Anatomic morphological study of thoracolumbar foramen in normal adults

Authors: Y. Wang, Y. Cai, Y. Xu, H. Guan, M. Gao, Y. He, L. Wang, H. Wang, X. Li, Z. Li, J. Yu, Y. Fu, Y. Zhang, Y. Zhao, D. Xin

DOI: 10.5603/FM.a2020.0107

Article type: ORIGINAL ARTICLES

Submitted: 2020-07-25

Accepted: 2020-08-19

Published online: 2020-09-02

This article has been peer reviewed and published immediately upon acceptance. It is an open access article, which means that it can be downloaded, printed, and distributed freely, provided the work is properly cited. Articles in "Folia Morphologica" are listed in PubMed.
Anatomic morphological study of thoracolumbar foramen in normal adults

Y. Wang¹, Y. Cai², Y. Xu¹, H. Guan¹, M. Gao³, Y. He², L. Wang⁴, H. Wang⁵, X. Li², Z. Li², J. Yu⁵, Y. Fu⁵, Y. Zhang⁵, Y. Zhao⁵, D. Xin⁵

¹School of Postgraduates of Inner Mongolia Medical University, Hohhot, China
²Human Anatomy of Inner Mongolia Medical University, Hohhot, China
³Digital Medical Center, School of Basic Medical Sciences, Inner Mongolia Medical University, Hohhot, China
⁴Inner Mongolia International Mongolian Medical Hospital, Hohhot, China
⁵The Second Affiliated Hospital of Inner Mongolia Medical University, China

Address for correspondence: Haiyan Wang; Xiaohe Li, Human Anatomy Inner Mongolia Medical University Basic Medical College, Hohhot, 10110, China, tel: +86 471 6657009, fax: +86 471 6657562, e-mail: 18647398868@163.com; 798242742@qq.com

Abstract

Background: Based on CT images of the thoracolumbar intervertebral foramen and its surrounding parameters, and analyzing the intervertebral foramen morphology and the correlation between the measured parameters, to provide an anatomical basis for clinical minimally invasive transvertebral surgery.

Materials and methods: Ten fresh adult cadaveric specimens (32-50 years old) with bilateral (T₁-S₁) spinal segments were selected for a total of 20 sides, a total of 340 intervertebral foramen, were measured with vernier calipers in the Department of Anatomy, Inner Mongolia Medical University. The intervertebral foramen height, the minimum sagittal diameter of the foramen, the width of the spinal ganglion, the
sagittal diameter of the spinal ganglion and the sagittal diameter of the intervertebral foramen were measured. This study was reviewed and approved by the local Ethics Committee.

**Results:** The results of the minimum sagittal diameter of the T9-10-L5/S1 intervertebral foramen were 6.93 ± 1.99 mm, 7.33 ± 1.44 mm, 7.41 ± 0.63 mm, 6.85 ± 1.08 mm, 6.79 ± 1.86 mm, 7.82 ± 3.25 mm, 8.23 ± 2.27 mm, 9.17 ± 2.33 mm, 8.38 ± 1.63 mm; the average height of the T2/3 to L5/S1 intervertebral space was 4.82 ± 1.88 mm, 3.95 ± 0.80 mm, 4.04 ± 0.52 mm, 4.26 ± 0.78 mm, 4.39 ± 1.16 mm, 5.15 ± 1.59 mm, 5.51 ± 1.49 mm, 5.97 ± 2.60 mm, 7.13 ± 2.07 mm, 8.94 ± 1.37 mm, 9.01 ± 1.47 mm, 11.63 ± 1.63 mm, 14.20 ± 1.37 mm, 14.22 ± 2.33 mm, 14.22 ± 2.33 mm, 13.32 ± 1.37 mm. Intervertebral foramen height, intervertebral foramen minimum sagittal diameter, spinal ganglion width, spinal ganglion sagittal diameter. $P > 0.05$ for comparison of the left and right sides of the intervertebral space, with no statistically significant difference. L4/5, L5/S1 segment left and right bilateral contrast with the middle height of the vertebral space $P < 0.05$, the difference is statistically significant. The remaining segments left and right bilaterally contrasted $P > 0.05$, and the difference was not statistically significant.

**Conclusions:** The minimum height of intervertebral foramen in the thoracolumbar segment was T6/7, and L1/2 was the minimum height in the lumbar segment. When placing a spinal endoscopic working channel safely into intervertebral foramen, it is necessary to perform an enlarging foraminoplasty to reduce the risk of injury to the exiting nerve root.

**Key words:** adult, thoracic spine, lumbar spine, intervertebral foramen, anatomical measurements

**INTRODUCTION**

The nucleus pulposus of the intervertebral disc decreases with age, leading to
disc degeneration, which is the cause of herniated discs. Major Cause. Thoracic disc herniation (TDH) has a low prevalence, literature reported to account for approximately 0.25-0.75% of spinal disc herniations, compared to an incidence of 0.1% in the general population-0.0001%[1]. It mainly occurs between T8-L1, most often between 30-50 years old, with an equal proportion of men and women, with complex and varied clinical manifestations, diagnostic difficulties and surgical difficulties[2]. Lumbar disc herniation (LDH) is a common orthopedic condition. The prevalence of lower back pain is estimated at 4.8 percent in men aged 35 years, exceeding the 2.5 per cent prevalence in women of that age. Spinal nerve entrapment due to intervertebral foramen stenosis, or spinal space herniation is more common[3]. For patients who have failed to respond to conservative treatment, surgery is often used, and minimally invasive surgery is used to treat herniated discs through lumbar intervertebral spondylolisthesis. The results are significant, and there is a large body of literature confirming the clinical superiority of the transvertebral pathway for LDH over traditional surgical approaches[4, 5]. Treatment of herniated discs using intervertebral endoscopic techniques can reduce peri-spinal muscle and soft tissue injury, increase spinal stability, and have a small trauma, rapid recovery and short hospital stay[6]. With the increasing development of a large number of intervertebral foramen techniques, there is a need for clinicians to further improve their understanding of intervertebral foramen anatomy. In this paper, we use adult cadaveric specimens to study the anatomical and morphological changes of intervertebral foramen in the thoracolumbar spine and to investigate the normal intervertebral foramen, spinal nerves and intervertebral space morphology, measurement of its diameter line, and correlation analysis of the spinal ganglion with the size of the intervertebral foramen. It provides anatomical basis for selection of position and angle for minimally invasive clinical transvertebral foramen path surgery.

MATERIALS AND METHODS

Ten were collected, ranging in age from 32-50 years, with an average age of
43.2 years, on the intact spine of a normal fresh adult (T₁ to S₁), bilaterally on 20 sides with a total of 340 intervertebral foramen. This study was reviewed and approved by the local Ethics Committee. The data in the literature are varied, mainly because of individual variations and the different degrees of degenerative change in the spine. In this study, none of the subjects had symptoms or any degenerative changes of the spine. Therefore, our results provide the normal morphometric anatomy for the nerve roots and dorsal root ganglion.

**Observational indicators**

Use of vernier calipers (Japan Mitutoyo, accuracy 0.02mm), compasses, stainless steel rulers (accuracy 1mm), medical power saws. Drill (Shanghai Bojin Medical Instrument Co., Ltd., BYJ-1) tools, surgical instruments: scalpels, surgical scissors, hemostatic forceps, dissecting instruments, etc. Forceps, hacksaw. Measure the height (vertical diameter) of the intervertebral foramen bilaterally at each spinal segment with reference to Wu Bo (Wu Bo 2017) defining the intervertebral intervertebral level at the upper margin of the intervertebral space. The distance from the anterior boundary of the foramen to the posterior boundary of the intervertebral foramen is the minimum sagittal diameter of the intervertebral foramen, the wide spinal ganglion, the sagittal diameter of the spinal ganglion, and the intervertebral space. Left, middle, and right heights. Measurements were taken by the same measurer familiar with the anatomical landmarks for which the relevant indexes were collected, and the recording length/mm (d/mm) was Unit.

Specimen Production Dissect the thoracic and lumbar segments of 10 adult cadaveric specimens, remove internal organs, and use a hacksaw to saw the upper end of the spinal specimen from the bulge. Horizontal dissociation, marking the 12th rib, identifying the lumbar segment, inferiorly dissociating horizontally from the hip joint, followed by local dissociative maneuvers, removing the skin. The lumbaris major muscle is carefully resected to expose the entire thoracic spine, lumbar spine, intervertebral space, intervertebral foramen, and the muscles and surrounding soft tissue structures. Nerve root structures, keeping the position of nerve roots within the
intervertebral foramen intact, and making morphological observations of the intervertebral foramen, nerve roots, and intervertebral spaces (Fig. 1). The upper end of the scalpel was detached from the vertebral space at the C7/T1 segment with a scalpel, and the lower end of the scalpel was used to divide the ribs one by one along the rib joint with a medical electric saw drill and the thoracic vertebrae (Figure 2). The intervertebral foramen height was measured, i.e., the distance from the superior to the inferior margin of the foramen; the minimum sagittal diameter of the foramen, i.e., the distance between the posterior margin of the intervertebral space and the distance; observation of the intervertebral foramen walking nerves (Figs. 3a, 3b, 3c); measurement of the intervertebral space height, i.e., the superior and inferior endplate levels distance between them (Fig. 4); the spinal sagittal diameter, which is the maximum distance between the axial edges of the spinal ganglia; the spinal width, which is the distance perpendicular to the maximum distance between spinal ganglion edges (Fig. 5).

**Statistical methods**

GraphPad Prism 8.0 was used and the measures were expressed as mean ± standard deviation (\( \bar{x} \pm s \)). Paired t-tests were used between left and right lateral comparisons and between ipsilateral comparisons; One-Way ANOVA was used between comparisons of different segments; determination of intervertebral foramen index and spinal ganglion index by bivariate correlation Pearson's correlation coefficient test the correlation between. Using Pearson's correlation coefficient test, the correlation coefficient (\( r \)) is interpreted as follows: < 0.2 indicates a weak correlation. 0.2-0.4 indicates weak correlation, 0.4-0.7 moderate correlation, 0.7-0.9 high correlation, >0.9 indicates almost perfect correlation. The test level was \( \alpha=0.05 \), \( P<0.05 \) was statistically significant.

**RESULTS**

Left and right bilateral comparison \( P >0.05 \) for the left and right sides of each measure, the differences are not statistically significant, and the statistical data are
combined. $T_{1/2} - L_5 / S_1$ segment intervertebral foramen height comparison $P < 0.0001$, the difference is statistically significant. $T_{9/10} - L_5 / S_1$ segment The minimum sagittal diameter of intervertebral foramen was $P > 0.05$, and the difference was not statistically significant. $T_{6/7} - L_5 / S_1$ segment interspinal nerve $P < 0.05$, statistically significant difference. $P < 0.05$ for $T_{7/8} - L_5 / S_1$ intersegmental chiropractic width. The differences were statistically significant. (Tables 1,2)

Measurement of anatomical parameters of the intervertebral space $P > 0.05$ for comparison of the left and right heights of the intervertebral space, the difference was not statistically significant, and statistical data were combined. $L_{4/5}$, $L_5 / S_1$ $P < 0.05$ for the comparison between the left and right sides of the $S_1$ segment and the middle height of the intervertebral space, the difference was statistically significant. The remaining segments left and right bilateral and vertebral space intermediate height contrast $P > 0.05$, the difference was not statistically significant. (Table 3)

Correlation analysis of spinal ganglion width and spinal ganglion sagittal diameter with intervertebral foramen height and intervertebral foramen minimum sagittal diameter, spinal ganglion sagittal diameter -The minimum sagittal diameter of the intervertebral foramen $r = 0.728$, with $r$ between 0.7 and 0.9, positively correlated and highly correlated. (Fig. 6)

Analysis of the correlation between intervertebral foramen height and the left, right, and median height of the intervertebral space (Fig. 7). The intervertebral foramen height is positively correlated with the left and right bilateral height of the intervertebral space $r = 0.917$, with $r$ between 0.7 and 0.9, and height correlation. The intervertebral foramen height is positively and highly correlated with the median height of the intervertebral space $r = 0.877$, with $r$ ranging from 0.7 to 0.9.

**DISCUSSION**

There are broadly two methods for measuring intervertebral foramen morphology in China: one is direct measurement and the other is indirect measurement. The direct measurement tool is used to collect data from cadaveric specimens, while the indirect measurement mainly uses X-ray technique, three-dimensional CT imaging and MRI
In addition, after software post-processing to reconstruct the intervertebral foramen image, the measurement is performed, while the presence of soft tissue shadowing affects the experiment using X-ray and MRI. In this paper, we collected 10 fresh cadaveric specimens and directly measured the morphology of the intervertebral foramen, which enabled direct, realistic and accurate observation of the intervertebral foramen. Wang Zi-xuan[8] measured cadavers under the X-ray technique similar to the measurements in this paper. The resultant anterior disc heights were 11.8 ± 1.2 mm, 13.0 ± 1.6 mm, 13.6 ± 1.9 mm, 14.3 ± 2.0 mm, 14.7 ± 2.5 mm, this study is consistent with previous literature and the results are reliable and accurate. Rühli FJ et al.[9] measurement of cadaveric specimens using vernier calipers. Comparing men and women revealed that the width of the intervertebral foramen was larger in women than in men at the lumbar segment. All specimens in this study were male, and the difference between the left and right sides of each measurement comparing the same individual was not statistically significant.

The bony border morphology of the intervertebral foramen has been described in the literature as an inverted teardrop, inverted pear shape, or oval shape, affecting the intervertebral foramen. There are many factors that contribute to size, such as degenerative changes in the bony borders of the intervertebral foramen, herniated discs, subluxation of the small joints, and hypertrophy of the ligamentum flavum [9]. Kai Zhu et al.[10] retrospectively analyzed the changes in intervertebral foramen morphology before and after unilateral transverse lumbar interbody fusion. Compared to the oblique or transverse cage approach, the transverse approach is preferred to reduce lumbar lordosis without affecting the contralateral side. The size of intervertebral foramen is good for decompression of lumbar spinal stenosis, and it is easy to determine the normal size of intervertebral foramen stenosis. The study observed that the transverse section of the spinal nerve root was oval in shape, the transverse section of the thoracic spinal nerve was smaller, and the intervertebral foramen went outward and backward, and the lumbar section was smaller. The spinal nerve cross-section is large and goes obliquely outward and downward after exiting
the intervertebral foramen. The wide thoracic segment of the spinal ganglion, T₆-T₁₂, has a gradually increasing trend; the lumbar segment, L₁-S₁, has an essentially unchanged trend of L₁/₂, L₃/₄ maximal, L₅/S₁ minimal. Spinal ganglion sagittal diameter thoracic segment T₇ to T₁₂ basically unchanged, lumbar segment L₁-S₁ change trend L₁/₂, L₂/₃ basic Unchanged, L₄/₅ maximal, L₅/S₁ minimal. The height of the intervertebral gap was larger in the middle and smaller in the left and right sides of the L₅/S₁ and L₄/₅ segments compared to the right and left sides of the L₅/S₁ and L₄/₅ segments. Because the intervertebral space morphology dictates that artificial intervertebral space designs cannot be designed to be directly rectangular[11], this study also found that the intervertebral gap height median height in the L₅/S₁ and L₄/₅ segments compared to the right and left sides of the spine Large in the middle and small on the left and right side need to be designed to have a large middle height of the vertebral space and a small height of the vertebral space on both sides, which can improve the biomechanics of the spine.

There are now five types of surgical access for the treatment of TDH, including anterior access, lateral access, pedicle access, intervertebral access, thoracoscopic Access. According to the literature, anterior surgical access is more difficult to learn and has a higher incidence of complications[1]. When encountering large disc size, disc calcification and central TDH, the intervertebral approach is not applicable, and there is a lack of treatment in the current literature Evidence for the safety of surgical access for TDH is attributed to, among other reasons, the low incidence of TDH. Currently, Percutaneous Endoscopic Lumbar Discectomy (PELD) has become the most promising treatment of lumbar intervertebral disc protrusion and minimally invasive spinal surgery. PELD is widely used in clinical practice with its advantages of less trauma, quicker recovery, shorter operation time, less pain, and improved lumbar spinal cord function[12]. Hoyland et al. [13]found that neural tissue accounted for less than 35% of the total intervertebral foramen. Other studies found the largest at L₅/S₁ and the smallest at L₁/₂. On the contrary, the L₅/S₁ intervertebral foramen was the smallest. In the study of Rühli FJ et al.[9], osseous intervertebral foramen at the L₅ level was found to be the largest. The value of the hole sagittal diameter is less than
the L1 level. The size of the working trocar used for minimally invasive interbody surgery is chosen to be less than the height of the intervertebral space measured in this paper, and the outer diameter of the annular saw is often chosen to be 7.5 mm [14], without articular projection enlargement, in intervertebral foraminoscopy. The operative space is small, and the lower intervertebral foramen is relatively safe compared to the upper, due to the small number of vital structures. The YESS technique requires Kambin triangle entry, this paper found that the spinal ganglion sagittal diameter is positively correlated with the minimum sagittal diameter of the intervertebral foramen, and careful attention should be paid during surgery. Identify the structures surrounding the intervertebral foramen to avoid damage to the surrounding spinal nerves. The TEYESS requires clipping of the supra-articular foramina to enlarge the intervertebral foramen without entering the intervertebral space through Kambin’s triangle. The trocar is more easily accessed by the enlarged intervertebral foramen.

In addition, T1/2 to L5/S1 intervertebral foramen height observes that the thoracic intervertebral foramen height changes in T2 to T12 with a trend of decreasing first. The trend of change from T2/3 to L5/S1 in the thoracic and lumbar segments is that the first one gradually increases, the second one increases after T6/7, and the third one is the smallest in T11/12. Decreasing to T6/7 minimum, then increasing to T7/8 greater, then decreasing, T9/10 smaller, then increasing, reaching larger at L3/4. Lumbar intervertebral foramen height is greater at L3/4, L4/5, smallest at L1/2, smaller at L5/S1; lumbar L1-S1 the minimum sagittal diameter of the intervertebral foramen tends to increase and then decrease, being smallest at L1/2 and largest at L4/5. Vialle [15] measured the lumbar segments of eight male adult specimens The mean value of the maximum longitudinal diameter of the spinal ganglion was 13.25 mm and the mean value of the minimum sagittal diameter of the spinal ganglion was 7.05 mm, which is similar to that of this paper. The findings were consistent. The intervertebral foramen height in the same segment was greater than the minimum sagittal diameter of the intervertebral foramen. The minimum sagittal diameter of intervertebral foramen in different segments is not statistically significant, and the influence of different
vertebral sequence changes can be ignored when designing. Knowing the change of intervertebral foramen in different segments of the thoracolumbar spine and choosing the correct intervertebral perforator trocar will help to improve the success rate of surgery and reduce the number of cases.

CONCLUSIONS

The minimum height of intervertebral foramen in the thoracolumbar segment was T6/7, and L4/5 was the minimum height in the lumbar segment. When placing a spinal endoscopic working channel safely into intervertebral foramen, it is necessary to perform an enlarging foraminoplasty to reduce the risk of injury to the exiting nerve root.

Acknowledgments

This study was supported by Study on the National Natural Science Foundation of China (81860383, 81560348, 81460330); Natural Science Foundation of Inner Mongolia Autonomous Region (2020MS08124); Young Science and Technology Talents Project of Inner Mongolia Education Department (nyjt-15-b05); Science and Technology Plan Project of Inner Mongolia Autonomous Region (2016, 2019GG115); Science and Technology Innovation Guidance Project of Inner Mongolia Autonomous Region (2017); Natural Science Foundation of Inner Mongolia Autonomous Region (2016ms08131, 2020MS08124). Inner Mongolia Scholarship Fund, Department of Human Resources and Social Services (TDK2017KJBW012).

The authors declare no conflict of interest

REFERENCES

1. Kerezoudisa P, Rajjouba KR, Goncalvesa S. Anterior versus posterior approaches for thoracic disc herniation: Association with postoperative complications. Clinical neurology and neurosurgery. 2018;167:pp17-23. DOI: 10.1016/j.clineuro.2018.02.009.
2. Court C, Mansour E, Bouthors C Thoracic disc herniation: Surgical treatment. Orthopaedics &
3. Bono CM. Lumbar Disc Herniation and Radiculopathy. In: Katz JN, Blauwet CA, Schoenfeld AJ, editors. Principles of Orthopedic Practice for Primary Care Providers. Cham: Springer International Publishing; 2018. p. 37-46.

4. Ahn S-S, Kim S-H, Kim D-W. Comparison of Outcomes of Percutaneous Endoscopic Lumbar Discectomy and Open Lumbar Microdiscectomy for Young Adults: A Retrospective Matched Cohort Study. World neurosurgery. 2016;86:pp250-258. DOI: 10.1016/j.wneu.2015.09.047.

5. He S, Sun Z, Wang Y. Combining YESS and TESSYS techniques during percutaneous transforminal endoscopic discectomy for multilevel lumbar disc herniation. Medicine. 2018;97(28):pp11240. DOI: 10.1097/md.0000000000011240.

6. Kanno H, Aizawa T, Hahimoto K. Minimally invasive discectomy for lumbar disc herniation: current concepts, surgical techniques, and outcomes. International Orthopaedics. 2019.

7. Cramer GD, Cantu JA, Dorsett RD. Dimensions of the lumbar intervertebral foramina as determined from the sagittal plane magnetic resonance imaging scans of 95 normal subjects. Journal of manipulative and physiological therapeutics. 2003;26(3):pp160-170. DOI: 10.1016/s0161-4754(02)54109-9.

8. Zi-xuan W, Tao S. Parameter measurement of lumbar disc related to artificial disc replacement in Chinese. Journal of Clinical Rehabilitative Tissue Engineering Research. 2011;15(48):pp8973-8976.

9. Rühli F, Müntener M, Henneberg M. Human Osseous Intervertebral Foramen Width. American journal of physical anthropology. 2006;129(2):pp177-188. DOI: 10.1002/ajpa.20263.

10. Zhu K, Yan S, Guo S. Morphological changes of contralateral intervertebral foramen induced by cage insertion orientation after unilateral transforminal lumbar interbody fusion. Journal of orthopaedic surgery and research. 2019;14(1):pp79. DOI: 10.1186/s13018-019-1121-1.

11. Tang R, Gungor C, Sesek RF. Morphometry of the lower lumbar intervertebral discs and endplates: comparative analyses of new MRI data with previous findings. European spine journal : official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society. 2016;25(12):pp4116-4131. DOI: 10.1007/s00586-016-4405-8.

12. DaBaYRaK S, YaMan O, YiIMaZ M. Transforminal approach in lumbar disc herniations: transforminal microdiscectomy (TFMD) technique. Turkish neurosurgery. 2015;25(1):pp29-35. DOI: 10.5137/1019-5149.Jtn.8197-13.1.

13. Hoyland J, Freemont A, Jayson M. Intervertebral foramen venous obstruction. A cause of periradicular fibrosis? Spine. 1989;14(6):pp558-568. DOI: 10.1097/00007632-198906000-00002.

14. Zhen-zhou L, Wen-wen W, Shu-xun H. Design and clinical application of the instrument for percutaneous posterolateral lumbar foraminoplasty. Chinese Journal of Orthopaedics. 2011(10):pp1026-1032.

15. Vialle E, Vialle LR, Contreras W. Anatomical study on the relationship between the dorsal root ganglion and the intervertebral disc in the lumbar spine. Revista Brasileira de Ortopedia (English Edition). 2015 2015/07/01/;50(4):pp450-454. DOI: https://doi.org/10.1016/j.rboe.2015.06.013.
Table 1. Measurements of the high of intervertebral foramens, Minimal sagittal diameter of intervertebral foramen (mean ± standard deviation)

| The high of intervertebral foramens (N=340, mm) | Minimal sagittal diameter of intervertebral foramen (N=180, mm) |
|-----------------------------------------------|---------------------------------------------------------------|
| Left                                         | Right                                         | bilateral | P-value | Left                                         | Right                                         | bilateral | P-value |
| T1/2 9.38±0.70                               | 9.03±1.10                                     | 9.20±0.91 | 0.516    | /                                             | /                                             | /         | /       |
| T2/3 9.44±0.83                               | 9.52±1.39                                     | 9.48±1.06 | 0.909    | /                                             | /                                             | /         | /       |
| T3/4 9.43±1.55                               | 8.95±1.73                                     | 9.19±1.55 | 0.359    | /                                             | /                                             | /         | /       |
| T4/5 7.29±1.24                               | 7.51±1.29                                     | 7.40±1.14 | 0.799    | /                                             | /                                             | /         | /       |
| T5/6 6.26±1.07                               | 6.09±1.26                                     | 6.17±1.09 | 0.754    | /                                             | /                                             | /         | /       |
| T6/7 5.49±1.25                               | 6.35±1.52                                     | 5.92±1.20 | 0.471    | /                                             | /                                             | /         | /       |
| T7/8 7.28±3.68                               | 7.69±3.40                                     | 7.48±3.34 | 0.504    | /                                             | /                                             | /         | /       |
| T8/9 10.01±5.97                              | 9.00±6.14                                     | 9.46±5.75 | 0.006    | /                                             | /                                             | /         | /       |
| T9/10 9.31±5.09                              | 9.10±4.74                                     | 9.21±4.64 | 0.626    | 6.63±0.52                                     | 7.23±3.36                                     | 6.93±1.99 | 0.815    |
| T10/11 9.84±3.41                            | 9.85±3.41                                     | 9.71±3.03 | 0.071    | 7.22±1.00                                     | 7.44±0.85                                     | 7.33±1.44 | 0.792    |
| T11/12 10.44±1.68                           | 10.57±1.74                                    | 10.51±1.73 | 0.842    | 7.40±0.56                                     | 7.42±0.82                                     | 7.41±0.63 | 0.976    |
| T12/L1 9.00±1.07                            | 10.23±1.68                                    | 9.50±1.41 | 0.371    | 7.38±1.01                                     | 6.32±0.83                                     | 6.85±1.08 | 0.104    |
| L1/2 12.22±2.10                             | 12.32±1.52                                    | 12.27±1.34 | 0.854    | 7.48±2.35                                     | 6.00±1.29                                     | 6.79±1.86 | 0.218    |
| L2/3 14.71±2.29                             | 15.01±1.26                                    | 14.86±2.36 | 0.799    | 8.70±3.90                                     | 6.94±2.56                                     | 7.82±3.25 | 0.468    |
| L3/4 16.68±2.27                             | 15.21±2.53                                    | 15.94±2.43 | 0.435    | 8.83±2.93                                     | 7.62±1.24                                     | 8.23±2.27 | 0.317    |
| L4/5 15.44±2.23                             | 15.40±2.75                                    | 15.42±2.34 | 0.964    | 9.02±2.61                                     | 9.30±2.22                                     | 9.17±2.33 | 0.789    |
| L5/S1 13.37±2.02                            | 12.40±2.06                                    | 12.88±2.13 | 0.194    | 8.85±2.07                                     | 7.92±1.78                                     | 8.38±1.63 | 0.128    |

F-value 11.27 P < 0.0001 1.91 P > 0.05

Table 2. The transverse diameter of the dorsal root ganglion (n=240, mean ± standard deviation) and longitudinal diameter of the dorsal root ganglion (n=220, mean ± standard deviation)

| The transverse diameter of the dorsal root ganglion(mm) | Longitudinal diameter of the dorsal root ganglion(mm) |
|---------------------------------------------------------|------------------------------------------------------|
| left          | right       | bilateral | P-value | left          | right       | bilateral | P-value |
| T6/7 5.03±1.80 | 4.79±1.49  | 4.91±1.48 | 0.556   | /             | /           | /         | /       |
| T7/8 4.38±0.85 | 4.39±1.18  | 4.38±0.92 | 0.984   | 6.22±0.35    | 7.33±1.00  | 6.95±0.95 | 0.251    |
| T8/9 4.94±1.90 | 5.10±2.00  | 5.02±1.75 | 0.216   | 7.35±1.42    | 6.56±0.22  | 6.96±1.03 | 0.283    |
| T9/10 5.05±1.52 | 4.74±1.67 | 4.90±1.51 | 0.068   | 7.13±0.93    | 6.10±1.21  | 6.71±1.05 | 0.467    |
| T10/11 5.87±1.38 | 5.46±1.65 | 5.66±1.42 | 0.433   | 8.37±2.53    | 7.01±1.07  | 7.69±1.94 | 0.384    |
| T11/12 5.77±1.13 | 5.46±0.81 | 5.61±1.41 | 0.647   | 7.61±1.24    | 7.03±1.14  | 7.31±1.07 | 0.675    |
| T12/L1 5.96±1.38 | 7.66±1.65 | 6.64±2.18 | 0.433   | 8.37±1.53    | 7.01±1.07  | 6.52±1.24 | 0.384    |
|        | Left     | Right    | P1     | Middle  | Bilateral | P2     |
|--------|----------|----------|--------|---------|-----------|--------|
| L1/2   | 6.65±2.10| 6.37±2.56| 0.602  | 6.50±1.55| 6.29±1.51 | 7.67±1.80| 0.806  |
| L2/3   | 6.42±2.26| 6.80±2.47| 0.472  | 9.31±1.21| 7.80±1.41 | 8.55±1.64| 0.499  |
| L3/4   | 8.15±4.11| 7.77±4.72| 0.681  | 12.01±2.20| 10.37±1.70| 11.19±1.14| 0.207  |
| L4/5   | 8.99±4.41| 9.20±6.10| 0.632  | 11.46±1.54| 9.43±1.36 | 10.82±1.09| 0.343  |
| L5/S1  | 4.65±0.46| 4.24±0.86| 0.198  | 10.41±1.61| 11.10±1.81| 10.46±1.49| 0.144  |

**F-value** 3.494  
\[ P < 0.05 \]

|        | Left     | Right    | P1     | Middle  | Bilateral | P2     |
|--------|----------|----------|--------|---------|-----------|--------|
| T2/3   | 3.80±1.37| 3.67±0.58| 0.851  | 5.78±2.11| 4.82±1.88 | 0.256  |
| T3/4   | 3.90±0.62| 3.62±0.60| 0.724  | 4.41±1.05| 3.95±0.8  | 0.388  |
| T4/5   | 3.92±0.38| 3.71±0.49| 0.657  | 4.49±0.38| 3.99±0.51 | 0.1    |
| T5/6   | 4.01±0.50| 4.00±0.84| 0.974  | 4.79±0.84| 4.26±0.78 | 0.268  |
| T6/7   | 4.03±0.91| 4.86±1.30| 0.072  | 4.27±1.39| 4.39±1.16 | 0.868  |
| T7/8   | 5.48±2.07| 5.28±0.73| 0.88   | 4.82±1.15| 5.21±1.5  | 0.651  |
| T8/9   | 5.25±2.21| 5.92±1.08| 0.634  | 4.93±1.23| 5.51±1.49 | 0.497  |
| T9/10  | 6.40±4.05| 6.17±2.47| 0.824  | 4.84±1.82| 6.61±2.87 | 0.3    |
| T10/11 | 6.34±1.83| 8.66±1.65| 0.148  | 6.42±2.55| 7.53±1.84 | 0.421  |
| T11/12 | 9.70±0.61| 8.83±0.81| 0.003* | 8.62±1.02| 8.94±1.37 | 0.674  |
| T12/L1 | 9.29±1.54| 8.94±1.12| 0.551  | 8.81±1.89| 9.01±1.47 | 0.787  |
| L1/2   | 13.39±3.00| 10.06±2.32| 0.229 | 11.45±1.67| 11.63±1.63| 0.888  |
| L2/3   | 15.27±2.53| 13.13±2.38| 0.059 | 14.19±2.37| 14.18±2.15| 0.993  |
| L3/4   | 14.56±2.73| 12.83±1.85| 0.236 | 15.26±2.21| 13.69±2.35| 0.293  |
| L4/5   | 13.72±2.06| 14.40±0.70| 0.558 | 18.22±2.21| 14.06±1.47| 0.002* |
| L5/S1  | 13.47±1.54| 13.16±1.34| 0.631 | 20.00±0.82| 13.32±1.37| 0.000* |

Note: P1 for left-right side comparison; P2 for middle and bilateral comparison. *: 
\[ P<0.05 \], the difference is statistically significant.
Figure 1. Lumbar intervertebral foramen of the thoracic vertebrae, measuring the height of the intervertebral disc.

Figure 2. Posterior view of the spinal canal.

Figure 3. a: sympathetic dry b: gray white traffic branch c: lumbar artery d: vertebral e: pedicle anterior branch.

Figure 4. measuring the right side of the intervertebral disc a vertebral body b intervertebral disc.

Figure 5. a: spinal ganglion wide b: spinal ganglion sagittal diameter c: dural sac d: pedicle e: spinal nerve posterior root.

Figure 6. The minimum sagittal diameter of the intervertebral foramen is positively
correlated with the sagittal diameter of the spinal ganglia.

**Figure 7.** High correlation analysis between the height of intervertebral foramen and the left and right sides and the middle of intervertebral space.