Research Square

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Lumbosacral fusion terminated to S1 for adult degenerative scoliosis: Technical innovation and finite element analysis

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Technical advance

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Abstract

Background: To evaluated the practicability and reliability of CBT+TT in the treatment of ADS by finite element analysis and the comparison of clinical effects.

Methods: 18 cases were enrolled from patients who were admitted to the department of Spine Surgery in Affiliated Hospital of Qingdao University with a strict standard which qualify for the surgical indications of L5-S1 long segment fusion. Based on different spinal-pelvic fusion techniques, those cases were divided into three groups including the groups of IS , S2AI and CBT+TT, 3, 4 and 11 cases recpectively. Clinical data of CBT+TT group such as VAS, ODI, coronal Codd angle, C7PL-CSVL and SVA were acquired preoperatively and compared with those measured at the end of follow-up. DICOM data of CT scan (1mm) of all postoperative patients in those 3 groups were used to created 3D models. The models were imported into software for the finite element analysis under different conditions such as flexion, extension, lateral flexion and rotation, to obtain the stress distribution properties of three fusion techniques.

Results: In CBT+TT group, the VAS score was 7.00±0.89 preoperatively and 0.91±0.70 at the end of follow-up. The ODI was 51.09±7.83% and 5.45±1.13%. There was a significant difference between the preoperative data and that at the end of follow-up ($P<0.001$). The Cobb angle was 49.10±11.51° and 12.33±3.96°. C7PL-CSVL was 27.27±17.61 mm and 12.20±8.04 mm. SVA was 25.33±18.21 mm and 8.60±5.31 mm. The results of the finite element analysis of simulated conditions, such as flexion, extension, lateral flexion and rotation, showed that in the IS group, the average extreme pressure value was 366.1 MPa, 183.1 MPa, 398.4 MPa, and 573.6 MPa; in the S2AI group, the values were 518.4 MPa, 259.2 MPa, 608.2 MPa, and 545.7 MPa; and in the CBT+TT group, the values were 390.0 MPa, 195.0 MPa, 353.7 MPa, and 476.8 MPa.

Conclusion: This innovative technique (CBT+TT, terminating at S1) has been proven to be reliable and practical in the treatment of degenerative scoliosis.

Background

ADS is a special type of scoliosis that results from age-related changes[1-3]. ADS is mainly caused by asymmetric degenerative changes in intervertebral discs and facet joints, manifesting as a Cobb angle>10° in the coronal plane[4]. Excluding external deformity, patients with degenerative scoliosis may present different symptoms[5]. In mild cases, lower back pain and fatigue, accompanied by lower limb pain and numbness, are the main symptoms.

Lenke-Silva et al[6] developed a classification system for degenerative scoliosis and proposed clinical treatment strategies based on this classification. Orthopaedic and long-segment fusion is required in patients with the following conditions: severe lower back pain and symptoms in the lower limbs, without definite responsible segments; symptoms of severe coronal and sagittal imbalance; and severe lumbar mechanical pain.

Segment selection in long-segment fusion and decompression is controversial[7], and whether the fusion terminates in S1 is the focus of the controversy. Velis et al[8] believed that degenerative scoliosis in middle-aged and elderly patients was often accompanied by moderate and severe osteoporosis. Long-segment (i.e., more than 4 segments) fusion across L5/S1 has many problems, such as high local stress, screw loosening, pseudarthrosis, and orthopaedic loss, so fusion rarely ends in S1[9].

Fixation to the sacrum or pelvis is required in the following conditions[10]: severe disc degeneration of L5/S1; spondylolysis; and previous surgical history of the segment. When the upper fusion segments exceed T12, the probability of disc degeneration of L5/S1 is greatly increased. The classification of imbalance in the coronal and sagittal planes was helpful to restore or maintain balance.

The main methods of lumbosacral fixation in degenerative scoliosis are S1 screws alone, S1\2 screws, S2AI and iliac screws. Screw loosening of the S1 screws alone leads to a high incidence of local pseudarthrosis formation[11]. Currently, lumbosacral fusion techniques, such as iliac screws and S2AI, are widely used in clinical practice [12]. However, both techniques have shortcomings, such as too much soft tissue dissection and difficulty in rod placement[13-15]. In addition, the S2AI technique also requires more x-ray exposure.

In this study, the lumbosacral fusion technique was modified: a satellite rod was placed with a CBT and a TT. Clinical efficacy was observed, and the stress distribution properties of three fusion techniques were compared with finite element analysis.

Methods

1. Inclusion and exclusion criteria

The inclusion criteria were as follows: 1. Diagnosis of degenerative scoliosis, requiring corrective surgery, regardless of sex or age; 2. Patients with level V and VI Lenke-Silva classification, accompanied by severe lower back pain and symptoms in the lower limbs, without definite responsible segments, severe coronal and sagittal imbalance of the spine, or severe lumbar mechanical pain. 3. Indications of lumbosacral fusion[16]: 1) L5/S1 severe disc degeneration; spondylolysis; and previous surgical history of this segment; 2) when the upper fixed segment was above T12, the probability of retained L5/S1 disc degeneration increased[17-19].

The exclusion criteria were as follows: 1. Other spinal or pelvic deformities or infections; 2. No strict follow-up within 6 months after surgery and incomplete clinical and imaging data; 3. Surgical absolute and relative contraindications. 4. Severe osteoporosis, i.e., bone mineral density T≤-2.5.

2.General information

From June 2014 to January 2018, 18 patients with degenerative scoliosis were included in this study, after strict screening according to the inclusion criteria. All 18 patients were female, aged 53-67 years (mean 57.1 years) and were diagnosed with degenerative scoliosis, with the main clinical manifestations being intermittent claudication, low back pain, spondylolisthesis, lumbar kyphosis and overall imbalance. All the above symptoms were consistent with the level V and VI manifestations of the Lenke-Silva classification[6].

Preoperative imaging examinations were performed on the patients, and surgical plans were developed according to the patients' conditions and Lenke-Silva classification. Patients were divided into three groups according to fixation method: 3 patients in the IS group, 4 patients in the S2AI group, and 11 patients in the CBT+TT group. The imaging examination results (figures 1-2) showed that 2 patients in the CBT+TT group had a lateral kyphosis deformity and pelvic obliquity.

The preoperative clinical data for the CBT+TT group showed that the Cobb angle was 49.10±11.51°. The C7PL-CSVL was 27.27±17.61 mm. The SVA was 25.33±18.21 mm. The ODI was 51.09±7.83%. The VAS score was 7.00±0.89.

CT (computerized tomography) scans showed scoliosis with vertebral rotation. Preoperative MRI (magnetic resonance imaging) showed no change in the intramedullary signal. After the completion of surgical treatment, long-term follow-up (at least 12 months) was conducted to observe the occurrence of complications such as broken nails, broken rods and orthopaedic loss.

3.Surgery Methods

The key technique was as follows: for fusion of more than 4 segments, terminating at S1, a multi-segmental SPO (Smith-Petersen osteotomy) was performed on the top cone of the deformed area. TLIF (transforaminal lumbar interbody fusion) or PLIF (posterior lumbar interbody fusion) was performed on the distal L4/5 and L5/S1 segments, according to the vertebral inclination. Stiffer or more deformed cases were treated by distraction of the short segment or sequential compression fixation. A bending bar was implanted on the lateral side, and cortical bone screws were inserted on S1 and across the target area with a satellite rod to achieve orthopaedic fixation, shown in Fig 3.

The patients were subjected to intraoperative SEPs (somatosensory evoked potentials) and MEPs (motor evoked potentials), ECG (electrocardiography) monitoring, low-flow oxygen, and monitoring of blood pressure, pulse and respiration. Meanwhile, complications such as pulmonary infection that might occur after general anaesthesia were considered. Routine anti-infection treatment was given for 2 days, and glucocorticoids were used to prevent postoperative spinal cord oedema. Early rehabilitation training, such as deep breathing, balloon blowing or effective coughing, was used to prevent complications. Patients were allowed to move out of bed after removal of the drainage tube and were asked to use a thoracolumbar brace for 3 months to prevent the internal fixation device from loosening and breaking.

Follow-up was at least 12 months. Cobb angle, C7PL-CSVL, SVA, VAS and ODI were recorded at the end of follow-up, as were symptomatic remissions and postoperative complications. In addition, a CT scan and 3D reconstruction of a thin layer (1 mm) were required during follow-up and were compared with preoperative images. DICOM data were obtained for finite element analysis.

4.Finite element analysis

DICOM data obtained from postoperative CT scans for each group were imported into MIMICS software (Materialise, Belgium) to construct the 3D models. Bone tissue and internal fixation devices were extracted according to different grayscales to reconstruct 3D models. Because the preliminary 3D models had massive grids and irregular sizes, the models were polished, and the number and quality of the grids were adjusted by Geomagic Studio (Raindrop company, USA) to achieve satisfactory conditions.

After the models were built, ANSYS software was used to conduct a finite element analysis under the simulated conditions of flexion, lateral flexion and rotation. The material parameters of each part of the model, such as the elastic modulus, Poisson's ratio and density[19-24], are shown in Table 1. It is assumed that the mechanical properties of the biomaterials were homogeneous, continuous and isotropic and that each element of the model had sufficient stability under stress.

Table 1 material parameters

material parameters	**elasticity modulus** (MPa)	**Poisson's ratio**	**density(t/mm^3)**
Bone	200	0.25	1.2×10^{-9}
Cartilage	13.3	0.45	1.0×10^{-9}
Titanium alloy	110000	0.3	4.5×10^{-9}

5.Statistical analysis

In terms of statistics, clinical data (Cobb angle, C7PL-CSVL, SVA, VAS and ODI) for the CBT+TT group were collected, and the statistical analysis was conducted by SPSS 21.0. A t test was adopted, and $P<0.05$ indicated statistical significance.

Results

The clinical results for the CBT+TT group are as follows:

The intraoperative blood loss of 11 patients was 1118.18±464.37 ml, the operative time was 247.64±44.96 min, and there were no abnormalities in the intraoperative SEPs or MEPs.

The VAS score was 7.00±0.89 preoperatively and 0.91±0.70 at the end of follow-up. The ODI was 51.09±7.83% and 5.45±1.13% preoperatively and at the end of follow-up, respectively. There was a significant difference between the preoperative data and that at the end of follow-up ($P<0.001$). The VAS and ODI scores at the end of follow-up were significantly improved compared with the preoperative results ($P < 0.001$), as shown in Table 2.

Table 2 The comparison of the VAS and ODI of preoperation and final follow-up(x±s)

	Pre-op	Final follow	t value	P value
VAS score	7.00±0.89	0.91±0.70	17.78	0.000
ODI score	51.09±7.83	5.45±1.13	20.98	0.000

The Cobb angle was 49.10±11.51° and 12.33±3.96°. C7PL-CSVL was 27.27±17.61 mm and 12.20±8.04 mm. SVA was 25.33±18.21 mm and 8.60±5.31 mm preoperatively and at the end of follow-up, respectively. There was a significant difference in the preoperative data and the data from the end of follow-up ($P<0.05$), as shown in Table 3.

Table 3 The comparison of the Cobb angle , C7PL-CSVL and SVA of preoperation and final follow-up(x±s)

	Pre-op	Final follow	t value	P value
Cobb angle	49.10±11.51	12.33±3.96	11.489	0.000
C7PL-CSVL(mm)	27.27±17.61	12.20±8.04	4.232	0.002
SVA(mm)	25.33±18.21	8.60±5.31	3.538	0.005

The total spine X-ray showed that no complications, such as screw loosening, implant breakage, or orthopaedic loss, occurred in the patients.

The results of the finite element analysis of the three groups are as follows:

The results of the finite element analysis of simulated conditions, such as flexion, extension, lateral flexion and rotation, showed that in the IS group, the average extreme pressure value was 366.1 MPa, 183.1 MPa, 398.4 MPa, and 573.6 MPa; in the S2AI group, the values were 518.4 MPa, 259.2 MPa, 608.2 MPa, and 545.7 MPa; and in the CBT+TT group, the values were 390.0 MPa, 195.0 MPa, 353.7 MPa, and 476.8 MPa, as shown in Table 4.

Table 4 Stress extremum results of patients in three groups under working condition

Statistical table of equivalent stress extremum (MPa)				
	forward flexion	**backward flexion**	**lateral flexion**	**rotation**
S_2AI	518.4	259.2	608.2	545.7
IS	366.1	183.1	398.4	573.6
CBT+TT	390.0	195.0	353.7	476.8

In flexion and extension, the minimum extreme pressure value was in the IS group, but there was no significant difference with that of the CBT+TT group. In lateral flexion and rotation, the minimum extreme pressure value was in the CBT+TT group, and a significant difference existed between that value and the value from the IS group. Furthermore, the extreme values in both the IS group and the CBT+TT group were less than that in the S2AI group, and a significant difference existed.

The minimum extremum of the stress under the forward flexion and backward flexion conditions was in the IS group, and there was no significant difference between that value and the value from the CBT+TT group. The minimum extremum of the stress under the lateral flexion and rotation conditions was in the CBT+TT group, and there was a significant difference between that value and the value from the IS group. Moreover, the extremums of stress in the CBT+TT group and IS group were less than those in the S2AI group under various working conditions, and the difference was significant. The stress distribution diagram for the three models under each working condition is shown in Fig.4-6.

Discussion

Because it is a serious degenerative disease, the incidence of degenerative scoliosis has significantly increased with the ageing of populations worldwide. According to statistics, approximately 60% of people over age 60 suffer from degenerative scoliosis[25].

Symptomatic degenerative scoliosis not only causes pain for patients but also imposes a heavy burden on families and society. Treatment for symptomatic degenerative scoliosis includes conservative and surgical treatment. Patients with severe low back pain or fatigue, severe mechanical pain, coronal and sagittal imbalance, and no clearly responsible segment are often treated with surgery[6].

Orthopaedic fusion of long segments sometimes requires fixation to the sacrum and pelvis[10]. Currently, the main methods of lumbosacral or pelvic fixation include the Luque-Galveston technique[26], iliac screws[27], S2AI[12-13], and sacral 1/2 fixation[28]. However, there are some drawbacks to these techniques, such as excessive intraoperative muscle exposure[29], high technical requirements for screw and rod setting in S2AI[30], excessive bone implantation[31] and damage to the internal fixation system[32]. Osteoporosis patients are especially prone to screw loosening. Too many implants, such as in double-rod fixation, result in a relatively high rate of pseudarthrosis.

In this study, the lumbosacral fusion technique was modified, terminating at S1 and combining CBT+TT and satellite rods. To verify the efficacy of this technique, thin-layer CT scanning and 3D reconstruction were adopted to obtain DICOM data for three different kinds of lumbosacral fusion. A biomechanical analysis was conducted under simulated conditions. The results of the finite element analysis showed that the stress extremum of CBT+TT was significantly lower than that of S2AI and IS in the lateral flexion and rotation conditions. For the forward flexion and backward flexion conditions, the extreme stress of the CBT+TT group was slightly higher than that of the IS group and significantly lower than that of the S2AI group.

As shown in figure 11, the cross-osteotomy and lumbosacral segments were subjected to less stress due to the extra satellite rod, which reduces the stress on the segments that were previously under greater stress. It not only ensures the orthopaedic integrity of the internal fixation device but also avoids the problem of a broken bar or orthopaedic loss caused by excessive local stress.

Clinical efficacy was observed and showed that by applying this innovative technique, the intensity of fixation in the lumbosacral or osteotomy region was improved, the risk of internal fixation system breakage and the incidence of pseudarthrosis in the lumbosacral region was decreased[33], and distal muscle dissection and intraoperative bleeding were reduced[34]. This was especially true for patients with osteoporosis, who had better cortical bone screw control and lower orthopaedic loss rates[33-34]. Furthermore, complications associated with the sacral 2 ilium or ilium screw technique were also reduced[35].

This study was based on an innovative surgical technique, with an insufficient research period, lack of long-term follow-up, and limited sample size. The modelling process was influenced by the model material, simplification and error control level. To address the above problems, methods such as prolonging the research period, expanding the sample size and making homogeneous models will be applied in future studies.

Conclusions

This innovative technique (CBT+TT, terminating at S1) has been proven to be reliable and practical in the treatment of degenerative scoliosis.

Abbreviations

1. CBT+TT: Cortical Bone Trajectory and Traditional Trajectory
2. ADS: adult degenerative scoliosis
3. IS: iliac screw
4. S2AI : Second Sacral Alar-iliac screw
5. VAS : Visual Analogue Scale
6. ODI : The Oswestry Disability Index
7. C7PL-CSVL: the distance between C7 plumb line and center sacral vertical linewere
8. SVA : sagittal vertical axis
9. DICOM: digital imaging and communications in medicine
10. CT: computerized tomography
11. MRI: magnetic resonance imaging
12. SPO: Smith-Petersen osteotomy
13. TLIF: transforaminal lumbar interbody fusion
14. PLIF: posterior lumbar interbody fusion
15. SEPs: somatosensory evoked potentials

16. MEPs: motor evoked potentials
17. ECG: electrocardiography

Declarations

Ethics approval and consent to participate：

The experimental protocol was established, according to the ethical guidelines of the Helsinki Declaration and was approved by the Human Ethics Committee of the Affiliated Hospital of Qingdao University. Written informed consent was obtained from individual or guardian participants.

Consent for publication：

Not applicable

Availability of data and materials：

All data generated or analysed during this study are included in this published article.

Competing interests:

The authors declare that they have no competing interests.

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Authors' contributions:

YD,JL collected clinical data and imaging data, ZZ, CW, KD, HH made the model, ZZ, YX, KD completed the finite element analysis, ZZ, JG were the majoy contributor in writing the manuscript. All authors read and approved the final manuscript.

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Figures

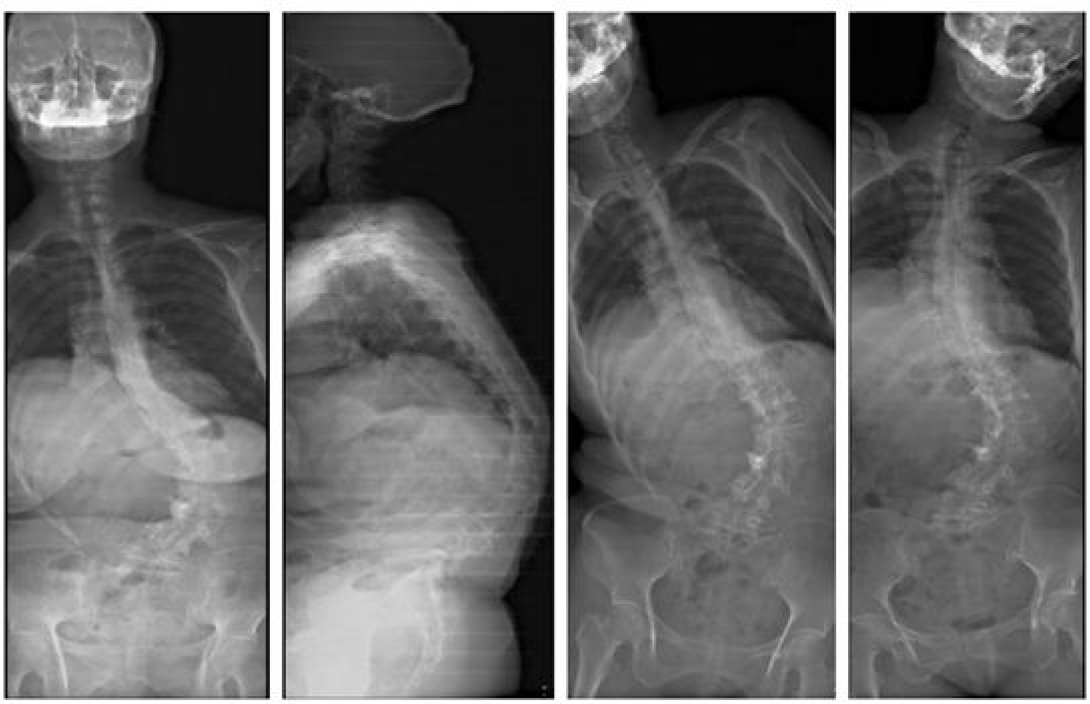

Figure 1

preoperative X-ray of CBT+TT group

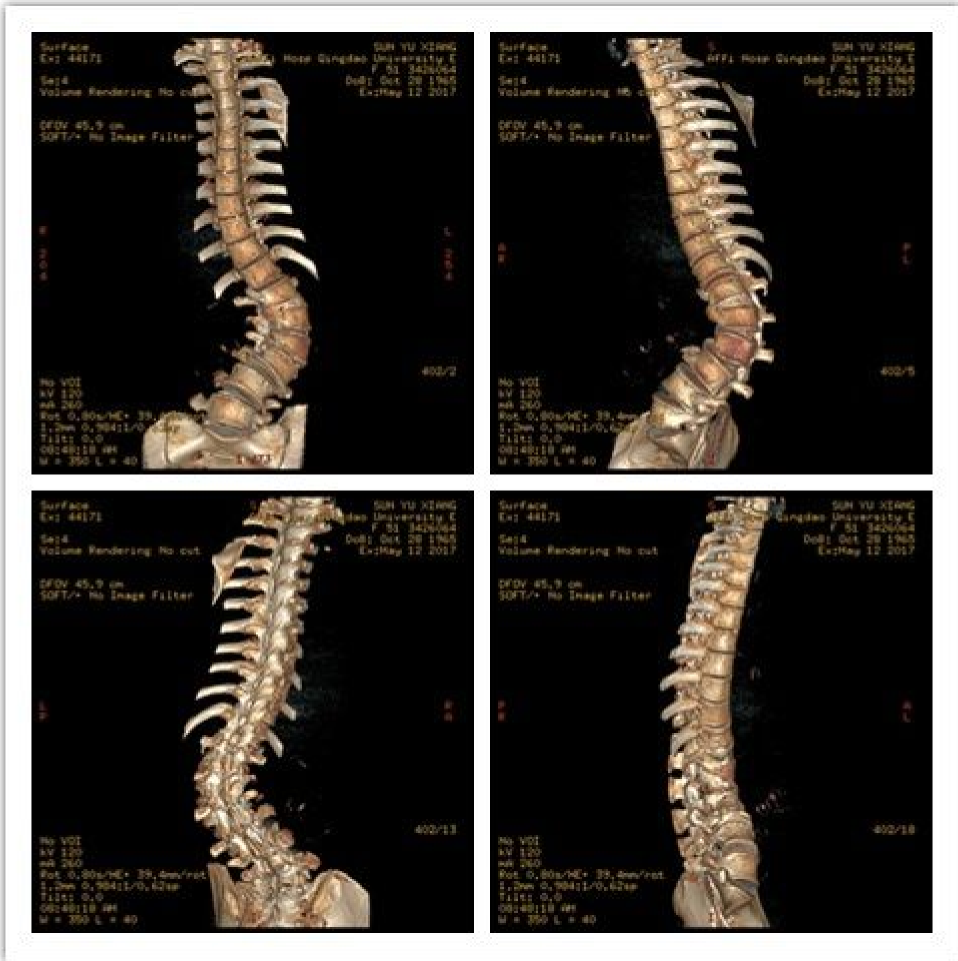

Figure 2

preoperative 3d reconstruction of CBT+TT group

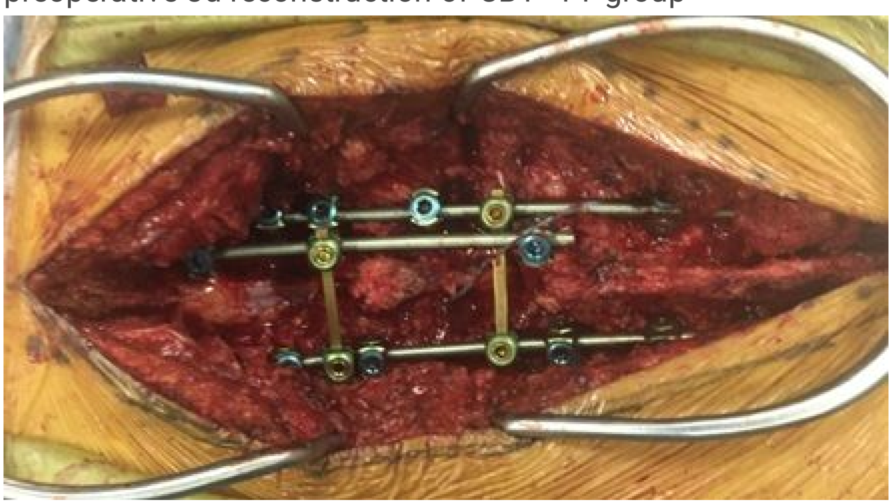

Figure 3

intraoperative photo

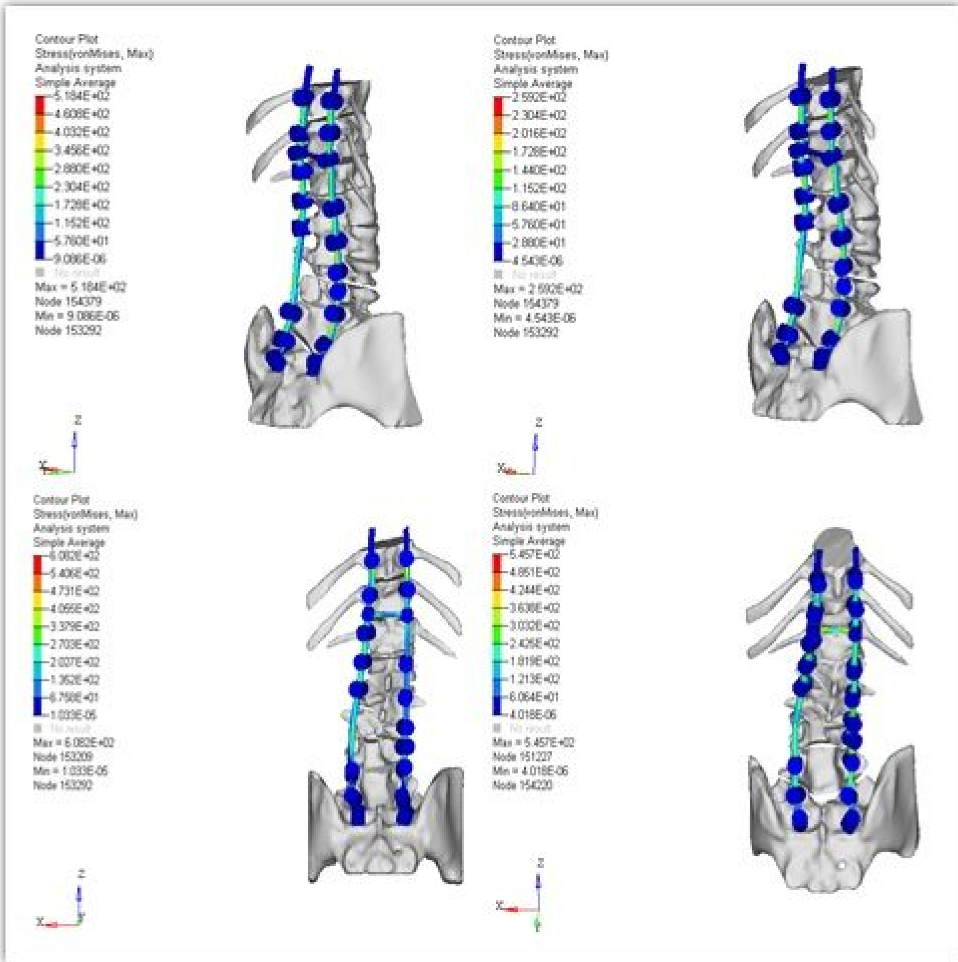

Figure 4

stress extreme value distribution of S2AI group. a forward flexion. b backward flexion. c lateral flexion. d rotation conditions

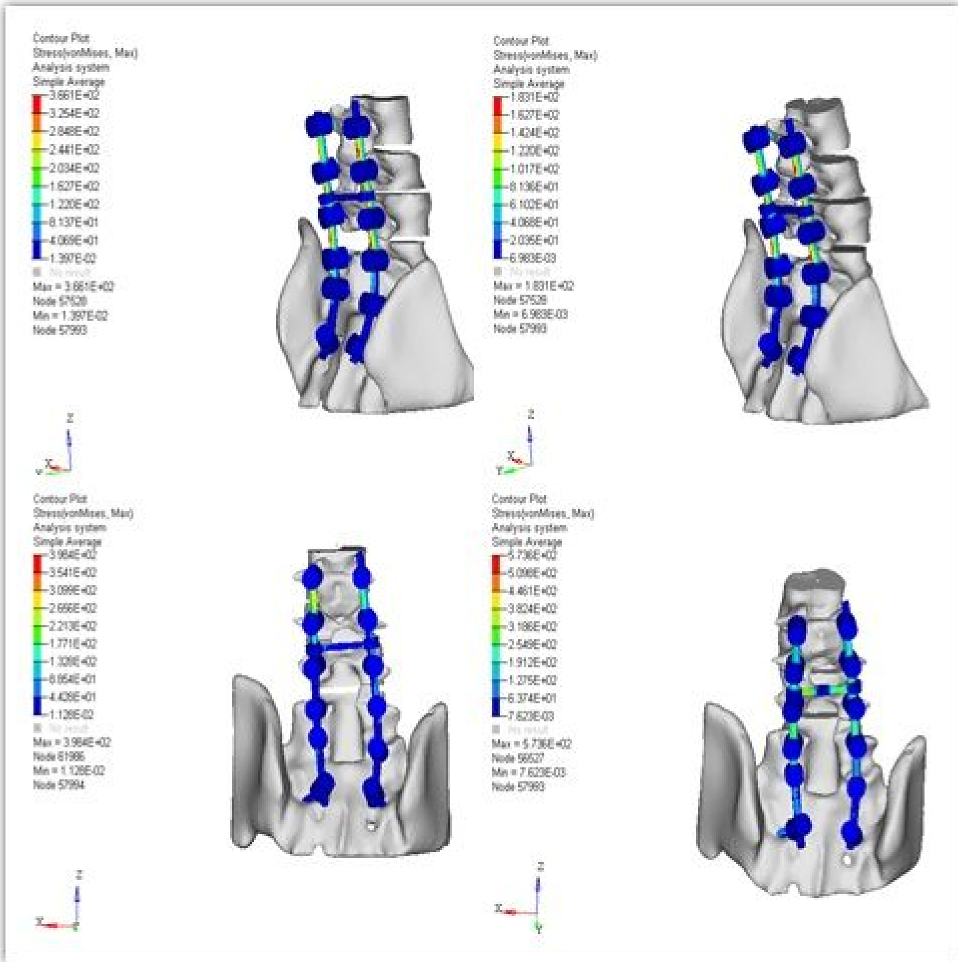

Figure 5

stress extreme value distribution of IS group. a forward flexion. b backward flexion. c lateral flexion. d rotation conditions

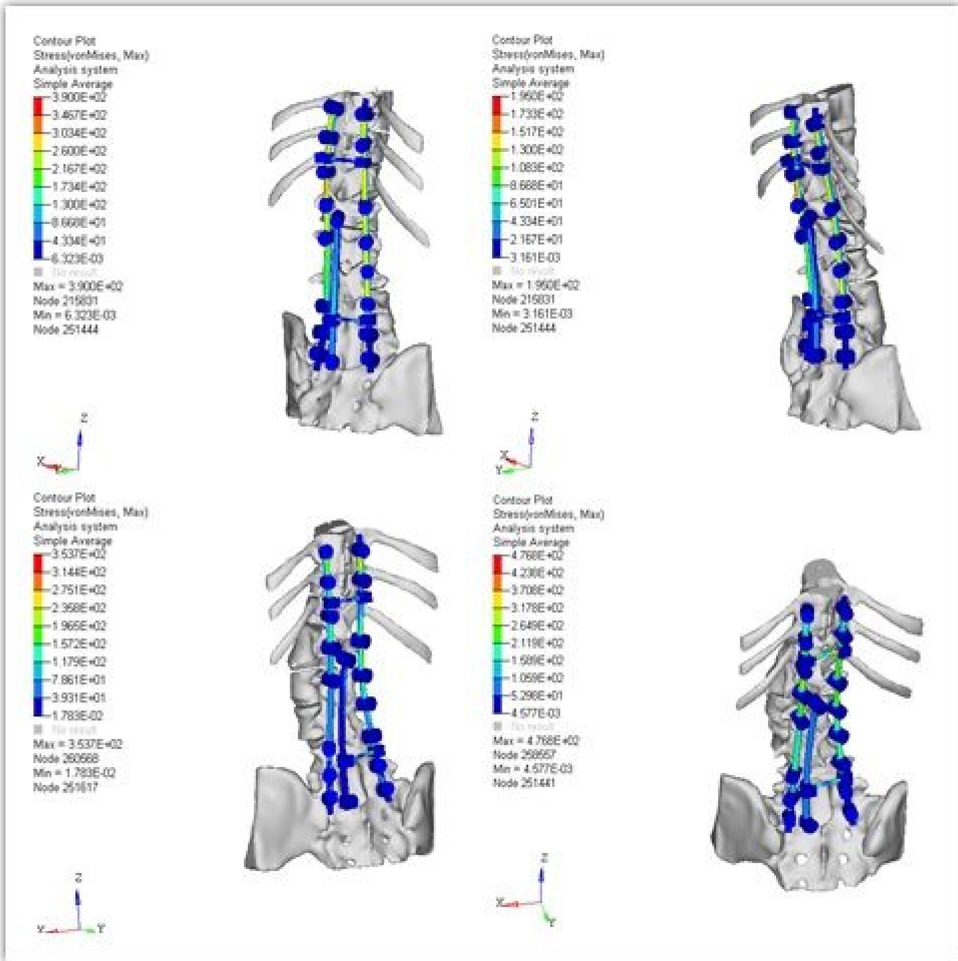

Figure 6

stress extreme value distribution of CBT+TT group. a forward flexion. b backward flexion. c lateral flexion. d rotation conditions