Clinical Outcomes of S2 Alar-Iliac (S2AI) Screw Technique in The Treatment of Severe Spinal Sagittal Imbalance: A Retrospective 2-Year Follow-Up Study

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Research Article

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Abstract

Background

The treatment of adult spinal deformity (ASD) remains a significant challenge, especially in elderly patients. This study aimed to evaluate the outcomes of the S2AI screw technique in the treatment of severe spinal sagittal imbalance with a minimum 2-year follow-up.

Methods

From January 2015 to December 2018, 23 patients with severe degenerative thoracolumbar kyphosis who underwent placement of S2AI screws for long segment fusion were retrospectively reviewed. Patients were divided into group A (no mechanical complications, 13 cases) and group B (with mechanical complications, 10 cases) according to the occurrence of mechanical complications at the last follow-up. Radiographic parameters were compared between groups preoperatively, 1 month postoperatively, and at the last follow-up. Risk factors for mechanical complications were analyzed.

Results

The incidence of mechanical complications was 43.5%, and the revision rate was 17.4%. At 1 month postoperatively, sagittal correction was better in group A than in group B ($P<0.05$). The lumbar lordosis (LL), pelvic incidence minus lumbar lordosis (PI-LL), T1 pelvic angle (TPA), and sagittal vertical axis (SVA) of both groups at the last follow-up were significantly different from corresponding values at 1 month postoperatively ($P<0.05$), and the sagittal correction was partially lost. Pearson correlation analysis revealed that the occurrence of mechanical complications was associated with sacral slope (SS), LL, PI-LL, and global alignment and proportion (GAP) score at 1 month postoperatively.

Conclusion

A high incidence of mechanical complications was observed in long-segment corrective surgery with the S2AI screw technique for severe spinal sagittal imbalance. Inadequate sagittal correction is a risk factor for the development of mechanical complications.

Introduction

The number of elderly patients with spinal deformities is increasing with the growth in the aging population, with a reported incidence rate of 60%.[1] Over the past decade, spine surgeons have recognized the importance of restoring sagittal balance for the treatment of spinal deformities given the significant relationship between sagittal balance and health-related quality of life.[2, 3] Patients with severe spinal sagittal imbalance may experience back pain and restrictions in daily activities. Moreover, a recent study reported an incidence of depression of 40.6% in patients with severe imbalances.[4] However, the treatment of spinal deformities remains challenging. Complication rates are high when long-segment posterior corrective surgery for spinal deformity ends at S1,[5] and long-term follow-up assessments have indicated that the rate of pseudarthrosis may be as high as 24%.[6]

In 2007, Sponseller and Kebaish[7] first reported the sacral-2 alar iliac (S2AI) screw technique. Biomechanical test results of long-segment fixation revealed that the S2AI screw technique significantly reduced the range of motion of flexion, extension, lateral flexion, rotation, and stress on the S1 screw.[8] Indications for this technique include long segment (≥ 5 vertebrae) spinal surgery ending at the sacrum, especially spinal corrective surgery, including degenerative scoliosis, rigid kyphosis with sagittal imbalance, and iatrogenic flat back deformity.[9] Although the clinical application of the S2AI screw technique is growing, relevant literature regarding this technique is scarce. The purpose of this study was to observe the outcomes and complications of the S2AI screw technique in the treatment of elderly patients with severe spinal sagittal imbalance.

Methods

Study Participants

Patients with severe degenerative thoracolumbar kyphosis who underwent long-segment corrective surgery in our hospital between January 2015 and December 2018 were retrospectively reviewed. All patients were diagnosed with "sagittal imbalance syndrome" based on medical history and physical and imaging examinations. The inclusion criteria were as follows: (1) the patient had typical symptoms of spinal sagittal imbalance, the location of the pain was consistent with kyphotic segments, the trunk exhibited a clear forward lean when standing and walking; (2) PI-LL>30°; (3) structural kyphosis confirmed on dynamic radiographs or extensive multifidus and erector spinal muscle atrophy and fatty infiltration confirmed as myogenic kyphosis on magnetic resonance imaging (MRI); (4) kyphosis was clearly aggravated during activities; (5) combined scoliosis, lumbar disc herniation, lumbar spinal stenosis, lumbar spondylolisthesis, or old vertebral compression fractures; (6) postural kyphosis caused by nerve compression was excluded; and (7) distal fixation extended to the pelvis using the S2AI technique. The exclusion criteria were as follows: (1) failure to complete the 2-year follow-up or incomplete data; (2) cervical spondylosis or cervical deformity; (3) infection, tumor, metabolic bone disease, or abnormal blood coagulation.

Before surgery, the patients underwent lumbar radiography, full-length spine X-ray, and thoracolumbar MRI examinations. At follow-up, the patients underwent lumbar X-ray and full-length spine X-ray examinations. Visual analog scale (VAS) score, Oswestry disability index (ODI) score, and type of complications were recorded. Computed tomography (CT) and MRI were performed as needed. This study was approved by the Ethics Committee of Peking University First Hospital (No. 2021-149). Written informed consent was obtained from all participants. All methods were carried out in accordance with relevant guidelines and regulations.

A total of 23 patients were recruited, comprising 2 men and 21 women (average age: 68.0±6.5 years, range: 60-84 years). The number of fused segments was 9.1±2.4, and the follow-up time was 32.2±6.2 months. Based on the occurrence of postoperative mechanical complications, the patients were divided into group A (no mechanical complications, n=13) and group B (with mechanical complications, n=10). No significant differences were observed in sex, age, body mass index, bone mineral density, fixed segment, operation time, method of osteotomy, intraoperative bleeding, and follow-up time between the two groups (P>0.05). The follow-up period for all patients was > 2 years. General patient information is presented in Table 1.

Table 1. General patient information

	All patients (n=23)	Group A (n=13)	Group B (n=10)	P
Follow-up period (months)	32.2±6.2	32.9±7.3	31.3±4.5	0.564
Sex (male: female)	2:21	2:11	0:10	0.486
Age (years)	68.0±6.5	68.5±6.3	67.5±7.0	0.733
BMI (kg/m^2)	25.0±3.7	23.9±3.4	26.5±3.7	0.097
BMD (T value)	-2.20±0.68	-2.18±0.67	-2.21±0.73	0.926
Number of fused segments	9.1±2.4	9.6±2.8	8.4±1.7	0.235
Operation time (minutes)	331±73	336.9±71.8	325.0±78.6	0.709
Method of osteotomy, (PSO: MPO)	7:16	3:10	4:6	0.650
Intraoperative bleeding (mL)	854±445	815.4±433.7	905.0±477.5	0.643

Abbreviations: BMI, body mass index; BMD, bone mineral density; PSO, pedicle subtraction osteotomy; MPO, multiple segment Ponte osteotomy.

Surgical Procedure

The paravertebral muscles were dissected using a conventional posterior approach, and the distal end of the incision reached the level of the S2 spinous process. S2AI screws were inserted during the navigation. The midpoint of the line connecting the lateral edges of the S1 and S2 foramina was selected as the entry point for the S2AI screw. The pedicle probe was directed 30-40° laterally in the axial plane and 20-30° caudally in the sagittal plane. When the pedicle probe penetrated the sacroiliac joint and entered the ilium, a ball-tip probe was used to confirm the integrity of the anterior, posterior, superior, and inferior walls of the ilium. The diameter and length of the S2AI screws were 7.5 mm and 60-80 mm, respectively.

Intraoperative CT was performed to confirm screw position. Seven patients underwent pedicle subtraction osteotomy (PSO) at the apical vertebrae and multi-segmental Ponte osteotomy, while the remaining patients underwent multi-segmental Ponte osteotomy (MPO). Decompression was performed for segments with spinal stenosis, lumbar disc herniation, or lumbar spondylolisthesis, and interbody fusion was performed if necessary. Bone grafting was routinely performed.

Data Collection and Radiographic Assessment

Types of complications were recorded. Patients' VAS and ODI scores preoperatively and at the last follow-up were recorded. Anteroposterior and lateral full-length spine radiographs were obtained preoperatively, at 1 month postoperatively, and at the last follow-up. Surgimap 2.0 software (Medicrea, New York) was used to measure the radiographic parameters, including pelvic incidence (PI), pelvic tilt (PT), SS, LL, thoracic kyphosis (TK), thoracolumbar kyphosis (TLK), TPA, SVA, Cobb angle (CA), and C7 plumb line - center sacral vertical line (C7PL-CSVL). GAP score[10] was calculated 1 month post-operatively.

Data and Statistical Analysis

Statistical analyses were performed using SPSS26.0 (IBM, Armonk, NY, USA). Basic descriptive analysis included Student's t test and Fisher exact test for continuous and categorical variables, respectively. Results are presented as mean (+standard deviation) for continuous variables and n for categorical variables. Preoperative and postoperative parameters were compared using a paired sample t-test. Groups A and B were compared using an independent sample t-test. The relationships between mechanical complications and parameters were evaluated using Pearson correlation analysis. Statistical significance was defined as a P value<0.05.

Results

Complications

One patient presented with a left foot dorsal flexor strength of grade 0 postoperatively and was treated with methylprednisolone on the same day. On the first postoperative day, surgical assessment revealed that the ligamentum flavum of the L4/5 segment was hypertrophic, and the L4/5 segment was decompressed. Postoperatively, the patient was administered neurotrophic therapy and rehabilitation exercises. At 6 months postoperatively, the left tibialis anterior muscle strength had recovered to grade IV.

Two patients underwent revision surgery due to proximal junctional failure (PJF); one case involved proximal screw cap displacement, and spinal canal stenosis caused lower limb muscle weakness. One patient underwent revision surgery due to broken bilateral connecting rods (combined with loosening of the distal screws). The revision rate was 17.4%. One case of broken rod, one case of distal screw loosening, five cases of proximal junctional kyphosis (PJK), and one case of superficial wound infection were observed, all of which were treated conservatively. Mechanical complications were observed in 10 patients, with an incidence rate of 43.5%.

Functional Outcomes by Group

In groups A and B, preoperative VAS scores were 7.5±1.9 and 7.1±1.1, respectively (P=0.573), and preoperative ODI scores were 64.2±7.0 and 66.5±10.3, respectively (P=0.523). In groups A and B, VAS scores at the last follow-up were 2.2±0.9 and 3.3±1.2, respectively (P=0.014), and ODI scores at the last follow-up were 28.6±7.8 and 49.5±9.6, respectively (P<0.01). At the last follow-up, the VAS and ODI scores were significantly improved compared with preoperative scores in both groups (P<0.01).

Radiographic Outcomes by Group

The radiographic parameters obtained preoperatively, postoperatively, and at the last follow-up are summarized in Table 2. Nine patients in group A and eight patients in group B presented with degenerative scoliosis; this difference was not statistically significant (P=0.581). Group A had greater preoperative CA compared to group B (34.9±9.0° vs 21.5±12.2°, P=0.020). Compared with preoperative values, CA was significantly improved at 1 month postoperatively and at the last follow-up in both groups (P<0.01). There were no significant differences in CA and C7PL-CSVL between the two groups at 1 month and at the last follow-up (P>0.05).

Preoperative LL was higher in group A than in group B (12.8±11.6° vs -0.9±10.2°, P<0.01). No significant differences were observed in other preoperative sagittal parameters between groups (P>0.05). At 1 month postoperatively, the PI of group B increased by 3.7±3.9° (P=0.015). No significant changes were noted in TK and TLK in both groups. In contrast, PT, SS, LL, PI-LL, TPA, and SVA were significantly improved compared with preoperative values. Group A had higher SS (28.8±8.5° vs 20.2±8.6°, P=0.027) and LL (39.6±6.7° vs 24.4±9.9°, P<0.01), and lower PI-LL (11.4±11.3° vs 22.7±12.5°, P=0.035) and GAP score (6.9±2.0 vs 10.9±2.4, P<0.01) compared to values in group B. At the last follow-up, significant differences were observed in SS, LL, PI-LL, and SVA between the two groups (P<0.05). Compared with values at 1 month postoperatively, LL decreased by 4.4±4.7°, PI-LL increased by 5.9±5.6°, TPA increased by 5.4±6.1°, and SVA increased by 3.1±4.7 cm in group A; whereas LL decreased by 8.1±7.3°, PI-LL increased by 7.4±10.2°, TPA increased by 5.8±7.8°, and SVA increased by 4.5±5.7 cm in group B; these changes were not significantly different between groups (P>0.05). Pearson correlation analysis revealed that the correlation coefficients between mechanical complications and SS, LL, PL-LL, and GAP scores at 1 month postoperatively were -0.462 (P=0.027), -0.692 (P<0.01), 0.442 (P=0.035), and 0.693 (P<0.001), respectively. Based on the occurrence of mechanical complications, ROC curve analysis of SS, LL, PL-LL, and GAP scores at 1 month postoperatively revealed areas under the curve were 0.762 (P=0.035), 0.896 (P<0.01), 0.754 (P=0.041), and 0.885 (P<0.01), respectively, and the best cutoff values were 24.1°, 32.75°, 12.0°, and 9.5, respectively.

Table 2. Comparison of radiographic parameters preoperatively, 1 month postoperatively, and at final follow-up

	Preoperation		1 month postoperation		Final follow-up	
	Group A (n=13)	Group B (n=10)	Group A (n=13)	Group B (n=10)	Group A (n=13)	Group B (n=10)
PI (°)	49.8±12.3	43.4±9.9	51.1±10.7	47.1±11.3□	52.5±10.1	46.4±11.1□
PT (°)	35.6±9.3	33.6±11.6	22.3±11.1□	26.9±10.4□	25.1±11.8□	28.1±11.9□
SS (°)	14.2±9.4	9.8±8.5	28.8±8.5□	20.2±8.6□□	27.4±8.1□	18.3±6.4□□
LL (°)	12.8±11.6	-0.9±10.2□	39.6±6.7□	24.4±9.9□□	35.2±8.5□□	16.3±9.8□□□
PI-LL (°)	37.0±5.4	44.3±14.3	11.4±11.3□	22.7±12.5□□	17.3±9.6□□	30.0±12.1□□□
TK (°)	17.9±15.4	13.6±19.6	22.5±11.6	20.6±8.7	27.9±10.3□□	23.2±14.7
TLK (°)	18.8±21.4	18.5±19.8	13.8±11.1	17.6±8.6	16.4±13.0	19.6±8.9
TPA (°)	33.6±7.8	36.2±17.2	18.7±10.0□	24.5±10.5□	24.2±10.5□□	30.3±11.2□
SVA (cm)	6.8±5.5	11.3±5.9	2.7±3.7□	5.8±4.7□	5.8±3.1□	10.3±3.4□□
GAP score	-	-	6.9±2.0	10.9±2.4□	-	-
Scoliosis	Group A (n=9)	Group B (n=8)	Group A (n=9)	Group B (n=8)	Group A (n=9)	Group B (n=8)
CA (°)	34.9±9.0	21.5±12.2□	18.6±7.7□	13.5±7.8□	18.9±8.2□	13.5±8.9□
C7PL-CSVL (cm)	2.9±3.0	2.4±2.0	1.2±0.7	1.8±1.7	0.8±0.4	1.1±0.5

Abbreviations: PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; LL, lumbar lordosis; PI-LL, pelvic incidence minus lumbar lordosis; TK, thoracic kyphosis; TLK, thoracolumbar kyphosis; TPA, T1 pelvic angle; SVA, sagittal vertical axis; GAP, global alignment and proportion; CA, Cobb angle; C7PL-CSVL, C7 plumb line - center sacral vertical line.

□Compared with group A at the same time, $p<0.05$

□Compared with preoperatively, $p<0.05$

□Compared with 1 month postoperatively, $p<0.05$

Case Presentation

Figure 1 depicts the mechanical complications of distal screw loosening in group B. The 66-year-old patient was diagnosed with degenerative kyphoscoliosis deformity and underwent T6-ilium correction and fusion. The sagittal correction was unsatisfactory. At 24 months follow-up, lumbar anteroposterior and lateral radiographs and lumbar CT indicated loosening of the S2AI screws.

Discussion

Long-segment corrective surgery is associated with a high complication rate. Scheer et al.[11] analyzed 138 patients aged 63.3±11.5 years with severe sagittal imbalance (PI-LL≥30°) and reported a postoperative complication rate of 74.6%, of which internal fixation-related complications constituted 30.4%. In our study, 10 patients (43.5%) presented with mechanical complications, and the revision rate was 17.4%. This could be associated with advanced age, severe preoperative sagittal imbalance, obesity, low bone density, and/or other factors. PJK was the most common complication, with an incidence of 21.7%. Previously reported risk factors for PJK include advanced age, damage to the posterior tension band, combined anterior and posterior surgery, fusion to the sacrum/pelvis, choice of upper fixed vertebrae, rod material, insufficient or excessive correction, and sarcopenia.[12] Unoki et al.[13] analyzed patients with long-segment corrective surgery and reported an incidence of PJK of 23.3%, 30.4%, and 29.2% for distal fixation to L5, the sacrum, and to the pelvis with S2AI screws, respectively. No significant difference between techniques was observed, suggesting that the S2AI screw technique did not increase the risk of PJK. At the last follow-up, two patients (8.7%) developed symptoms of S2AI screw loosening in our study, which manifested as sacroiliac joint pain. Both patients were treated conservatively. Their BMDs were -2.91 and -2.84, respectively, which were considered osteoporotic. In the literature, the breaking rate of S2AI screws is reported to be 0.0-1.0%, and 7.8-10.4% of patients with S2AI screws demonstrated visible translucent bands around the screws on imaging at more than 1 year follow-up[14,15], which was consistent with our findings. Further, two patients presented with rod breakage. Because elderly patients often have osteoporosis, we used a titanium alloy rod with a 5.5-cm diameter rather than a 6.0-cm diameter in order to reduce the risk of PJK and stress at the junction of the bone and screw; nevertheless, this reduced rod strength. Therefore, we recommend adding satellite rods to the kyphotic apex area to reduce the risk of rod breakage.

Compensation in patients with sagittal imbalance may be achieved via various mechanisms, including pelvic retroversion, reduction of thoracic kyphosis, hip hyperextension, and knee flexion. In this study, PT was greater than SS preoperatively, confirming significant pelvic retroversion in both groups. At 1 month postoperatively, PT was decreased, SS was increased, and pelvic retroversion improved in both groups. No significant differences were observed in PI, PT, and SS between 1 month postoperatively and at the last follow-up, suggesting that the S2AI screw technique maintained the relative position of the pelvis effectively. Accordingly, for patients with sagittal imbalance and severe retroversion of the pelvis, especially those with lumbosacral muscle atrophy, we recommend using S2AI screws for sacral pelvic fixation if long-segment corrective surgery is performed.

We observed that the PI increased by 3.7±3.9° in group B at 1 month postoperatively. In this regard, S2AI screws may stabilize the sacroiliac joint and change the morphology of the pelvis, thus changing the PI. Ishida et al. [16] used S2AI screws for pelvic fixation in 46 adult patients aged 61.5±10.7 years with spinal deformity. In their study, the preoperative PI was 63.4±12.3°, and the postoperative PI decreased by 6.0±12.5°. Wei et al.[17] reported that the use of S2AI screws for pelvic fixation reduced PI after surgery in patients with high PI (PI≥60°); conversely, PI increased after surgery in patients with normal or low PI (PI<60°). In this study, preoperative PI was 43.4±9.9° and the degree of kyphosis was severe in group B, which could partly explain the increase in postoperative PI.

Although postoperative VAS and ODI scores in both groups were significantly improved compared with preoperative values, VAS and ODI scores were significantly better in group A than in group B at the last follow-up. This indicates that the occurrence of mechanical complications significantly worsens surgical outcomes. Preoperatively, LL in group B was -0.9±10.2°, indicating a kyphotic curve, whereas that in group A was 12.8±11.6°, with a significant difference between groups. As patients in group B had more severe preoperative sagittal imbalance, greater correction was required during surgery. This suggests that the risk of postoperative mechanical complications is higher in patients with severe sagittal imbalance and lumbar kyphosis. Therefore, sagittal alignment should be carefully evaluated preoperatively, and a detailed surgical plan should be designed to correct this imbalance.

At 1 month postoperatively, SS, LL, and PI-LL in group B were 20.2±8.6°, 24.4±9.9°, and 22.7±12.5°, respectively, indicating that sagittal reconstruction was insufficient. In group A, SS, LL, and PI-LL were 28.8±8.5°, 39.6±6.7°, and 11.4±11.3°, respectively, indicating that the sagittal alignment was significantly better than that in group B. Pearson correlation analysis demonstrated that mechanical complications were significantly associated with SS, LL, and PL-LL at 1 month postoperatively, highlighting the importance of restoring lumbar lordosis. In our study, the best cutoff values of SS, LL, and PI-LL were 24.1°, 32.75°, and 12.0°, respectively. SS represents lower lumbar lordosis, and normal lower lumbar lordosis accounts for approximately two-thirds of the total lordosis curve. Therefore, the recovery of L4-S1 lordosis during operation is important. In the L4/5 and L5/S1 segments, we opted to release and distract the intervertebral space and subsequently placed a cage with a large lordosis angle to restore the local lordosis angle. Based on our experience, we propose that for the upper lumbar segments, lordosis can be reconstructed via intervertebral space release and posterior multi-segment Ponte osteotomy, whereas for areas with large local kyphosis, PSO should be considered.

At the last follow-up, LL was significantly reduced, and PI-LL, TPA, and SVA were significantly increased in both groups. Patients underwent long-segment fixation, and the pelvis was in a relatively stable position. Therefore, the loss of sagittal correction was predominantly caused by the reduction in lumbar lordosis during the follow-up period. LL decreased by 4.4±4.7° in group A and by 8.1±7.3° in group B, but the change in LL was not significantly different between the two groups ($P>0.05$). In group B, the restoration of LL was insufficient at 1 month postoperatively, and the further reduction in LL may have partly underpinned the occurrence of mechanical complications. Nakazawa et al.[18] and Im et al.[19] reported that insufficient restoration of the PI-LL could lead to progressive worsening of sagittal imbalances after long-segment orthopedic surgery with sacropelvic fixation. Therefore, we should also consider the reduction of lumbar lordosis in the preoperative planning.

The average age of the patients in our study was 68.0±6.5 years. As natural degeneration of the spine is accompanied by an increase in positive sagittal balance, age is a key factor affecting sagittal alignment. In elderly patients with sagittal imbalance, the intervertebral discs, articular processes, paravertebral ligaments, muscles, and other structures have adapted to a positive balance for a long time. Immediate correction to the "ideal" state after surgery did not seem to improve clinical outcomes, but increased the incidence of mechanical complications.[20] Lafage et al.[21] emphasized that for elderly patients aged over 75 years, the ideal sagittal parameters were PT=28.5°, PI-LL=16.7°, and SVA=7.8 cm. In our study, PT, PI-LL, and SVA in group A were 25.1±11.8°, 17.3±9.6°, and 5.8±3.1 cm at the last follow-up. According to the sagittal modifiers of SRS-Schwab classification,[22] these parameters were classified as positive if 20°≤PT≤30°, 10°≤PI-LL≤20°, and 4 cm≤SVA≤9.5 cm. These results indicated that the sagittal alignment was in a moderate positive balance, and the VAS and ODI scores of the patients were significantly improved. Zhang et al.[23] performed long-segment corrective surgery on 44 patients aged 65.1±2.8 years with spinal deformities and reported that postoperative PI-LL was between 10° and 20°, which was similar to the results of our study. As such, we did not consider it necessary to perform corrections to the state of LL = PI ± 9° in elderly patients.

The GAP score was used to predict mechanical complications in patients undergoing long-segment corrective surgery for adult spinal deformities. The GAP score includes five categories: relative pelvic version, relative lumbar lordosis, lordosis distribution index, relative spinopelvic alignment, and age. The GAP score enables the calculation of the ideal sagittal parameters based on PI and emphasizes the significance of lordosis distribution in the lumbar spine. The PI value influences the morphology of the spine and pelvis. Patients with a small PI have less sagittal compensation ability, and the requirements for reconstruction of lumbar lordosis are stricter.[24] In our study, mechanical complications were significantly correlated with GAP scores. The average GAP scores were 6.9±2.0 and 10.9±2.4 in groups A and B, respectively. In a study by Yilgor et al.,[10] the ideal GAP score after surgery was ≤4, and the incidence of mechanical complications at 7 points and 11 points or above was 72.7% and 100%, respectively. These results are discordant with our findings, which could be related to individual differences, such as age and degree of deformity. Ham et al.[25] retrospectively evaluated 84 patients aged 70.5 ± 7.7 years old with severe sagittal imbalances and reported that the area under the curve for predicting mechanical complications based on the GAP score was 0.839, similar to our study. Moreover, 82% of patients with mechanical complications had a GAP score ≥ 7. For elderly patients with severe sagittal imbalance of the spine, a postoperative GAP score ≥ 10 indicated a high risk of mechanical complications, which should be carefully monitored during follow-up.

This study has several limitations. First, it was a retrospective study and lacked a randomized control group with distal fixation to the S1 or ilium. Second, the sample size was small, and selection bias may have occurred. Due to the lack of a unified standard for evaluating the strength of the lower back muscles, this study did not include muscle-associated factors. Further, full-length radiographs of the lower extremities were lacking; hence, the compensation status of the hip and knee joints could not be analyzed in detail. At present, there is a paucity of studies discussing the surgical treatment of elderly patients with severe kyphosis, and long-term follow-up with a large sample is warranted to confirm the effects of long-segment corrective surgery using the S2AI screw technique.

Conclusion

The incidence of mechanical complications in long-segment corrective surgery with the S2AI screw technique for severe spinal sagittal imbalance remains high. Inadequate sagittal correction is a risk factor for the development of mechanical complications. Our findings suggest that the ideal sagittal balance for elderly patients is LL>30° and 10°≤PI-LL≤20 °. A postoperative GAP score of ≥ 10 indicates a high risk of mechanical complications. Further studies are needed to determine the ideal postoperative sagittal parameters for elderly patients with severe kyphosis

List Of Abbreviations

S2AI: S2 Alar-Iliac

ASD: adult spinal deformity

MRI: Magnetic resonance imaging

CT: Computed tomography

VAS: Visual analog scale

ODI: Oswestry disability index

BMI: Body mass index

BMD: Bone mineral density

PSO: Pedicle subtraction osteotomy

MPO: Multiple segment Ponte osteotomy

PI: Pelvic incidence

PT: Pelvic tilt

SS: Sacral slope

LL: Lumbar lordosis

TK: Thoracic kyphosis

TLK: Thoracolumbar kyphosis

TPA: T1 pelvic angle

SVA: Sagittal vertical axis

CA: Cobb angle

C7PL-CSVL: C7 plumb line - center sacral vertical line

GAP: Global alignment and proportion

PJF: adult spinal deformity

PJK: proximal junctional kyphosis

Declarations

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Availability of data and materials

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

Authors' contributions

YZ and BYX contributed equally to this work.

YZ and BYX wrote the main manuscript text. YZ, BYX, and LTQ collected the data. LTQ analyzed the data. CDL designed the study and revised the manuscript. ZRY, HLS and SJW edited the manuscript.

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Ethics approval and consent to participate

This retrospective research was approved by the Ethics Committee of Peking University First Hospital (No. 2021-149). Written informed consent was obtained from all participants. All methods were carried out in accordance with relevant guidelines and regulations.

Consent for publication

Not applicable.

Competing interests

No conflict of interest.

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Figures

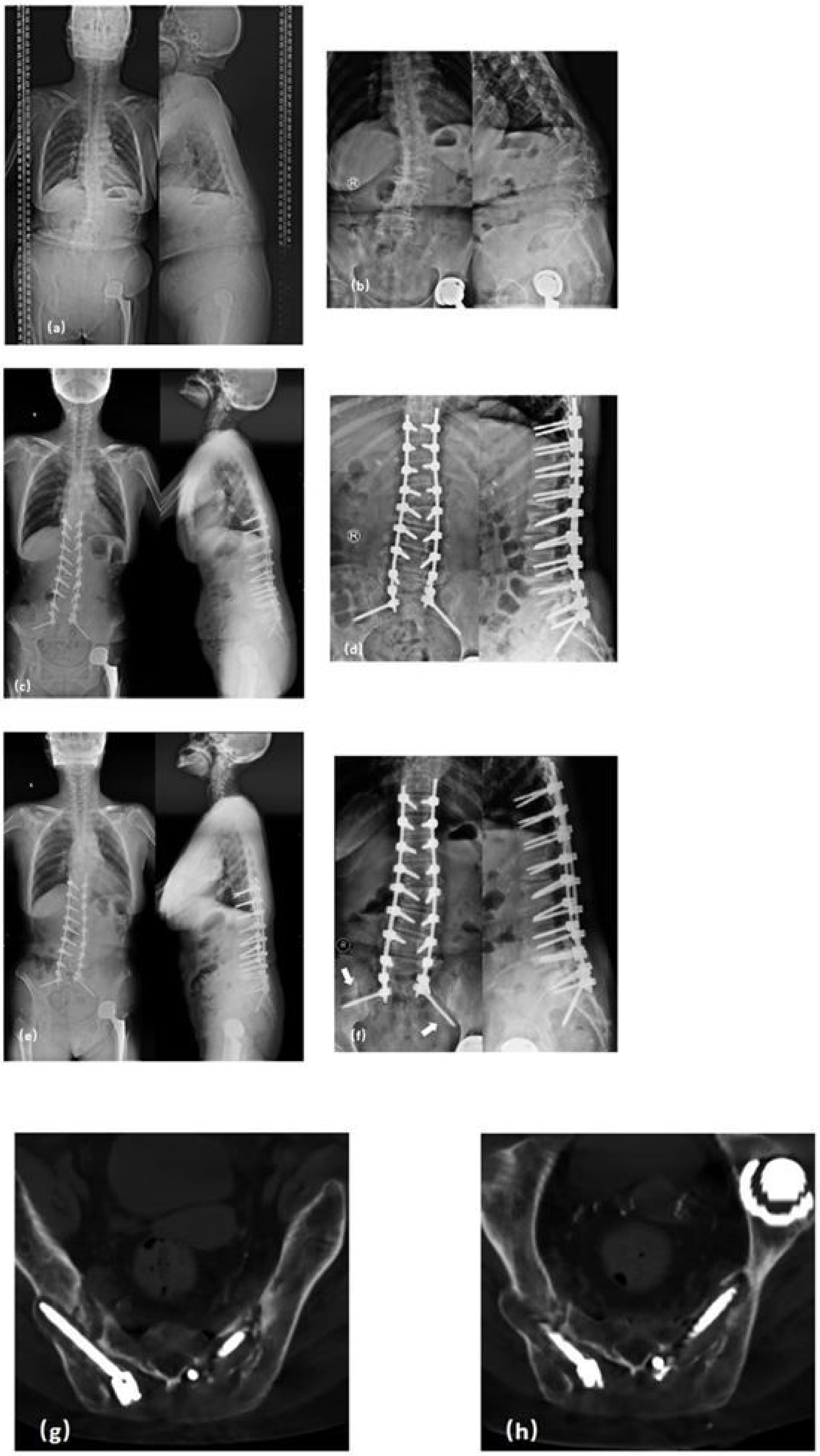

Figure 1

(a) Full-length X-ray of the spine preoperatively demonstrated PI=43.4°, PT=20.1°, SS=23.2°, LL=-7.6°, PI-LL=50.9°, TK=-9.6°, TLK=33.4°, TPA=27.7°, SVA=13.6 cm, CA=37.2°, and C7PL-CSVL=-3.9 cm. The patient's VAS and ODI scores were 8 and 78, respectively. (b) Lumbar anteroposterior and lateral X-rays pre-operatively. (c) Full-length X-ray of the spine at 1 month postoperatively demonstrated PI=49.0°, PT=21.0°, SS=28.0°, LL=17.1°, PI-LL=31.9°, TK =12.9°, TLK=9.5°, TPA=28.9°, SVA=13.2 cm, CA=17.5°, and C7PL-CSVL=-3.8 cm. The sagittal correction was unsatisfactory, and the GAP score was 12. (d) Lumbar anteroposterior and lateral X-rays at 1 month postoperatively. (e) At 24 months follow-up, a full-length X-ray of the spine demonstrated PI=48.2°, PT=24.7°, SS=23.4°, LL=13.3°, PI-LL=34.8°, TK=7.2°, TLK=7.2°, TPA=26.8°, SVA=8.7 cm, CA=20.0°, and C7PL-CSVL=-2.7 cm. The patient's VAS and ODI scores were 6 and 62, respectively. (f) At 24 months follow-up, lumbar anteroposterior and lateral X-rays revealed an obvious radiolucent zone around the S2AI screw (write arrows). (g), (h) CT examination revealed absorption of the bone around the S2AI screws and expansion and thinning of the cortical bone, indicative of S2AI screw loosening.