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Article

# Comparison of surgical strategies and corrective efficacy score for AS kyphotic correction

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**Abstract:** Thoracolumbar kyphosis in ankylosing spondylitis poses multiple hazards to patients. To optimize the surgical correction of internal fixation, the biomechanical characteristics and corrective efficacy of different strategies for surgical correction of kyphosis were analyzed based on finite element analysis. The outcome revealed that there were significant deformational displacement differences and stress differences between the different orthopedic internal fixation schemes. Cortical bone track screw fixation significantly reduced the deformation displacement in flexion-extension and lateral flexion conditions. Among the proximal stresses, the cortical bone track screws had the highest stresses in the rotational condition, which could reach 446.661 MPa and 398.16 MPa. They were more resistant to pullout as the traditional all-pedicle screws. Different internal fixation protocols produced different orthopedic clinical outcomes. Patients in the experimental group of conventional all-pedicle screws versus cortical trajectory screw fixation had better Cobb angle, Oswestry incapacity index, sagittal equilibrium distance, and Scoliosis Research Society-22 patient questionnaire scores. This study may provide optimized recommendations for the development of surgical corrective internal fixation protocols and guide the development of surgical strategies, which in turn may promote patient recovery and reduce complications.

**Keywords:** ankylosing spondylitis; kyphotic correction; biomechanics; pedicle screws; internal fixation

## 1. Introduction

AS is a long-term inflammatory condition that impacts the spine, peripheral joints, paraspinal soft tissues, and sacroiliac joints. Although the exact pathophysiology of AS is unknown, it is generally accepted to be influenced by a number of variables, including immunity, infection, environment, and genetic vulnerability. The clinical symptoms of AS manifest as pain and stiffness in the low back, with pain negatively radiating to the buttocks, groin, and lower extremities [1,2]. With the progression of the disease, irreversible changes such as different degrees of bone destruction, abnormal joint structure, and joint deformity will occur in the affected joints. Among them, thoracolumbar kyphosis deformity is the most common. The kyphotic deformity causes serious physical and psychological harm to the patients, leading to persistent or intermittent back pain, and at the same time resulting in a great degree of restriction of the human body's form and function. Currently, osteotomies and orthopedic surgeries show unique advantages in the treatment of thoracolumbar kyphosis in AS, which can significantly improve spinal morphology and help patients restore spinal function. However, orthopedic osteotomy requires a high level of surgical skill and preoperative planning. It relies on internal fixation to provide the necessary support for the spine to prevent displacement or misalignment of the osteotomy site, thus ensuring the immediate stability of the spine [3]. Meanwhile, internal fixation can also establish long-term support, increase the fusion rate of the osteotomy site, and promote the regeneration and repair of skeletal tissues. Pedicle screws play a crucial role in the internal fixation of the spine, especially the screws at the adjacent vertebrae above and below the osteotomized vertebrae are critical [4]. The patient's bone density here is low, the characterization is poor, and the ligament ossification here makes initial nail placement difficult. Therefore, it is important to analyze the stability of internal fixation of pedicle screws in this area. However, the internal structure of the human spine is complex, and there are few human specimens available to study severe kyphosis, which limits the depth and application of traditional biomechanical testing methods to analyze the characteristics of AS kyphosis [5]. In recent years, the use of computer-aided design and analysis software to carry out biomechanical analysis has become a new development trend in medical orthopedics, which can help researchers better understand the biomechanical characteristics of severe kyphosis of the spine. To better guide the development of surgical strategies and optimize the design of internal fixation of pedicle screws, the study innovatively employs finite element analysis to compare the biomechanical properties of different internal fixation surgical strategies and analyze their corrective efficacy.

## 2. Related works

AS is a chronic, progressive, inflammatory disease. With the advancement of medical technology, more and more researchers have begun to pay extensive attention to the epidemiologic features, genetic basis, clinical manifestations, diagnostic difficulties, and therapeutic strategies of AS, and have conducted extensive research around the correction of AS. Yu et al. retrospectively evaluated the efficacy of laminectomy for the treatment of cervicothoracic kyphosis in individuals with AS. By analyzing the records of eight patients with AS treated with C7 row laminectomy, the average follow-up was 19 months. It was found that all patients had a successful surgery, with a mean 47.6° resection osteotomy angle, a mean 61.2° improvement in the vertical angle of the chin brow, and a mean 53.2 mm correction of cervical sagittal imbalance. There were no intraoperative complications, and there was a significant improvement in the cervical disability index, JOA, and VAS ($P < 0.01$) [6]. The impact of bi-vertebral transpedicular wedge osteotomy on the treatment of severe kyphosis in AS was examined by Li et al. by looking back at 21 male AS patients who had internal fixation and parallel thoracolumbar transpedicular wedge osteotomy. The bleeding volume was 725.5 mL, and the average surgery time was 5.8 h. The correction rate of postoperative kyphosis was 60.8% at 1 week, and the correction rate was 72.2% at long-term follow-up, and the angular indexes were significantly improved. The patient's ability to walk upright and lie supine was restored, and clinical symptoms improved [7].

Hu et al. evaluated the efficacy and safety of staged lateral osteotomy for the treatment of severe kyphosis in AS by performing this procedure in 23 patients with a single-segment Ponte osteotomy followed by a pedicle reduction osteotomy. The study found a mean follow-up of 30.8 months. There was significant improvement in parameters such as total lordosis, such as an average correction of 68.5° in total lordosis and improvement in SVA to 5.1 ± 1.8 cm. The Oswestry Disability Index and Scoliosis Research Society-22 patient questionnaire scores also improved significantly ($P < 0.05$). Mild complications were noted in 4 cases, indicating that this procedure was safe and effective in correcting sagittal imbalance of the spine with easy positional placement [8]. Ding et al. evaluated the efficacy of an anteriorly supported posterior transforaminal osteotomy for the treatment of AS. The procedure was performed on four patients with software to simulate the surgery and aid in preoperative planning, and with more than 1 year of postoperative follow-up. The patients were found to have good correction rates, with the mean Cobb angle decreasing from 90.5° preoperatively to 43.5° postoperatively, and blood loss averaging 500 mL. Neurologic function improved without complications. The SRS-22 questionnaire showed significant improvement in pain, self-image, and mental health [9]. Zhang et al. investigated the effect of single-segment vertebral body debridement in correcting AS thoracolumbar kyphosis and the optimal osteotomized vertebral body. Eighty-six patients were categorized into four groups according to the osteotomized vertebrae: T12, L1, L2, and L3, and the surgical results of each group were compared. It was found that spondylolisthesis correction and quality of life (QOL) were significantly improved in all patients. The L2 group had the greatest correction of local and overall kyphosis, and the T12 group had the greatest correction of thoracic kyphosis and chin-brow angle. The L2 and L3 groups corrected lumbar lordosis and SVA better than the T12 and L1 groups, but the T12 and L1 groups had a higher complication rate [10].

In order to explore effective strategies for the treatment of severe posterior convexity secondary to AS, Luo J et al. retrospectively analyzed 70 patients with AS posterior convexity treated with this strategy, measured spinal and pelvic parameters, and evaluated clinical outcomes using a single-segment modified osteotomy combined with shoulder lift correction. The results revealed that the patients, with a mean age of 39.8 years and a follow-up of 29.3 months, showed significant improvement in parameters such as overall postoperative kyphosis, and harmonious spine-pelvis alignment was achieved. All patients demonstrated favorable clinical outcomes, with only 1 case requiring revision surgery and the rest achieving solid bone fusion [11]. In order to compare the clinical outcomes and biomechanical characteristics of 1-segment, 2-segment, and 3-segment pedicle subtraction osteotomies for the treatment of ankylosing spondylitis and to establish preoperative selection criteria, Lv et al. selected patients who underwent pedicle subtraction osteotomies, grouped them according to the number of osteotomies to evaluate the clinical and imaging results, and compared the biomechanical characteristics by finite element analysis. It was found that three-level pedicle subtraction osteotomy resulted in significant improvement in sagittal plane parameters but increased operative time and bleeding. Multi-segment pedicle subtraction osteotomy had better correction and better stress distribution, but surgical risks and outcomes need to be weighed [12]. In order to determine the vertebral apex method of pedicle subtraction osteotomy in orthopedic surgery for patients with ankylosing spondylitis combined with thoracolumbar kyphosis, Li et al. selected vertebrae by retrospectively analyzing the medical records of 235 patients using the Kim's apex method and grouped them for comparison. The results showed that the correction of sagittal vertical axis, global kyphosis, and thoracolumbar kyphosis was significantly better than that of group B after selecting vertebrae for vertebral subtraction osteotomy by Kim's apex method [13]. In order to categorize and evaluate the coronal deformity secondary to ankylosing spondylitis and to propose a treatment strategy, Qiao et al. focused on the efficacy of asymmetric pedicle subtraction osteotomy. Methodologically, 65 patients with AS combined with coronal and sagittal deformities underwent surgery, were categorized into four patterns based on deformity characteristics, and were treated with asymmetric pedicle subtraction osteotomy or conventional pedicle subtraction osteotomy, respectively. The results showed that all patients had significant improvement in sagittal parameters and that asymmetric pedicle subtraction osteotomy had a long-lasting effect on the correction of coronal deformity types I to III [14]. In order to construct a mathematical model to predict the change of abdominal median sagittal plane area in ankylosing spondylitis patients undergoing two-segment pedicle subtraction osteotomy, Yin et al. carried out a single-center retrospective study with prospective data on 11 adult AS patients, measured the relevant parameters, and established a mathematical model by CT, substituting the angle of the vertebral body of the planned osteotomy into the model to obtain the predicted value. The results showed that the predicted rate of area change was not significantly different from the actual value, nor was the planned osteotomy vertebral body angle significantly different from the actual osteotomy vertebral angle, while there was a significant improvement in all the evaluated variables before and after surgery [15].

Although the above studies have made some progress, significant progress has been made in the surgical treatment of AS, and the spinal deformity and clinical symptoms of patients have been effectively improved by different surgical approaches. However, there are still limitations in the existing studies, which mainly focus on the single surgical effect and safety, and less on the analysis of the biomechanical characteristics of the internal fixation approach. At present, there is still a research gap on the internal fixation of bi-segmental osteotomy and orthopedic surgery, which is of great significance for optimizing the surgical plan and improving the surgical results. Therefore, it is necessary to further explore this field in depth.

## 3. Experimental materials and methods

### 3.1. Object of study

In the study, a volunteer with AS posterior convexity was selected from the spine surgery department of a tertiary medical hospital in China for the construction and analysis of a finite element model, whose age was 45 years old, gender was male, height was 174 cm, weight was 62 kg. The patient met the 1984 revised clinical diagnostic criteria for AS in New York, USA. It was also combined with full spine frontal and lateral radiographs, three-dimensional CT scans, and clinical diagnosis by a physician to exclude other pathologies of the spine and spinal cord. On examination, the patient had a 68° posterior convexity of the twelfth thoracic vertebra, a 38° posterior convexity angle of the thoracolumbar segment, and a 5° posterior convexity angle of the lumbar vertebrae. The spine had an offset distance of 259.56 mm in the sagittal plane relative to the normal position, complete loss of cervical spine flexibility, and a maxillofacial angle of 70°. The experiments conducted in the study were in strict compliance with ethical guidelines and were reviewed by the hospital ethics committee as well as the consent of the patients themselves and their families.

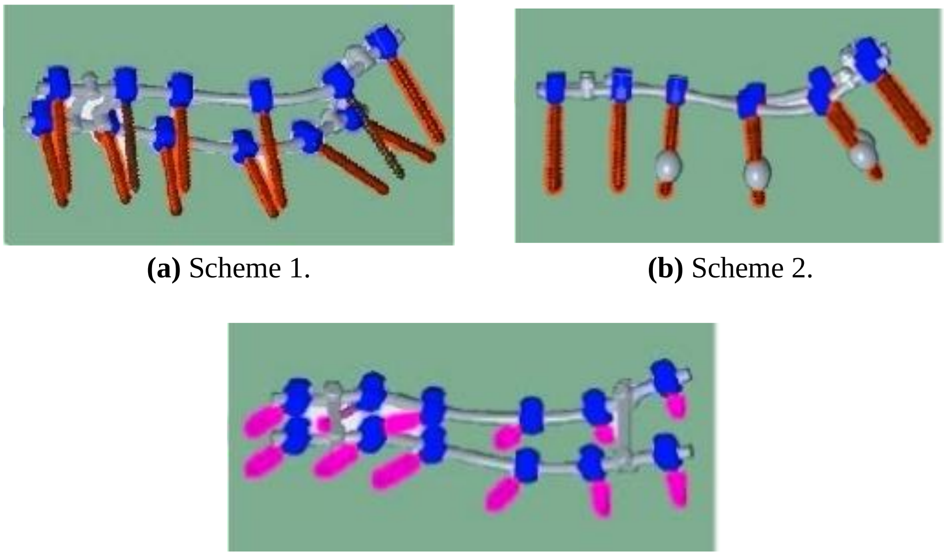
### 3.2. Corrective program design for research subjects

Combining the size of the theoretical and actual pelvic tilt angles in this patient, the future postoperative result of an optimal jaw and brow angle was achieved. The spinal osteotomy angle was designed with a reserved angle of 15°, and the CBVA-PT-true proximal joint angle tPT-15° was 73°. Bisegmental transpedicular osteotomies were performed on the L1 and L3 spinal segments, with osteotomies of 40° and 33°, respectively.

The study identified three different options for internal fixation. Scheme 1: Fixation of the tenth through twelfth thoracic vertebrae, as well as the second, fourth, and fifth lumbar vertebrae, using conventional all-pedicle screws. Scheme 2: Fixation of the tenth and eleventh thoracic vertebrae and fifth lumbar vertebrae with conventional all-pedicle screws, and fixation of the second and fourth lumbar vertebrae and twelfth thoracic vertebrae with injectable cemented pedicle screws. Scheme 3: Fixation of the lumbar and thoracic vertebrae requiring fixation using cortical bone track screws.

### 3.3. Backlash 3D modeling and finite element analysis

In the study, DSCT was first used to scan the spine with 1 mm intervals between adjacent layers to ensure high resolution and the ability to capture detail in the images. 1463 two-dimensional tomographic images were acquired with a resolution of 512 × 512 and saved in DICOM format. Then, Mimics software was used to import the DICOM-formatted CT image data, and the “Convert” operation was used to complete the conversion of the data. Which converted the image data into a format that could be recognized by the software. The brightness, contrast, and other parameters of the images were adjusted to observe and analyze the spinal structure [5,16]. Meanwhile, the “Thresholding” command was used to adjust the gray value range of different tissues in the CT image, and the appropriate threshold range was set in order to observe different structural tissues. Using the “Thresholding” function of Mimics software, a suitable threshold value is set according to the gray value range of different tissues in the CT image. By adjusting the threshold range, the structural tissues of the spine, such as the vertebral body, pedicle, and vertebral plate, can be clearly differentiated. In Mimics software, a preliminary 3D model of the spine is established based on the image data after threshold division. The preliminary model created by Mimics was imported into Geomagic Studio 12.0 to complete the refinement of the model and construct a non-uniform rational B-spline surface. Finally, the solid model of the spine from the sixth thoracic vertebra to the sacrum was built by importing UG NX8.5 software [17,18]. The schematic diagrams of the models with three different fixation methods are shown in **Figure 1**.



**(a)** Scheme 1. **(b)** Scheme 2.

**(c)** Scheme 3.

**Figure 1.** Schematic diagram of three types of internal fixation models.

After constructing the solid spine model, in order to ensure the accuracy and reliability of the model, the study further adopted a comparison validation method with the models of previous healthy volunteers to assess the degree of conformity between the constructed model and the actual human spine structure, and to ensure the accuracy of the finite element model. Multiple validated 3D models representing healthy adult spine structures from publicly available databases were selected as reference standards, and the reference models were constructed based on high-quality clinical imaging data. Comparison results show that the solid spine models constructed in the study are highly consistent with previous models of healthy volunteers in terms of key anatomical features and overall structure, and the geometric similarity index meets the expected standard. After completing the 3D modeling, the study used Hypermesh software to process the model for different internal fixation modalities and Ansys software to complete the force analysis of the model. First, the components of the model were created in Hypermesh software according to the osteotomy and internal fixation methods. The components were meshed in Hypermesh software. Subsequently, the material editing interface was entered in the "Material" tab to complete the assignment of material properties, as shown in **Table 1**.

Finally, the vertebral body-intervertebral disc was set as bound in Ansys software, and the value of each structure was assigned according to the previously set material properties and mesh division. A loading plane was established at the top of the sixth thoracic vertebra, and appropriate loads were applied to calculate the displacement and stress distribution of the model under load. The trend of stress distribution of fixation screws under different fixation methods was also analyzed [19].

**Table 1.** Details of material attribute allocation.

| Number | Material | | Elastic modulus (MPa) | Poisson's ratio |
|---|---|---|---|---|
| 1 | Cortical bone | Intervertebral disc | 12,000.0 | 0.3 |
| | | Anterior longitudinal | 12,000.0 | 0.3 |
| | | Posterior longitudinal ligament | 12,000.0 | 0.3 |
| | | Zygapophysial joint | 12,000.0 | 0.3 |
| | | Posterior vertebral plate | 12,000.0 | 0.3 |
| 2 | Cancellous bone | / | 500.0 | 0.25 |
| 3 | Implant | / | 11,500.0 | 0.3 |
| 4 | Intervertebral osteophyte | / | 12,000.0 | 0.25 |
| 5 | Bone cement | / | 3000.0 | 0.3 |

## 3.4. Clinical efficacy analysis of posterior convexity correction

### 3.4.1. General Information

Thirty patients who attended the Department of Spine Surgery of a public tertiary hospital in China from 1 January 2020 to 31 June 2024 to be treated with pedicle vertebral osteotomy were selected as experimental subjects. They were divided into three different groups according to the principle of randomization and control. The surgeries were all performed by the same medical team to ensure the consistency of the surgical process. The included subjects were followed up for a total average of 26 months, with initial follow-ups set at 6 months postoperatively.

Diagnostic Criteria: The study utilized the 1984 revised New York criteria for patients presenting with low back pain and stiffness for more than 3 months. The patient had limited lumbar frontal and sagittal plane motion. Thoracic extension was less than that of a healthy person of corresponding age and sex. Among the imaging criteria, patients had bilateral sacroiliac arthritis grades (SAGs) II-IV or unilateral SAGs III and IV [20,21].

Inclusion criteria: (1) Patients diagnosed with AS thoracolumbar kyphosis deformity by clinical and imaging examinations. (2) The patient's kyphosis angle reaches a certain degree, the angle of the maxillofacial angle or the overall kyphosis angle of the spine > 70°, affecting the QOL and needing surgical correction. (3) The age of the patients, in line with the requirements of the study, was between 20–55 years old. (4) The patients and their families gave informed consent to the surgical treatment plan. Exclusion criteria: (1) There was serious dysfunction of the heart, lung, liver, kidney, and other important organs, unable to tolerate the operation. (2) There were coagulation dysfunctions, infectious diseases, etc. (3) Patients had abnormal hip joint movement or the presence of other spinal cord diseases [8,10].

### 3.4.2. Research method

The appropriate pre-coronary vertebrae were selected and the pre-coronary angles were calculated based on the patient's diagnostic medical imaging data as well as the body structural parameters. Cobb angle, ODI, SRS-22, JOA scoring method, VAS, and SVA were used to evaluate the preoperative and postoperative results. The Cobb angle was determined by measuring the angle between the endplates of two specific vertebrae on spinal radiographs. Scoliosis was graded and diagnosed based on the size of the Cobb angle. A Cobb angle of less than 10 degrees was considered a curvature of the spine, while 10 degrees or more was diagnosed as scoliosis. The ODI assessed the patient's level of functional impairment, covering pain, self-care in daily living, lifting, walking, sitting, standing, sleeping, sexuality, social activities, and traveling. The SRS-22 corresponded to the patient's functional status/mobility, pain, self-image, psychological status, and satisfaction with treatment. A higher score indicated a better QOL for the patient in that dimension. The JOA score was primarily used to evaluate human cervical spinal cord function, which usually includes four components: upper extremity motor function, lower extremity motor function, sensation, and bladder function. VAS was a subjective, quantitative pain assessment method used to evaluate the intensity and degree of neck pain in patients. SVA was an important indicator of the presence or absence of imbalance in the sagittal position of the spine. Sagittal imbalance was usually considered to be defined when the SVA exceeded 4 cm or 5 cm. When SVA exceeded 9.5 cm, it was a severe sagittal imbalance [22].

#### 3.4.3. Statistical methods

The experimental data were statistically analyzed using SPSS 25.0 and Excel software, and the significance level $\alpha = 0.05$ was set. Data not obeying normal distribution were tested by the Mann-Whitney U rank sum test in the nonparametric test, and the *t-test* was used for conforming to normal distribution. When $P < 0.05$, it represented that there was a statistically significant difference (SSD) in results. When $P < 0.01$, it represented that the results were statistically significant.

## 4. Analysis of experimental results

### 4.1. Analysis of deformation displacement

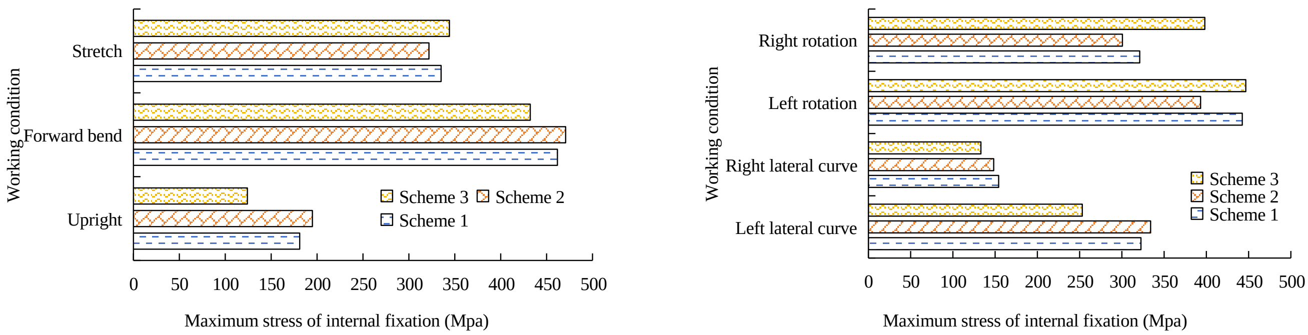
**Table 2.** Comparison of deformation displacement among three fixed schemes.

| **Scheme** | **Upright** | **Forward bend** | **Stretch** | **Left lateral curve** |
|---|---|---|---|---|
| Scheme 1 | 1.197 | 10.657 | 8.796 | 2.339 |
| Scheme 2 | 1.186 | 10.764 | 8.808 | 2.306 |
| Scheme 3 | 0.960 | 9.675 | 8.299 | 2.092 |
| Scheme | Right lateral curve | Left rotation | Right rotation | / |
| Scheme 1 | 1.145 | 2.477 | 2.026 | 1.398 |
| Scheme 2 | 1.138 | 2.434 | 2.032 | 1.858 |
| Scheme 3 | 1.177 | 2.073 | 2.559 | 1.926 |

The results of the comparison of the deformation displacement of the three fixed schemes are shown in **Table 2**. The deformation displacements of Scheme 1 and Scheme 2 under different working conditions were close to each other. However, the displacements under the right rotation condition were smaller, with values of 2.026 mm and 2.032 mm, respectively. It can be concluded that these two solutions had certain advantages in stability. The injectable cementable pedicle screws used bone cement during fixation, which provided additional stability and reduced deformation displacement under rotational conditions. Cortical bone track screws provided greater fixation strength by expanding the contact area with the cortical bone, which helped to reduce deformation displacement in flexion, extension, lateral flexion, and other conditions.

### 4.2. System stress analysis

The results of the comparative analysis of the maximum stresses under different internal fixation schemes are shown in **Figure 2**. In **Figure 2a**, the internal fixation performed by Scheme 1 and Scheme 2 showed higher stresses in anterior flexion, and the stresses took the values of 461.767 MPa and 470.732 MPa, respectively. Overall, the stresses in Scheme 3 were relatively small. Scheme 2 with injectable cementable-type screws exhibited greater stresses. In **Figure 2b**, the stresses under left rotation and right rotation conditions in Scheme 3 using cortical bone track screw fixation were significantly greater than those in Scheme 1 and Scheme 2, with values of 446.661 MPa and 398.16 MPa. This was due to the fact that the cortical bone track screws could be more closely contacted with the hard cortical bone in the posterior part of the vertebral body and pedicle root. It could rotate; the working condition will produce a larger friction force, which had a higher biomechanical stability but also led to stress concentration. Higher stresses may lead to fatigue of the internal fixation system, which is susceptible to material fatigue after being subjected to high stresses for a long period of time, which may lead to loosening or fracture of the screws. As a result, fatigue failure may affect the stability of the spine or lead to recurrence or aggravation of spinal deformity, adversely affecting the patient's recovery and quality of life. In addition, high stresses may adversely affect the bone-implant interface. When the internal fixation system is subjected to excessive stress, the bone-implant interface may become micromanipulated, which in turn affects the osseointegration process.

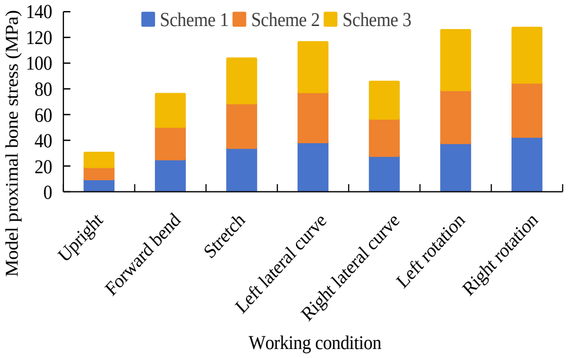



**(a)** Upright, flexion and extension. **(b)** Lateral flexion, rotation.

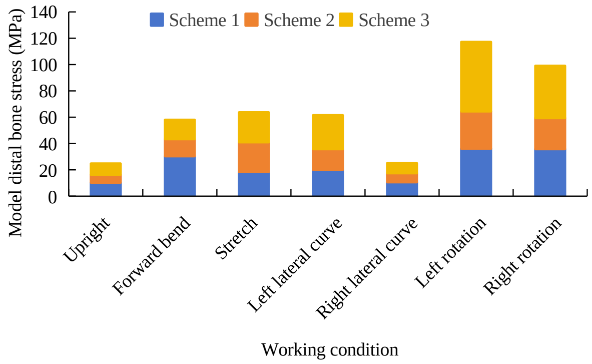
**Figure 2.** Comparison of maximum stress of internal fixation system.

### 4.3. Proximal and distal stress analysis

The study took the 2nd lumbar vertebra as the boundary, divided the 6th thoracic vertebra to the 1st lumbar vertebra as the proximal end, and the 3rd lumbar vertebra to the 1st sacral vertebra as the distal end, and carried out the proximal and distal stress analyses for the model, and **Figure 3** displays the findings. In **Figure 3a**, the proximal stress analysis of scenario 3 had the highest stresses in the two rotational conditions, which amounted to 46.232 MPa and 42.223 MPa. The cortical bone track screws provided stronger support for the spine, which increased the bone stress to some extent. In **Figure 3b**, Scheme 1 showed greater bone stresses of more than 30 MPa in forward flexion with both rotational working conditions. This might be due to the fact that the fixation of conventional pedicle screws exerted more pressure on the distal spinal segments, resulting in a concentration of stress. Taken together, Scheme 2 showed relatively less stress at the most distal end, and the use of bone cement provided additional fixation strength to distribute and reduce bone stress.




**(a)** Model proximal bone stress.

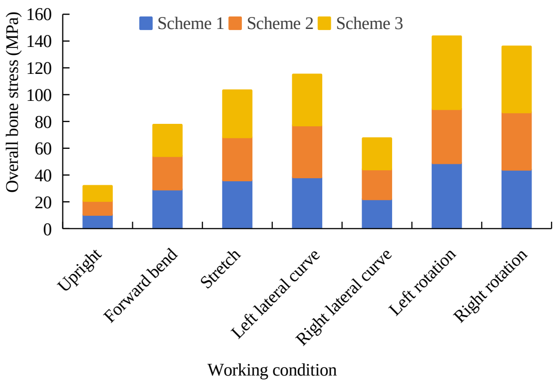



**(b)** Model distal bone stress.

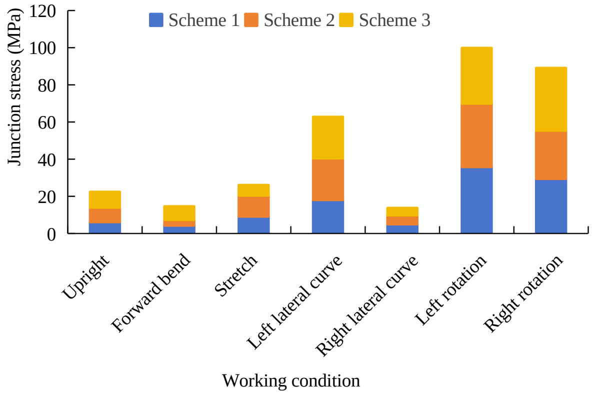
**Figure 3.** Proximal and distal stress analysis.

### 4.4. Integral bone stress and junction stress analysis

The results of the overall bone stress and junction stress analysis are shown in **Figure 4**. In **Figure 4a**, the overall bone stress for Scheme 1 was greater in forward flexion at 29.393 MPa. The overall bone stress for Scheme 3 was greater in rotation at 53.914 MPa. The cortical bone trajectory screw allowed more rotational activity, resulting in greater stress during rotation. In **Figure 4b**, the stress in the junction area was less than the stress in the proximal and distal areas in **Figure 3**.




**(a)** Overall bone stress.




**(b)** Junction stress.

**Figure 4.** Integral bone stress and junction stress analysis.

### 4.5. Comparison of COBB corner and SVA

The statistical results of preoperative and postoperative Cobb angle and SVA in different groups of subjects are shown in **Table 3**. There was no SSD between the preoperative COBB angle and SVA of patients in different experimental groups ($P$ > 0.05). Postoperatively, the COBB angle and SVA were significantly improved.

Among them, Scheme 1 and Scheme 3 showed better improvement compared with Scheme 2. There was an SSD in the scores ($P < 0.05$). The degree of improvement in the Cobb angle is closely related to the degree of correction of the patient's spinal deformity, with greater Cobb angle improvement implying more significant correction of the spinal deformity, as well as better functional recovery. Specific improvement thresholds may vary depending on the individual patient, the type and severity of the spinal deformity, and other factors, but more significant improvement results in better functional recovery.

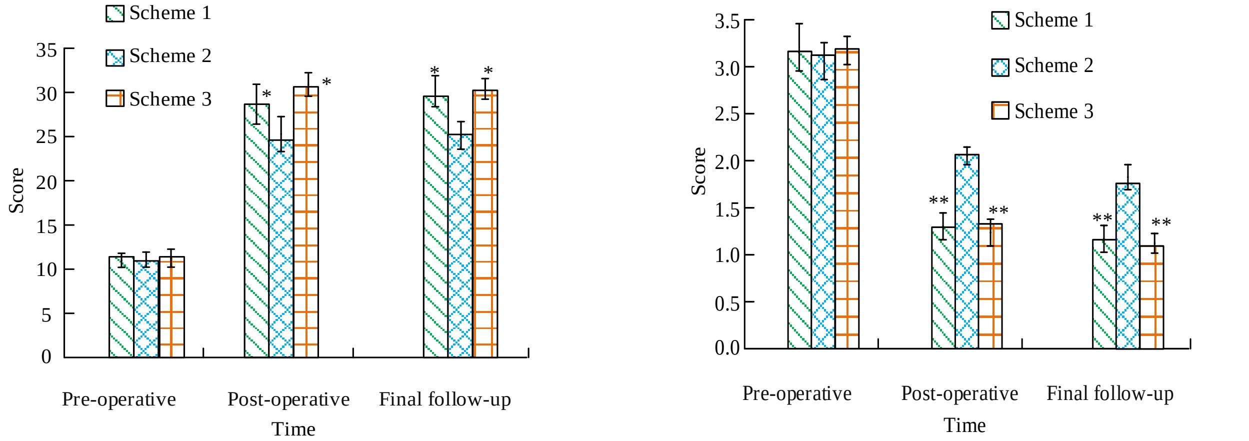
**Table 3.** Comparative analysis of COBB angle and SVA.

| **Assessment indicators** | **Time** | **Scheme 1** | **Scheme 2** | **Scheme 3** | ***P*** |
|---|---|---|---|---|---|
| COBB angle (°) | Pre-operative | 53.67 ± 4.57 | 53.23 ± 4.02 | 53.88 ± 4.70 | 0.002 |
| | Post-operative | 13.25 ± 4.57b | 16.31 ± 3.89a | 13.36 ± 4.18b | 0.004 |
| | Final follow-up | 11.52 ± 2.47b | 13.08 ± 4.88a | 11.04 ± 2.70b | 0.004 |
| SVA (cm) | Pre-operative | 38.28 ± 3.69 | 38.68 ± 3.60 | 39.81 ± 4.18 | 0.001 |
| | Post-operative | 9.92 ± 2.15b | 12.92 ± 4.18a | 9.15 ± 3.03b | 0.004 |
| | Final follow-up | 9.57 ± 3.96a | 10.03 ± 2.09a | 9.09 ± 2.41a | 0.003 |

Note: The group with the highest mean is labeled as "a", and if the difference is significant, it is labeled as "b" or "c". "*P*" indicates preoperative and postoperative comparisons in the same group of patients.

### 4.6. Comparison of JOA and VAS scores

The results of preoperative and postoperative JOA and VAS scores of subjects in different groups are shown in **Figure 5**. In **Figure 5a**, there was an SSD in JOA scores of subjects in different groups preoperatively ($P > 0.05$), and the subsequent experimental comparisons were analytically significant. Postoperatively, there was a SSD in the JOA scores of Scheme 1 and Scheme 3 compared with Scheme 2 ($P < 0.05$). The JOA score was an important index for assessing the function of the cervical spine, and its improvement reflected the positive impact of surgery on patients' QOL. The internal fixation protocol of Scheme 2 was slightly less effective. In **Figure 5b**, the VAS scores of Schemes 1 and 3 were equally superior to Scheme 2. The VAS score of Scheme 2 only decreased from (3.898 ± 1.521) to (2.417 ± 0.947), with an SSD ($P < 0.01$). However, the results in **Figure 3** showed that the stress in the most distal end of option 2 was relatively small, which differed from the performance of the clinical effect. This is due to the fact that the uniformity of the distribution of bone cement in pedicle screws is crucial for their mechanical properties and clinical effects, and when the distribution of bone cement in the screws is uneven, it may lead to a weakening of the bonding force between the screws and the vertebral body, which may affect the fixation effect and stability of the screws. Factors such as technical differences in the surgical procedure, insufficient amount of bone cement injected, or inaccurate injection position contribute to the phenomenon of uneven distribution. Future studies should strengthen the monitoring and evaluation of the distribution of bone cement to ensure its uniform distribution in the screws.

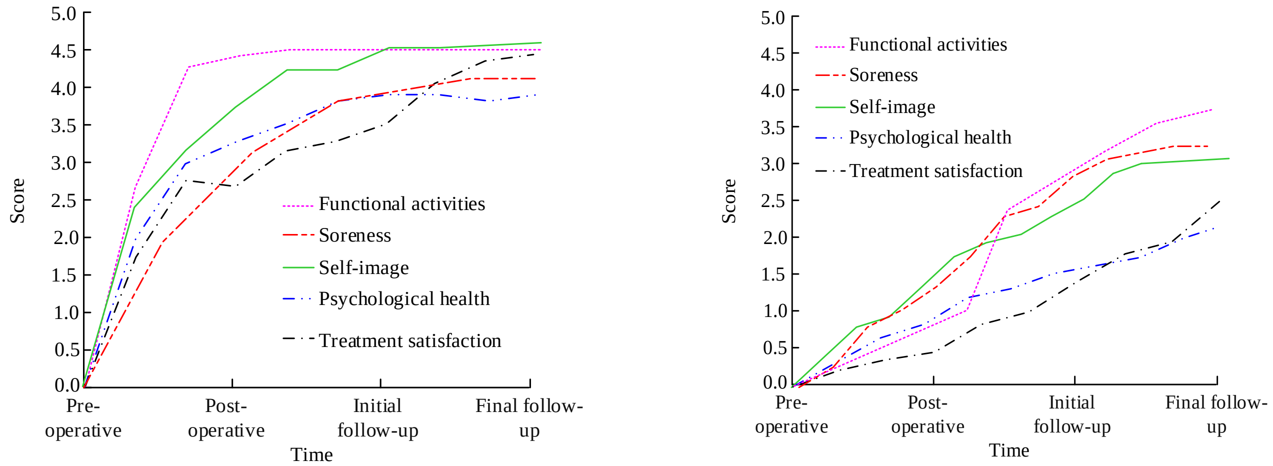



**(a)** JOA. **(b)** VAS.

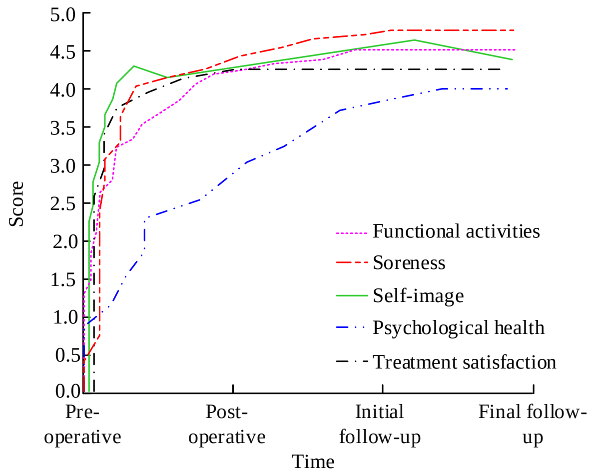
**Figure 5.** Comparison of JOA and VAS scores.

Note: Compared with Scheme 2. "*" represents $P < 0.05$ and "**" represents $P < 0.01$.

### 4.7. Comparison of SRS-22 scores




**(a)** Scheme 1. **(b)** Scheme 2.




**(c)** Scheme 3.

**Figure 6.** SRS-22 scores of patients in different experimental groups.

The preoperative and postoperative statistics of SRS-22 scores of patients in different experimental groups are shown in **Figure 6**. Under the three internal fixation schemes, the patients' SRS-22 scores showed an increasing trend in the functional activity, pain, self-image, mental health, and treatment satisfaction sub-dimensions. Comparing **Figure 6a–c**, the improvement of SRS-22 scores was slightly worse in option two. There was an SSD ($P$ < 0.05) when compared with Schemes 1 and 3. Scheme 1 and 3 could make the patients' QOL in different dimensions better.

### 4.8. Comparison of ODI scores

The statistical results of ODI scores of patients in different groups before and after surgical orthopedics are shown in **Figure 7**. Before surgical orthopedics, there was no SSD in the ODI scores of the three experimental groups ($P$ > 0.05). After the intervention of three different internal fixation protocols, the ODI scores of the experimental groups decreased significantly after the surgery, and there was an SSD from the pre-surgical period ($P$ < 0.01). The degree of dysfunction of the patients was significantly reduced. It can be seen that the ODI score fully verifies the effectiveness of surgical treatment in improving the dysfunction of patients with ankylosing spondylitis retrovertebral deformity; regardless of the internal fixation scheme, the degree of dysfunction of the patients after surgery was significantly reduced, and the quality of life was significantly improved; the surgical treatment not only relieves the pain symptoms of the patients, but also significantly improves the ability of the patients to carry out daily activities and improves the quality of life.

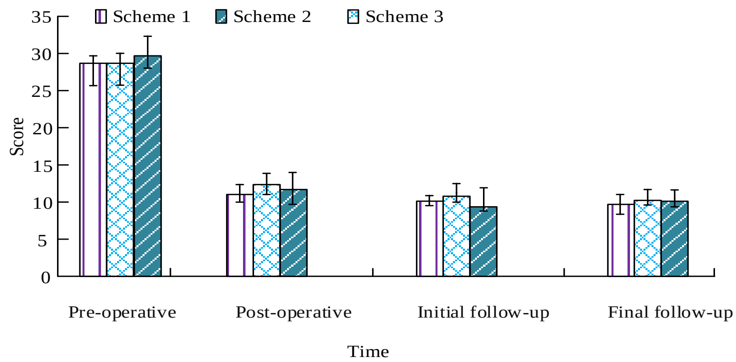



**Figure 7.** ODI score statistics results.

## 5. Conclusion

To improve the surgical treatment effect of AS retrovertebral deformity and optimize the treatment plan, the study analyzed the mechanical characteristics of different internal fixation strategies for surgical correction of retrovertebral deformity based on the finite element, and compared the clinical corrective effect of the different plans. It was found that the internal fixation performed in scheme 1 and Scheme 2 had higher stresses in anterior flexion and smaller deformation displacement. In contrast, the proximal stress analysis of Scheme 3 using cortical bone track screw fixation showed higher stresses in left and right rotation. Scheme 2 had relatively small stresses at the most distal end. The overall bone stress for Scheme 1 was greater in forward flexion at 29.393 MPa. The overall bone stress for Scheme 3 was greater in rotation at

53.914 MPa. The patients' postoperative COBB angle, SVA, JOA, and VAS with SRS-22 scores were significantly improved, and the ODI index was significantly decreased. The effect of Scheme 1 and Scheme 3 was more significant than that of Scheme 2 ($P < 0.05$). The results of the study may provide a scientific basis for clinicians to select ASkyphotic correction surgical strategies and help them to develop a personalized surgical plan based on the patient's specific situation. However, there are various ASkyphotic correction surgical strategies, including different osteotomies, planes, numbers, and angles. The differences between these surgical approaches may result in different postoperative outcomes, and it is difficult to directly apply the results of this study to all surgical strategies. Future research requires more in-depth studies.

The study still has some shortcomings. First, the finite element modeling was performed based on the CT data of the same case, and the influence of different anatomical structures or disease severity on the internal fixation effect was not considered. Individual differences are an important factor in spinal diseases, which will affect the stress distribution and fixation effect of internal fixation models, and also led to the fact that the study did not develop a statistical analysis in the finite element analysis part to determine whether the differences in stress distribution between different internal fixation models were statistically significant. Therefore, future studies should add multi-case analyses to construct diverse spine models by collecting CT data from more patients in order to more comprehensively evaluate the performance of different internal fixation models under different anatomical structures and disease severity; meanwhile, statistical analyses should be conducted to validate the reliability and accuracy of the results of the finite element analysis. Second, the study performed biomechanical assessments and comparative analyses in the short and medium term, and the long-term follow-up data are important for assessing the stability and efficacy of the internal fixation system, but there are still deficiencies in the long-term follow-up data and the assessment of complications. In addition, the study did not adequately assess complications. Spinal internal fixation surgery may be accompanied by a variety of complications, such as adjacent segment degeneration, internal fixation loosening, and bone resorption; complications adversely affect surgical outcomes, patient recovery, and quality of life. Future studies should strengthen the monitoring and evaluation of complications, including the timely detection and management of complications through imaging and laboratory tests, in order to reduce surgical risk and improve patient satisfaction.

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**Ethical approval:** Not applicable.

**Conflict of interest:** The authors declare no conflict of interest.

## Abbreviations

| | |
|---|---|
| AS | Ankylosing Spondylitis |
| JOA | Japanese Orthopaedic Association Score |
| VAS | Visual Analog Scale |
| CBVA | Chin-Brow Vertical Angle |
| PT | Proximal Junction Angle |
| tPT | True Proximal Junction Angle |
| DSCT | Dual-Source Computed Tomography |
| DICOM | Digital Imaging and Communications in Medicine |
| ODI | Oswestry Disability Index |
| SVA | Sagittal Vertical Axis |
| SRS-22 | Scoliosis Research Society-22 Patient Questionnaire |

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