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Effects of C5/C6 Intervertebral Space Distraction Height on Pressure on the Adjacent Intervertebral Disks and Articular Processes and Cervical Vertebrae Range of Motion

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Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
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Background: This study aimed to investigate the association between range of motion of the cervical vertebrae and various C5/C6 intervertebral space distraction heights.

Material/Methods: The cervical vertebrae from 6 fresh adult human cadavers were used to prepare the models. Changes in C4/C5 and C6/C7 intervertebral disk pressures, articular process pressure, and range of motion of the cervical vertebrae before and after the distraction of the C5/C6 intervertebral space at benchmark heights of 100%, 120%, 140%, and 160% were tested under different exercise loads.

Results: The pressure on the adjacent intervertebral disks was highest with the standing upright position before distraction, varied with different positions of the specimens and distraction heights after distraction, and was closest to that before distraction at a distraction height of 120% ($P<0.05$). The pressure of the adjacent articular processes was highest with left and right rotations before distraction, varied with different positions of the specimens and distraction heights after distraction, and was lowest under the same exercise load with different positions at a distraction height of 120% ($P<0.05$). The ranges of motion of the cervical vertebrae and intervertebral disks were largest without distraction and at a distraction height of 120% after distraction, respectively ($P<0.05$).

Conclusions: When removing the C5/C6 intervertebral disk and implanting an intervertebral bone graft, a benchmark height of 120% had little influence on the pressure of the adjacent intervertebral disks and articular processes and range of motion of the cervical vertebrae and is therefore an appropriate intervertebral space distraction height.

MeSH Keywords: Cadaver • Cervical Vertebrae • Intervertebral Disc

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Background

Anterior surgery was first described in the 1950s and is widely accepted as a standard surgical treatment for cervical spondylosis refractory to conservative management [1,2]. Cervical disk removal, interbody fusion, and intervertebral disk replacement are commonly-used surgical approaches in the treatment of cervical spondylosis, but many studies have found that cervical fusion can lead to the degeneration of adjacent vertebral bodies [3–5]. Degeneration of adjacent vertebral bodies is mainly characterized by changes in the pressure of adjacent intervertebral disks and articular processes, and the range of motion of cervical vertebrae. In this study, we simulated the anterior approach of the cervical intervertebral disk (C5/C6) as an example. In accordance with the various distraction heights of the cervical intervertebral space, we analyzed the change patterns in the pressure of adjacent intervertebral disks and articular processes, as well as the range of motion of the C5/C6 cervical vertebrae, to gain better understanding of the degeneration of adjacent vertebral bodies after anterior-approach cervical fixation.

Material and Methods

Materials

Six fresh young adult male human cadavers provided by Southern Medical University were selected. Before the selection, medical records were reviewed, and frontal and lateral radiographs of the cervical spine were taken. No carotid vertebra trauma, cervical tumor, severe osteoporosis, or severe cervical degenerative disease were found in the 6 cadavers. The ages of the cadavers at time of death ranged from 24 to 40 years (mean ±SD: 29.6±8.30 years). The heights ranged from 1.65 to 1.80 m (1.73±0.0 m) and body weights from 63 to 83 kg (71.6±6.20 kg). The time of sample collection was 3.5 to 5.0 h (4.2±0.8 h) after death, and the storage time was 15 to 25 days (21.6±3.9 days).

Model preparation

The C1 to T1 vertebrae of each cadaver were used to prepare the specimen. The skin, subcutaneous fat, fascia, and other soft tissues surrounding the specimens were removed. The ligaments, intervertebral disks, and articular capsules stabilizing the vertebral bodies were retained, sealed with double-layer plastic bags, and stored at -20°C in a refrigerator. The specimens were thawed naturally 24 h before the experiment.

Experimental methods

Model installation

Denture-based, resin solution type II self-coagulation denture drops were dripped into denture-based resin type II self-coagulation care powder and evenly mixed to embed the C1–C3 vertebral bodies and C7–T1 vertebral bodies of all the specimens (Shanghai New Century Dental Materials Co., Ltd.). The embedded specimens were fixed on a BOSE moving/static material testing machine, with the upper and lower ends parallel to the docking interface of the Instron digital electrohydraulic server fatigue testing machine, so that the cervical specimens were in the normal physiological bending state.

Measurement methods of intervertebral disk and articular process pressure of the specimens

A micro-pressure transducer (Precision Measurement [US], model 060, serial No. 7307; measuring range, 0–3.4 Mpa; diameter, 1.5 mm; and thickness, 0.3 mm) was connected to an amplifier, and the micro-pressure sensor was placed in the center of the C4/C5 and C6/C7 intervertebral disks and articular processes by using a Kirschner wire with a diameter of 2 mm. To prevent sensor detachment, the puncture holes were closed with Pattex Adhesive (batch No. 120835, Henkel Adhesive Co., Ltd.). The changes in the pressures of the intervertebral disk (Figure 1A) and articular process (Figure 1B) at standing upright (i.e., cervical vertebral flexion position under a natural state), 30° flexion, 30° extension, and 30° left- and right-side bending positions under a 2.50-Nm force moment load, which was the natural state of the anterior cervical flexion position, were measured. Each experiment was first conducted with a preload to remove the impact of cervical soft tissue creep relaxation. Then, the measurement was repeated 3 times, and the average values of the 3 measurements were taken as the values for the intervertebral disk and articular process pressure.

Measurement method of range of motion of the cervical vertebrae

A mechanical testing machine (MX-5000N-350, Shenzhen Chuang Lian Da Tooling Co. Ltd.) was used to test the range of motion of the cervical vertebrae under a 2.50-Nm force moment load (Figure 2).

Intervertebral disk resection and intervertebral bone graft

The Smith-Robinson intervertebral disk resection method was used to remove the anterior longitudinal ligament, intervertebral disk, and cartilage endplate in front of the C5/C6 intervertebral space, while the posterior longitudinal ligament was

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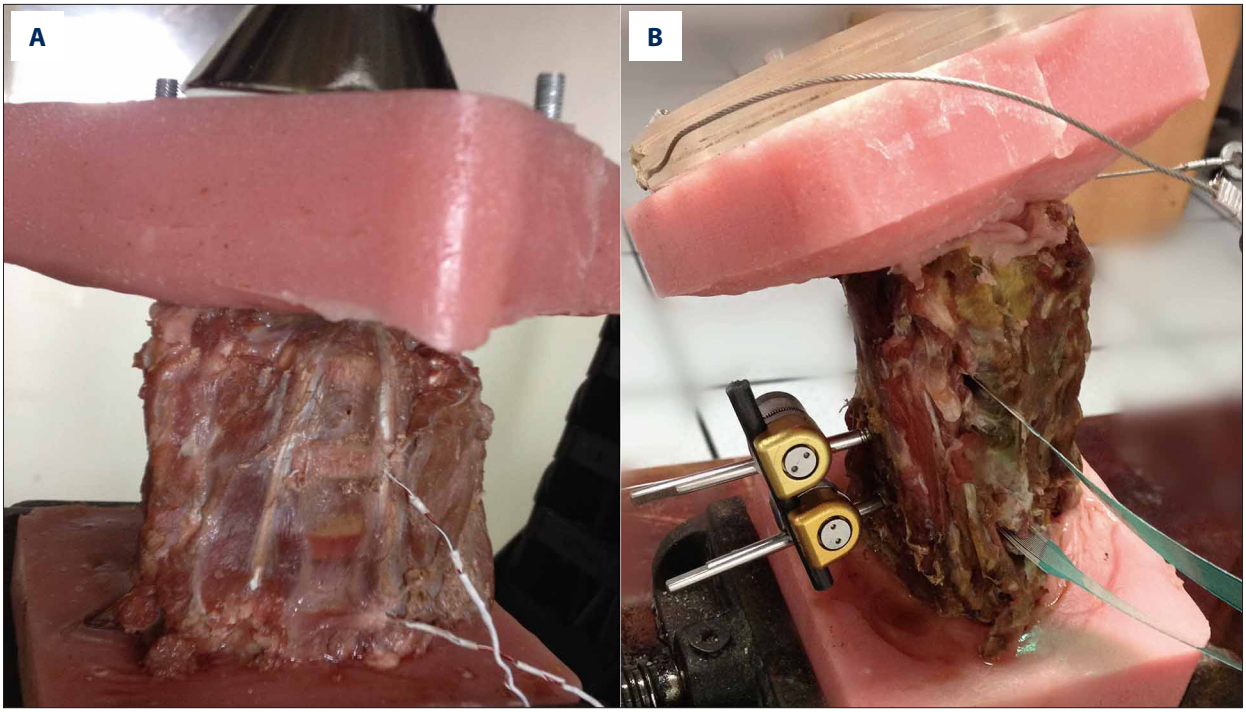

Figure 1. Pressures in the intervertebral disk (**A**) and articular process (**B**) tests.

Figure 2. The test method for the range of motion of the cervical vertebrae under a 2.50-Nm force moment load.

retained. A distraction screw was inserted in the center of the C5 and C6 vertebral bodies, and a distraction device (provided by Shandong Weigao Group Medical Polymer Co., Ltd. – Guo Shi Yao Xie Zi [Zhun] 2013 No. 3650801) was used to open the intervertebral space to simulate a clinical bone graft (Figure 3A).

Intervertebral height measurement

The height of the anterior edge of the C5/C6 intervertebral space was accurately measured on the basis of the lateral radiograms of the cervical vertebra specimens. The mean height of the anterior edges of the C4/C5 and C6/C7 intervertebral spaces was used as the benchmark height for C5/C6 intervertebral bone grafting, and 100% (i.e., benchmark height, M), 120%, 140%, and 160% of the benchmark height were calculated (Figure 3B). Panjabi's hybrid test method was used to study the effect of the simulated surgery on adjacent sections. In this experiment, 5 states were tested in the following order: (1) normal intact cervical vertebrae (i.e., before distraction); (2) simulated bone graft at 100% of the benchmark height; (3) simulated bone graft at 120% of the benchmark height; (4) simulated bone graft at 140% of the benchmark height; and (5) simulated bone graft at 160% of the benchmark height.

Statistical methods

Statistical Package for the Social Sciences version 19.0 software was used to conduct one-way analysis of variance on intervertebral disk pressure, articular process pressure, and range of motion of the cervical vertebrae in the C4/C5 and C6/C7 segments of the 6 specimens in the 5 states. After obtaining homogeneity of variances, multiple comparisons (least significant difference test) among the experimental groups were performed. Differences with P values of <0.05 were considered significant.

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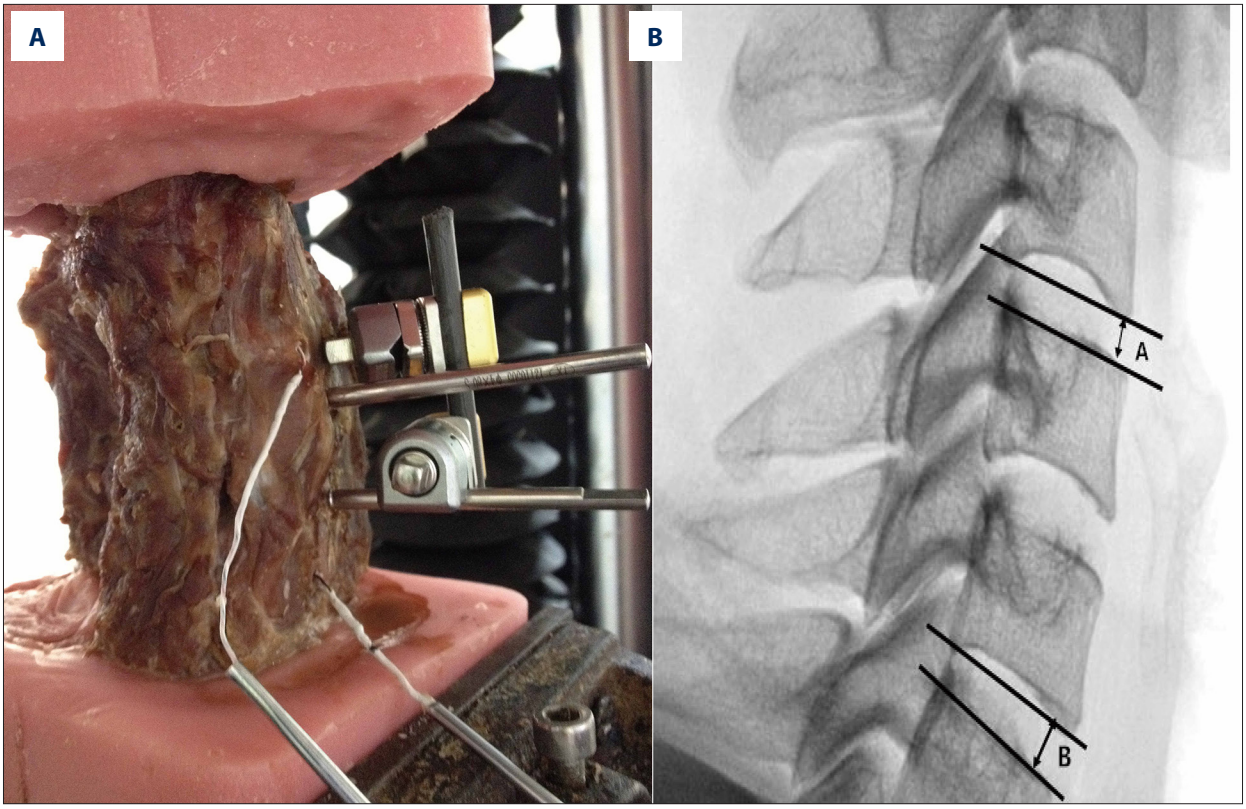

Figure 3. Methods of intervertebral bone graft (**A**) and intervertebral height measurements (**B**).

Results

Through the measurement and statistical analysis of the radiographic results of the lateral cervical spine models, the mean C5/C6 heights of the 6 models were derived as 6.80 mm, that is, 120% M (8.16 mm), 140% M (9.52 mm), and 160% M (10.88 mm). Therefore, the distraction heights were 1.36, 2.72, and 4.08 mm, respectively. Before and after the biomechanical test, no vertebral fracture or collapse was observed in the models by comparing the radiograms of the models and gross observation.

The results in Table 1 and Figure 4 shows that the pressure of the adjacent intervertebral disks was highest with the upright standing position among the various positions before distraction. Furthermore, after distraction, the pressure of the adjacent intervertebral disks varied with different positions of the specimens and distraction heights, and the pressure of the adjacent intervertebral disks at a distraction height of 120% was closest to that before distraction ($P<0.05$).

The results in Table 2 and Figure 5 show that the pressure of the adjacent articular processes was highest with left and right rotations. However, with the upright standing position, the bone graft height had little influence on the articular process pressure, without any significant differences among the groups before distraction ($P>0.05$). After distraction, the pressure of the adjacent articular processes varied with different positions of the specimens and distraction heights, and the pressure of the adjacent intervertebral disks under the same exercise load with different positions at a distraction height of 120% was lower than that at other distraction heights ($P<0.05$).

The results in Table 3 show that the range of motion of the cervical vertebrae was largest without distraction. After distraction, under the same moment of force, the range of motion of the intervertebral disks was largest at a distraction height of 120% ($P<0.05$).

Discussion

After cervical anterior discectomy, and vertebral distraction, fixation, and fusion, the original range of motion of the vertebral segments is compromised, resulting in changes in the physiological mechanics of the adjacent segments, accelerating their degeneration [6,7]. After the adjacent segments degenerate, the water content in the adjacent disks decreases, the intervertebral height significantly reduces, the cervical disk pressure distributed in the facet joints significantly increases, and the facet joints are often prone to serious secondary injury with loss of range of motion of the intervertebral disks. At the same time, the shear force and rotation load of

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Table 1. Comparison of values of intervertebral disc pressure of C4/5 and C6/7 intervertebral discs with different distraction heights and different directions under a 2.50 Nm force moment load (MPa).

Open height	Group	Neutral position	Flexion 30°	Extension 30°	Left and right lateral bending 30°	Left and right lateral rotation 30°
Before distraction	C4/5	0.9434±0.0042	0.9217±0.0027	0.1261±0.0026	0.6157±0.0031	0.8432±0.0034
	C6/7	0.9156±0.0054	0.8367±0.0074	0.1083±0.0034	0.5224±0.0038	0.4124±0.0039
100%	C4/5	0.9782±0.0045	1.0354±0.0028	0.1678±0.0018	0.7421±0.0025	0.8124±0.0024
	C6/7	1.0036±0.0024	0.9487±0.0034	0.1584±0.0034	0.7120±0.0034	0.4467±0.0038
120%	C4/5	0.9609±0.0029	0.0812±0.0018	0.0704±0.0030	0.0710±0.0026	0.8467±0.0038
	C6/7	0.9184±0.0024	0.0818±0.0024	0.0420±0.0022	0.0513±0.0027	0.5038±0.0024
140%	C4/5	1.0428±0.0026	0.0817±0.0024	0.0814±0.0028	0.1320±0.0026	0.8618±0.0022
	C6/7	1.0824±0.0028	0.0841±0.0026	0.0641±0.0028	0.1101±0.0021	0.4156±0.0023
160%	C4/5	1.1001±0.0028	1.0348±0.0020	0.1896±0.0027	0.7218±0.0031	0.8240±0.0024
	C6/7	1.0628±0.0021	0.9546±0.0019	0.1868±0.0018	0.6898±0.0018	0.5180±0.0026

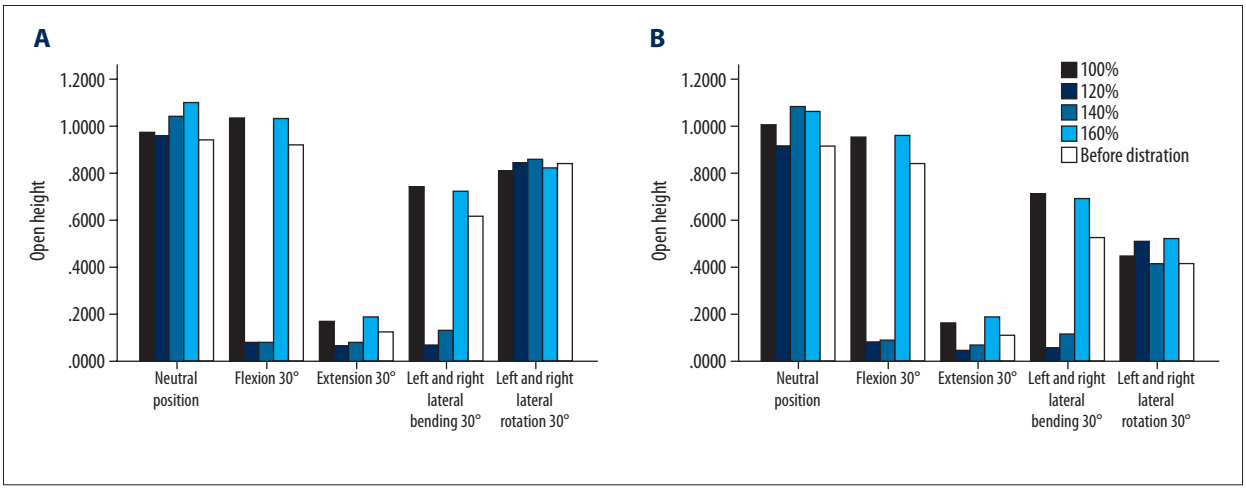

Figure 4. Intervertebral disk pressures at C4/C5 (**A**) and C6/C7 (**B**) with different distraction heights and different directions under a 2.50-Nm force moment load (MPa).

the adjacent articular joints are significantly increased owing to increased stiffness of the fixed area and displacement of the rotation center. Even without exceeding their physiological limits, the adjacent facet joints work long-term at a high load, further accelerating the degeneration of the segments adjacent to the fusion site [8]. In recent years, we found that effective intraoperative intervertebral height recovery plays an important role in preventing the degeneration of adjacent segments [9,10]. Appropriate intervertebral distraction height can effectively restore the physiological curvature of the cervical spine, reduce pressure on the adjacent disks, and restore the tension of knee joint capsules [11], thereby slowing the degeneration of adjacent joints. Therefore, attention should be paid to the intraoperative recovery of intravertebral height. However, a unified understanding of intervertebral height recovery is lacking.

Brower et al. analyzed the data of 59 patients who underwent anterior cervical interbody fusion and found that the possibility of nonunion increased when the distraction height was >4 mm [12]. Bayley et al. measured intervertebral foramens after different cervical bone graft modes and considered 5 mm to be the optimal intervertebral distraction height for bone graft, but the study lacked an analysis of preoperative intervertebral space height [13]. An et al. used fresh cervical specimens from 6 cadavers for C4/C5 disk decompression and bone grafting with different heights of the iliac bones for intervertebral bone grafting and found that with a single gap distraction of

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Table 2. Comparison of C4/5 and C6/7 facet joint pressures value of in 2.5 Nm loading phase when different open height and different direction (MPa).

Open height	Group	Neutral position	Flexion	Extension	Left lateral bending	right lateral bending	Left lateral rotation	Right lateral rotation
Before distraction	C4/5	0.9710± 0.0051	0.5972± 0.0034	1.8014± 0.0043	1.4750± 0.0039	1.4666± 0.0035	1.6613± 0.0025	1.6592± 0.0037
	C6/7	0.9393± 0.0059	0.5689± 0.0072	1.6761± 0.0036	1.5132± 0.0047	1.5205± 0.0042	1.6294± 0.0018	1.6015± 0.0036
100%	C4/5	0.9802± 0.0028	0.5810± 0.0031	1.8557± 0.0057	1.5011± 0.0074	1.5075± 0.0026	1.7008± 0.0030	1.6881± 0.0031
	C6/7	0.9441± 0.0039	0.5692± 0.0086	1.7643± 0.0049	1.5326± 0.0070	1.5298± 0.0031	1.6667± 0.0041	1.6708± 0.0028
120%	C4/5	0.9775± 0.0035	0.5315± 0.0029	1.7559± 0.0022	1.3816± 0.0055	1.3821± 0.0048	1.5509± 0.0028	1.5635± 0.0024
	C6/7	0.9411± 0.0040	0.5660± 0.0046	1.6308± 0.0034	1.4453± 0.0035	1.4408± 0.0045	1.6045± 0.0022	1.6127± 0.0019
140%	C4/5	1.0124± 0.0030	0.5301± 0.0039	1.7706± 0.0025	1.5254± 0.0028	1.5176± 0.0034	1.5991± 0.0026	1.5900± 0.0038
	C6/7	0.9605± 0.0027	0.5655± 0.0021	1.6478± 0.0033	1.5417± 0.0023	1.5403± 0.0029	1.6476± 0.0031	1.6471± 0.0022
160%	C4/5	1.0402± 0.0035	0.5712± 0.0045	1.7699± 0.00238	1.6240± 0.0031	1.6273± 0.0035	1.6515± 0.0020	1.6602± 0.0034
	C6/7	0.9839± 0.0033	0.5598± 0.0050	1.6653± 0.0032	1.6127± 0.0029	1.6032± 0.0024	1.6546± 0.0033	1.6619± 0.0030

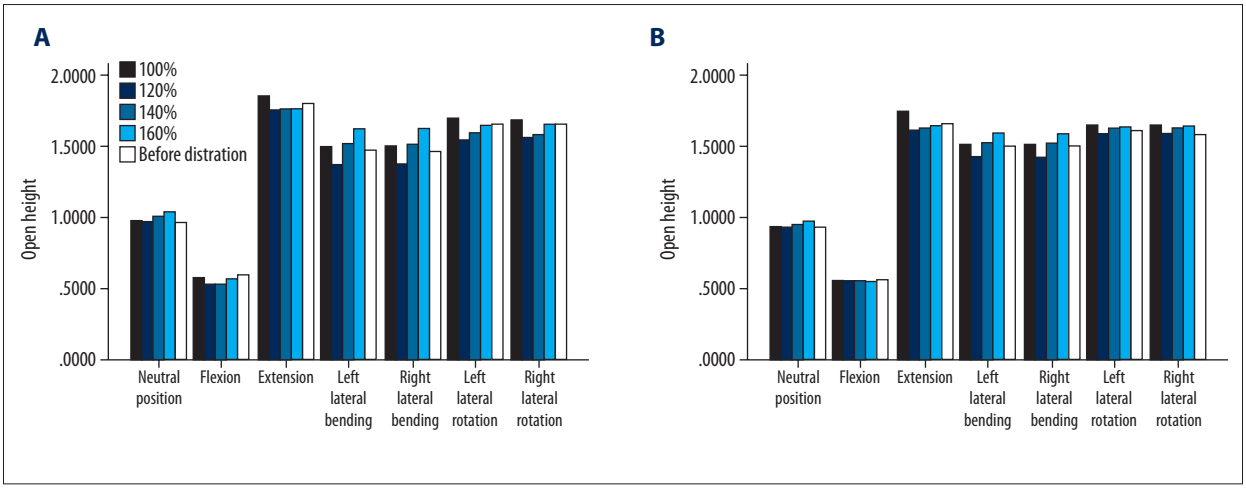

Figure 5. C4/C5 (**A**) and C6/C7 (**B**) facet joint pressure values in the 2.5-Nm loading phase with different open heights and directions (MPa).

Table 3. Comparison of cervical activity in 2.5 Nm load torque when different opening height.

	Before distraction	100%	120%	140%	160%
Flexion	58.26±7.14	43.55±8.61	45.90±6.59	41.83±7.25	40.27±7.82
Extension	61.04±6.92	48.81±7.73	52.65±7.03	48.76±7.39	48.05±7.11
Lateral bending	30.11±7.33	24.63±7.02	26.17±7.56	23.98±6.95	22.67±7.35

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2–3 mm, the corresponding height and area of the intervertebral foramens significantly increased. This can effectively restore the curvature of the cervical spine while reducing the stress on the bone graft. However, distraction of >3 cm did not significantly increase the area of the intervertebral foramen. Owing to the existence of individual differences in the error factors, the numerical results of previous distractions do not provide a better guide in clinical practice [14]. In the present study, the mean height of the intervertebral space, rather than the height of the surgical intervertebral space, was selected as the benchmark height. Reduction of intervertebral distraction and bone graft surgery usually result in more severe degeneration and larger variation. At the same time, individual differences in the height of the intervertebral disks and intervertebral spaces exist, so we chose the heights of 100%, 120%, 140%, and 160%. In addition, considering that in the Chinese population, cervical disk lesions mostly occur in the C5/C6 segments, we selected the C5/C6 segment for the simulation of an experimental vertebra, so the measured results can be more widely used in most patients, reducing the error caused by the individual differences. The selected 30° flexion, 30° extension, and 30° left and right bending positions in this experimental study due to degeneration of the disk were closely related to the 30° torque load [15,16]. The rate of apoptosis of normal medullary nucleus cells was increased, and the angle of fiber arrangement in the fiber ring was changed if the twist angle was >30° and then caused irreversible degeneration of the disk [17].

The findings of this study indicate that under the same pressure load, the measurements of intervertebral disk pressure with different intervertebral distraction heights also differ with different cervical curvatures. At different levels of intervertebral distraction height, the 30° cervical disk posterior extension position has the smallest intervertebral disk pressure, which is related to the fact that when the pressure sensor is located in the center of intervertebral disks, the pressure sensor receives a small stimulation. At 120% of the benchmark height, the pressure values of the C4/C5 and C6/C7 intervertebral disks at the 30° cervical extension, 30° flexion, and 30° side bending were lower than those at other reference levels. During upright standing, the pressure values of the C4/C5 and C6/C7 intervertebral disks were less than those measured at 100%, 120%, and 160% of the benchmark height, and greater than the intervertebral disk pressure values measured before distraction. This may be related to the fact that before the distraction, the articular process is similar to normal tissues. Furthermore, we conclude that with different intervertebral distraction heights, the articular process pressure is lowest when the cervical vertebra is flexed at 30°. This may be because the pressure sensor is located at the center of the articular capsule and receives little stimulation. During cervical flexion, the articular process pressures in C4/C5 and C6/C7 were lower than the measured pressure values at 100%, 140%, and 160% of the benchmark height, and greater than those measured before the distraction. This may be related to the fact that before the distraction, the articular process is similar to normal tissues. It is easy to understand that during extension of the cervical vertebrae, the load on the articular processes is increased. In contrast, during left and right rotation, owing to the existence of lateral bending and posterior extension of the coupling, resulting in uneven distribution of articular process pressure, the load on the facet joint is increased, thus accelerating the articular process degeneration. Therefore, after cervical spine internal fixation surgery, in addition to the necessary activities and functional exercise, excessive extension and left and right rotations should be avoided so as not to accelerate degenerative changes of the articular processes. Finally, the range of motion was largest before distraction, which shows that fixed fusion had an important effect on the range of motion of the cervical vertebrae. As fixed fusion surgery is inevitable for cervical spondylosis, a suitable distraction height should be chosen to reduce the incidence of complications. Obviously, 120% of the distraction height had minimum impact on the range of motion after C5/C6 fixed fusion. When the distraction height was >120%, as the distraction height increased, the range of motion of the cervical vertebrae gradually decreased. Especially, the flexion function decreased obviously, which may be related to the limitation of the posterior ligament structure tension. During side bending, the concave side of the joint slips backward, which can cause rotation in the same direction. Therefore, side bending movement is often accompanied by ipsilateral rotation [18]. However, excessive distraction height increases the contact of the upper and lower articular processes, reduces the slippage of the articular surfaces, and reduces the degree of side bending. Therefore, the range of motion of the cervical vertebrae was lowest at 160% of the distraction height during left- and right-side bending. Thus, choosing an appropriate height is particularly important for maintaining the range of motion of the cervical vertebrae and preventing the degeneration of adjacent segments.

Conclusions

In conclusion, we found that in intervertebral disk removal and bone grafting of the C5/C6 intervertebral disk, 120% of the benchmark height can reduce the pressure of adjacent articular processes and intervertebral disks and increase the range of motion of adjacent intervertebral disks, thus delaying the degeneration of adjacent segments. Therefore, it is an appropriate intervertebral distraction height that can be used as the reference distraction height for clinical intervertebral bone grafting. This experimental study was conducted with young adult specimens with mild cervical vertebra degeneration, and

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only C5/C6 fixation was performed. However, in clinical practice, most patients have severe degeneration, which is not limited to C5/C6. Therefore, other factors that affect the pathological changes of adjacent segments should be considered, with attention to individual differences. In addition, owing to the small sample size of the experiment, the experimental results have certain limitations.

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