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Radiographic anatomy of the intervertebral cervical and lumbar foramina (vessels and variants)

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Abstract The intervertebral foramen is an orifice located between any two adjacent vertebrae that allows communication between the spinal (or vertebral) canal and the extraspinal region. Although the intervertebral foramina serve as the path traveled by spinal nerve roots, vascular structures, including some that play a role in vascularization of the spinal cord, take the same path. Knowledge of this vascularization and of the origin of the arteries feeding it is essential to all radiologists performing interventional procedures. The objective of this review is to survey the anatomy of the intervertebral foramina in the cervical and lumbar spines and of spinal cord vascularization.

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The intervertebral foramen is an orifice located between any two adjacent vertebrae that allows communication between the spinal (or vertebral) canal and the extraspinal region. Although the intervertebral foramina serve as the path traveled by spinal nerve roots, vascular structures, including some that play a role in vascularization of the spinal cord, take the same path. Knowledge of this vascularization and of the source of the arteries feeding the spinal cord is therefore essential to all radiologists performing interventional procedures in view of the iatrogenic risks they present. We will first review the anatomy of spinal cord vascularization, and then the topographic anatomy of the cervical and lumbar intervertebral foramina, as these are the most frequent sites of injections performed by radiologists.

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Review of the anatomy of spinal cord vascularization

Origin of the radiculomedullary arteries

While the encephalon receives blood from large arterial trunks arising from the aortic arch (internal carotid and vertebral arteries), vascularization of the spinal cord comes from arteries of multiple and varied origins that enter it all along the spinal canal [1], going through the intervertebral foramina.

At early stages of embryo development, each nerve root carries a radicular artery divided into an anterior and a posterior radicular artery that will help vascularize the spinal cord. This vascularization is then segmented, to correspond to the metameric structure of the cord during development. Some arteries regress while others grow larger. There is no fixed number of radicular arteries. Although the number theoretically should be 31 on each side, in reality the number is always lower.

In the cervical region the radicular arteries are furnished essentially by branches of the subclavian arteries and more particularly by the vertebral arteries.

In the thoracic and lumbar regions, they arise from the parietal, thoracic and lumbar collaterals of the aorta, which in turn divide into end arteries. The anterior end arteries include the intercostal or lumbar arteries and the posterior end arteries the dorsal spinal arteries. The dorsal spinal arteries themselves divide into a large artery headed toward the posterior vertebral muscle mass and a thinner radicular artery that reaches the intervertebral foramina in the company of the corresponding spinal nerve [1].

The radicular artery divides into an anterior and a posterior radicular artery. As a general rule, the radicular arteries course along the anterior side of the corresponding roots (Figs. 1 and 2). Nonetheless we want to stress that 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 (Fig. 3). The caliber of the radicular arteries ranges from 0.2 mm to 2 mm. The caliber of the anterior radicular artery is generally larger than that of its posterior counterpart.

The radicular arteries are not all of the same importance, as Adamkiewicz reported in 1882 [1]. The number of radiculomedullary arteries actually participating in the vascularization of the spinal cord can vary from one person to another. Accordingly different authors have estimated their numbers differently: 3 to 10 for Adamkiewicz, 5 to 10 for Kaydi, and 6 to 8 for Lazothes [1]. In summary, it seems that only one artery out of 8 to 10 actually reaches the spinal cord.

Accordingly, we distinguish:

- the radicular arteries that are very small and become lost along the roots before reaching the spinal cord.
- the radiculopial arteries, which reach the pial plexus. These arteries are part of the coronary plexus of the spinal cord, from which the arteries intended to vascularize the white matter of the anterolateral funiculi detach;
- the radiculomedullary arteries, which feed the pial plexus and irrigate the spinal cord. They are found mainly in the...

Figure 1. Sagittal slice through a lumbar intervertebral foramen, showing anterior (arrow) and posterior (arrowhead) radicular arteries circulating on the anterior side of the anterior (AR) and posterior (PR) roots. Also note the artery in the lower part of the intervertebral foramen (wavy arrow). The foraminal veins (curved arrows) are located on the upper part of the foramen in front and back of the nerve roots, as well as in the lower part of the foramen. VB: vertebral body; ID: intervertebral disc.

Figure 2. Medial view of a sagittal slice of the lumbar column showing anterior (arrow) and posterior (arrowhead) radicular arteries circulating on the anterior sides of the anterior (AR) and posterior (PR) roots. VB: vertebral body; ID: intervertebral disc.
The radiculomedullary arteries furnish the spinal cord with the bulk of its arterial irrigation. They feed the gray matter and the deep part of the white matter.

Arterial vascularization of the spinal cord

Cord vascularization is schematically ensured by three vertical systems anastomosed by a horizontal perimedullary plexus and fed by the radiculomedullary arteries described above [1,2]. Accordingly, we distinguish an anterior spinal axis and two posterolateral spinal axes traveling respectively in the ventral median fissure and the posterolateral sulci of the cord (Fig. 5). The anterior spinal axis, made up of the anterior branches of the radiculomedullary arteries, is of considerable functional importance because by its penetrating branches it feeds the anterior two thirds of the spinal cord. The posterior spinal arteries, made up of the posterior branches of the radiculomedullary arteries, provide blood to the posterior last third of the cord, via its penetrating branches.

The anterior spinal artery is not always a continuous anastomotic pathway. It can be divided into three functional parts: cervicothoracic, mid-thoracic and thoracolumbar [2]. The upper or cervicothoracic region comprises the cervical cord and the first two or three thoracic segments (Figs. 6 and 7). The rich vascularization of this segment comes from several distinct sources that nonetheless all originate from the subclavian artery: vertebral arteries, deep and ascending cervical arteries, and finally the cervico-intercostal trunk. Within this region, we distinguish:

- the upper cervical spinal cord, fed most often by two anterior spinal arteries from the intracranial portion of the vertebral arteries. The anastomosis of these arteries rarely descends below the fourth cervical segment;
- the mid-cervical spinal cord, fed by two to three anterior radiculomedullary arteries from the vertebral arteries;
- the lower cervical and upper thoracic spinal cord, vascularized by an anterior radiculomedullary artery from the right or left cervico-intercostal trunk, accompanying roots C7, C8 or T1. It is often the principal vascular source of cervical enlargement.

Figure 3. Sagittal slice through a lumbar intervertebral foramen. Note that within this foramen we identify one artery (arrow) in front at a distance from the anterior root (AR) and another behind the posterior root (arrowhead). VB: vertebral body; ID: intervertebral disc; SAP: superior articular process of the vertebra below; PI: inferior articular process of the vertebra above; Rn: nerve root; curved arrows: foraminal veins.

Figure 4. Anterior view of a dissected spinal cord, showing the artery of Adamkiewicz (arrow) and its characteristic inflection to join the anterior arterial axis (arrowhead).

Figure 5. Macroscopic horizontal slice of the cervical cord, showing the anterior arterial axis (arrow) and the dorsolateral axes (arrowhead).
Radiographic anatomy of the intervertebral cervical and lumbar foramina

The mid-thoracic spine, from the 3rd to the 9th thoracic segment, is usually fed by a single thin anterior radiculomedullary artery (internal diameter: 0.2–0.4 mm) [3]. It normally arises from the posterior dorsal spinal branch of the 4th or 5th intercostal, artery, more often on the left (80% of cases) than the right.

The lower—thoracolumbar—area is little vascularized, unlike the areas above and below it. This area is usually fed by the radiculomedullary artery of the lumbosacral enlargement (artery of Adamkiewicz), with an internal diameter ranging from 0.5 to 0.8 mm [3] (Fig. 4). Depending on the series, this artery originates on the left side in 85% of cases and between Th9 and L2 in 85%, according to Lasjaunias and Berenstein [4]; on the left side in 67.7% and between Th12 and L3 in 83.9%, according to Biglioli et al. [5].

Venous vertebral system

Venous drainage of the spinal cord

The system of venous vascularization of the spinal cord is basically modeled on that of arterial vascularization. From the capillary network, blood is drained by vessels

Figure 6. Anterior view of a dissected spinal cord showing the contribution of radiculomedullary arteries (arrows) from the intervertebral C4–C5, C5–C6, C6–C7 and C7–T1 left and C2–C3 and C4–C5 right foramina, on the anterior spinal axis (arrowheads).

Figure 7. Medial view of a sagittal slice of the cervical column showing a radiculomedullary artery from a C3–C4 intervertebral foramen.

Figure 8. Schematic diagram of the vertebral venous system: a: in the axial plane; b: in the frontal plane, in a posterior view. IVC: inferior vena cava; ALV: ascending lumbar vein; BVV: basivertebral vein; RTVP: retrocorporeal transverse venous plexus; FV: foraminal vein; LV: lumbar vein; PEVP: posterior epidural venous plexus; AEVP: anterior epidural venous plexus.
in a radial arrangement that flows into the perimedullary veins [1].

We also find longitudinal pathways at these veins: two unpaired and median, situated in the anterior and posterior sulci (anterior and posterior spinal veins) and two other smaller lateral pairs on each side, traveling the entire path along which the spinal roots emerge. From these longitudinal veins venous blood drains into the anterior and posterior radicular veins and then into the epidural venous plexuses. The epidural venous plexuses communicate with the extravertebral system through the foraminal veins.

The epidural veins

The large veins comprising the epidural venous plexuses travel through the epidural space. The spinal venous system is extremely important physiologically [6–8]. It is an avalvular venous system that serves, together with the superior and inferior venae cavae, as the body’s
posterior drainage network. This venous system, because of its numerous anastomoses with the caval venous system, can function as a backup network in the case of caval compression or obstruction. The anatomy of the venous plexuses can be described at the vertebral segment level because the anastomoses of the different superimposed venous segments form a continuous chain that makes up the longitudinal venous network of the spine. The epidural venous plexuses are constituted by the anterior and posterior longitudinal plexuses (Figs. 8 and 9). The anterior longitudinal plexuses are the most developed and can be best analyzed in axial and coronal slices. They appear to comprise on each side two longitudinal venous networks, one lateral and the other medial. The anterior epidural venous plexuses are located within connective adipose areolar tissue between the posterior longitudinal ligament and the posterior side of the vertebral body (Fig. 9). The two right and left longitudinal plexuses come closer to one another at the pedicle and move further apart at the intervertebral disc. A study in the axial plane shows that the internal vertebral plexuses are linked by transverse plexuses passing in front of and behind the dural sheath, forming an epidural venous ring that is more developed in its anterior segment (Fig. 9). The largest transverse plexuses are behind the middle part of the vertebral body, where they receive the anastomosis of the basivertebral veins (posterior drainage vein of the vertebral bodies). The epidural venous plexuses communicate through the foraminal veins and, depending on the segment considered, with the vertebral, intercostal, lumbar or sacral veins (Figs. 1, 3, 9–11, 13). Any radiologist practicing vertebroplasty procedures must therefore know the anatomy of this spinal venous system, given the possibility that cement will leak into the epidural space during the filling of the vertebral body [8].

**Topographic anatomy of the intervertebral foramina in the cervical and lumbar regions**

**The cervical intervertebral foramen**

The container

In the cervical spine, the intervertebral foramen must be studied with the two anatomic regions adjacent to it (medially and laterally), because the anatomical continuum makes any division impossible (Figs. 12 and 13). That is, the nerve root must cross three successive areas to go from the intradural to the extravertebral region [9]. We therefore describe:

- a medial area equivalent to the lateral lumbar recess where the roots have a relatively large amount of space, just within the medial orifice of the intervertebral foramen; the yellow ligament forms its posterior wall;
- a narrow intermediate area between the uncus in front and the posterior facet (zygapophyseal) joint behind, with the pedicle below, constitutes the intervertebral foramen, strictly speaking. The uncus truly serves as a protective wall for the vertebral artery and the spinal ganglion, vis-à-vis the intervertebral disc [10];
- a lateral area, which is no longer involved with the nerve roots but with the spinal nerve, which rests in the furrow of the transverse process. The bottom of this transverse furrow is perforated by the vertebral foramen, providing passage to the vertebral artery, and thus constituting an essential relation to the cervical nerve (in particular during injections). On a transverse slice, we can clearly see at the transverse furrow an ovoid space that shelters the vertebral artery in front of it and the spinal ganglion behind it.
These three areas are aligned according to an axis oriented at 45° forward compared with the sagittal plane, the whole constituting a canal 20 mm in length [10]. Because of this oblique angle, the bony borders of the cervical intervertebral foramen are visible only on three-quarter images.

The contents
The cervical nerves result from the confluence of an anterior and a posterior root (Figs. 12 and 13). The anterior motor root is thin, made up of four to seven rootlets from the anterior collateral sulcus of the spinal cord. The posterior sensory root, which is composed of three times larger than the anterior root, is made up of four to 10 rootlets that penetrate the posterior collateral sulcus [11]. The anterior root thus constitutes closer connections with the vertebral uncus in front of it and with the pedicle of the vertebra beneath it. The usual position of the posterior root is behind and above the anterior root [12, 13]. Its connections are with the superior articular process of the vertebra below it. Each posterior root carries a spindle-shaped swelling containing the cell bodies of sensory neurons: the spinal ganglion. The spinal ganglion is thus positioned between the vertebral artery in front of it and the posterior facet joint behind it. On a parasagittal slice with the posterior aspect of the vertebral body in the front, at the level of the uncus, the pedicle of the overlying vertebra above, and the pedicle of the vertebral body below, we find the anterior and posterior root, either at the same level as or below the disc plane. The very abundant epidural veins in the cervical region communicate with the venous plexuses located around the vertebral artery, thus serving as shock absorber in crossing the intervertebral foramen. At the cervical level, the nerve components attach more to the venous components than to the epidural fat, as at the lumbar level. A herniated cervical often tends to manifest laterally just behind the junction between the uncus and the vertebral body, causing not only venous stasis that engenders edema but also direct compression of the root and the ganglion, causing the pain and muscle disorders encountered during cervicobrachial neuralgia. The nerve roots within the intervertebral foramen become closely connected to the radicular artery and the branches of its division, as we described above, with as a general rule one anterior branch traveling along the anterior aspect of the anterior root and a posterior branch along the anterior aspect of the posterior root.

The lumbar intervertebral foramen

The container
This orifice has two parts: one anterosuperior, in the form of a rigid immobile ring, made up of the inferior part of the pedicle and the posteroinferior part of the vertebral body; 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 disc in front (Figs. 1, 3, 9) [13]. This second articular part is the one that undergoes motion-related or degenerative changes. At the lumbar level, 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. We must underline the importance of the changes in the dimensions of the intervertebral foramen on movement [14, 15]. In extreme flexion, all the diameters of the intervertebral foramen are at their maximum; the pedicles move apart from each other, disc convexity is minimal, because of the tension of the posterior longitudinal ligament; the posterior facet capsule and the yellow ligament press against the posterior articular processes [14]. During extension, all the diameters diminish; the pedicles move closer to each other, reducing the height of the foramen by approximately 20% [15, 16].

The greater the collapse of the intervertebral disc, the greater the reduction in foraminal height. Accordingly, the passage of nerve components in the bony upper part of the foramen protects the root somewhat from disc protrusion, posterior facet joint osteoarthrosis, and ascension of the inferior articular process during extension movements (as long as the height of the intervertebral space remains satisfactory).

The contents
Numerous components are mixed closely together in the intervertebral foramen: nerve roots and spinal ganglia, foraminal fat, foraminal veins, radicular arteries, lymph vessels, the meningeal nerve (sinuvertebral nerve) and foraminal ligaments (Figs. 1, 3, 9, 11). The total area of the neurovascular bundle accounts for 20 to 50% of the total foraminal area [15]. The anterior motor root joins the posterior sensory root just after the birth of the spinal ganglion to

**TAKE-HOME MESSAGES**

- The intervertebral foramina, regardless of the segment considered, are traveled by nerve roots but also by vein and arteries, some going to the spinal cord.
- The radicular arteries are branches of the subclavian arteries at the cervical spine and of the aorta at the thoracic and lumbar spines. They divide into two branches, anterior and posterior, usually traveling down the side of the corresponding nerve roots.
- They vary in position, number, caliber, and division.
- Some radicular arteries help feed the spinal cord.
- The foraminal veins drain the epidural venous plexuses, particularly developed on the anterior aspect of the spinal canal, at the middle level of the vertebral bodies.
- The drainage veins of the vertebral bodies communicate with the epidural veins and the perivertebral veins.
- In the cervical intervertebral foramen, the nerve roots are usually located at or below the disc plane, protected from it by the uncus.
- The lumbar intervertebral foramen has two parts, one superior and rigid, where nerve components pass and usually the radicular or radiculomedullary arteries; the other inferior part is more mobile and exposed to disc changes. It is difficult to systematize the veins, which can be found in both parts.
form the mixed spinal nerve. The spinal ganglion is located below the pedicle, on which it sometimes leaves its imprint [17].

At the foramen exit, the spinal nerve usually divides into a relatively large anterior branch and a thinner posterior branch. It is difficult to systematize the foraminal veins. They allow connections between the internal and external vertebral venous plexuses, as at the cervical level. The foraminal veins can nonetheless be individualized at the upper part of the foramen in back and front, above the spinal ganglion, and at the lower part [6]. As we have seen, the radicular arteries are usually found on the anterior side of the anterior and posterior roots. Foraminal fat plays an especially important functional role, similar to that of orbital fat, allowing flexible maintenance of the vascular structures [10].

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

References