DOI 10.1007/s11055-018-0544-1
Neuroscience and Behavioral Physiology, Vol. 48, No. 2, February, 2018

Structural Organization and Morphometric Characteristic of the Vertebral Canals in the Cervical Segment of the Spine

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UDC 611.93

Translated from Morfologiya, Vol. 151, No. 1, pp. 62–66, January–February, 2017. Original article submitted July 1, 2016. Revised version received January 22, 2017.

The aim of the present work was to study the topographic anatomical characteristics of the intervertebral canal. Studies were performed using 37 anatomical preparations including 185 intervertebral canals in section complexes of the of the cervical segment of the spines of people dying at age 58–78 years. Histological investigations were performed using 32 preparations of ligamentous structures. Five pairs of true intervertebral canals were identified in segments C2–C7. The mean parameters of intervertebral canals were: length 1.46–2.0 mm; outer opening 0.8–1.4 mm; inner opening 0.4–0.8 mm. Histological studies confirmed data showing that the structures observed were ligaments, with diameters ranging from 0.1 to 0.3 mm and length from 0.4 to 0.6 mm. Intervertebral canals could be divided into three groups: those with clearly defined true ligaments (46%), ligaments with additional false ligaments (fibrotic bands) compressing the spinal nerve (43%), and canals without ligaments but with bony and fibrotic protuberances compressing the spinal nerve (11%).

Keywords: spine, cervical segment, intervertebral canals, lateral canal, medial opening of intervertebral canal.

According to the international anatomical nomenclature (2003), there is no anatomical term "intervertebral canal" for the cervical segment of the spine, though the term "intervertebral foramen" does exist [6].

However, we described the walls of the actual intervertebral canal in the lumbosacral segment of the spine in 1999 [8].

The intervertebral canal of the cervical segment of the spine is a functionally important structure, as it is a protective support for the vessels and nerves in this location (the spinal nerves, spinal ganglia, radicular arteries, and veins, passing transversely to the vertebral vessels). These vessels support the trophics of the brain, spinal cord, and its trunks, as well as the innervation of the upper limbs.

At the same time, the literature contains no detailed description of the topography of the intervertebral canals of the cervical segment of the spine. Most studies use the term "intervertebral foramen" [10]. The absence from the literature of what we will describe as the intervertebral canal of the cervical spine with consideration of the topographical anatomy of all the lateral structures of the cervical segment of the spine which, along with the intervertebral foramen, form a typical canal, has had the result that most authors using the term "intervertebral canal" actually mean the intervertebral foramen [1, 12].

Parts of the walls of the intervertebral foramina and canals are involved in degenerative-dystrophic processes in the spine (osteochondrosis, lateral stenosis, spondylosis, etc.), giving rise to pathologies such as root syndrome, periarthritis, vertebrobasilar insufficiency syndrome, and others, leading to impairments to the functions of the organs and upper limbs and degradation of quality of life and work capacity and, not infrequently, death [4].

Considering the medical and social significance of this pathology and addressing the needs of current clinical medicine, which focus on detailed investigation and supplementation of clinical morphological scientific data, morphometric and morphological studies of the intervertebral canals of the cervical segment of the spine and their soft tissues were conducted.

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The aim of the present work was to carry out topographical anatomical, morphometric, and morphological studies to characterize the intervertebral canal of the cervical segment of the spine, identifying its intraforaminal ligaments.

Materials and Methods. Topographical anatomical studies were performed at the Department of Pathological Anatomy, Sklifosovskii Research Institute of Emergency Care and the Department of Pathological Anatomy, Sechenov First Moscow State Medical University. The investigation was approved by the local ethics committee, Protocol No. 04-16 of April 13, 2016. A set of different study methods was used, including preparation, histological analysis, photographic recording, and statistical data processing.

Investigations were performed using 37 anatomical preparations of the cervical segment of the spine, including 185 intervertebral canals obtained from 37 embalmed bodies, aged 58–80 (mean 69) years, of which 17 were male and 20 were female. Topographical anatomical studies were performed on corpses without organs (Shore preparations) of section complexes including a single block of the base of the skull and the cervical segment of the spine to the T1 level. Specimens of connective tissue structures were fixed in 10% formaldehyde solution for 24 h. Histological specimens were then processed using standard methods with a Leica TP 1020 tissue processor (Germany). After fixation and impregnation with paraffin, tissues were embedded in a paraffin mixture, after which blocks were prepared and cut into slices of thickness 5 μm. Sections were deparaffinated and then stained with hematoxylin and eosin and with van Giessen picrofuchsin using standard protocols. Morphological studies of micropreparations was performed by light microscopy with a Leica DM 2000 microscope (Germany). A total of 32 histological preparations were studied.

Measurements were made using calipers with a Vernier scale and depth gauge with accuracy to 0.1 mm.

Data were processed statistically. Values are presented as arithmetic mean and standard deviation ($\bar{x} \pm s_{\bar{x}}$).

Results. A total of five pairs of intervertebral (lateral) canals with identical structure were identified in the cervical segment of the spine. In shape, the intervertebral canal is reminiscent to a cone of size decreasing in the medial direction to a point; it has a lateral and a medial opening and walls (Fig. 1).

The lateral opening of the intervertebral canal is formed by four walls, including bony, ligamentous, and muscular elements. The inferior wall of the lateral opening is delimited by the lateral margin of the transverse processes of the vertebra beneath, while the superior wall is formed by the lateral margin of the transverse process of the vertebra above; the anterior wall is formed by the lateral margin of the intertransverse muscle and the posterior wall consists of the lateral margin of the posterior intertransverse muscle. The medial opening of the intervertebral canal is delimited above by the inferior vertebral notch of the vertebra above and below by the superior vertebral notch of the vertebra below. The lateral opening is covered above by elements of the lateral wall, which is made up of fibers of the scalenius anterior et medius, scalenius posterior, and levator scapulae muscles. The spinal nerve emerges from the canal through the gaplike space between the bellies of these muscles.

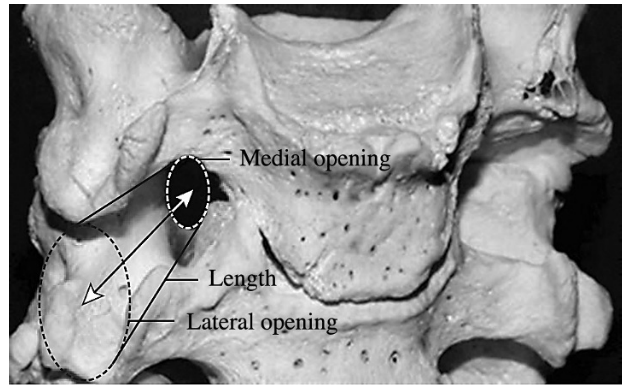

Fig. 1. Model of intervertebral canal in the cervical segment of the spine. Biomannikin. Projection of the lateral and medial openings.

The superior wall of the intervertebral canal of the cervical segment of the spine is formed by the inferior surface (keel) of the transverse process above. The inferior wall of the intervertebral canal is formed by the transverse process of the vertebra below (with a groove for the branch of the spinal nerve). The anterior wall of the intervertebral canal is formed by the anterior transverse muscles. Formation also involves the longus colli muscle. The posterior wall consists of the posterior intertransverse muscles.

The mean diameters of the lateral and medial openings and the lengths of the intervertebral canals are shown in Table 1.

Among the intervertebral canals are the intraforaminal trabeculae consisting structurally of soft tissues. On histological preparations, these formations are made up of densely formed fibrous tissue, where collagen fibers form first-order bundles. These bundles, surrounded by thin layers of loose fibrous unformed connective tissue with blood vessels, form second-order bundles, or ligamentous bundles. These structures were also separated by layers of loose fibrous connective tissue, i.e., endotendineum. These data point to an ordered structure, such that they can be termed ligaments.

With the aim of identifying the role of the ligament apparatus in canal stenosis, histological studies of the intraforaminal ligaments and their adjacent tissues were carried out. Processes of fragmentation and destruction of the nerve were detected at the contact points of these ligaments with fibrous protuberances with spinal nerves, with atrophy of some nerve fibers. Signs of deep dystrophy, i.e., calcinosis, were seen on histotopographic sections of blocks containing parts of spinal nerves and ligaments. Many areas of transition from ligament to bony tissue were seen. Calcified marginal parts of ligaments accreted with fibrosed periosteum were wedged into the structures of spinal nerves.

TABLE 1. Diameters of the Medial and Lateral Openings and Lengths of Intervertebral Canals in the Cervical Segment of the Spine, mm

Parameter	Study level	$\bar{x} \pm s_{\bar{x}}$	Min	Max
Diameter of medial opening of intervertebral canal	C2–C3	0.40 ± 0.16	0.30	0.50
	C3–C4	0.400 ± 0.020	0.39	0.42
	C4–C5	0.45 ± 0.22	0.30	0.60
	C5–C6	0.59 ± 0.16	0.50	0.70
	C6–C7	0.70 ± 0.17	0.60	0.80
Diameter of lateral opening of intervertebral canal	C2–C3	0.8 ± 0.3	0.60	1.00
	C3–C4	0.95 ± 0.22	0.80	1.10
	C4–C5	1.10 ± 0.16	1.00	1.20
	C5–C6	1.15 ± 0.20	0.90	1.30
	C6–C7	1.20 ± 0.16	1.00	1.40
Length of intervertebral canal	C2–C3	1.5±0.7	1.00	1.90
	C3–C4	1.7 ± 0.3	1.50	1.90
	C4–C5	1.80 ± 016	1.70	1.90
	C5–C6	1.8 ± 0.3	1.60	2.00
	C6–C7	1.85 ± 0.22	1.70	2.00

The total numbers of ligaments detected on preparations were counted in relation to the level and side of the intervertebral canal, with identification of type, and three variants of intervertebral canals were found. The first variant had clearly identifiable true ligaments and accounted for 46% of the total number of preparations studied. The second variant had, along with true ligaments, associated false ligaments (bands) and numerous fibrous protuberances (43%). Preparations of the third group lacked ligaments, though fibrous-bony protuberances were seen. The third variant was present in 11% of study preparations. Ligament size ranged from 0.4 mm in C2–C3 to 0.6 mm in C6–C7, and in width were from 0.15 mm in C2–C2 to 0.3 mm in C6–C7.

Discussion. Studies of the topography of the anatomical elements of the cervical segment of the spine demonstrated the presence of anatomical formations consisting of a canal with input and output openings, walls, and contents, allowing the overall anatomical formation to be defined as the "intervertebral canal of the cervical segment of the spine." The intervertebral canal is mentioned in a number of publications, though the term usually refers to the intervertebral foramen [2, 11, 14].

Intervertebral canals were shown to be present in five pairs. They are located at vertebromotor segments C2–C3, C3–C4, C4–C5, and C5–C6, ending at the level of C6–C7. There are not eight, considering the number of spinal nerves, as the first two pass behind the lateral joints of the atlas and axis and do not have properties of canals; level C7–T1 has no sign of an intervertebral canal of the cervical segment of the spine because it has a rib.

Canal size changed depending on the level of the segment. The lower the level of the segment, the longer and wider the canal. Furthermore, the sizes of the canals and their openings are affected by head position.

Studies of intervertebral canals showed them to contain connective tissue structures, which is consistent with data reported by other authors [9], as well as clefts, through which the fatty tissue of the epidural space communicates with the perintervertebral cellular tissue. These connective tissue structures are analogous to the ligaments of the lumbar segment, which Nikolaev termed intraforaminal ligaments [8].

Ligamentous structures occupying a transverse position in the canal above the spinal nerve may be true or false ligaments or may be absent, as a result of fibrous-bony protuberances. Nerve compression can occur at sites at which peripheral nerves pass through anatomically narrow spaces delimited by hard structures. These cases also show other pathogenetic factors – hormonal, metabolic, or traumatic – which can induce edema of connective tissue structures, further narrowing already limited spaces, leading to compression of the nerve [5].

It can be suggested that the presence of fibrosed ligaments leads to decreases in the reserve space. Increasing compression of segment of the spinal nerve and vessels along the ligament occurs as a result of the actions of fibrous fibers in hypertrophied ligaments on structures of the spinal nerve, resulting in radicular symptomatology.

This in our view provides further support for the principles described in [7], whereby diagnoses based on radiological detection of morphological changes at the early (I; II) stages of lateral stenosis do not correspond to the clinical signs of illness, for example, severe radicular syndrome [3]. Thus, for example, in severe radicular syndrome, x-rays do not show osteophytes or, if they do, they are very minor. In MRI investigations, intervertebral disk prolapses are either not seen or are very small.

The fact that a previously unknown pattern of development of compression of neurovascular bundles in intervertebral canals was found in the lumbar segment of the human spine, whereby true ligaments in the lateral openings of the intervertebral canals of the lumbar segment of the spine, operating as a soft frame, along with the occurrence of pathology in the lumbar segment (osteochondrosis, intervertebral disk hernias, trauma, functional blockade, etc.), produce additional compression of neurovascular formations, leading to enhanced compression of the neurovascular bundle and more severe radicular syndrome than occurs in the anatomical variant without true ligaments [7], confirms and supplements the view that the intraforaminal apparatus is involved in producing stenosis of intervertebral canals in the cervical segment of the spine.

Studies of intraforaminal ligaments of the lumbar segment reported by non-Russian authors demonstrate the importance of studying these in relations to clinical questions [12].

Thus, histological study data point to a tendency to develop lateral stenosis of the intervertebral canal, ligaments playing an important role in this.

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