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Abstract: Objective To explore the endoscopic anatomical structures of lumbar surgery. **Methods** A total of 290 patients who underwent lumbar endoscopic surgery due to lumbar intervertebral disc (IVD) herniation from September 2020 to September 2022 were retrospectively reviewed in our hospital, 179 patients had complete surgical video recordings, including 108 males and 71 females, aged from 19 to 65 years, with an average age of 41±16 years. The endoscopic structures through the intervertebral foramen and interlaminar space were independently identified by 3 doctors with more than 3 years of related surgery experience. When there were differences of opinions, the three doctors would discuss and come to a consensus. The probability, location, and neighboring structures of each specific structures were statistically analyzed. **Results** The anatomical structures observed through the lumbar foramen under endoscopy include muscles and ligaments attached to the superior articular process (SAP), main blood vessels inside the intervertebral foramen, blood vessels on the surface of IVD, and blood vessels on the surface of the dural sac and nerve root. The major anatomical structures observed through interlaminar space are multifidus, the conjugated ligament of ligament flavum and capsule ligament (capsule part of flavum ligaments), edges of the lamina, specific vessel bundle to facet with exit nerve root. **Conclusion** The anatomical structures under spinal endoscopy have certain characteristics, which are grossly different from those under open surgery. Familiarity with these anatomical structures has important clinical significance.

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Spinal endoscopy can enlarge the structures by 3-10 times, or even higher [1]. This is significantly different from the structures seen in traditional open surgery, where submillimeter-sized structures cannot be observed by the naked eye. Although microscopic surgery also has a magnifying effect, it is far less clear than in aqueous medium. Through spinal endoscopy, one can clearly see the accompanying blood vessels of the nerve roots, blood vessels on the anulus fibrosus, ligaments attached to the facet joints, and as far as we know, some of which have not been named anatomically. In open surgery, we often ignore some microscopic structures, seemingly without affecting the completion of the surgery. However, neglecting these structures under endoscopy may result in bleeding, affecting the surgical field of view, and causing injury to nerves and blood vessels. These submillimeter-sized blood vessels, nerves, and ligaments are also part of the local anatomic microenvironment. Protecting them as much as possible can reduce invasion to the local microenvironment, and help the nerves obtain enough nutrients and recover their function [2,3]. Studying these submillimeter-sized microstructures and their characteristics can help distinguish the operative anatomic location and anatomical structures in a timely manner, and have certain clinical significance.

1. Clinical Data and Methods

1.1. General Information

The study collected data from patients who underwent full spine endoscopic surgery at our hospital from September 2020 to September 2022, including their age, gender, chief complaint, diagnosis, surgical method, surgical approach, and surgical videos.

Inclusion criteria: patients aged between 18 and 80; underwent the first lumbar spine full endoscopic surgery; have no history of lumbar intervention or surgery.

Exclusion criteria: have a history of mental illness; have lumbar spondylolisthesis; have structural abnormalities such as congenital spine cleft or segmentation anomaly; have suspected spinal infections; have primary or secondary tumors in the spine; and have no high-definition video during surgery or do not cooperate with the research protocol.

1.2. Methods

According to the surgical approach, the enrolled patients were divided into two groups: interlaminar approach and transforaminal approach. The high-definition videos of operation were reviewed by 3 members of the research group independently. The names of the microscopic structures were approved if recognized consistently by the method, or the structure with different views were assigned to all study group members for discussion.

For these microscopic anatomical structures, the probability of occurrence, variation, origin position, function and other structural characteristics were further studied, so as to clarify their spatial position and clinical significance in spinal endoscopic surgery.

1.3. Statistics

SPSS 20.0 was used to calculate the probability of occurrence of the newly discovered specific structures and the probability of variation, and the value of $P \leq 0.05$ indicates that differences are statistically significant.

2. Results

A total of 290 patients who underwent lumbar endoscopic surgery were included in this study. After excluding 111 patients without complete surgical videos, a total of 179 patients who underwent lumbar endoscopic surgery with IVD herniation were finally included, with 108 males and 71 females, aged 19 to 65 years old, with a mean age of 41±16 years. There were no significant differences in general information between patients with the two approaches. The intervertebral foramen approach was the most commonly used approach for lumbar endoscopic surgery, followed by the interlaminar space approach, both of which are common approaches of minimal invasive spine surgery. In addition to some well-known anatomical structures, this study also found the distribution of some blood vessels on the IVD and annulus fibrosus, ligaments and blood vessels in the intervertebral foramen area, and the distribution of blood vessels on the dura mater and nerve roots (seen in Table 1).

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Table 1. The main structures and their functions observed under the foraminal endoscopic approach.

	Structural names	Origins	Insertions	Innervative nerve	Route	Functions	Probability of existence	Variation rate
Muscles attached to SAP	Multifidus muscle (MM)	Transverse process	Spinus process, lamina	Posterior rami	fan-shaped from the down - outside to the up-inside	Dorsal extension, lateral flexion, rotating vertebral body	100%	
	intertransversarii mediales lumborum	Accessory process, lateral side of transverse	Accessory process of upper level, transverse process of upper level	The dorsal ramus of spinal nerve	From inferior to superior	Lateral bending, keeping spine in balance	100%	
	intertransversarii lateral lumborum	Accessory process, lateral side of tranverse	Accessory process of upper level, transverse process of upper level	The dorsal ramus of spinal nerve	From inferior-lateral to superior-medial	Lateral bending, keeping spine in balance	100%	
Ligaments attached to SAP	capsule ligaments	SAP	Inferior articular process (IAP)	The medial branch of dorsal ramus of spinal nerve (same level and upper level)	Wrapped up	Keep facet joint in place	20%	
	Superior corporotransverse ligaments	Posterior lateral side of vertebral body	Transverse process of same level	The medial branch of dorsal ramus of spinal nerve (same level and upper level)	From inferior-lateral to superius-medial obliquely	Protects the blood vessels and nerves in the foramen	78%	30%
	inferior corporotransverse ligaments	Posterior lateral side of vertebral body	Transverse process of inferior level	The medial branch of dorsal ramus of spinal nerve (same level and upper level)	From superius-lateral to inferior - medial obliquely	Protect the blood vessels and nerves in the foramen	69%	

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	superior-transforaminal ligament	Posterior lateral side of vertebral body	Inferior pedicle notched	The medial branch of dorsal ramus of spinal nerve (same level and upper level)	From anterior to lateral posterior foramen	Protect the blood vessels and nerves in the foramen	84%
	mid-transforaminal ligament	Posterior lateral corner of annular fibrosis (AF)	Flavum ligament of posterior facet processes and facet capsule	The medial branch of dorsal ramus of spinal nerve (same level and upper level)	From anterior to lateral posterior foramen	Protect the blood vessels and nerves in the foramen	71%
	inferior-transforaminal ligament	Posterior inferior side of vertebral body	Pedicle notched area of vertebral body	The medial branch of dorsal ramus of spinal nerve (same level and upper level)	From anterior to lateral posterior foramen	Protect the blood vessels and nerves in the foramen	89%
Arteries in foramen (seen in the Figure 1)	anterior spinal canal branch (ascb.)	lumbar artery (la.)	running inferiorly into the foramen	Accompanying nerves of vascular sheath	From superius to inferior	Supplies the soft tissues in front of the foramen	98%
	Lumbar ascending branch (ab.)	LA gives a new branch, ab. after the ascb. and lateral branch.	Foramen to posterior MM.	Modulated by accommodated nerves from the dr.	Running superiorly	Supplies the tissues in the foramen and the same level MM.	100%
	Lumbar descending branch (desc.)	Continuted ending branch of LA	Ends at the MM. and facet joints	Branch of dr.	Running inferiorly	Supplies the tissues in the facets, IVD and the inferior level MM.	85%
	posterior spinal canal branch (pscb)	Originating from (lumbar artery, LA)	Ends at the intervertebral foramen	Modulated by accommodated nerves in vessel sheath	From superius to inferior	Supplies the tissues in the posterior foramen	99%

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	branches accompanying dorsal ramus of spinal nerve (dr.)	originating from mscb of LA	ending in base of transverse process and facet	Modulated by accommodated nerves in vessel sheath	running along the dr. irregularly	Supplies the dr, facet jonts received supplies from both medially and laterally	99%
	posterior branch related to the pars interarticularis of the lamina (ia.)	Continuing of LA	crossing the joining area of pedicle and transverse, running to the posterior spinous process and facet process	Modulated by accommodated nerves in vessel sheath		Supplies the spinous process, and paraspinal muscles	100%
veins in the foramen (seen in the Figure 1)	medial venous plexus of lumbar canal		joining lumbar ascending vein	descending branch of the medial branch of dorsal ramus of spinal nerve	From inferior to superior	Draining the veins in lumbar canal and foramen	97%
	Lumbar ascending vein	iliolumbar vein	left conjoining with left renal vein; right joining with inferior vena cava		From inferior to superior	Drain Vertebral body (VB) through central vein, lumbar segmental vein, and veins in foramen	100%
	Central vein	Central vein sinus	medial - anterior veinous plex of lumbar canal		from anterior to posterior	Drain VB	100%
veins on the surface of IVD (seen in	intervertebral vein (IVV)		Joining lumbar ascending vein		Underneath the pedicle, accompaied with	Drain the region of foramen, lumbar	100%

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the Figure 1)					exit nerve root, from inferior lateral to superius medial	canal and nerve root	
	lateral transverse branch	Communicated with IVV	Join the IVV		Lies in the lumbar canal anteriorly and posteriorly	Drain the lumbar canal	91%
	vein plex in the anterior of dura sac	drain the veins in the foramen and the veins lying in the anterior lumbar canal	joining segmental lumbar vein	sinuvertebral nerve (svn.)	longitudinal distribution in both ventral sides of dura sac from inferior to superior	Drain VB, foramen and annulus of IVD	100%
arteries on the surface of IVD (seen in the Figure 1)	anastomosis over the surface of the intervertebral IVD (ana.)	metaphysial anastomosis (man.)		svn.	distributed on the surfaces of AF.	supplies the lumbar IVD	95%
	metaphysial anastomosis	communicated with ana. and primary periosteal artery (ppa.)			distributed on endplate epiphysis	supplies the endplate epiphysis and cartilage	92%
	anterior spinal canal branch (ascb.)	Originated from segmental artery, communicated with adjacent segmental artery			distributed along the nerve root and foramen	supplies the nerve root and connective tissues in the foramen	89%
vessels on the dura and nerve root	generally, there are two main longitudinal veins and their communicated	joining the lateral transverse vein and lumbar ascending				drain connective tissues surrounding dura	100%

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venous plex, while the vessels on the ventral side is hard to observe	vein through aivvp.

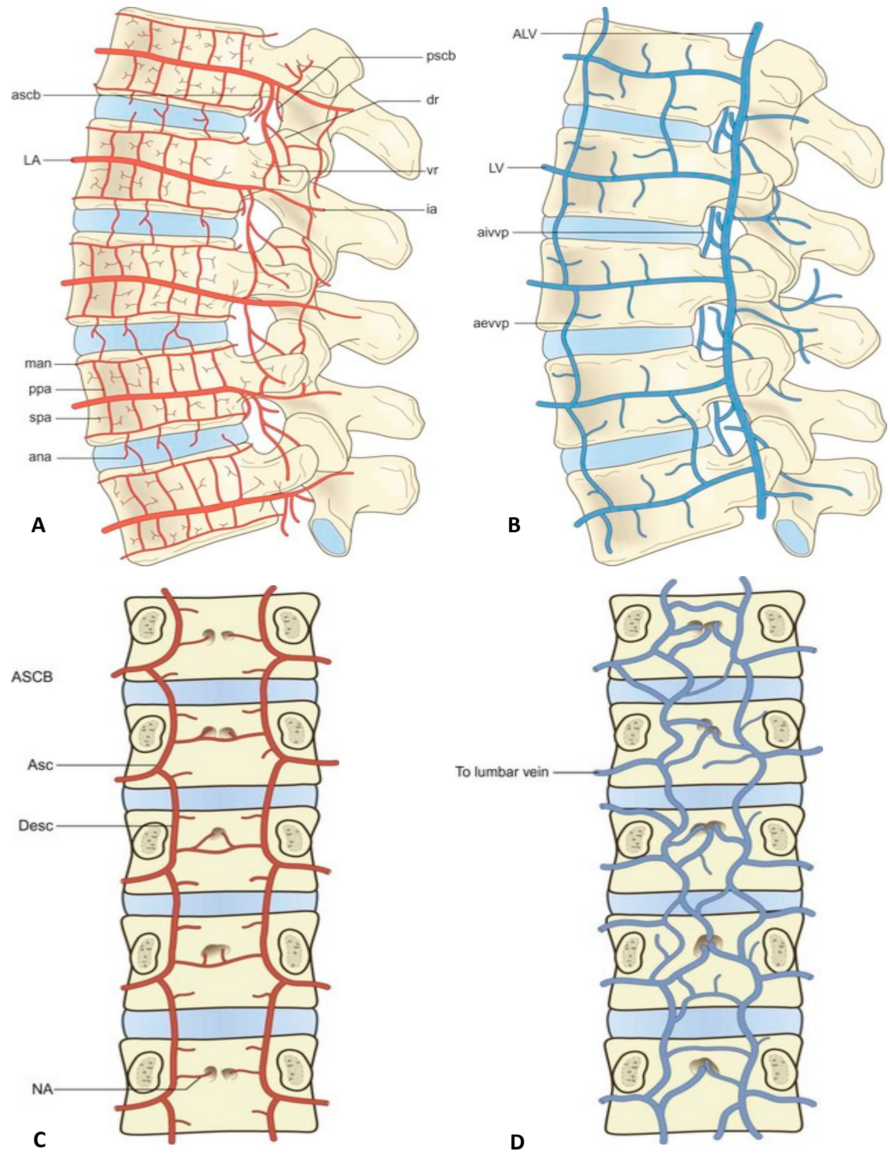

Figure 1. Diagram of lumbar vessel system. (A) Diagram of lumbar artery system from sagittal view. (B) Diagram of lumbar venous system from sagittal view. (C) Diagram of lumbar artery system on the ventral side of dura sac (posterior vertebral body). (D) Diagram of lumbar venous system on the ventral side of dura sac. The use of these images has been approved by the copyright owner (https://clinicalgate.com/blood-supply-of-the-lumbar-spine/#bib3).

ana, anastomosis over the surface of the lumbar IVD; ascb, anterior spinal canal branch; dr, branches accompanying dorsal ramus of spinal nerve; ia, posterior branch related to the pars interarticularis of the lamina; LA, lumbar artery; man, metaphysial anastomosis; ppa, primary periosteal artery; pscb, posterior spinal canal branch; spa, secondary periosteal artery; vr, branches accompanying ventral ramus of spinal nerve; NA, nutrient arteries; lumbar ascending branch (ab.); lumbar descending branch (desc.)

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aevvp, elements of the anterior external vertebral venous plexus; pevvp, posterior external vertebral venous plexus; aivvp, elements of the anterior internal vertebral venous plexus; ALV, ascending lumbar vein; LV, lumbar vein;

medial AIVV; pivvp, posterior internal vertebral venous plexus, basivertebral vein; IVV, intervertebral vein.

After removing part of the bone from the ventral side of the SAP, the ligamentum flavum in the ventral side of the articular process can be seen (Figure 2A,B), and there are cross-linked ligaments in the annulus fibrosus and the posterior longitudinal ligament of IVD, which assist in fixing the dura and nerve roots (Figure 2C). The nerve root ventral to the ligamentum flavum and the ventral IVD to the nerve root form a disc-nerve root-ligamentum flavum, sandwich structure (Figure 2D). The sandwich structure is a unique mirror image seen under the foraminal approach, especially after the removal of part of the ventral SAP, it is more clearly visible, and is an important anatomical symbol under the microscope. The dorsal is the yellow ligament, the ventral is the posterior longitudinal ligament or IVD, and the nerve root is in the middle. After the removal of the ventral bone of the SAP, the ligamentum flavum was exposed.

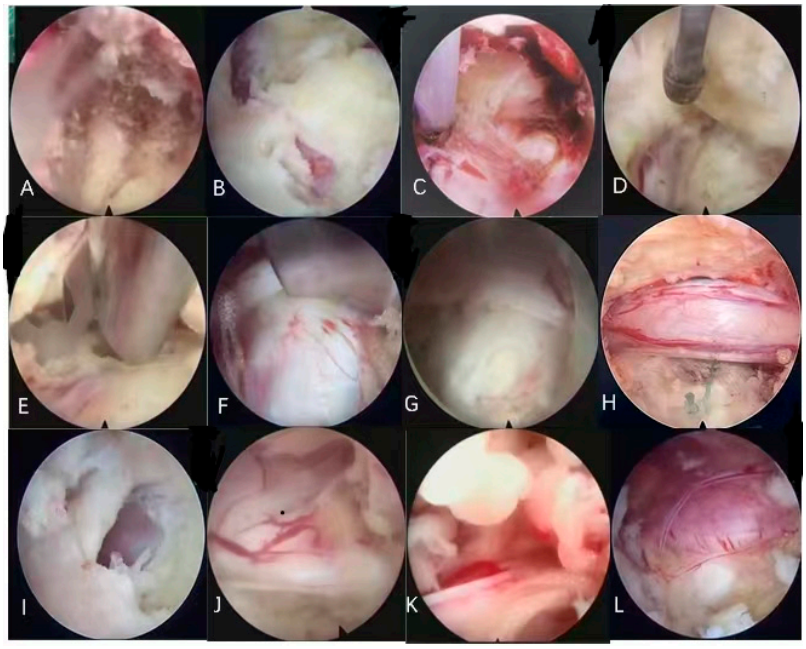

Figure 2. Some typical endoscopic structures of foraminal approach (A-H) and interlaminar approach (I-L). (A) the ligaments ventral to the apex of the SAP; (B) Endoscopic image of the ventral flavum ligamentum of the SAP; (C) The ligaments connecting the annulus fibrosus, dural membrane and nerve roots on the surface of the lumbar disc below the ventral ligaments of the SAP, and the soft tissues; (D) After the removal of the ventral part of the SAP, the flavum ligament and traversing root on the ventral can be seen, and the three constitute the "sandwich structure"; (E) Endoscopic view of the distribution of blood vessels on the surface of the disc on the ventral side of ligamentum flavum of the SAP; (F) The vascular distribution on the surface of the IVD below the ventral SAP and traversing root; (G) Disc herniation below the microscope, the annulus fibrosus is broken and the traversing root is compressed. (I) The "penetration of the ligament flavum" is the key procedure of the interlaminar space approach, and the epidural space can be seen after the flavum ligament is removed; (J) the location of the nerve root, and the distribution of its blood vessels; (K) epidural fat and the central folds on the dorsal dural membrane; (L) Protruding nucleus pulposus and the tensioned dura on the dorsolateral, and blood vessels surrounding the dural can be seen in the interlaminar approach.

2.1. Ligaments Attached to the SAP

The SAP is one of the most important anatomical symbols through the foraminal approach, and many ligaments attach to it, as well as MM. There are generally three muscular ligaments attached to the SAP, namely the MM, the medial intertransverse muscle and the lateral intertransverse muscle, which connect the articular process with the spinous process and the transverse process. In addition, there are also ligaments in the transverse process and the posterior vertebral body, namely, superior corporotransverse ligaments, inferior corporotransverse ligaments, superior-transforaminal ligament, mid-transforaminal ligament and inferior-transforaminal ligament (Table 1).

2.2. IVD and AF Under Endoscopy

In patients with degenerated IVD, the annulus fibrosus is usually porcelain white (Figure 2E, 2F), accompanied by inflammatory hyperplasia, and bulge. If the outer annulus fibrosus is perforated, there will often be serious local inflammatory tissue encapsulation, and protruding nucleus pulposus and annulus fibrosus can often be found after removing the inflammatory tissue (Figure 2G). A network of blood vessels can be seen on the surface of the microscopic ring (Figure 2F), which are usually distributed transversely and have branches that are often cross-linked with each other. The annulus fibrosus of the IVD is directly connected to the posterior longitudinal ligament, which cross-link to the ligamentum flavum (Figure 2C). The annulus fibrosus and the posterior longitudinal ligament are cross-linked ligaments, which are important anatomical markers, located between the ventral dural and the IVD, starting from the IVD, oblique, about 5-10mm in diameter, and their main function is to fix the dural and nerve roots. Sometimes, in order to show the ventral dural, this ligament has to be cut (Figure 2C).

2.3. Vascular System on the Dura and Nerve Root

After removal of the ventral bone of the SAP by a lateral-posterior approach, the walking root, dural sac, and ventral disc were visible (Figure 2D). The epidural fat on the traversing roots was stripped away to expose the nerve root. It can be seen that there are mainly 2 vascular bundles on the dorsal side of the walking roots, which are distributed longitudinally paralleling to the nerve roots, and there are vascular network connections between them (Figures 1 and 2H).

The key anatomic marker in the interlaminal approach is the ligamentum flavum, and the removal of part of the ligamentum flavum is a landmark step in the surgical process (Figure 2I). After breaking through the ligamentum flavum, epidural fat and dural membrane can be seen, and the surface of the dural membrane is covered by a loose layer of disintegrated tissue (Figure 2K), which is composed of epidural fat and vascular network. This membrane may be the last protective barrier of the dural membrane and should be retained unless necessary. The dorsal central fold of the dural membrane can also be found in the approach of interlaminar space (Figure 2K). The nerve root sleeve and its vessel distribution (Figure 2J) can also be clearly found. It can be seen that these blood vessels are mainly distributed longitudinally along the dural membrane and nerve roots, and there are slightly smaller communicated blood vessels distributed among them. These blood vessels are the main blood supply to the dural membrane, arachnoid membrane and the superficial part of the nerve roots, and the protection of these blood vessel networks is very important in procedures. The central bulging disc can be seen after significantly pushing of the dura and nerve root, besides that, the vascular network distributed on the dura, and the protruding nucleus pulposus can be seen in the interlaminar approach (Figures 1 and 2L).

3. Discussions

Familiarity with the above anatomical structures is the basis for carrying out surgery. From this, it can be discovered which points are most prone to bleeding, such as the nutrient blood vessels of muscles at the dorsal articular processes, the accompanying blood vessels of the dorsal ramus, the venous plexus on the ventral side of the lumbar canal, the accompanying blood vessels of the exit nerve roots, the cephalad side of the vertebral pedicles, and the base of the articular processes.

Hemorrhage caused by injury to the venous plexus on the ventral side of the dura sac or accompanying blood vessels of the exit nerve roots can be particularly profuse and difficult to stop, often requiring the use of gelatin sponge packing for compression hemostasis. After becoming familiar with these anatomical structures, it is possible to timely identify them during surgery and avoid damage to blood vessels and nerves.

During the procedure, the author noted some specific structures under the endoscope, such as the small ligaments (not the flavum ligament) running obliquely from the ventral and apex of the SAP to the exit root above, the ventral annulus fibrosus, and the transverse process at the caudal end. These ligaments on the SAP are important fixation structures for the contents of the intervertebral foramen. They can fix the exit nerve roots and accompanying blood vessels from different directions, combined with fatty tissues, thus reliably fixing the exit nerve roots and accompanying structures in the intervertebral foramen. The space between the ligaments contains a lot fatty tissue, which acts as a good cushion and protection for the nerve roots. There is also a flat vein (distributed longitudinally) perpendicular to the IVD, located on the outer side of the traversing roots, along the edge of the intervertebral foramen, and the position is relatively constant. Sometimes, it is necessary to coagulate it when dealing with the bulging IVD. In addition, accompanying blood vessels of the nerve roots and the dura mater, as well the protective fat tissues, they both have a protective, cushioning, and lubricating effect on the nerve roots and dura mater. These structures can be clearly displayed under the endoscope. Excessive damage to them can cause problems such as dural degeneration, scar proliferation, adhesion, etc., which may probably affect postoperative recovery. Many of these structures have a submillimeter size. The magnifying effect of the endoscope allows us to clearly distinguish and protect them.

It should be emphasized that the presence of ligaments in all intervertebral foramina is not always guaranteed, but if present, the probability of all ligaments being present in all intervertebral foramina is approximately 47% [5]. The most common is the superior corporotransverse ligaments (27%), and the inferior corporotransverse ligaments connect two independent bones. Many studies believe that the anatomical position of the ligaments occupies the space of the intervertebral foramen, which is the main cause of nerve root compression and radiating pain. These ligaments can reduce the cross-sectional area of the intervertebral foramen by 30% [6,7]. However, there are also different opinions. Kuofi mapped the spatial position of the ligaments [8] and believed that these ligaments are continuously present in the intervertebral foramen, and their presence not only does not cause nerve compression or radiating pain, but also has a protective effect on the blood vessels and nerves in the intervertebral foramen [5,9]. This study found that the probability of the presence of ligaments (inferior corporotransverse ligaments) was highest in the lower intervertebral foramen (89%), followed by the superior corporotransverse ligaments (84%) and the middle corporotransverse ligaments (71%). These ligaments should be preserved as much as possible and generally do not affect microscopic operations. It should be stressed that the anatomical structures discovered in this study have some anatomical differences in occurrence rates, positions, sizes, and branching situations. However, these anatomical differences have a relatively low incidence and do not affect the clinical reference value of this study.

4. Conclusion

This study successfully explored the occurrence of specific structures under lumbar endoscopy to guide precise intraoperative operations. Secondly, after the structure is confirmed, it is necessary to transition from structural research to functional research, and there is still a lot of work to be done. Thirdly, understanding these endoscopic structures and their functions will promote further development of minimally invasive spine technology.

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