Effect of Cervical Artificial Disc Replacement on Adjacent Inferior Intervertebral Space Stress

L-K Chen[1], K-H Li[2]

ABSTRACT

Purpose: *The aim of this study was to investigate the effects of $C_{5/6}$ cervical artificial disc replacement (CADR), discectomy and intervertebral fusion on adjacent inferior ($C_{6/7}$) intervertebral space stress, and provide a basis for application of CADR.*

Methods: *Eleven fresh-frozen multisegmental (C_3-T_1) cervical spine specimens from healthy adults were studied. For analysis of stress on the adjacent inferior ($C_{5/6}$) segment, they were divided into intact group, discectomy group, CADR group and interbody fusion group. The axial load (25−150 N) was exerted on each group. The changes of the adjacent inferior ($C_{6/7}$) intervertebral space stress were observed.*

Results: *The adjacent inferior intervertebral space stress in the CADR group was near to that of the intact group, without significant difference ($p > 0.05$). The stress in the discectomy group was significantly higher than in the intact group, and lower than in the interbody fusion group ($p < 0.05$ and $p < 0.01$, respectively). The stress in the interbody fusion group was significantly higher than in the intact and CADR groups, respectively ($p < 0.01$).*

Conclusion: *The intervertebral fusion and intervertebral disc discectomy can significantly affect the adjacent inferior intervertebral space stress. There is no obvious effect of CADR on adjacent inferior intervertebral space stress.*

Keywords: Cervical artificial disc replacement, discectomy, interbody fusion, intervertebral space

Efecto del Reemplazo del Disco Cervical Artificial sobre el Estrés del Espacio Intervertebral Inferior Adyacente

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RESUMEN

Propósito: *El objetivo de este estudio fue investigar los efectos del reemplazo del disco cervical artificial $C_{5/6}$ (RDCA), la discectomía, y la fusión intervertebral, sobre el estrés del espacio intervertebral inferior adyacente ($C_{6/7}$), y proporcionar una base para la aplicación del RDCA.*

Métodos: *Se estudiaron once especímenes de columna cervical (C_3–T_1) multisegmentales frescos congelados de adultos sanos. De acuerdo con el tratamiento del segmento ($C_{5/6}$) inferior adyacente, los mismos fueron divididos en grupo intacto, grupo de discectomía, grupo RDCA y grupo de fusión intersomática. La carga axial (25−150 N) fue ejercida sobre cada grupo. Se observaron los cambios de la tensión del espacio intervertebral ($C_{6/7}$) inferior adyacente.*

Resultados: *El estrés del espacio intervertebral inferior adyacente en el grupo RDCA estuvo cerca de su homólogo en el grupo intacto, sin diferencia significativa ($p > 0.05$). El estrés en el grupo de discectomía fue significativamente mayor que el estrés en el grupo intacto y menor que en el grupo de fusión intersomática ($p < 0.05$ y $p < 0.01$, respectivamente). El estrés fue significativamente más alto en el grupo de fusión intersomática que en el grupo intacto y de RDCA respectivamente ($p < 0.01$).*

Conclusión: *La fusión intervertebral y la discectomía del disco intervertebral pueden afectar significativamente la tensión del espacio intervertebral inferior adyacente. No hay ningún efecto evidente del RDCA sobre el estrés del espacio intervertebral inferior adyacente.*

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Palabras claves: Reemplazo del disco cervical artificial, discectomía, fusión intersomática, espacio intervertebral

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INTRODUCTION

Cervical disc degenerative disease (CDDD) is one of the common orthopaedic diseases, and intervertebral disc degeneration (IDD) is the main pathological basis. Since anterior cervical decompression and fusion with autologous bone graft were conducted by Smith, Robinson and Cloward in the 1950s, anterior cervical discectomy and fusion (ACDF) has been the most effective method for treating CDDD. However, with the extension of follow-up time, this surgery can lead to postoperative adjacent segment degeneration (ASD), which has gained more and more attention. Restoring the functions of degenerated intervertebral disc is a hotspot of current research.

Cervical artificial disc replacement (CADR) can reconstruct intervertebral disc space height, restore stress distribution, keep vertebral ganglion mobility and maintain biomechanical properties of cervical vertebra (1). In this study, the effects of $C_{5/6}$ CADR, discectomy and intervertebral fusion on stress in adjacent inferior ($C_{6/7}$) intervertebral space stress were analysed. The objective was to provide a theoretical basis for clinical application of CADR.

SUBJECTS AND METHODS

Eleven fresh-frozen multisegmental (C_3-T_1) cervical spine specimens from healthy adults were studied. There were nine males and two females. This study was conducted in accor-dance with the Declaration of Helsinki. Approval was granted by the Ethics Committee of the Second People's Hospital of Hunan Province. Written informed consent was obtained from all participants. The paraspinal muscles and fascia on the segment were removed, retaining the ligament, intervertebral disc and articular capsule. For analysis of stress on the adjacent inferior ($C_{5/6}$) segment, they were divided into intact group, discectomy group, CADR group, and interbody fusion group.

Biomechanical test

Methylmethacrylate was used to embed and fix 2/3 part from the highest (C_3) and lowest (T_1) vertebral body, respectively. The modified micro-pressure sensor was placed in the $C_{6/7}$ intervertebral space. The axial load (25, 50, 75, 100, 125 and 150 N, respectively) was exerted on each specimen. The graded load moment was 0.25, 0.50, 0.75, 1.00, 1.25 and 1.50 Nm, respectively. The change in the adjacent inferior ($C_{6/7}$) intervertebral space stress was recorded and statistically analysed.

Statistical analysis

Data are expressed as mean ± SD. Statistical analysis was performed using SPSS 12.0 statistical software. One-way analysis of variance (ANOVA) was conducted on the variation of adjacent inferior intervertebral space stress. The least significant difference (LSD) *t*-test and paired samples *t*-test were performed for comparison within and between two groups, respectively.

RESULTS

Variations of stress in inferior ($C_{6/7}$) intervertebral space under axial load are shown in the Table. The stress in the CADR group was near to that of the intact group, with no significant difference ($p > 0.05$). The stress in the discectomy group was significantly higher than in the intact group, and lower than in the interbody fusion group ($p < 0.05$ and $p < 0.01$, respectively). The stress in the interbody fusion group was significantly higher than in the intact and CADR groups ($p < 0.01$).

DISCUSSION

Cervical disc, as a composite structure, is one part of the functional spinal unit. It plays a decisive role in maintaining the stability of cervical bone structure. Damage of the cervical disc will impact the whole functional spinal unit (2). The cervical disc and bilateral intervertebral joints bear 36% and 64% of intervertebral stress, respectively (3). Taylor *et al* (4) found that a long period of abnormal stress load can induce degeneration of the intervertebral disc. Hutton *et al* (5) con-firmed that, under high load, the amount of matrix materials such as proteoglycan synthesized by the

Table: Variation of inferior ($C_{6/7}$) intervertebral space stress (N)

Loads	Intact group	Discectomy group	Interbody fusion group	CADR group
25N	8.19 ± 1.53	12.13 ± 5.47*	17.13 ± 3.24$^{\#}$	9.41 ± 3.49$^{\square}$
50N	15.25 ± 5.27	23.50 ± 7.33*	30.68 ± 7.17$^{\#}$	17.65 ± 6.90$^{\square}$
75N	24.94 ± 4.80	34.16 ± 5.94*	40.54 ± 5.09$^{\#}$	27.74 ± 8.06$^{\square}$
100N	37.61 ± 4.52	46.64 ± 6.62*	51.59 ± 6.75$^{\#}$	38.10 ± 4.28$^{\square}$
125N	46.40 ± 4.64	56.16 ± 7.56*	63.59 ± 8.10$^{\#}$	46.83 ± 4.58$^{\square}$
150N	55.01 ± 6.70	67.96 ± 6.42*	76.92 ± 5.62$^{\#}$	55.88 ± 6.45$^{\square}$

$^{*}p < 0.05$, compared to intact group and CADR group; $^{\#}p < 0.01$, compared to CADR group and intact group; $^{\square}p > 0.05$, compared to intact group.
CADR = cervical artificial disc replacement

intervertebral disc cells is reduced, with exuberant secretion of matrix degrading enzymes. This leads to changes in matrix biochemical struc-ture and mechanical properties, thus damaging the inter-vertebral disc tissue and structure.

The intervertebral space stress can be directly and indirectly measured (6). In direct measurement, the instrument is placed in the intervertebral space to measure the actual stress under outer load or in motion. In indirect measurement, the intervertebral space stress is inferred and calculated through related data or mathematical models. The disc shaped micro-sensor used in this study is made based on the principle of electric measurement. This instrument has advantages of simple operation and high accuracy. However, it is only applicable for *in vitro* specimens.

In this study, the variations of adjacent inferior ($C_{6/7}$) intervertebral space stress under different loads in the intact, discectomy, CADR and intervertebral fusion groups were observed. The effects of different intervertebral disc surgery on adjacent inferior intervertebral discs and the feasibility of the CADR were evaluated. In the experiment, the maximum load with supraphysiological range was avoided. Using axial graded loads (25−150 N) not only simulates the true loads for human physiological activity, but also avoids the destruction of specimens. In addition, the suitable linear relationship between intervertebral space stress and load can be obtained. Therefore, measurement of intervertebral space stress is significantly important for biomechanical study on spine. However, this experiment only simulates the instant state of intervertebral disc surgery. The long-term impacts on adjacent segments cannot be displayed. This needs to be further studied in clinical follow-up.

The application of simple anterior cervical discectomy was first reported by Hirsch *et al* in 1960. It has a better efficacy for patients with cervical soft disc herniation, and a poor effect on patients with cervical rigid disc herniation. After discectomy, the intervertebral disc height decreases, with narrowing of the intervertebral space. This easily leads to spinal biomechanical dysfunction (7), the instability of anterior and central cervical column, decrease of cervical curvature, and even cervical recreation (8, 9). Normal intervertebral disc height and intradiscal stress are the premise of the intervertebral disc motility and biomechanical function (10). Discectomy of the intervertebral disc nucleus pulposus can lead to decrease of intervertebral height, and changes of environment and stress distribution in the intervertebral disc, resulting in the appearance of stress peak due to stress concentration on fibre ring, and accelerated degeneration of the fibre ring. Cervical discectomy causes cervical instability and amplification of abnormal cervical motility scope, especially in lateral bending (11). In addition, it leads to narrowing of the intervertebral space, diminution of the intervertebral foramina, hypertrophy of small joint, thickening of spinal ligament fold, and fibre ring relaxation and eventration, thus resulting in stenosis in the vertebral canal (10).

At present, the simple anterior cervical discectomy is seldom used for clinical treatment of CDDD. In this study, in order to show the mechanism of regression and kyphosis after discectomy, the adjacent inferior intervertebral space stress after discectomy was measured. Results show that the stress in the discectomy group is significantly higher than in the intact and CADR groups. The reasons may be that, after discectomy, the decreased intervertebral stability, increased activity, decline of cervical viscoelasticity and shock absorption capacity, and change of stress distribution cause the increase of adjacent inferior intervertebral space stress, thus resulting in regression in the intervertebral disc.

For many patients with CDDD combined with cervical instability or serious intervertebral space stenosis, the cervical interbody fusion is often used to stabilize the spine and maintain intervertebral space height. Bohler *et al* firstly conducted anterior cervical fixation with plates and screws in 1964. With the improvement of fixation devices, the success ratio of anterior cervical fusion increased significantly, with a fusion rate of 90−100% (12, 13). After 50 years of development and improvement, anterior cervical fusion has become a gold standard for treatment of CDDD, trauma, infection, tumour and other diseases. This surgery can restore the stability of the fused segment and maintain the intervertebral space height. However, it sacrifices the lesion segment motility and causes compensatory increase of adjacent segmental motility, resulting in disorder of spinal function (14, 15). From a biomechanical perspective, the Young's modulus of internal fixation device and grafting material are bigger than the original intervertebral disc tissue. The cervical fixation will cause a change in the biomechanical environment of adjacent segments, leading to change of stress distribution.

In this study, after discectomy of the intervertebral disc tissue, the intervertebral space was filled with cement, followed by fixation with Zephir anterior cervical plate. The interbody fusion model is made, and confirmed by radiography. Results show that the adjacent inferior intervertebral space stress in the interbody fusion group is significantly higher than in the intact, CADR and discectomy groups. This in-dicates that, after interbody fusion, the motility of the fused segment is lost, with increase of stiffness, leading to increase of adjacent inferior intervertebral space stress. This easily causes degeneration of the adjacent inferior intervertebral disc, cervical instability, intervertebral disc herniation and cervical spinal stenosis, thus resulting in corresponding clinical signs and symptoms.

At present, there are still many different views on the effects of cervical interbody fusion on the adjacent segment. Adjacent segment degeneration mainly refers to the degenerative changes and clinical symptoms of the adjacent non-fused segments after interbody fusion. It was first reported by Hilibrand *et al* (16), followed by a succession of similar reports. Some scholars (17−19) have conducted long-term follow-up for patients with cervical diseases and found that there is ASD with different degree after cervical fusion. However, some scholars believe that the cervical ASD is more closely related to the previous degeneration before fusion.

Anterior cervical discectomy and interbody fusion have adverse impacts on spinal biomechanics, thus affecting the efficacy. Simple cervical discectomy will lead to collapse of the intervertebral space, cervical spinal stenosis, stability decline and joint degeneration due to change in small joint stress. Anterior cervical fusion can maintain the intervertebral space height, but after surgery, the motility of the fused segment is lost. This causes increase of the adjacent segment stress and motility, leading to acceleration of degeneration and recurrence of symptoms (20). Theoretically, application of CADR to the reconstructed spinal structure is a more ideal approach. It can restore the stability and motility of the spine and intervertebral disc and prevent the increase of adjacent segment stress and motility (21, 22). At present, the Bryan artificial disc is most commonly used in clinical application. It is a non-limiting prosthesis, and can satisfy the requirement of spine motility in three rotational axes, which is similar to the normal intervertebral disc.

Results of this study show that the adjacent inferior intervertebral space stress in the CADR group is near to that of the intact group, with no significant difference. The stress in the CADR and intact groups was significantly lower than in the discectomy and interbody fusion groups. The CADR with Bryan artificial disc has no obvious influence on adjacent inferior intervertebral space stress. In this study, fresh cervical specimens were studied, which can better reflect *in vivo* results. However, the muscle tissue, an important exogenous stable system, is removed in the experiment. This may have a certain impact on experimental results. In addition, cervical motility is extremely complex and cannot be completely simulated by experimental modes. The related *in vivo* studies need to be further conducted.

Intervertebral fusion and intervertebral discectomy can significantly affect the adjacent inferior intervertebral space stress. There is no obvious effect of CADR on adjacent inferior intervertebral space stress.

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