Radiographic findings for surgery-related complications after pedicle subtraction osteotomy for thoracolumbar kyphosis in 230 patients with ankylosing spondylitis

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OBJECTIVE The purpose of this study was to investigate the rate of and the risk factors for surgery-related complications demonstrated on radiography after pedicle subtraction osteotomy (PSO) for thoracolumbar kyphosis in patients with ankylosing spondylitis (AS).

METHODS The authors retrospectively reviewed the medical records of 230 consecutive patients with thoracolumbar kyphosis due to AS who had undergone 1-level PSO at a single institution in the period from 2010 to 2017. The causes of surgery-related complications were divided into two types: surgical/technical failure and mechanical failure.

RESULTS The patients consisted of 20 women and 210 men, with an average age of 43.4 years. The average follow-up period was 39.0 months. The preoperative sagittal vertical axis was 18.5 ± 69.3 cm, which improved to 4.9 ± 4.6 cm after PSO. Of the 77 patients (33.5%) who experienced minor or major surgery-related complications, 56 had complications related to surgical/technical failure (overall incidence 24.3%) and 21 had complications related to mechanical failure (overall incidence 9.1%). Fourteen patients (6.1%) underwent reoperation. However, among the 77 patients with complications, the rate of revision surgery was 18.2%. The most common radiological complications were as follows: sagittal translation in 24 patients, coronal imbalance in 20, under-correction in 8, delayed union in 8, and distal junctional failure and kyphosis in 8. The most common causes of reoperation were coronal imbalance in 4 patients, symptomatic malposition of pedicle screws in 3, and distal junctional failure in 3. Delayed union was statistically correlated with posterior sagittal translation ($p = 0.007$).

CONCLUSIONS PSO can provide acceptable radiographic outcomes for the correction of thoracolumbar kyphosis in patients with AS. However, a high incidence of surgery-related complications related to mechanical failure and surgical technique can develop. Thorough radiographic investigation before and during surgery is needed to determine whether complete ossification occurs along the anterior and posterior longitudinal ligaments of the spine.

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KEYWORDS ankylosing spondylitis; kyphosis; pedicle subtraction osteotomy; complication; incidence; deformity

DESPITE an emphasis on early recognition and advances in medical treatment for ankylosing spondylitis (AS), severely disabled patients with advanced kyphotic deformities of the thoracolumbar spine are still seen, and definitive surgical correction of their deformity is a major challenge.^{1–3} Restoration of normal sagittal balance is critical, as it leads to improvements in quality of life for AS patients afflicted with thoracolumbar kyphosis. Various surgical procedures to correct sagittal

deformities have been introduced.^{4–7} The most popular surgeries for correction of thoracolumbar kyphosis are pedicle subtraction osteotomy (PSO) and Smith-Petersen osteotomy (SPO). In a systematic review, Liu et al.⁸ reported that both SPO and PSO are effective in correcting kyphotic deformity in AS and have similar risks for most complications.

PSO allows more restoration of lumbar lordosis and reduction of the sagittal vertical axis (SVA) to reposition

ABBREVIATIONS ALL = anterior longitudinal ligament; AS = ankylosing spondylitis; CI = coronal imbalance; DJA = distal junctional angle; DJF = distal junctional failure; DJK = distal junctional kyphosis; LIV = lower instrumented vertebra; PJA = proximal junctional angle; PJF = proximal junctional failure; PJK = proximal junctional kyphosis; PSO = pedicle subtraction osteotomy; SVA = sagittal vertical axis; UIV = upper instrumented vertebra.

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the head over the pelvis, thereby producing good functional results.³ However, PSO is technically demanding and fraught with the risk for neurological deficits. The main causes of neurological complications include residual dorsal bony impingement combined with dual buckling and intraoperative vertebral subluxation.^{9,10} Sagittal translation, a potential complication of PSO, can result in neurological damage. The PSO procedure involves three-column release of the spine, and restricted movement of the hinge on the anterior column, if ruptured, can produce sudden sagittal translation at the osteotomy site. This may be more prominent in the ankylosed and mostly osteoporotic spine observed in patients with AS, and it can dramatically increase the risk for neurological complications.³ However, little is known about the rate of surgery-related complications after PSO for thoracolumbar kyphosis in the AS patient. Therefore, the purpose of this study was to investigate the incidence of and the risk factors for surgery-related complications after PSO for correction of a kyphotic deformity of the thoracolumbar spine in AS patients. To the best of our knowledge, this is the first study to comprehensively evaluate the radiographic findings for surgery-related complications in thoracolumbar kyphosis in AS patients.

Methods

We retrospectively reviewed the medical records of 230 patients with thoracolumbar kyphosis due to AS who had undergone 1-level PSO performed by a single surgeon at one institute in the period from 2010 to 2017. All patients had fixed global sagittal imbalance on a lateral radiograph of the whole spine. However, we excluded patients who had undergone multiple-level osteotomy and posterior vertebral column resection. Indications for surgery were an inability to stand upright in balanced alignment, an inability to maintain a horizontal gaze, compression of the viscera, low-back pain, and a poor cosmetic appearance.

Surgery-related complications were divided into two types: surgical/technical failure and mechanical failure. In addition, cases in which there was under-correction, as compared to the planned osteotomy resection angle seen on intraoperative radiographs, requiring osteotomy at another level, were classified as a surgical failure. Under-correction was defined as a $< 15^\circ$ lordotic angle in an osteotomized level.¹¹ Surgical failures included malposition of pedicle screws, under-correction, sagittal translation, and postoperative coronal imbalance (CI) greater than preoperative CI. Mechanical failure consisted of metallic failure, delayed union or pseudarthrosis, proximal junctional failure (PJF), and distal junctional failure (DJF).

Radiographic Assessment

Preoperative, postoperative, and follow-up radiographic assessments were performed with standing lateral radiography of the whole spine. CI was considered present if the horizontal distance between the C7 plumb line (C7PL) and the central sacral vertical line was > 4 cm lateral to the central sacral vertical line.¹² The correction angle was defined as the angle between the superior endplate of the level above the osteotomy and the inferior endplate of the

level below the osteotomy. Sagittal translation was defined as 2 mm of translation at the osteotomy site in an anterior or posterior direction that was displaced between the lower posterior edge of the cranial vertebra and the lower posterior edge of the caudal vertebra at the osteotomized level.^{10,13} Proximal junctional kyphosis (PJK) and distal junctional kyphosis (DJK) were respectively defined as a proximal or distal junctional angle (PJA or DJA) $\geq 10^\circ$ and at least 10° greater than the preoperative measurement.¹⁴ The PJA was measured as a sagittal Cobb angle between the caudal endplate of the upper instrumented vertebra (UIV) and the cranial endplate of the two suprajacent vertebra (UIV+2). The DJA was defined as a sagittal Cobb angle between the cranial endplate of the lower instrumented vertebra (LIV) and the caudal endplate of the two subjacent vertebra (LIV-2).

Statistical Analysis

Data were analyzed using the statistical software program SPSS version 18.0 for Windows (SPSS Inc.). Fisher's exact test was used to compare categorical variables to analyze the association between delayed union and implantation failure as well as anterior or posterior vertebral subluxation and under-correction. To analyze risk factors for delayed union after PSO, logistic regression analysis was performed. For all statistical tests, a p value < 0.05 was considered significant.

Results

Patient Data

The patients included 20 women and 210 men (mean age 43.4 years, range 21–71 years; Table 1). The average bone mineral density (T-score) was -1.4 ± 1.8 (range -5.6 to 2.8). The mean follow-up period was 39.0 months (range 16–131 months). Twenty-five PSOs were done at the thoracic level and 205 at the lumbar level. The most frequent level of osteotomy was L2 (110 operations [47.8%]), followed by L1 (68 operations [29.6%]). Preoperative SVA was 18.5 ± 69.3 cm (range 7–48 cm), which improved after PSO (4.9 ± 4.6 cm, range -2 to 15 cm).

Surgery-Related Complications

Overall, 77 patients (33.5%) had either minor or major complications due to surgical/technical failure or mechanical failure (Table 2). Fourteen patients (6.1%) underwent reoperation (Table 3). However, among the 77 patients with surgery-related complications, the rate of revision surgery was 18.2%. We analyzed each cause of complications and risk factors for reoperation.

Radiographic Findings of Complications Caused by Surgical/Technical Failure

Fifty-six patients (24.3%) had complications resulting from surgical/technical failure, including malposition of pedicle screws, under-correction, sagittal translation, and CI.

Screw Malposition. While all patients did not undergo postoperative CT evaluation for confirmation of screw position, 4 patients (1.7%) were found to have malpositioned

TABLE 1. Demographic and clinical data for 230 patients with thoracolumbar kyphosis due to AS

Parameter	Value
Age in yrs (range)	43.4 ± 9.4 (21–71)
Sex: M/F	210/20
Bone mineral density: T-score (range)	−1.4 ± 1.8 (−5.6 to 2.8)
Follow-up period in mos (range)	39.0 ± 33.8 (16.0–131.0)
PSO level, no. (%)	
T10	1 (0.4)
T11	2 (0.9)
T12	22 (9.6)
L1	68 (29.6)
L2	110 (47.8)
L3	23 (10.0)
L4	4 (1.7)

screws; 2 of them suffered from radiating pain, while the other 2 showed postoperative motor weakness. Of these 4 patients, 3 underwent screw repositioning, and their neurological symptoms and weakness improved immediately after reoperation. However, the fourth patient, who complained of radiating pain, did not undergo reoperation because the neurological symptoms and pain were improving and the patient did not want to undergo reoperation.

Under-Correction. Eight patients (3.5%) showed under-correction, whose cause may have been a parallel collapse of the osteotomized vertebral column. The postoperative osteotomy resection angle at the PSO site was $0.6^\circ \pm 6.0^\circ$. Of these 8 patients, only 1 underwent revision surgery. In this case, we performed an additional osteotomy with partial PSO at another level after confirming the correction angle on intraoperative radiographs, which showed unsatisfactory intraoperative correction angle results at the osteotomy site. Seven patients did not undergo reoperation even though a sufficient resection osteotomy angle had not been obtained.

Sagittal Translation. Sagittal translation at the osteotomy site developed in 24 patients (10.4%); anterior and posterior sagittal translation developed in 11 and 13 patients, respectively. Neurological deficits developed in 2 patients; thus reoperation was performed. Of the 13 patients with posterior translation, 4 had delayed union, although union was achieved within 12 months for all of them (Fig. 1).

Coronal Imbalance. CI developed in 20 patients (8.7%), and the mean preoperative CI was 39.2 ± 20.9 mm. At the last follow-up, the mean CI was 54.3 ± 15.8 mm. Eleven of the patients with CI whose deformity was not corrected after surgical correction had shown preoperative CI, but 9 patients developed new CI after PSO. Of the 20 patients with CI, 4 of them underwent a rebalancing reoperation.

Radiographic Findings of Complications Caused by Mechanical Failure

Implantation failure, delayed union, and PJFs or DJFs were the sources of complications resulting from mechanical failure in 21 patients (9.1%).

TABLE 2. Post-PSO radiological complications in 77 patients with AS

Radiological Complication	Value
Surgical/technical failure, no. (%)	56 (24.3)
Malposition of pedicle screws, no. (%)	4 (1.7)
Root pain/motor weakness	2/2
Under-correction, no. (%)	8 (3.5)
Postop osteotomy angle at PSO site in $^\circ$	0.6 ± 6.0
Preop kyphotic angle at PSO site in $^\circ$	23.8 ± 6.8
Sagittal translation, no. (%)	24 (10.4)
Ant sagittal translation	11
Pst sagittal translation	13
Delayed union	4
CI	
Preop CI, no. of patients	11
Mean preop CI in mm	39.2 ± 20.9
Postop CI, no. of patients (%)	20 (8.7)
Mean postop CI in mm	54.3 ± 15.8
Newly developed cases, no. of patients	9
Mechanical failure, no. (%)	21 (9.1)
Metallic/implantation failure, no. (%)	3 (1.3)
Screw breakage only	2
Screw breakage w/ delayed union	1
Delayed union at PSO site, no. (%)	8 (3.5)
PJF & kyphosis, no. (%)	2 (0.9)
PJA (UIV+2) in $^\circ$	31.4 ± 5.8
PJF w/ fixation failure, screw pullout at UIV, no.	2
DJF & kyphosis, no. (%)	8 (3.5)
DJA (LIV−2) in $^\circ$	16.4 ± 12.5
DJF w/ fracture at LIV	6
DJF w/ fixation failure, screw pullout at LIV	2

ant = anterior; pst = posterior.

Metallic/Implantation Failure. Three patients (1.3%) had implantation failure and showed screw breakage at the lowest distal screws, and 1 of the patients also showed delayed union. However, no patients experienced pseudarthrosis or complained of pain related to implantation failure. Therefore, no patients underwent revision surgery for implantation failure.

Delayed Union. Eight patients (3.5%) had delayed union at the osteotomy level, and 1 patient underwent reoperation. However, the remaining 7 patients showed delayed union until postoperative year 1 without collapse of the osteotomy site, loss of correction, or metallic failure. Spontaneous fusion was observed along the anterior longitudinal ligament (ALL) beginning after 6 months postoperatively. Interestingly, 4 patients with delayed union had posterior sagittal translation. No pseudarthrosis was observed at the osteotomy level at the final follow-up.

Proximal Junctional Failure and Kyphosis. PJF with fixation failure by screw pullout at the UIV developed in 2 patients (0.9%), and their PJAs were 27.3° and 35.5° . Immediate postoperative radiographs showed PJF, but

TABLE 3. Causes of reoperation in 14 patients who underwent PSO

Factor	No.
Surgical/technical failure	10
Malposition of pedicle screws	3
Root pain/motor weakness	1/2
Under-correction	1
Sagittal translation	2
Ant	1
Pst	1
CI	4
Mechanical failure	4
Pseudarthrosis	1
DJF w/ fracture at LIV	3

follow-up radiographs did not reveal further collapse that would require revision operation.

Distal Junctional Failure and Kyphosis. Eight patients (3.5%) had DJF, and the mean DJA was $26.4^{\circ} \pm 12.5^{\circ}$. Two patients experienced fixation failure by pullout of the pedicle screws and loosening at the LIV. Six patients developed vertebral body fracture at the LIV, and 3 patients with the vertebral body fracture underwent reoperation (Fig. 2). However, the other patients with DJF did not

undergo revision surgery; 4 patients did not show further kyphosis, and 1 patient refused revision surgery and was lost to follow-up.

Comparison of Implantation Failure, Anterior and Posterior Sagittal Translation, and Under-Correction Between Delayed Union and Union Groups

The patient cohort was divided into two groups: delayed union and union. After comparison of implantation failure, anterior and posterior sagittal translation, and under-correction between the two groups, only posterior sagittal translation showed a statistically significant result ($p = 0.007$; Table 4). To analyze risk factors for delayed union after PSO, implantation failure, anterior and posterior vertebral subluxation, and under-correction were included in the logistic regression analysis. We found that posterior vertebral subluxation was a significant risk factor (OR 8.333, $p = 0.031$).

Discussion

Previous studies have shown that the reoperation rate for complications after surgical correction for thoracolumbar kyphosis due to AS ranges from 0% to 20.0%, which varies by osteotomy procedure.^{15–19} In the present descriptive cohort study of 230 consecutive patients who had undergone 1-level PSO, we aimed to analyze minor or major surgery-related complications for the formulation of adequate treatment and risk reduction with regard to

FIG. 1. A: Radiograph showing thoracolumbar kyphosis from AS in a 37-year-old male. **B:** Posterior sagittal translation with fracture of the anterior hinge after PSO. **C:** Nine months after surgery, solid union was not achieved, as demonstrated by the lucent line at the osteotomy site. Loss of correction and metallic failure did not develop. **D:** Eighteen months after surgery, solid fusion with bony remodeling was noted at the PSO site without loss of correction.

FIG. 2. Radiographs (**A and B**) showing thoracolumbar kyphosis from AS with the apex at T11–12 in a 43-year-old female. Complete maturation of the ALLs was not observed. PSO at T12 was performed (**C**). Twenty months after surgery (**D**), DJF with posterior listhesis of L3 on L4 and kyphosis were noted. Reoperation by anterior interbody fusion and extension of the posterior instrumentation to the sacrum was performed (**E**).

these complications and reoperation. Among the 77 patients (33.5%) with radiographic findings of surgery-related complications, 14 (6.1%) underwent reoperation. The most common causes of reoperation were CI in 4 patients, symptomatic malpositioning of pedicle screws in 3, and DJF in 3. Most reoperations were performed within the 1st year after initial operation, suggesting that a 1-year follow-up period would capture the majority of revisions. To the best of our knowledge, this is the first study to comprehensively evaluate radiographic findings of surgery-related complications after PSO for thoracolumbar kyphosis in 230 patients with AS.

The possibility of sagittal translation must always be considered because it can cause neurological complications after osteotomy.^{9,10} Qian et al.³ reported the mechanisms of vertebral subluxation during PSO for AS. The predisposing factors were as follows: 1) early fracture of the anterior cortex of the osteotomized vertebra; 2) excessive decancellation from the vertebral body, causing parallel collapse of the vertebral column; 3) improper manual osteoclasts due to insufficient decancellation; and 4) inappropriate application of the cantilever technique and concomitant long instrumentation. However, Qian et al.³ also reported that no patients with sagittal translation experienced a devastating neurological deficit postoperatively. Park et al.¹⁰ reported that the incidence of sagittal translation after PSO was 30.2% and was closely related to the severity of AS and that sagittal translation can cause neurological injury. In our study, 24 patients (10.4%) experienced sagittal translation; 11 patients suffered anterior translation and 13 experienced posterior translation. Two

patients with sagittal translation developed neurological deficits and underwent emergency reoperation. After reoperation, their neurological deficits were completely resolved. Four patients experienced sagittal translation combined with delayed union. However, all patients developed complete union because of their superior fusion capacity in AS.³ Further analysis could be helpful for identifying the causes of delayed union in patients with sagittal translation.

Eight patients manifested under-correction without sagittal translation, caused by parallel collapse of the vertebral column by excessive decancellation, and of these 8 patients, only 1 underwent additional osteotomy at the segment below the PSO level after confirmation on intraoperative radiographs. In our study, we defined under-correction as below 15° of the osteotomy resection angle because PSO yields an approximately 15° to 60° lordotic angle in a single level.^{11,20,21}

TABLE 4. Effect of implantation failure, anterior and posterior vertebral subluxation, and under-correction on delayed union

Complication	Delayed Union (n = 8)	Solid Union (n = 222)	p Value
Implantation failure	1 (12.5)	2 (0.9)	0.101
Ant vertebral subluxation	1 (12.5)	10 (4.5)	0.329
Pst vertebral subluxation	3 (37.5)	10 (4.5)	0.007
Under-correction	0	8 (3.6)	0.750

n = number of patients.

In our study, the incidence of postoperative CI was 8.7% (20 patients), a rate similar to that in patients with congenital kyphoscoliosis (range 9.1%–20.8%).^{22–24} Bao et al.²⁵ reported that the incidence of CI was 30.4% in patients with degenerative lumbar scoliosis. The main mechanisms underlying CI remain unknown, but it was suggested that the asymmetrical wedge osteotomy and/or uneventful compression at the osteotomy site when trying to close the osteotomy could be potential causes. Therefore, intraoperative radiographs may be needed to confirm CI immediately after PSO. In our case, 4 patients underwent a rebalancing reoperation for correction of the postoperative CI because we did not expect the compensation for CI to occur at the proximal or distal segments because of the ankylosed spine.

Wang et al.²⁶ reported that PJK developed in 14.5% of AS patients after osteotomy. In addition, they reported that risk factors for PJK include a larger preoperative SVA, larger PJA, and larger osteotomy angle, and they postulated that AS patients are often younger with possibly active disease, resulting in the aggravation of kyphosis.²⁶ Kiaer and Gehrchen²⁰ reported that there were no patients with PJF after PSO for AS. However, in our study, 2 patients (0.9%) developed PJF, including PJK. The different results could be associated with fusion level and degree of AS severity because immature or mature ossification of the ALL and annulus fibrosus above the UIV would lead to PJF. Zhao et al.²⁷ reported that the proportion of patients with adequate ossification of the ALL was significantly greater in the non-rod fracture group than in the rod fracture group at the final follow-up. Lazennec et al.²⁸ postulated that neither ossification of the ALL nor the aspect of the disc had any influence on the surgical strategy utilized in posterior wedge osteotomies.

Interestingly, in our patients, DJF developed in 8 patients, and none of them showed sound ossification of the ALL at the distal segments of the lower lumbar spine on plain radiographs. In these cases, long fusion to the sacrum may prevent DJF. Among the patients with DJF, 3 underwent reoperation. More attention should be paid to patients who do not show complete maturation in ossification of the ALL. This study's results suggest that bone SPECT or bone scanning should be performed before surgery to confirm the severity of AS. Recently, we performed bone SPECT to identify whether or not the ALL and annulus fibrosus were mature or immature.

The present study was retrospective with a limited focus on radiographic outcomes after PSO. The most critical limitation was that this study did not include any patient-reported outcomes (PROs). Except in reoperation cases, PROs must be a more effective tool to evaluate surgical results than radiographic findings. Also, we did not include other critical complications such as deep vein thrombosis, wound infection, or pneumonia. However, the advantage of our study is that it presented a large number of cases performed by a single surgeon who utilized the same technique and same indications at one institute. Therefore, this study provides assessment of a large single-center database of patients with thoracolumbar kyphosis in AS. Despite our abundant surgical experience, many unexpected minor or major surgery-related complications developed after PSO

for AS. Interestingly, patients with DJK or PJK showed immature ossification of the ALL. Therefore, it may be necessary to assess ossification of the spinal segments to reduce postoperative complications, such as PJK and DJK, after PSO. We did not perform bone SPECT or bone scanning for evaluation of the ALL to ascertain whether or not it was completely mature in the present study.

Conclusions

PSO could be the most effective surgical procedure for the correction of thoracolumbar kyphosis in patients with AS. However, a high incidence of complications related to mechanical failure and surgical technique can develop. Therefore, thorough radiographic assessment before and during surgery is needed to reduce surgery-related complications.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Ha. Acquisition of data: JW Lee. Analysis and interpretation of data: KH Lee. Drafting the article: Ha. Critically revising the article: Ha, YC Kim. Reviewed submitted version of manuscript: YC Kim. Statistical analysis: KH Lee, JW Lee. Administrative/technical/material support: KH Lee, KT Kim, YC Kim, JW Lee. Study supervision: KT Kim.

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