Preoperative prediction of sagittal imbalance in kyphosis secondary to ankylosing spondylitis after one-level three-column osteotomy

jianzhou luo
Shenzhen University Health Science Center
kai yang
Xi'an Red Cross Hospital: Honghui Hospital
zili yang
Shenzhen University Health Science Center
chunguang duan
Shenzhen University General Hospital
jiayi chen
The Third Affiliated Hospital of Southern Medical University
zhengji huang
Shenzhen University General Hospital
zhenjuan luo
Shenzhen University General Hospital
huiren tao
Shenzhen University General Hospital
tailin wu (TL_spine@163.com)
Shenzhen University General Hospital https://orcid.org/0000-0002-3209-4422

Research Article

Keywords: Ankylosing spondylitis, Osteotomy, Sagittal imbalance, Preoperative prediction, Optimal sagittal vertical axis,

Posted Date: March 28th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1323696/v1

Abstract

Background: This study aimed to determine preoperative predictions of sagittal imbalance in kyphosis secondary to ankylosing spondylitis (AS) after one-level three-column osteotomy.

Methods: A total of 55 patients with AS who underwent one-level three-column osteotomy were enrolled. The patients were divided into two groups according to sagittal vertical axis (SVA) value at the final follow-up (group A: SVA>5 cm; group B: SVA≤5 cm). The radiographic measurements were measured, including global kyphosis, lumbar lordosis (LL), pelvic tilt (PT), pelvic incidence (PI), sacral slope, T1 pelvic angle (TPA), SVA, osteotomized vertebral angle and PI and LL mismatch (PI-LL).

Results: Fifty-five AS patients were followed up for 30.6 ± 10.2 months averagely (range, 24–84 months). Preoperatively and postoperatively, group A had larger LL, PT, PI - LL, TPA, and SVA values than group B (P<0.05). And the preoperative LL, PT, PI - LL, TPA, and SVA values had significantly positive relationships with the follow-up SVA value (P<0.05). The preoperative TPA>40.9°, PI-LL>32.5°, and SVA>13.7 cm were the top three predictions with the best accuracy to predict sagittal imbalance. The construction of postoperative SVA<7.4 cm was the key factor for decreasing the chance of sagittal imbalance on follow-up.

Conclusions: The preoperative TPA>40.9°, PI - LL>32.5°, and SVA>13.7 cm could predict sagittal imbalance for AS kyphosis after one-level three-column osteotomy, and additional osteotomies were recommended for this condition. The postoperative SVA<7.4 cm was an optimal alignment for preventing sagittal imbalance.

Level of evidence: IV

Introduction

Ankylosing spondylitis (AS) is a chronic inflammatory disease, which mainly affects the axial skeleton [1]. In advanced stages, AS can lead to progressive ossified spinal ligament, proliferative osteophyte, and rigid thoracolumbar kyphosis [1, 2]. Patients with AS with advanced conditions often have trouble in standing upright, lying flat, and looking straight ahead, which seriously restricts patients' daily activities and impairs their quality of life [3, 4]. Therefore, corrective osteotomy is often recommended for these patients to correct kyphosis and restore sagittal balance[5].

Actually, not all patients with AS who undergo osteotomy achieve a satisfactory sagittal balance at the follow-up, which is mainly attributed to the inadequate kyphosis correction and failed postoperative sagittal realignment [6–8]. Patients with unbalanced sagittal realignment might have a poor clinical outcome, which increases the risk of pseudoarthrosis, delay union, and instrumental failure, and may even require a second surgery [9, 10]. Thus, it is necessary to find preoperative predictions to predict sagittal imbalance in advance, and then, to determine the optimal postoperative goal for sagittal alignment construction [11, 12], so as to decrease the rate of sagittal imbalance in patients with AS at the follow-up. However, preoperative predictions with clear threshold values and the optimal postoperative alignment in kyphosis secondary to AS following one-level three-column osteotomy have not been well documented yet. Qian et al. [9] reported that preoperative sagittal vertical axis (SVA) and pelvic incidence (PI) were the predictors for sagittal imbalance; however, the thresholds of these predictors could not be figured out. Schwab et al. [10, 11, 13] suggested that the postoperative SVA <5 cm was successful realignment for adult spinal deformity (ASD), and postoperative SVA >10 cm was failed realignment. But there was still not clear that whether or not Schwab's result was suitable for AS kyphosis correction because of the different pathologic process between AS and ASD. Therefore, the preoperative predictions with clear threshold values and optimal postoperative goals in AS patients need further exploration.

In this study, we retrospectively investigated a series of patients with kyphosis secondary to AS who underwent one-level three-column osteotomy and aimed to (1) identify the difference between patients with and without sagittal imbalance; (2) figure out preoperative predictions with clear threshold values to predict sagittal imbalance; and (3) determine key factor with an optimal goal for preventing sagittal imbalance.

Materials And Methods

Patients

Eighty-two consecutive patients with kyphosis secondary to AS who underwent three-column osteotomy from January 2011 to January 2019 were reviewed retrospectively. The inclusion criteria were as follows: (1) patients who underwent one-level three-column osteotomy; (2) those who were followed up for a minimum of 2 years; and (3) those with complete radiographic and clinical materials. The exclusion criteria were as follows: (1) patients with a history of previous spinal surgery; (2) those with postoperative pseudarthrosis and instrumentation failure; and (3) those with ankylosed hip or knee joints. Twenty cases with two-level osteotomy, 2 cases with previous spinal operation history, and 5 cases with incomplete imaging or clinical data, were excluded. Finally, a total of 55 patients with AS (47 men, 8 women) met the criteria and were enrolled in this study. The average age was 36.6 years (range, 20–60 years), and the average follow-up duration was 30.6 months (range, 24–84 months).

Data Collection

Standing anteroposterior and lateral radiographs of the whole spine were obtained preoperatively, postoperatively, and at the finial follow-up. The following parameters were measured using lateral radiographs: global kyphosis (GK), lumbar lordosis (LL), T1 pelvic angle (TPA), pelvic tilt (PT), PI, sacral slope (SS), osteotomized vertebral angle (OVA) and PI and LL mismatch (PI − LL) (Fig. 1). The clinical outcome was evaluated using the Scoliosis Research Society-22 (SRS-22) questionnaire and Oswestry Disability Index (ODI). The patient with follow-up SVA of >5 cm was regarded as sagittal imbalance [14].

Surgical Technique

A modified pedicle subtraction osteotomy was performed in the apical region of kyphosis, and somatosensory- and motor-evoked potentials were monitored throughout the procedure.

After general anesthesia, the pedicle screws were implanted at the planned fusion levels. The resection area included the spinous process, upper part of the lamina, and superior articular processes of the osteotomized vertebra, as well as the lower part of the lamina and inferior articular processes of the cranial adjacent vertebra. The transverse process of the osteotomized vertebra was exposed and resected. Subsequently, subtotal resection was performed along the upper part of the pedicles to the front of the vertebral body, which usually allowed resection of one third to half of the upper part of the vertebral body together with the cranial adjacent intervertebral disk. After osteotomy, bilateral temporary rods were implanted firmly at the osteotomized site at least two vertebrae above and below. During the correction, the surgeons slightly closed both sides of the osteotomized ends by compressing the rods to shorten the spinal cord mildly in advance because the spinal cord tended to lengthen in correction. Then, the circuit nurse and technician lifted the patient's shoulders and gradually removed the postural pads to correct kyphosis. Simultaneously, the surgeons used the point of the rods at the osteotomized gap as a hinge and bent it while the patient's shoulders were still lifted to restore spinal realignment. After achieving satisfactory correction, the temporary rods were replaced with precontoured rods successively. Subsequently, a local bone graft and a cage filled with autogenous bone were implanted in the osteotomy space, and the rods were further compressed. The bone autograft was paved on the surface of the lamina to facilitate spinal fusion.

Statistical analysis

Statistical analysis was performed using SPSS software (version 22.0, SPSS Inc., IL, USA). All numeric parameters were expressed as mean ± standard deviation. The differences in quantitative data between the two groups were compared with independent-samples *t* tests. The qualitative data were analyzed by the χ^2 test or Fisher's exact test. The correlations between the follow-up SVA and the pre-/postoperative parameters were analyzed with Pearson correlation coefficients. The receiver-operating characteristic (ROC) analysis was performed to determine the preoperative predictors and to figure out their thresholds. The logistic regression analysis was performed to determine the key postoperative parameter, and the threshold of this key parameter was evaluated using the ROC. A P value <0.05 was considered statistically significant.

Results

Clinical and radiographic data

The follow-up SVA was >5 cm in 37 patients in group A and ≤5 cm in 18 patients in group B after a minimum follow-up of 2 years. These two groups were equivalent with regard to average age, sex distribution, and osteotomy sites ($P > 0.05$); and the operative time, blood loss and fusion levels were also similar ($P > 0.05$) (Table 1). Preoperatively and postoperatively, group A patients had larger LL, PT, PI − LL, TPA, and SVA than group B patients ($P < 0.05$). Both groups obtained similar kyphosis corrections postoperatively ($P > 0.05$). No significant difference was found in GK, PI, SS, OVA, ODI score and SRS-22 score between these two groups ($P > 0.05$) (Table 2).

Table 1
Comparison of demographic and surgical data between two groups

Variables	Group A (n=37)	Group B (n=18)	*P* value
Age (year)	38.3±8.2	34.9±8.1	0.152
Sex (M/F)	33/4	14/4	0.472
Operative time (min)	333.1±91.6	331.8±58.2	0.956
Blood loss (ml)	1145.1±871.9	1673.5±1092.9	0.062
Osteotomy sites (n)			
T12	1	1	0.752
L1	8	5	
L2	22	8	
L3	6	4	
OVA (°)	39.5±13.4	33.5±11.3	0.110
Fusion level (n)	6.3±1.1	6.5±1.7	0.709
Follow-up (month)	29.1±4.0	32.2±3.9	0.862

OVA, osteotomized vertebral angle.

Table 2
Differences of radiographic measurements between group A and group B

Measurements	Group A (n=37)	Group B (n=18)	*P* value
Pre-GK (°)	79.4±21.7	74.7±16.3	0.425
Post-GK (°)	35.0±14.4	36.4±18.8	0.769
Correction-GK (°)	43.8±14.2	38.3±14.9	0.198
Pre-LL (°)	8.1±21.4	-7.3±16.6	0.010*
Post-LL (°)	-30.5±14.6	-41.5±18.9	0.020*
Correction-LL (°)	38.5±14.1	34.3±18.8	0.354
Pre-PT (°)	41.0±11.1	34.1±8.4	0.024*
Post-PT (°)	30.9±9.9	23.5±9.7	0.011*
Correction-PT (°)	10.0±10.0	10.7±8.3	0.820
Pre-PI (°)	48.5±13.4	44.9±14.6	0.374
Post-PI (°)	48.9±12.3	45.3±12.2	0.313
Correction-PI (°)	0.5±6.9	0.4±6.5	0.962
Pre-SS (°)	7.5±12.6	10.8±13.1	0.374
Post-SS (°)	18.0±10.2	21.9±14.6	0.256
Correction-SS (°)	10.5±9.2	11.0±9.2	0.837
Pre-PI-LL (°)	56.5±18.5	37.6±20.3	0.001*
Post-PI-LL (°)	18.4±15.2	3.7±11.4	<0.001*
Correction-PI-LL (°)	38.1±14.0	33.9±20.4	0.376
Pre-TPA (°)	58.6±15.9	42.2±14.6	0.001*
Post-TPA (°)	23.2±7.1	16.3±8.6	<0.001*
Correction-TPA (°)	25.3±12.0	22.2±13.2	0.399

GK, global kyphosis; LL, lumbar lordosis; PT, pelvic tilt; PI, pelvic incidence; SS, sacral slope; PI-LL, PI minus LL value; TPA, T1 pelvic angle; SVA, sagittal vertical axis; SRS-22, Scoliosis Research Society-22 questionnaire; ODI, Oswestry Disability Index.

Negative number represents lordosis, positive number represents kyphosis.

*The difference between group A and B was statistically significant ($P < 0.05$).

Measurements	Group A (n=37)	Group B (n=18)	*P* value
Pre-SVA (cm)	23.2±7.1	16.3±8.6	0.002*
Post-SVA (cm)	10.9±3.6	3.6±3.1	<0.001*
Correction-SVA (cm)	12.5±5.9	12.6±9.4	0.959
Pre-ODI score	18.8±11.3	20.6±6.0	0.411
Post-ODI score	10.4±6.6	8.6±8.3	0.095
Correction- ODI score	8.4±12.1	12.0±9.5	0.099
Pre-SRS22 score	2.63±0.69	2.91±0.50	0.277
Post-SRS22 score	3.95±0.49	4.05±0.62	0.067
Correction- SRS22 score	1.32±0.77	1.14±0.68	0.758
GK, global kyphosis; LL, lumbar lordosis; PT, pelvic tilt; PI, pelvic incidence; SS, sacral slope; PI-LL, PI minus LL value; TPA, T1 pelvic angle; SVA, sagittal vertical axis; SRS-22, Scoliosis Research Society-22 questionnaire; ODI, Oswestry Disability Index.			
Negative number represents lordosis, positive number represents kyphosis.			
*The difference between group A and B was statistically significant (*P* < 0.05).			

Preoperative Predictions For Sagittal Imbalance At The Follow-up

The correlations between the follow-up SVA and the preoperative parameters demonstrated that the preoperative LL, PT, PI − LL, TPA, and SVA values had significantly positive relationships with the follow-up SVA value (*P*<0.05, Table 3). The ROC analysis was performed for these significantly relevant preoperative parameters, and the area under the ROC curves (AUC) was calculated. The AUC value of LL, PT, PI − LL, TPA, and SVA was 0.712, 0.700, 0.770, 0.798, and 0.749, respectively. The top three parameters (TPA, PI − LL, and SVA) with the largest AUC value were regarded as the predictions, which indicated the best accuracy for predicting sagittal imbalance. The TPA>40.9° was to predict sagittal imbalance with a sensitivity of 89.2% and a false-positive rate (1-specificity) of 33.3% (Fig. 2a); The PI − LL>32.5° was to predict sagittal imbalance with a sensitivity of 94.6% and a false-positive rate of 44.4% (Fig. 2b); And the SVA>13.7 cm was to predict sagittal imbalance with a sensitivity of 97.3% and a false-positive rate of 44.4% (Fig. 2c).

Table 3
Correlations between the follow-up SVA and the pre-/postoperative parameters

Parameters	Coefficient, r	*P*
Preoperative GK	0.124	0.367
Preoperative LL	0.281	0.038*
Preoperative PT	0.392	0.003*
Preoperative PI	0.233	0.087
Preoperative SS	-0.078	0.574
Preoperative PI-LL	0.437	0.001*
Preoperative TPA	0.454	<0.001*
Preoperative SVA	0.386	0.004*
Postoperative GK	0.039	0.781
Postoperative LL	0.389	0.003*
Postoperative PT	0.437	0.001*
Postoperative PI	0.218	0.111
Postoperative SS	-0.159	0.245
Postoperative PI-LL	0.661	<0.001*
Postoperative TPA	0.669	<0.001*
Postoperative SVA	0.834	<0.001*

GK, global kyphosis; LL, lumbar lordosis; PT, pelvic tilt; PI, pelvic incidence; SS, sacral slope; PI-LL, PI minus LL value; TPA, T1 pelvic angle; SVA, sagittal vertical axis.

* indicated that the correlation was statistically significant ($P < 0.05$).

The efficacy of these preoperative predictions with the thresholds was verified in this cohort. The result showed that patients with two or three predictions meeting the threshold values could significantly predict the sagittal imbalance at the follow-up, whereas only one prediction meeting the threshold value could not exactly predict the sagittal imbalance (Table 4 and Fig. 3).

Table 4
Efficacy of these preoperative predictors with the threshold values to predict sagittal imbalance

Numbers of predictors met the thresholds	**Cases**	**Sagittal balance**	**Sagittal imbalance**	***P***
No predictor met	9	9	0	/
One predictor met	3	2	1	0.250
Two predictors met	7	1	6	0.001*
All predictors met	36	6	30	<0.001*

* Compared with “No predictor met”, the difference was statistically significant (*p*<0.05).

Key Factor For Preventing Sagittal Imbalance

The immediate postoperative PI – LL, TPA, and SVA values were the top three relevant parameters with the highest coefficient to sagittal imbalance, and then were entered into the logistic regression analysis. The result revealed that the preoperative SVA value was a significant independent key factor for sagittal imbalance (*P*<0.001, Table 5). The ROC analysis of postoperative SVA demonstrated that SVA≤7.4 cm for preventing sagittal imbalance at the follow-up was with an AUC of 0.941, a sensitivity of 88.9%, and a false-positive rate of 5.6% (Fig. 2d). The patients with postoperative SVA of ≤7.4 cm had smaller SVA and lower incidence of sagittal imbalance at the follow-up than those with postoperative SVA >7.4 cm. There was no significant difference in ODI score and SRS-22 score between the two groups (*P* < 0.001, Table 6).

Table 5
Logistic regression analysis of the postoperative parameters for sagittal imbalance

Variable	**B**	**SE**	**Wald**	***P***	**Exp(B)**	**95%CI of Exp(B)**	
						Lower	**Upper**
Postoperative SVA	0.680	0.192	12.555	<0.001	1.975	1.355	2.877
(Constant)	-4.054	1.322	9.403	0.002	0.017		

With the follow-up sagittal imbalance as dependent variable; SVA, sagittal vertical axis.

Table 6
Efficacy of the post-SVA with the threshold value for sagittal imbalance

Variable	**Above threshold value** (>7.4 cm)	**Below threshold value** (≤7.4 cm)	***P***
Cases (n)	34	21	/
Postoperative SVA (cm)	11.5±3.1	3.6±2.4	<0.001*
Follow-up SVA (cm)	11.4±3.4	4.1±3.3	<0.001*
Incidence of the follow-up sagittal imbalance	97.1% (33/34)	19.0% (4/21)	<0.001*
Follow-up ODI score	11.3±6.8	10.2±6.39	0.644
Follow-up SRS-22 score	3.89±0.50	4.04±0.51	0.382

SVA, sagittal vertical axis, SRS-22, Scoliosis Research Society-22 questionnaire; ODI, Oswestry Disability Index.

* indicated that the difference was statistically significant ($P < 0.05$).

Complications

Sixteen postoperative complications were noted in 11 patients, including 1 pleural effusion, 4 transient neurological damage, 5 vertebral subluxation and 6 dural tear (all of them with dural tear complicated with Andersson lesions at the osteotomized sites). No screw loosening, rod breakage and pseudoarthrosis were not observed at the final follow-up.

Discussion

Osteotomy is an effective method to correct kyphosis and restore the sagittal alignment in patients with AS, which greatly improves their daily living activities and quality of life [5, 9, 12, 15]. However, clinically, not all patients with kyphosis who undergo osteotomy can achieve a satisfactory sagittal balance at the follow-up, leading to an increased risk of implant failure, delayed union, pseudoarthrosis, and correction loss [8, 16]. Until now, few studies have attempted to specifically determine the preoperative predictions with clear threshold values to predict sagittal imbalance in patients with AS, and the optimal postoperative goal for preventing sagittal imbalance in these patients is still less known [9, 12, 13].

In this study, the patients in group A had larger LL, PI − LL, TPA, and SVA values than those in group B preoperatively, which indicated that the patients with follow-up sagittal imbalance often had more severe preoperative sagittal imbalance and spinopelvic deformity. These patients were supposed to undergo a matching larger correction to construct their sagittal alignment with the apparently preoperative sagittal deformity. However, in fact, they only received the same amount of correction as those in the group B, leaving much residual postoperative deformity. As a result, patients in group A were more likely to experience failed sagittal realignment than those in group B at the follow-up. This was consistent with that observed by Schwab et al. [13], who indicated that one-level three-column osteotomy may not always achieve a satisfactory outcome, particularly in those with severe preoperative sagittal imbalance and lumber kyphosis; additional osteotomy was recommended for these patients [13, 17].

The Pearson coefficient analysis demonstrated that the follow-up SAV value significantly corelated with preoperative parameters, which made it possible to predict sagittal imbalance at the final follow-up with preoperative parameters. Based on the significant relationship between the follow-up SVA value and preoperative parameters, ROC analysis showed that the top three AUC values were those for TPA, PI − LL, and SVA, which indicated that these three preoperative parameters were the optimal predictions with the best accuracy for predicting sagittal imbalance. Moreover, the optimal threshold value of these preoperative predictions for predicting sagittal imbalance was TPA >40.9°, PI − LL >32.5°, and SVA >13.7 cm. Similarly, Qian et al. [9] found that the SVA and PI were the radiographic predictors for the postoperative sagittal imbalance; however, the optimal threshold value of these two predictors could not be evaluated. In this study, the preoperative predictions were the three most relevant parameters with the largest AUC; and their threshold values were evaluated clearly for predicting sagittal imbalance, making them useful in surgical decision-making. Although the preoperative LL and PT values showed a statistical relevance with sagittal imbalance, the accuracy and coefficient were relatively lower than the other three parameters; thus, they were not included in the further analysis. Additionally, the efficacy of these three predictions was validated with the present cohort. The results showed that patients in whom two or three predictions met the threshold values significantly increased the rate of sagittal imbalance at the final follow-up. This revealed that the predictive ability of these predictions was effective when two or three predictions met their threshold values concurrently. Only one prediction meeting the threshold value might not be enough to predict sagittal imbalance accurately. Therefore, according to the results, two or three preoperative predictions were recommended to be taken into consideration concurrently when doing preoperative planning and judging the postoperative sagittal realignment.

Predicting sagittal realignment in advance was the first step for preventing sagittal imbalance, while correcting kyphosis and constructing sagittal alignment should be the most important step. The main cause for failed sagittal realignment in most patients has always been inadequate intraoperative correction [13]. Schwab et al. [11] suggested that the goal for postoperative SVA should be <4.7 cm for ASD after osteotomy. However, for kyphosis in patients with AS, the optimal postoperative SVA value for correction has not been reported yet. In this study, based on the relationship between the follow-up SVA and postoperative parameter, we investigated the key parameter for sagittal imbalance with logistic regression analysis. The top three postoperative parameters (PI − LL, TPA, and SVA) with the highest coefficient were entered into logistic regression analysis to determine the independent key parameter of sagittal imbalance. The results demonstrated that the postoperative SVA was the independent key factor of sagittal imbalance. Subsequently, the optimal postoperative SVA was analyzed with the ROC, and the result showed that the optimal threshold of postoperative SVA for preventing sagittal imbalance was <7.4 cm, with an AUC of 0.941, a sensitivity of 88.9%, and a false-positive rate of 5.6%.

To further verify the effectiveness of the postoperative SVA with a threshold of 7.4 cm, the cohort was divided into two groups to compare the differences in SVA and the incidence of sagittal imbalance at the follow-up. Reliably, the results indicated that patients with postoperative SVA <7.4 cm had a smaller SVA and lower incidence of sagittal imbalance than those with postoperative SVA of >7.4 cm. This result was in line with that of Kim et al. [8] who reported that restoration and maintenance of postoperative SVA <8 cm was important to the ultimate sagittal reconstruction in fixed sagittal imbalance. In this study, these patients with an immediate postoperative SVA of <7.4 cm maintained an acceptable sagittal realignment at the follow-up. Similarly, Wang et al. [18] also reported that patients with AS with the postoperative SVA of 8.6 cm usually did not show an obvious correction loss or severe sagittal imbalance at the follow-up. Kim and his colleague[5] observed 248 AS patients and found that the patients with SVA of 7.0 cm or less obtained the best clinical outcome after surgery. These results commonly reminded that for AS patients with severe kyphosis, the SVA would not be required to correct to a normal range, and the postoperative SVA of ≤7.4 cm might be enough for most patients to obtain satisfied clinical outcome.

Interestingly, a phenomenon that patients with AS with a larger immediate postoperative SVA might partially decrease to a smaller range at the follow-up was found in this study. In general, the spine of AS patients was stiff and rigid in the advanced stage, which could not be reflexed and extended. However, the pelvis functioned as a compensatory mechanism with the femoral heads as the fulcrum to rotate anteriorly after surgery. As the pelvis rotated backward to compensate sagittal imbalance preoperatively, the backward rotated pelvis could anteriorly rotate to some extent postoperatively provided the hip joints were not ankylosed. Of note, the pelvis rotation anteriorly could not be accomplished immediately after surgery because the AS with severe pelvic retroversion usually complicated with the contracture of hip joints for the tense ligaments, which could be gradually corrected to a certain extent with rehabilitation exercise [4, 19, 20]. Second, the patients with AS were still accustomed to the preoperative anterior center of gravity; thus, they kept on flexing the trunk when standing until they got used to the new center of mass after a period. And these interesting findings also were observed in previous studies [18, 21].

Limitations

First, although the choices of osteotomized sites and the degree of correction might influence sagittal realignment, they were not compared separately because of the limited sample size. Second, the hip flexibility of these patients has not been qualified, which might influence the recovery of SVA postoperatively. Third, the patients with postoperative SVA <7.4 cm still had 19.0% incidence of sagittal imbalance, and further analysis with a larger sample size was needed to obtain a precise threshold.

Conclusions

The AS patients with larger preoperative sagittal alignment were more likely to experience sagittal imbalance. The preoperative TPA >40.9°, PI − LL >32.5°, and SVA >13.7 cm could predict sagittal imbalance at the follow-up, and additional osteotomies are recommended for this condition. The postoperative SVA should be <7.4 cm for preventing sagittal imbalance.

Abbreviations

AS
ankylosing spondylitis
SVA
sagittal vertical axis
GK
global kyphosis
LL, lumbar lordosis
PT
pelvic tilt
PI
pelvic incidence
SS
sacral slope
TPA
T1 pelvic angle
OVA
osteotomized vertebral angle
PI-LL
PI and LL mismatch
ASD
adult spinal deformity
SRS-22
Scoliosis Research Society-22 questionnaire
ODI
Oswestry Disability Index.

Declarations

Ethics approval and consent to participate

This retrospective study involving human data was in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The Human Investigation Committee (IRB) of Shenzhen

University General hospital approved this study. Informed consent was obtained from all individual participants included in the study

Consent to publish

The authors affirm that human research participants provided informed consent for publication of the images in Figure(s) 1 and 3.

Availability of data and materials

The patients' data were collected in the Shenzhen University General hospital. The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Funding

This study was supported by National Natural Science Foundation of China (81970761), Shenzhen Major Project of Fundamental Research (JCYJ20200109114233670), Sanming Project of Medicine in Shenzhen (SZSM201911011), Key Research and Development Program of Guangdong Province (2020B0909020002) and Natural Science Foundation of Guangdong Province (2020A1515010726).

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Jianzhou Luo, Kai Yang, Zili Yang, Chunguang Duan, Jiayi Chen and Zhengji Huang. The first draft of the manuscript was written by Jianzhou Luo, and was revised by Zhenjuan Luo, Huiren Tao and Tailin Wu. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Acknowledgements

Not applicable.

References

1. Ward MM, Learch TJ, Gensler LS, Davis JC Jr, Reveille JD, Weisman MH. Regional radiographic damage and functional limitations in patients with ankylosing spondylitis: differences in early and late disease. Arthritis Care Res. 2013;65(2):257–65.
2. El Maghraoui A. Extra-articular manifestations of ankylosing spondylitis: prevalence, characteristics and therapeutic implications. Eur J Intern Med. 2011;22(6):554–60.

3. Jalai CM, Cruz DL, Diebo BG, Poorman G, Lafage R, Bess S, Ramchandran S, Day LM, Vira S, Liabaud B, et al. Full-Body Analysis of Age-Adjusted Alignment in Adult Spinal Deformity Patients and Lower-Limb Compensation. Spine (Phila Pa 1976). 2017;42(9):653–61.
4. Qian BP, Jiang J, Qiu Y, Wang B, Yu Y, Zhu ZZ. The presence of a negative sacral slope in patients with ankylosing spondylitis with severe thoracolumbar kyphosis. J Bone Joint Surg Am. 2014;96(22):e188.
5. Kim KT, Park DH, Lee SH, Lee JH. Results of Corrective Osteotomy and Treatment Strategy for Ankylosing Spondylitis with Kyphotic Deformity. Clin Orthop Surg. 2015;7(3):330–6.
6. Shah AA, Lemans JV, Zavatsky J, Agarwal A, Kruyt MC, Matsumoto K, Serhan H, Agarwal AK, Goel V. **Spinal Balance/Alignment - Clinical Relevance and Biomechanics**. J Biomech Eng 2019.
7. Lee KH, Kim KT, Kim YC, Lee JW, Ha KY. **Radiographic findings for surgery-related complications after pedicle subtraction osteotomy for thoracolumbar kyphosis in 230 patients with ankylosing spondylitis**. Journal of neurosurgery Spine 2020:1–7.
8. Kim YJ, Bridwell KH, Lenke LG, Cheh G, Baldus C. Results of lumbar pedicle subtraction osteotomies for fixed sagittal imbalance: a minimum 5-year follow-up study. Spine (Phila Pa 1976). 2007;32(20):2189–97.
9. Qian BP, Jiang J, Qiu Y, Wang B, Yu Y, Zhu ZZ. Radiographical predictors for postoperative sagittal imbalance in patients with thoracolumbar kyphosis secondary to ankylosing spondylitis after lumbar pedicle subtraction osteotomy. Spine (Phila Pa 1976). 2013;38(26):E1669–75.
10. Schwab F, Patel A, Ungar B, Farcy JP, Lafage V. Adult spinal deformity-postoperative standing imbalance: how much can you tolerate? An overview of key parameters in assessing alignment and planning corrective surgery. Spine (Phila Pa 1976). 2010;35(25):2224–31.
11. Schwab FJ, Blondel B, Bess S, Hostin R, Shaffrey CI, Smith JS, Boachie-Adjei O, Burton DC, Akbarnia BA, Mundis GM, et al. Radiographical spinopelvic parameters and disability in the setting of adult spinal deformity: a prospective multicenter analysis. Spine (Phila Pa 1976). 2013;38(13):E803–12.
12. Huang JC, Qian BP, Qiu Y, Wang B, Yu Y, Qiao M. What is the optimal postoperative sagittal alignment in ankylosing spondylitis patients with thoracolumbar kyphosis following one-level pedicle subtraction osteotomy? Spine J. 2020;20(5):765–75.
13. Schwab FJ, Patel A, Shaffrey CI, Smith JS, Farcy JP, Boachie-Adjei O, Hostin RA, Hart RA, Akbarnia BA, Burton DC, et al. Sagittal realignment failures following pedicle subtraction osteotomy surgery: are we doing enough?: Clinical article. J Neurosurg Spine. 2012;16(6):539–46.
14. Rose PS, Bridwell KH, Lenke LG, Cronen GA, Mulconrey DS, Buchowski JM, Kim YJ. Role of pelvic incidence, thoracic kyphosis, and patient factors on sagittal plane correction following pedicle subtraction osteotomy. Spine (Phila Pa 1976). 2009;34(8):785–91.
15. Kiaer T, Gehrchen M. Transpedicular closed wedge osteotomy in ankylosing spondylitis: results of surgical treatment and prospective outcome analysis. Eur Spine J. 2010;19(1):57–64.
16. Willems KF, Slot GH, Anderson PG, Pavlov PW, de Kleuver M. Spinal osteotomy in patients with ankylosing spondylitis: complications during first postoperative year. Spine (Phila Pa 1976).

2005;30(1):101–7.
17. Xu H, Zhang Y, Zhao Y, Zhang X, Xiao S, Wang Y. Radiologic and clinical outcomes comparison between single- and two-level pedicle subtraction osteotomies in correcting ankylosing spondylitis kyphosis. Spine J. 2015;15(2):290–7.
18. Wang T, Zhao Y, Liang Y, Zhang H, Wang Z, Wang Y. Risk factor analysis of proximal junctional kyphosis after posterior osteotomy in patients with ankylosing spondylitis. J Neurosurg Spine. 2018;29(1):75–80.
19. Hu J, Qian BP, Qiu Y, Wang B, Yu Y, Zhu ZZ, Jiang J, Mao SH, Qu Z, Zhang YP. Can acetabular orientation be restored by lumbar pedicle subtraction osteotomy in ankylosing spondylitis patients with thoracolumbar kyphosis? Eur Spine J. 2017;26(7):1826–32.
20. Wang T, Zhao Y, Zheng G, Wang Y, Wang C, Wang Z, Wang Y. Can pelvic tilt be restored by spinal osteotomy in ankylosing spondylitis patients with thoracolumbar kyphosis? A minimum follow-up of 2 years. J Orthop Surg Res. 2018;13(1):172.
21. Wei HY, Dong CK, Zhu YT, Zhou J, Yi P, Yang F, Tan MS. A modified posterior wedge osteotomy with interbody fusion for the treatment of thoracolumbar kyphosis with Andersson lesions in ankylosing spondylitis: a 5-year follow-up study. Chin Med J (Engl). 2020;133(2):165–73.

Figures

Figure 1

Illustration of parameters measurements. GK: the angle between the superior endplate of the maximally tilted upper-end vertebra and the inferior endplate of the maximally tilted lower-end vertebra; LL: the cobb angle from L1 upper endplate to S1 upper endplate; SVA, the distance between the C7 plumb line and the posterior–superior corner of S1; TPA: the angle between the line from the center of T1 vertebral body to the center of femoral head axis and the line from the center of S1 upper endplate to the center of femoral head axis; PT: the angle between the vertical line and the line from the center of S1 upper endplate to the center of femoral head axis; PI: the angle between the perpendicular line to the S1 upper endplate and the line from the center of S1 upper endplate to the center of femoral head axis; SS: the angle between S1 upper endplate and the horizontal line; OVA: the angle between the lower end plate of the osteotomized vertebra and the upper end plate of the cranial adjacent vertebra.

Figure 2

Receiver-operating characteristic (ROC) curve for determining the cutoff point of the preoperative TPA (a), preoperative PI-LL (b), preoperative SVA (c) and postoperative SVA (d), with an area under the curve (AUC), a sensitivity and a false-positive rate (1-specificity). TPA, T1 pelvic angle; PI-LL, PI minus LL value; SVA, sagittal vertical axis.

Figure 3

A 46-year-old man developed thoracolumbar kyphosis secondary to AS for 15 years. (a) Preoperatively, the patient presented a thoracolumbar kyphosis and sagittal imbalance with TPA = 29.3° (<40.9°), PI − LL = 18.7° (<32.5°), and SVA = 10.1 cm (<13.7 cm), who met no threshold value of the preoperative predictors and was predicted a good sagittal realignment after one-level 3-column osteotomy; (b) After an osteotomy on L3, the kyphosis was corrected and the sagittal alignment was restored properly with the SVA of 1.7 cm (< 7.4 cm), which was less than the optimal postoperative SVA; (c) At the follow-up of 33 months, the patient displayed a maintained correction and a good sagittal alignment with the SVA of 1.7 cm (sagittal balance), which was consistent with the result of the prediction with preoperative predictors.