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Original Article

Study on biomechanical analysis of two-level cervical Mobi-C and arthrodesis

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Abstract: Objective: To investigate the range of motion (ROM) index of a two-level cervical arthroplasty. Methods: Seven human cadaveric spines were biomechanically examined from C2 level to T1 level under intact status and the following conditions: 2-level arthroplasty (C4-C6) employing Mobi-C devices (MM group), 2-level anterior cervical discectomy and fusions (2-ACDFs) (FF group), and both as a hybrid surgery (HS) (MF group and FM group). Multidirectional flexibility examination was conducted according to the Panjabi hybrid testing protocol. Unconstrained intact moments of ±1.5 NM were performed for axial rotation (AR) flexion/extension (FE), and lateral bending (LB). Results: No statistical differences were found between the intact spine and MM group at the operative- and adjacent-level kinematics in the three loading conditions, except that C4-C5 ROM significantly increased in the axial rotation loading ($P<0.05$). Compared with the intact spine, MF group led to a significant decrease at the arthrodesis segment ROM C5-C6 in the three loading ($P<0.05$), with corresponding significantly increased at C4-C5 in FE and AR ($P<0.05$). FM group resulted in a significant decrease in ROM C4-C5 ($P<0.05$) with corresponding significantly increased at C5-C6 in FE, AR and LB ($P<0.05$). There was not any difference for non-operative level kinematics between MF group and FM group and intact spine. Compared with the intact spine, FF group led to a significant decrease at the arthrodesis-levels ($P<0.05$) and marked increase at the non-operative level kinematics. Conclusion: A two-level Mobi-C and Hybrid construct generated better biomechanical conditions. This study suggested that two-level cervical total disc replacement or HS could become an alternative approach for therapy of two-level consecutive cervical spondylosis.

Keywords: Biomechanics, Mobi-C, two-level, ROM, cervical disc arthroplasty

Introduction

For decades anterior cervical discectomy and fusion (ACDF) has become the main method for the operative therapy of various degenerative cervical vertebral disease [1]. However, this approach not only exerts increased stress of adjacent segments, but also leads to less mobility of the treated segment. The long-term sequelae of fusion may develop adjacent segment disease (ASD) [2-6]. As an alternative, cervical total disc replacement (TDR) was proposed and proved to prevent degeneration of adjacent segments. Although the causes of adjacent segment disease are debatable [7-13], it cannot be denied that the change of biomechanical environment after fusion is an important reason. In fact, cervical disc arthroplasty (CDA) has been extensively assessed in multiple randomized controlled trials with very few long-term data, which suggested that CDA was an effective and safe therapeutic method for both one- and two-level cervical degenerative disc disease [14-21].

Considering the greater loss of mobility in two-level ACDF, the TDR inserted two levels or combined with ACDF is an attractive reconstructive option to treat two consecutive levels cervical spondylosis. Early results from clinical reports have also demonstrated that two-level TDR and hybrid surgery (HS), including TDR plus ACDF, may become a reasonable alternative approach for two-level ACDF [14, 16, 19-30]. In the HS conditions, the severely spondylotic segment was fused while the more mobile and less involved segment was treated using the TDR method. In the clinic, TDR was conducted in the

Figure 1. The testing setup used in this study.

segment that had more physiologic motion [29, 30]. Previous *in vitro* biomechanical studies involving multilevel TDR are few and always use a semi-constrained prosthesis design [31-36]. In addition, the authors always put the prosthesis above the fusion segment to simulate the condition of hybrid surgery [34-36]. Currently, the Mobi-C disc prosthesis (LDR, Troyes, France), consisted of one mobile core of ultra-high-molecular-weight polyethylene and two metal base plates, has been the only FDA-approved prosthesis for 2-level TDR use. It was reported that CDA with Mobi-C continues to be an effective and safe treatment approach for patients with 1- or 2-level cervical disc diseases [21].

However, as far as we know, there is not any biomechanical trial evaluating the different options in the treatment of 2 consecutive level cervical disc diseases using an unconstrained prosthesis Mobi-C. The aim of this study was to investigate the kinematic changes at operative and adjacent levels for a 2-level Mobi-C (MM), 2-level ACDF (FF), and simulated hybrid constructs of Mobi-C/Fusion (MF) and Fusion/Mobi-C (FM), which would provide an experimental basis for treatment of two-level consecutive cervical spondylosis.

Materials and methods

Specimen preparation

This research passed the examination and approval of the Ethics Committee of our hospital (No. 2021-1176). Seven frozen fresh adult male human cadaveric cervical spines from C1-T2 (age from 34 to 63 old years) were obtained from the department of anatomy of Southern Medical University. Before biomechanical analysis, standard anteroposterior and lateral plain films were harvested to exclude specimens with degenerative, metastatic disease, tumoral, traumatic pathology or other conditions that had obvious effects on the spine biomechanics. Once obtained, each spine was immediately kept in double-thickness plastic bags under the condition of -20°C. Before biomechanical testing, the cervical spines were thawed under the condition of room temperature and cleaned of all paravertebral musculature, with care being taken to preserve the discs, all ligamentous attachments and facet joint capsules.

The superior endplate of the C1 vertebral body was fixed by the method of screw placements into C2, leading to the motion segment between C1 and C2 was immobilized. The T1-T2 segment was fixed through the similar method. The most superior and most inferior segments (extending into C1-C2 and T1-T2 segments) were fixed in cylindrical pots employing polymethylmethacrylate and pins.

To position the cervical spine in a neutral (upright) orientation, an alignment frame was used. The potting fixtures were employed to attach the cadaveric spines loaded onto a mechanical examination and simulation loading frame (MTS 858 MiniBionix, USA). Intersegmental motion examination consisted of specialized markers, including four noncolinear infrared light emitting diodes. One marker was firmly attached to each vertebral level (from C2 to T1) and oriented to permit detection by an optoelectronic motion analysis system (OptoTrak 3020, Northern Digital Inc., Waterloo, Ontario, Canada), configured with a Dell Dimension XPS T500 Personal Computer, as shown in **Figure 1**.

Reconstruction procedures

Anterior cervical surgery was conducted at C4-C5 and C5-C6. the approach included spine arthroplasty employing a Mobi-C disc prosthesis (LDR Medical, Troyes, France) and ACDF employing a CSLP anterior cervical plate, ACF Plastic Spacers and screw system (Ceres Spine, Guang Zhou, China). A complete diskectomy was conducted between the C4-C6 interbody levels before prosthesis implantation. To avoid destruction of the osseous endplate, the carti-

Table 1. Implant of Mobi-C or ACDF at C4-C5 or C5-C6 according to treatment group

Level	II	MM	MF	FM	FF
C4-C5	Intact	Mobi-C	Mobi-C	ACDF	ACDF
C5-C6	Intact	Mobi-C	ACDF	Mobi-C	ACDF

Note: MM: Mobi-C/Mobi-C; MF: Mobi-C/Fusion; FM: Fusion/Mobi-C; FF: Fusion/Fusion; ACDF: Anterior cervical discectomy and fusion.

lage portion in the endplate was cleaned through the curette. Care was taken to preserve uncovertebral joints intact, while the posterior longitudinal ligament was removed. The size selection was based on the anatomy in each specimen. All reconstructions were performed according to the manufacturers' instruction. Final position of TDR in the disc space was evaluated employing lateral fluoroscopy as would be done clinically.

After analysis of the intact spine, each specimen was reconstructed at C4-C6 (two-level) motion segments according to the following methods: 1) a Mobi-C placement group: Mobi-C insertions at both C4-C5 and C5-C6 (MM); 2) the Mobi-C/Fusion (MF) group: A hybrid of a Mobi-C inserted at C4-C5 and a ACDF conducted at C5-C6; 3) an Fusion/Mobi-C (FM) group: A hybrid of an ACDF at C4-C5 and Mobi-C inserted at C5-C6; 4) a fusion (FF) group: ACDFs were conducted at both C4-C5 and C5-C6. To minimize any time-dependent effects, each specimen went through the therapy groups MM, MF, FM, and FF in varying order, as shown in **Table 1** and **Figure 2**.

Three-dimensional flexibility testing

First, biomechanical examinations were conducted on intact specimens under load control in six different modes of motion: left and right lateral bending (LB), flexion/extension (F/E) and left and right axial rotation (AR) to a 1.5 nm maximum moment loading with 0.15 nm steps. Examination of angular and linear displacements was harvested employing a three-dimensional optoelectronic measurement system (OptoTrak 3020, Northern Digital Inc., Waterloo, Ontario, Canada). Typical load-displacement curves were harvested for different testing modes allowing for the determination of the intact segment's full range of motion (ROM). According to the hybrid testing protocol proposed by Panjabi [37], the system was reprogrammed to operate in displacement control after intact specimen analysis, and the reconstructed specimens were conducted under displacement control with the intact segment's full ROM. Each examination was repeated at a rate of 3 degrees/second for three loading and unloading cycles.

Data and statistical analysis

The graphic software used in this study was GraphPad Prism 8.0.1. The statistical analysis was performed using SPSS13.0. All data were expressed as Mean ± SD. A repeated measures analysis of variance with Student-Newman-Keuls test was conducted for comparisons among groups. $P<0.05$ was considered a significant difference.

Results

ROM analysis of operative levels

The results for segmental ROM from C2-C3 to C7-T1 are shown in **Figure 2** and **Tables 2-4**. For group MM, the ROMs of both operative levels (C4-C6) remained essentially unchanged compared with the intact spine in F/E, left-right AR and left-right LB loadings, except C4-C5 ROM significantly increased in AR loading ($P<0.05$).

For group MF, the ROM for inferior arthrodesis level (C5-C6) was less than that for the same level in intact spine, group MM, and group FM for the three loading conditions ($P<0.05$), with corresponding increase of ROM in the three loading conditions at superior arthroplasty level (C4-C5) compared to intact spine and other treatment groups. However, this increase was statistically significant only compared with FM group and FF group in FE, LB, and AR loadings and also in AR and F/E loadings compared to intact spines ($P<0.05$).

The segmental motion in the superior fused level (C4-C5) from FM groupdecreased in contrast to that in the intact spine, MM group, and MF groups in FE, LB, and AR ($P<0.05$), whereas motions at the inferior arthroplasty level (C5-C6) were increased compared with the other groups ($P<0.05$) in F/E and AR loading, and also increased compared to the intact spine, MF group, and FF group in LB loading. As expected, the obvious reduction of ROM at the two operative levels in FE, AR, and LB was found in the FF

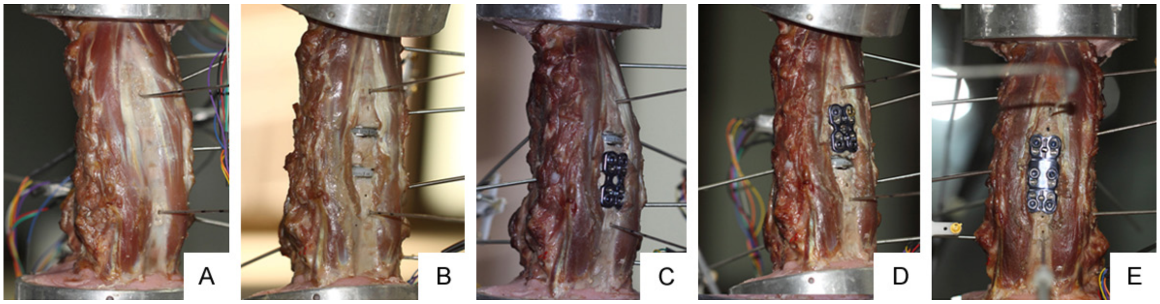

Figure 2. Testing conditions. A. Intact spine (II); B. Mobi-C at both C4-C5 and C5-C6 (MM); C. Mobi-C at C4-C5 and arthrodesis at C5-C6 (MF); D. Arthrodesis at C4-C5 and Mobi-C at C5-C6 (FM); E: Arthrodesis at both C4-C5 and C5-C6 (FF).

Table 2. Comparison of treatment groups versus intact group in the segmental ROMs of FE using displacement-control test (Unit: n=7)

Level	Intact	MM	MF	FM	FF	F value	*P* value
C2-C3	5.37±1.12	4.97±1.10	5.44±1.03	5.88±1.10	7.16±1.32*	3.846	0.012
C3-C4	9.67±3.28	9.09±3.24	10.20±2.90	11.18±3.09	13.64±3.28	2.228	0.090
C4-C5	12.30±1.79	13.09±2.12	15.59±2.24*	4.29±0.63*	4.81±0.78*	67.428	<0.001
C5-C6	10.95±2.58	11.59±2.70	4.15±0.99*	14.59±2.61*	4.46±0.85*	33.33	<0.001
C6-C7	8.86±2.83	8.99±2.84	11.53±2.56	10.96±2.99	14.17±2.64*	4.290	0.007
C7-T1	4.85±0.97	4.38±0.90	5.27±1.04	5.20±0.98	7.85±1.56*	10.357	<0.001
Total	52.01±8.80	52.12±8.86	52.18±8.81	52.11±8.83	52.09±8.82	0.001	1.000

Note: *indicated statistically significant differences in values from that of intact spine.

Table 3. Comparison of treatment groups versus intact group in the segmental ROMs of LB using displacement-control test (Unit: n=7)

Level	Intact	MM	MF	FM	FF	F value	*P* value
C2-C3	10.20±1.89	10.08±1.95	10.47±1.83	10.39±1.99	11.14±1.83	0.330	0.856
C3-C4	9.47±3.23	9.61±3.26	9.84±3.28	10.28±2.94	11.27±3.10	0.368	0.830
C4-C5	7.66±1.19	7.41±1.16	8.38±1.22	3.89±0.65*	4.19±0.57*	30.999	<0.001
C5-C6	7.00±1.21	7.61±1.18	4.20±0.54*	8.60±1.22*	4.46±0.72*	25.930	<0.001
C6-C7	6.70±2.22	6.49±2.30	7.70±2.08	7.44±2.35	8.36±1.37	0.924	0.463
C7-T1	4.10±0.60	3.90±0.58	4.50±0.65	4.52±0.66	5.70±0.78*	7.917	<0.001
Total	45.11±6.40	45.08±6.38	45.09±6.40	45.11±6.44	45.12±6.41	0.001	1.000

Note: *indicated statistically significant differences in values from that of intact spine.

Table 4. Comparison of treatment groups versus intact group in the segmental ROMs of AR using displacement-control test (Unit: n=7)

Level	Intact	MM	MF	FM	FF	F value	*P* value
C2-C3	4.61±0.95	4.60±0.92	4.91±1.01	4.90±0.87	5.58±0.97	1.234	0.317
C3-C4	7.96±2.73	6.75±2.57	6.44±2.59	8.16±2.80	9.20±2.87	1.196	0.333
C4-C5	7.86±1.17	9.72±1.79*	11.53±1.47*	4.39±0.82*	4.90±0.90*	44.086	<0.001
C5-C6	8.20±1.84	8.50±1.86	4.63±1.07*	10.93±1.93*	5.22±1.11*	18.038	<0.001
C6-C7	7.24±2.32	6.15±2.38	7.98±2.71	7.37±2.32	8.94±2.32	1.230	0.307
C7-T1	4.18±0.76	4.32±0.73	4.47±0.75	4.40±0.75	6.20±0.99	7.671	<0.001
Total	40.05±7.31	40.03±7.23	39.96±7.24	40.15±7.21	40.04±7.30	0.001	1.000

Note: *indicated statistically significant differences in value from that of intact spine.

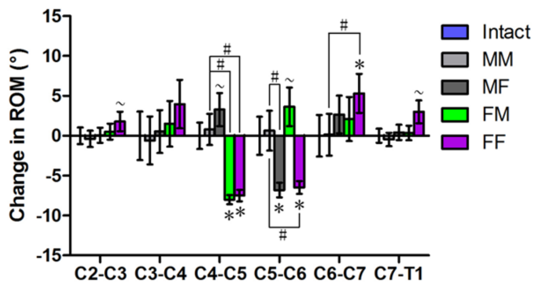

Figure 3. Change in range of motion (ROM) with respect to that of the intact spine is depicted graphically for Flexion-Extension. The asterisks (*) indicate statistically significant differences in values from that of intact spine, the pound signs (#) indicate statistically significant differences in values between treatment groups, and the tilde (~) indicates statistically significant differences in values from that of all the other groups.

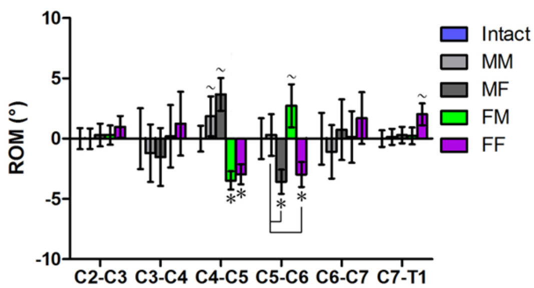

Figure 4. Change in range of motion (ROM) with respect to that of the intact spine is depicted graphically for AR. The asterisks (*) indicate statistically significant differences in values from that of intact spine, the pound signs (#) indicate statistically significant differences in values between treatment groups, and the tilde (~) indicates statistically significant differences in values from that of all the other groups.

group compared with the intact spine and MM groups.

ROM analysis of adjacent levels

Flexion-extension loading demonstrated that the MM group remained essentially unchanged from the intact condition at both upper two and lower two adjacent segments. However, the FF group showed an obvious ROM increase at adjacent non-operated segments (C2-C3 and C6-T1) in contrast to the intact spine and MM group ($P<0.05$). For the hybrid construct (FM group and MF group), an increased ROM of lower two and upper two adjacent segments was observed in contrast to the intact spine and MM group, but it was not statistically significant. Moreover, for the MF group, the C7-T1

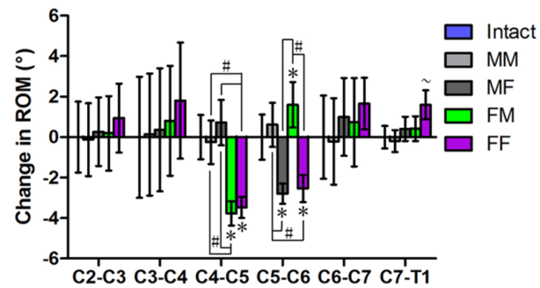

Figure 5. Change in range of motion (ROM) with respect to that of the intact spine is depicted graphically for LB. The asterisks (*) indicate statistically significant differences in values from that of intact spine, the pound signs (#) indicate statistically significant differences in values between treatment group, and the tilde (~) indicates statistically significant differences in values from that of all the other groups.

ROM was increased in contrast to the MM group ($P<0.05$), as shown in **Figure 3**.

Axial rotation loading demonstrated that the MM group remained essentially unchanged under the intact condition at both upper two adjacent segments (C2-C3 and C3-C4) and lower two adjacent segments (C6-C7 and C7-T1) segment ($P>0.05$). As expected, the most pronounced increase in the ROM of adjacent segments was found in the FF group, and there were statistically significant differences for C7-T1 ($P<0.05$), as shown in **Figure 4**.

Lateral bending suggested that the least obvious differences were found with regard to ROM changes of adjacent upper two segments (C2-C3 and C3-C4) and lower C6-C7 segment ($P>0.05$). The ROM at C7-T1 from FF group was significantly more than that of other groups ($P<0.05$), as shown in **Figure 5**.

Discussion

For multilevel surgery, stress reduction on adjacent segments and less loss of mobility are very important. However, there is still no consensus on the therapeutic methods for 2 consecutive level cervical spondylosis: 2-level ACDF, 2-level TDR or hybrid surgery. In addition, there is a dearth of biomechanical evidence of the selected segment to perform TDR in HS when both segments are suited to perform TDR. Currently, the Mobi-C disc is the only FDA-approved prosthesis artificial disc for two-level CDA. Recent prospective, randomized, controlled multicenter clinical trials have reported that the clinical outcomes specifically demonstrate the advantages of 2-level Mobi-C disc prosthesis over 2-level ACDF in treatment of 2 contiguous levels of the cervical spine diseases with two to ten years follow-up [14, 16, 19-21]. In addition, Shin et al. [30] compared hybrid surgery (HS), including Mobi-C plus ACDF, with two-level fusion in therapy of two-level consecutive disc disease in a prospective study and concluded that HS group has advantages of less neck pain, less adjacent ROM increase, better NDI recovery and faster C2-C7 ROM recovery compared with 2-level ACDF group. However, it is not clear about the long-term follow-up results. DiAngelo et al. [38] have concluded that the pure-moment loading methods did not replicate the physiologic response and are less suitable for assessing non-fusion hardware and disc arthroplasty. The concept of displacement-control approach has been proposed to evaluate spinal adjacent-level effects, which better replicates *in vivo* pattern for all segments of the cervical spine. In our study, we first investigated *in vitro* two-level unconstrained TDR (Mobi-C) applying the concept of displacement-control protocol to compare the biomechanical properties of simulating different surgical methods for the treatment of 2 consecutive level cervical disc diseases. In addition, in previous *in vitro* biomechanical studies, the analysis of adjacent segments was confined to the two segments which most close to the operative levels. In the present study, all intervertebral discs of whole cervical spine specimens (C1-T1) were included. The adjacent segments (C2-C4 and C6-T1) were extended to superior two and inferior two segments to the operative levels (C4-C6). In addition, we simulated the two conditions of hybrid surgery: Mobi-C at C4-C5 and arthrodesis at C5-C6 (MF), and arthrodesis at C4-C5 and Mobi-C at C5-C6 (FM).

In the sub-axial cervical spine, it was reported that *in vivo* motion is greatest for flexion-extension motion [39]. The proportions of motion at levels C4-C5 and C5-C6 were functions of the total *in vivo* ROM [40-42]. The greatest ROM occurred at C4-C5 level in our study, and accounted for an average 26.3% of the whole C2-C7 ROM. The data matched well with the *in vivo* data on a normal Chinese population from Holmes et al. [43] (The average greatest ROM occurred at C4-C5, and accounted for 27.1% of the whole C2-C7 ROM). Previous *in vitro* biomechanical studies involving 2 levels TDR are few [31-33, 36]. To our knowledge, there are only one *in vitro* study and one finite element-based study evaluating the biomechanical properties of 2-level TDR applying the concept of a displacement-control test [34, 44]. Cunningham et al. [34] reported that 2 level TDR implanted by PCM at C5-C7 segments significantly increased the F/E motion at the superior operative level (C5-C6), whereas motion at the inferior operative level (C6-C7) remained essentially unchanged from intact spine, and also increased ROM in AR motion at both implanted segments. In LB motion, 2 level TDR increased ROM at the superior surgical level, whereas it decreased ROM at the inferior implanted level. Faizan et al. [44] showed that the implant level motions were higher for the Bi-TDR models than that for the intact spine.

Contrary to previous trials [32, 33, 36], the implantation of TDR at 2 levels did not result in either significant hypermobility of the superior operative segments or a reduction at implanted levels. We noted that ROMs of implanted segments after two-level Mobi-C were increased for the three loading conditions, except that in LB they were decreased at inferior implanted segments; and the difference was significant only at ROMC4-C5 in AR loading. The results were in accordance with those of the finite element-based study reported by Faizan et al. [44]. In addition, the displacement-control test is thought to simulate a postoperative clinical status. Under this condition, the patients would try to reproduce the preoperative motion end points of the cervical spine [29, 30]. Our data also matched well with a postoperative clinical follow-up study [16]. For example, compared to intact spines, the MM group resulted in increased ROM from 12.3°±1.7° to 13.1°±2.0° (mean variation of +6.5%) in F/E, but led to a reduced ROM from 7.7°±1.3° to 7.4°±1.2° (mean variation of -3.9%) in LB at the superior level. Moreover, the MM group was associated with increase of ROM from 10.9°±2.5° to 11.6°±2.7° (mean variation of +6.4%) in F/E, from 7.0°±1.2° to 7.6°±1.2° (mean variation of +8.6%) in LB at the inferior level, which is similar to the ROM result of two-level total disc replacement with Mobi-C cervical artificial disc in a prospective, randomized study [16]. 330 patients with degenerative disc disease were enrolled in that trial, of which 225 patients received two-level Mobi-C, and 105 patients received ACDF. For TDR patients, the mean ROM was increased from 9.1°±4.9° to 10.0°±6.0° in F/E (mean variation of +9.9%) and decreased from 5.8°±3.4° to 5.5°±3.6° (mean variation of -5.2%) in LB at the superior level. At the inferior level, the mean ROM was increased from 7.4°±4.3° to 8.2°±5.3° in F/E (mean variation of +10.8%) and increased from 4.9°±3.3° to 5.1°±3.4° (mean variation of +4.1%) in LB.

In the present research, HS groups (MF group and FM group) led to an obvious decrease of ROM under the three loading conditions, with corresponding significant increase of ROM at the arthroplasty level compared to the intact group. It is still not known whether hypermobility could generate an adverse impact on the prosthesis *in vivo*. Our results were in agreement with previous biomechanical and clinical studies. Cunningham et al. [34] also demonstrated that the two-level HS group of arthroplasty (C5-C6) and arthrodesis (C6-C7) significantly increased the arthroplasty ROM compared with that of the intact group in AR and F/E. In the clinical study, Shin et al. [30] compared HS versus 2 levels ACDF in treatment of two-level consecutive disc disease. The authors reported that the ROM of C2-C7 in HS group recovered to the preoperative value after 2 years follow-up. In another *in vitro* biomechanical study employing 7 cadaveric C4-T1 spine samples applying a load control protocol, Cho et al. [32] reported ACDF/ProDisc-C hybrid surgeries did not change the ROM of C4-T1 compared to an intact spine. However, the HS groups significantly increased the arthroplasty ROM in F/E motion. In addition, group fusion/ProDisc-C also significantly increased the ROM of prosthesis in AR motion. As expected, the FF group in this study caused significant reduction of ROM under the three loading conditions as in previous reports [26-30].

In the literature, we found that only two *in vitro* biomechanical studies and one finite element-based study that investigated ROM on adjacent segments involving two-level TDR, HS, and two-level ACDF using a displacement-controlled protocol [34, 36]. Compared to the intact spine, Cunningham et al. [34] reported that neither 2 levels TDR nor HS generated significant change in adjacent-level motion, whereas ROM of lower adjacent level significantly increased after 2-level ACDF in FE, AR and LB. In 2012 Barrey et al. [36] revealed that 2-level ACDF led to increase of contribution of both upper and lower adjacent levels; however, a significant increase of the contribution wasnoted only at lower level for 2-level TDR and HS groups. Faizan et al. [44] showed that the ROM decreased at both the adjacent levels for Bi-TDR models in a finite element based study. In addition, the decrease at the superior adjacent level was greater than that at the inferior adjacent level. The ROM increased in all the loading modes at the superior and inferior adjacent levels for the Hybrid model. However, the most marked increase was observed for the two level fusion mold.

This study indicated that ROMs of MM group remained essentially unchanged from that of the intact condition of adjacent segments. For HS groups, the ROM increased at both the superior and the inferior adjacent levels in F/E and LB, but this increase was statistically insignificant. In addition, considering the effect on the adjacent segments, there is no statistical significance between the MF group and FM group. In the FF group, it produced an exaggerated increase in ROM at the adjacent levels as a result of significant reduction at the operative levels. In 2011, Lee et al. [33] also reported that increased ROM of TDR adjacent to the fusion could not make up for the total motion lost. It was also suggested that the spine with a hybrid construct had significant biomechanical advantages over two-level ACDF.

As far as we know, there have been only two clinical studies evaluating radiographic outcomes of the adjacent levels in patients who underwent two-level Mobi-C or HS (Mobi-C combined with ACDF) vs. ACDF for two-level contiguous cervical DDD. Davis et al. [16] demonstrated that two-level ACDF group experienced higher subsequent operative rate and displayed more frequent adjacent-segmental degeneration than those in two-level Mobi-C group over a follow-up of 4 years in the IDE study. Our data indicated that the adjacent ROMs of MM group were markedly smaller compared with those of FF group, especially in F/E loading, which may be ascribed to the higher rate of adjacent-segmental degeneration in the two-level ACDF group. Shin et al. [30] compared ROMs of the adjacent segments of HS (Mobi-C combined with ACDF) vs. ACDF for two-level contiguous cervical DDD during a 2-year follow-up. The mean ROMs for the 2-ACDF group increased from preoperative 16.9°±10.6° to 17.8°±4.0° and from preoperative 12.9°±4.8° to 16.5°±7.8° in the superior and the inferior adjacent segments, respectively. For the HS group, the corresponding ROM decreased from 13.4°±5.1° to 11.2°±5.4° and increased from 10.6°±3.2° to 11.0°±5.3° in the superior and the inferior adjacent segments, respectively. However, significant differences occurred only at the inferior adjacent segments between the groups. Our results also showed that the increased amplitude of adjacent segment ROMs in HS groups was less than that of adjacent segment ROMs in FF group; however, statistical difference occurred in C2-C3 ROM and C7-T1 ROM.

This study has some limitations: a small sample size, without evaluation of "wear and tear" during the biomechanical examination, the impossibility of simulating the complexity of human musculature action, and not reflecting the contributions of adhesions, fibrosis, and other processes that would be expected to contribute to long-term rotational stability after clinical operative recovery. However, we were the first to investigate *in vitro* two-level unconstrained TDR.

In conclusion, two-level Mobi-C produced kinematics similar to intact spine. Hybrid construct (ACDF plus Mobi-C) led to a hypermobility of prosthesis in F/E; however, it is not clear whether the hypermobility of the ROM has an adverse effect on the spinal structure *in vivo*. In addition, considering the effect on the adjacent segments, there is no significant difference between the MF group and FM group. Considering the adjacent level, two-level Mobi-C and Hybrid construct generated better biomechanical conditions than two-level ACDF by limiting the contribution of these segments to global ROM. This trial supports the option of two-level arthroplasty and hybrid construct in the cervical spine, and suggests that two-level TDR or HS could become an alternative approach for treating two-level consecutive disc disease, even though long-term and large cohort follow-ups are necessary to shed more light on two-level Mobi-C and HS.

Disclosure of conflict of interest

None.

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