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The Morphology of the Lumbosacral Articular Processes in Adult Chinese and Its Biomechanical Implication

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Authors' contributions

This work was carried out in collaboration between all authors. Authors LQX and YJX jointly designed the study. Author YJX prepared the specimens and took photos. Author LQX analyzed the data and prepared the first draft. Author QPM managed the literature searches and finalized the manuscript. All authors read and approved the final manuscript.

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Short Research Article

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ABSTRACT

Aim: The morphology of the lumbosacral intervertebral joints in the Chinese race was investigated in the present study to understand the relationship between the articular joint interface and intervertebral disc prolapses.
Methods: Spine specimens (N=30) from both male and female adults with ages ranging from 30 to 60 years old were used. They were fixed with 3% formaldehyde, frozen and cut through the intervertebral joints and the intervertebral disc. The angle between the facet joint interface and the median sagittal line on both sides was measured for each joint.

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Results: The angle between the facet joint interface and the median sagittal line increased gradually from the L1-L2 joint to L5-S1 joint, and the angles in the L4-L5 and L5-S1 joints were both significantly wider than those of other lumbar intervertebral joints. When the angles on the left side were compared with those of the right side, those on the left side were significantly wider than those on the right side. Since the force acting toward the intervertebral disc can be decomposed into one component perpendicular to the facet joint interface and one parallel to the facet joint interface, when the facet joint interface is in a more sagittal position, it blocks less shearing force that acts to slide the vertebra anteriorly. When the facet joint interface is in a more coronal position, it blocks most of the force.

Conclusion: Although the L1 –S1 are more coronal in positions on the left side, most disc prolapses happen on the left side, suggesting that some adaptive processes might contribute to the more coronal orientation of these facet joint interfaces or the shearing force act more along the facet joint interface on the other side.

Keywords: Intervertebral joints; facet joint interface; disc prolapses; lumbrosacral; sagittal line.

1. INTRODUCTION

In a motion segment, the intervertebral disc and the articular processes work synergistically to ensure the stability and mobility of the spine in all spatial planes [1]. The articular processes, which can undergo movements of rotation and translation, are like tracks to guide the movement of one vertebra with respect to an adjacent one. The occurrence of unwanted movements of translation or shearing forces is pronounced in the lower lumbar spine. The shearing forces at the level of the lumbosacral interface are most pronounced as it is tilted with respect to the horizontal plane (30°). The alignment of the articular processes might affect the forces acting on the intervertebral disc [2,3].

Several studies have examined the relationship between the intervertebral disc prolapse and the articular processes both in Chinese and in other races, using magnetic resonance imaging (MRI) or computed tomography [3-7]. These studies tend to be more interested in examining the proportion of facet tropism among subjects and its relationship with disc herniation and other disc problems [5,6], or focusing on the L4-L5 facet joint angulations [7]. The tropism has been defined as a difference of 5° [8], 7° [6], 8° [7] or 10° [5] in facet joint angles between right and left sides. The proportion of tropism depends on the criterion being used, and the one using 10° has the smallest proportion of tropism among the subjects examined.

The aim of the present study is to measure the facet joint angles in lumbosacral segments with lumbar spine sections, and examine their difference between the right and left sides, and its biomechanical implications in the Chinese race. Since previous studies have been mainly performed with MRI or computed tomography [5-7], it is worthwhile to investigate with anatomical techniques whether any particular features of lumbosacral vertebrae and their processes contribute to the stability of intervertebral discs or whether the intervertebral disc prolapse and the orientation of the articular processes are highly correlated in Chinese subjects.

2. MATERIALS AND METHODS

Thirty lumbosacral spine specimens preserving muscle tissues and ligaments were collected from 30 adult Chinese cadavers (27 males and 3 females, whose ages range from 30 to 60 with an average age of approximately 40) fixed with 3% formaldehyde solution. These specimens included had no observable fracture, tumors or deformations caused by tuberculosis or arthritis. Specimens with obvious fracture, tumors or deformations caused by tuberculosis or arthritis would be excluded. The spine specimens were stored in 3% formaldehyde for 72 hours, frozen at -20℃, and cut through the intervertebral joints and the intervertebral disc (as shown in Fig. 1). The median sagittal line was determined first and then the line connecting the two ends of each inter-vertebral facet joint drawn to represent the facet joint interface (Fig. 2). The angle formed by the facet joint interface and the median sagittal line represents the sagittalization of the articular process, which has been hypothesized to be correlated with disc prolapse [3].

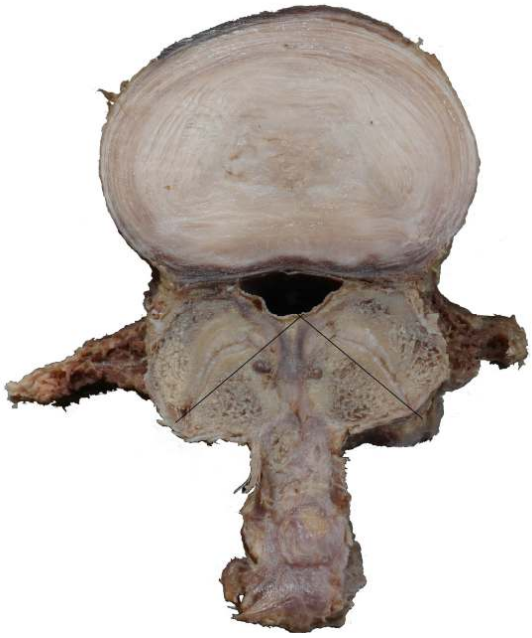

Fig. 1. Sectional view of an L3-L4 intervertebral disc

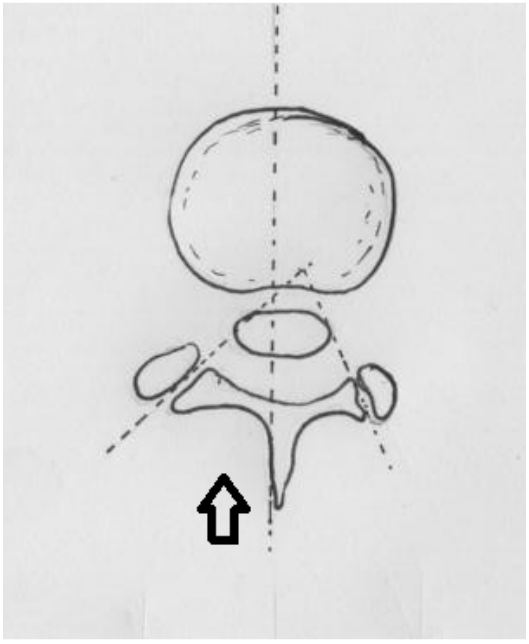

Fig. 2. A sketch to illustrate how the median sagittal line and the facet joint interface are determine. The median sagittal line was the line that divides the intervertebral joints into equal halves; the facet joint interface was represented by the line connecting the two ends of each inter-vertebral facet joint. The arrow indicates the angle on the left side

Five lumbosacral intervertebral joints, L1-L2, L2-L3, L3-L4, L4-L5 and L5-S1, were examined. For each joint, the angle between the facet joint interface and the median sagittal line on both sides was measured. All data are expressed as mean ± SD. The significance of the difference between the angles on the left and right sides of the intervertebral joints was examined by Student *t*-test. Normality test was conducted and the null hypothesis of normality was not rejected. The significance of differences between angles of different joints was examined by the one-way analysis of variance (ANOVA) followed by the post-hoc Tukey test. A probability $P<0.05$ was considered significant.

The potential relationship between the sagittalization of the articular process and the disc prolapse was analyzed by the components of the force acting on the intervertebral disc and the articular process. The force was decomposed according to the parallelogram law.

3. RESULTS

The alignments of the articular process joint on the two sides were not symmetric. As shown in Table 1, the angle between the facet joint interface and the median sagittal line increased gradually from the L1-L2 joint to L5-S1 joint, and there were significant differences in this angle among these lumbosacral intervertebral joints in the angles formed by the facet joint interface and the median sagittal line (ANOVA, $P<0.05$). The post-hoc Tukey test showed that the angles in the L4-L5 and L5-S1 joints were both significantly wider than those of other lumbar intervertebral joints, i.e. the facet joint interfaces in the L4-L5 and L5-S1 joints are in less sagittal positions than those in other intervertebral joints. When the angle on the left side was compared with that of the right side, those on the left side were significantly wider than those on the right side (*t*-test, $P<0.001$), that is, the facet joint interface on the right side are in more sagittal positions than those on the left side.

The few specimens from females were not noticeably different from those from males. As the specimens in the present study were mainly from males, these observations are insufficient to draw any conclusion on the relationship between facet asymmetry and gender. The specimens in the present study did not show any clear relationship between facet asymmetry and age either. This finding could be due to either that the sample size of the present study is not large

enough, or that there is really no clear relationship between facet asymmetry and age.

Table 1. Angles between the facet joint interface and the median sagittal line in lumbar and sacral segments (mean±SD)

	Left	Right	Paired *t* test
L1-L2	33.6±1.3	31.5±1.3	***
L2-L3	35.2±1.4	30.3±1.3	***
L3-L4	41.4±1.7	37.0±1.7	***
L4-L5	50.1±1.9	44.4±1.8	***
L5-S1	54.2±1.9	48.0±1.9	***

*** *P<0.001*

4. DISCUSSION

If a difference of 10° in facet joint angles between right and left sides is defined as being asymmetric or tropism [5], these intervertebral joints in the present observations are not asymmetric in their facet joint angles, which is consistent with the finding of Chadha et al. [5]. If a difference of 7° is defined as being asymmetric or tropism [6], only 1 in 30 of the L4-L5 joint is asymmetric and there is no tropism in other lumbar joints, which is consistent with the finding of Samartzis et al. [7], indicating a much lower incidence of tropism than that found by Kong et al. [6]. With the definition of a difference of 5° [8], a high proportion of lumbar joints would be found to have tropism.

As the angle formed by the articular process joint and the median sagittal line is asymmetric with the left side wider than the right side, the force exerted on the intervertebral disc from the back is also asymmetric. In terms of the role of the articular process, the force acting toward the intervertebral disc can be decomposed into one component perpendicular to the facet joint interface and one parallel to the facet joint interface. Biomechanical analysis suggests that a facet joint interface in a more coronal position is more efficient in blocking the shearing force. When the facet joint interface is in a more sagittal position, it blocks less shearing force that acts to slide the vertebra anteriorly. When the facet joint interface is in a more coronal position, it blocks most of the force. The morphology of the intervertebral joints seems to suggest that the right side be more likely to have disc prolapse.

The present study found that in the L4-L5 and L5-S1 intervertebral joints the facet joint interfaces are in more coronal positions than those in other joints, and the facet joint interfaces on the left side also in more coronal positions than those on the right side in the Chinese race. However, clinical observations on Chinese patients found that most intervertebral disc prolapses occurred in L4-L5 and L5-S1 level, about 60% of which are in L4-L5 intervertebral disc. Moreover, more cases happened on the left side than on the right side [9]. This apparent contradiction between the biomechanical analysis and clinical observations might be explained by adaptive changes or the shearing force act more along the facet joint interface on the other side. As the L4-L5 and L5-S1 discs bear more compressive and shearing forces, the facet articular interface at this level need to be more coronal to relieve the shearing force acting on the intervertebral discs. Similarly, muscles on the right side tend to be stronger and various movements of the spine might exert more forces on the left side of the vertebrae and intervertebral discs, therefore the facet joint interfaces on the left side need to be in more coronal positions. These findings in the Chinese race are consistent with those reported by Kénési and Lesur [3].

In a multicenter (33 institutions) study of 349 patients from Asia Pacific region including many Chinese, the mean angle of the left side facet joint is 48.2° with a range between 20.0° and 85.0° and an SD of 13.7°, and the mean angle of the right side facet joint is 46.1° with a range between 22.0° and 86.0° and an SD of 12.9°, in the 82 patients without L4-L5 degenerative spondylolisthesis [7]. The present results on the L4-L5 joint are in line with the study by Samartzis et al. [7], which has not examined L1-L2, L2-L3, L3-L4, and L5-S1 joints. The smaller SD in the present study is probably due to the fact the subjects were more homogeneous than the multicenter study in terms of race. The angles between the facet joint interface and the median sagittal line in the present study are also similar to those reported on those in black and white population [4]. Masharawi and colleagues report that the facets of L3-L5 are oriented away from the median sagittal line with a mean range of 40.40° to 56.30° in black and white adults. Because they examined a larger and more diverse sample size with both black and white adults, the range of the angles between the facet joint interface and the median sagittal line is wider than these found in this study. The tropism of facet joints in the present study is also similar to those reported by Chadha et al. [5], when their definition of tropism is used.

The intervertebral disc and the articular processes form a synergistic complex to ensure the stability and mobility of the spine in all spatial planes. When the spine undergoes movement, the articular processes and the intervertebral joints provide some protection to the intervertebral disc in front. Since the L5-S1 interface slants at 30° with respect to the horizontal plane, its weight bearing force exerts a shearing effect on the intervertebral disc. This shearing force contributes partially to high incidence of L5-S1 disc prolapses [3]. Comparatively, the L4-L5 interface slants at a much smaller angle with respect to the horizontal plane, so that the weight bearing force has a smaller shearing effect on the intervertebral disc at this level. The higher incidence rate of the L4-L5 disc prolapse appears to arise due to factors other than weight bearing.

When the body is bending forward to lift a weight, the lumbosacral disc bears a much increased compressive force because of a very large lever arm about the sacrum [10]. If it is weakened by age or injury, the disc can herniate or extrude to the point that nerves in the surrounding tissues are irritated, causing pain and muscle spasms. The erector spinae is a muscle group responsible for extending the vertebral column. It is attached to the medial crest of the sacrum, to the spinous processes of the lumbar, and to the lateral crests of the sacrum etc., such that other lumbar intervertebral discs also suffer from a substantial compressive force when the body is bending to lift a weight. The higher incidence of L4-L5 disc prolapses might be due to such factors.

The current study has a relatively small sample size, making it not possible to examine the relationship between age and articular interface asymmetry. It is also difficult to determine a criterion to differentiate interfaces with marked asymmetry from those with less asymmetry. A larger sample size is needed to obtain more detailed information.

5. CONCLUSION

The facet joint interfaces in the Chinese race observed in the present study have two features, 1) from L1-L2 to L5-S1 the facet joint interface become more aligned coronally; 2) the facet joint interface is more sagittal on the right side. Although from L1–L2 to L5-S1 the facet joint interfaces are more coronal in positions on the left side, most disc prolapses happen on the left side, suggesting that some adaptive processes might contribute to the more coronal orientation of these facet joint interfaces or the shearing force act more along the facet joint interface on the other side.

CONSENT

It is not applicable.

ETHICAL APPROVAL

All authors hereby declare that all experiments have been examined and approved by the appropriate ethics committee and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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