The spinal nerve root complex is not static when the spine and extremities move: the spinal nerves and nerve roots adapt to the changes in spinal position by stretching and slackening, possibly also with some sliding within the intervertebral foramina.12 The intervertebral foramina form a series of canalized tunnels through which the spinal nerve roots emerge from the radicular canal. The radicular canal contains the nerve root, sinuvertebral nerves, sympathetic fibers, intervertebral arteries and veins, small lymphatic vessels, fatty areolar tissue, and foraminal ligaments. Regular physical activities that produce flexion, extension, lateral bending, or axial rotation in the spine without any pain or symptoms affect the anatomical relationship of the nerve root and adjacent connective tissue. These structures of the intervertebral foramen reduce the space available for the nerve root and have been implicated in nerve root compression and impingement causing pain.

The purpose of this study was to investigate the intraforaminal ligaments and their relationship to nerve root movement and the surrounding structures.

### Methods

Foraminal anatomy was studied in 11 previously prepared, whole cadavers (5 females, 6 males) whose ages at the time of death ranged from 16 to 71 years. The cadavers had been prepared with formaldehyde, whose ages at the time of death ranged from 16 to 71 years. The thoracic and lumbar spinal columns were separated from the cervical and sacral segments en bloc using an electric band saw. The paraspinal muscles and their attachments were removed by sharp and meticulous dissection, and the thoracic and lumbar intervertebral foramina were examined under a surgical microscope. The intervertebral foraminal ligaments and nerve roots were exposed. The foraminal contents were identified and studied in detail. The intraforaminal ligaments were stained using H & E to determine ligamentous fiber.

The foraminal contents were identified and studied in detail. The various foraminal ligaments were outlined and identified at all thoracic and lumbar levels. Intraforaminal ligaments were stained with H & E to make them more visible.

### Results

Intraforaminal ligaments connect the periosteum and transforaminal ligaments to the nerve root sleeves and vessels within the fatty areolar tissue. Histologically, the ligamentous attachment of the nerve roots within the foramina consists of adipose and connective tissue.

### Conclusions

Intraforaminal ligaments connect the periosteum and transforaminal ligaments to the nerve root sleeves and vessels within the fatty areolar tissue. Histologically, the ligamentous attachment of the nerve roots within the foramina consists of adipose and connective tissue. The nerve roots are surrounded by intraforaminal ligaments, which may act in conjunction with the dura and periosteum to protect the nerve roots mechanically. (DOI: 10.3171/2010.3.SPINE09799)

### Key Words

- intervertebral foramina
- ligaments
- nerve root
- spine
Results

Anatomical Considerations

Bone. The generalized radicular canal is bounded rostrally by the inferior vertebral notch of the pedicle of the superior vertebra. The floor is the superior vertebral notch of the pedicle of the inferior vertebra. The anterior border is formed by the posterior aspect of the adjacent vertebral bodies, intervertebral disc, and the lateral expansion of the posterior longitudinal ligament. Posteriorly lie the superior articular process of the inferior vertebra and inferior articular process of the superior vertebra (Fig. 1 left), covered by the articular capsule into which blends the lateral prolongation of the ligamentum flavum. The intervertebral foramen’s length and direction varied with adjacent pedicle and level of the spine.

Transforaminal Ligaments. The detailed anatomy of the transforaminal ligaments in the thoracic and lumbar regions has been described systematically. In most cases the transforaminal ligaments grossly diminished the space available for the emerging nerve root. These ligaments were easily distinguished from the fibrous covering. The width and thickness of these strong and unyielding ligaments ranged from 2 to 5 mm. Five types of transforaminal ligaments were noted and were anatomically designated as follows (Fig. 1 right): 1) The superior corporopedicular ligament runs from the superior pedicle and vertebral notch obliquely, anteriorly, and inferiorly to the posterolateral aspect of the vertebral body and adjacent anulus fibrosus. 2) The inferior corporopedicular ligament runs from the inferior pedicle and vertebral notch obliquely, superiorly and anteriorly to the posterolateral aspect of the vertebral body and adjacent anulus. 3) The superior transforaminal ligament runs from the articular capsule and posterior vertebral notch obliquely, superi- orly to the superior pedicle. 4) The midtransforaminal ligament extends from the articular capsule across the midforamen to the anulus and superior corporopedicular and inferior corporopedicular ligaments. 5) The inferior transforaminal ligament extends from the superior facet joint across the superior vertebral notch to the junction of the anulus and vertebral body.

Intraforaminal Ligaments. Besides the aforementioned ligaments, this study focused on intraforaminal ligaments within the neural foramen that connect the periosteum and transforaminal ligaments to the nerve root sleeves and vessels within the fatty areolar tissue. These intraforaminal ligaments extend around the transforaminal ligaments, periosteum, and vessels to the nerve root (Fig. 2). These ligaments were visible throughout the length of the foramina in each level of each cadaver’s spine. There was no noticeable decay or reduction in number of these ligaments in the older cadavers.

Histologically, the ligamentous attachment of the nerve roots within the foramen consists of adipose and connective tissue. There are small capillaries within the fibrous connective tissue (Fig. 3).

Nerve Root. The radicular nerve separated from the dura mater was composed of ventral and dorsal roots, and these occupied 35% of the foramen’s diameter. The dorsal and ventral root approach each other inside the dural sheath in the intervertebral foramen. At each segment the motor and sensory roots pass dorsolaterally to the intervertebral disc. The dorsal roots have larger diameters than the ventral roots. The nerve roots lack a perineurium and have poorly developed epineural connective tissue; therefore, they may be more susceptible to compression. Peripheral nerves have well-developed epineural connective tissue as they pass close to bones and joints, where the nerves are subjected to mechanical forces such as compression and tension.
Spinal intraforaminal ligaments

Discussion

This is the first study to specifically focus on the small intraforaminal ligaments within intervertebral foramina. Much more attention has been paid to the nerve roots and transforaminal ligaments.

Golub and Silverman reported on transforaminal ligaments in 1969. In a cross-sectional study of the lumbar spine, Rausching described the foraminal ligaments. Studies by Novicki et al. and Akdemir et al. on intervertebral transforaminal ligaments identified the most common ligaments of this type. These ligaments can be easily distinguished from the fibrous tissue and the space available for the emerging root. Transforaminal ligaments located in the foramen limit nerve root excursion and protect the nerve root by distributing tensile forces to the bony portion of the foramen through these ligamentous attachments.

Intraforaminal structures around the spinal nerve root were recognized by Hofmann, who observed that within the neural foramen the nerve root dural sleeves were linked to the periosteum by firm strands of fibers. Testut and Laterjet have described a filamentous fiber that connected the periosteum surrounding the intervertebral foramen to the nerve root dural sleeve. Some authors have described an envelope around the nerve root within the foramen that is formed by periosteal or membranous structures. These authors have given these structures different names, such as peridural or epidural, circumneural sheath, or membrane.

Grimes et al. described the anatomical relationships and biomechanical properties of the attachment of the nerve root dural sheath to the surrounding structures within the intervertebral foramina. They found 4 ligamentous fibers from the surrounding intervertebral structures to the nerve root. They described them as “intraforaminal,” but they are actually the ligaments that other studies call “transforaminal.” The histological structures are distinct from the structures of the intraforaminal ligaments examined here. The most prominent attachments were the facet capsule, pedicles, and intervertebral discs.

Positional changes and physical activity that produce flexion, extension, lateral bending, or axial rotation in the spine affect the anatomical relationship of the nerve root and adjacent connective tissue.

Nerve fibers react to trauma with demyelination or axonal degeneration, which leads to changes in nerve function. The impairment of intraneural microcirculation and formation of intraneural edema are also important factors underlying functional deterioration.

The nerve roots, however, are surrounded by CSF, which may act in conjunction with the dura and arachnoid membranes to protect the nerve roots mechanically.

These ligaments radially surround the roots (Fig. 2). The foramen attaches to the root sheath. On histological examination, the collagen is located in the fatty tissue. The ligaments, which are not very taut, surround the root and are loosely attached to it. Their length and width are measured in fractions of millimeters. Together with the fatty tissues, they provide support inside the root foramen and prevent it from touching the surrounding tissues. In this way, friction during the root’s flexion, extension, and lateral bending movements is eliminated. Additionally, these ligaments surrounding the dura make electrophysiological transmission, CSF flow, and blood circulation easier.

As can be seen in the illustration of the root in a state of rest (Fig. 4 left), ligaments formed for the intervertebral foramen, the periosteum, and other similar structures cause the foramen to be shaped like a tunnel. The root, fatty tissues, intraforaminal vessels, and the abundant intraforaminal ligaments, which surround the root, are located within the structure of this tunnel. When the straight-leg raise test is performed, the intraforaminal root and the nearby ligaments extend from the inside to the outside at the foramina (Fig. 4 right).

While the root is being stretched in the straight-leg raise test, it is believed that the most significant factors providing resistance are the tensile strength of nerve root-
The structures within the root do not only consist of ligaments. There are also vascular structures, which also affect the movement of the root. It is known that dilated venous structures can sometimes cause pain.

In cases of disc surgery for herniation of disc material or conditions such as spondylolisthesis, the foramina can become degraded. Degenerative processes such as spinal stenosis or postoperative scar tissue cause constriction in the foramina and affect the intraforaminal ligaments. These kinds of pathological developments interfere with the intraforaminal ligaments and fatty tissues and obstruct the root’s mechanical movement or increase friction within the root foramen, causing pain. Any kind of foraminotomy affects the ligamentous structures and is believed to be responsible for postoperative pain.

Normal intraforaminal ligament regeneration provided by fatty tissues aids recovery following degenerative wounds or spinal surgery. However, sometimes regeneration continues after healing is completed. Excessive regeneration results in postoperative granulation.

The radicular canal operates as a cohesive unit. This unit is made up of pedicles, vertebral bodies, the intervertebral disc, articular processes, the ligamentum flavum, transforaminal ligaments, the nerve root, sinuvertebral nerves, intervertebral arteries and veins, fatty areolar tissue and intraforaminal ligaments. All these structures work in conjunction to allow the root to move unrestricted without pain. The intraforaminal ligaments are as important to this operation as the other structures. They should be kept in mind with regard to spinal lesions and in the approach to surgery.

Conclusions

The information gathered during this study suggests that the pain and neurological deficits patients experience following surgery or degenerative diseases can be caused by damage to these intraforaminal ligaments. Surgeons should bear in mind that there are fragile ligaments around the nerve root besides the better-known transforaminal ligaments. Damage to the intraforaminal ligaments could cause friction during root movements in situations such as stenosis, and the presence of too many transforaminal ligaments causes problems for the patient. The removal of intraforaminal ligaments, on the other hand, causes an increase in friction during root movements.

Disclosure

The author reports no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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**Fig. 4.** Left: Schematic drawing of the nerve root supported by intraforaminal ligaments centrally located in the foramen while the leg is at rest. Right: Schematic drawing demonstrating the distal displacement of the nerve root and intraforaminal ligaments during straight-leg raise test.
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