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Critical Review

Influence of lumbar disc degeneration on the efficacy of lumbar fixed-point rotation manipulation in sitting position: a finite element study

腰椎退变对坐位腰椎定点旋转手法疗效影响的有限元分析

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Abstract

Objective: To investigate the influence of lumbar disc degeneration on the efficacy of lumbar fixed-point rotation manipulation in sitting position in treating lumbar intervertebral disc herniation (LIDH).

Methods: We simulated lumbar fixed-point rotation manipulation of sitting position using three finite element models including a normal model, a mild degeneration model and a moderate degeneration model of L_{3-5}, in which the herniated disc was assumed at the left rear of L_4 disc and the rotation manipulation was carried out on the right side. The displacement and stress at the left rear of L_4 disc of the three models were analyzed.

Results: When lumbar fixed-point rotation manipulation in sitting position was carried out, a displacement and stress were generated at the left rear of L_4 intervertebral disc of the three models directing forward. The displacement and stress in degeneration models were less than those in the normal model, and the smallest values were found in the moderate degeneration model. From normal model to mild and then to the moderate degeneration model, the displacement decreased by 36% and 59%, and the stress decreased by 22.3% and 45.2%, respectively.

Conclusion: The lumbar disc degeneration affects adversely the effectiveness of lumbar fixed-point rotation manipulation in sitting position in the treatment of LIDH. The severer the lumbar degeneration, the greater the influence.

Keywords: Tuina; Massage; Intervertebral Disc Degeneration; Lumbar Fixed-point Rotation Manipulation in Sitting Position; Finite Element Analysis

【摘要】目的：研究腰椎间盘退变对坐位腰椎定点旋转手法治疗腰椎间盘突出症疗效的影响。**方法：**应用 L_{3-5} 正常模型、轻度退变模型与中度退变模型模拟坐位腰椎定点旋转手法，假定椎间盘突出发生于 L_4 椎间盘左后方，行右侧手法操作。分析 3 个模型中 L_4 椎间盘左后方的应力与位移。**结果：**手法作用下，L_4 椎间盘左后方发生向前的应力与位移，退变模型的应力与位移值小于正常模型，最小值见于中度退变模型；自正常模型至轻度与中度退变模型，位移值分别降低 36%和 59%，应力值降低 22.3%和 45.2%。**结论：**腰椎退变影响坐位腰椎定点旋转手法治疗腰椎间盘突出症的疗效，退变越重影响越大。

【关键词】推拿；按摩；椎间盘退化；坐位腰椎定点旋转手法；有限元分析
【中图分类号】R244.1　　**【文献标志码】**A

Low back pain (LBP) is one of the intractable chronic diseases, and lumbar disc herniation (LIDH) alone accounts for about 50% of low back pain cases[1], seriously affecting the patients' quality of life (QOL)[2-3]. In addition, LIDH aggravates the burden of social insurance system and leads to the loss of labor force. Therefore, it has attracted high attention in the field of health care. Non-surgical treatments have been regarded as the primary option, with an average success rate of 67%[4].

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Tuina is often used in the treatment of LBP in traditional Chinese medicine (TCM), and its effect has been confirmed by numerous clinical reports[5-7]. In the field of tuina, lumbar fixed-point rotation manipulation in sitting position is one of the most commonly used manipulations in the treatment of LIDH. Many clinical studies have confirmed its effect. Some scholars studied the manipulation using finite element technique. In a study of finite element, Wu S, *et al* found that lumbar fixed-point rotation manipulation in sitting position present with more significant safety and effect when compared with straight lumbar rotation manipulation[8]. In another study, Xu HT, *et al* concluded that different flexion angle may affect the effect of this manipulation[9].

Moreover, lumbar disc degeneration is common in patients with LIDH. Lumbar disc degeneration results in disc height loss and alterations of disc components, accompanied by decreased elasticity and increased stiffness in lumbar intervertebral disc, and leads to the changes of the biomechanics of lumbar segment[10]. As a result, we speculate that lumbar disc degeneration may affect stress and displacement of intervertebral discs during the process of lumbar fixed-point rotation manipulation in sitting position, and affect the effect of the manipulation. However, no relevant studies have been published in English up to now.

Therefore, we carried out a comparative study using three-dimensional finite element models of L_{3-5}, to determine the biomechanical influence of lumbar disc degeneration on the efficacy of lumbar fixed-point rotation manipulation in sitting position in treating LIDH.

1 Material and Methods

1.1 Models

A normal model, a mild degeneration model, and a moderate degeneration model of L_{3-5} were developed and validated in our previous study, and were used in the current study (Figure 1)[11].

The degeneration models were developed from the normal model and the degeneration was assumed to be at L_4 level[10]. In clinic, lumbar fixed-point rotation manipulation in sitting position is performed much less frequently for severe degeneration discs, so in the current study we didn't analyze the severe degeneration model. The material properties of the models were defined based on our previously published literatures (Table 1)[10-11].

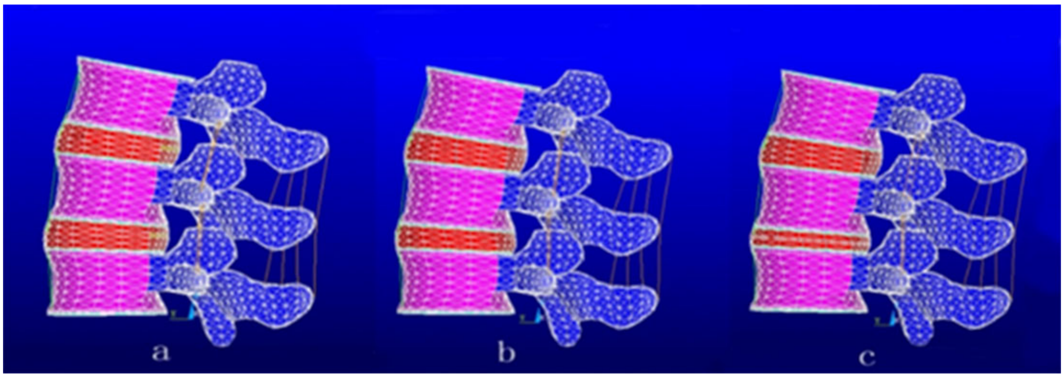

Figure 1. Model (Note: a. normal model; b. mild degeneration model; c. moderate degeneration model)

Table 1. The material properties in the finite element models

Item	Young's modulus (MPa)	Poisson's ratio	Element type	Element number	Cross-section (mm^2)
Cortical bone	12 000	0.3	Solid186	/	/
Cancellous bone	100	0.2	Solid186	/	/
Fiber	92	0.45	Solid186	/	/
Endplate	500	0.25	Solid186	/	/
Posterior elements	3 500	0.30	Solid186	/	/
Facet cartilage	3 500	0.25	Solid186	/	/
Capsular ligament	7.7	0.39	Link180	24	102.5
Anterior longitudinal ligament	11.9	0.39	Link180	20	75.9
Posterior longitudinal ligament	12.5	0.39	Link180	10	51.8
Ligamentum flavum	2.4	0.39	Link180	6	78.7
Interspinous ligament	3.4	0.39	Link180	6	36.3
Supraspinous ligament	3.4	0.39	Link180	2	75.7
Transverse ligament	3.4	0.39	Link180	10	2

The normal model was created based on the computed tomography scan of a 26 year-old healthy male volunteer. It consisted of vertebrae, intervertebral discs, endplates, superior and inferior facet articulating surfaces, ligaments and capsules. The vertebrae and intervertebral discs, which were meshed using eight-node solid 186 elements, consisted of 155 304 elements. The seven spinal ligaments were represented by link 180 elements, not offering any resistance under compression. The surfaces of facet joints were simulated by a cartilaginous layer, and the contact between the facet joints was surface-to-surface contact elements without friction. The facet joints had a gap of 0.5 mm and can only transmit compressive forces[10].

The intervertebral discs consisted of nucleus pulposus and annulus fibrosus. The nucleus pulposus, modeled by an incompressible material, was 43% of the total disc volume and located slightly posterior to the center of the disc[11]. The annulus fibrosus was assumed to be a composite of a homogenous ground substance reinforced by collagen fibers. The nucleus and annulus ground substance were modeled using the isotropic, incompressible, hyper-elastic Mooney-Rivlin (C_1, C_2) formulation, in which the material constituents of C_1 and C_2 were defined according to previously accepted values (Table 2)[10].

Table 2. Material properties for annulus ground substance and nucleus pulposus in L_{4-5} segment of the three models

Location	Normal model	Mild degeneration model	Moderate degeneration model
Nucleus pulposus	E=0.9 MPa	E=1.07 MPa	E=1.25 MPa
	C_1=0.12	C_1=0.14	C_1=0.17
	C_2=0.03	C_2=0.035	C_2=0.041
Annulus ground substance	E=1.35 MPa	E=1.35 MPa	E=1.35 MPa
	C_1=0.18	C_1=0.18	C_1=0.18
	C_2=0.045	C_2=0.045	C_2=0.045

Note: E=Modulus of elasticity

The mild and moderate degeneration models were developed from the normal model. Compared to the normal healthy L_{4-5} disc, the mild and moderate degeneration discs had 20% and 40% less height respectively. The corresponding C_1 and C_2 coefficients of degenerative discs were from previous values (Table 2)[11]. We assumed that disc degeneration had no effect on the material properties of the annulus ground substance[10-11]. In addition, the endplates of L_{4-5} in degenerative models were modified according to previous methods[10].

2 Boundary and Loading Conditions

In the study, we assumed that the disc herniation should occurr on the left rear of L_4 intervertebral disc. Based on the recognized principle, the manipulation should be performed in the opposite direction of the disc herniation, i.e., on the right[12]. To simulate lumbar fixed-point rotation manipulation in sitting position, the inferior endplate surface of L_5 was fixed in all directions, a 15 Nm right axial rotation moment under 300 N compressive loading was imposed on L_3 superior endplate, a 3 Nm moment was imposed on the right lateral area of L_4 spinous process in the left front 30° direction, along with 9° forward flexion and 6° lateral bending on the right. The time at the end of the load steps was defined as 0.25 s, and the maximum load was achieved in fifteen substeps for each model[8]. The displacement and stress in the intervertebral disc of L_4 were investigated.

3 Results

When lumbar fixed-point rotation manipulation in sitting position was carried out, a displacement which directed forwards concentrated on the left rear of the intervertebral disc. The displacement in mild and moderate degeneration models presented with similar distribution to that in the normal model, but the displacement in degeneration models was less than that in normal model, and the smallest displacement was found in the moderate model. From normal to mild and moderate degeneration model, the displacement decreased by 36% and 59% respectively (Figure 2).

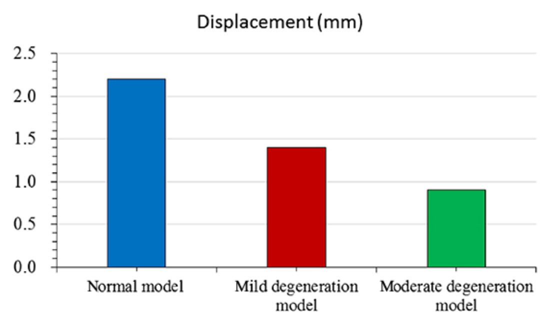

Figure 2. Displacements at the back of intervertebral disc of L_4 in three models

In the current study, the value and direction of stress were consistent with the distribution of displacement. In addition, the stress in mild and moderate degeneration models presented with similar distribution to that in the normal model, but the stress intensity in degeneration models was less than that in the normal model, and the value in moderate degeneration model was less than that in mild degeneration model. From normal to mild and moderate degeneration model, the stress decreased by 22.3% and 45.2% respectively (Figure 3).

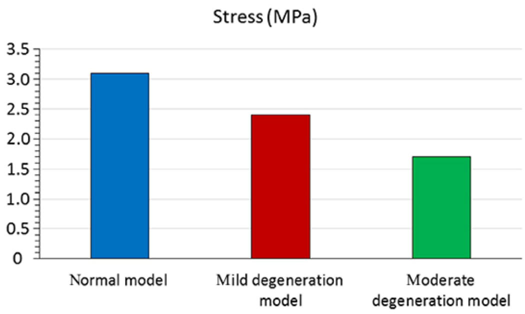

Figure 3. The stress at the back of L_4 disc in three models

4 Discussion

In the current study, we evaluated the influence of lumbar disc degeneration on the efficacy of lumbar fixed-point rotation manipulation in sitting position in the treatment of LIDH. Compared with a clinical study, a finite element technique has many advantages. It presents with high reproducibility and repeatability, and can simulate different degenerative conditions of lumbar spine or different tuina manipulations by adjusting the material properties, model geometry and loading conditions[10,13-14]. Hence, we adopted finite element techniques to carry out the current study.

In terms of the mechanism of tuina for the treatment of LIDH, most physicians advocate that displacement and stress produced between nerve roots and the protruded intervertebral discs during the process of manipulations[12-15] can reduce the compression, alleviate the edema and release the adhesion of nerve roots, resulting in the improvement of symptoms[16-17]. Consequently, in the study we focused on the comparison of the stress and displacement of intervertebral disc between different degeneration models.

We found that, under lumbar fixed-point rotation manipulation in sitting position, displacement and stress intensity at the left rear of L_4 disc presented with the largest value in the normal model, but decreased gradually with the increase of intervertebral disc degeneration. From normal to mild and moderate degeneration model, the displacement decreased by 36% and 59%, and the stress decreased by 22.3% and 45.2%, respectively. This demonstrates that lumbar disc degeneration may adversely affect the efficacy of lumbar fixed-point rotation manipulation in sitting position, i.e., under the same manipulation forces, the biomechanical effect on patients with moderate disc degeneration may be not as satisfying as that on those with mild degeneration. During the process of lumbar degeneration, the material properties as well as materials parameters in intervertebral discs will change, resulting in the increase of stiffness, and affecting the stress conduction and displacement distribution[10-11]. This may explain the current outcomes.

In addition, when lumbar fixed-point rotation manipulation in sitting position is carried out, the stress in intervertebral disc is much less than that in the back structure. Also, the stress in the facet joints is much lower than the magnitude which may cause articular cartilage fracture. This indicates that lumbar fixed-point rotation manipulation in sitting position is safe and won't result in the injury of intervertebral disc or facet joints, which is consistent with some published studies[12, 18].

In short, we have concluded from the current study that lumbar disc degeneration can adversely affect the result of lumbar fixed-point rotation manipulation in sitting position. However, this study only focused on the influence of lumbar disc degeneration on lumbar fixed-point rotation manipulation in sitting position, but didn't study other manipulations. Different manipulations may present with different biomechanical features, and the influence of disc degeneration on other manipulations is yet unclear. Subsequently, to clarify these issues, more studies are expected in the future.

Conflict of Interest

The authors declared that there was no potential conflict of interest in this article.

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