanding of the anatomic complexity of the lumbar plexus and psoas muscle is essential for performing the procedure safely.

The anatomy of the psoas muscle and lumbar plexus has been well described in previous surgical, anatomic, cadaveric, and radiographic studies.[5-17] The objective of this chapter is to review the relevant anatomy of the psoas muscle and lumbar plexus with respect to the XLIF approach and summarize the pertinent studies in the literature.

MUSCULAR ANATOMY

The psoas major (or psoas) muscle is the key muscle traversed with blunt dissection (or spreading of the muscle fibers) during the XLIF approach. The psoas muscle is a long muscle that originates from the anterolateral aspect of the lumbar vertebral bodies, transverse processes, and their intervening disc spaces.[6,16,18,19] It comprises superficial and deep parts with components of the lumbar plexus lying between them. The psoas muscle descends anterolaterally, deep to the inguinal ligament, where it is joined by the iliacus muscle, and together they insert into the lesser trochanter of the femur. Together they are referred to as the iliopsoas muscle. As it progresses inferiorly from approximately the L1 level, the diameter of the psoas muscle steadily increases (Fig. 2-1) as it is contributed to by insertions at each subsequent level. The psoas major muscle receives innervations from the second to fourth lumbar spinal nerves as tiny intrinsic branches off the femoral nerve. The main action of the psoas muscle is hip flexion.

In approximately 50% of the population, there is a smaller accompanying muscle lying on the ventromedial

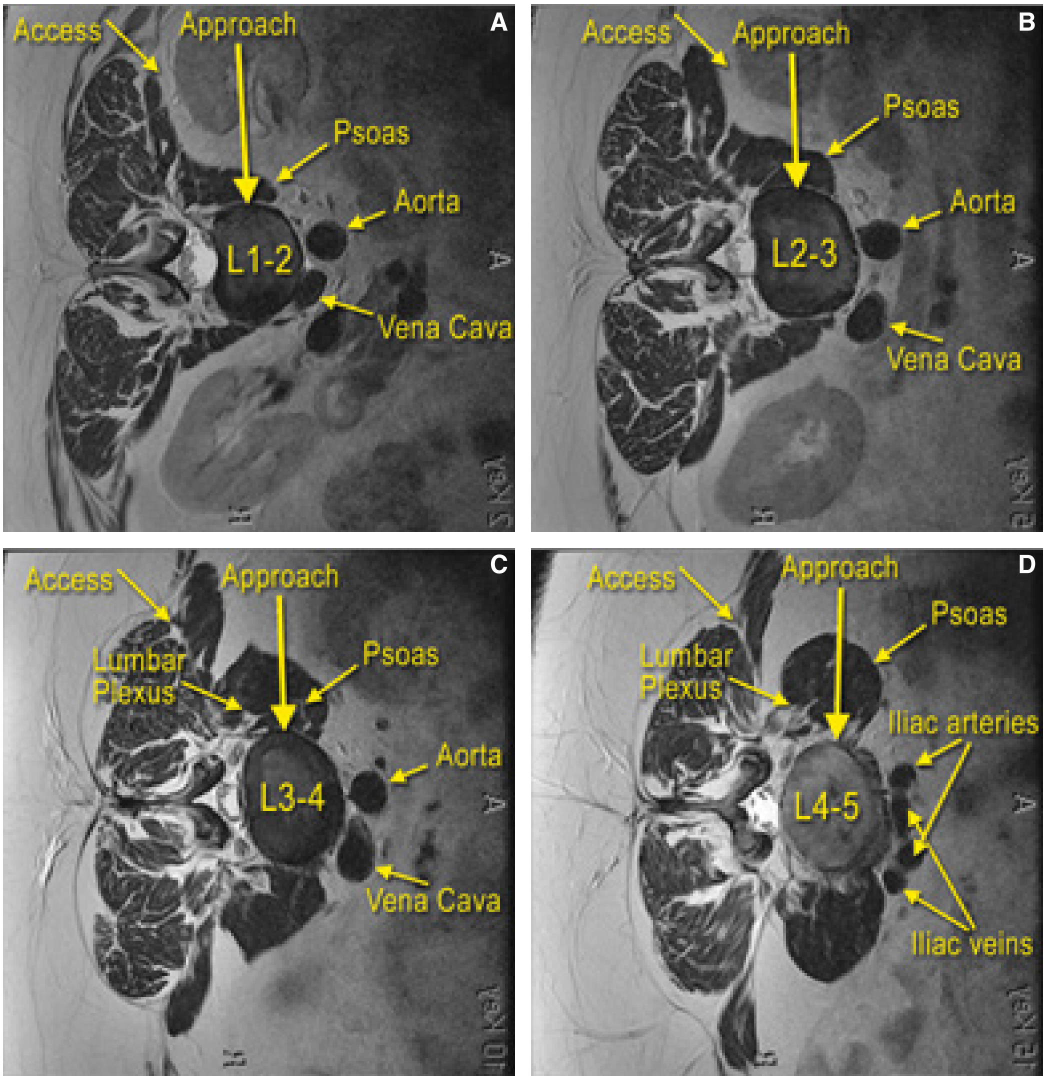

FIG. 2-1 Lumbar anatomy as it relates to the lateral transpsoas approach for interbody fusion on axial MRI from L1-2 to L4-5. Note the progressively increasing psoas major diameter.

surface of the psoas major muscle, known as the psoas minor muscle. It originates from the anterolateral surface of the twelfth thoracic and first lumbar vertebrae and the intervertebral disc between them. The psoas minor muscle ends in a long flat tendon that inserts into the superior ramus of the pubis. It is innervated by a branch of the first or second lumbar spinal nerves; its action is as a weak flexor of the trunk.

NEURAL ANATOMY

The neural anatomic structures most relevant to the XLIF approach are the nerves of the lumbar plexus, which lie within and around the lateral disc space, within and upon the psoas muscle, within the lateral retroperitoneal space, and within and between the superficial muscles of the abdominal cavity. The nerves of the lumbar plexus include, from cranial to caudal, the

TABLE 2-1 Sensory and Motor Nerves of the Lumbar Plexus and Their Functions

Nerve	Segment	Innervated Muscle(s)	Action	Cutaneous Branches	Sensation
Iliohypogastric	T12-L1	Transversus abdominis Internal oblique	Anterior abdominal wall contraction	Anterior cutaneous n. Lateral cutaneous n.	Inferior abdominal wall Upper lateral buttock
Ilioinguinal	L1	Internal oblique	Anterior abdominal wall contraction	Anterior scrotal nerves (M) Anterior labial nerves (F)	Proximomedial anterior thigh Genitalia
Genitofemoral	L1-2	Cremaster in males	Raise and lower scrotum	Femoral ramus Genital ramus	Genitalia Upper femoral triangle
Lateral femoral cutaneous	L2-3	—	—	Lateral femoral cutaneous	Anterior, lateral, posterior aspect of thigh
Obturator	L2-4	Obturator externus Adductor longus Gracilis Pectineus Adductor magnus	Thigh adduction Lateral hip rotation	Cutaneous ramus	Posterior medial thigh Medial knee Hip
Femoral	L2-4	Iliopsoas Pectineus Sartorius Quadriceps femoris	Hip flexion Adduction of thigh Knee extension	Anterior cutaneous branches Saphenous	Anterior medial thigh Anterior thigh Hip and knee
Short, direct muscular branches	T12-L4	Psoas major Quadratus lumborum Iliacus Lumbar intertransverse	Hip flexion Trunk lateral bending Trunk extension Trunk flexion	—	—

F, Female; *M,* male; *n*, nerve.

iliohypogastric and ilioinguinal, genitofemoral, lateral femoral cutaneous (sensory only), obturator, femoral, and short and direct muscular (intrinsic) branches (motor only) (Table 2-1). While the femoral nerve is the nerve most commonly discussed with respect to lateral approach surgery, as it represents the most apparent risk of motor injury, there are other important nerves that can be monitored with neuromonitoring and understanding the location of nerves at each level relative to the lateral approach will allow for improved identification and, where necessary, avoidance of these structures.

Lumbar Plexus

The lumbar plexus is formed by the nerves originating from the anterior divisions of the twelfth thoracic (T12) subcostal nerve and the first four lumbar spinal nerves. The plexus is a retroperitoneal structure that is situated in the posterior part and mostly (genitofemoral, femoral, and obturator nerves) within the substance of the psoas major muscle, between the superficial and deep layers.[6,18,19] It also contains nerves that travel outside the psoas muscle (subcostal, iliohypogastric, ilioinguinal, and lateral femoral cutaneous nerves) in the retroperi-

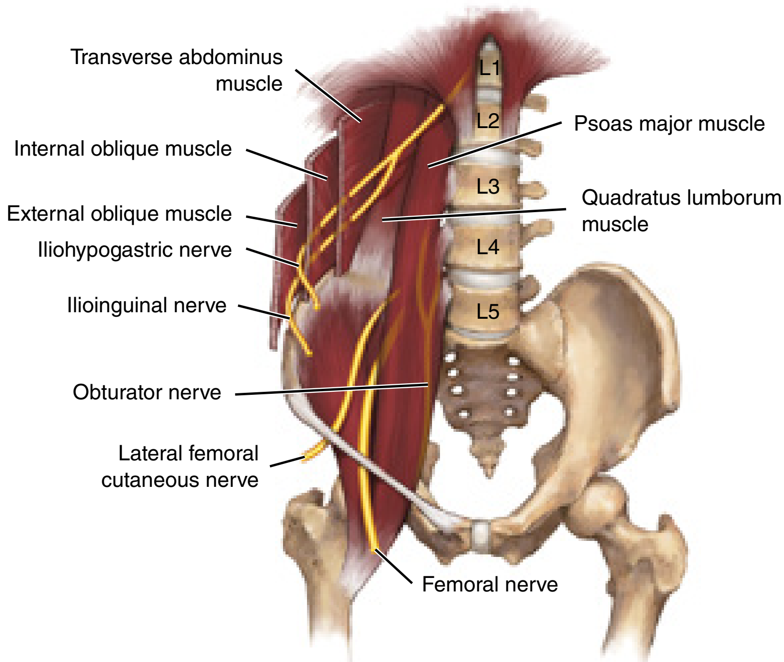

FIG. 2-2 Anterior view of the spine and pelvis, showing the deep and superficial nerves and musculature relevant to the lateral transpsoas approach.

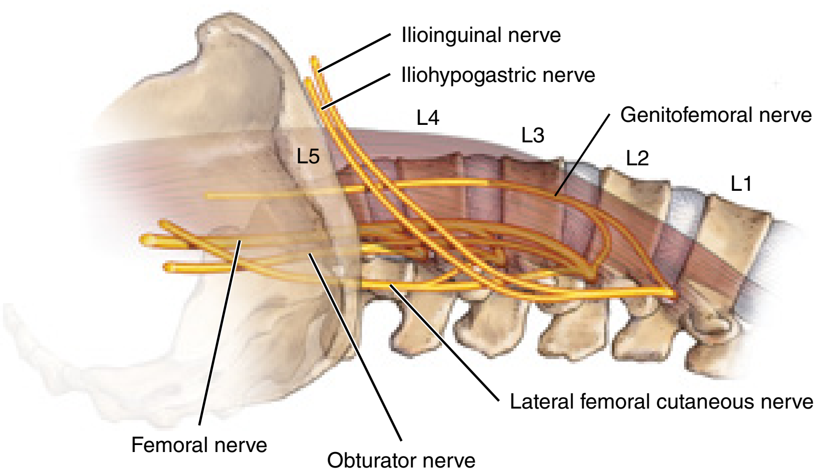

FIG. 2-3 Lateral view showing the nerves of the lumbar plexus.

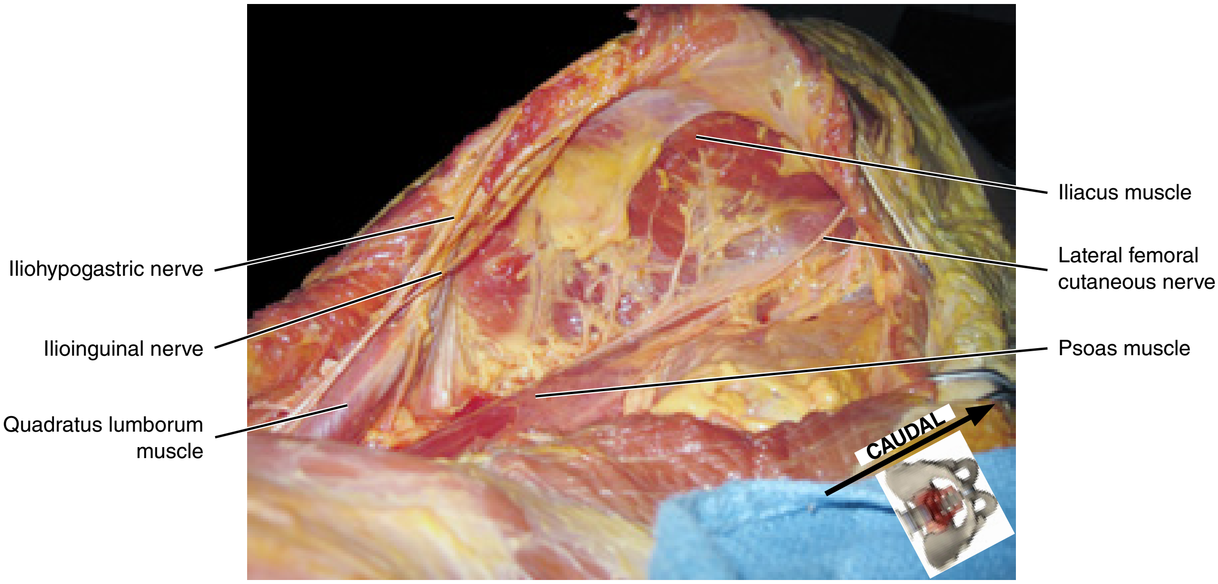

FIG. 2-4 Oblique and inferior view showing the superficial nerves and musculature relevant to the lateral transpsoas approach.

toneum (Fig. 2-2).[16] Viewed in the lateral decubitus position, the lumbar plexus is located on the posterior aspect of the vertebral body at upper lumbar levels, covering incrementally more area (ventrally) as is passes caudally (Fig. 2-3). The nerves pass obliquely outward, behind, and through the fibers of the psoas muscle, distributing small (intrinsic) branches to it. There is progressive anterior migration of the distal members of the plexus as it descends within the muscle at each of the disc spaces.[5,6,8,10,16,20] Its components enter, give off branches, pass through, and leave the psoas muscle at various sites to run obliquely downward through to the pelvic area, where they leave the pelvis mainly under the inguinal ligament (Fig. 2-4). The exceptions to this include the obturator nerve, which exits the pelvis through the obturator foramen, and the subcostal, iliohypogastric, and ilioinguinal nerves, which course superficially to reach the anterior iliac crest.

Subcostal Nerve

The most cranial nerve of the lumbar plexus is the subcostal nerve. It originates from the twelfth spinal nerve (T12) and accompanies the subcostal vessels along the inferior border of the twelfth rib (Fig. 2-2). It passes behind the lateral arcuate ligament and kidney and travels anterior to the upper part of the quadratus lumborum. The subcostal nerve then perforates the aponeurosis of the origin of the transversus abdominis muscle and travels between the transversus abdominis and internal oblique muscles in a medial and inferior course. A lateral cutaneous branch pierces the internal and external obliques before reaching the costal angle. The subcostal nerve continues its course within the abdominal wall medially until it reaches the edge of the rectus abdominis, where it perforates to give rise to the anterior cutaneous branches. It supplies the muscles of the anterior abdominal wall, especially the external oblique, and provides sensation to the anterior gluteal skin. Irritation or injury to this nerve, the potential for which may exist when treating the upper lumbar levels with XLIF, may result in abdominal wall paresis and pseudohernia.[21] It also occasionally communicates with the iliohypogastric nerve to give off a branch to the pyramidalis muscle.

Retroperitoneal Nerves

During the XLIF approach, the retroperitoneal space is accessed with the patient in the lateral decubitus position. A variable amount of adipose tissue fills this space superficial to the psoas muscle. The retroperitoneal space is bordered anteriorly by the abdominal and peritoneal structures, posteriorly by the quadratus lumborum and iliacus muscles, superiorly by the diaphragm, and inferiorly by the retroperitoneal pelvic space.[18,19] In this retroperitoneal space the ilioinguinal, iliohypogastric, and lateral femoral cutaneous nerves course[16] as described in detail in the following sections.

Iliohypogastric and Ilioinguinal Nerves

Below the subcostal nerve, the iliohypogastric and the ilioinguinal (usually smaller than the iliohypogastric) nerves are the most cranial nerves of the lumbar plexus (Figs. 2-2 through 2-5). The iliohypogastric and ilioinguinal nerves have both motor and sensory components. The lateral cutaneous branch of the iliohypogastric nerve provides sensation to the posterolateral gluteal skin, whereas its anterior cutaneous branch innervates the suprapubic skin. The ilioinguinal nerve supplies the medial skin of the thigh and either the root of the penis and upper part of the scrotum in men or the mons pubis and labia majora in women. The iliohypogastric and ilioinguinal nerves supply the muscles of the anterior abdominal walls, especially the transversus abdominis and internal oblique muscles.[16,18,19] The ilioinguinal and iliohypogastric nerves are usually reciprocal in size.

The iliohypogastric nerve originates from the first lumbar spinal nerve (L1) and emerges from the upper lateral border of the psoas major muscle. It runs obliquely embedded on the retroperitoneal adipose tissue behind the kidney to continue in front of the quadratus lumborum muscle (Fig. 2-5). Above the iliac crest, it perforates the posterior part of the transversus abdominis and divides into lateral and anterior cutaneous branches. The lateral cutaneous branch pierces the internal and external oblique muscles just above the iliac crest and slightly behind the lateral cutaneous branch of the subcostal nerve. The anterior branch runs anteriorly and inferiorly superior to the iliac crest between the

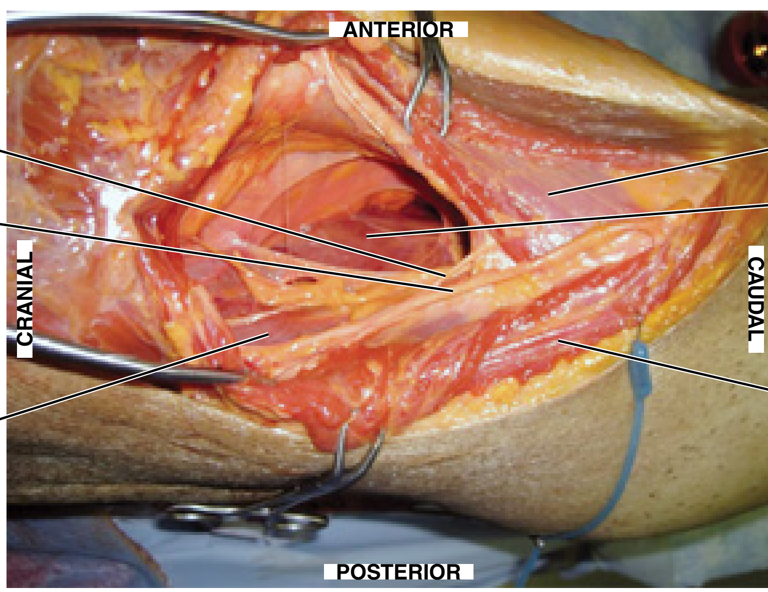

FIG. 2-5 Lateral cadaveric photograph showing the position of the ilioinguinal and iliohypogastric nerves in relation to the musculature relevant to the lateral transpsoas approach.

transversus abdominis and internal oblique muscles until just medial to the anterior superior iliac spine, where it pierces the internal and external obliques.

Similar to the iliohypogastric nerve, the ilioinguinal nerve arises from L1 and emerges from the lateral border of the psoas major just caudal to the iliohypogastric nerve. It then passes obliquely across the quadratus lumborum muscle and the upper part of the iliacus in the retroperitoneal space. Near the anterior portion of the iliac crest, it pierces the transversus abdominis muscle and courses anteriorly and inferiorly parallel to the iliohypogastric nerve (Fig. 2-4). Medial to the anterior iliac spine, it pierces the internal oblique muscle to travel within the inguinal canal and emerges from the superficial inguinal ring.

Lateral Femoral Cutaneous Nerve

The lateral femoral cutaneous nerve originates from the second (L2) and third (L3) lumbar spinal nerves (Fig. 2-3) and emerges from the lateral border of the psoas major muscle at approximately the fourth lumbar vertebrae and courses obliquely across the iliacus muscle toward the anterior superior iliac spine (Fig. 2-2). Within the iliac fossa, the right nerve passes posterolateral to the cecum and the left passes behind the descending colon. Both sides then course either through or below the inguinal ligament approximately 1 cm medial to the anterior superior iliac spine. The lateral femoral cutaneous nerve will ultimately divide into anterior and posterior branches. It is a purely sensory nerve with no somatic motor component. It supplies sensation to the anterior and lateral area of the thigh.

LUMBAR PLEXUS NERVES FOUND WITHIN THE PSOAS

Femoral Nerve

The largest branch of the lumbar plexus is the femoral nerve, formed from branches of the second, third, and fourth lumbar spinal nerves (Fig. 2-6).[6,18,19] It is found

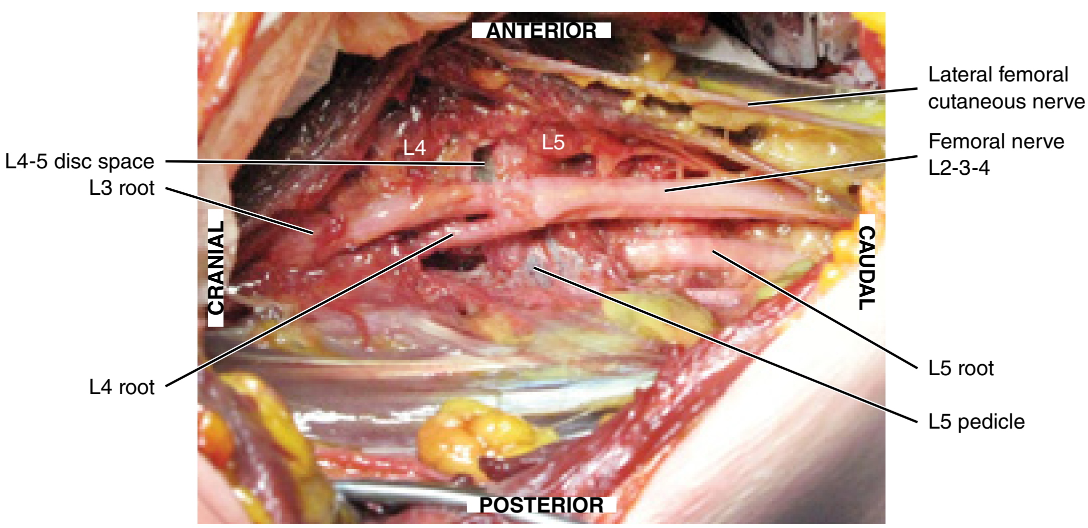

FIG. 2-6 Lateral cadaveric photograph showing the lateral L4-5 disc space, as accessed in the lateral transpsoas approach, with the deep nerves of the lumbar plexus as well as the lateral femoral cutaneous nerve visualized.

deep in the substance of the psoas muscle descending in a gradual posterior-to-anterior trajectory and crosses at the L4-5 disc space (Fig. 2-7). It continues inferiorly between the psoas and the iliacus muscle, beneath the inguinal ligament, and into the thigh, where it gives off the anterior cutaneous and muscular branches. It innervates the iliopsoas, pectineus, sartorius, and quadriceps femoris muscles.

Genitofemoral Nerve

The other relevant nerve that travels within the psoas muscle is the genitofemoral nerve (Fig. 2-8).[6,16,18,19] The genitofemoral nerve originates from the first (L1) and second (L2) lumbar spinal nerves and travels obliquely in a cephalocaudal direction through the substance of the psoas major from posterior to anterior. It travels obliquely in the substance of the psoas muscle from

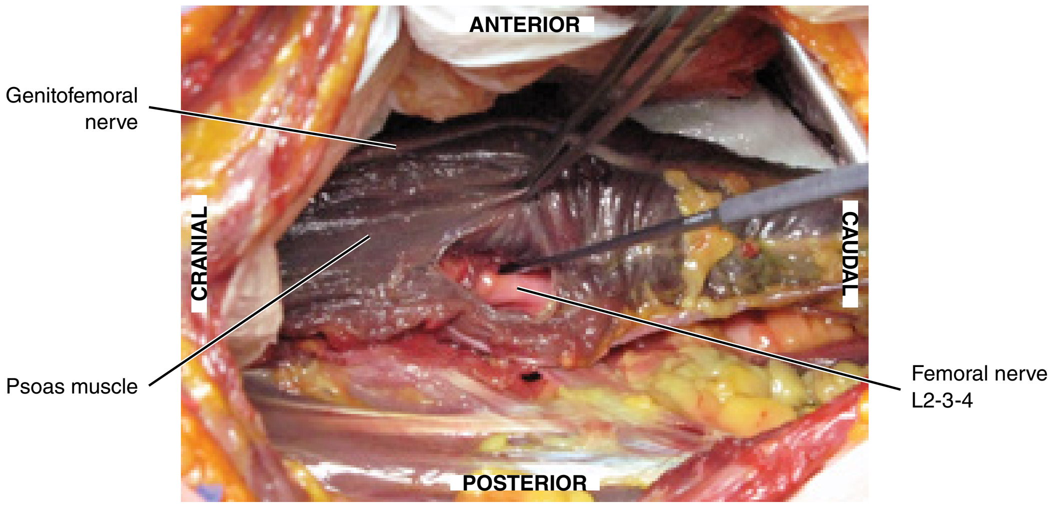

FIG. 2-7 Lateral cadaveric photograph showing the position of the femoral nerve deep and genitofemoral nerve superficial to the psoas major muscle.

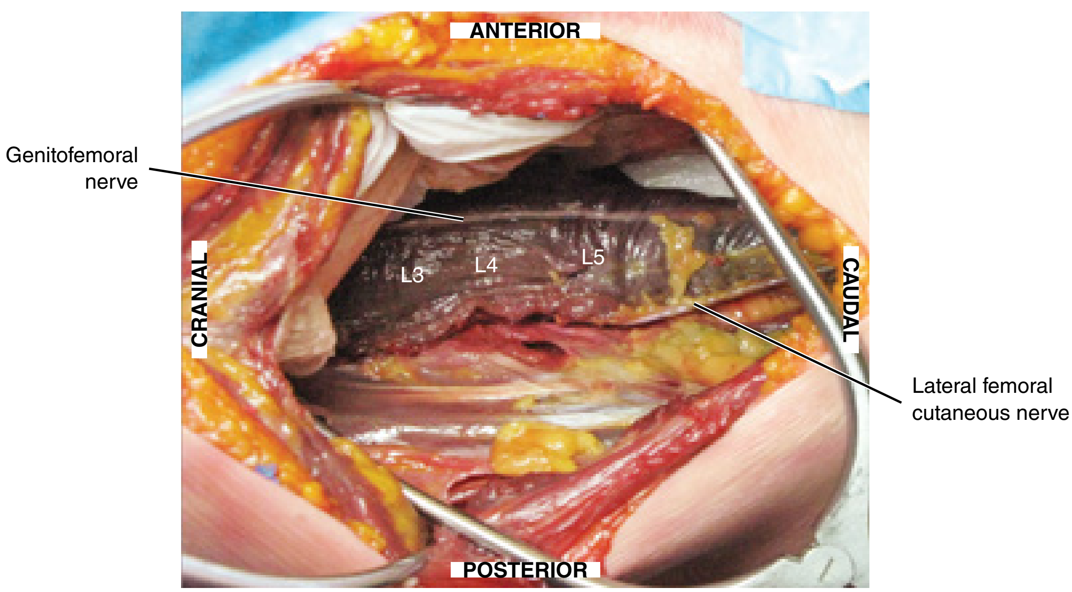

FIG. 2-8 Lateral cadaveric photograph showing the genitofemoral and lateral femoral cutaneous nerves with respect to the lateral transpsoas approach.

its origin, crossing at the L2-3 disc space, and emerges from its medial border superficial and anterior at the L3-4 level. It then descends on the surface of the psoas major, underneath the peritoneum, and on the anterior quarter of the L4 and L5 vertebral bodies on its way to reach the fascia transversalis, entering the abdominal wall around the inguinal ring. It divides into the external spermatic and lumboinguinal nerves to supply the skin around the inguinal and genital areas and anterior and medial upper part of the thigh. In males, it innervates the cremaster muscle.

LITERATURE REVIEW

From the lateral view, it is difficult to visualize the location of the nerves of the lumbar plexus relative to the intervertebral disc spaces. Uribe et al[6] reported an anatomic study describing the location of nerves relevant to XLIF and their location relative to the disc spaces while attempting to identify the safe corridors for the lateral surgical approach. In this study, the authors divided the area between the anterior and posterior edges of the vertebral body into four zones from a lateral perspective as follows: Zone I (anterior quarter), Zone II (anterior middle quarter), Zone III (posterior middle quarter), and Zone IV (posterior quarter). At the L1-2 disc space, all spinal nerves were found in Zone IV and posterior (L1, ilioinguinal, and iliohypogastric nerves). Here, the psoas muscle forms a thin layer that is easily dissected (Fig. 2-1). At the L2-3 disc space, all the spinal nerves and divisions were found in Zone IV (L2), with the exception of the genitofemoral (L1, L2) nerve, which was found in Zone II crossing from posterior to anterior. At the L3-4 disc space, all spinal nerves were found in Zone IV (L2 division to lumbar plexus, L3, and lateral femoral cutaneous nerve [L2, L3]). The genitofemoral nerve was found in Zone I. Here, the psoas muscle is larger in diameter (Fig. 2-1), and at this level the majority of the neural structures were found in Zone IV (L2 division to lumbar plexus, L3 spinal nerve, and lateral femoral cutaneous nerve [L2, L3]). At the L4-5 disc space, the contributions from the lumbar plexus to the femoral nerve (L2 and L3 divisions and L4 spinal nerve), the intrinsic branches to the psoas muscle, and the obturator nerves were found in Zones III and IV. The genitofemoral nerve was identified on the anterior surface of the psoas in Zone I, having emerged from within it at around the L3-4 disc space or L4 vertebral body. The femoral nerve was found in Zones III and IV, and the obturator nerve was found in Zone IV (Fig. 2-3).

This anatomic study suggests that the potential approach zones at the lateral disc spaces to prevent direct nerve injury during an XLIF procedure are the middle posterior quarter of the intervertebral discs (Zone III) from L1-2 to L3-4 and at the midpoint of the disc at the L4-5 level (Zone II–III junction). There is risk of direct injury to the genitofemoral nerve anteriorly (Zone I) at the lower lumbar levels (L3-4 and L4-5) and at Zone II at L2-3. Risk of injury to the intrinsic muscular branches of the psoas muscle exists in all zones at the L3-4 and L4-5 levels. Adherence to advanced neuromonitoring that provides proximity and directionality information about the relative position of motor nerves to the XLIF approach through discrete-threshold responses on EMG encourages more posterior approach corridors and avoidance of the genitofemoral nerve anteriorly, which cannot be monitored using EMG.[22,23]

In a similar study, Gu et al[14] determined that the safe zone for performing a discectomy should be located between the spinal nerves and the sympathetic trunk, which runs along the anterior third of the vertebral bodies. In addition, the genitofemoral nerve was responsible for narrowing this safe zone at the L2-3 disc space. Benglis et al[5] dissected the lumbar plexus in a total of three specimens (12 levels) in the lateral position to determine the ratio of the location of the plexus from the posterior endplate to the total length of the disc space at each level. They noted a general trend of progressive ventral migration of the plexus at the lower lumbar segments; the mean ratios of the location of the plexus to total disc space length at L1-2, L2-3, L3-4, and L4-5 were 0%, 11%, 18%, and 28%, respectively. If extrapolated to quadrants, as in Uribe et al,[6] these results would similarly show motor nerves present in quadrant IV from L1-4 and in quadrant III and IV at L4-5. The authors recommended avoiding placement of the dilator or retractor in a posterior position on the disc spaces to prevent injury to large conjoined nerves.

Imaging studies of the lumbar plexus with respect to the lateral approach have largely been consistent with cadaveric studies. Regev et al[8] in a morphometric analysis of MRI, identified the anatomic position of the ventral nerves and the retroperitoneal vessels in normally aligned and deformed spines. The authors concluded that the safe corridor for performing discectomy and inserting the intervertebral cage from a lateral approach narrows from the L1-2 to the L4-5 level. As in Benglis et al,[5] Regev et al[8] found that from L1-2, L2-3, L3-4, to L4-5, motor nerves were present at 10.5%, 15.5%, 16.4%, and 25.9%, respectively, of the disc space from the posterior margin of the disc to the anterior margin of the lumbar plexus. However, the authors also noted that this corridor may be further narrowed with rotational deformities of the spine. They recommended using preoperative MRI to assess the relationship of the neurovascular structures to the lower vertebral endplate.

In a summary of the literature examining the location of neural structures with respect to lateral approach surgery, Smith et al[20] found that despite methodologic differences between the six primary papers available at the time, results were nearly uniform in that the motor nerves of the lumbar plexus migrate anteriorly on the lateral aspect of the spine as they travel inferiorly, but that the first two quadrants (anterior and anterior middle) are regularly free of motor nerves, as is the majority of the third quadrant (posterior middle).With the common presence of the genitofemoral nerve in the anterior quadrant (I) at L4-5, advanced neuromonitoring is recommended to enhance identification, avoidance, and protection of motor nerves during more posterior approaches to the lateral disc space.

CONCLUSION

Accessing the retroperitoneal cavity presents potential risk of injury to the nerves that travel outside the psoas. These nerves include the subcostal, iliohypogastric, ilioinguinal, and lateral femoral cutaneous, which, from the lateral view, run along the posterior abdominal wall and then course obliquely across the surgical corridor within the abdominal muscles. They can be injured while accessing the retroperitoneum during the flank or lateral incision or while performing blunt digital dissection of the retroperitoneal cavity, and care should be taken when performing the initial exposure.

Neural structures deep within the psoas musculature are also at risk but have the ability to be more actively monitored during the XLIF approach and procedure, and thus are better able to be protected. Although knowledge of the neuroanatomy relevant to the XLIF approach will not completely eliminate the risk of injury to these structures, such knowledge will offer intraoperative guidance following preoperative planning (axial MRI) to assist in the proper identification and protection of these structures, supported by the necessary use of advanced neuromonitoring.

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