Defining the safe working zones using the minimally invasive lateral retroperitoneal transpsoas approach: an anatomical study

Laboratory investigation

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Object. The lateral retroperitoneal transpsoas approach is being increasingly employed to treat various spinal disorders. The minimally invasive blunt retroperitoneal and transpsoas dissection poses a risk of injury to major nervous structures. The addition of electrophysiological monitoring potentially decreases the risk of injury to the lumbar plexus. With respect to the use of the direct transpsoas approach, however, there is sparse knowledge regarding the relationship between the retroperitoneum/psoas muscle and the lumbar plexus at each lumbar segment. The authors undertook this anatomical cadaveric dissection study to define the anatomical safe zones relative to the disc spaces for prevention of nerve injuries during the lateral retroperitoneal transpsoas approach.

Methods. Twenty lumbar segments were dissected and studied. The relationship between the retroperitoneum, psoas muscle, and the lumbar plexus was analyzed. The area between the anterior and posterior edges of the vertebral body (VB) was divided into 4 equal zones. Radiopaque markers were placed in each disc space at the midpoint of Zone III (middle posterior quarter). At each segment, the psoas muscle, lumbar plexus, and nerve roots were dissected. The distribution of the lumbar plexus with reference to the markers at each lumbar segment was analyzed.

Results. All parts of the lumbar plexus, including nerve roots, were found within the substance of the psoas muscle dorsal to the posterior fourth of the VB (Zone IV). No Zone III marker was posterior to any part of the lumbar plexus with the exception of the genitofemoral nerve. The genitofemoral nerve travels obliquely in the substance of the psoas muscle from its origin to its innervations. It emerges superficially and anterior from the medial border of the psoas at the L3–4 level and courses along the anterior medial fourth of the L-4 and L-5 VBs (Zone I). The nerves of the plexus that originate at the upper lumbar segments emerge from the lateral border of the psoas major and cross obliquely into the retroperitoneum in front of the quadratus lumborum and the iliacus muscles to the iliac crest.

Conclusions. With respect to prevention of direct nerve injury, the safe anatomical zones at the disc spaces from L1–2 to L3–4 are at the middle posterior quarter of the VB (midpoint of Zone III) and the safe anatomical zone at the L4–5 disc space is at the midpoint of the VB (Zone II–Zone III demarcation). There is risk of direct injury to the genitofemoral nerve in Zone II at the L2–3 space and in Zone I at the lower lumbar levels L3–4 and L4–5. There is also a potential risk of injury to the ilioinguinal, iliohypogastric, and lateral femoral cutaneous nerves in the retroperitoneal space where they travel obliquely, inferiorly, and anteriorly to the reach the iliac crest and the abdominal wall.
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Key Words • **safe zone** • **transpsoas retroperitoneal approach** • **anatomy** • **lumbar interbody fusion** • **lateral access** • **surgical technique**

The minimally invasive lateral retroperitoneal transpsoas approach is being increasingly employed to treat common spinal disorders, including degenerative disc disease, spondylolisthesis, traumatic injuries, and spinal deformity.[9] This approach provides anterior access to the disc space from L-1 to L-5 without an "access surgeon." One limitation of this approach is the close proximity of the lumbar plexus to the surgical pathway and the resultant risk of injury to the nerves of the plexus.[9]

A thorough understanding of the anatomical complexity of the lumbar plexus with the aid of intraoperative real-time nerve monitoring and biplanar fluoroscopy can reduce the risk of injury to the plexus. Though technically straightforward, dissection of the iliopsoas must be performed carefully so as not to injure the nerves of the

Abbreviation used in this paper: VB = vertebral body.

lumbar plexus when traversing the muscle with the dilator or positioning the retractor over the disc space. The anatomy of the lumbar plexus has been well described, but previous surgical anatomical cadaveric and morphometric radiographic studies of the lumbar plexus using a retroperitoneal endoscopic or minimally invasive transpsoas approach have failed to identify the location of the main nerve roots with respect to the intervertebral spaces.[7] The objective of this cadaveric study is to analyze the anatomical location of the lumbar plexus in the retroperitoneal space relative to the disc spaces and delineate potential safe zones to prevent nerve injuries during the lateral retroperitoneal transpsoas approach (L1–5).

Methods

A total of 5 fresh male cadavers were studied. Direct radiological evaluation of the VBs, intervertebral disc space, and surrounding soft tissue structures was performed in all cadaveric specimens. Each cadaver was systematically evaluated prior to dissection for evidence of scoliosis (coronal plane curve of greater than 10°), compression fractures (VBs with loss of more than 10% of anterior height when compared with the posterior VB height and to adjacent cranial or caudal vertebrae), and evidence of spondylolisthesis (Grade II or greater). Cadavers with any of the above findings were excluded from this study. Twenty lumbar segments were dissected using microsurgical techniques and studied from L-1 to L-5. Dissections were performed at the University of South Florida biomechanical spine laboratory and at the cadaveric laboratory of NuVasive, Inc.

The specimens were placed in a lateral decubitus position with guidance from lateral and anteroposterior fluoroscopic imaging. Specimen positioning was adjusted until orthogonal imaging was obtained in both planes. The area between the anterior and posterior edges of the VB was divided into 4 zones as follows: Zone I (anterior quarter), Zone II (middle anterior quarter), Zone III (posterior middle quarter), and Zone IV (posterior quarter) (Fig. 1). A linear skin incision at the midaxillary line was made from the T-12 rib to the anterior iliac crest. The abdominal musculature was then incised, and the retroperitoneal space was identified and defined. With fluoroscopic image guidance and the use of sequential tube dilators, the psoas muscle was bluntly dissected at the disc spaces (L1–5). Stainless steel guide wires were inserted into the midpoint of Zone III (middle posterior quarter) and used as radiopaque markers at the disc spaces from L-1 thorough L-5 (Fig. 2). The nerve branches of the lumbar plexus that traverse the retroperitoneal space were dissected from the adipose and connective tissue. The iliopsoas muscle was then exposed and the radiopaque markers were sharply cut at the muscle surface.

The relationship between the psoas muscle and the lumbar plexus was analyzed and compared with previous anatomical descriptions.[2,8] At each disc space, the psoas muscle, lumbar plexus, and nerve roots were dissected. Each specimen was photographed and analyzed. The distribution of the lumbar plexus in reference to the markers at each lumbar segment was evaluated and recorded.

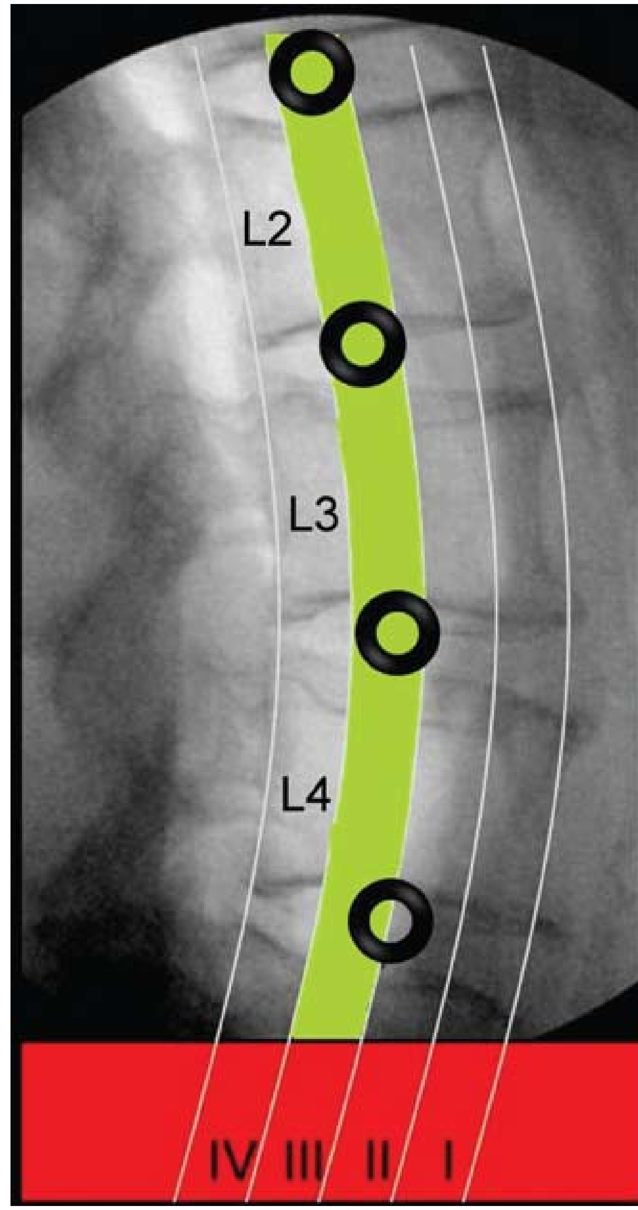

Fig. 1. Lateral radiograph of the lumbar spine demonstrating the division of the VB into 4 zones (Zones I–IV) from anterior to posterior. The relative "safe zone" (Zone III) is depicted in *green*. The recommended safe working zones to prevent direct nerve injury have been indicated with *black circles* at each level.

Results

Our findings are consistent with previous anatomical descriptions.[2,8] The lumbar plexus is formed by the nerves originating from the anterior divisions of the first 3 and the greater part of the fourth lumbar nerve. The distribution and origins of these nerves are described in Table 1. The plexus is a retroperitoneal structure that is situated in the posterior part and mostly within the substance of the psoas major. It also lies in front of the transverse processes of the lumbar vertebrae.

Viewed in the lateral decubitus position, the lumbar plexus is located from the posterior fourth of the VB

(Zone IV) and dorsally. The nerves pass obliquely outward, behind, and through the fibers of the psoas muscle, while distributing filaments to it. Progressive anterior migration of the distal members of the plexus as it descends within the muscle at each disc spaces was noted in this study. No radiopaque marker was posterior to any part of the lumbar plexus, with the exception of the genitofemoral nerve and the intrinsic muscular branches to the psoas major at L2–3, L3–4, and L4–5 (Fig. 3, Video 1).

Video 1. Clip obtained in a cadaveric specimen in the right lateral decubitus position with the psoas muscle removed illustrating the placement of radiopaque markers relative to the femoral and genitofemoral nerves and disc spaces using a lateral radiograph overlay. Click here to view with Windows Media Player. Click here to view with Quicktime.

The femoral nerve, formed from branches of the L-2, L-3, and L-4 roots, is the largest branch of the lumbar plexus and was found deep in the substance of the psoas muscle descending in a gradual posterior-to-anterior trajectory (Zone III) at the L4–5 disc space (Fig. 4, Video 2).

Video 2. Clip obtained in a cadaveric specimen in the left lateral decubitus position with an instrument placed in the L4–5 disc space illustrating the relationship of the femoral nerve to the disc spaces using a lateral radiograph overlay. Click here to view with Windows Media Player. Click here to view with Quicktime.

It continues down 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 (Fig. 5, Video 3).

Video 3. Clip obtained in a cadaveric specimen in the left lateral decubitus position with the psoas muscle reflected anteriorly illustrating the relationship of the femoral nerve to the disc spaces using a lateral radiograph overlay. Click here to view with Windows Media Player. Click here to view with Quicktime.

Most of the sensory nerves of the plexus that originate at L-1 (ilioinguinal, iliohypogastric) and the lateral femoral cutaneous nerve at L-2 and L-3 emerge from the posterolateral border of the psoas major (Zone IV and dorsal). They cross obliquely into the retroperitoneal space in front of the quadratus lumborum and the iliacus muscles to reach the iliac crest (Fig. 6). The exception is the genitofemoral nerve. It travels obliquely in the substance of the psoas muscle from its origin, crossing the L2–3 disc space at Zone II, 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 (Zone I) of the L-4 and L-5 VBs. It divides into the external spermatic and lumboinguinal nerves to supply the skin around the inguinal and genital area and anterior and medial upper part of the thigh (Fig. 7).

With respect to the vascular structures, we did not find any major vessel from Zone I to Zone IV. In our specimens, we found the segmental vessels at the mid-VB running from Zone I to Zone IV; we did not encounter any anatomical variation of these vessels as previously described.[6]

Fig. 2. Lateral radiograph of the lumbar spine illustrating placement of guide wires in the midpoint of Zone III at the disk spaces from L-1 to L-5.

The relationship between the lumbar plexus, nerve roots, branches, and radiopaque markers at the disc spaces may be seen in Fig. 3 and Video 1. All the members of the lumbar plexus were found posterior to the radiopaque markers with some exceptions as described below.

At L1–2, all the nerve roots were found in Zone IV and posterior (L-1 root, ilioinguinal, and iliohypogastric nerves).

At L2–3, all the nerve roots and divisions were found in Zone IV (L-2 root), with the exception of the genitofemoral (L-1, L-2) nerve that was found in Zone II.

At L3–4, all nerve roots were found in Zone IV (L-2 division to lumbar plexus, L-3 root, and lateral femoral cutaneous nerve [L-2, L-3]). The genitofemoral nerve was found in Zone I.

At L4–5, the contributions from the lumbar plexus to the femoral nerve (L-2 and L-3 divisions and L-4 root), 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.

Discussion

The minimally invasive lateral retroperitoneal transpsoas approach allows for anterior access to the disc space with potential complications similar to those associated with a transabdominal procedure. Although it has been reported to be safe and reproducible, the minimally invasive lateral retroperitoneal transpsoas approach is not without complication,[1,4,9] and patient positioning, adequate biplanar fluoroscopy, nerve monitoring, and a thorough knowledge of the regional anatomy of the lumbar plexus with relation to the psoas muscle and disc spaces

TABLE 1: Nerves of the lumbar plexus

Nerve	Segment	Innervated Muscles	Cutaneous Branches
iliohypogastric	T12–L1	• transversus abdominus • abdominal internal oblique	• anterior cutaneous • lateral cutaneous
ilioinguinal	L-1		• anterior scrotal nerves in males • anterior labial nerves in females
genitofemoral	L1–2	• cremaster in males	• femoral ramus • genital ramus
lateral femoral cutaneous	L2–3		• lateral femoral cutaneous
obturator	L2–4	• obturator externus • adductor longus • gracilis • pectineus • adductor magnus	• cutaneous ramus
femoral	L2–4	• iliopsoas • pectineus • sartorius • quadriceps femoris	• anterior cutaneous branches • saphenous
short, direct muscular branches	T12–L4	• psoas major • quadratus lumborum • iliacus • lumbar intertransverse	

are critical to avoid them. Moreover, dissection of the iliopsoas must be performed carefully to avoid injury to the nerves of the lumbar plexus or the psoas major.

Previous anatomical studies have attempted to identify the location of the lumbar contributions to the lumbar plexus in relation to the disc spaces to prevent complications using minimal invasive retroperitoneal approaches. Moro et al.[7] analyzed 6 lumbar spines in the axial plane to study the distribution of the lumbar plexus in relation to the psoas muscle in order to prevent nerve injuries during endoscopic spine surgery. In that same study, the location at which the genitofemoral nerve emerged on the surface of the muscle was also analyzed in 24 cadavers. They concluded that the "safety zone," excluding the genitofemoral nerve, is at L4–5 and above. In a similar study, Gu et al.[3] determined that the safe zone for performing a discectomy should be located between the nerve roots and the sympathetic trunk, which runs along the anterior third of the VBs. Additionally, the genitofemoral nerve was responsible for narrowing this safe zone at the L2–3 disc space. Benglis et al.[1] dissected the lumbar plexus in a total of 3 specimens using the lateral position. They noted a general trend of progressive ventral migration of the plexus at the lower lumbar segments. The locations of important motor and sensory nerve branches (including the genitofemoral nerve) were not identified. The authors recommended avoiding placement of the dilator/retractor in a posterior position on the disc spaces to prevent injury to large conjoined nerve roots.

Imaging studies of the lumbar plexus have also been reported. Regev et al.,[10] in a morphometric analysis of MR imaging, identified the anatomical position of the ventral roots and the retroperitoneal vessels in normally aligned and deformed spines. They concluded that the safe corridor for performing discectomy and inserting the intervertebral cage narrows from the L1–2 to the L4–5 level. This corridor is further narrowed with rotational deformity of the spine. They recommended using preoperative MR imaging to assess the relationship of the neurovascular structures to the lower vertebral endplate. However, they only made recommendations regarding avoiding injury to the exiting nerve roots and large vessels. This study was limited by its reliance on imaging analysis alone. The authors did not reliably locate the genitofemoral nerve or other branches of the lumbar plexus that travel in the adipose tissue of the retroperitoneal space (iliohypogastric

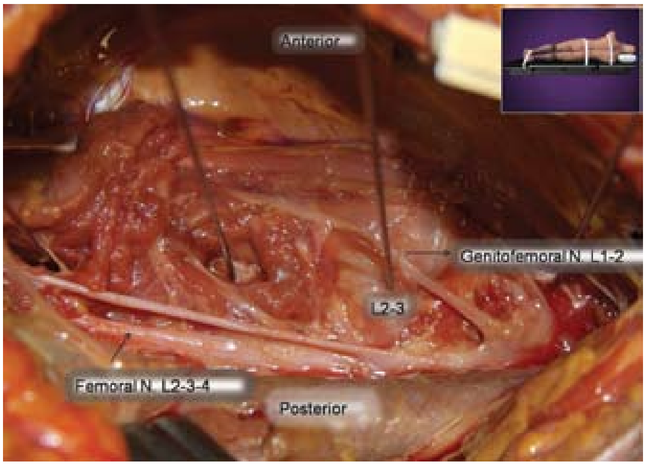

Fig. 3. Cadaveric specimen in the right lateral decubitus position with the psoas muscle removed demonstrating the placement of radiopaque markers relative to the femoral and genitofemoral nerves (N.).

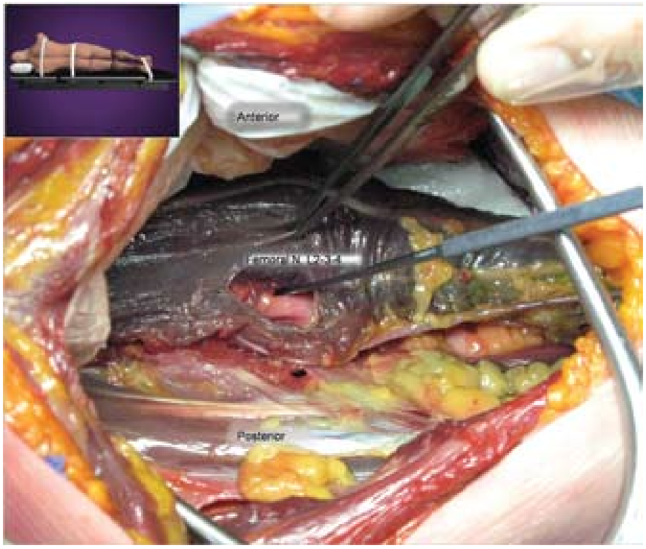

FIG. 4. Cadaveric specimen in the left lateral decubitus position demonstrating the femoral nerve deep to the psoas muscle with an instrument placed in the L4–5 disc space.

and ilioinguinal nerves) and face significant risk of injury during the approach. Even though in our study we did not find any large arteries or veins that encroached on Zones I–IV, we recommend careful evaluation with preoperative imaging in every case to ensure that vascular structures do not cross in an aberrant manner either due to scoliosis or developmental anomalies.[6,10,11]

Surgical Anatomy of the Retroperitoneal Space Related to the Lateral Retroperitoneal Transpsoas Approach

When the retroperitoneal space is approached with the patient in the lateral decubitus position, a generous amount of adipose tissue fills the space above the psoas muscle. It is bounded anteriorly by the abdominal and peritoneal structures, posteriorly by the quadratus lumborum and the iliacus muscles, superiorly by the diaphragm, and inferiorly by the retroperitoneal pelvic space. In this space the ilioinguinal, iliohypogastric, and lateral femoral cutaneous nerves course freely downward to reach the anterior iliac crest.

From this view, visualizing the orientation of the lumbar plexus is challenging (Fig. 8). The lateral aspects of the lumbar vertebrae are covered by the psoas muscle. 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. The exceptions to this include the obturator nerve, which exits the pelvis through the obturator foramen, and the iliohypogastric and ilioinguinal nerves, which course superficially to reach the anterior iliac crest.

At the L1–2 disc space, the psoas muscle forms a thin layer that is easily dissected, and the contributors to the lumbar plexus (ilioinguinal and genitofemoral nerves) were found posterior to Zone IV on the cleft. At the level of the L2–3 disc space, the genitofemoral nerve was found crossing from posterior to anterior between Zones I and II. At the L3–4 disc space the psoas muscle is larger in diameter; at this level the majority of the neural structures were found in Zone IV (L-2 division to lumbar plexus, L-3 nerve root, and lateral femoral cutaneous nerve [L-2, L-3]). The genitofemoral nerve was found in Zone I. At the L4–5 level the femoral nerve was found in Zones III and IV and the obturator nerve was found in Zone IV. The genitofemoral nerve was identified on the anterior surface of the psoas in Zone I.

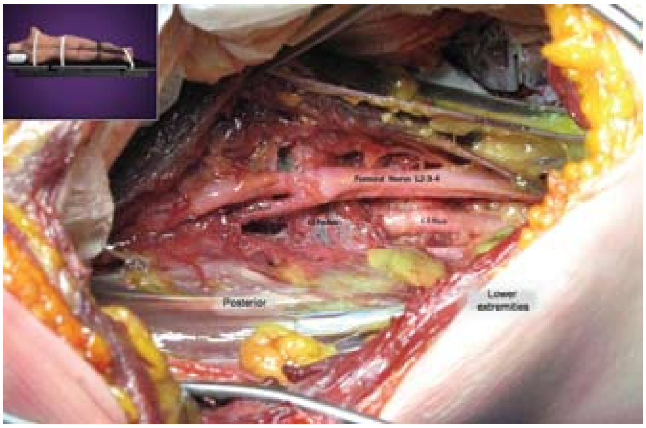

FIG. 5. Cadaveric specimen in the left lateral decubitus position with the psoas muscle reflected anteriorly showing the femoral nerve and its contributions from the L2–4 nerve roots.

The Genitofemoral Nerve

The genitofemoral nerve originates from the first and second lumbar nerves and travels obliquely in a cephalocaudal direction through the substance of the psoas major from Zone IV to Zone I. The segment in which the nerve pierces the muscle and continues descending on its surface was found around the L-3 and L-4 vertebrae (Fig. 7). From this point, the nerve travels in Zone I beneath the peritoneum on its way to reach the fascia transversalis and enter the abdominal wall around the inguinal ring.

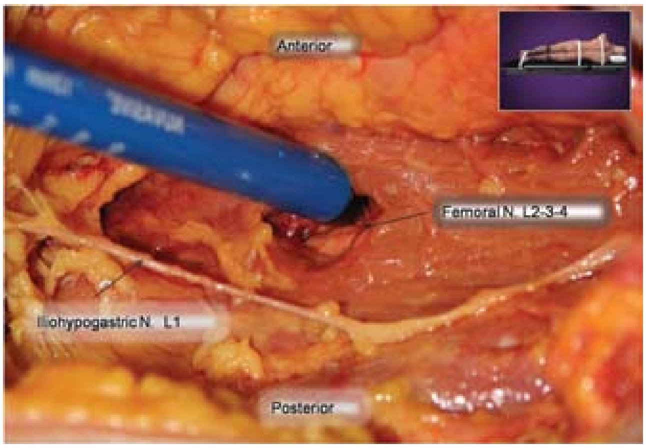

FIG. 6. Cadaveric specimen in the right lateral decubitus position demonstrating the placement of an initial dilator through the psoas muscle anterior to the femoral nerve and its relationship to the iliohypogastric nerve.

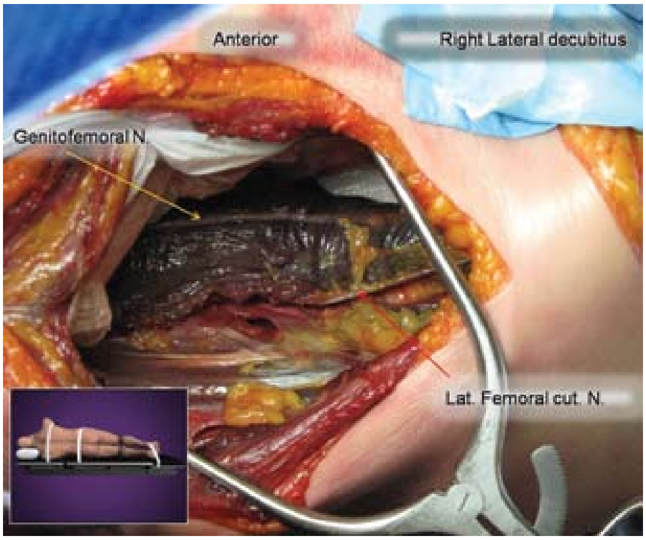

Fig. 7. Cadaveric specimen in the left lateral decubitus position illustrating the position of the genitofemoral and lateral femoral cutaneous nerves relative to the psoas muscle.

This nerve deserves special consideration; it is vulnerable to injury with the dilator instrument while traversing the psoas muscle in the anterior portion of the disc (Zone I) at all levels and in Zone II at the L2–3 disc space. Additionally, intraoperative electromyographic monitoring will not detect this primary sensory nerve unless the cremasteric muscle in males is also monitored. A thorough understanding of its anatomical trajectory at each level is the best way to prevent injury.

Value of the Safe Working Zones

Nerve injury is one of the complications that should be avoided during the lateral retroperitoneal transpsoas approach. The results of this study suggest that Zone III is a potentially safe anatomical area in most of the levels. The middle posterior quarter of the VB is close to the instantaneous axis of rotation and to the neutral load zone, and this area provides enough VB and foraminal distraction without compromising the integrity of anterior or posterior longitudinal ligaments. Thus, this zone is also a biomechanically favorable area for placement of intervertebral devices.[5] However, at each level the anatomical configuration varies.

When spreading the muscle, there is also a risk of injury to the intrinsic motor branches. These are small nerve fibers compared with the other branches of the plexus, and we found most of them arranged in clusters, branching from the femoral nerve around the caudal L-3, L-4, and L-5 VBs.

Complication Avoidance

In addition to a thorough understanding of the regional anatomy, we advocate a combination of useful adjuncts to minimize nerve injuries directly or indirectly during the minimally invasive retroperitoneal transpsoas approach.

Positioning the patient in a true 90° lateral decubitus position with the table flexed so as to increase the distance between the iliac crest and the rib cage will place tension and traction on the psoas and the lumbar plexus itself. We observed that tension on the neuromuscular structures could be reduced by decreasing the amount of lateral bending of the specimen and by flexing the hips.

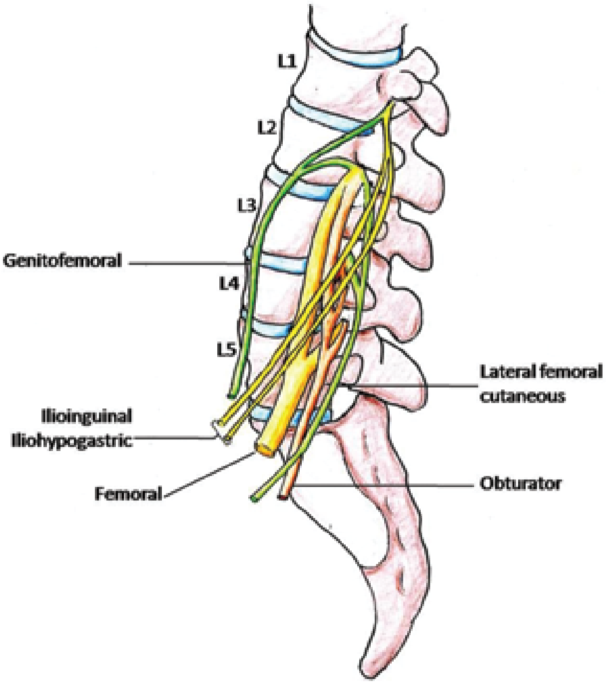

Fig. 8. Schematic drawing of the lumbar plexus from the lateral view. The locations of the major sensory and motor nerves are illustrated in relation to the disc spaces.

During the early stages of the approach, the blunt dissection of the retroperitoneal space requires special care. We suggest early identification of the posterior wall of the retroperitoneum (quadratus lumborum muscle) and gentle dissection of the space from posterior to anterior and inferior to superior until the transverse process and the psoas muscle are identified. Careful development of the space is important in order not to injure the peritoneal or the retroperitoneal structures and to avoid injury to the mainly sensory nerves that run freely in the retroperitoneal cavity.

Electrophysiological monitoring is a necessary tool to prevent nerve injury while traversing the psoas muscle and during placement of the retractor. In particular, monitoring of the psoas muscle also can yield useful information. We believe that systems with hunting algorithms and directional electromyography provide the most useful information about the location of the main motor components of the lumbar plexus. Obtaining stimulation of muscle groups during directional electromyographic stimulation both anteriorly and posteriorly should prompt the surgeon to change the dilator position to a more anterior one where only posterior stimulation provokes muscle activity. This maneuver should avoid splitting the elements of the plexus with the retractor.

Conclusions

This anatomical study suggests that the potential safe working zones at the disc spaces to prevent direct nerve injury from L-1 to L-4 is the middle posterior quarter of the VB (Zone III) and at the midpoint of the VB at the L4–5 (Zone II–III junction, Fig. 1). 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. There is potential risk of injury to other major branches at the retroperitoneal space where they travel in oblique direction and anterior to the reach the iliac crest toward the abdominal wall. Risk of injury to the intrinsic muscular branches to the psoas muscle exists at all zones at the L3–4 and L4–5 levels.

Disclosure

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Author contributions to the study and manuscript preparation include the following. Conception and design: Uribe. Acquisition of data: Arredondo. Critically revising the article: Dakwar. Reviewed final version of the manuscript and approved it for submission: all authors. Study supervision: Vale.

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Supplemental online information:

Video 1: http://mfile.akamai.com/21490/wmv/digitalwbc.download.akamai.com/21492/wm.digitalsource-na-regional/09766_1.asx (Media Player).

http://mfile.akamai.com/21488/mov/digitalwbc.download.akamai.com/21492/qt.digitalsource-global/video_09766_1.mov (Quicktime).

Video 2: http://mfile.akamai.com/21490/wmv/digitalwbc.download.akamai.com/21492/wm.digitalsource-na-regional/09766_2.asx (Media Player).

http://mfile.akamai.com/21488/mov/digitalwbc.download.akamai.com/21492/qt.digitalsource-global/video_09766_2a.mov (Quicktime).

Video 3: http://mfile.akamai.com/21490/wmv/digitalwbc.download.akamai.com/21492/wm.digitalsource-na-regional/09766_3.asx (Media Player).

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