# Changes of Adjacent Segment Biomechanics After Anterior Cervical Interbody Fusion With Different Profile Design Plate: Single- Versus Double-Level

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**Research Article**

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# Abstract

**Background:** Low-profile angle-stable spacer Zero-P is claimed to reduce the morbidity associated with traditional plate and cage construct (PCC). Both Zero-P and PCC could achieve comparable mid- and long-term clinical and radiological outcomes in anterior cervical discectomy and fusion (ACDF). It is not clear whether Zero-P can reduce the incidence of adjacent segment degeneration (ASD), especially in multi-segmental fusion. This study aimed to test the effect of fusion level with Zero-P versus with PCC on adjacent-segment biomechanics in ACDF.

**Methods:** A three-dimensional finite element (FE) model of an intact C2–T1 segment was built and validated. Six single- or double-level instrumented conditions were modeled from this intact FE model using Zero-P or the standard PCC. The biomechanical responses of adjacent segments at the cephalad and caudal levels of the operation level were assessed in terms of range of motion (ROM), stresses in the endplate and disc, loads in the facets.

**Results:** When comparing the increase of adjacent-segment motion in single-level PCC fusion versus Zero-P fusion, a significantly larger increase was found in double-level fusion condition. The fold changes of PCC vs. Zero-P of intradiscal and endplate stress, and facet load at adjacent levels in the double-level fusion spine were significantly larger than that in the single-level fusion spine during the sagittal, the transverse, and the frontal plane motion. The increased value of biomechanical features was greater at above segment than that at below. The fold changes of PCC vs. Zero-P at adjacent segment were most notable in flexion and extension movement.

**Conclusions:** Low-profile device could decrease adjacent segment biomechanical burden compared to traditional PCC in ACDF, especially in double-level surgery. Zero-P could be a good alternative for traditional PCC in ACDF. Further clinical/in vivo studies will be necessary to explore the approaches selected for this study is warranted.

# 1. Introduction

Anterior cervical discectomy and fusion (ACDF) has been a well-established and successful treatment for cervical spondylotic myelopathy and radiculopathy since it was firstly descripted by Smith and Robinson[1]. After that, much advancement has been made in surgical technique and prosthesis options. Plate and cage construct (PCC) is often used to achieve stability and promote fusion in ACDF procedure. In order to address some problems resulted from plate design and additional anterior dissection, zero-profile anchored spacer (Zero-P) devices have been developed[2]. The Zero-P devices have been shown to provide biomechanical stability comparable to PCC in both single- and double-level ACDF[3-5].

With the increase of the number of cervical spine fusion surgery annually, adjacent segment disease (ASD) has become a major concern after cervical fusion surgery[6]. There are many factors have been implicated in the development of ASD although the etiology is unclear. ASD is not only driven by the natural history but also by the changes of mechanical environment in adjacent segment[7]. The anterior disc and bilateral facet joints form the central path for the transmission of the loads along the spine. Load sharing of the spine occurs anteriorly through the disc and posteriorly through the facet joints. Altered biomechanical environment resulted from the fused motion segment possibly play roles in the development of ASD.

Compared with single- level ACDF group, there is a trend for a greater rate of ASD in the double-level ACDF group[8]. There is increased adjacent-segment motion at the adjacent levels after a double-level compared with a single-level ACDF using PCC construct[9]. A Meta-Analysis has demonstrated that, compared with the PCC group, the Zero-p group had a significantly reduced incidence of ASD[10]. Over the 2-year follow-up, ACDF with traditional PCC showed a higher incidence of ASD than ACDF with stand-alone cages in double-level ACDF patients[11].

To our knowledge, there is no study specifically examining the effect of fusion level on adjacent-segment biomechanics of Zero-P versus PCC in ACDF. This study aimed to compare the biomechanical effects between double-level and single-level fusion with Zero-P versus PCC. We hypothesized that increased number of operated segment will lead to obviously more greater biomechanical changes at adjacent segments in PCC fusion model than that in Zero-P fusion condition. A three-dimensional computational study was carried out to examine these effects.

## 2 Materials And Methods

# 2.1 Model Development and Validation

A nonlinear three-dimensional finite element (FE) model of cervical spine segments (C2–T1) was developed. The bony geometry was derived from computed tomography (CT) scan images of a healthy 38-year-old male. The male subject was scanned with the slice thickness of 0.75 mm and the slice increment of 0.69 mm thickness from C2 to T1. The Cobb angle was in the reported range of the subaxial cervical spine[12]. Lordosis of C2-C7 in current model was 23.7°. The DICOM images were imported into the software 3D-DOCTOR software (Able Software Corp) to construct the geometric structure of C2-T1. The mesh structure was prepared using the preprocessing software Hypermesh (Altair Technologies Inc) and then was imported into Abaqus (Simulia, Providence, RI) to solve. The FE model included cortical bone, cancellous bone, bony posterior elements, annulus fibrosus (AF), nucleus pulposus (NP), posterior facets, end plates, anterior longitudinal ligament, posterior longitudinal ligament, ligamentum flavum, interspinous ligament, and capsular ligaments. The insertion points and areas of the ligaments were closely matched with published data[13]. The model components, the element type and the material properties are shown in Table 1[13-18]. The fluid-like behavior of the disc was simulated to be nearly incompressible using eight-node hybrid hexahedral elements. The facet joint was built as a nonlinear three-dimensional contact problem with surface-to-surface contact elements. Hexahedral elements with an isotropic-elastic material model were used to model facet cartilage. Major ligaments of the cervical region were represented by truss elements.

Table 1
Material properties of cervical spine structures and instrumentations.

| Component | Element Type | Young's Modulus (MPa) E | Poisson Ratio μ | Cross Sectional Area ($mm^2$) |
|---|---|---|---|---|
| Cortical bone | Shell elements | 12000 | 0.29 | - |
| Cancellous bone | 3-D solid elements (4 node) | 450 | 0.25 | - |
| Facet cartilage | 3-D solid elements (4 node) | 10.4 | 0.4 | - |
| Annulus fibers | 3-D solid elements (8 node) | 48 | 0.4 | - |
| Nucleus pulposus | 3-D solid elements (8 node) | 1.0 | 0.49 | - |
| Endplate | 3-D solid elements | 500 | 0.4 | - |
| Anterior longitudinal ligament | 3-D tension truss elements | 30 | 0.3 | 33 |
| Posterior longitudinal ligament | 3-D tension truss elements | 20 | 0.3 | 33 |
| Interspinous ligament | 3-D tension truss elements | 1.5 | 0.39 | 13 |
| Ligamentum flavum | 3-D tension truss elements | 5 | 0.3 | 50.1 |
| Capsular ligaments | 3-D tension truss elements | 20 | 0.3 | 46.6 |
| PEEK cage | 3-D solid elements (4 node) | 3600 | 0.3 | - |
| Titanium plate | 3-D solid elements (4 node) | 110000 | 0.3 | - |
| Screw | 3-D solid elements (4 node) | 110000 | 0.3 | - |

To validate the FE model, range of motion (RoM) of each cervical segment was the major indicator. Subaxial RoM and functional spinal unit RoM (movement in sagittal plane, coronal plane and axial plane) were chosen for comparison with the published experimental results[19-22]. The subaxial RoM was defined as the measurement of the total motion between the C2 and C7 vertebrae. The functional spinal unit RoM, intersegmental motion, was the motion between two adjacent vertebrae. The same boundary and loading conditions were simulated with the controlled experiments. All degrees of freedom (DoF) were constrained on the lower surface of T1 in our FE model. Pure moments of 2-Nm were applied to the superior surface of C2 in the three main planes to produce flexion, extension, lateral bending and axial rotation respectively. Using the follower load technique, a compressive follower load of 100 N was also applied to the upper surface of C2 to simulate physiologic compressive loads. The validation and following FE analysis were performed in ABAQUS (Simulia, Providence, RI). Subaxial RoM and functional spinal unit RoM were recorded.

## 2.2 Surgery Simulation, Generation of Implant Models and Boundary Conditions

From the intact C2–T1 FE model (Figure 1), a single- or double-level ACDF was performed. Fusion models were created by removing the anterior longitudinal ligament, the intervertebral disc and cartilaginous endplate. To study the efficacy of fusion on the adjacent level biomechanics, and to make the target level be the same segment, six fusion conditions to be tested were designed according to Prasarn et al.’s method[9]. As shown in Figure 2, six fusion models were created. C4-C5 was chosen as the segment for comparing the fusion action on the superior adjacent level in Model A-D (Figure 2). In order to test the influence of fusion on the inferior adjacent segment, biomechanical features of C6-C7 segment was observed in Model C-F (Fig. 2). In single-level conditions, C5-C6 intervertebral disc was removed. In double-level models, C4-C5 and C5-C6, or C5-C6 and C6-C7 intervertebral discs were removed. Thereafter, six FE models received instrumentation with PCC or Zero-p (Fig. 3 Model A-F). In the standard PCC fusion model, a rigid anterior cervical plate was used. Plate (width 16 mm, thickness 2 mm) and fixed screws (diameter 4 mm, length 14 mm) were rigidly fixed in the fused segment (Figure 3). The 4-screw anchored Zero-P system (Synthes, Oberdorf, Switzerland) were adopted in the current study (Figure 3). Fixed screws (diameter 3 mm, length 16 mm) were adopted in the Zero-P system. The same PEEK interbody spacer (width 15 mm, length 16 mm, and height 6 mm) was used in both PCC and Zero-P fusion model to maintain the sagittal alignment after operation. The titanium alloy plate and PEEK material properties were assigned to the respective implants (Table 1). In the standard PCC surgical model, the above and below distance of the plate to the adjacent disc were 5.5 mm and 5 mm in one level PCC construct model, 5.5 mm and 5.2 mm in C4-C5 and C5-C6 fusion model, and 5.7 mm and 5.3 mm in C5-C6 and C6-C7 fusion model. The C2-7 Cobb angle were 22° for one level (C5-C6) fusion, 24° for C4-C5 and C5-C6 fusion model and 23° for C5-C6 and C6-C7 fusion model. In all loading conditions, the inferior surface of T1 vertebra was fully constrained. A pure moment of 2 Nm combined with a follower load of 100 N were similarly imposed on C2. The external (range of motion, RoM) and internal (endplate, disc and facets load sharing) responses adjacent to fusion of single- and double level ACDF surgeries in six models were assessed. Stresses in the endplate and disc were calculated using the average von-Mises stresses. The facet loads at a motion segment was defined as the average loads on the right and left articulating facets.

# 3 Results

## 3.1 Validation of the FE Model

The intact cervical spine FEM consisted of 152608 elements and 41797 nodes (Figure 1). The present intact cervical model of C2-T1 vertebrae was compared with previously published experimental results to assess the validity. The predicted segmental RoM of the flexion-extension, lateral bending, and axial rotation of the intact cervical model were well in agreement with previous experiments studies (Figure 4) [19-22].

## 3.2 Kinematics of Adjacent Segments after One- and Two-Level Fusion

When comparing single-level PCC fusion versus Zero-P fusion, RoM in proximal adjacent segment (C4-C5) showed an increase of 6.5% in the sagittal plane, 4.9% in the transverse plane, and 5.6% in the frontal plane (Figure 5, Model C, D). In distal adjacent segment (C6-C7), RoM of 3.8%, 2.6%, 4.8% increases were observed in the sagittal, transverse and frontal planes, respectively (Figure 5, Model C, D).

Whereas, in double-level fusion models, the above (C4-C5) (Figure 5, Model A,B) and below (C6-C7) (Figure 5, Model E,F) adjacent segments had RoM increases of 16.7% and 5% in the sagittal motion, 7.7% and 6.1% in the transverse motion, and 13.7% and 5.6% in the frontal motion, respectively.

## 3.3 Biomechanical Changes in Disc, Endplate and Facet in Adjacent Levels

As shown in Figure 6, at the superior adjacent segment (C4–C5), single level fixation produced mildly higher flexion, extension and lateral bending intradiscal and endplate stress, and facet load in the PCC fusion model than that in the Zero-P fusion model. When compared with the single level Zero-P fusion, during flexion, extension and lateral bending, the biomechanical value in the PCC fixation surgery increased by 1.5%, 2.2% and 1.0% of the intervertebral disc stresses (Figure 6, Model C,D); by 3.8%, 4.2% and 1.2% of the endplate stresses (Figure 6, Model C,D); and by 7.6%, 14.9% and 12.2% of the facet loads (Figure 6, Model C,D). Whereas, in the double level fusion procedure compared with the Zero-P fusion condition, there were significant increases of flexion, extension, axial rotation and lateral bending biomechanical parameters above fusion: 70.9%, 152.4%, 35.5%, 38.7% of intradiscal stresses (Figure 6, Model A,B); 125.9%, 204.8%, 49.1%, 57.5% of endplate stresses (Figure 6, Model A,B); and 151.7%, 193.5%, 33.4%, 36.6% of facet loads (Figure 6, Model A,B).

Figure 7 displayed biomechanical changes in disc, endplate and facet below the fusion (C6–C7). When compared with the Zero-P fusion, single level fixation was associated with mildly higher biomechanical response at the inferior adjacent segment in the PCC fusion model. During flexion, extension and lateral bending, the fold changes of PCC vs. Zero-P increased by 1.4%, 2.4%, 1.6% in intervertebral disc (Figure 7, Model C,D); 3.0%, 4.0%, 1.9% in endplate (Figure 7, Model C,D); and 7.1%, 8.9%, 10.3% in facet (Figure 7, Model C,D). In the double level procedure, the fold changes of PCC vs. Zero-P value were obviously enlarged. Compared with the Zero-P fusion condition, there were significant increases of flexion, extension, axial rotation and lateral bending: 21.3%, 43.6%, 97.8%, 2.9% of intradiscal stresses (Figure 7, Model E,F); 35.2%, 56.9%, 15.6%, 12.1% of intraendplate stresses (Figure 7, Model E,F); and 61.3%, 67.6%, 12.3%, 34.8% of intrafacet loads (Figure 7, Model E,F). The increased values of the fold changes of PCC vs. Zero-P rate were larger at the superior than that at the inferior segment.

# 4 Discussion

The role of ACDF in patients with cervical spine disc disease has long been established. To reduce various intraoperative and postoperative complications associated with PCC, while maintaining the benefits of interbody cages with anterior plating, low-profile angle-stable spacer Zero-P has been developed. The current investigation was performed predominantly to evaluate the effect of fusion level on adjacent-segment biomechanics of Zero-P versus PCC in ACDF. In the present computational simulation, compared with single-level fusion, double-level fusion will lead to obviously much bigger biomechanical changes of the ratio of PCC to Zero-P at adjacent segments was shown.

Zero-p spacers with integrated fixation can simplify the surgical technique while maintaining the stability of the construct. The promising biomechanical data for two-level use has been reported[23, 24]. Zero-P device showed comparable stability to traditional PCC for two-level fusion[4]. Clinical studies showed that Zero-p device may be associated with a reduced rate of ASD compared to using the PCC construct in single and double level ACDF[10, 11, 25, 26]. The present study provided biomechanical evidences for these clinical results. The fold changes of PCC vs. Zero-P of intradiscal and endplate stresses, and facet loads at adjacent levels in the double-level fusion models were significantly larger than that in the single-level fusion models during the sagittal, the transverse, and the frontal plane motion (Figure 6,7). Our results showed that the fold changes of PCC vs. Zero-P were most notable in flexion and extension movement (Figure 6,7). The current computational simulation indicated that, compared to using the PCC construct, the low rate of biomechanical effects might be occurred in Zero-p device fusion condition. And the rate of ASD might be higher in double level ACDF using Zero-P vs. PCC construct than that in single level.

The number of levels included in the fusion construct has been considered as an important factor for contribution to the development of ASD following ACDF. Since fusion of cervical spinal segments may lead to excessive stress on the unfused adjacent segments, therefore, longer fusions may cause greater stresses at adjacent levels after spine fusion and likely lead to ASD. Clinical investigation has demonstrated an increased risk of degeneration with increasing length of fusion. Greater rate of ASD in double-level ACDF group than in the single-level group has been reported through 5-year follow-up[8]. ASD is a long-term complication of cervical spine fusion procedures. It has been reported that over the course of 10 years after ACDF, symptomatic ASD developed at an incidence of 2.9% per year[27]. Although Basques et al.[28] considered that multi-level procedures may not be a significantly greater risk of developing ASD compared to single-level procedure. This might be due to short follow-up time, 2 years, in their investigation. Prasarn et al.[9] had proven that the biomechanics affecting adjacent levels in the cervical spine after ACDF do change from a single- to a multilevel fusion. Similar to their results, the present study also showed that there was increased adjacent-segment motion at the levels above and below, after a double-level compared with a single-level ACDF with both PCC and Zero-P constructs (Figure 5). The increased value was larger at the superior than that at the inferior segment (Figure 5). The increased mechanical response (Figure 6,7), in combination with the aging process, may synergistically hasten the process of degeneration adjacent to the cervical fusion level. With time, ASD may require additional surgical intervention.

Mechanical irritation against the adjacent segment caused by a traditional PCC is regarded as a predisposing factor of ASD[29]. Goffin et al.[30] suggested that the shortest plate possible be used to avoid producing an effect on adjacent segments. Zero-P spacer implant was developed to avoid such possible irritation. Compared to traditional plates, such all-in-one fusion device is contained within the disc space allowing for maximum distance from the adjacent level disc. Our computational simulation indicated that, in both single- and double-level fusion models, higher biomechanical features were occurred in PCC fusion models (Figure 5-7). So we supposed that, Zero-P spacer may lower the biomechanical effects on adjacent level for a no-additional-plate restriction in anterior vertebrae, especially, in the double-level ACDF surgery. However, future more clinical studies with high methodological quality and long-term follow-up periods are needed to evaluate the PCC vs. Zero-P ACDF procedures for multilevel cervical spondylotic myelopathy treatment.

FE analysis is an effective simulation method for predicting the trend in biomechanics after different surgical procedures and thereby providing certain guidance for clinical management. However, there are some limitations in the current study which should be taken into account. First, caution should be taken when interpreting the results of the current study, because the intact FEM is based on a single scan of a normal man. The FE simulation aimed to provide the trend rather than the actual data. FE analysis has limitations, similar to the cadaver studies and other published FE studies. Second, Truss elements were used for ligaments modeling. The contact interaction between ligaments and vertebrae does not take into account such simplification, but this has the advantage of avoiding unrealistic shearing forces in the ligaments and thus has a reduced computation time. Third, the absence of neck muscles may affect the finite element biomechanical features, for instance, motion and stress. Because of the role of these muscles is to control the cervical range of motion. The biomechanical behavior of different fusion devices should be evaluated with future clinical studies and in vivo biomechanical works are warranted.

## 5 Conclusions

Zero-p device was associated with different biomechanical effects compared to the PCC construct in ACDF. The present computational simulation show that, compared with Zero-P device, PCC could bring about higher ROM changes at adjacent segment in both single- and double-level fusion models, especially in double level fusion condition. Compared with single-level fusion, double-level fusion could bring about increased changes of stress in the disc and endplate, and changes of facet load ratio of PCC to Zero-P at adjacent segments. It may be possible that the rate of ASD is lower in double level ACDF with Zero-P vs. PCC construct than that in single level. The results of this study may be important for surgical decision-making and may provide potential biomechanical rationale for using Zero-P implants in double-level ACDF.

# Abbreviations

Plate and cage construct: PCC, Anterior cervical discectomy and fusion: ACDF, Adjacent segment degeneration: ASD, Finite element: FE, Range of motion: ROM, Computed tomography: CT.

# Declarations

## Author's contribution

Conceived and designed the experiments: XFL, LYJ, XXS. Performed the experiments: XFL, LYJ, HLY. Analyzed the data: XFL, LYJ, HLY. Wrote the paper: XFL, LYJ, HLY, XXS. All authors read and approved the final manuscript.

## Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

## Ethics approval and consent to participate

The study is conducted according to the Declaration of Helsinki and approved by the institutional review board of Baoshan branch of Renji Hospital, and the written informed consent of volunteers has been obtained.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Not applicable.

## Consent for publication

Not applicable.

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# Figures

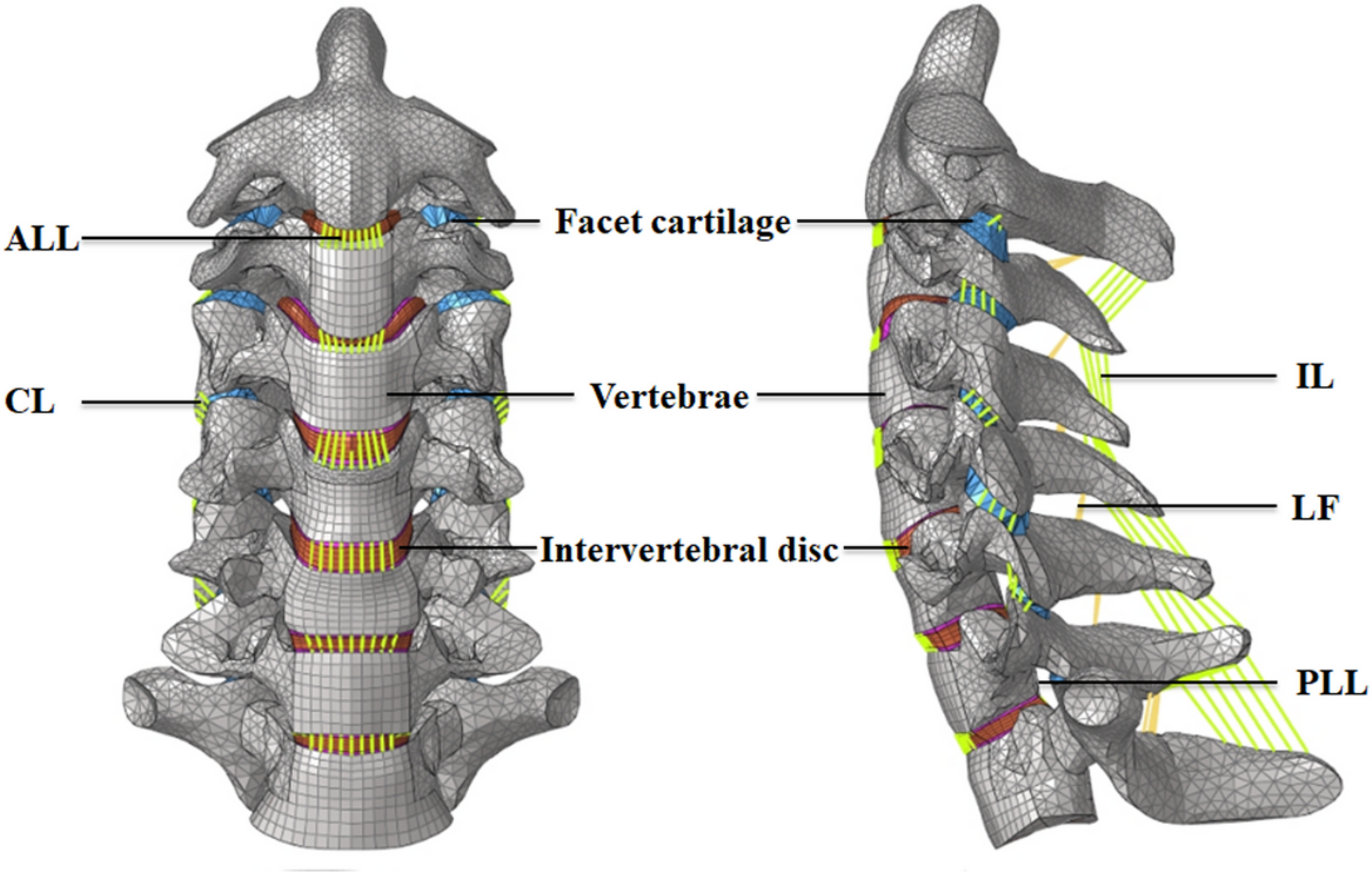


**Figure 1**

Anteroposterior and lateral view of a three-dimensional finite element model of intact C2–T1 segment. CL: Capsular Ligament, ALL: Anterior Longitudinal Ligament, PLL：Posterior Longitudinal Ligament, LF: Ligamentum Flavum, IL: Interspinous Ligament.

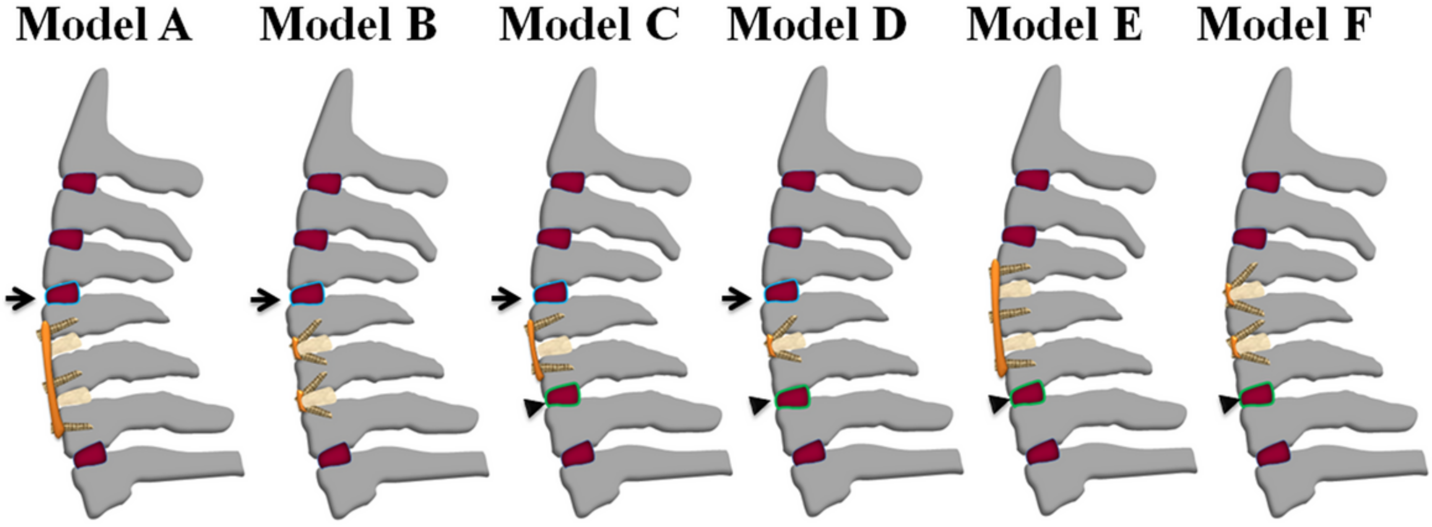


**Figure 2**

Six fusion surgery designs were simulated according to Prasarn et al.'s method. Arrow: C4-C5 segment was chosen as the target superior adjacent level. Triangle: C6-C7 segment was chosen as the target superior adjacent level.

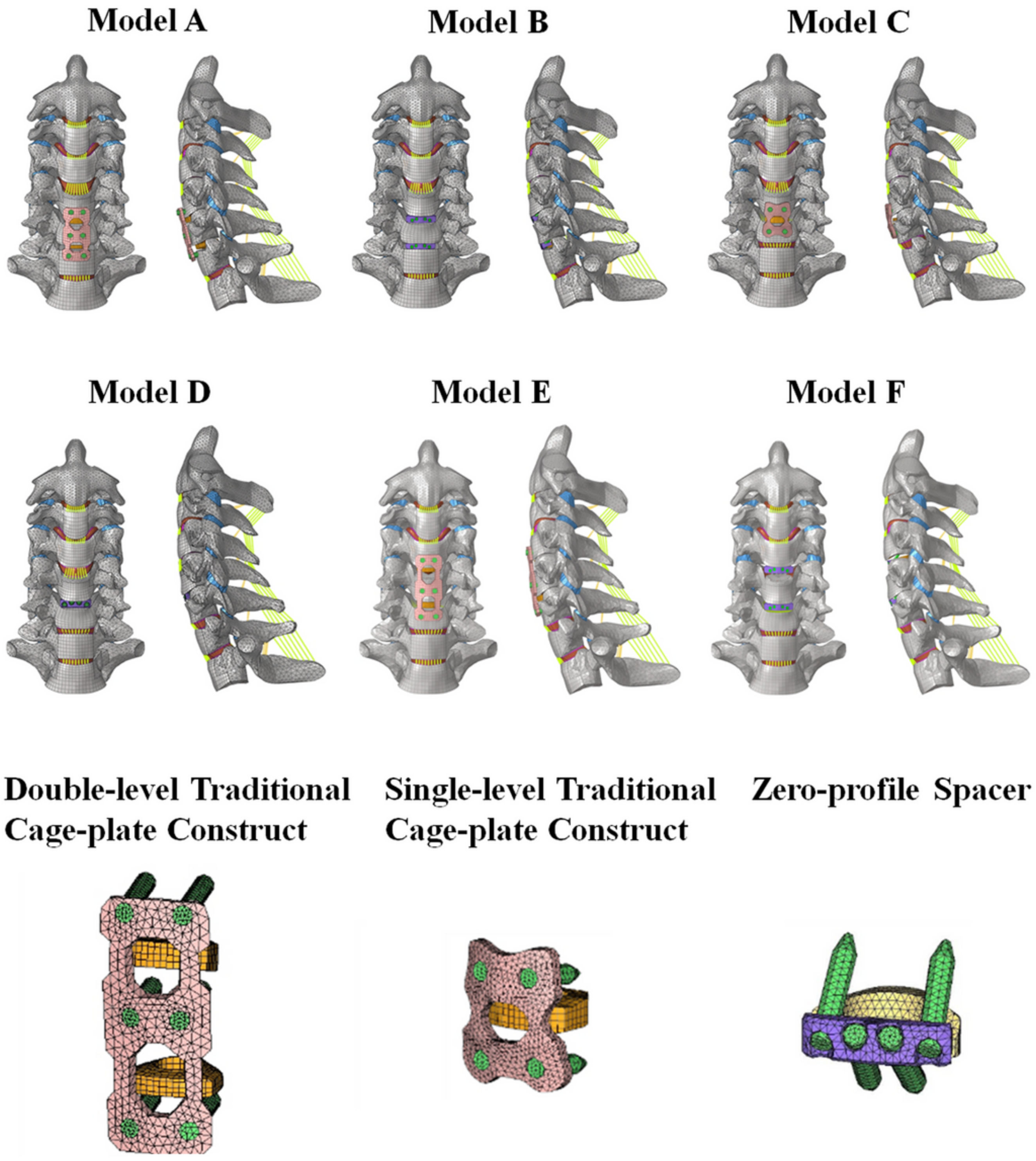


**Figure 3**

Finite element models of six fusion surgery and anterior cervical surgery implants.

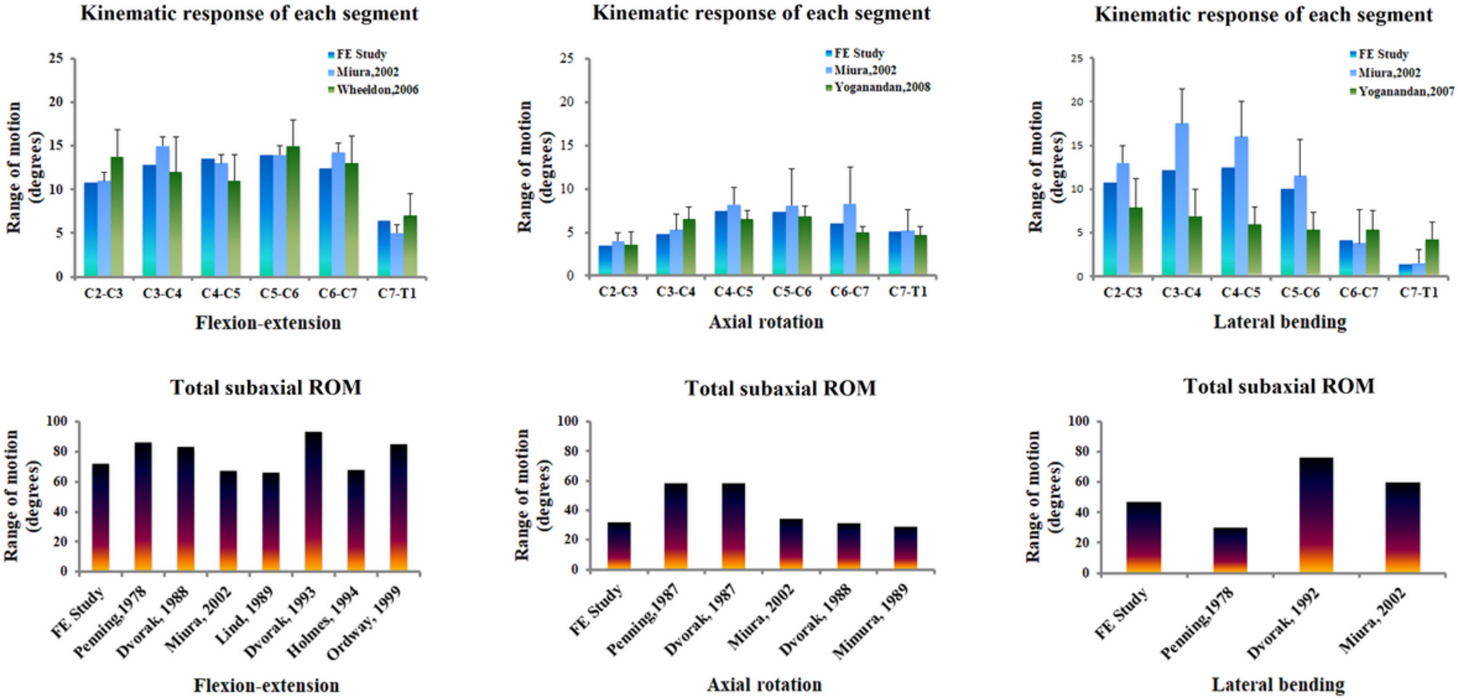


Figure 4

Comparison of the total subaxial RoM (A) and the kinematic response of each segment (B) of finite element model with the in vivo and in vitro studies during flexion-extension, axial rotation, and lateral bending.

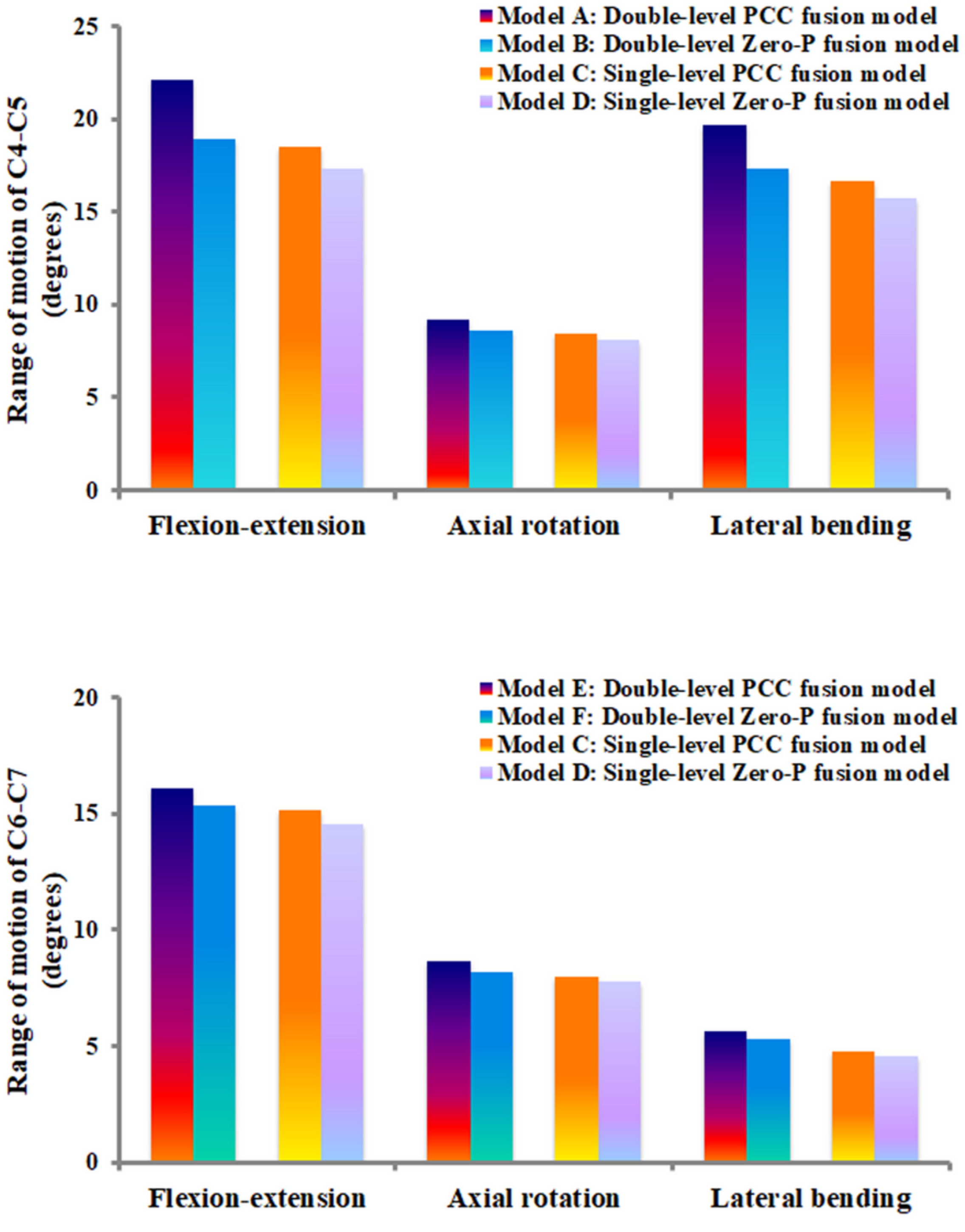
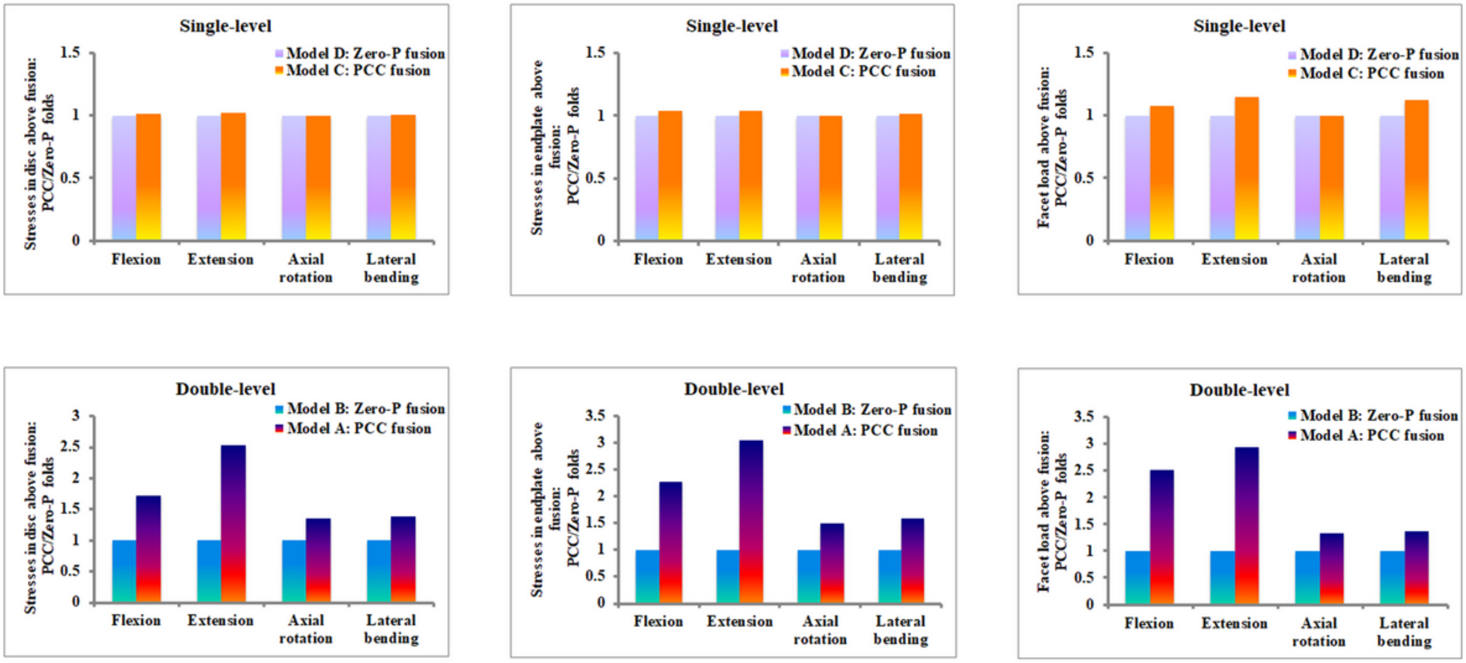


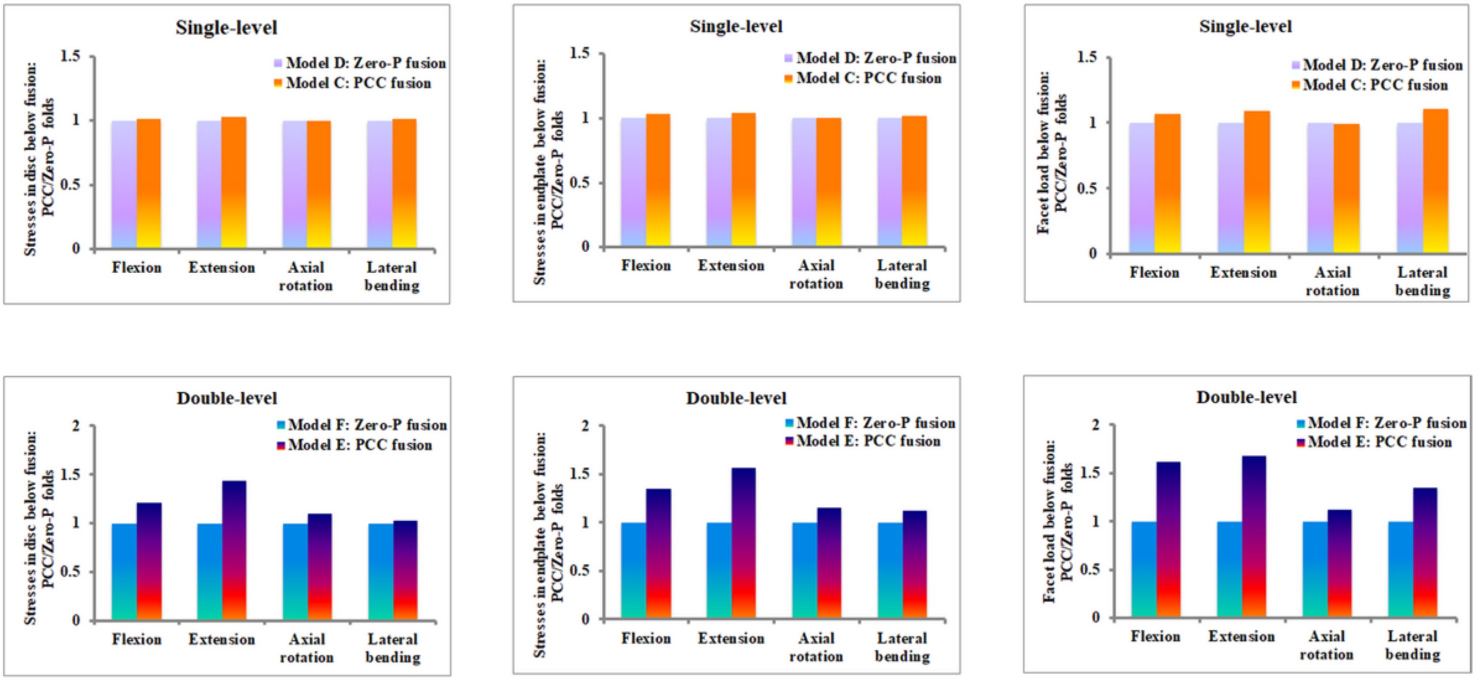
Figure 5

Kinematics changes at the proximal (C4-C5) (A) and distal (C6-C7) (B) adjacent levels in different fusion models.



## Figure 6

PCC/Zero-P folds changes of adjacent intradiscal and endplate stresses and facet load above fusion segment in different ACDF models during flexion, extension, axial rotation and lateral bending movement.



## Figure 7

PCC/Zero-P folds variations of adjacent intradiscal and endplate stresses and facet load below fusion segment in different ACDF models during flexion, extension, axial rotation and lateral bending movement.