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Morphoscopic and Morphometric Characteristics of Intervertebral Foramina in the Lumbar Segment of the Spine

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Multispiral computerized tomography (CT) of the lumbar segment of the spine in 70 patients of both genders aged 25–74 years, along with use of specialist software were used to study a number of morphoscopic and morphometric characteristics of the intervertebral foramina (IVF). Comparative analysis of the resulting data was performed between IVF in different areas and in subjects of different genders. Four types of IVF were found: elliptical, reniform, pyriform, and teardrop. The frequencies of the different types of IVF were determined. The main morphometric parameters were measured: the height of the interval between the bodies of neighboring vertebrae at the level of the IVF; the height of the IVF; the distance from the superior margin of the pedicle of the vertebra beneath to the spinal nerve; the superior and inferior diameters of the IVF; the area of the IVF; and the area of the access zone (reserve space) for transforaminal endoscopic access to structures in the vertebral canal. Decreases in all parameters were seen from the upper lumbar segments to the lumbosacral junction. These results may be useful as indicators of the normal range in the diagnosis of foraminal stenosis and in planning endoscopic transforaminal access to structures of the lumbar segment of the spine and vertebral canal.

Keywords: intervertebral foramen, lumbar segment of the spine, endoscopic transforaminal access.

Lower back pain is one of the most relevant medical-social problems of our times. Data from the World Health Organization indicate that the lower back pain in industrial countries occurs in the lives of 60–70% of the population (the annual prevalence is 15–45% and the incidence in the adult population is 5% per year). The peak incidence occurs at working age, 35–55 years [6]. Spinal pain in 5–10% of patients is accompanied by radiculopathy. Radiculopathy encountered in 5–22 per 1000 people per year [11].

One of the many causes of lower back pain combined with radiculopathy is foraminal stenosis. Studies reported by Spivak et al. [15] and Kaneko et al. [10] described the influences of the geometry of the intervertebral foramina (IVF) on the formation of root pain in spondylolisthesis and degenerative scoliosis, respectively, emphasizing the importance of the data obtained for improving the diagnosis and surgical treatment of radiculopathies. Despite the fact that the literature contains extensive reports on the morphometric characteristics of pathologically altered IVF, there is still no generally accepted view as to what normal IVF parameters are [3–5, 7]. Significant differences in measurement results from different investigators are associated with the large assortment of methods available for studying foraminal geometry. In addition, the data described in most sources often fail to reflect all the anatomical-topographic parameters required for planning transforaminal surgical procedures. One of the best methods of obtaining relatively precise morphometric data is provided by studies of the three-dimensional geometry of the IVF in cadavers. Nonetheless, we believe that these studies have certain drawbacks. These are primarily the absence of muscle tone, which can influence foraminal geometry, altering both the curvature of spinal lordosis and

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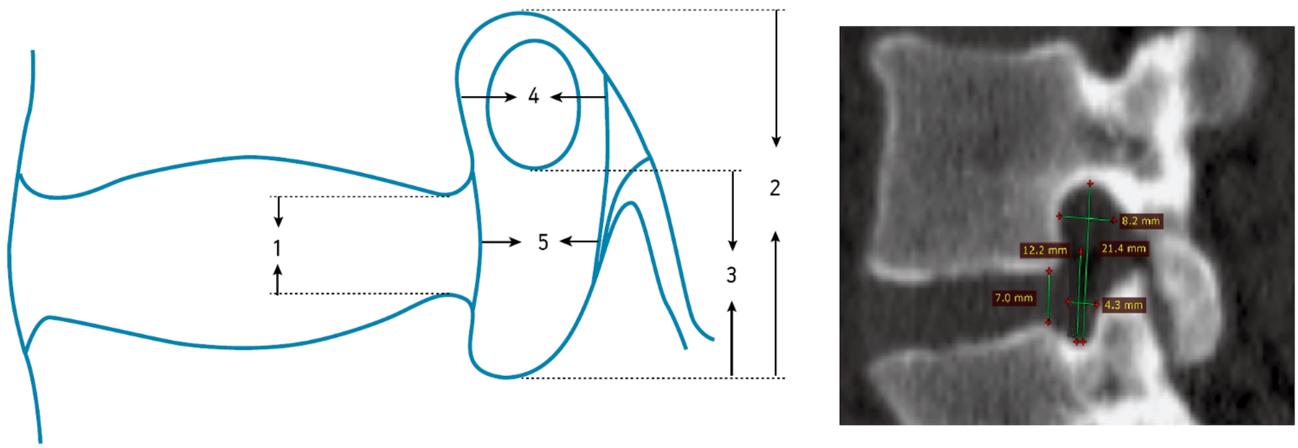

Fig. 1. Method for measurement of morphometric parameters. *1*) Height of intervals between the bodies of neighboring vertebrae at the level of the intervertebral foramen; *2*) height of intervertebral foramen; *3*) distance from superior margin of the peduncle of the underlying vertebra to the spinal nerve; *4*) superior diameter of the intervertebral foramen; *5*) inferior diameter of the intervertebral foramen.

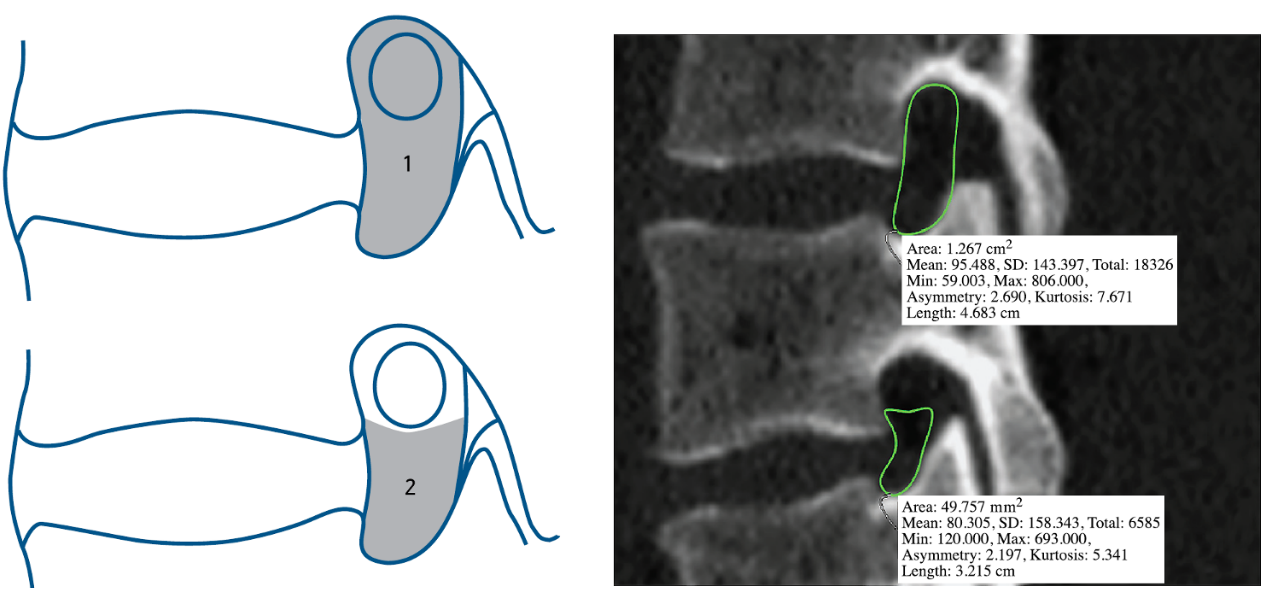

Fig. 2. Method for measurement of morphometric parameters. *1*) Area of intervertebral foramen; *2*) area of access zone.

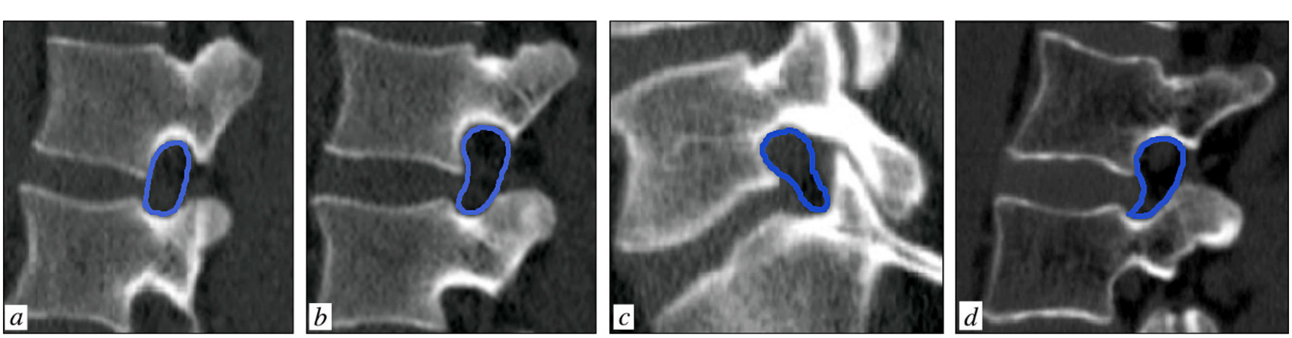

Fig. 3. Shapes of intervertebral foramina. *A*) Elliptical (patient, K, 39 years); *b*) reniform (patient K, 39 years); *c*) pyriform (patient S, 52 years); *d*) teardrop (patient D, 63 years).

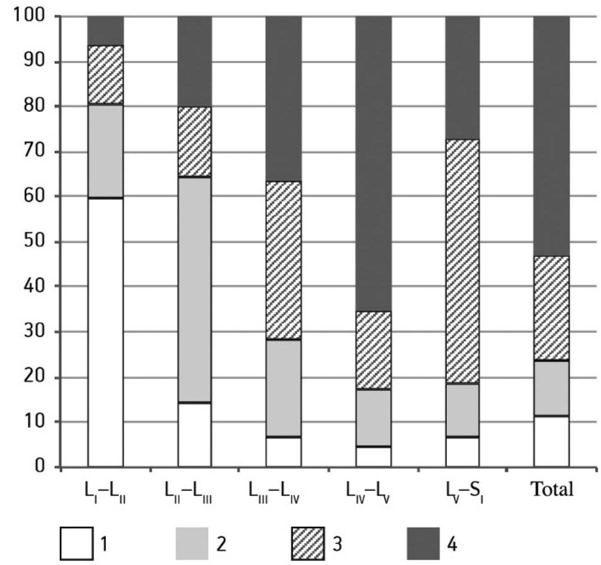

Fig. 4. Frequencies of different shapes of intervertebral foramina. *1*) Elliptical; *2*) reniform; *3*) pyriform; *4*) teardrop. The abscissa shows levels of intervertebral foramina; the ordinate shows incidence (%).

the interaction of different structures of the vertebromotor segments. Various methods of vital imaging such as magnetic resonance imaging (MRI) and computerized tomography (CT) overcome this drawback, and have been used by increasing numbers of researchers [1, 2, 13, 14, 16, 17].

There is considerable interest in the topographical anatomical aspects of transforaminal (particularly endoscopic) access to structures in the lumbar segment of the spine and vertebral canal, which defined the aim of the present work – to study the spondylometric characteristics of IVF by CT.

Materials and Methods. Studies were performed on computerized tomograms of the lumbar segment of the spine in adults (n = 70) obtained using an Aquilon 64 (Toshiba, Japan) tomograph at the Department of x-Rays and Radiology, Kirov Military Medical Academy. Studies were approved by the independent ethics committee of the Academy (protocol No. 169 of December 22, 2015).

Studies of the morphometric characteristics of IVF were performed using CT in 30 subjects (15 men, 15 women) without lumbar vertebral pathology. Mean age was 34.1 ± 4.9 years (range 25–44 years). Morphoscopic studies (visual assessment of IVF shape) were performed using CT data from 40 patients aged 26–74 (mean 47.4 ± 13.7) years. Computerized tomograms were studied using RadiAnt DICOM viewer version 1.9.16 and OsriX 8.0.1. Sagittal projections were used for assessment of the following spondylometric parameters: the height of the interval between the bodies of neighboring vertebrae at the level of the intervertebral foramen; the height of the intervertebral foramen; the distance from the superior margin of the peduncle of the underlying vertebra to the spinal nerve; the maximum anteroposterior size of the intervertebral foramen (the superior diameter of the intervertebral foramen); the distance from the mid part of the interval between the bodies of neighboring vertebrae to the posterior margin of the bodies of the vertebrae to the ventral margin of the superior articular process (the inferior diameter of the intervertebral foramen); the area of the intervertebral foramen; and the area of the access zone (the reserve space) for transforaminal endoscopic access to structures of the vertebral canal (Figs. 1 and 2).

Studies were performed on both sides using 30 subjects (60 measurements were made for each morphometric parameter).

These parameters were selected on the basis of the need for them to be studied in detail in each individual case for planning endoscopic transforaminal discectomy for intervertebral disc hernias.

The morphometric characteristics of IVF were studied at the levels of intervertebral disks L1/L2 (n = 60), L2/L3 (n = 60), L3/L4 (n = 60); L4/L5 (n = 60), and L5/S1 (n = 60), and IVF shape was studied at the L1/L2 (n = 78), L2/L3 (n = 80), L3/L4 (n = 80), L4/L5 (n = 77), and L5/S1 (n = 78) levels.

Data were analyzed statistically in StatSoft Statistica 10.0 for Windows. Morphometric data for the whole set were analyzed for each parameter in terms of the mean (M), the standard deviation (SD), the minimum and maximum values (Min–Max), and the coefficient of variation. In addition, the distributions of each parameter were checked for normality using the Shapiro–Wilks test. When distributions were normal, the morphometric parameters of intervertebral foramina at different levels of the lumbar segment of the

TABLE 1. Morphometric Characteristics of Intervertebral Foramina

Morphometric parameters (measurement units)	Level of IVF	$\bar{x}$, arithmetic	SD, standard deviation	Coefficient of variation
Height of intervertebral interval, mm	L1–L2	6.03	1.03	17.14
	L2–L3	6.65	0.84	12.74
	L3–L4	6.73	0.86	12.91
	L4–L5	5.85	1.38	23.65
	L5–S1	4.79	1.32	27.58
Height of IVF, mm	L1–L2	18.29	1.22	6.68
	L2–L3	19.74	1.72	8.72
	L3–L4	19.09	1.83	9.59
	L4–L5	17.95	1.62	9.05
	L5–S1	15.95	1.65	10.34
Distance from superior margin of the peduncle of the underlying vertebra to the spinal nerve, mm	L1–L2	10.75	0.95	8.81
	L2–L3	11.68	1.12	9.56
	L3–L4	11.55	1.55	13.40
	L4–L5	9.72	1.56	16.05
	L5–S1	9.19	0.87	9.50
Superior IVF diameter, mm	L1–L2	9.54	0.85	8.89
	L2–L3	9.76	0.84	8.59
	L3–L4	9.39	0.72	7.62
	L4–L5	9.02	0.71	7.92
	L5–S1	8.87	1.18	13.26
Inferior IVF diameter, mm	L1–L2	7.99	1.01	12.70
	L2–L3	7.43	0.80	10.72
	L3–L4	6.94	0.60	8.68
	L4–L5	6.41	0.91	14.18
	L5–S1	5.79	0.91	15.68
IVF area, mm^2	L1–L2	146.3	18.15	12.40
	L2–L3	150.9	22.54	14.93
	L3–L4	137.2	22.73	16.57
	L4–L5	114.4	21.52	18.81
	L5–S1	104.6	15.46	14.78
Area of access zone, mm^2	L1–L2	91.0	12.95	14.23
	L2–L3	90.4	15.47	17.10
	L3–L4	81.6	16.42	20.11
	L4–L5	63.2	12.99	20.56
	L5–S1	57.2	10.27	17.94

spine were compared using Student's t test with the Bonferroni correction. When distributions were non-normal, the Kruskal–Wallis test was used. When statistically significant differences were found, pairwise comparisons were performed using the Mann–Whitney test. Levels of significance were determined for all differences. The statistical significance of different IVF shapes at different levels was determined by analysis of arbitrary continency tables using the Pearson χ^2 test.

Results. Morphoscopic studies identified four types of IVF: elliptical, reniform, pyriform, and teardrop (Fig. 3). The frequencies of these shapes in our cohort, at different IVF levels, without taking account of age or gender differences, are shown in Fig. 4 ($p < 0.001$).

Our morphometric studies did not identify any statistically significant differences in relation to gender for any of the parameters studied except the superior and inferior diameters of all IVF. These parameters were significantly greater in men at all levels ($p < 0.01$). In addition, there were no differences in the data obtained for the right and left sides ($p > 0.05$). Table 1 shows the results of measurements at different levels of IVF independently of gender and side of the IVF.

The height of the interval between the bodies of neighboring vertebrae at the level of IVF varied from 1.7 to 8.5 mm. This distance, like the distance from the superior margin of the peduncle of the underlying vertebra to the spinal nerve, increased towards the apex of the lumbar lordosis (levels L2/L3, L3/L4 – 11.7 ± 1.1 and 11.5 ± 1.5 mm, respectively) and decreased in the caudal direction (L4/L5 and L5/S1 – 9.7 ± 1.6 and 9.2 ± 0.9 mm, respectively) ($p < 0.01$). The minimal distance from the superior margin of the peduncle of the underlying vertebra to the spinal nerve was 6.6 mm and the maximum distance was 14.3 mm. Mean IVF height reached a maximum at the level of the L2/L3 IVF – 19.7 ± ± 1.7 mm, decreasing to the lumbosacral junction (L5/S1 – 15.9 ± 1.6 mm). The value of this parameter in the study cohort was in the range 11.6–23.4 mm. In contrast to the superior IVF diameter which, like the parameters described above, reached its maximum at the apex of the lumbar lordosis, the maximum value of the inferior diameter was at the IVF of L1/L2. The spread of values for these parameters was 5.8–11.5 mm for the superior IVF diameter and 3.2–10.1 mm for the inferior IVF diameter. As with most of the characteristics studied, IVF area and access zone (AZ) area for transforaminal intervention decreased in the craniocaudal direction, reaching a minimum at the L5/S1 level. The minimal and maximal values for IVF area and AZ area were from 66.1 to 188.8 mm^2 and from 33.5 to 120.3 mm^2, respectively. Statistical analysis of the results demonstrated decreases in all parameters from the superior lumbar segments to the lumbosacral junction. The characteristics of the levels most frequently affected by degenerative processes, L4/L5 and L5/S1, were significantly smaller than the analogous values for the above-lying levels ($p < 0.05$).

Discussion. The present study, like studies by other authors [1, 8], showed that the shapes and sizes of IVF were characterized by marked topographic variability. However, differences in analysis methods and cohort sizes have the result that our data are only partially consistent with previous reports in the literature on IVF size [3–5, 7]. Most publications have noted that the maximum values of the morphometric parameters of IVF were either at the superior lumbar level or at the peak of the lumbar lordosis and decreased in the causal direction.

Furthermore, decreases in IVF sizes may result from the formation of osteophytes on the posterolateral surfaces of the bodies of the vertebrae of the articular processes [9]. The studies of Yoshimura et al. [18] and O'Neill et al. [12] indicate that the incidence of lumbar spondylosis with osteophyte formation stenosing IVF is 81.5–84% in men and 65.5–74% in women in patients aged more than 40–50 years. Thus, we assessed the normal values of the morphometric characteristics of IVF in a group of young patients (mean age 34.1 ± 4.9 years) without marked signs of degenerative-dystrophic lesions in the lumbar area of the spine.

Use of these data for pre-operative planning of transforaminal access may promote successful surgical outcomes. Thus, considering that the size of the external diameter of the working tube established in the intervertebral foramen during endoscopic transforaminal access was 7.5 mm and in the vast majority of cases was greater than the inferior IVF diameter, there is need for foraminoplasty in the process of each such access. In addition, a distance from the superior margin of the peduncle of the underlying vertebra to the spinal nerve of greater than 7.5 mm excludes the possibility of iatrogenic injury.

One limitation of the present study was that measurements of IVF parameters were made using CT data with the patient in the supine position without any axial load on the vertebrae. The influence of load on the morphometric parameters of IVF and their correlation with the height of the intervertebral foramen was demonstrated in the studies of Iwata et al. [8]. Nonetheless, changes in foraminal geometry identified on investigation of patients in the supine position, along with clinical signs of radiculopathy in the standing position, may be criteria for the diagnosis of foraminal stenosis.

Thus, these results may be useful as measures of the normal range in the diagnosis of intervertebral stenosis and for planning of transforaminal access to structures in the lumbar segment of the spine and vertebral canal.

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