Biomechanical comparison of stand-alone and bilateral pedicle screws fixation for oblique lumbar inter-body fusion surgery – a finite element analysis

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Abstract

Objectives: The aim of this study was to evaluate the biomechanical stability and safety in patients undergoing oblique lumbar inter-body fusion (OLIF) surgery with stand-alone (SA) and Bilateral pedicle screw fixation (BPSF). Methods: A finite element model of L4-L5 spinal unit was established and validated. Based on the validated model technique, function surgical models corresponding to SA, BPSF were created. Simulations employing the models were performed to investigate the OLIF surgery. A bending moment of 7.5 Nm and a 500 N follower load were applied to the models in flexion, extension, axial rotation and lateral bending. Finite element(FE) models were developed to compare the biomechanics of the intact group, SA, BPSF group. Results: Compared with the Range of motion (ROM) of the intact lumbar model, SA model decreased by 79.5% in flexion, 54.2% in extension, BPSF model decreased by 86.4% in flexion, 70.8% in extension. Compared with the BPSF, the maximum stresses of L4 inferior endplate (IEP) and L5 superior endplate (SEP) increased significantly in SA model, L4 IEP increased to 49.7MPa in extension, L5 SEP increased to 47.7MPa in flexion. Conclusions: OLIF surgery with BPSF could reduce the max stresses of the endplate which may reduce cage sedimentation incidence. However, OLIF surgery with SA could not provide enough rigidity for the fusion segment in osteoporosis patients which may increase the cage sedimentation incidence. Keywords: OLIF; Pedicle screw fixation; spinal fusion; finite element

Introduction

OLIF was introduced in 2012 by Silvestre [1]. The stand-alone procedure brings low risk of post-treatment trauma or bleeding and offers good stability and quick recovery. However, the complications associated with this technique have been reported frequently [2–5]. Abe reported 155 patients with OLIF surgery, 75 complications were reported (incidence rate, 48.3%). The most common complication was endplate fracture/subsidence (18.7%) [6]. Shun-wu Fan reviewed 235 patients with OLIF surgery and found 22 cases of endplate damage [7]. The mechanics of endplate fracture in OLIF surgery was still unclear. Avoiding such complications could be a major factor in deciding to use this procedure. Whether OLIF surgery with BPSF could provide enough stability and reduce the complication was still unknown.

Finite element analysis (FEA) in lumbar biomechanics has become popular in the recent decades, as a complement for the cadaver test [8,9]. FE models of cage and spine were used for the evaluation of surgery feasibility and the design of instruments. The purpose of this study was to evaluate safety of OLIF surgery with SA and BPSF.

Materials And Methods

The intact lumbar FE mode development

A L4/5 three-dimensional lumbar model was created by the Mimics 20.0 software (Materialise, Leuven, Belgium). The data came from the demo file in Mimics 20.0 software. The lumbar intervertebral discs, endplates, and facets were created according to the contour of the adjacent vertebral body. Seven major ligaments, including anterior longitudinal ligament, posterior longitudinal ligament, flava ligament, facet capsular ligament, inter-transverse ligament, inter-spinous ligament and supra-spinous ligament, were modeled by axial connectors (Figure 1). The mechanical properties of the model were also adopted from the literature (table 1) (9).

Table 1 Assigned Material Properties for the Finite Element Models

The load process had two steps. At the First step, the follower load of 500 N was applied to represent the upper body weight and the strength of the muscles. The moment of 7.5 Nm was applied on the surface of L4 to test the six movement directions of the lumbar spinal model: flexion/extension, right/left lateral bending and right/left axial rotation. All degrees of freedom at the bottom of the L5 surface were constrained. All the simulations were performed using FEA software ABAQUS 6.14 (Dassault Systèmes, Vélizy-Villacoublay, France).

OLIF FE model’s development

An OLIF cage was assembled to L4-L5 functional spinal unit (FSU) model (Figure 2) to simulate the Stand-alone model. Four pedicle screws and two rods were assembled to both sides of L4-L5 FSU to simulate the BPSF model (Figure 2). The properties were the same as the intact lumbar model. The bottom of the L5 vertebral body was fully constrained. A 500 N axial load and 7.5 NM moment were applied on the top of the L4 vertebral body.

Results

Model validation

The overall ROM of intact model was compared with those for in vitro and in vivo kinematics (Figure 3) [10–12]. The results were in good agreement with the pre-studies from Pearcy M, Wilke J and Yamamoto I, which meant the intact lumbar model was validated.

ROM and displacement in the OLIF model

Compared with ROM of the intact lumbar model, Stand-alone model decreased by 79.5% in flexion, 54.2% in extension, 62.5% in lateral bending, 42.8% in axial rotation, BPSF model decreased by 86.4% in flexion, 70.8% in extension, 80.8% in lateral bending,58.6% in axial rotation (Figure4). These results showed that OLIF procedure with BPSF could reduce ROM of fusion segment significantly. However, OLIF with SA could not reduce the extension and axial rotation motion effetely.

Stress implant model

Compared with the BPSF, the maximum stresses of L4 IEP and L5 SEP increased significantly in SA model, L4 IEP increased to 49.7MPa in extension, L5 SEP increased to 47.7MPa in flexion (Figure 5, Figure6, Figure 7 and Figure 8). L4 IEP of SA model had 339% higher stress than BPSF model in extension moment and L5 SEP of SA model had 64% higher stress than BPSF model in flexion moment. These results indicated that OLIF with SA got high risky in endplate fracture in flexion and extension motions. OLIF with BPSF could decrease the Mises stress of endplate greatly which may reduce the risk.

The maximum stresses of cage decreased significantly in BPSF model in the flexion and extension moment, compared with SA model. Cage of BPSF model had 39.6% lower stress than SA model in flexion moment and 84.1% lower stress in extension moment. (Figure 9, Figure10).

Discussion

OLIF surgery has become popular recent years. Stand-alone procedure offer patients many benefits：small incision and scar, less blood loss, less pain, less hospitalization time, faster recovery [1–5]. Nevertheless, the complications fluctuate from 3.7%to 66.7% [1–5,13–14]. Shun-wu Fan reviewed 235 patients with OLIF surgery and found 22 cases of endplate damage. The cage sedimentation incidence in the stand-alone group was higher than in the OLIF combined with posterior pedicle screw fixation [7]. Avoiding such complications could be a major factor in deciding to use this procedure. The mechanics of endplate fracture was unclear. Whether OLIF surgery with BPSF could provide enough stability and reduce the complication was still unknown.

In this study, the OLIF model was developed using published biomechanical assessment methods. A validated lumbar FE lumbar model enabled the accuracy and reliability of the simulation results. In validation, ROMs were compared with those in the literature [10–12]. The results were in good agreement with the pre-studies. The FE model was validated successfully, and it was considered reliable for lumbar biomechanical predictions.

Based on the validated lumbar model, OLIF models including Stand-alone, BPSF at the level of FSU (L4-L5) developed. The simulation showed that both BPSF could reduce ROM of the lumbar significantly. However, OLIF with SA could not reduce the extension and axial rotation motion effetely.

The maximum stresses of L4 IEP were 49.7 MPa in extension movement, the maximum stresses of L5 SEP were 47.7 MPa in flexion movement. While the yield stress of lamellar bone was 60 MPa [15], and the yield stress of bone in the osteoporosis patients was less than 60 MPa. This suggested the maximum stresses of endplate in flexion and extension were close to lamellar bone's yield point in osteoporosis patients after a stand-alone OLIF procedure, which may result in endplate fracture and cage subsidence. L4 IEP of BPSF model had 77.2% lower stress than SA model in extension moment and L5 SEP of BPSF model had 39.0% lower stress than SA model in flexion moment.

This indicated the OLIF with BPSF was safer than OLIF with SA in cage subsidence. Lumbar intervertebral fusion with BPSF are the standard for instrumentation, providing rigid fixation and increased fusion rates.

In all, the FEA revealed SA could not provide enough rigidity in OLIF surgery in osteoporosis patients. The maximum stresses of L4 IEP and L5 SED increased largely in SA model in flexion and extension moment, which may be a key risk factor of cage subsidence. Therefore, the OLIF surgery with SA is not favored for osteoporotic spine.

From the study, we also found additional BPSF could share the stresses of endplate, restrict the flexion and extension of lumbar, which may be an effective method to reduce the complication of cage subsidence. The Clinical study had proven that BPSF can decrease the ratio of cage displacement [16]. In conclusion, additional BPSF was essential for OLIF surgery in osteoporosis patients.

Limitations

The post-operative residual annular fibrous were not constructed in the stand-alone OLIF model. The risk factors of endplate fracture may be multiple, including endplate damage, obesity, high iliac crest, poor stability of lesion segments and so on [7].

Conclusion

The FEA indicated that OLIF procedure with SA could not stabilized the lumbar, especially in flexion and extension movement. The Maximum stresses of L4 IEP and L5SEP of SA model in flexion and extension increase significantly which may be a potential factor of cage subsidence. OLIF with additional pedicle screw-rod system was essential for osteoporosis patients.

Abbreviations

OLIF: oblique lumbar inter-body fusion

SA: stand-alone

BPSF: Bilateral pedicle screw fixation

ROM: Range of motion

IEP: inferior endplate

SEP: superior endplate

FE: Finite element

FSU: functional spinal unit

FEA: Finite element analysis

Declarations

Ethics approval and consent to participate

This article did not involve the experiments of human and all the data came from the demo file in Mimics 20.0 software.

Consent for publication

Not applicable.

Availability of data and material

The data came from the demo file in Mimics 20.0 software.

Competing interests

None.

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Authors’ contributions

Dr. Fang Guofang and Dr. Lin yunzhi had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Dr. Sang Hongxun designed the study protocol.

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Tables

Table 1 Assigned Material Properties for the Finite Element Models

Tissues	Modulus (MPa)	Poisson’s ratio	Element type	Thickness
Cortical bone	12000	0.3	Shell	1mm
Cancellous bone	100	0.2	Solid	/
Bony endplate	12000	0.3	Shell	0.8mm
Facet	35	0.4	Shell	0.2mm
Annular ground substance	c1 = 0.18, c2 = 0.045	/	Solid	/
Nucleus pulposus	c1 = 0.12, c2 = 0.03	/	Solid	/
Annular collagen fiber	450	0.3	Surface	/
PEEK (polyetheretherketone)	3700	0.3	Solid	/
Titanium (Ti-6Al-4V)	110000	0.3	Solid	/

Figures

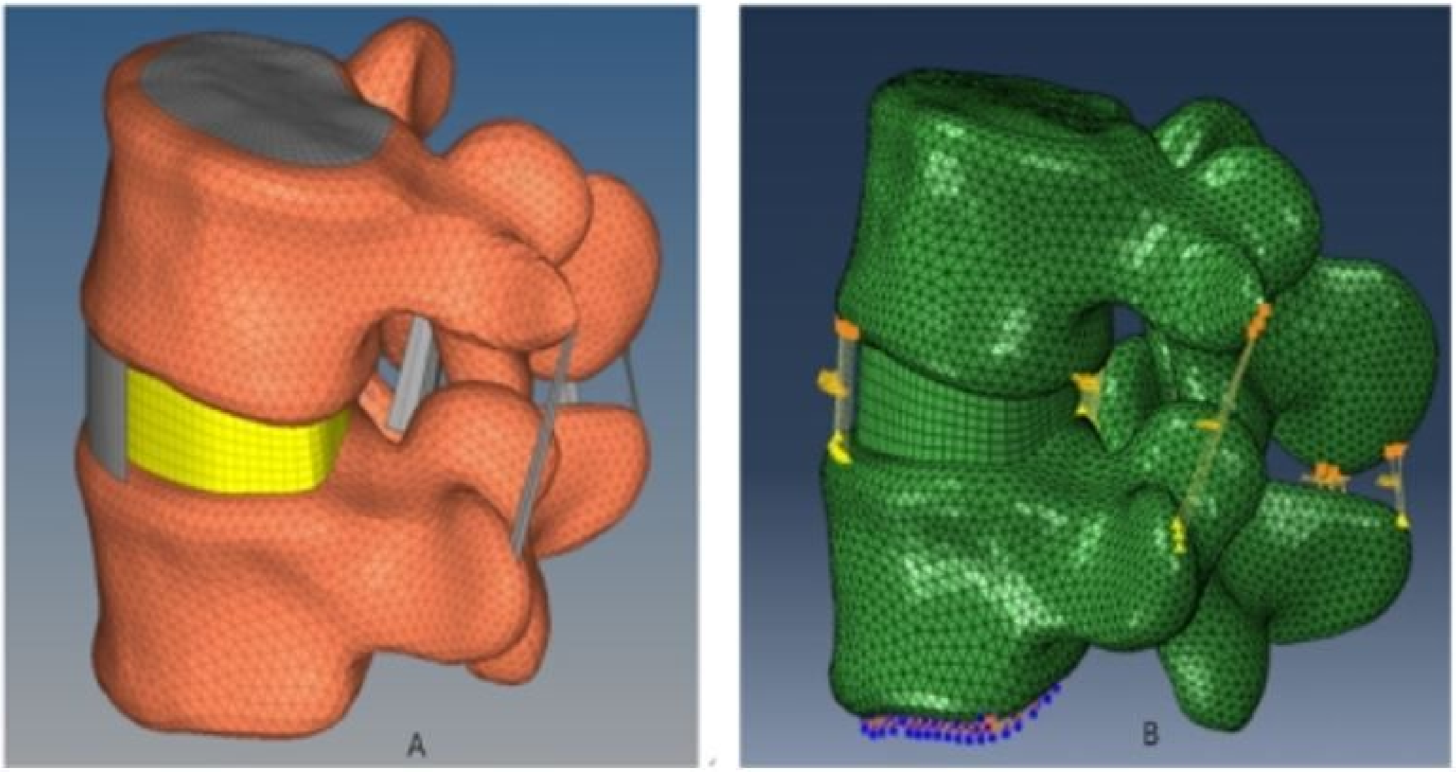

Figure 1

The intact models of lumbar (A: geometric model B: FE model)

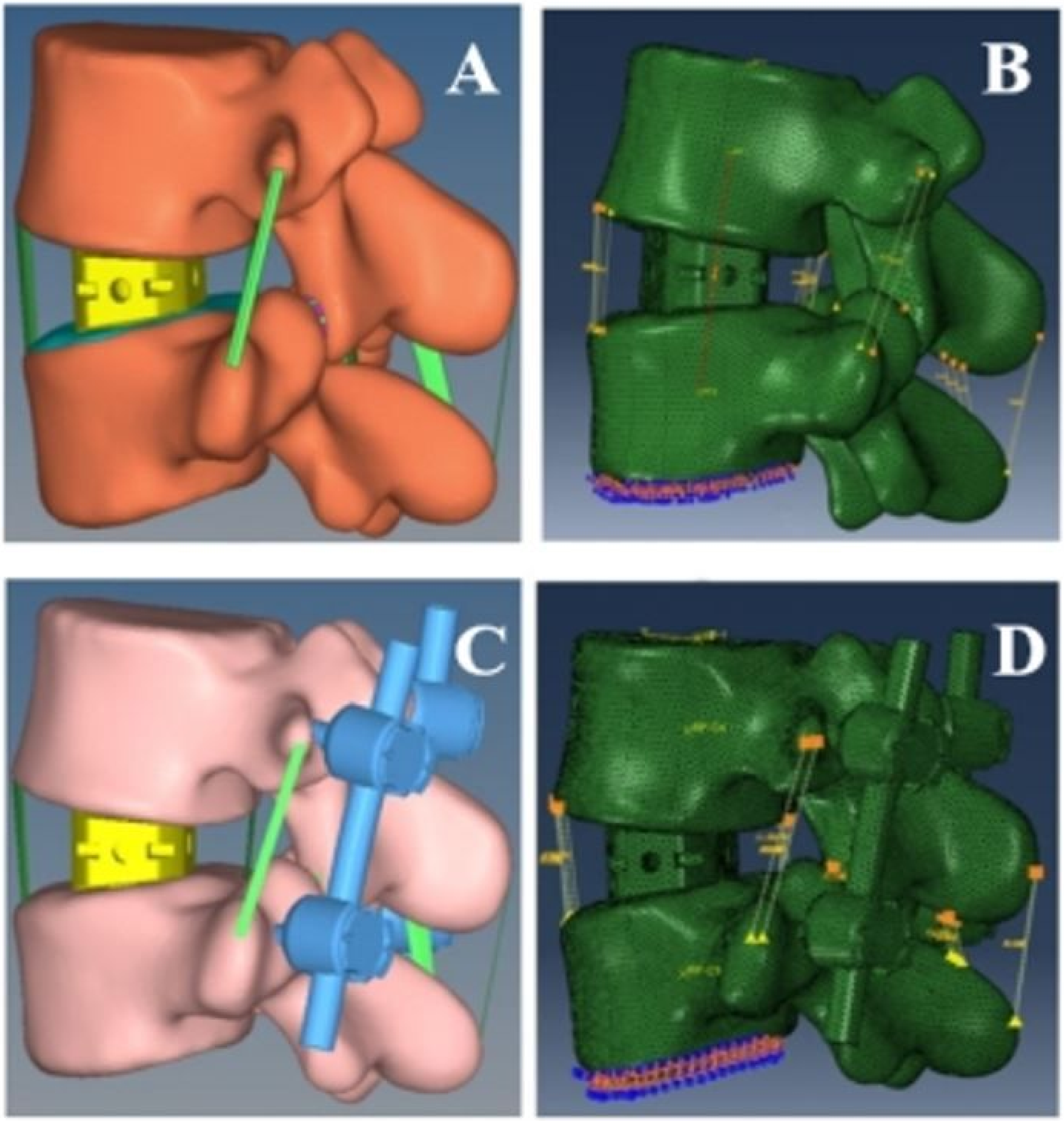

Figure 2

The models of OLIF with SA, BPSF (A:SA geometric model B:SA FE model C: BPSF geometric model D: BPSF FE model)

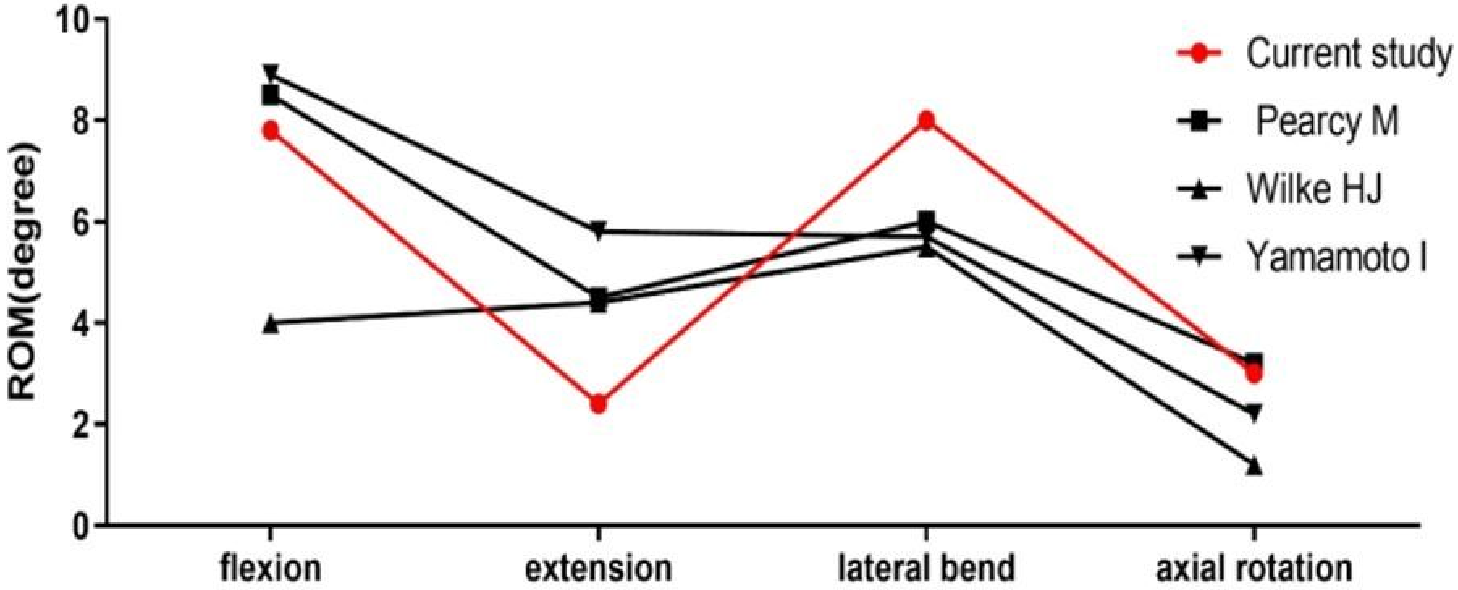

Figure 3

ROM of intact FE lumbar model and pre-studies

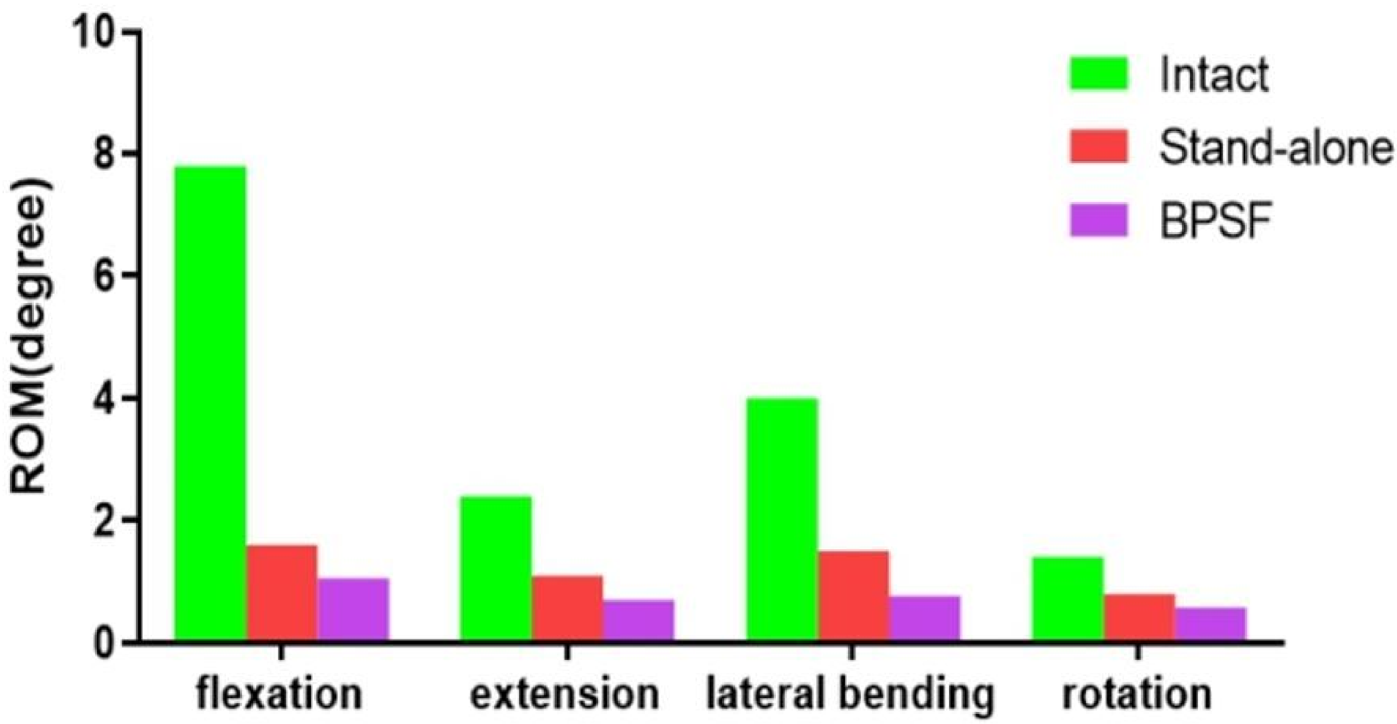

Figure 4

ROM of OLIF with Stand-alone and BPSF

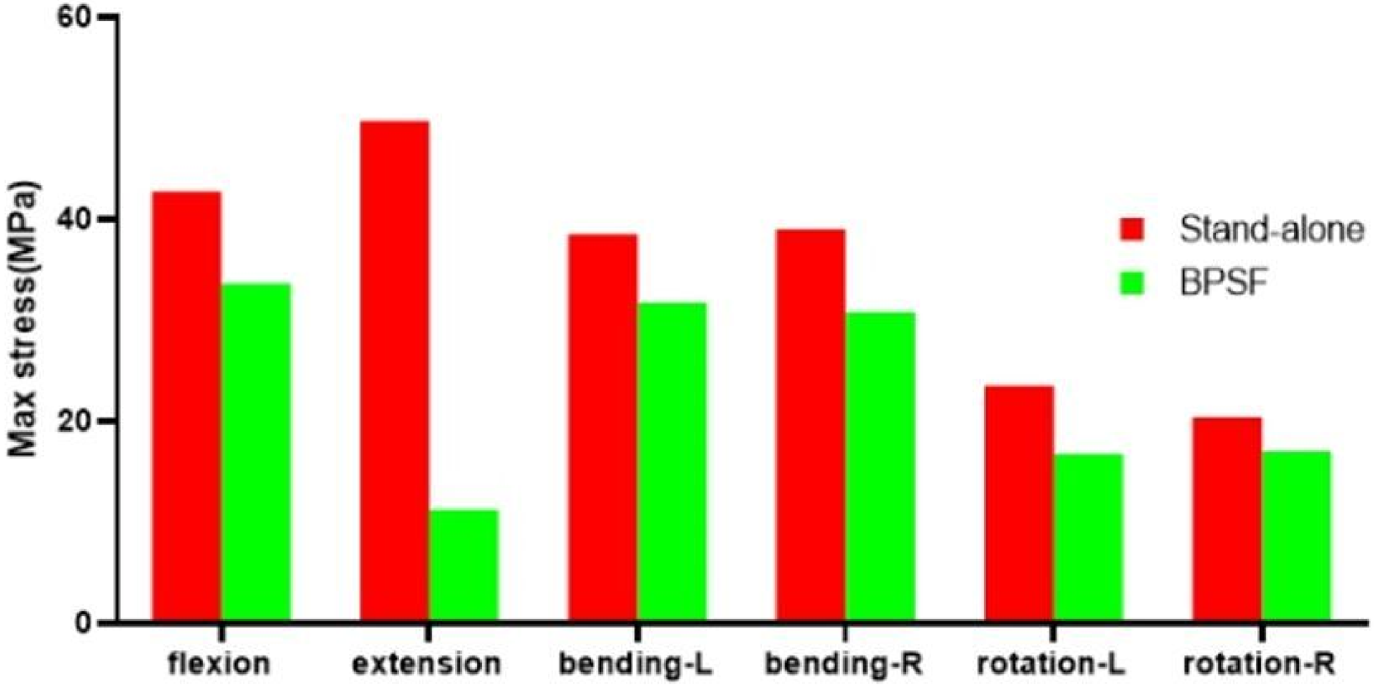

Figure 5

The maximum von Mises stress of L4 inferior endplate in all models

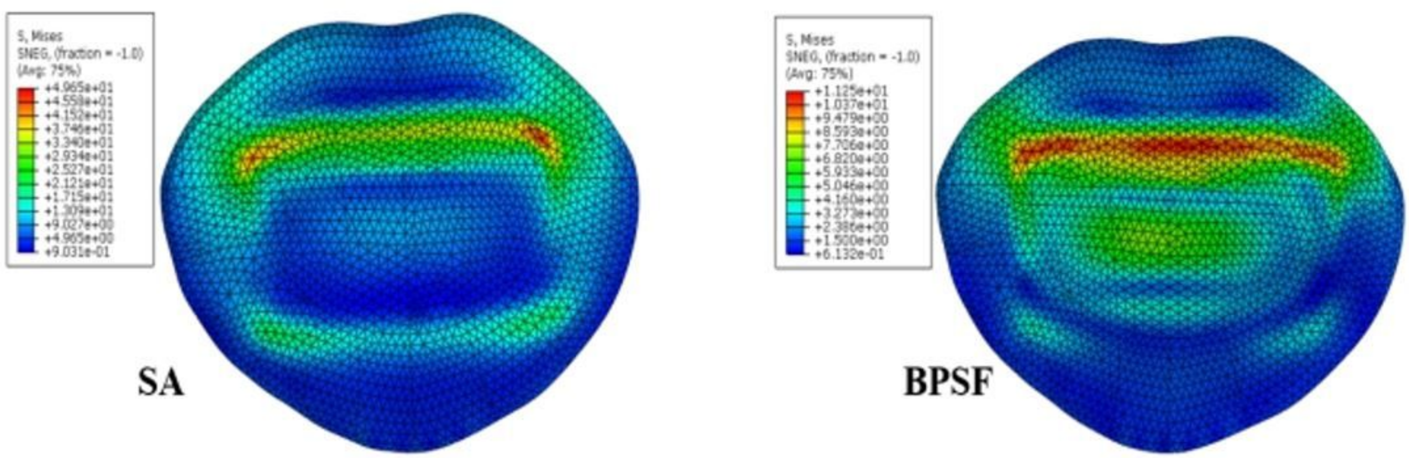

Figure 6

Distribution of maximum stresses and strain in L4 IEP in extension motion

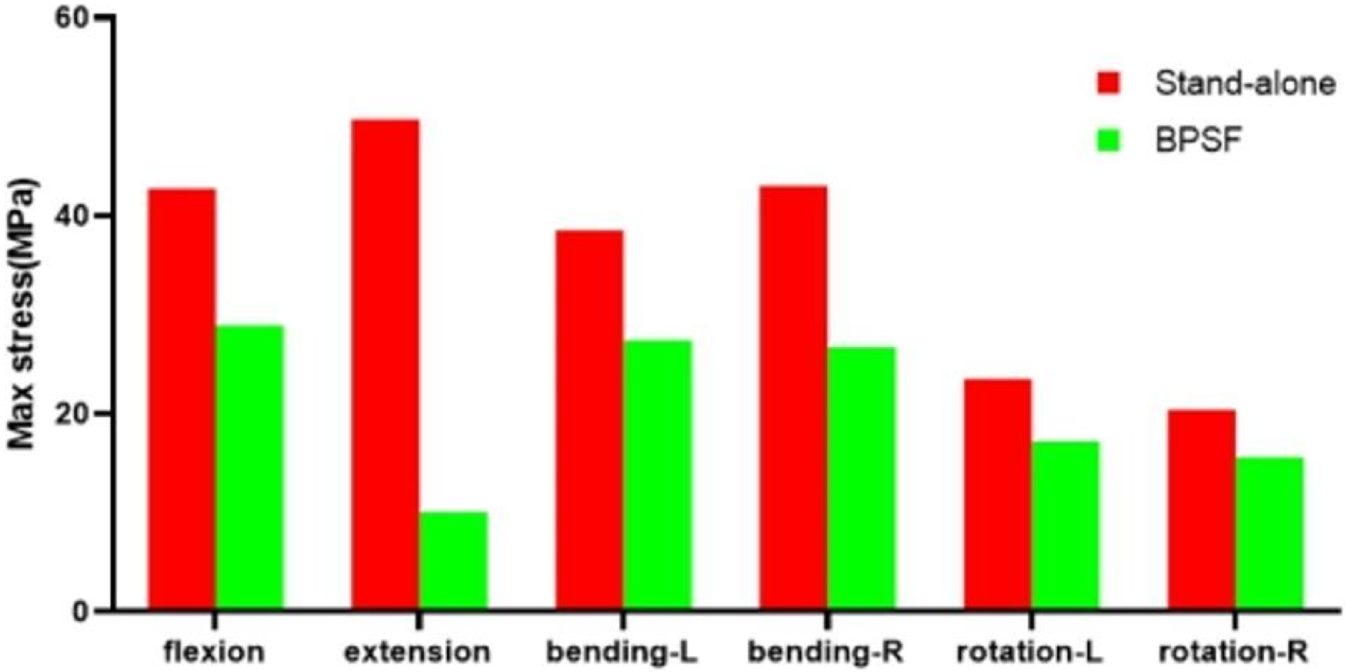

Figure 7

The maximum von Mises stress of L5 SEP in all models

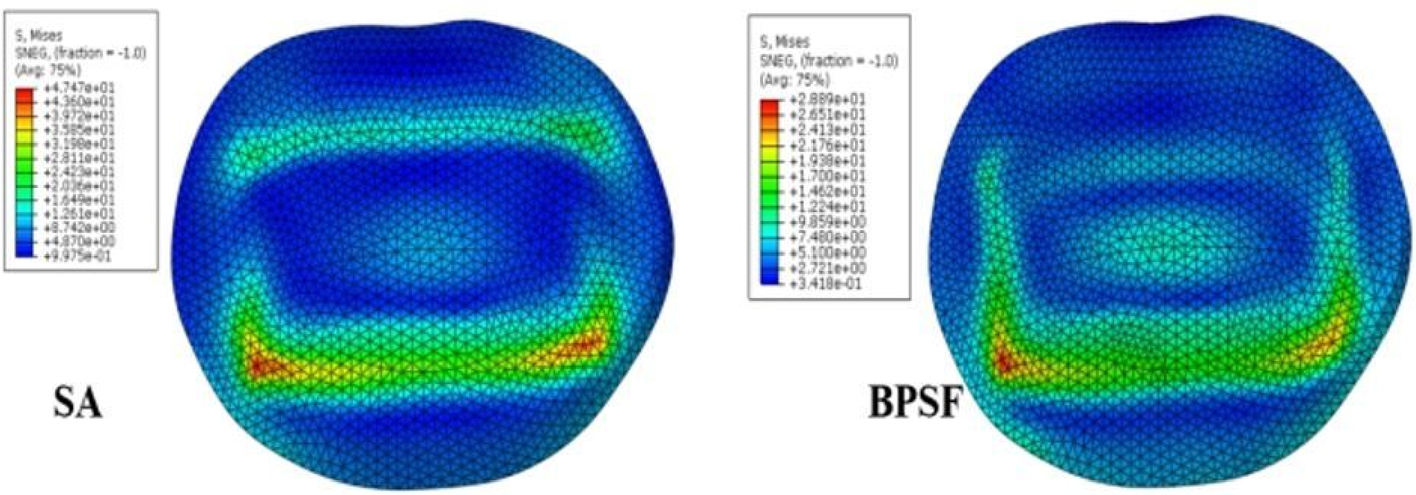

Figure 8

Distribution of maximum stresses and strain in L5 superior endplate in flexion

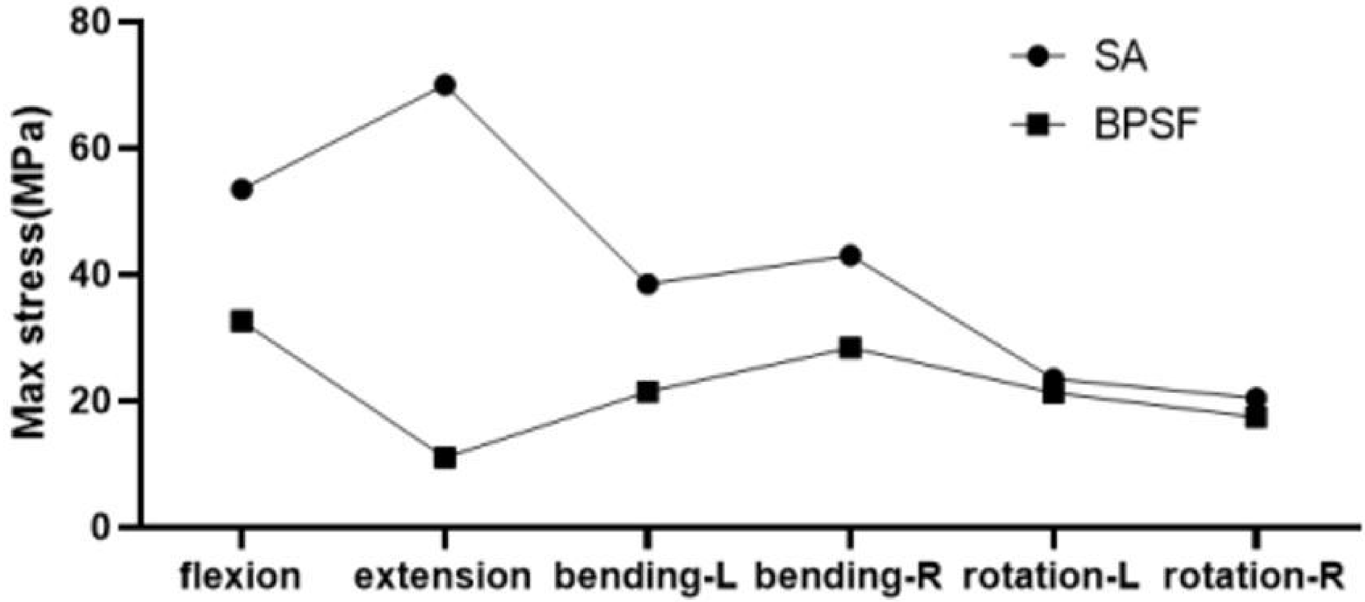

Figure 9

The maximum von Mises stress of cage in all models

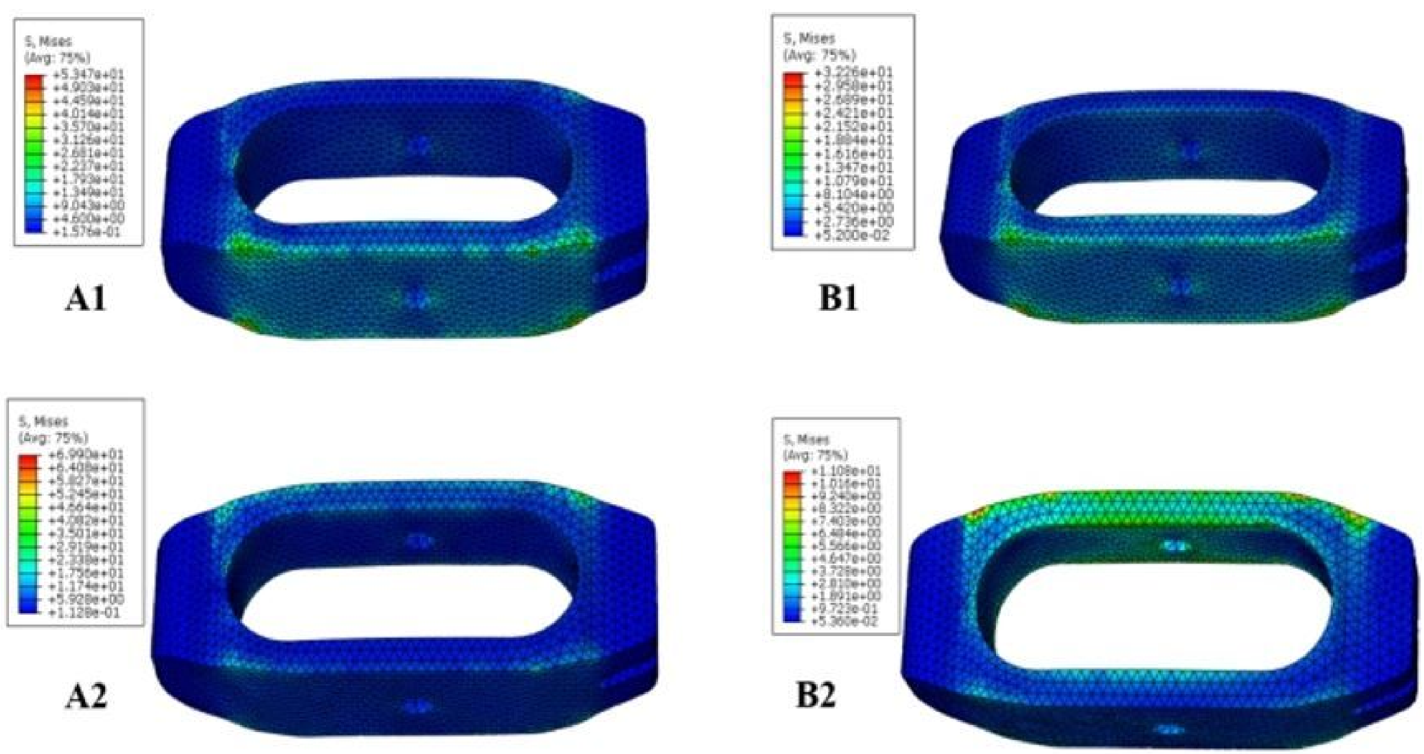

Figure 10

Distribution of maximum stresses of cage in flexion and extension moment (A1:SA model in flexion A2: SA model in extension B1: BPSF model in flexion B2: BPSF model in extension)