10 Anatomical Considerations

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10.1 The Lumbar Vertebrae and the Sacrum

10.1.1 Lumbar Vertebrae

The five lumbar vertebrae are easily identified by their heavy bodies and thick, blunt spinous processes for attachment of powerful back muscles. They are the largest vertebrae of the vertebral column. A typical lumbar vertebra consists of an anterior drum-shaped body, which is in contact with intervertebral discs above and below. The vertebral arch is attached to the posterior surface of the body and is composed of two supporting pedicles and two arched laminae. The space formed by the vertebral arch and body is the vertebral foramen, through which the spinal cord and cauda equina pass. Between the pedicles of adjacent vertebrae are the intervertebral foramina, through which spinal nerves emerge as they branch off the spinal cord. Seven processes arise from the vertebral arch of a typical vertebra: the spinous process, two transverse processes, two superior articular processes, and two inferior articular processes (Fig. 10.1). The spinous process and transverse processes serve for muscle attachment and the superior and inferior articular processes limit twisting of the vertebral column. The spinous process protrudes posteriorly and inferiorly from the vertebral arch. The transverse processes extend laterally from each side of a vertebra at the point where the lamina and pedicle join. The superior articular processes of a vertebra interlock with the inferior articular processes of the bone above [1–3]. Their articular processes are also distinctive in that the facets of the superior pair are directed medially instead of posteriorly and the facets of the inferior pair are directed laterally instead of anteriorly. The upper lumbar facet joints are oriented mostly in the sagittal plane, whereas the lower facets are oriented more coronally [2, 4, 5] (Fig. 10.2).

10.1.2 Sacrum

The wedge-shaped sacrum provides a strong foundation for the pelvic girdle. It consists of four or five sacral vertebrae that become fused. The superior processes of the first sacral vertebra articulate with the inferior processes of the L5 vertebra. The sacrum has an extensive auricular surface on each lateral side for the formation of a slightly movable sacroiliac joint with the ilium of the hip. Massive, dense ligaments maintain the stability of the sacroiliac joints. A median sacral crest is formed along the posterior surface by the fusion of the spinous processes. Posterior sacral foramina on either side of the crest allow for the passage of nerves from the spinal cord (Fig. 10.3).

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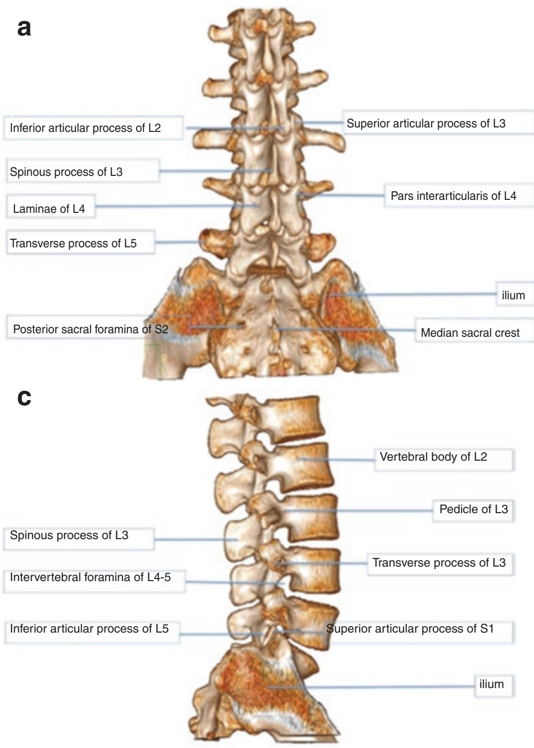


Fig. 10.1 The lumbar vertebral and sacrum. A: Posterior view. B: Anterior view. C: Right lateral view. D: Right oblique view

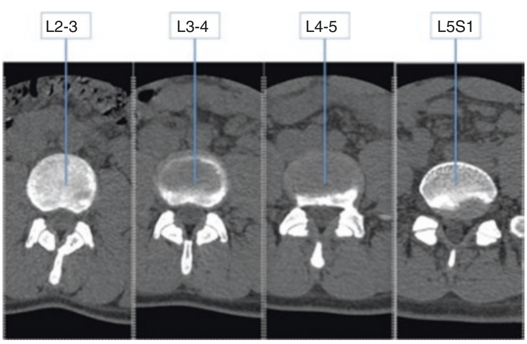


Fig. 10.2 Orientation changes of facet joints

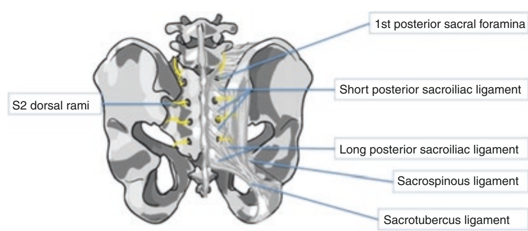


Fig. 10.3 Anatomy of sacrum and its surrounding structures

The sacral canal is the tubular cavity within the sacrum that is continuous with the vertebral canal. The sacral spinal canal is triangular in shape and is relatively large, providing ample space for the cauda equina. Paired superior articular processes arise from the roughened sacral tuberosity along the posterior surface. The smooth anterior surface of the sacrum forms the posterior surface of the pelvic cavity. It has four transverse lines denoting the fusion of the vertebral bodies. At the ends of these lines are the paired pelvic foramina (anterior sacral foramina). The anterior rami of the S2 through S5 roots conduct the parasympathetic fibers that are responsible for the bladder and rectum. The superior border of the anterior surface of the sacrum, called the sacral promontory, is an important obstetric landmark for pelvic measurements [6–9].

10.2 The Intervertebral Joint and the Intervertebral Discs

Three joints are formed between any two consecutive lumbar vertebrae. The intervertebral disc is formed between the two vertebral bodies. The paired zygapophysial joints are formed by the articulation of the superior articular process of one vertebra with the inferior articular processes of the vertebra above.

10.2.1 The Intervertebral Disc

The intervertebral discs are large fibrocartilaginous structures that connect the vertebral bodies while allowing significant mobility (Fig. 10.4). These excellent load-bearing shock absorbers maintain the distance between the vertebrae, thus preserving foraminal patency. They also resist shear stress. The discs consist of two major parts: the nucleus pulposus and the annulus fibrosus (Fig. 10.5). The nucleus pulposus consists of ground substance containing cells, collagen, and proteoglycans that have a high water-retaining capacity. Normally the nucleus consists of up to 90% water. With aging, the water-retaining capacity of the discs decreases, and the discs tend to lose height. The annulus fibrosus surrounds the nucleus as a multilayered crisscrossing set of rings and attaches to the vertebral bodies. The periphery of the annulus consists of dense collagen with low water retention capacity. The inner annulus is less dense and lacks the organization of the outer annulus. The annulus fibrosis is made up of a series of concentric fibrocartilaginous lamellae, which run at an oblique angle of about 30° orientations to the plane of the disc. The fibers of adjacent lamellae have similar arrangements, but run in opposite directions. The fibers of the outer annulus lamella attach to the vertebral body and mingle with the periosteal fibers. The fibrocartilaginous end plates are made up of hyaline cartilage and attach to the subchondral bone plate of the vertebral bodies (Fig. 10.4). There are multiple small vascular perforations in the end plate, which allow nutrition to pass to the disc [10–12].

In adolescence the nucleus pulposus is well contained within the annular ring. It has a whitish, cotton-ball endoscopic appearance (Fig. 10.6). The nucleus breaks off and separates easily. It is not

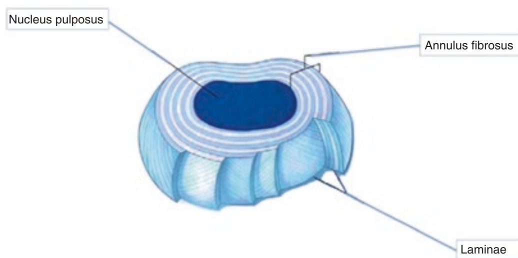


Fig. 10.5 The basic structure of intervertebral disc and detailed structure of the annulus fibrosus

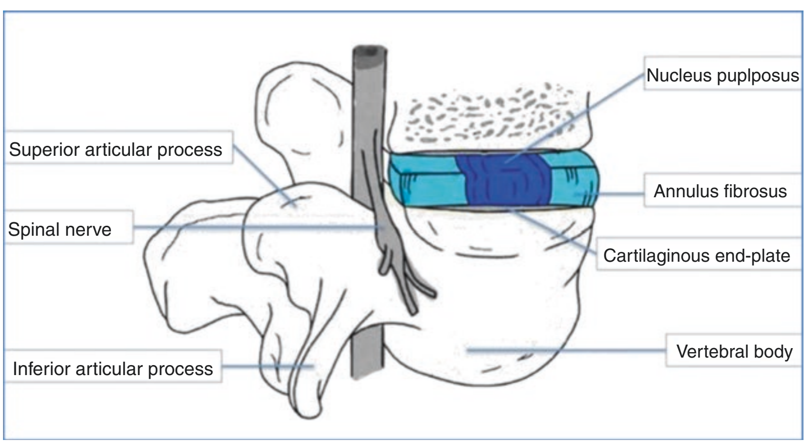


Fig. 10.4 The intervertebral disc and its relation to surrounding structures

liquid and does not flow. Nuclear tissue absorbs a considerable amount of fluid and has a tendency to swell. By contrast, the nucleus will become dehydrated and partially collagenized in the fifth and sixth decades of life. A mixture of collagenized tissue and whitish soft nucleus may be observed within the intervertebral disc in this older group of patients. In addition, multiple collagenized free fragments floating within the disc space may also be seen.

Endoscopic differentiation between the torn annulus and nucleus may be difficult. Intraoperative injection of diluted indigo carmine has a tendency to stain the nucleus and the torn fibers of annular tissue while sparing intact annular fibers (Fig. 10.7).

10.2.2 The Zygapophysial Joints

The zygapophysial joints (often called facet joints for brevity) are synovial joints between the superior and the inferior articular processes of adjacent vertebrae (Fig. 10.8). Each joint is surrounded by a thin, loose joint capsule, which is attached to the margins of the articular surfaces of the articular processes of adjacent vertebrae. The circumferential fibrous capsule, which is continuous with the ligamentum flavum ventrally, joins the two facet surfaces. Fibroadipose vascular tissue extends into the joint space from the capsule, particularly at the proximal and distal poles. This tissue has been referred to as a meniscoid, which can become entrapped between the facets. The zygapophysial joints permit gliding movements between the articular processes; the shape and disposition of the articular surfaces determine the types of movement possible. The range of movement is determined by the size of the intervertebral disc relative to that of the vertebral body. In the lumbar regions, these joints bear some weight, sharing this function with the intervertebral discs particularly during lateral flexion [13]. The zygapophysial joints are innervated by articular branches that arise from the medial branches of the posterior rami of

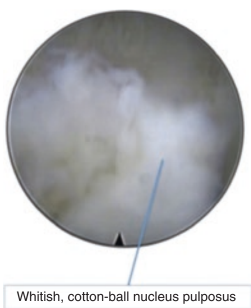


Fig. 10.6 Endoscopic view of fresh nucleus pulposus

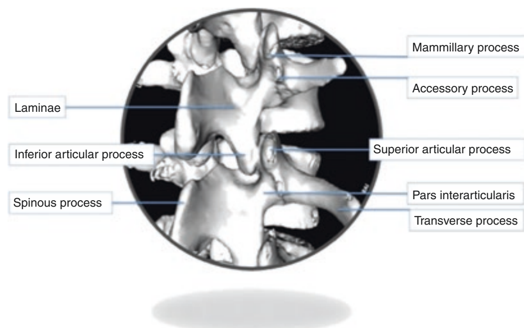


Fig. 10.8 Bony structures of the zygapophysial joints

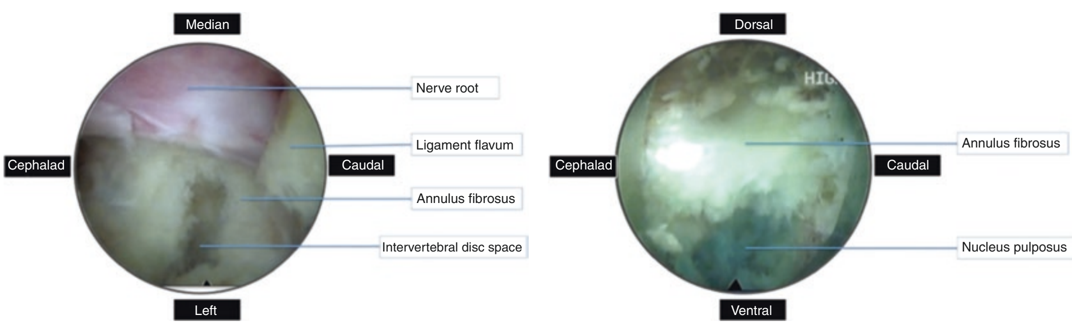


Fig. 10.7 Endoscopic differentiations between the torn annulus and nucleus. A: Endoscopic view through left L5S1 interlaminar approach. B: Endoscopic view through left L5S1 transforaminal approach with diluted indigo carmine staining

spinal nerves (Fig. 10.9). As these nerves pass posteroinferiorly, they lie in grooves on the posterior surfaces of the medial parts of the transverse processes [14, 15] (Fig. 10.10). Each articular branch supplies two adjacent joints; therefore, each joint is supplied by two nerves. Each zygapophysial joint is innervated by two articular branches, one branch from the posterior ramus exiting the intervertebral foramen above the joint, and a second branch from the posterior ramus exiting below the joint [16].

10.3 The Ligaments of the Lumbar Spine

The lumbar vertebrae are connected by a series of longitudinally oriented ligaments (Fig. 10.11). The most important ligament from a clinical perspective is the posterior longitudinal ligament, which connects to the vertebral bodies and posterior aspect of the vertebral disc and forms the anterior wall of the spinal canal [17–19]. The ligamentum flavum, which has a higher elastin content, attaches between the lamina of the vertebra and extends into the anterior capsule of the zygapophysial joints; it attaches to the pedicles above and below, forming the posterior wall of the vertebral canal and part of the roof of the lateral foramina through which the nerve roots pass [20–24] (Fig. 10.12). There are also dense fibrous ligaments connecting the spinous processes and the transverse processes, as well as a number of ligaments attaching the lower lumbar vertebrae to the sacrum and pelvis [6, 25, 26].

10.3.1 The Posterior Longitudinal Ligament

The posterior longitudinal ligament is represented throughout the vertebral column (Fig. 10.13). In

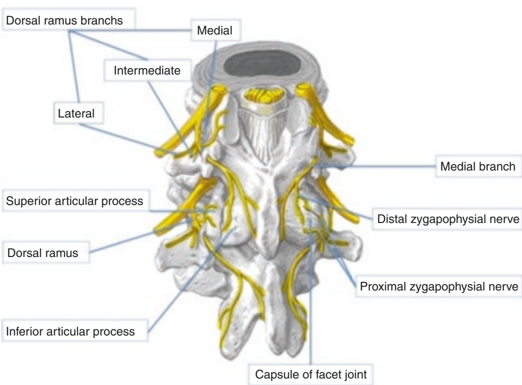


Fig. 10.9 Innervation of the zygapophysial joints

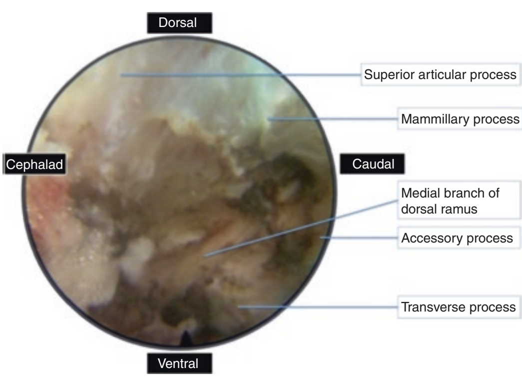


Fig. 10.10 Endoscopic view of medial branch of dorsal ramus

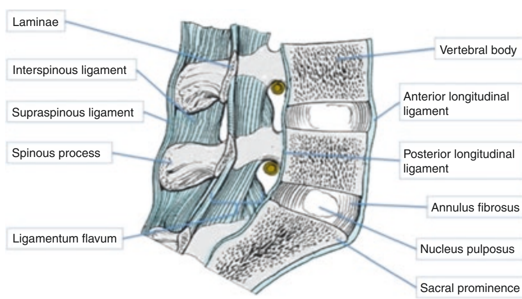


Fig. 10.11 A median sagittal section of the lumbar spine to show its various ligaments

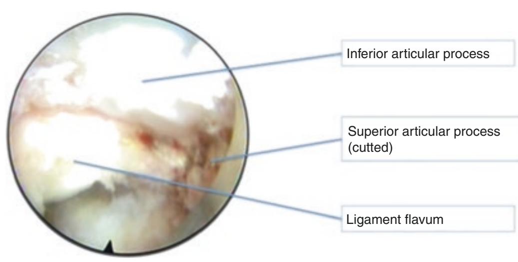


Fig. 10.12 Endoscopic view of ligament flavum as part of the posterior roof of the intervertebral foramen. (left L5S1 through transforaminal approach with foraminoplasty)

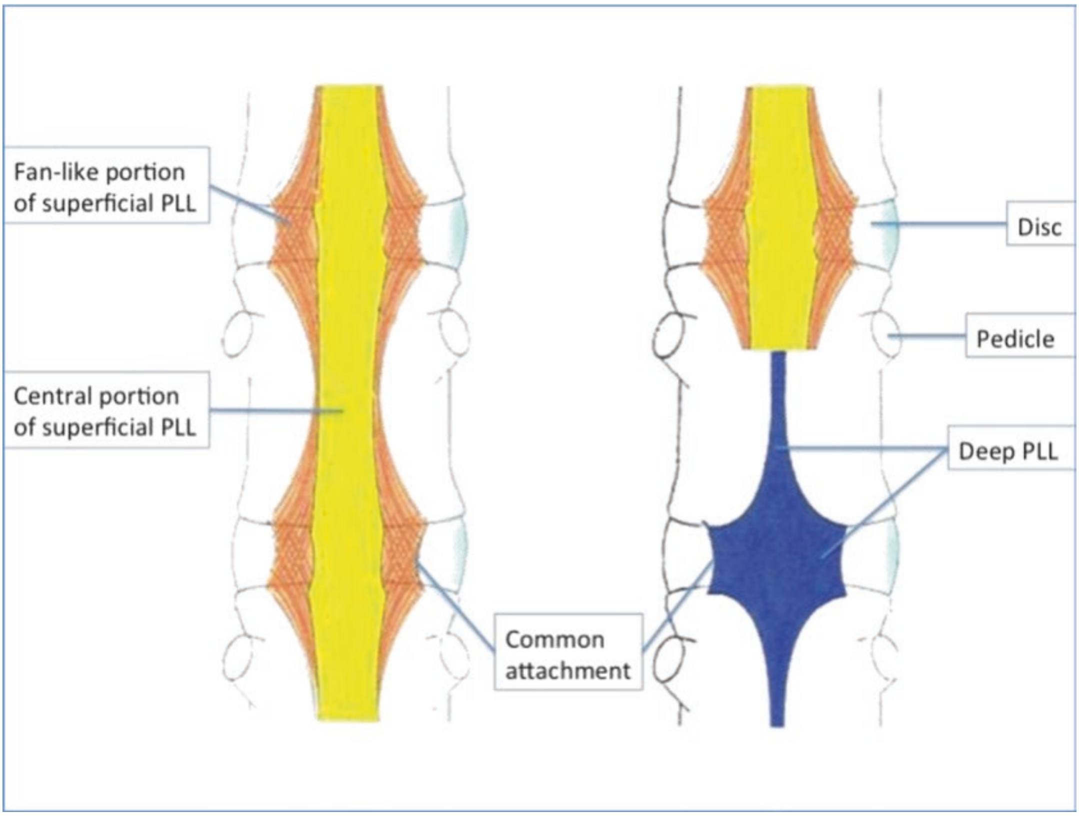


Fig. 10.13 The posterior longitudinal ligament

the lumbar region, it forms a narrow band over the backs of the vertebral bodies, which often bridge fat and vessels between the ligament and the bony surface (Fig. 10.14), but expands laterally over the backs of the intervertebral discs to give it a serrated, or saw-toothed, appearance. Its fibers mesh with those of the annular fibrosus but penetrate through the annular to attach to the posterior margins of the vertebral bodies. The deepest and shortest fibers of the posterior longitudinal ligament span two intervertebral discs. Starting at the superior margin of one vertebra, they attach to the inferior margin of the vertebra two levels above, describing a curve concave laterally as they do so. Longer, more superficial fibers span three, four, and even five vertebrae [17, 19, 27].

The dorsal surface of the posterior longitudinal ligamentum may be observed when discectomy to a disc herniation has been accomplished. Visualization of space between the dorsal surface of the posterior longitudinal ligamentum and the nerve root and dura sac signifies that adequate decompression has been accomplished. Endoscopically, the fibers of the posterior longitudinal ligamentum run perpendicular to the vertebral plates and are seen as avascular structures (Fig. 10.15).

10.3.2 The Ligamentum Flavum

The laminae of adjacent vertebral arches are joined by broad, pale yellow elastic tissue called the ligamentum flavum. These yellow ligaments extend almost vertically from the lamina above to the lamina below, those of opposite sides meeting and blending in the midline. The ligaments bind the lamina of the adjoining vertebrae together, forming alternating sections of the posterior wall of the vertebral canal. The ligamentum flavum is thickest in the lumbar region. These ligaments

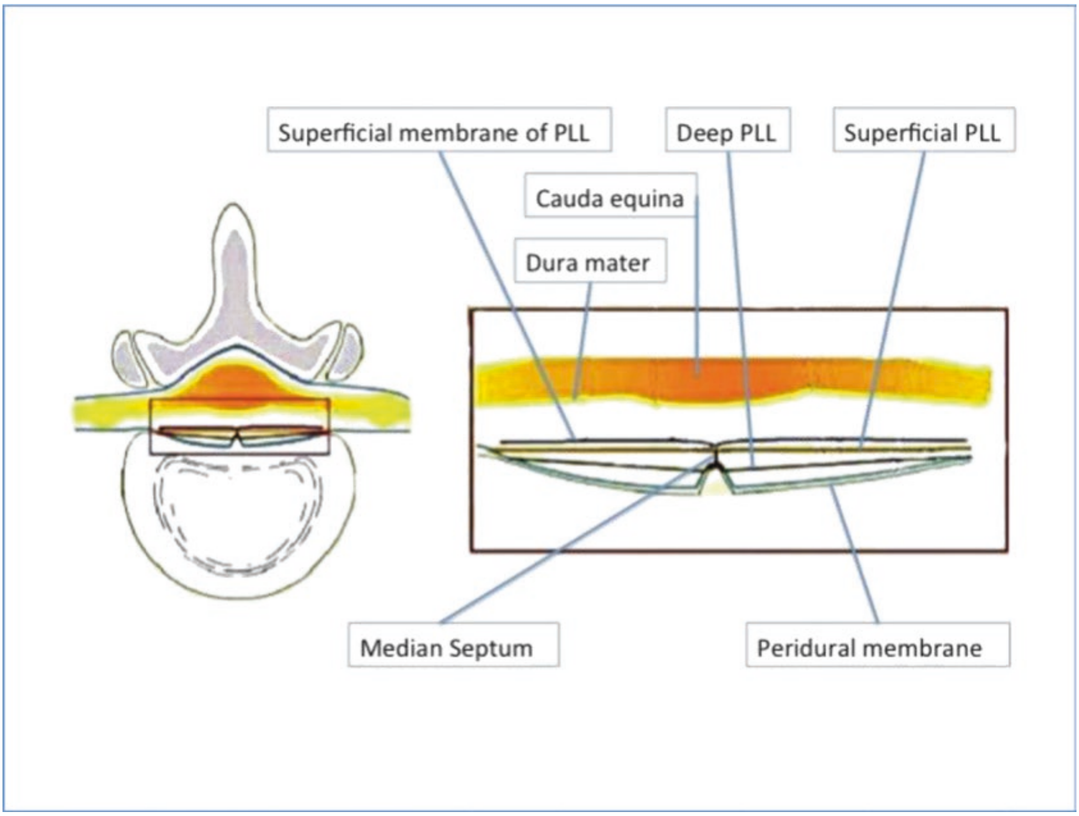


Fig. 10.14 Transection anatomy of the posterior longitudinal ligament through vertebral body

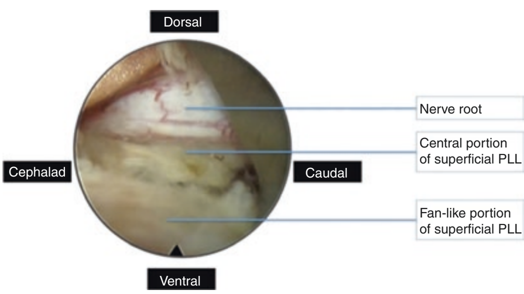


Fig. 10.15 Endoscopic view of the posterior longitudinal ligament through left L4–5 transforaminal approach with foraminoplasty

resist separation of the vertebral lamina by arresting abrupt flexion of the vertebral column and thereby preventing injury to the intervertebral discs. The strong elastic ligamentum flavum helps preserve the normal curvatures of the vertebral column and assists with straightening of the column after flexing [20–24]. Spinal degeneration exposes the ligamentum flavum to added stress, which causes them to hypertrophy and thicken. This may contribute to canal narrowing, known as spinal stenosis.

During percutaneous endoscopic intracanalicular surgery, opening of the ligamentum flavum is the most important step to allow the endoscope and instruments enter the spinal canal. Endoscopically, the ligamentum flavum is observed as an avascular tissue (Fig. 10.16).

10.4 The Lumbar Muscles and Their Fasciae

The muscles of the back are arranged in three layers (Fig. 10.17). The most superficial or outer layer is made up of large fleshy erector spinae muscles, which attach to the iliac and

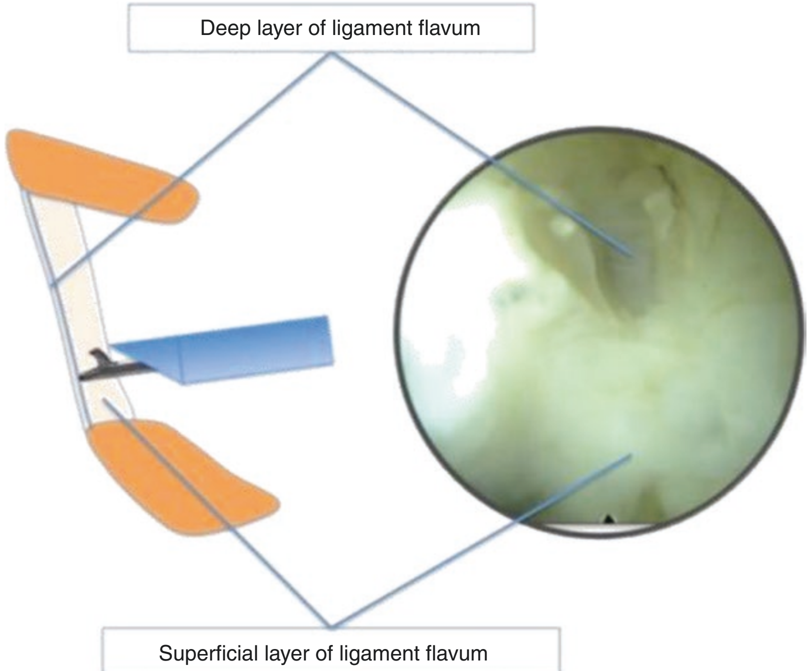


Fig. 10.16 Endoscopic view of the ligamentum flavum through left L5S1 interlaminar approach

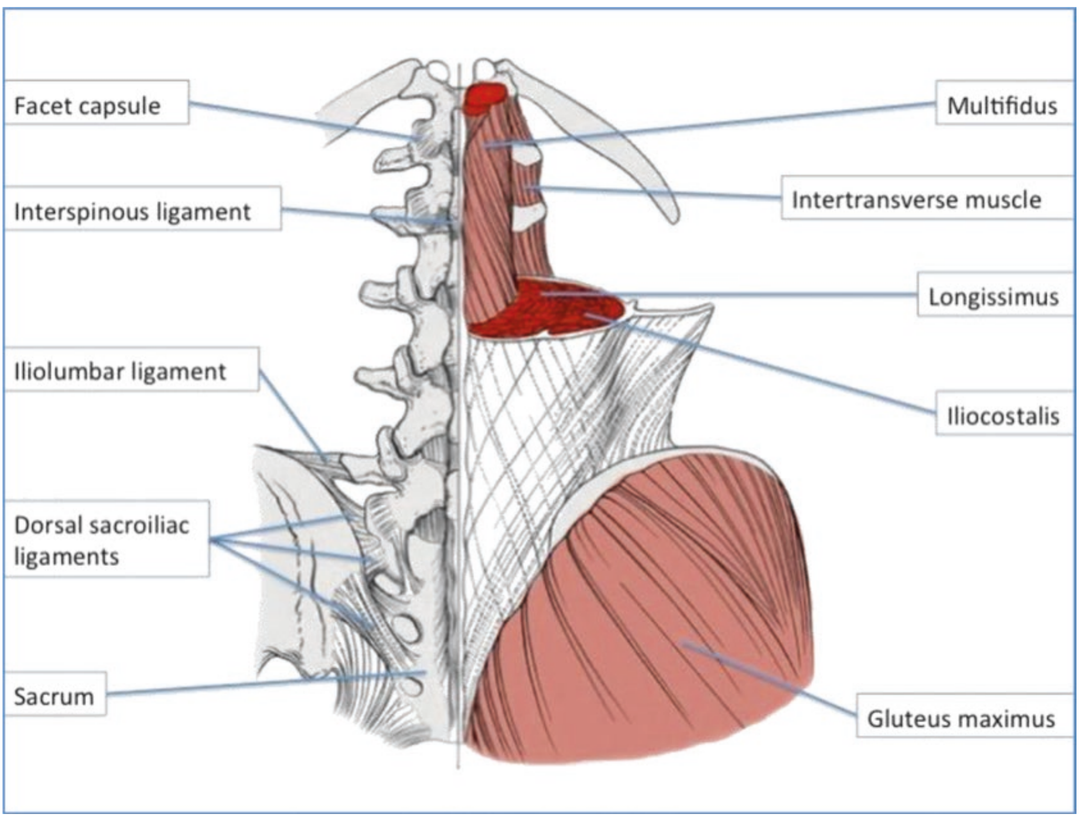


Fig. 10.17 The lumbar muscles and fasciae

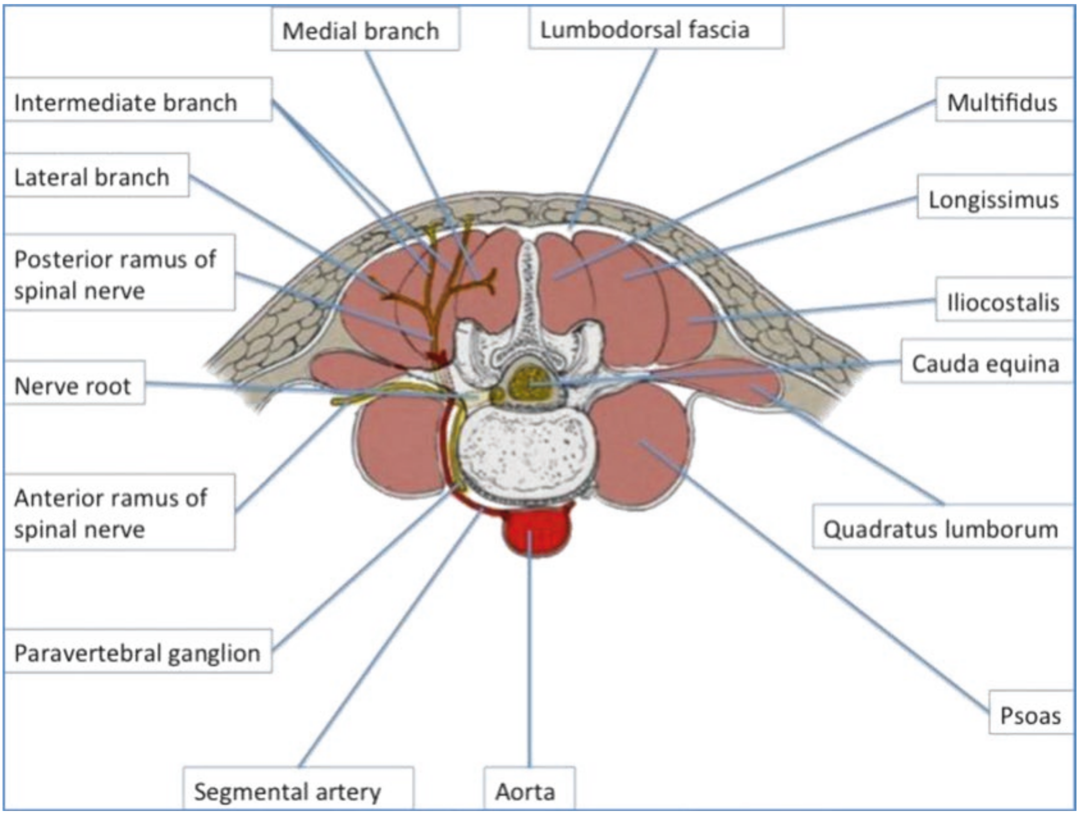


Fig. 10.18 Tra

sacral crests inferiorly and to the spinous processes throughout the spine. In the lower lumbar region, it is a single muscle, but it divides into three distinct columns of muscles, separated by fibrous tissue. Below the erector spinae muscles is an intermediate muscle group, made up of three layers that collectively form the multifidus muscle [28–32]. These muscles originate from the sacrum and the mammillary processes that expand backwards from the lumbar pedicles. They extend cranially and medially to insert into the lamina and adjacent spinous processes, one, two, or three levels above their origin. The deep muscular layer consists of small muscles arranged from one level to another between the spinous processes, transverse processes, and mammillary processes and the lamina. In the lumbar spine, there are also large anterior and lateral muscles including the quadratus lumborum, psoas, and iliacus muscles, which attach to the anterior vertebral bodies and transverse processes [3, 25, 33] (Fig. 10.18).

The thoracic and lumbar parts of the deep fascia constitute the thoracolumbar fascia. It extends laterally from the spinous processes and forms a thin covering for the deep muscles in the thoracic region and a strong thick covering for muscles in the lumbar region. The deep back muscles are grouped into superficial, intermediate, and deep layers according to their relationship to the surface [34, 35].

Endoscopically, the sacrospinalis, quadratus lumborum, and psoas major muscles appear as reddish bundles that are readily visualized under endoscopic magnification and illumination (Fig. 10.19). The thoracolumbar fascia appears as a heavy band of interwoven, whitish fibers that lacks a blood supply (Fig. 10.20).

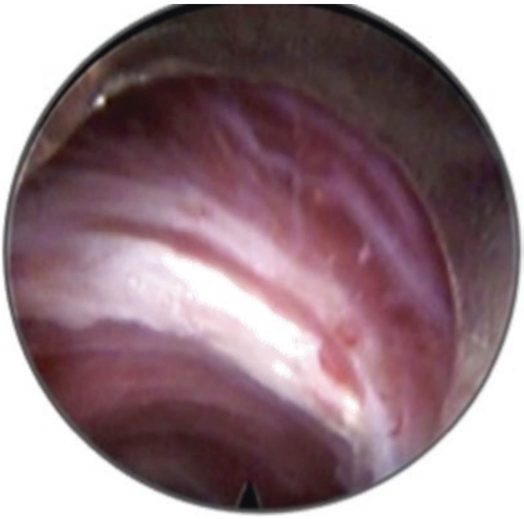


Fig. 10.19 Endoscopic view of the lumbar muscle

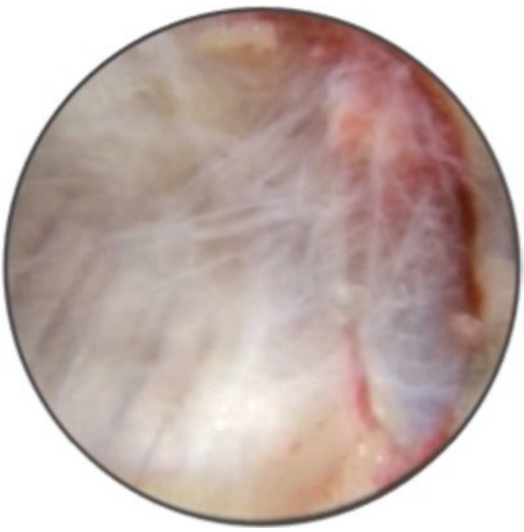


Fig. 10.20 Endoscopic view of the thoracolumbar fascia

10.5 Blood Supply of the Lumbar Spine

10.5.1 Blood Supply of Vertebrae

Segmental arteries supply typical lumbar vertebrae (Fig. 10.21). In the lumbar regions, each vertebra is encircled on three sides by paired lumbar arteries that arise from the aorta. The segmental arteries supply equatorial branches to the vertebral body, and posterior branches supply the vertebral arch structures and the back muscles. Spinal branches enter the vertebral canal through the intervertebral foramina to supply the bones, periosteum, ligaments, and meninges that bound the epidural space and radicular or segmental medullary arteries that supply nervous tissue (spinal nerve roots and spinal cord) [36].

10.5.2 Venous Drainage of Lumbar Vertebral Column

The venous drainage parallels the arterial supply and enters the external and internal vertebral venous plexuses (Fig. 10.22). There is also anterolateral drainage from the external aspects of the vertebrae into segmental veins. The vertebral canal contains a dense plexus of thin-walled valveless veins, the internal vertebral venous plexuses, which surround the dura mater (Fig. 10.23). Anterior and posterior longitudinal venous sinuses can be identified in the internal vertebral venous plexus. Basivertebral veins from the vertebral body drain primarily into the anterior internal vertebral venous plexus, but they may also drain to the anterior external plexus [37, 38].

10.5.3 Vasculature of the Spinal Cord and Spinal Nerve Roots

Blood supply to the lumbar spinal nerve roots occurs proximally from branches of the longitudinal vessels of the conus medullaris. The remaining proximal portions of the nerve roots receive blood supply via the dorsal and ventral proximal radicular arteries (Fig. 10.21). These blood vessels are derived from the dorsal longitudinal spinal artery and accessory anterolateral artery, respectively. The proximal radicular arteries enter the nerve root and follow the length of the nerve distally to anastomose with the distal radicular artery. Their entrance into the proximal nerve roots occurs slightly distal to the roots' exit from the spinal cord. This delay in contact is most likely due to proximal regions of the nerve root already receiving vascular supply

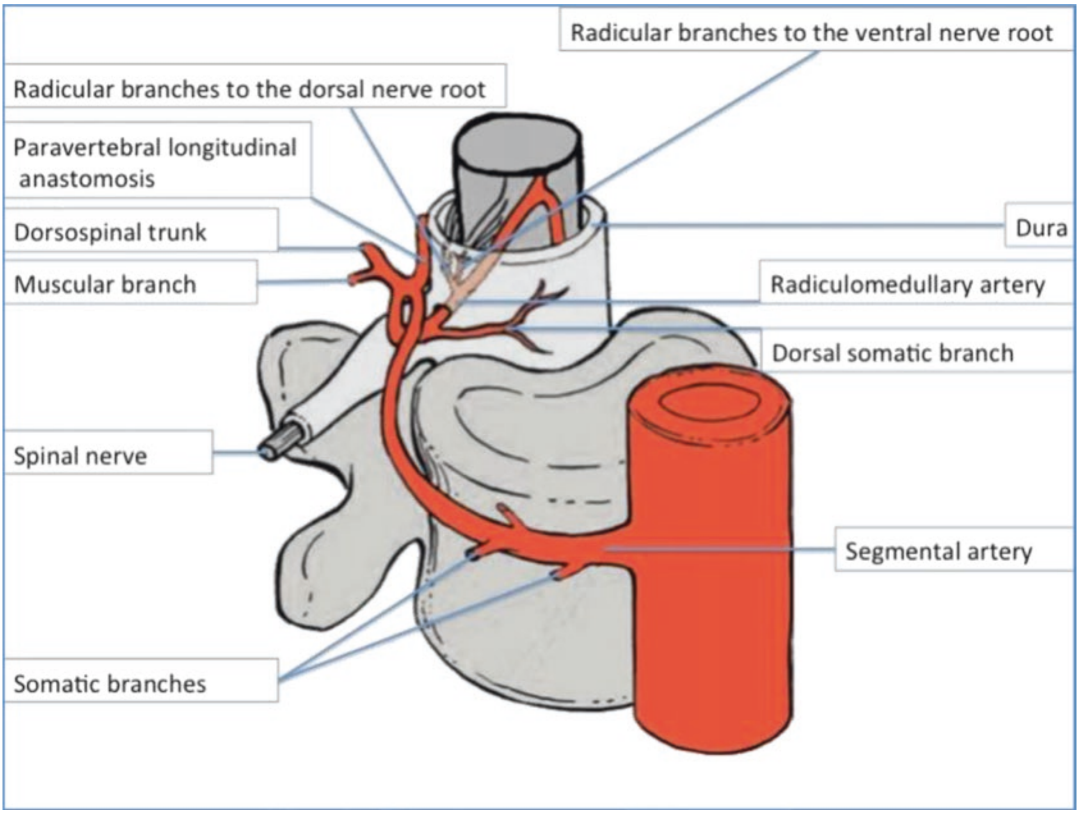
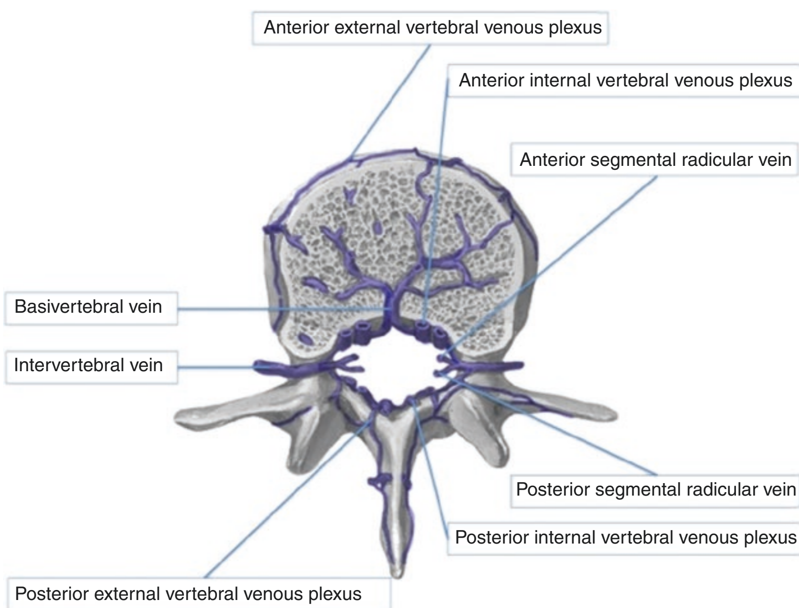


Fig. 10.21 Blood supply of the lumbar spine

Fig. 10.22 Venous drainage of the lumbar spine



from the dorsal and anterior longitudinal vessels. As the proximal radicular artery enters the nerve root it follows along with one of the main fascicular bundles. A number of collateral branches occur directly off of the main radicular artery (Fig. 10.24). These smaller branches tend to form parallel courses along other nerve root fascicles. Precapillary branching from these long-running parallel vessels gives supply to the subdivisions of fiber bundles not directly overlying the radicular arteries. These branches are unique in that they are coil shaped. Coiling of these precapillary vessels has been noted to endow these vessels with a resistance to compression during flexion and extension moments of the spine, thereby preventing ischemia to nerve root fascicles. The distal radicular artery branches from the lumbar artery at the level of the intervertebral foramen. It then divides into two branches, one entering each dorsal and ventral root. At this point it travels both proximally and distally along the length of the nerve roots giving it blood supply (Fig. 10.25). As the distal radicular artery travels proximally it forms numerous arteriovenous anastomoses with neighboring veins

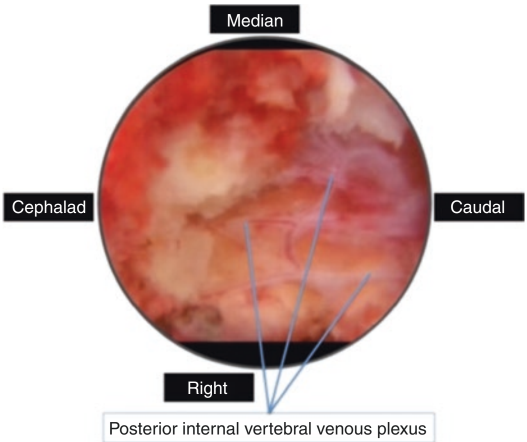


Fig. 10.23 Endoscopic view of the posterior internal vertebral venous plexus through right L4–5 interlaminar approach

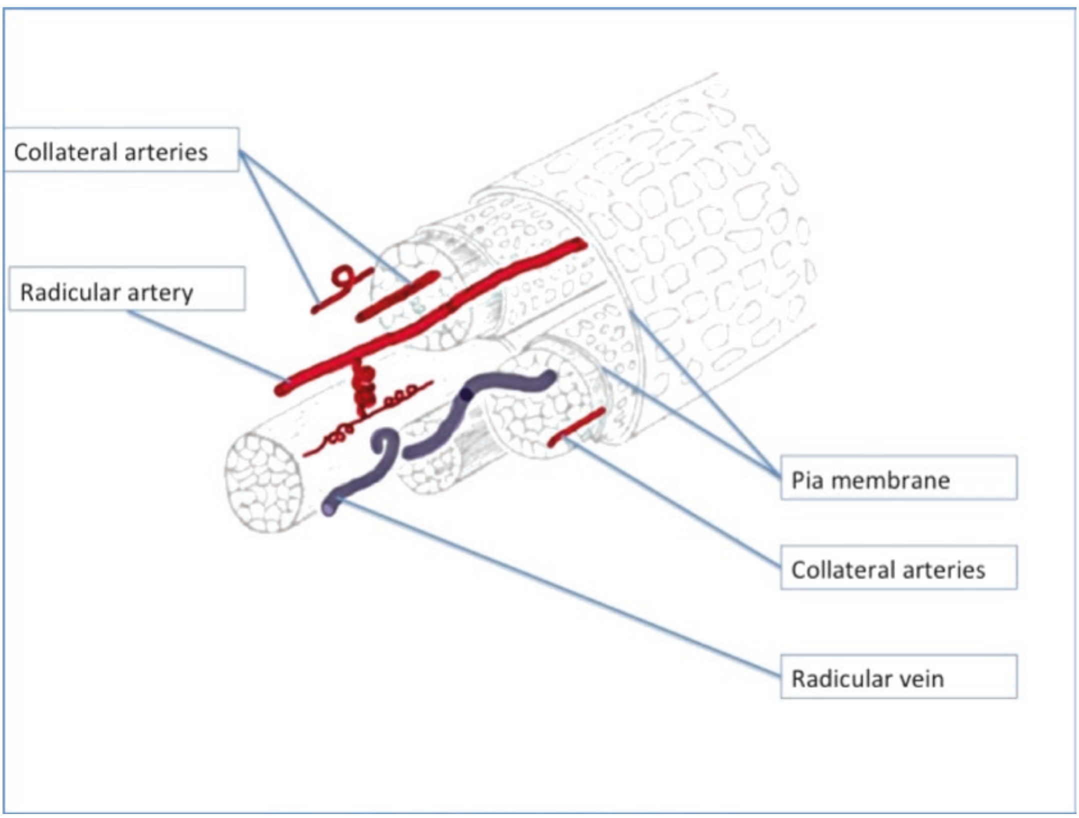


Fig. 10.24 Vasculature of spinal nerve root

[37–39]. There are two venous systems involved in drainage of the lumbar nerve roots, which are divided into proximal and distal radicular venous systems. The distal radicular veins drain into the lumbar vein at the level of the intervertebral foramen. The proximal radicular veins drain into the spinal cord venous plexuses. They have been documented to return via the vasa corona and then pass proximally in the anterior and posterior longitudinal veins of the cord [36, 40].

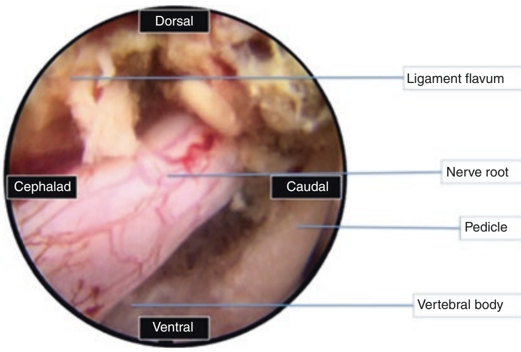


Fig. 10.25 Endoscopic view of left L5 nerve root through left L4–5 transforaminal approach with foraminoplasty

10.6 The Lumbar Spinal Canal and the Nerve Root Canal

10.6.1 The Lumbar Spinal Canal

The lumbar spinal canal can be divided into distinct zones (Fig. 10.26), which are useful in determining the site of the nerve root compression as well as managing the resulting radicular pathology. The central zone contains the traversing nerve roots bilaterally as well as the nerve roots for the caudal segments. A midline herniation invades the central zone. The lateral recess or subarticular zone is the region between the center of the spinal canal and the medial border of the pedicle. A posterolateral disc herniation will

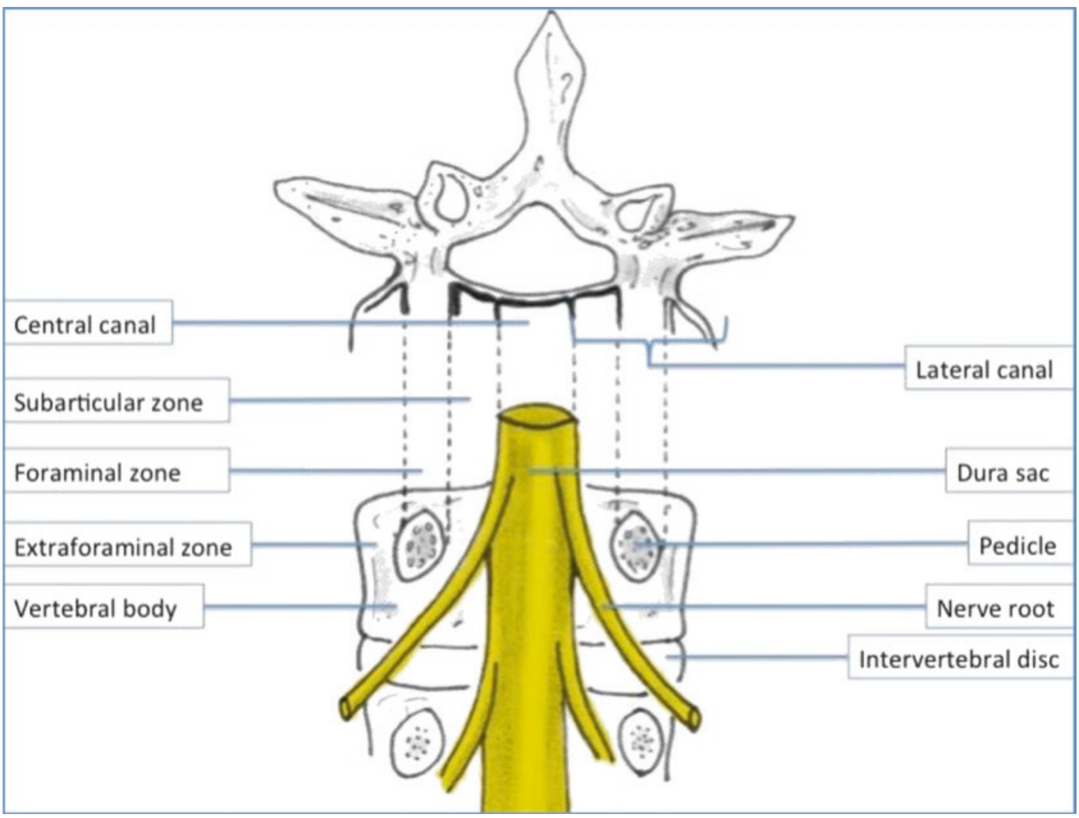


Fig. 10.26 Distinct zones of lumbar spinal canal

enter this zone and impinge upon the anterior and lateral aspect of the traversing nerve root. A posterolateral herniation is the most common type of lumbar disc herniation. The foraminal zone is the area within the intervertebral foramen containing the exiting nerve root. Lateral to the foramen, the exiting nerve root travels within the extraforaminal or far-lateral zone and may be compressed by a far-lateral disc herniation [41–44].

10.6.2 The Nerve Root Canal

In the lumbar spine, the nerve roots regularly exit the thecal sac approximately one segmental level above their respective foraminal canal. They take an oblique course downwards and laterally toward the intervertebral foramen. This oblique angle has modest differences based upon the lumbar level in question. In the upper lumbar nerve roots their orientation is more at a right angle to the dural sac than the distal nerve roots. This right angle makes the intraspinal portions of the upper nerve roots very short. In fact, in the upper lumbar area the thecal sac lies against the medial wall of the pedicles; therefore the nerve roots exit immediately into the intervertebral foramen. Distal to the L3 vertebral body level the dural sac is seen to taper progressively. The distal nerve roots are seen to exit from the thecal sac at more oblique angles after the L3 level [42, 43, 45].

The intraspinal course of the lumbosacral nerve roots is successively longer for each caudal level encountered. Epidural fat surrounds each nerve root throughout their course to the intervertebral foramen. Just prior to its entrance to the neural foramen the lumbar roots fit into an osseous groove at the medial base of the pedicle. This groove may be more pronounced at the level of the fifth lumbar vertebral foramen secondary to a more trefoil shape of the spinal canal. The term lateral recess has been used to describe this well-defined area. Narrowing of this groove, or lateral recess stenosis, could cause radicular leg pain in patients.

As the nerve root slides under the medial edge of the pedicle it takes an inferior and oblique direction away from the pedicle. At this point the nerve roots are located within the neural foramen, and they commonly combine to form the spinal nerve. Just prior to the formation of the spinal nerve a small enlargement of the dorsal root is noted. This enlargement is called the dorsal root ganglion (DRG), which contains the cell bodies of sensory neurons. The DRG location in perspective to the foramen can be quite variable. However, there are some general trends that are consistently reproduced in anatomical studies. The majority of DRGs in the lumbar levels are located within the anatomic boundaries of the intervertebral foramen. Most commonly, the position of DRG within the foramen is located directly beneath the foramen. Only at the S1 level is this rule not applicable. Studies have reported that the S1 DRG exists within the spinal canal approximately 80% of the time. This intraspinal placement places the S1 DRG at increased risk of injury from disc herniations or degenerative changes of the L5–S1 intervertebral disc.

In the foramen, nerve roots typically occupy approximately 30% of the available foraminal area, but numbers as high as 50% have been reported. As the spinal nerve reaches the foraminal outlet it curves around anterolaterally the base of the subjacent pedicle and transverse process. Around this exit zone of the foramen the spinal nerve divides into primary anterior and posterior rami.

Just outside the foramen the primary rami run between the deep layers of the psoas muscle and the vertebral column. Within the psoas muscle the lumbar nerves coalesce into trunks that run down vertically along the surface of the junctional area between the body and the pedicle of the lumbar spine [41, 46–48].

10.7 Nerves of the Lumbar Spine

The spinal cord ends at approximately the L1–2 intervertebral disc level, as the conus medullaris continues as a loose collection of spinal nerve roots known as the cauda equina. The lumbosacral nerves within the cauda equina run downward and laterally before exiting their respective foramina. The nerve root then traverses the intervertebral foramen as it passes beneath the pedicle. The DRG lies within the intervertebral foramen. Distal to the pedicle, the nerve root runs laterally to the caudal disc space (Fig. 10.27). The spinal cord is ensheathed by the three layers of the meninges. The pia mater invests the conus medullaris and rootlets. The outer layer, or dura mater, is separated by a potential subdural space to the arachnoid meninges. The subarachnoid space, which separates it from the pia mater, is filled with cerebrospinal fluid, which circulates up and down the spinal canal. The dura mater and pia mater continue distally, ensheathing the spinal nerves to the exit points (Figs. 10.28 and 10.29). Nerve roots in the lumbar spine consist of motor and sensory roots and an associated dorsal root ganglion (DRG). Within the spinal canal, a thin, rich dural sheath encloses the nerve roots.

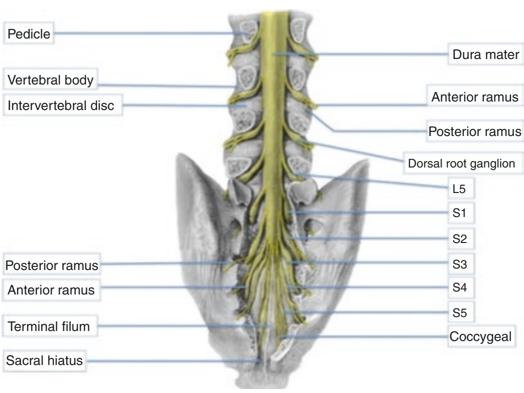


Fig. 10.27 A sketch of the lumbar nerve roots and the dura sac

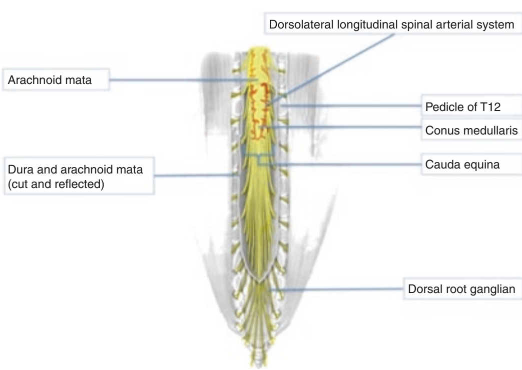


Fig. 10.28 A sketch of the spinal cord, nerve roots, and meningeal coverings

At the DRG, the sensory and motor nerve fibers mix to form the spinal nerve. At this point, the dura is transformed into the epineurium of the peripheral nerve. Nerve roots within the cauda equina lack epineurium and perineurium and only have a thin endoneurium root sheath, which potentially makes them more susceptible to compression forces than peripheral nerves [49, 50].

A spinal nerve divides into several branches immediately after it emerges through the intervertebral foramen. The small meningeal branch reenters the vertebral canal to innervate the meninges, vertebrae, and vertebral ligaments (Fig. 10.30). A larger branch, called the dorsal ramus, innervates the muscles, joints, and skin of the back along the vertebral column. A ventral ramus of a spinal nerve innervates the muscles and skin on the lateral and anterior sides of the trunk. Combinations of anterior rami innervate the limbs. The rami communicantes are two branches from each spinal nerve that connect to a sympathetic trunk ganglion, which is part of the autonomic nervous system. The rami communicantes are composed of a gray ramus, containing unmyelinated fibers, and a white ramus, containing myelinated fibers (Fig. 10.31) [51–53].

The existence of anomalies of the nerve roots has been reported [54, 55], which may make transforaminal endoscopic procedures contraindicated. The clinically most significant anomalies of the lumbar nerve roots are aberrant courses and anastomoses between nerve roots; the morphology of these anomalies is summarized in Fig. 10.32.

Type 1 anomalies are aberrant courses. Two pairs of nerve roots may arise from a single dural

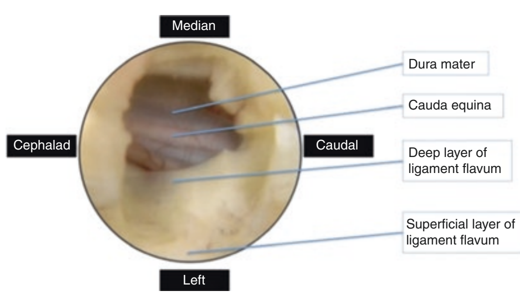


Fig. 10.29 Endoscopic view of cauda equina ensheathed in dura sac through left L5S1 interlaminar approach

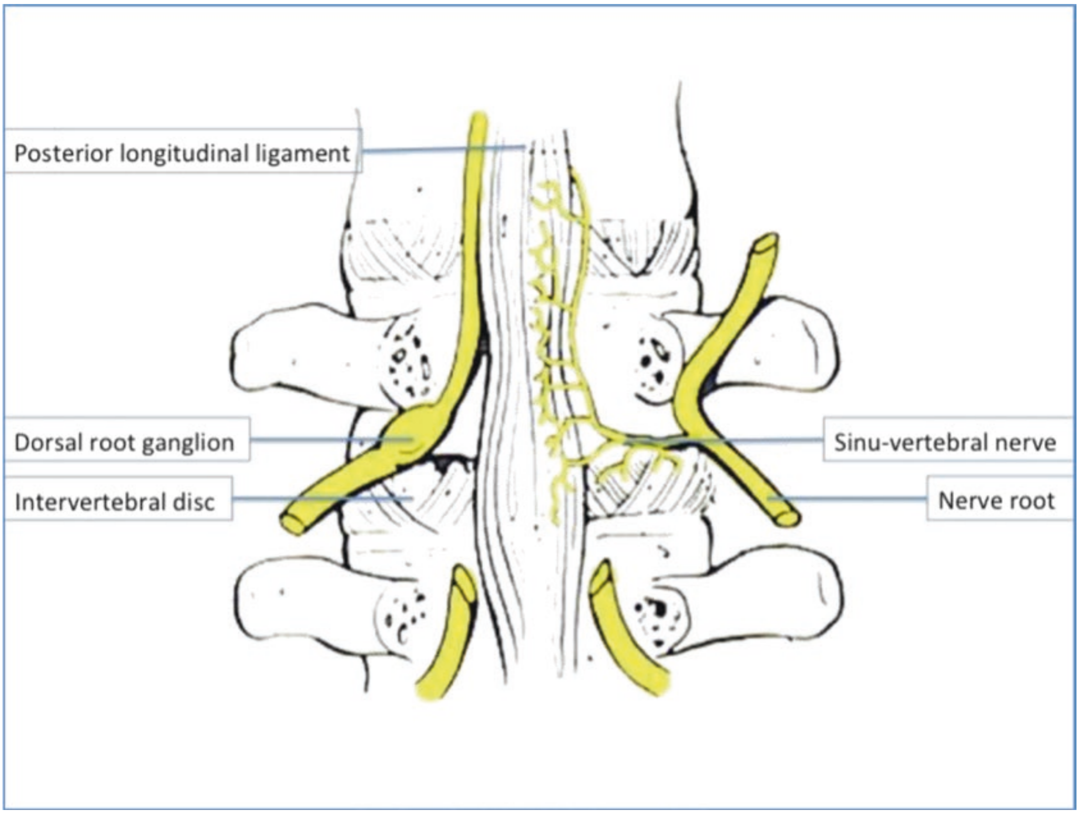


Fig. 10.30 A sketch showing the course and distribution of the lumbar sinu-vertebral nerves

sleeve (type 1A), or a dural sleeve may arise from a low position on the dural sac (type 1B). Type 2 anomalies are those in which the number of roots in an intervertebral foramen varies. A foramen may be unoccupied by a nerve (type 2A), in which case the foramen above or below contains two sets of roots, or a foramen may contain a supernumerary set of roots (type 2B). Type 3 anomalies are extradural anastomoses between roots in which a bundle of nerve fibers leave one dural sleeve to enter an adjacent one. This type of anomaly may be superimposed on a type 2 anomaly.

Furcal nerve has been found responsible for the atypical neurological finding in some patients with sciatica. Neurologic symptoms, suggestive of two roots being involved, may be due to four causes. The first is that two roots are compressed by a single lesion. Second, two lesions may be present. Third, there is an anomaly of nerve root emergence with two nerve roots emerging through the same foramen. Finally, the furcal nerve may be involved.

An anatomic and clinical study of furcal nerve showed the following: the furcal nerve was found in all dissections, and it arises at the L4 root level in most dissections (93%); the furcal nerve has its own anterior and posterior root fibers and its own dorsal nerve root ganglion. This proves that the furcal nerve is an independent nerve root. The furcal nerve distributes branches to the lumbar and sacral plexuses. It has branches going to the femoral and obturator nerves and the lumbosacral trunk. At the level of the intervertebral foramen, the furcal nerve could be seen running beside the L4 nerve root.

The furcal nerves were classified into six types by the level of their emergence (Fig. 10.33): A, two furcal nerves at the L3 and L4 root levels, respectively; B, one furcal nerve at the cephalad side of the L4 nerve root; C, a furcal nerve at the L4 root level, the L4 nerve root following

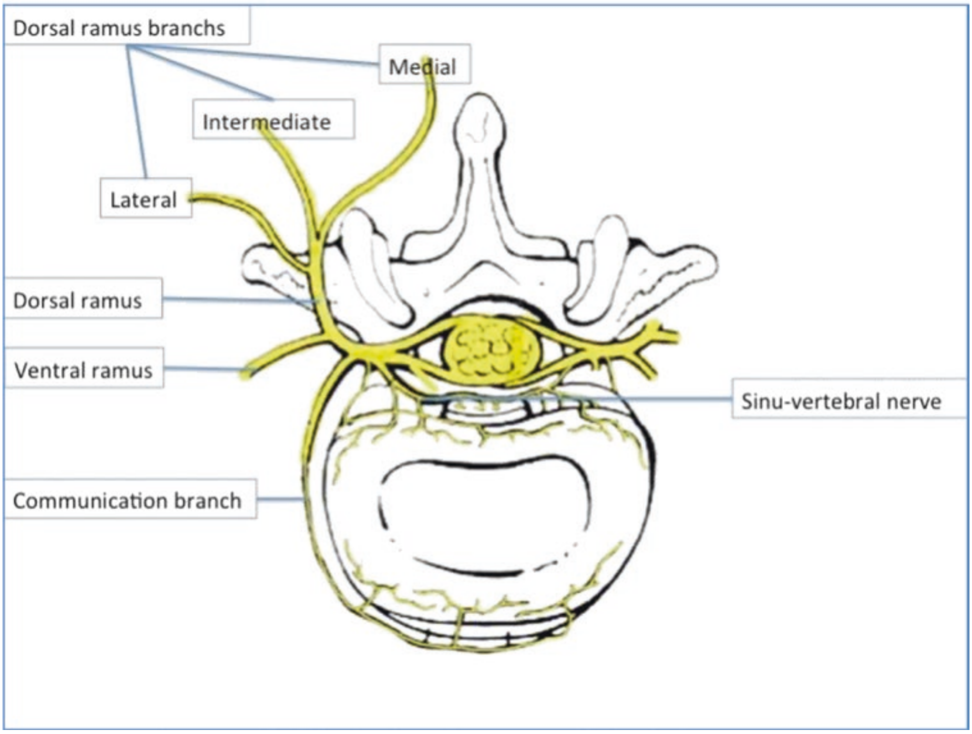


Fig. 10.31 A sketch of transverse section through the vertebral canal and intervertebral foramina to demonstrate the relations of the lumbar nerve root and its branches

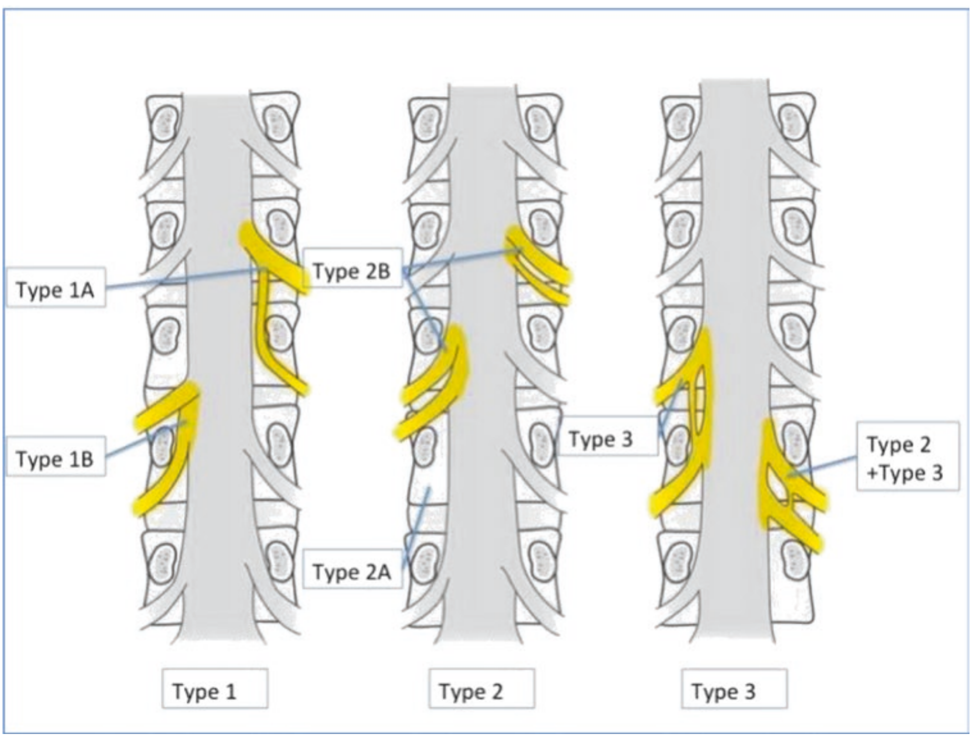


Fig. 10.32 Anomalies of nerve roots

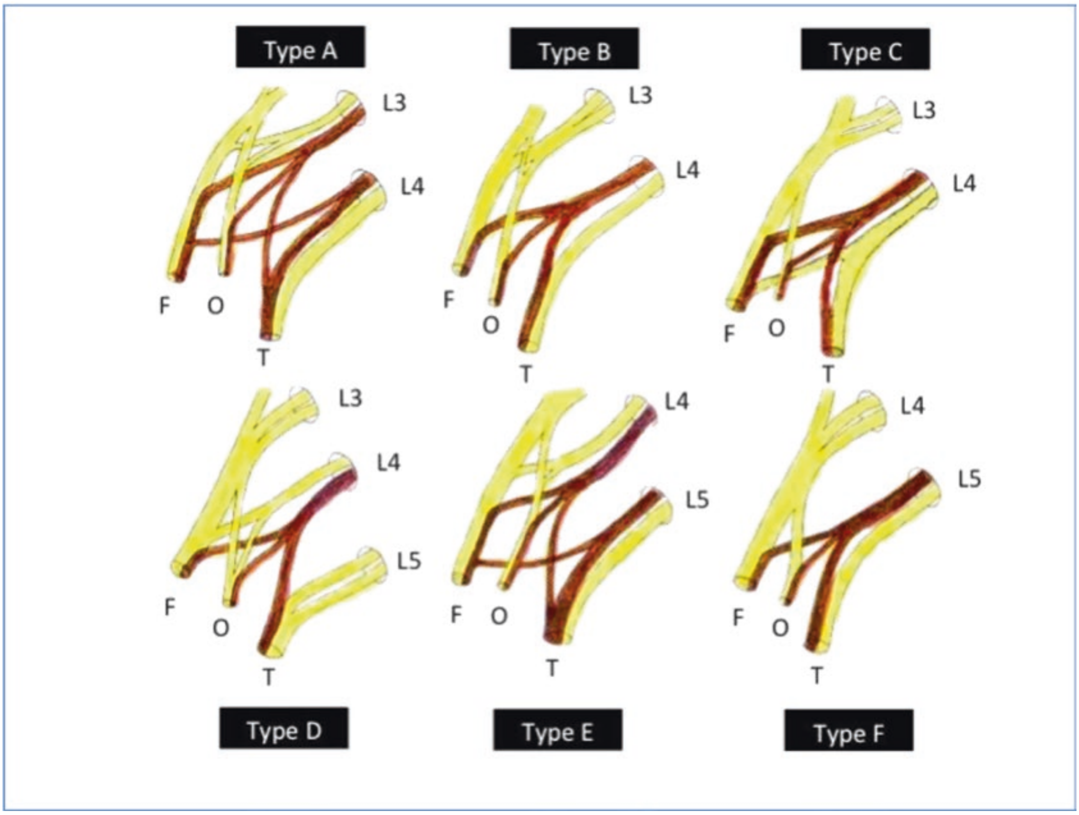


Fig. 10.33 Classification of furcal nerve (red)

the same course; D, a furcal nerve at the caudal side of the L4 nerve root; E, two furcal nerves at the L4 and L5 root levels, respectively; and F, a furcal nerve at the cephalad side of the L5 nerve root [56, 57].

Both the anomalies of nerve root and furcal nerve can be injured in transforaminal endoscopic procedures. Preoperative CT or MRI should be carefully evaluated to find possible nerve anomalies so that transforaminal approach can be avoided [54, 58, 59] (Figs. 10.34 and 10.35).

10.8 Triangular Working Zone

The triangular working zone is a safe zone on the posterolateral surface of the annulus adjacent to the spinal canal. The annular surface in the triangular working zone is bordered anteriorly by the exiting root, inferiorly by the proximal plate of the inferior lumbar segment, medially by the dural sac and the traversing root, and posteriorly by the articular processes of the adjacent segment (Fig. 10.36). It is suitable for safe lodging of instruments during posterolateral access to the intervertebral disc and the spinal canal. The annular surface in the triangular working zone is covered with loosely woven globules of adipose tissue. It should be noted that the fatty tissue is relatively stationary and does not move in and out of the cannula as the patient breathes. Small-caliber veins that may have to be coagulated may be observed on the surface of the triangular working zone. Coarse fibrous bands of the annulus are observed after removal of the adipose tissue. At times, a thin layer of fibers of the psoas muscle is observed on the dorsolateral surface of the annulus in the triangular working zone [60–62].

Both exiting and traversing roots that form the lateral and medial boundaries of the triangular

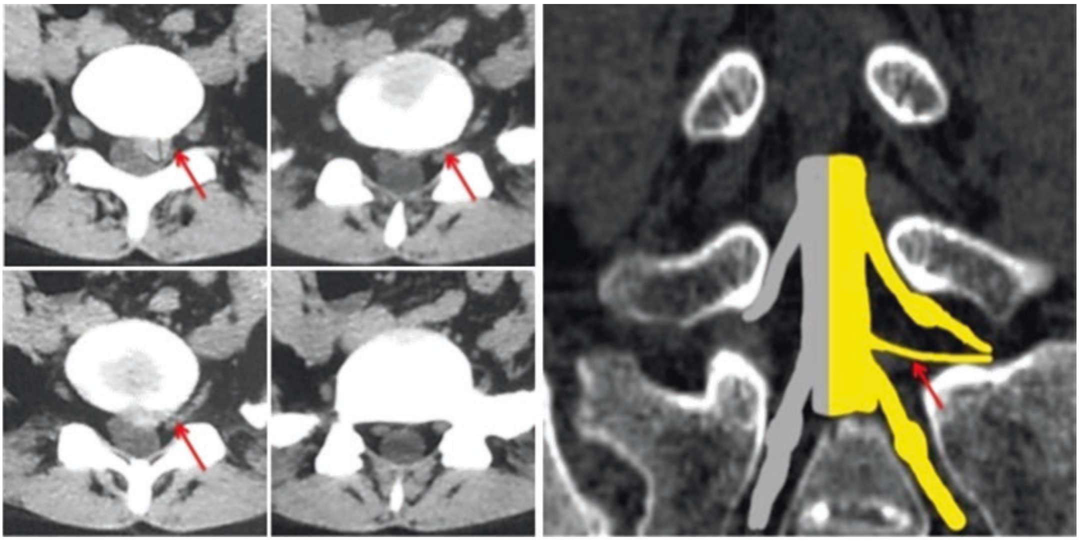


Fig. 10.34 Type 2B anomaly of nerve root confirmed on preoperative CT scan (red arrows)

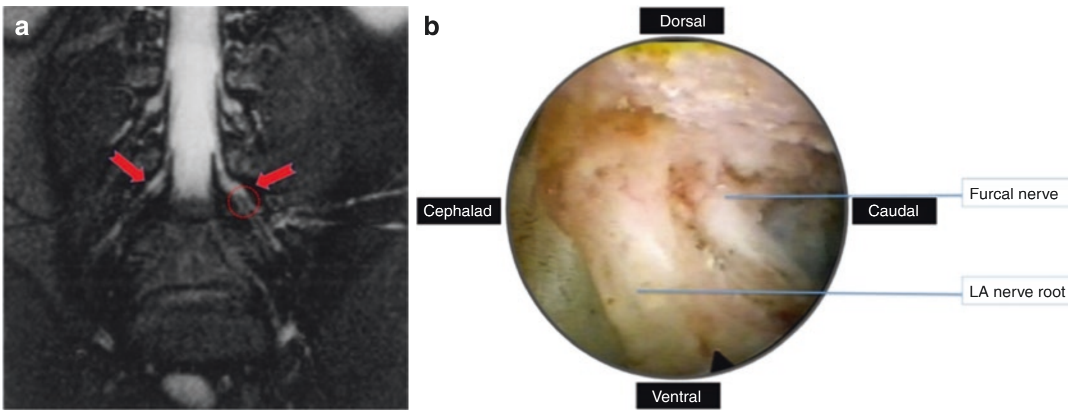


Fig. 10.35 Furcal nerve. (**a**) Furcal nerve on preoperative MRI (red arrows); (**b**) endoscopic view of furcal nerve

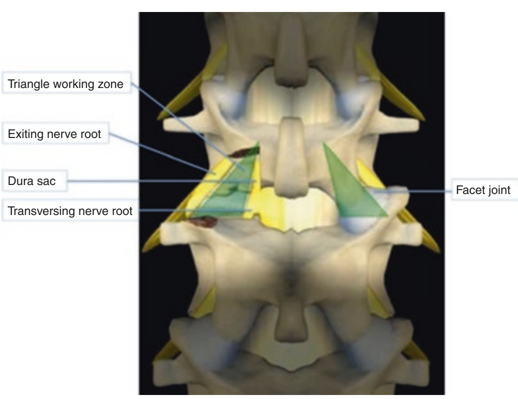


Fig. 10.36 Triangle working zone and its boundaries

working zone are in the path of dorsolaterally inserted instruments and may be subject to insult during intradiscal or extra-annular approaches to the lumbar spine. At the onset of endoscopic disc surgery, the final and proper positioning of the instruments is best determined by accurate placement and documentation of the tip of the inserted instruments on the annular surface in the triangular working zone. The fibers of the posterior longitudinal ligament extend laterally into the triangular working zone and extraforaminal region. These fibers are innervated by branches of sinu-vertebral nerve and are highly sensitive to palpation by the inserted instruments. The superficial layer of the annulus and the expansion of the posterior longitudinal ligament must be adequately anesthetized during the operative procedure and annular fenestration [60].

10.9 Intervertebral Foramen

The intervertebral foramen transmits the spinal nerves, spinal arteries and veins, recurrent meningeal nerves, and lymphatics. When looking outward through the intervertebral foramen from the spinal canal the foramen takes on the appearance of an oval, round, or inverted teardrop-shaped window. The roof of the intervertebral foramen is the inferior aspect of the vertebral notch of the pedicle of the superior vertebra, the ligamentum flavum at its outer free edge, and posteriorly lie the pars interarticularis and the zygapophysial joint. The floor of the nerve root canal is the superior vertebral notch of the pedicle of the inferior vertebra. Multiple structures are involved in bounding the anterior aspect of the foramen. They include the posterior aspect of the adjacent vertebral bodies, intervertebral disc, lateral expansion of the posterior longitudinal ligament, and anterior longitudinal venous sinus. The medial canal border contains the dural sleeve. The lateral boundary is a fascial sheet and overlying psoas muscle. A distal and proximal oval perforation is seen in the fascia. The distal perforation houses the nerve root, and the smaller proximal perforation regularly has blood vessels traversing through them (Fig. 10.37). The height of the foramen is dependent upon the vertical height of the corresponding intervertebral disc. With aging there is a natural tendency toward disc degeneration and loss of disc height. This decrease in disc height has direct anatomic consequences to the area of the foramen and resultant

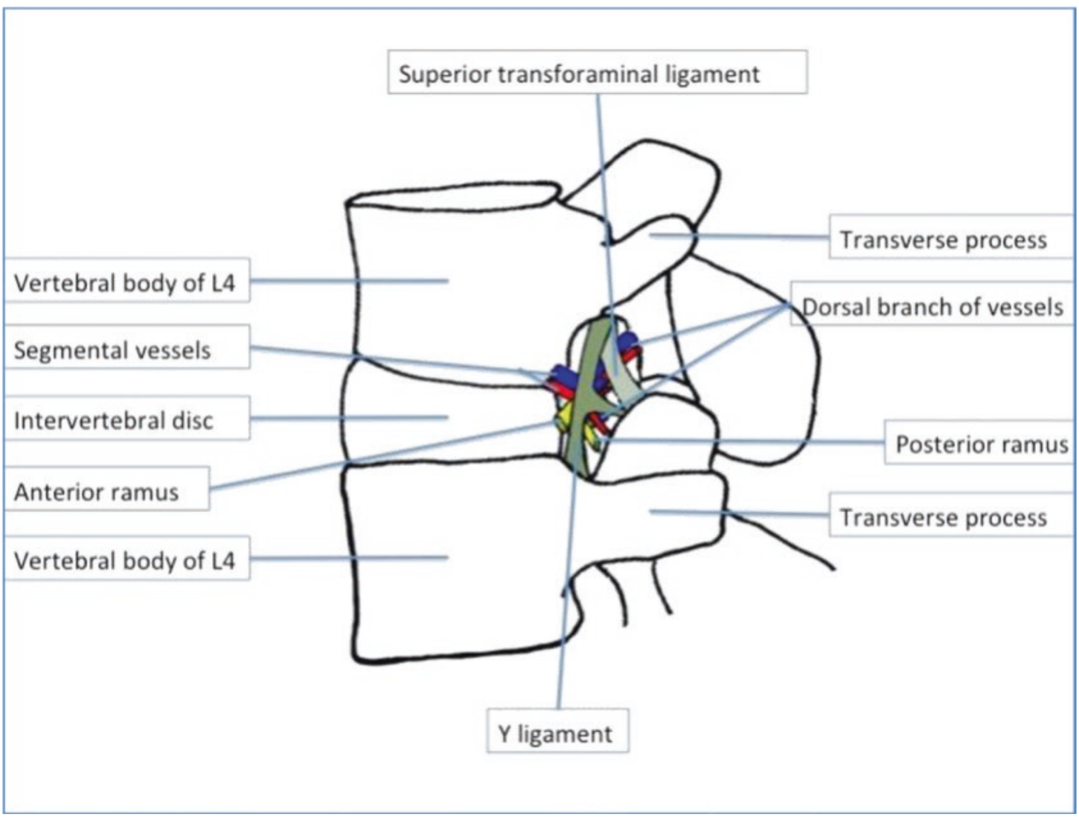


Fig. 10.37 Lateral boundary of intervertebral foramen

availability of space for neurovascular structures to pass [63, 64].

Direct cadaveric measurements of lumbar foraminal heights have varied from 11 mm to 19 mm. Magnusson also reported on foraminal width measurements of the lumbar spine. An average measurement of 7 mm was reported from the front to the back of the foramen [65, 66].

Ligaments of the intervertebral foramen, which were identified in 1969 by Golub and Silverman [67], include five major types of transforaminal ligaments: superior corporotransverse, inferior corporotransverse, superior transforaminal, midtransforaminal, and inferior transforaminal. The superior corporotransverse ligament was the most frequently observed ligament (Fig. 10.38).

The ligaments exist in three different zones of the lumbar foramen: internal, intraforaminal, and external zones. The internal ligaments were commonly found in the inferior aspect of the medial portion of the foramen. They were broad ligaments attaching to the posterolateral aspect of the intervertebral disc and anterior surface of the superior articular facet. These attachments gave the ligaments an obliquely running course inferiorly and posteriorly. In its course the internal ligament bridges across the top of the superior vertebral notch, thereby converting it into a sub-compartment in the lower foraminal canal. Veins were commonly noted to be running through this sub-compartment. The intraforaminal ligaments ran in three typical distributions. The first type traveled from the root of the pedicle to the inferior border of the same vertebral body. The recurrent meningeal nerve and a branch of the spinal artery were observed within the compartment formed by this ligament. A second distribution was the attachment to the angle between the posterior end of the pedicle and the root of the transverse process extending to the posterolateral surface of

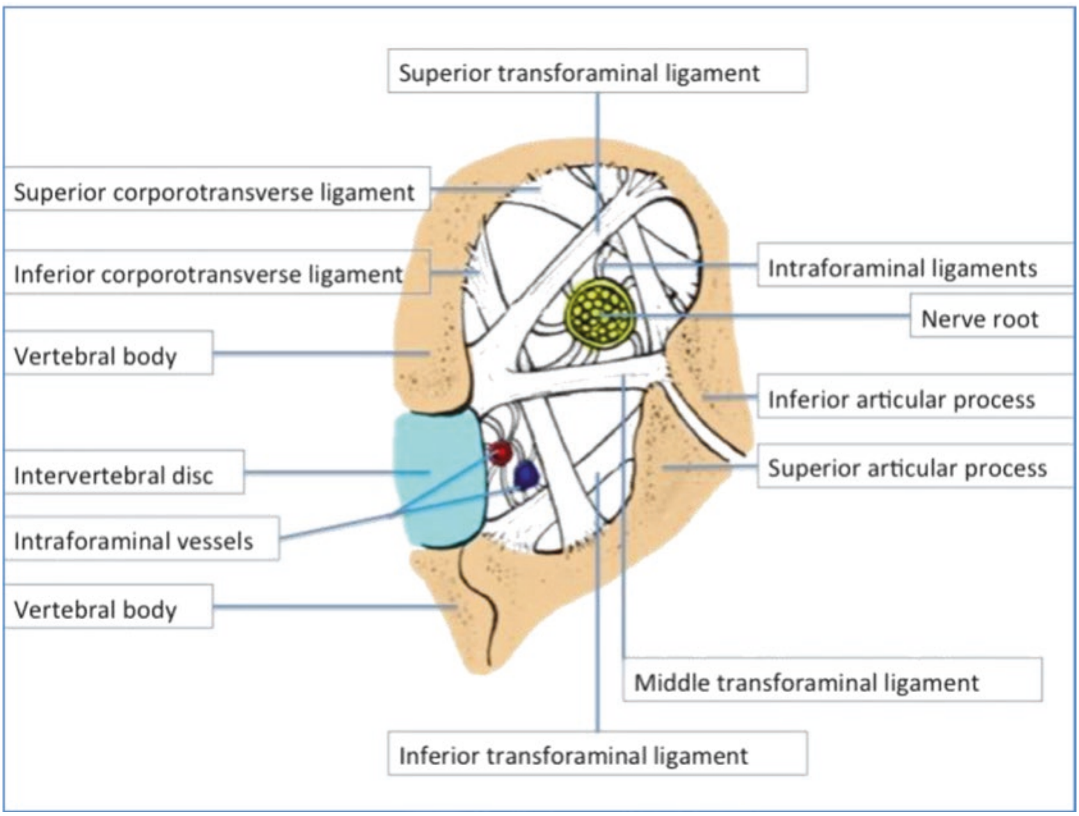


Fig. 10.38 Ligaments of intervertebral foramen

the same vertebral body. These attachments create an anterosuperior compartment through which a large branch of the segmental artery was observed to travel in all specimens examined. The last intraforaminal ligament noted was a strong, transversely oriented band originating from the anterior upper portion of the superior articular facet and attaching to the posterolateral surface of the vertebra above. The exiting spinal nerve was noted to lie directly over the top of this ligament in all specimens. The external ligaments all had a common attachment to the root of the transverse process. From this position the bands ran in a superior, inferior, and transverse direction. All bands were seen to insert into the vertebral bodies at the same level and the level below. These three external ligaments have also been called the superior, middle, and inferior corporotransverse ligaments. The position of these ligaments creates multiple sub-compartments just external to the foramen. A large central compartment was seen encasing the exiting ventral rami. Anterior and superior to this central compartment are two smaller openings through which the spinal artery, recurrent meningeal nerve, and a small branch of the segmental artery travel. Inferior to the ventral rami foramen are typically two or more small compartments through which veins were seen traversing. In the posterior aspect of the external foramen exist superior and inferior compartments. The superior compartment contained the medial division of posterior primary ramus and branches of the lumbar artery and vein. The inferior tunnel transmitted the lateral division of the posterior ramus and branches of the segmental artery and veins [68–70].

10.10 Interlaminar Window

Interlaminar window is covered with ligamentum flavum. Its boundaries consist of facet joint laterally, base of spinal process medially, inferior rim of cephalad lumbar vertebra superiorly, and superior rim of caudal lumbar vertebra inferiorly (Fig. 10.39) [3, 21, 24].

Interlaminar approach has been used for conventional open lumbar intervertebral disc excision, in which resection of ligamentum flavum

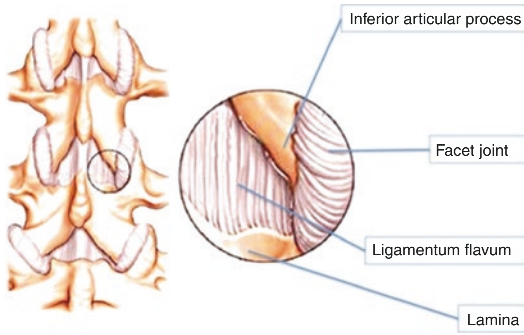


Fig. 10.39 Interlaminar window and its boundaries

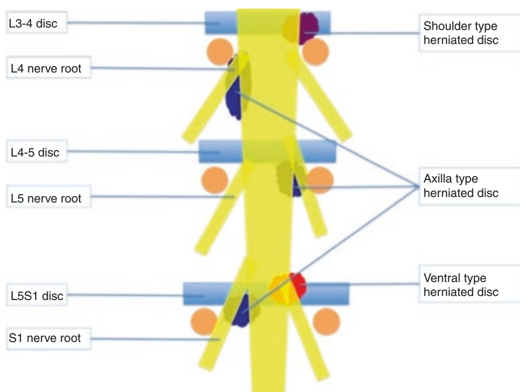


Fig. 10.40 Location of herniated disc and its relation with traversing nerve root

and medial facetectomy are usually performed. With the assistance of microscopic endoscope, certain iatrogenic injury has been significantly improved, but it may lead to potential epidural scar adhesion. Percutaneous endoscopic discectomy through interlaminar approach can avoid the potential drawback. Percutaneous endoscopic discectomy through interlaminar approach causes no damage to joints and no iatrogenic instability; moreover, the treatment of yellow ligament may effectively reduce the formation of epidural scar adhesion [71, 72]. The opening sites for percutaneous endoscopic discectomy through interlaminar approach should be based on the locations of herniated disc and its relation to the traversing nerve root [71] (Fig. 10.40). In most cases, opening of the interlaminar window through ligamentum flavum is enough to approach the herniated disk with ventral or shoulder type around the

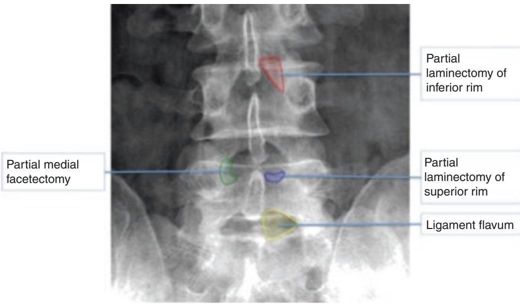


Fig. 10.41 Sites for opening the interlaminar window

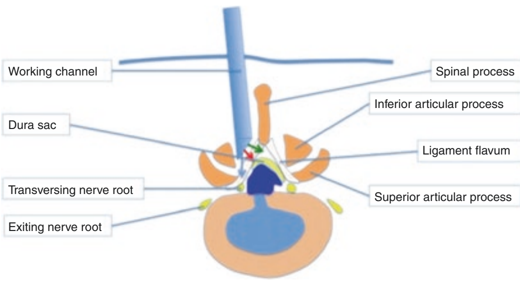


Fig. 10.42 Start points for opening the ligamentum flavum. Center of the ligamentum flavum (red arrow) that the dura sac intimately contacts with should be avoided from being the start point to prevent the iatrogenic dura tear or cauda equina injury

disc level. For highly upward migrated herniated disc, partial laminectomy of low part of cephalad lamina is needed. For highly downward-migrated herniated disc, partial laminectomy of upper part of caudal lamina is needed. For disc herniation combined with lateral recess stenosis, medial facetectomy will benefit the exposure and decompression of the nerve root and herniated disc (Fig. 10.41). Opening of the ligamentum flavum should start from the sites adjacent to the base of spinal process or the superior articular process; center of the ligamentum flavum where the dura sac contacts intimately should be avoided from being the start point to prevent the iatrogenic dura tear or cauda equina injury (Fig. 10.42).

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