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Review Article

Clinical anatomy and significance of the lumbar intervertebral foramen: A review

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ARTICLE INFO

Article history:
Received 8 August 2015
Accepted 26 October 2015
Available online 23 November 2015

Keywords:
Lumbar intervertebral foramen
Anatomy
Clinical
Triangular working zone
Safe zone
Review

ABSTRACT

The objective of this review is to summarize the knowledge about the anatomy of the lumbar intervertebral foramen (IVF) as an anatomic entity. The intervertebral or neural foramen is an orifice located between any two adjacent vertebrae that allows communication between the spinal canal and the extraspinal region. We describe the osseous structure of the lumbar foramen, the adjacent ligaments and its components including the arteries and veins passing through or neighboring it, and the spinal nerves and roots. Although lumbar spine structures are familiar to spinal surgeons and many procedures are performed in the area of the lumbar IVF, yet surprisingly little is known about the precise anatomy of the foramen and the triangular working zone of it.

1. Introduction

Generally, the lumbar spine consists of five moveable vertebrae numbered L1–L5. The lumbar spine is characterized by complex anatomy, which is a remarkable combination of these strong vertebrae, multiple osseous elements linked by joint capsules, and flexible ligaments/tendons, large muscles, and highly sensitive nerves. It also has a complicated innervation and vascular supply as described by Drake et al.[1] It is designed to be incredibly strong, protecting the highly sensitive spinal cord and spinal nerve roots. At the same time, it is highly flexible, providing mobility in many different planes including flexion, extension, side bending, and rotation as mentioned.[2,3]

The intervertebral foramen (IVF), referring to the lumbar IVF also, serves as the path between the spinal canal and periphery, through which canal neurovascular structures pass. This foramen is unique in comparison to other foramens of the body due to its boundaries consisting of two movable joints: the ventral intervertebral joint and the dorsal zygapophysial joint. The proximity of these joints increases susceptibility of

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Abbreviations: IVF, intervertebral foramen; CSF, cerebrospinal fluid; DRG, dorsal root ganglia; TFL, transforaminal ligament; LSTV, lumbosacral transitional vertebra; ED, endoscopic discectomy; MRN, magnetic resonance neurography; PELD, posterolateral endoscopic lumbar discectomy.

http://dx.doi.org/10.1016/j.jasi.2015.10.003

Table 1 – Articles where the anatomy of lumbar IVF is described as a whole.

Level of evidence	Study aim	Date	Authors	Journal
Level IV	Ligament, nerve, and blood vessel anatomy of the lateral zone of the lumbar intervertebral foramina	2015	Yuan SG, Wen YL, Zhang P, Li YK	Int Orthop
Level V	Radiographic anatomy of the intervertebral cervical and lumbar foramina (vessels and variants)	2012	Demondion X, Lefebvre G, Fisch O	Diagn Interv Imaging
Level IV	Anatomy of the intervertebral foramen	2002	Gilchrist RV, Slipman CW, Bhagia SM	Pain Phys
Level IV	Lumbar lateral recess and intervertebral foramen. Radio-anatomical study	2000	Demondion X, Manelfe C, Prere J, Francke JP	J Radiol
Level IV	Chirurgische Anatomie und Pathologie der lumbalen Intervertebralforamina [Surgical anatomy and pathology of lumbar intervertebral foramina]	1994	Steinsiepe KF	Aktuelle Probl Chir Orthop

narrowing from arthritic structural alterations and lesions. Specifically, the lumbar IVF has a critical role in spinal stenosis and other degenerative spine disorders.[4,5]

Although lumbar spine structures are familiar to spinal surgeons, yet surprisingly little is known about the precise anatomy of the IVF as an anatomic entity (as seen in Table 1), particularly the ligamentous structure associated with this canal. Furthermore, only a few studies have described the anatomy of this region but not in depth and not as a whole. Additionally, a lack of schematic depiction of the foraminal components and their anatomical relationships can be observed. To elucidate the clinical significance of the lumbar IVF, we study this foramen as an anatomical entity including spinal nerve roots, vessels, and osseous and ligamentous structures, and we further proceed to their schematic illustration. The following review is a thorough anatomic description of the IVF, with its contents, from L1 to L5 level.

2. The lumbar IVF

2.1. *Anatomical boundaries*

This foramen has two parts: one anterosuperior, made up of the inferior part of the pedicle and the posteroinferior part of the vertebral body (see Fig. 1); the other is inferior and mobile; it is formed by the posterior articular lamina covered by the yellow ligament, in the back, and by the posterolateral aspect of the intervertebral disk in front.[6,7] This second articular part is the one that undergoes motion-related or degenerative changes. At the lumbar spine, the foramen has an oval shape with a large vertical axis. The L5-S1 foramen is the roundest and the smallest of the lumbar intervertebral foramina. The spinal ganglion occupies the largest part of the foramen at this segment.[8,9] In extreme flexion, all the diameters of the IVF are at their maximum; the pedicles move apart from each other, disk convexity is minimal as reported by Revel et al.[10] On the other hand, during extension, all the diameters diminish; the pedicles move closer to each other, reducing the height of the foramen by approximately 20%.[11,12] The collapse of the lumbar IVF equals to the reduction in foraminal height. Thus, as long as the height of the intervertebral space remains satisfactory, the passage of nerve components in the bony upper part of the foramen is protected in a way from disk protrusion, posterior facet joint osteoarthritis, and ascension of the inferior articular process during extension movements.

2.2. *Components*

The vertebral canal contains the spinal cord, its meninges, spinal nerve roots, and blood vessels supplying the cord, vertebrae, joints, muscles, and ligaments. The vertebral bodies and discs compose the anterior border, while the laminae and ligamentum flavum create the posterior border of the canal. Laterally, spinal nerves and vessels travel through the IVF.

Numerous components are together in the IVF: nerve roots and spinal ganglions, foraminal fat, foraminal veins, radicular arterioles, lymph vessels, the meningeal nerve and foraminal ligaments (see Fig. 2). The total area of the neurovascular bundle is estimated at 20–50% of the total foraminal area.[11] The anterior motor root joins the posterior sensory root just after the spinal ganglion in order to form the mixed spinal nerve. The spinal ganglion is located below the pedicle. At the foramen exit, the spinal nerve usually divides into a relatively

Fig. 1 – (1) Vertebral body, (2) Intervertebral disk, (3) Pars interarticularis, (4) Transverse process, (5) Intervertebral foramen, (6) Superior vertebral notch, (7) Inferior vertebral notch, (8) Superior articular process, (9) Inferior articular process, (10) Zygapophysial joint, (11) Lamina, (12) Spinous process, (13) Lumbo-sacral joint, (14) Sacrum.

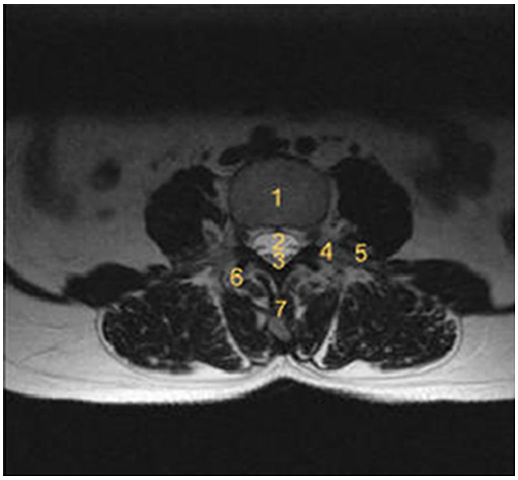

Fig. 2 – Disk angled axial T2 FSE at L4/5 level. (1) Disk, (2) Spinal canal, (3) Nerve roots, (4) Intervertebral foramen with its components, (5) Exiting nerve root, (6) Facet joints, (7) Spinous process.

large anterior branch and a thinner posterior.[13] It is difficult to categorize the foraminal veins. The foraminal veins can be individualized at the upper part of the foramen in back and front, above the spinal ganglion, and mostly at the lower part.[14] Usually the radicular arteries are found on the anterior side of the anterior and posterior roots. Foraminal fat has a critical functional role allowing flexible maintenance of the vascular structures.[15] The same numbered spinal nerve root, recurrent meningeal nerves, and radicular blood vessels pass through each foramen.

2.3. *Osseous structure*

The lumbar vertebrae, numbered L1–L5, have a vertical height that is less than their horizontal diameter. They are composed of the following 3 functional parts: The vertebral body, the vertebral (neural) arch, the bony processes (spinous and transverse). The size of the vertebral body increases from L1 to L5, indicative of the increasing loads. The L5 vertebra has the heaviest body, smallest spinous process, and thickest transverse process (see Fig. 3). Each vertebral arch is composed of 2 pedicles, 2 laminae, and 7 different bony processes (1 spinous, 4 articular, 2 transverse), connected by facet joints and

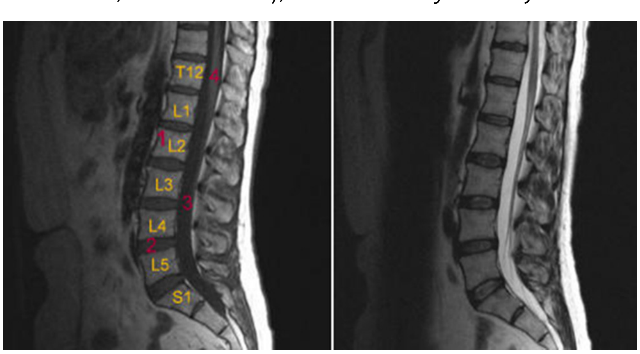

Fig. 3 – Midline sagittal T1 SE; Midline sagittal T2 FSE, (1) Vertebrae, (2) Normal disk, (3) Spinal canal, (4) Spinal cord.

ligaments. Each IVF is bounded superiorly and inferiorly by the pedicle, anteriorly by the intervertebral disk and vertebral body, and posteriorly by facet joints.

When looking outward from the spinal canal the IVF has the appearance of an oval, teardrop-shaped window. The upper border of the IVF 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 lays the pars interarticularis and the zygapophysial joint. The lower point of the nerve root canal is the superior vertebral notch of the pedicle of the inferior vertebra, postero-inferior margin of the superior vertebral body, the intervertebral disk, and the postero-superior margin of the inferior vertebral body.

One of the major symptoms referred to the lumbar spine and the lumbar IVF is low back pain. Its origins have been a matter of great controversy and have been linked to spinal stenosis. While spinal stenosis is now radiologically depictable, the alteration of the foramen borders is less clear. The narrowing of the maximum IVF width is excluded as the only cause of radiculopathy or spinal stenosis and in a similar way the decrease of the IVF height is considered insignificant.[16,17] Findings indicate that the posterior elements are primitive locations of degenerative spinal and perispinal disease that may accompany or even precede degenerative disk disease. It is important to mention that radicular, referred and/or local low back pain symptoms should be considered in the evaluation of the symptomatic patient presenting with a clinical lumbosacral syndrome. Imaging recommendations include the acquisition of high-resolution multiplanar CT reconstructions, and fat-suppressed T2 weighted fast-spin or turbo-spin-echo sequence MRI in at least one plane in every examination of the lumbar spine.[18]

3. Vessels

3.1. *Arteries*

Lumbar vertebrae are contacted anterolaterally by paired lumbar arteries that arise from the aorta, opposite the bodies of L1–L4. Each pair travels anterolaterally around the side of the vertebral body to a position immediately lateral to the intervertebral canal and leads to various branches. The periosteal and equatorial branches supply the vertebral bodies. Spinal branches of the lumbar arteries enter the IVF at each level. They divide into smaller anterior and posterior branches, which pass to the vertebral body and the combination of vertebral arch, meninges, and spinal cord, respectively.[5,9] These arteries continue to the ascending and descending branches that connect with the spinal branches of adjacent levels. Arteries providing nutrition from the anterior vertebral canal travel anteriorly and supply most of the red marrow of the central vertebral body (see Fig. 4). The larger branches of the spinal branches continue as radicular arteries, distributed to the nerve roots and to the spinal cord, respectively.[5,8]

3.2. *Veins*

The venous drainage is parallel to the arterial supply. Venous plexuses are formed by veins along the vertebral column both

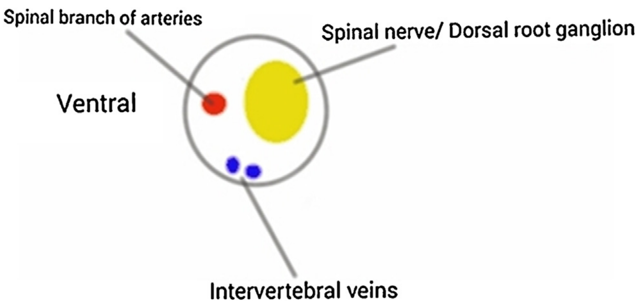

Fig. 4 – A view illustrating some of the components of the lumbar IVF including the spinal branch of arteries (anteriorly), the spinal nerve/dorsal root ganglion (posteriorly), and the intervertebral veins (inferiorly).

inside and outside of the vertebral canal (internal/epidural and external vertebral venous plexuses). The large basivertebral veins, within the vertebral bodies, rise from the foramen on the posterior surfaces of the vertebral bodies, and drain into the internal vertebral venous plexuses, which may form large longitudinal sinuses. The intervertebral veins connect with veins from the cord and venous plexuses as they accompany the spinal nerves through the foramen to drain into the lumbar segmental veins.[4,9]

3.3. *Vessels of the foramina*

The dorsal spinal arteries divide into a large artery headed posteriorly to the vertebral muscle mass and a thinner radicular artery that reaches the IVF parallel to the corresponding spinal nerve. The radicular artery divides into an anterior and a posterior radicular artery. Usually, the radicular arteries route along the anterior side of the corresponding roots (see Fig. 4). Nonetheless the two branches can be separate from the beginning, that one of them can be missing, and that we have observed posterior radicular arteries located behind, posterior to, posterior roots. The number of radiculomedullary arteries actually participating in the vascularization of the spinal cord can vary from one person to another.[15] We can distinguish: the radicular arteries, the radiculopial arteries, the radiculomedullary arteries.

4. Spinal nerves and roots

All lumbar spinal nerve roots originate at the T10 to L1 vertebral level, where the spinal cord ends as the conus medullaris. A dorsal or posterior (somatic sensory) root from the posterolateral aspect of the spinal cord and a ventral or anterior (somatic motor) root from the anterolateral aspect of the cord join in the spinal canal to form the spinal nerve root. The roots then travel down through the spinal canal, forming the cauda equina, until they exit at their respective IVF as a single pair of spinal nerves.[5]

These roots proceed independently toward their respective foramen, traversing the subarachnoid space within the dural sac/sleeves. They pierce the dura separately before they blend with each other at the foramen. In the lateral portion, they travel in the dural sleeve. There may be separate dural sleeves around the posterior and anterior roots for a given spinal nerve, or the 2 sleeves may be fused. Each root is surrounded by CSF from a separate arachnoid sheath around it. It is known that at the medial line of the IVF, the disk-root distance gradually increases from L1-L2 to L5-S1 and that for the lateral line, the distance between an intersection point between the medial edge of the nerve root and the superior edge of the disk and lateral line of the foramen consistently increases from L1-L2 to L5-S1.[19–21]

Cell bodies of the motor nerve fibers are located in the ventral or anterior horns of the spinal cord; however, those of the sensory nerve fibers are in a dorsal root ganglion (spinal ganglion) at each lumbar and sacral level. Dorsal root ganglia (DRG) tend to be located within the IVF. Moreover, at the low lumbar (and sacral) levels, the DRG tends to be proximal to the neural foramina, within the spinal canal, as found in 11–38% of cases at L5 and 71% at S1.[22–24] The DRG are attached to the borders of IVF.

4.1. *Exit levels of spinal nerves*

Lumbar spinal nerves exit the vertebral canal by passing inferior to the pedicles of the corresponding vertebrae. The first division of the spinal nerve takes place within the IVF resulting in the posterior and anterior (dorsal and ventral) rami. The posterior rami pass posteriorly, while the anterior rami proceed laterally to supply the body wall and the lower limbs.[22,25]

4.2. *Relations of the roots and spinal nerves*

In the lumbar vertebral canal, the posterior and anterior roots of a given nerve (enclosed in their dural sacs) cross the intervertebral disk that is located above the pedicle below which the nerve exits. For example, the L2 nerve roots cross the disk between L1 and L2 vertebrae before reaching the appropriate foramen, below the pedicle of the L2 vertebra.

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 IVF. 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 portion of the pedicles; therefore, the nerve roots exit immediately into the IVF.[24] As the spinal nerve reaches the foraminal border, it curves around anterolaterally the base of the subjacent pedicle and transverse process. 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 unite into trunks that run down vertically along the surface of the junctional area between the body and the pedicle of the lumbar spine.

5. Ligamentous structure

The anterior longitudinal ligament covers the ventral surfaces of lumbar vertebral bodies and discs. It is intimately attached to the anterior annular disk fibers and widens as it descends the vertebral column. This ligament maintains the stability of the joints and limits extension. The posterior longitudinal ligament is located within the vertebral canal over the posterior surface of the vertebral bodies and discs. It limits flexion of the vertebral column, except at the lower lumbar spine, where it is narrow and weak. The supraspinous ligament joins the tips of the spinous processes of adjacent vertebrae from L1 to L3. The interspinous ligament connects the spinous processes, from root to apex of adjacent processes. Sometimes described together as the interspinous/supraspinous ligament complex, they resist spinal separation and flexion.[16,26]

The ligamentum flavum bridges the interlaminar interval, attaching to the interspinous ligament medially and the facet capsule laterally, forming the posterior border of the vertebral canal. It has a broad attachment to the undersurface of the superior lamina and inserts onto the leading edge of the inferior lamina. It maintains constant disk tension. In degenerative scoliotic curves, lateral translation is associated with rotation. Anteroposterior olisthesis is correlated to the dural sac anteroposterior diameter and cross-sectional area. With increased segmental Cobb angle, foraminal cross-sectional area enlarges in the convexity and does not decrease in the concavity. Presence of intervertebral rotation alone does not appear to be associated with reduced neural canal dimensions. Ligamentum flavum hypertrophy, posterior disk bulging, and bony overgrowth are more likely to contribute to stenosis unrelated to scoliosis.[27]

The intertransverse ligament joins the transverse processes of adjacent vertebrae and resists lateral bending of the trunk. The iliolumbar ligament arises from the tip of the L5 transverse process and connects to the posterior part of the inner lip of the iliac crest. It helps the lateral lumbosacral ligament and the ligaments mentioned above stabilize the lumbosacral joint.

There are various types of transforaminal ligament. Five major types of TFLs have been described: superior corporotransverse, inferior corporotransverse, superior transforaminal, midtransforaminal, and inferior transforaminal as mentioned by Park et al.[28] (see Fig. 5). The superior

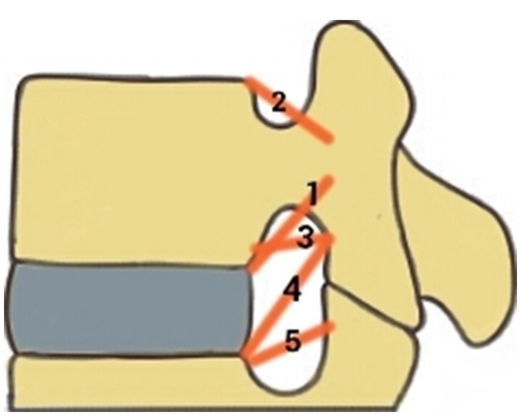

Fig. 5 – Schematic illustration depicting various types of transverse ligament: Corporotransverse superior (1) and inferior (2) ligament, Superior transforaminal (3) ligament, Mid-transforaminal (4) ligament, Inferior transforaminal (5) ligament.

corporotransverse ligament is the most frequently observed ligament. In the study of Min et al.,[26] data show that TFLs occupy a mean cross sectional area of 28.5–18.8% in the lumbar IVF up to a maximum of 89.2%, suggesting that TFLs can reduce the available space for the spinal nerve root. Direct compression or restriction of movement of the spinal nerve root during motion may be induced by the transforaminal ligament. In the same report, additional data proved that the variations were found in 82.8% of the IVFs. The oblique inferior transforaminal ligament was the most common. The mean area of the IVFs was $155.8 \pm 51.1\ mm^2$, and the mean area occupied by the ligaments was $46.3 \pm 37.6\ mm^2$. The mean percentage of the IVF area occupied by the TFLs was $28.5 \pm 18.8\%$. TFLs are common structures in the IVF and may reduce the space available for the spinal nerve root within the IVF. Future work is needed to correlate neurological symptoms with variations of TFL based on radiological imaging.

6. Anomalies of the lumbar vertebral column

Normally, 5 human lumbar vertebrae exist. However, approximately 4–21% of the general population and 10% of adults seen with symptomatic degenerative conditions of the low back have a lumbosacral transitional vertebra (LSTV). These anomalies are mainly failures of symmetrical or asymmetrical segmentation. In these cases, the last lumbar vertebra contains an elongation of its transverse process, with varying degrees of fusion to the "first" sacral segment. The term LSTV is now recommended over "sacralized L5" or a "lumbarized S1." LSTV is classified by plain radiographs per the Castellvi system. A Ferguson view of the lumbosacral junction and an anteroposterior view of the thoracolumbar junction are recommended.[29]

No standard method is established for vertebral numbering based only on sagittal lumbar magnetic resonance images. The iliolumbar ligament is well identifiable on axial L-spine MRI and always arises from the L5 vertebra. By identifying L5, physicians can increase their confidence of correctly assigning lumbar levels.[29,30] Congenital vertebral anomalies consist of a collection of malformations of the spine. Most are not clinically significant, but they may cause compression of the spinal cord and nerves, or they may cause instability.

A specific type of LSTV was first described by Bertolotti in 1917; with this syndrome, a large transverse apophysis in one or both sides of a lumbar transitional vertebra articulates with the sacrum or with the iliac bone. The posterior arch or transverse apophysis of the vertebra usually has both lumbar and sacral characteristics, occurring most commonly at L5, but these can also occur at L6.[31] Most patients with Bertolotti syndrome are asymptomatic, and little is known about the biomechanical effects of such abnormal vertebra and its relation to low back pain.

LSTV has been frequently discussed by experts as a possible cause of lower back pain. One systematic review by van Tulder et al.[32] and some authors[33–35] have concluded that the incidence of LSTV is equal in those with and without back pain, stating it only an incidental finding on imaging. Other authors report higher incidences in back pain populations, ranging from 16% to

30%,[36–39] as well as higher incidences of disk degeneration above the LSTV[40,41] and herniations occurring at a younger age.

A study by Deport et al.[41] showed the frequency of LSTV to be 30% in the low back pain population. Review of the literature makes apparent that having an LSTV is not necessarily symptomatic, but those with LSTV who do get symptoms tend to have specific etiology. The following have all been shown to be common entities associated with a transitional vertebra: internal disk disruption of the level above, contralateral facet pain, and pain from the articulation with the transverse process. The transitional vertebra may be more relevant in younger populations and no greater incidence of spondylosis exists in those with an LSTV.[39]

7. Triangular working zone

Traditionally, minimally invasive techniques for surgical discectomy have been defined as smaller incisions, tubular retractors, microscopically assisted tissue dissection, and conservative removal of only extruded or sequestered nucleus pulposus with preservation of the annulus.[42]

The aim of surgical treatment for a lumbar disk herniation is sufficient decompression and minimizing operation-induced trauma. A faster recovery is needed in modern society, allowing patients to have their normal activities sooner. By using microsurgical or microendoscopic techniques through small incisions, nerve root decompression is performed with minimal complication risk and preserves normal anatomy.

Many percutaneous spinal procedures, especially percutaneous endoscopic discectomy, have recently become commonly performed operations. However, there is currently available only a general anatomic description of the areas that are being operated upon. This zone, what is called the "triangular working zone," may be topographically described as the area within a right-angle triangle, of which the inferior border is formed by rim of the vertebral plate inferior to the target disk, the posterior border is formed by the lateral edge of the superior articular process or otherwise the traversing nerve root[43] of the next inferior vertebra, and the hypotenuse is provided by the medial border of the associated spinal nerve, as it exits from the foramen (see Fig. 6). Great care must especially be taken at the hypotenuse of this triangle during procedures, yet studies concerning the dimensions of this working zone are rare.[44]

Endoscopic lumbar discectomy (ED) is growing in popularity for treating disk herniation. ED has several theoretical advantages over conventional open surgery. Most current percutaneous endoscopic discectomy techniques are based on the Kambin's transforaminal approach and offer favorable outcomes for soft disk herniation. The most important point of successful endoscopic treatment is an accurate approach for the proper indication. Some propose that the "safe triangle" approach to transforaminal epidural injections is not safe and that transforaminal injections should be performed at the inferior aspect of the foramen, known as Kambin's triangle.[45] The available angle to reach around the superior boundary of the foramen is much larger than that around the inferior boundary of the foramen. Therefore, this allows endoscopic instruments a sufficient angle to pass through the foramen into the upper portion of the spinal canal and easily remove cephalad-migrated disk material. Whereas, the inferior border of the foramen limits reaching the spinal canal below the disk level in cases of a caudal-migrated disk herniation. Overmanipulation of spinal canal content and compression of the exiting root and ganglia by a horizontally positioned cannula may cause neural injury or postoperative pseudocausalgic pain in the index extremity. The surgical approach has evolved from the traditional posterolateral approach into a transforaminal approach. As a result, estimation of the dimensions of the working zone appropriate for the transforaminal approach is required. The obturator guiding technique is a modification of standard endoscopic lumbar discectomy, in which, obturator is used to access triangular working zone instead of a guide needle. It provides easier manipulation and decreases the steps of inserting instruments and takes safer route from the peritoneum.[46]

The working zone dimensions have clinical significance in the practice of endoscopic discectomy. According to Mirkovic et al., the average triangular safe zone was 18.9 mm wide and

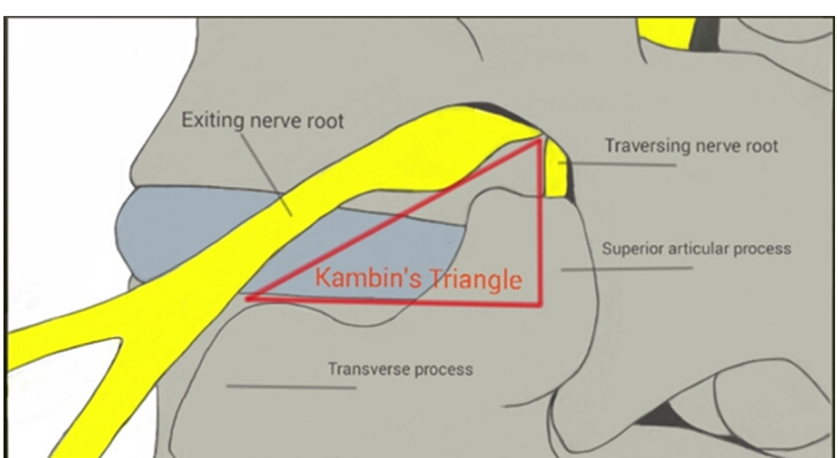

Fig. 6 – The Kambin's triangle. The area within a right-angle triangle of which the inferior border is formed by rim of the vertebral plate inferior to the target disk, the posterior border is formed by the traversing nerve root and the hypotenuse is provided by the medial border of the associated spinal nerve as it exits from the foramen.

12.3 mm high; the hypotenuse measured 23.0 mm. The maximum C1 diameter ranged 5.0–10.0 mm. The corresponding safe point of insertion lay along the medial one third of the pedicle. The maximum C2 diameter ranged 4.0–8.9 mm. The corresponding safe point of insertion lay in the midline of the pedicle.[47] Data suggest that radiological measurements including the spinal root axial and coronal angle and foraminal areas should be obtained before endoscopic discectomy surgery to provide for a safe procedure. Guan et al. indicated that magnetic resonance neurography was a feasible noninvasive tool to evaluate the anatomic dimensions in the Kambin's working zone. Before posterolateral endoscopic lumbar discectomy, radiologic measurements of this working zone were recommended to perform a safer procedure.[48] As regards to the accessing of the triangular working zone, this could be gained with angles of insertion ranging from 38° to 65°. At angles <35°, there was a significant risk of nerve injury. It is concluded that some thoracic discs can be safely removed through this approach, and that the lumbar ventral ramii are very vulnerable to injury because of their proximity to the annulotomy.[49]

8. Conclusion

The lumbar IVF continues to be a poorly defined and depicted region of the spinal canal. The anatomy of the lumbar IVF is complex; however, it is a significant entity among surgeons. The safe working zone seems to be the connection between anatomy and clinical significance of the foramen. Thus, it is crucial to understand the precise anatomy of this canal in order to accomplish successful outcomes in spine surgeries.

Conflicts of interest

The authors have none to declare.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:10.1016/j.jasi.2015.10.003.

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