# 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

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## Abstract

**Background:** Andersson lesions (ALs), also known as spondylodiscitis, destructive vertebral lesions and spinal pseudarthrosis, usually occur in patients with ankylosing spondylitis (AS). Inflammatory and traumatic causes have been proposed to define this lesion. Different surgical approaches including anterior, posterior, and combined anterior and posterior procedure have been used to address the complications, consisting of mechanical pain, kyphotic deformity, and neurologic deficits. However, the preferred surgical procedure remains controversial. The aim of this study was to illustrate the safety, efficacy, and feasibility of a modified posterior wedge osteotomy for the ALs with kyphotic deformity in AS.

**Methods:** From June 2008 to January 2013, 23 patients (18 males, 5 females) at an average age of 44.8 years (range 25–69 years) were surgically treated for thoracolumbar kyphosis with ALs in AS via a modified posterior wedge osteotomy in our department. All sagittal balance parameters were assessed by standing lateral radiography of the whole spine before surgery and during the follow-up period. Assessment of radiologic fusion at follow-up was based on the Bridwell interbody fusion grading system. Ankylosing spondylitis quality of life (ASQoL) and visual analog scale (VAS) scores were performed to evaluate improvements in daily life function and back pain pre-operatively and post-operatively. Paired $t$ tests were used to compare clinical data change in parametric values before and after surgery and the Mann-Whitney $U$ test was employed for non-parametric comparisons. The radiographic data change was evaluated by repeated measure analysis of variance.

**Results:** The mean operative duration was 205.4 min (range 115–375 min), with an average blood loss of 488.5 mL (range 215–880 mL). Radiographical and clinical outcomes were assessed after a mean of 61.4 months of follow-up. The VAS back pain and ASQoL scores improved significantly in all patients ($7.52 \pm 1.31$ vs. $1.70 \pm 0.70$, $t = 18.30$, $P < 0.001$; $13.87 \pm 1.89$ vs. $7.22 \pm 1.24$, $t = 18.53$, $P < 0.001$, respectively). The thoracolumbar kyphosis (TLK) changed from $40.03 \pm 17.61°$ pre-operatively to $13.86 \pm 6.65°$ post-operatively, and $28.45 \pm 6.63°$ at final follow-up ($F = 57.54$, $P < 0.001$), the thoracic kyphosis (TK) changed from $52.30 \pm 17.62°$ pre-operatively to $27.76 \pm 6.50°$ post-operatively, and $28.45 \pm 6.63°$ at final follow-up ($F = 57.29$, $P < 0.001$), and lumbar lordosis (LL) changed from $-29.56 \pm 9.73°$ pre-operatively to $-20.58 \pm 9.71°$ post-operatively, and $-20.73 \pm 10.27°$ at final follow-up ($F = 42.50$, $P < 0.001$). Mean sagittal vertical axis (SVA) was improved from $11.82 \pm 4.55$ cm pre-operatively to $5.12 \pm 2.42$ cm post-operatively, and $5.03 \pm 2.29$ cm at final follow-up ($F = 79.36$, $P < 0.001$). No obvious loss of correction occurred, according to the lack of significant differences in the sagittal balance parameters between post-operatively and the final follow-up in all patients (TK: $27.76 \pm 6.50°$ vs. $28.45 \pm 6.63°$, TLK: $13.86 \pm 6.65°$ vs. $14.42 \pm 6.7°$, LL: $-20.58 \pm 9.71°$ vs. $-20.73 \pm 10.27°$, and SVA: $5.12 \pm 2.42$ cm vs. $5.03 \pm 2.29$ cm, all $P > 0.05$, respectively).

**Conclusions:** The modified posterior wedge osteotomy is an accepted surgical procedure for treating thoracolumbar kyphosis with ALs in AS and results in satisfactory local kyphosis correction, solid fusion, and good clinical outcomes.

**Keywords:** Ankylosing spondylitis; Andersson lesions; Kyphosis; Modified posterior wedge osteotomy

## Introduction

For ankylosing spondylitis (AS) patients, due to progressive spinal rigidity and osteoporosis, fractures may occur under a minor trauma or even spontaneously.[1-3] With persistent motion and repeated inflammatory stimuli at the fracture site, the healing process stops and non-union occurs, which leads to a pseudarthrosis, also known as Andersson lesions (ALs).[4,5] The reported prevalence of ALs in AS ranges from 1.5% to 28%.[6,7] However, patients with AS often experience progressive back pain;

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thus, it is difficult to distinguish patients with early stage ALs due to the similarity of the symptoms. The initial radiologic study in early AL patients is always negative, and physicians cannot diagnose ALs immediately without computed tomography (CT) and magnetic resonance imaging (MRI).[8] The result of delayed management in AL-complicated AS is progressive kyphotic deformity and neurologic deficits, for which conservative treatments are often unsuitable.[9,10]

Surgical intervention is considered the most suitable management in AL patients for the correction of kyphosis causing sagittal imbalance and considerable disturbances in posture.[11] Different surgical methods, including posterior fixation and fusion, anterior fixation and fusion, and a combination of the anterior and posterior approaches, have been proposed for the excellent correction of kyphosis in patients with ALs,[10-13] and each surgical procedure has its advantages and disadvantages.[4,10,13-18] To the best of our knowledge, few studies have developed a surgical protocol based on the modified posterior wedge osteotomy for the treatment of thoracolumbar kyphosis with ALs in AS. The current study aimed to illustrate the effectiveness and safety of a modified posterior wedge osteotomy.

## Methods

### Ethical approval

Our retrospective study was approved by the Institutional Ethics Committee of the China-Japan Friendship Hospital

(No. 2018-GZR-154). All patients provided written informed consent.

### Patients

From June 2008 to January 2013, 23 consecutive patients were surgically treated for thoracolumbar kyphosis with ALs in AS via a modified posterior wedge osteotomy in our department. There were 18 males and 5 females, with an average age of 44.8 years (range 25–69 years). The mean follow-up period was 61.4 months (range 45–80 months). All patients complained of back pain, postural changes, and progression of the kyphosis deformity. All patients underwent conservative or no-treatment before they visited our hospital, then underwent surgical treatment for different degrees of progressive thoracolumbar kyphosis. Neurologic deficits were assessed according to American Spinal Injury Association (ASIA) grading system: one patient had a neurologic deficit graded as ASIA B, two had deficits grades as ASIA C, and six had deficits grades as ASIA D [Table 1].

### Surgical techniques

After general anesthesia was induced, the patient was placed in a prone position suitable for fitting the kyphotic spine on the adjustable spine frame. After positioning under C-arm X-ray, the spine was exposed through a standard posterior midline approach with sub-periosteal stripping. Then, pedicle screws were placed 2 to 3 levels

**Table 1: Patient clinical information obtained pre-operation and post-operation.**

| Patients | Age (years) | Gender (F/M) | Lesion segment | Follow-up (months) | operative duration (min) | Blood loss (mL) | VAS (Pre/FFU) | ASQoL (Pre/FFU) | Neurological deficit (Pre/FFU) | Bone-fusion time (months) | Complications |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 67 | F | T11/T12 | 58 | 345 | 650 | 7/2 | 12/5 | ASIA D/ASIA E | 3 | Dural tears |
| 2 | 47 | M | T12/L1 | 80 | 375 | 810 | 6/3 | 12/7 | ASIA C/ASIA D | 6 | None |
| 3 | 26 | M | L1/L2 | 49 | 195 | 560 | 5/1 | 11/8 | ASIA E/ASIA E | 4 | None |
| 4 | 32 | M | T12/L1 | 61 | 225 | 670 | 7/1 | 14/9 | ASIA E/ASIA E | 3 | None |
| 5 | 69 | F | T10/T11 | 64 | 185 | 630 | 6/1 | 11/8 | ASIA E/ASIA E | 4 | None |
| 6 | 25 | M | T11/T12 | 69 | 285 | 400 | 6/2 | 13/8 | ASIA E/ASIA E | 5 | None |
| 7 | 65 | M | T11/T12 | 63 | 320 | 740 | 8/1 | 12/7 | ASIA D/ASIA E | 5 | None |
| 8 | 26 | M | T12/L1 | 67 | 270 | 880 | 5/2 | 12/6 | ASIA E/ASIA E | 4 | None |
| 9 | 65 | M | T10/T11 | 55 | 280 | 205 | 9/1 | 16/7 | ASIA D/ASIA E | 5 | None |
| 10 | 62 | F | T11/T12 | 66 | 270 | 360 | 8/1 | 17/8 | ASIA C/ASIA D | 5 | None |
| 11 | 41 | M | T11/T12 | 79 | 220 | 485 | 7/2 | 15/8 | ASIA E/ASIA E | 3 | None |
| 12 | 44 | F | T12/L1 | 59 | 150 | 780 | 8/2 | 13/5 | ASIA E/ASIA E | 6 | Dural tears |
| 13 | 28 | M | T10/T11 | 49 | 195 | 430 | 8/2 | 14/7 | ASIA D/ASIA E | 4 | None |
| 14 | 59 | M | L1/L2 | 63 | 160 | 550 | 9/1 | 14/8 | ASIA E/ASIA E | 5 | None |
| 15 | 68 | F | T12/L1 | 68 | 135 | 320 | 10/2 | 16/8 | ASIA E/ASIA E | 4 | None |
| 16 | 39 | M | T10/T11 | 57 | 125 | 305 | 7/3 | 18/9 | ASIA B/ASIA C | 6 | None |
| 17 | 42 | M | T10/T11 | 65 | 155 | 330 | 8/1 | 13/6 | ASIA E/ASIA E | 4 | None |
| 18 | 27 | M | L1/L2 | 56 | 140 | 280 | 9/2 | 15/8 | ASIA E/ASIA E | 4 | None |
| 19 | 38 | M | T12/L1 | 45 | 125 | 215 | 9/2 | 15/7 | ASIA D/ASIA E | 5 | None |
| 20 | 46 | M | T11/T12 | 64 | 170 | 235 | 8/3 | 16/9 | ASIA D/ASIA E | 3 | Dural tears |
| 21 | 45 | M | T11/T12 | 57 | 135 | 360 | 7/1 | 13/5 | ASIA E/ASIA E | 3 | None |
| 22 | 41 | M | T10/T11 | 65 | 115 | 460 | 8/1 | 13/7 | ASIA E/ASIA E | 5 | None |
| 23 | 29 | M | T11/T12 | 53 | 150 | 580 | 8/2 | 14/6 | ASIA E/ASIA E | 3 | None |

VAS: Visual analog scale; FFU: Final follow-up; ASQoL: Ankylosing spondylitis quality of life; F: Female; L: Lumbar; M: Male; Pre: Pre-operation; T: Thoracic; ASIA: American Spinal Injury Association.

above and below the lesion using C-arm X-ray guidance and a freehand technique, and bone cement-augmented screws were applied in osteoporosis patients. The modified closing wedge osteotomy defined as resection of a substantial portion of the posterior vertebral body, posterior elements with pedicles, and at least a portion of one endplate with the adjacent inter-vertebral disc was then performed[19] [Figures 1 and 2].

First, the bilateral laminae, articular processes, and transverse processes of the lesion site were resected. The spinal cord and nerve roots were then carefully exposed and protected by a sponge. After a temporary rod was fixed on one side of the pedicle screws, bilateral external

walls of the target vertebral body are exposed with a gauze and periosteal stripper. A transpedicular wedge osteotomy was performed at the site of the target vertebral body with a pedicle probe and drill to create a wedge resection space toward the upper segment of the damaged inter-vertebral disc. The sclerotic bone around the pseudarthrosis was also resected. Simultaneously, the fibrous tissue, residuary disc tissue, and fibrocartilage were debrided by bone curettes. The resected specimens were examined histopathologically. The most important thing was to resect enough bone around the inter-vertebral foramen to ensure that the nerve root was not squeezed when the osteotomy was closed. Then, the osteotomy was closed by slowly extending the spine frame while applying compressive pressure on the
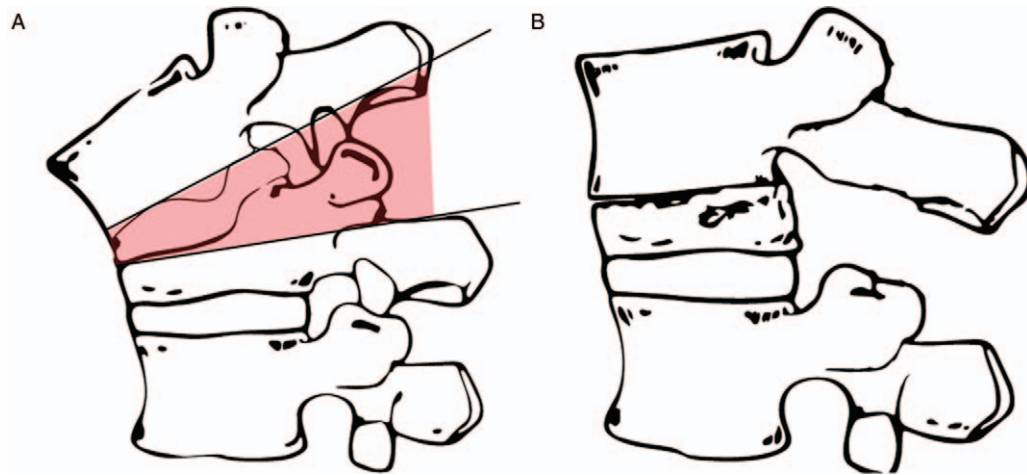


**Figure 1:** Modified posterior wedge osteotomy. (A) Resection of affected inter-vertebral disc and cartilage endplate and the segment of the posterior vertebral body. (B) Anterior spinal column achieves bone-on-bone solid fusion.
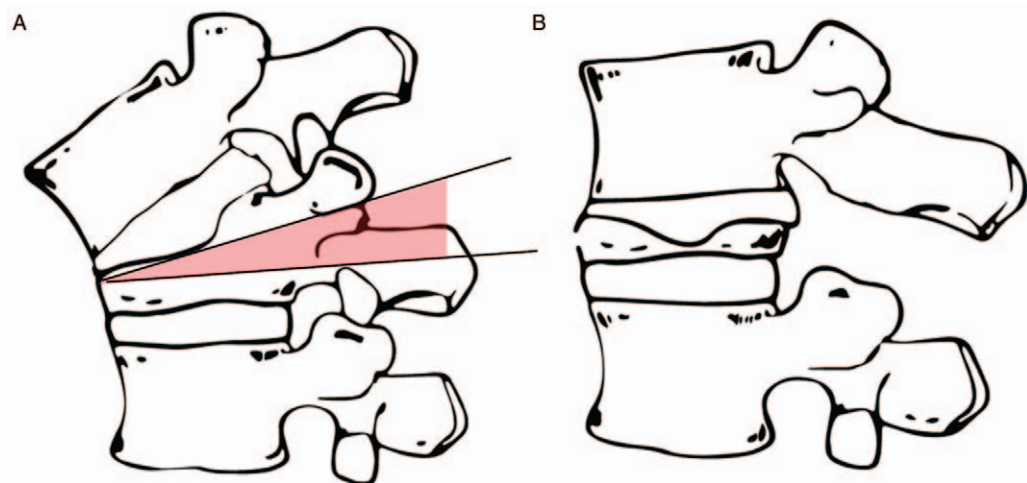


**Figure 2:** Traditional pedicle subtraction osteotomy. (A) Resection of a segment of the posterior vertebral body and a portion of the posterior vertebral elements with pedicles. (B) Damaged upper disc will rest on the cancellous bone of the remaining vertebra, which can result in non-solid anterior fusion.

pedicle screws above and below the osteotomy. Finally, the anterior cavity was filled with autologous or artificial bone via transforaminal. All patients underwent postero-lateral bone grafting after posterior fixation [Supplementary video: http://links.lww.com/cm9/A168].

Somatosensory-evoked potentials and motor-evoked potentials were monitored in the spinal cord throughout the surgical procedure. Patients were allowed to walk until 1 week after surgery while wearing a brace. Orthosis was used for at least 3 months until complete bone fusion was achieved.

### Radiographical assessment

Pre-operatively, patients underwent radiographical and CT examinations. MRI was not performed in patients with severe kyphosis and a tumor, tuberculosis, and infection were ruled out according to the imaging characteristics. All patients experienced a progressive thoracolumbar kyphosis due to ALs located from the T10 to L2 levels [Table 1]. The following sagittal balance parameters were measured:

1. Thoracic kyphosis (TK: the angle between the upper endplate of T5 and the lower endplate of T12, determined using the standard Cobb method).
2. Thoracolumbar kyphosis (TLK: the angle between the upper endplate of T10 and the lower endplate of L2).
3. Lumbar lordosis (LL: the angle between the superior endplate of T12 and S1).
4. Sagittal vertical axis (SVA: the horizontal distance from a plumb line of the C7 (C7PL) vertebral body center to the posterior-superior corner of the S1 endplate; and the SVA is positive if the C7PL is anterior to the posterior-superior corner of S1, otherwise it is negative).

All of the above parameters were assessed by standing lateral radiography of the whole spine before surgery and during the follow-up period. The data were obtained by taking the average of two measurements which were obtained by two senior independent spine surgeons. The post-operative fusion criteria were based on the Bridwell interbody fusion grading system.[20]

### Clinical evaluation

The visual analog scale (VAS) and AS quality of life (ASQoL) scores were used to evaluate the clinical function results before surgery and during the follow-up period. The neurologic status was assessed using the ASIA grading system.

### Statistical analysis

SPSS 20.0 statistical software (SPSS, Inc., Chicago, IL, USA) was used for all statistical analyses. All data are expressed as the mean ± standard deviation. Paired $t$ tests were used to compare clinical data change in parametric values before and after surgery and the Mann-Whitney $U$ test was employed for non-parametric comparisons. The radiographic data change was evaluated by repeated measure analysis of variance. A $P$ value $< 0.05$ was considered to indicate a statistically significant difference.

## Results

### Surgical results

The average operating duration was 205.4 min (range 115–375 min). The mean intra-operative blood loss was 488.5 mL (range 205–880 mL). Dural tears with cerebrospinal fluid leakage were encountered in three cases, which were covered intra-operatively by fascia tissue, and lumbar drainage was placed and removed after 7 days. There were no complications consisting of neurologic injury, wound infection, fixation failure, or main vascular injury [Table 1]. Typical cases are shown in Figures 3 and 4.

### Clinical results

The VAS scores decreased from 7.52 ± 1.31 (range 5–10) pre-operatively to 1.70 ± 0.70 (range 1–3) at the final follow-up ($P < 0.05$). The ASQoL score decreased from 13.87 ± 1.89 (range 11–18) pre-operatively to 7.22 ± 1.24 (range 5–9) at the final follow-up ($P < 0.05$) [Table 2]. All patients with neurologic deficits showed improvement, with the one ASIA B patient recovering to ASIA C, the two ASIA C patients improving to ASIA D, and the six ASIA D patients improving to ASIA E at final follow-up. All patients were satisfied with the surgical results [Table 1].

### Radiologic findings

All patients showed transdiscal extensive lesions in our study and all the lesions distribution in thoracolumbar junction. The level of AL was T10/T11 in six cases (26.1%), T11/T12 in eight cases (34.8%), T12/L1 in six cases (26.1%), and L1/L2 in three cases (13.0%) [Table 1].

All sagittal balance parameters, including TK, TLK, LL, and SVA, were determined pre-operatively, post-operatively, and at the final follow-up. Post-operative correction achieved in all the patients immediately. The TLK changed from 40.03 ± 17.61° pre-operatively to 13.86 ± 6.65° post-operatively, and 28.45 ± 6.63° at final follow-up ($F = 57.54$, $P < 0.001$), the TK changed from 52.30 ± 17.62° pre-operatively to 27.76 ± 6.50° post-operatively, and 28.45 ± 6.63° at final follow-up ($F = 57.29$, $P < 0.001$), and LL changed from −29.56 ± 9.73° pre-operatively to −20.58 ± 9.71° post-operatively, and −20.73 ± 10.27° at final follow-up ($F = 42.50$, $P < 0.001$). Mean SVA was improved from 11.82 ± 4.55 cm pre-operatively to 5.12 ± 2.42 cm post-operatively, and 5.03 ± 2.29 cm at final follow-up ($F = 79.36$, $P < 0.001$). No obvious loss of correction occurred, according to the lack of significant differences in the sagittal balance parameters between post-operatively and the final follow-up (TK: 27.76 ± 6.50° vs. 28.45 ± 6.63°, TLK: 13.86 ± 6.65° vs. 14.42 ± 6.7°, LL: −20.58 ± 9.71° vs. −20.73 ± 10.27°, and SVA: 5.12 ± 2.42 cm vs. 5.03 ± 2.29 cm, all $P > 0.05$, respectively). Solid fusion was obtained in all patients at the final follow-up according to radiologic evidence, and no obvious loss of correction, progressive kyphosis, or recurrent lesion occurred [Figure 5].
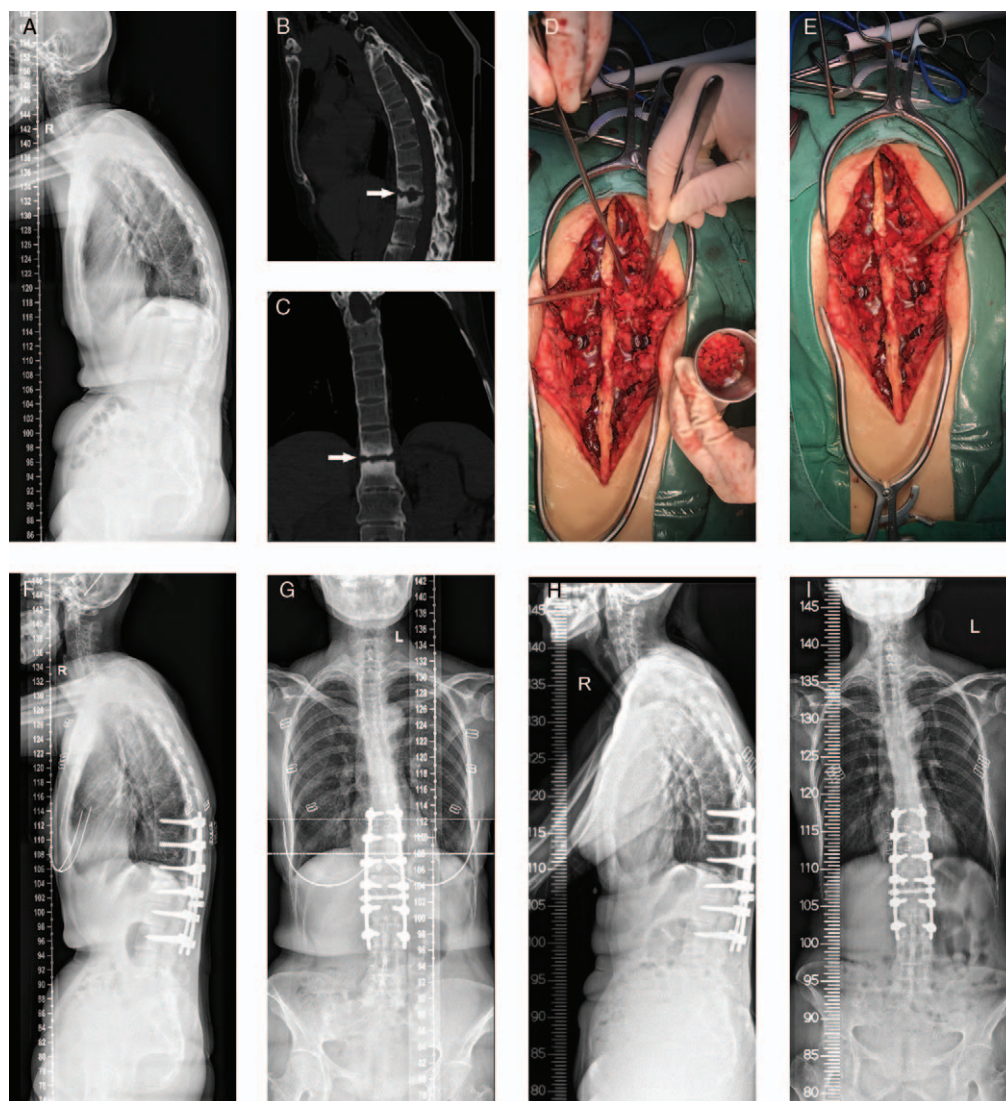
**Figure 3:** A 44-year-old woman experienced an Andersson lesion-complicating ankylosing spondylitis at the T12/L1 level. (A–C) Pre-operative radiographs show a kyphosis in the thoracolumbar spine with a thoracolumbar kyphosis of 31.8° and a thoracic kyphosis of 52.1°. The computed tomography showed that the lesions were surrounded by reactive sclerosis (arrow). (D, E) Intra-operative photographs show that the deformity correction achieved. (F, G) Post-operative X-ray display of a thoracic kyphosis of 32.5° and a thoracolumbar kyphosis of 15.8°. (H, I) At the final follow-up of 59 months, radiographs show solid bone fusion achieved and no loss of correction.

## Discussion

Since ALs was first proposed in 1937, the exact etiology of the lesions is under debate and two main theories have been proposed to designate the cause and pathology of the lesions: inflammatory and traumatic.[7] Support for the inflammation etiology is based on the presence of no previous traumatic history, characteristics of chronic non-bacterial inflammation on the pathologic examination, and improvement in pain and radiologic characteristics with anti-inflammatory drugs.[7] Park et al[7] suggested that anti-TNF agents be used to treat the pain of inflammatory lesions, and usually there is no need to treat by surgery. However, operative treatment is used to alleviate the pain, deformity, and instability of traumatic lesions. The complete ankylosed and osteoporotic spine in AS patients are prone to pseudarthrosis after direct trauma or chronic mechanical stress, which is supported histologically by the presence of hyperplasia fibrous and degenerative fibrocartilage tissue.[13] The thoracolumbar junction, as a site of local stresses increasing dramatically, especially in a long ankylosed thoracolumbar kyphotic spinal column, is the most common site of pseudarthrosis.[21] In the study, all the lesions distribution in the thoracolumbar junction is concordant to previous studies.[10-13,22,23]

Various surgical osteotomy management strategies, including Smith-Petersen osteotomy (SPO) and pedicle subtraction osteotomy (PSO), have been used to restore the sequence and reconstruct the stability of the spine. Smith-Petersen et al[24] originally performed SPO, also known as opening wedge osteotomy, to correct kyphotic deformity using two- or three-level osteotomies through the L1, L2, and L3 facet joints in AS. Chang et al[18] treated AL patients with SPO and pedicle screw fixation at the level of pseudarthrosis without anterior fusion and obtained a 38° correction of the local kyphosis and no
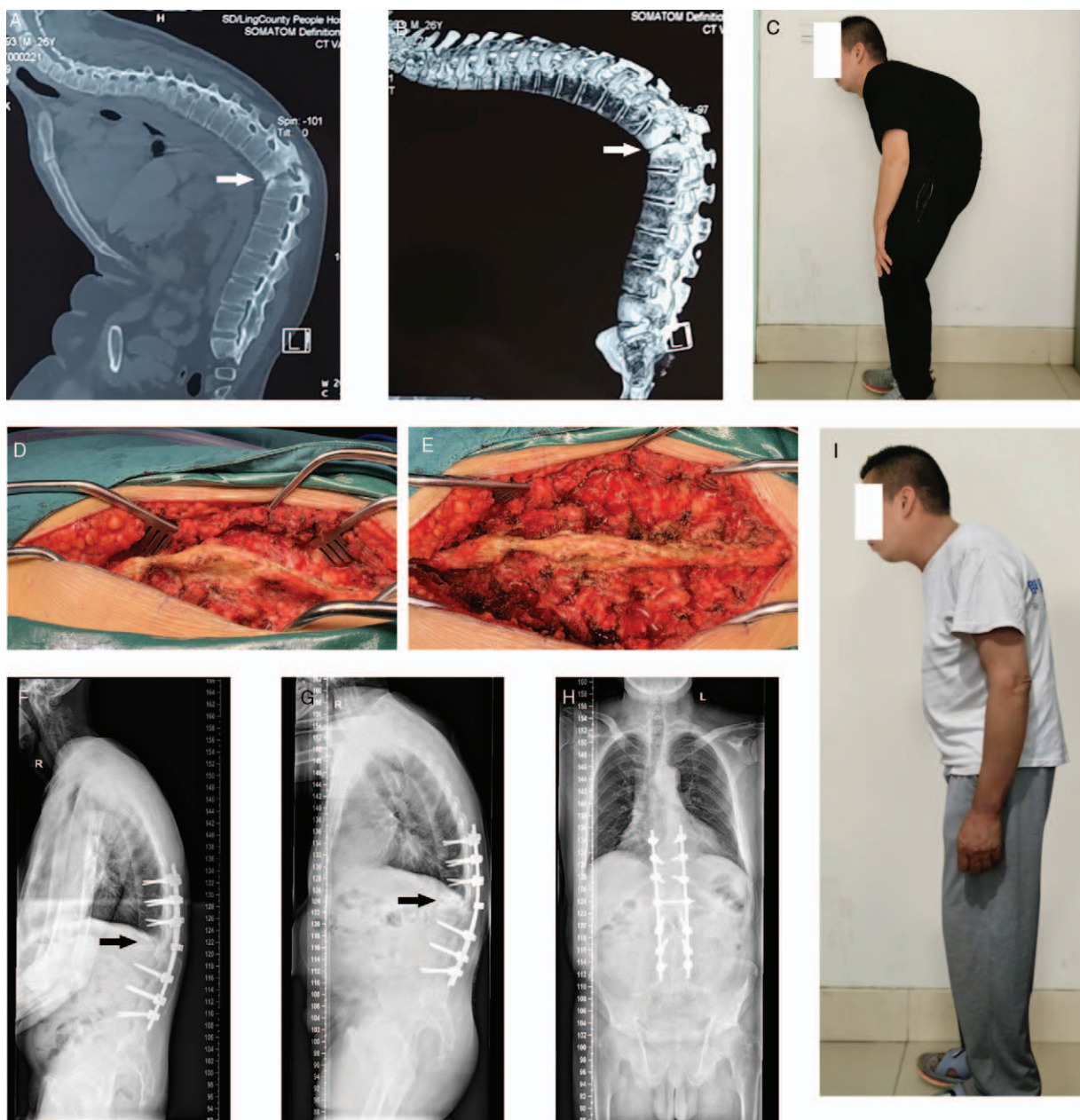
**Figure 4:** A 26-year-old man suffering from an Andersson lesion-complicating ankylosing spondylitis at the T12/L1 level. (A, B) Pre-operative radiographs show a remarkable kyphosis in the thoracolumbar spine. The computed tomography three-dimensional reconstruction showed that the lesions were surrounded by reactive sclerosis (arrow). (C–E) Pre-operative photographs show a kyphotic deformity in the lesion segment. (F) Post-operative radiograph shows satisfactory correction achieved via posterior closing wedge osteotomy. (G–I) Radiographs and appearance photograph at final follow-up of 67 months show that solid bone fusion achieved and no loss of correction.

**Table 2: Clinical outcomes before operation and after operation.**

| Parameters | Pre-operation ($n = 23$) | Final follow-up ($n = 23$) | $t$ | $P$ |
|---|---|---|---|---|
| VAS | $7.52 \pm 1.31$ | $1.70 \pm 0.70$ | 18.30 | <0.001 |
| ASQoL | $13.87 \pm 1.89$ | $7.22 \pm 1.24$ | 18.53 | <0.001 |

VAS: Visual analog scale; ASQoL: Ankylosing spondylitis quality of life.

loss of correction during the follow-up period. They believed that the superior fusion ability of bone in AS allows solid fusion to be achieved under rigid internal fixation. However, Kim *et al*[17] reported a surgical approach consisting of one-stage SPO with anterior interbody fusion at the lesion level in a series of 12 patients with kyphotic pseudarthrosis-complicated AS. The mean correction of the kyphotic angle at the level of the pseudarthrosis was 20.9°, and the radiologic union of the pseudarthrosis was achieved in 4.2 months. They
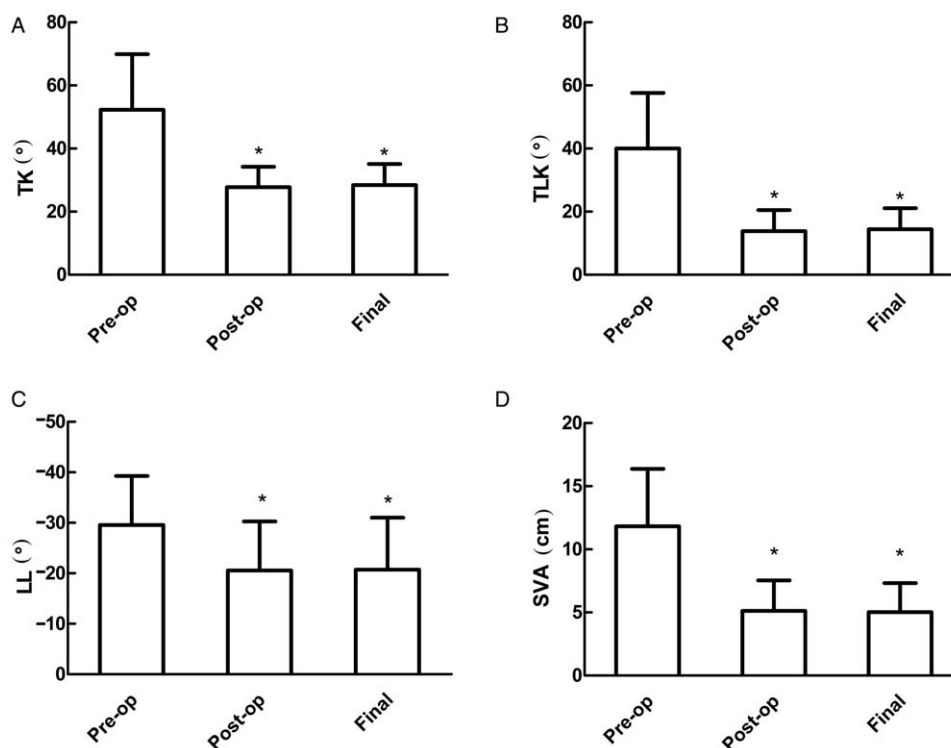
**Figure 5:** Radiologic sagittal balance parameters change outcomes. $*P < 0.05$ compared with pre-operative data. (A) Thoracic kyphosis (TK) changed from $52.30 \pm 17.62°$ pre-operatively to $27.76 \pm 6.50°$ post-operatively, and $28.45 \pm 6.63°$ at the final follow-up. (B) Thoracolumbar kyphosis (TLK) changed from $40.03 \pm 17.61°$ pre-operatively to $13.86 \pm 6.65°$ post-operatively, and $28.45 \pm 6.63°$ at the final follow-up. (C) Lumbar lordosis (LL) changed from $-29.56 \pm 9.73°$ pre-operatively to $-20.58 \pm 9.71°$ post-operatively, and $-20.73 \pm 10.27°$ at final follow-up. (D) Sagittal vertical axis (SVA) was improved from $11.82 \pm 4.55$ cm pre-operatively to $5.12 \pm 2.42$ cm post-operatively, and $5.03 \pm 2.29$ cm at the final follow-up. Pre-op: Pre-operation; Post-op: Post-operation. Final: Final follow-up.

concluded that anterior fusion for repairing pseudarthrosis could promote fusion and reduce the time to union. Theoretically, in the absence of anterior fusion, this process produces a large anterior gap as a result of substantial tension in posterior implants which increases the risk of implant failure, delayed union or non-union, and loss of correction. Chang et al[25] reported the three rods broke due to delayed healing after SPO in the osteotomy site and they also observed a mean loss of correction of 2° during the follow-up period in another study.[18] Furthermore, this procedure was thought to be associated with severe neurovascular complications due to the elongation of the anterior column.[8] Previous research also has shown that deformity correction by SPO was limited to only a small degree in AL patients, and resulted in an additional osteotomy at the segment below L1 in cases of severe kyphosis, which increases operative time, blood loss, and risk, especially for the elderly with multiple medical conditions.[12,17] Pedicle subtraction osteotomy (PSO), also known as closing wedge osteotomy, was first described for the correction of AS-related sagittal deformity in 1962.[26] In recent years, several scholars have reported the procedure as a relatively safe method in AL patients with significant kyphotic correction ranging from 30° to 45°.[5,11,22] Qian et al[11] reported a series of patients with a 45° correction of global kyphosis in AS-related symptomatic thoracolumbar pseudarthrosis via PSO at the level of the pseudarthrotic lesion combined with supplemental anterior fusion. Liang et al[22] used PSO and debridement of the ALs to correct severe kyphosis in AS

patients, achieving a mean correction of 44° and good fusion at the same time. However, to the best of our knowledge, few studies define an osteotomy procedure for the treatment of kyphotic deformity with ALs in AS base on pathologic changing.

In 1972, Cawley et al[27] first proposed dividing ALs into three types in 1972: Type I involves the discal surface of the vertebral rim, without cartilaginous part of the vertebral endplate; Type II involves the central part of the inter-vertebral disc vertebral body and cartilage endplate; Type III involves a single segment, above and below which the spine shows advanced ankylosis. Among them, type I and II lesions are localized, concurrent with the early stage, whereas type III lesions are extensive, usually seen in the advanced stage of AS, associated with spinal ankyloses, osteoporosis, and stress concentration. Bron et al[28] summarized three different lesions according to the etiology: (1) Localized lesions; (2) Extensive lesions without fractured posterior elements; and (3) Extensive lesions with fractured posterior elements resulting from direct trauma or chronic mechanical stress and may be located transdiscal or transvertebral. Furthermore, regard-less of the type of lesion, extensive lesions are characteristic as the extensive damage to disc with upper and lower endplates in the final-stage ALs with progressive kyphotic deformity, sagittal imbalance, intractable pain, and neurologic deficit.[10,13] In the current study, all patients had transdiscal extensive lesions when they first presented at the hospital.

Compared with PSO, a partial wedge resection of a segment of the posterior vertebral body and a portion of the posterior vertebral elements with pedicles,[19] the modified posterior wedge osteotomy in our series, a resection of affected inter-vertebral disc and cartilage endplate and the segment of the posterior vertebral body which is different from the grade 4 osteotomy,[19] is more suitable. When a regular PSO is attempted, the level injured disc is exposed, simultaneously. When you close the space, the damaged upper disc will rest on the cancellous bone of the remaining vertebra, and bony fusion is difficult to achieve in this situation. Relatively, our modified posterior wedge osteotomy in this study allows more effective kyphosis correction due to greater debridement of destructive lesions and wider resection of the posterior elements. Furthermore, the inferior bony endplate of the upper vertebra is set on the cancellous bone of the remaining vertebra to achieve solid fusion.[9]

For AL patients, greater debridement of destructive lesions, including the affected inter-vertebral disc and cartilage endplate is needed and the excessive shortening of the area may result in extremely dangerous complications such as buckling of the dura and spinal cord. We performed adequate anterior bone grafting after osteotomy confirmed the following advantages: First, adequate bone grafting can maintain the inter-vertebral height of the osteotomy site to avoid potential excessive spinal cord curving, or kinking.[10] Second, the procedure is similar to spinal shortening, and the anterior bone grafting can be used to create a fulcrum osteotomy site to increase the kyphotic correction and prevent the correction at one level from exceeding 40° kyphosis.[11] Third, an anterior graft provides bone contact and support to reduce the stress acting on the internal fixation, which could reduce the incidence of complications, such as the loss of correction or instrumentation failure.[21]

Although an anterior fixation approach seems to be the most suitable option for both AL debridement and correction, the exposure provided by the anterior approach allows for direct elimination of the lesions, and anterior plate fixation has the following major drawbacks in these patients[15,29,30]: Firstly, osteoporosis is frequently associated with AS and reduces the strength of screw anchorage. Secondly, long-lever arm fractures require long segment fixation, but it is difficult to implant longer plates via an anterior approach in a rigid kyphotic spine. In addition, the pulmonary disease is often more prevalent in AS patients due to chest rigidity, and post-operative pulmonary complications are frequently observed when the anterior approach is applied and is associated with increased morbidity. Some other scholars have proposed a combined anterior and posterior surgery with an increasing operative duration and blood loss, which is not suitable for patients with serious medical conditions, especially for elderly individuals.[11,17]

In our current study, the blood loss and operation time were significantly lower than the values reported by previous literature.[10,12,13,21,22,26] The modified posterior wedge osteotomy, which removes fibrous tissue, fibrocartilage, and necrotic bone around the pseudarthrosis cavity, could significantly decrease the blood loss. In addition, the epidural vein under the chronic compression of the apex of the kyphosis degenerated and calcified and the bone removed near the line between the pedicles was also sclerotic, which reduced epidural hemorrhage.[12] Furthermore, the radiologic union was achieved after a mean of 4.3 months without instrumentation complications, which was similar to previous reports.[11,17] Although Chang et al[18] reported that solid fusion could also be achieved at final follow-up without an anterior fusion because of the superior fusion ability of AS, we consider that the anterior fusion could reduce the incidence of instrumentation complications. Satisfactory correction was achieved through the modified posterior wedge osteotomy procedure in our series. Solid bone fusion was achieved, and no loss of correction was observed in any patients.

Some limitations of this study need to be addressed. First, we did not establish a control group that underwent a traditional PSO treatment. Second, we confess that the lesions in all our cases are transdiscal in final-stage ALs, the efficacy and feasibility of the modified posterior wedge osteotomy in transvertebral cases of early stage ALs are not within the scope of this discussion. Third, our research was retrospective, and the sample size was small, a large randomized controlled study will be needed to verify the safety, reliability, and feasibility of this method.

In conclusion, the modified posterior wedge osteotomy is an acceptable surgical procedure to treat thoracolumbar kyphosis in AS patients with ALs considering lesion characteristics of extensive damage to disc with upper and lower endplates in the final stage. This method makes significant contributions to achieving the satisfactory correction of local kyphosis, solid bone fusion, and extensive relief of back pain with reduced blood loss and operation time.

## Conflicts of interest

None.

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