Clinical Results and Surgery Tactics of Spinal Osteotomy for Ankylosing Spondylitis Kyphosis: Experience with 448 Patients

Category

Kyphosis

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Title

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Summary: Spinal osteotomy for severe ankylosing spondylitis (AS) kyphosis is a technically demanding method. The optimal surgical procedure, osteotomy site and exact corrective angle for treatment of AS kyphosis remain controversial. The lack of a widely accepted consensus contributes to the variation in surgical decision making.

Hypothesis: Systematic review of the clinical data of single spine center is help to make surgical decision

Design: A retrospective study

Introduction: The aim of this study is to report the clinical results and surgical tactics of spinal osteotomy for severe AS kyphosis based on the experience of single spine center.

Methods: From January 2003 to January 2015, totally 448 patients suffering from AS kyphosis who underwent spinal osteotomy in our hospital were reviewed, and 428 patients had reach a 2-year minimum follow-up. Among them, Patients, with an average chin-brow vertical angle (CBVA) of 51.5° (range, 28° to 108.1°) and average global kyphosis (GK) of 59.6° (range, 32.4°-110.6°), were selected to underwent one or two-level pedicle subtraction osteotomy (PSO) or vertebral column decancellation (VCD), and the osteotomies were performed range from T12 to L3 according to the apex of kyphosis. Pre or postoperative radiological parameters were measured. Intraoperative, postoperative, and general complications were recorded.

Results: All patients could walk with horizontal vision and lie on their backs postoperatively. The CBVA was improved from 68.3° to 8.2° (P=0.000) in two-level group and from 46.2° to 4.2° (P=0.000) in one-level group. The mean sagittal vertical axis (SVA) was improved from 29.4cm to 8 cm (P=0.000) in two-level group and from 18.0cm to 4.3 cm (P=0.000) in one-level group. The mean amount of correction was 27.8° at the superior site of the osteotomy and 42.1° at the inferior site of the osteotomy in two-level group and was 46.2° in one-level group. No major acute complications such as death or complete paralysis occurred. 32 patients suffered one or two complications including: CSF leaks (n=21, 9 in two-level group and 12 in one-level group), transient neurological deficit (n=3, in two-level group), vascular laceration bleeding (n=1, in two-level group), infections (n=2, 1 in two-level group and 1 in one-level group), postoperatively low back pain (n=5, 2 in two-level group and 3 in one-level group), spinal rod broken (n=3, 2 in two-level group and 1 in one-level group), distally pedicle screws pull out (n=4, 2 in two-level group and 2 in one-level group), and non-fusion at osteotomy site (n=4, 3 patients associated with Andersson's lesion preoperatively).

Conclusion: Spinal osteotomy, such as PSO and VCD, can improve the living quality of AS patients secondary to the correction of kyphotic deformities. VCD, a new technique of spinal osteotomy by make a 'Y' shaped osteotomy rather than 'V' shaped in PSO, can reduce the shorten distance of middle column and then decrease the neurological complication rate. One-level spinal osteotomy shows lower complications rate, while two-level spinal osteotomy is a relatively aggressive procedure which is more suitable to correct severe AS patients with hyperkyphosis in thoracolumbar spine in combination with the loss of lumbar lordosis.

Key Word： Ankylosing spondylitis; Spinal deformity; Vertebral column decancellation; Pedicle subtraction osteotomy; Osteotomy.

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How many patients were eligible for inclusion from all study sites during this time frame? Unknown

How many patients were enrolled from all study sites? 448 patients

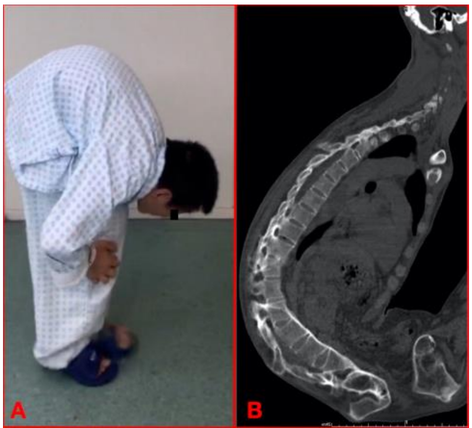
Were the patients enrolled consecutively? Yes

What was the minimum time period of follow-up? 2 years

How many patients reached the minimum follow-up time? 428 patients

Introduction

Ankylosing spondylitis (AS) is a chronic spondyloarthropathy, which primarily involves the spine and sacroiliac joints [1-3]. At advanced stages of the AS, many cases result in spinal deformities, such as the loss of lumbar lordosis or an increase in thoracic kyphosis, which can lead to structural and functional impairments and a decrease in the quality of life [3]. Additionally, AS may be associated with severe sagittal imbalance, trunk collapse, and flexion-contracture deformities of the spine in the later stages, which may cause back pain, horizontal vision loss, or neurological deficits [4, 5]. Complications, such as walking difficulties, abdominal viscera compression, or lung dysfunction, may occur in patients with severe kyphotic deformities [6-8], as shown in Figures 1 to 3.



➤ **Figure 1.** A 36-year old patient with severe spinal deformity caused by AS. A, lateral photo of the patient with free-standing posture pre-operatively, shows that horizontal vision is limited. B, computerized tomography sagittal reconstruction image revealed the spinal deformity even leads to compression of the abdominal viscera.

➤ **Figure 2.** A 39-year-old man presented with a "folding shape" deformity, involves the spine and hip joints. A, lateral photo of the patient demonstrated that the patient presented with severe deformity. B, 3-D computerized tomography reconstruction image revealed the severe spinal deformity of the patient just like a folding man.

➤ **Figure 3.** A 38-year-old man suffering AS kyphosis. A, lateral photo of the patient with sagittal imbalance, and the loss of horizontal gaze. B, a sagittal computerized tomography reconstruction image revealed the spinal deformity even leads to a compression of abdominal viscera.

Surgical correction of kyphosis is necessary for many patients with AS deformities to restore the sagittal balance and the ability to see straight ahead [1, 9, 10]; however, the most effective and safe surgical procedure for AS-related symptomatic kyphotic deformities is still controversial [2, 8], and the plans, which have been explored to calculate the exact angle required for an osteotomy, carry some limitations as well [11].

The purpose of this study was to report the radiographic and clinical results of spinal osteotomy for AS kyphosis based on the experience of our single spine center, and in addition, to evaluate the efficacy and feasibility of vertebral column decancellation (VCD) as a new osteotomy technique for correcting kyphosis secondary to AS focus on technical advantages and key points.

Materials and Methods

Patient selection

After Institutional Review Board approval, we retrospectively reviewed 448 AS patients who underwent spinal osteotomies, including the pedicle subtraction osteotomy (PSO) and VCD, for AS-related kyphotic deformities at our hospital between January 2003 and January 2015. The inclusion criteria for the study were as follows: (1) 18 to 60 years of age and the pre-operative diagnosis of AS was made according to the modified New York criteria [12]; (2) kyphosis in lumbar, thoracolumbar, or thoracic spine and unable to lie flat in bed and/or look straight forward owning to the kyphotic deformities; and (3) a minimum of 2-years of follow-up after surgery and all of the radiographic and clinical data were complete. The exclusion criteria were as follows: (1) previous spinal surgery; and (2) severe concomitant disease, such as spinal tumors or infections.

As a result, a total of 428 patients (392 males and 36 females) with an average age of 34.8 years (range, 18-60 years) and a mean duration of AS was 14.2 years (range, 3.3-36.2 years) met the aforementioned inclusion criteria and were enrolled in this study. Table 1 summarizes the clinical characteristics and radiological findings in the study.

Table 1. Clinical characteristics, radiological findings and osteotomy methods in 428 AS patients.

Variable		Value*
Sex		
	male	392
	female	36
Age (yrs)		
	mean	34.8
	range	18-60
Osteotomy method		
	one-level	339
	two-level	89
Duration of AS (yrs)		
	mean	14.2
	range	3.3-36.2
GK (°)		
	mean	59.6
	range	32.4-110.6
SVA (cm)		
	mean	21.3
	range	6.3 to 49.5
CBVA (°)		
	mean	51.5
	range	28-108.1
Follow-up (yrs)		
	mean	2.8
	range	2.4-14

Note: * Values represent the number of patients, unless otherwise indicated; GK, global kyphosis; SVA, sagittal vertical axis; CBVA, chin-brow vertical angle.

Surgical strategies making

To choose the appropriate osteotomy approach, site, and corrective angle, the following principles were taken into consideration:

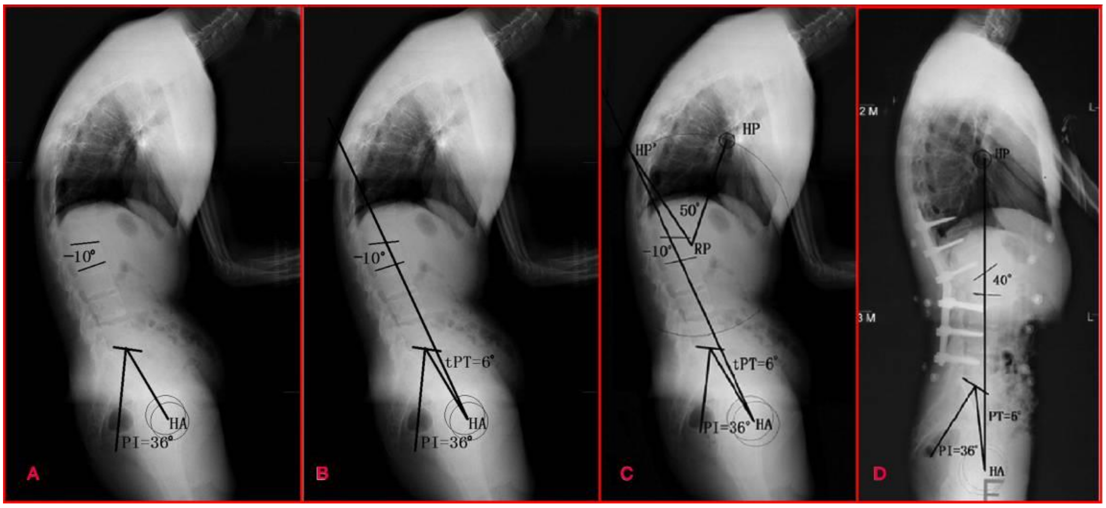
(1) the osteotomy site was located at the lower thoracic and upper lumbar vertebrae, usually range from T12 to L3;

(2) for one-level osteotomy, the corrective angle should no more than 40° for PSO [9, 13] or 50° for VCD [4, 14, 15], if the required angle is more than this, two-level osteotomy was considered;

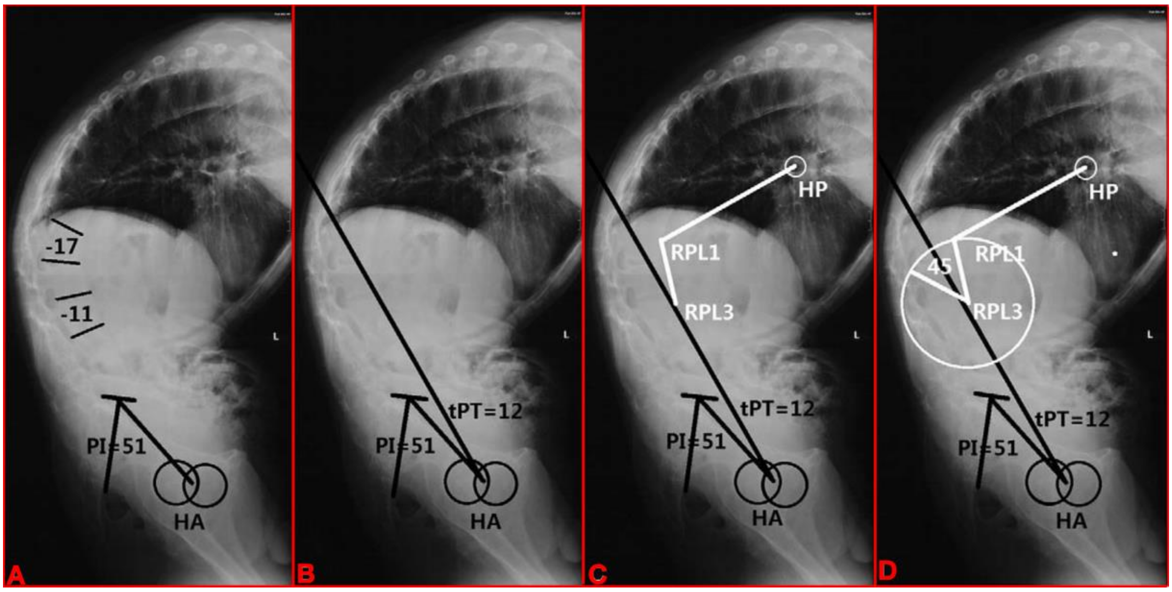
(3) two-level spinal osteotomies should not be performed with continuous segments, especially in spinal cord regions;

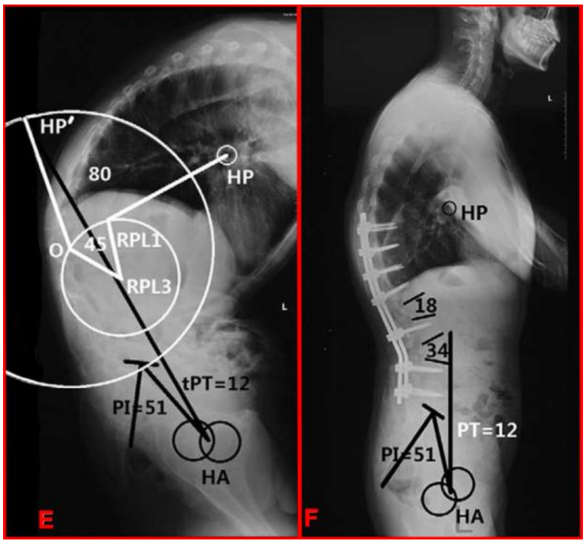
(4) for thoracic kyphosis, we prefer T12 or L1 as osteotomy sites; for thoracolumbar or lumbar kyphosis, we prefer L2 or L3 as osteotomy sites;

(5) then the osteotomy angle at the site was calculated based on our new osteotomy angle calculation principle [11, 16], that the center of gravity (CG) of the trunk should nearly over the hip axis (HA) when the pelvic and lower extremity joints are in the neutral position (Figures 4 and 5).



➤**Figure 4.** The osteotomy angle calculation method of one-level osteotomy [11]. A 26-year-old female with AS. (A) The preoperative PI was 36° and the kyphosis of the osteotomy site was 10°. (B) Thus, the postoperative individual theoretic PT (tPT) was given by the following mathematical equation: tPT = 0.37 × PI – 7. For this patient, the tPT=6°. The postoperative plumbline was drawn according to the tPT. (C) A circle was drawn by taking the anterior column of the second vertebra as the center (RP), and the distance between this point to the hilus pulmonis as the radius. The included angle was 50°, thus the exact required osteotomy angle was 50°. (D) Postoperative lumbar lordosis was 40°, PT was 6°, and the real osteotomy angle was 40°+ 10° = 50°. Good sagittal balance was achieved. HA indicates hip axis; HP, hilus pulmonis; RP, rotation point; PI, pelvic incidence; PT, pelvic tilt; AS, ankylosing spondylitis; tPT, theoretic PT.



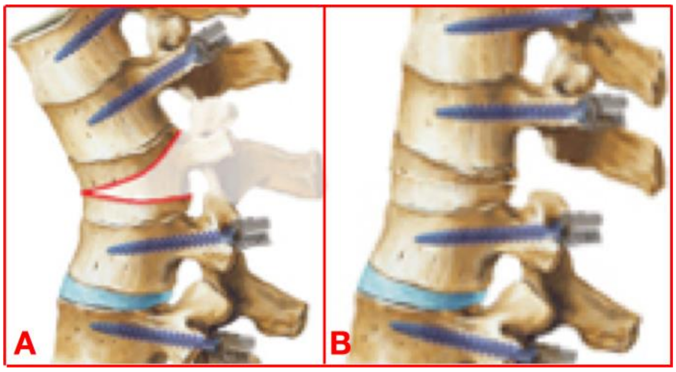


➤ **Figure 5.** The osteotomy angle calculation method of two-level osteotomy [16]. A, We measured the preoperative PI (51°), and the theoretical PT (tPT = 0.37 × PI – 7) was calculated. B, We used the tPT to locate exact pelvic neutral positional line (HA-HP'). C, We marked RPL3 (rotation point at L3: the middle point at the front edge of inferior osteotomy vertebra) and RPL1 (rotation point at L1: the middle point at the front edge of superior osteotomy vertebra). D, We placed a circle with RPL3 as the center and RPL3-RPL1 as the radius rotated 45° anticlockwise and marked the new site of RPL1 as O. E, We placed another circle with O as the center and RPL1-HP as the radius; HP' is the intersection with SP-HA. The theoretical osteotomy angle for L3 was designed as ∠O-RP3-RP1=45°. The theoretical osteotomy angle for L1 was determined as ∠HP'-O-RP1-HP - ∠O-RP3-RP1=85°-45°=35°. F, After achieving a osteotomy angle in L3 of 45° (34° postoperative lordosis + 11° preoperative kyphosis), and a osteotomy angle in L1 of 35° (18° postoperative lordosis + 17° preoperative kyphosis) for a total of 80°, the postoperative PT was equal to 12° and individual pelvic neutral position was successfully reconstructed. HA indicates hip axis; HP, hilus pulmonis; RP, rotation point; PI, pelvic incidence; PT, pelvic tilt; AS, ankylosing spondylitis; tPT, theoretic PT.

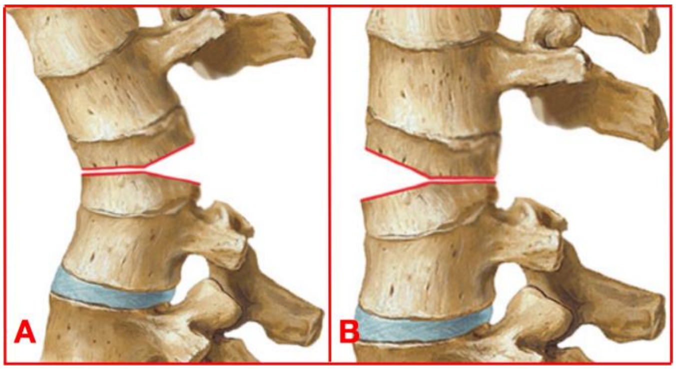
Surgical technique

PSO (Figure 6), which was based on the method of Thomasen and Bridwell [17, 18], was performed in 138 patients. VCD (Figure 7-9), was performed in the remaining 290 patients, which begun with probing and dilation of the both sides pedicles of the osteotomized vertebrae by the pedicle probe or drill. After that, a special spacer was used to enlarge the pedicle holes. Through the bilaterally pedicle holes, the cancellous bone of the middle column of the osteotomized vertebra was partly removed. The anterior cortex and lateral walls of the osteotomized vertebra were thinned by a curette or high-speed drilling via both pedicle holes. Then laminectomy was performed at the osteotomy site. Then, the bent rods were installed into pedicle screws above and below the osteotomy site respectively. The posterior wall of vertebral body and the bilateral pedicles residual medial wall were removed used forceps or Kerrison rongeur. By now, a ‘Y’ shaped osteotomy rather than ‘V’ shaped have been made. Subsequently, the middle column was closed by gradual extension of the operating table and continuous pressure on the pedicle screws above and below the osteotomy. In this procedure, the anterior column served as the hinge at beginning and the hinge moved to the middle column at last.

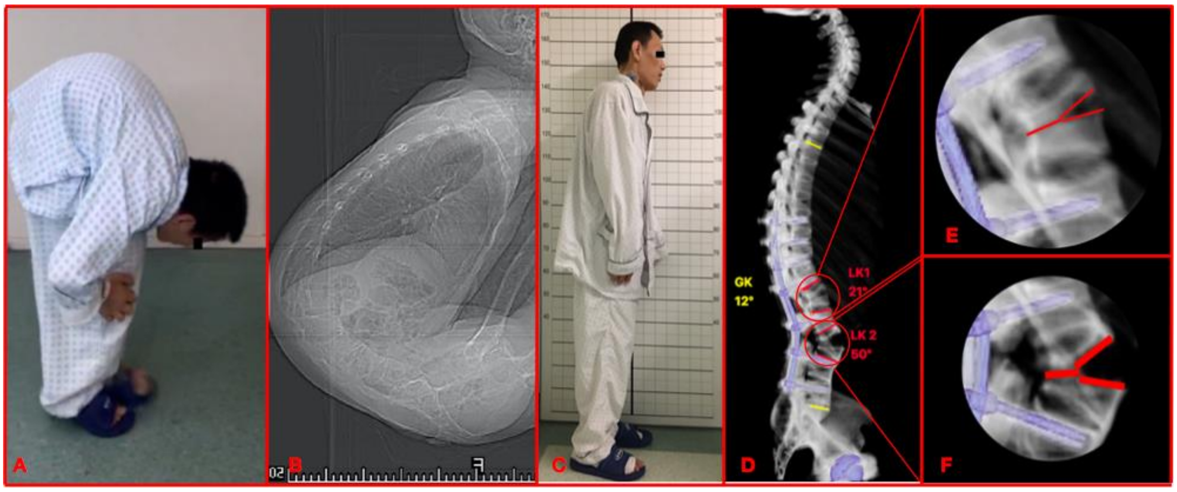
There are several technical advantages to VCD as a corrective technique: (1) for the same correction degree as requested, opening the anterior cortex of the osteotomized vertebrae will decreases the required shorten distance of the middle column and lead to a reduced risk of neurologic deficits; (2) intra-operatively, the degree of correction was adjusted by a movable hinge, the anterior column served as the hinge at the beginning, then the hinge was moved to the middle column subsequently when the osteotomy gap of middle column was closed; (3) the order of this procedure is from inside to outside (with the eggshell and cancellous bone compression technique) rather than from outside to inside, which means it is not necessary to expose the segmental vessels in most cases, less blood loss and vascular complications was expectable [19, 20]; and (4) residual bone of the middle column of the osteotomized vertebrae, serves as a ‘bony cage’, could avoiding the occurrence of sagittal translation intra-operatively and bring better fusion in the future [14, 19].



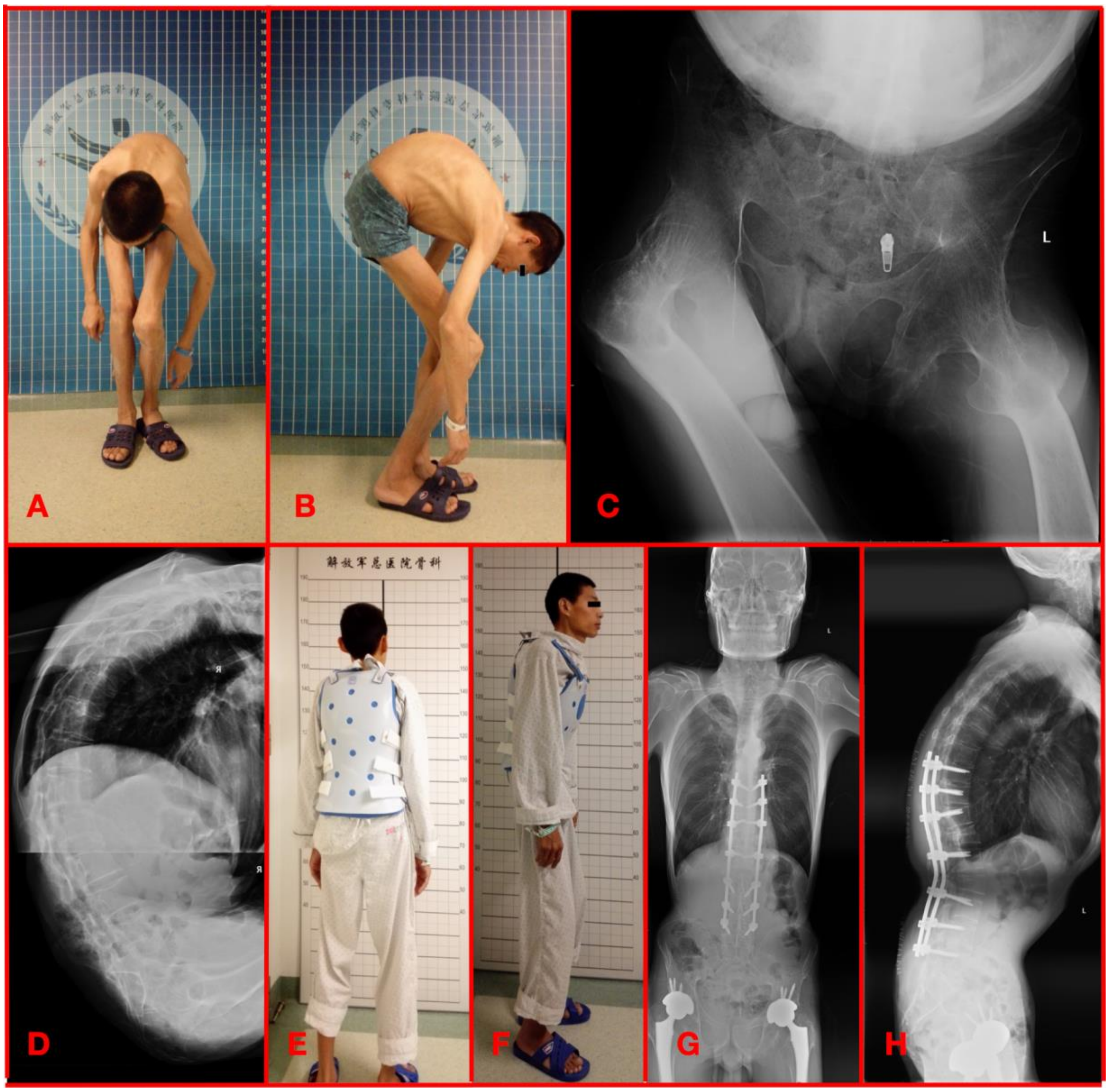
➤ **Figure 6.** Pedicle subtraction osteotomy: A, Both of the pedicles and a V-shaped bony wedge of the vertebral body are resected. B, The correction was obtained by closing the osteotomy gap with the anterior cortex acting as a hinge.



➤ **Figure 7.** Vertebral column decancellation: A, The anterior and middle of vertebra was removed as less as possible while with the posterior column removed completely. The osteotomy gap is 'Y' shape rather than 'V' shape. B, anterior column served as the hinge at beginning and then the hinge moved to the middle column at last.



➤ **Figure 8.** Two-level VCD osteotomy in a 38-year-old man: preoperative clinical photo (A) and radiographs (B) show 96 °global kyphosis. Postoperative clinical photo (C) and lateral radiograph (D) after two-level VCD performed at L1 and L3 show his excellent sagittal alignment with the global kyphosis corrected to 12 °and the osteotomy vertebrae were posterior column closing with anterior column opening just like shape "Y" (E, F).



➤**Figure 9.** Spinal osteotomy in a 38-year-old man with severe kyphotic deformity caused by ankylosing spondylitis. A and B, preoperative photograph demonstrating a “folding shape”. C and D, preoperative radiographs. E and F, postoperative photographs demonstrating a significant improvement of appearance. G and H, postoperative standing anteroposterior and lateral radiographs of the entire spine.

Postoperative management

Postoperative management was same in all patients and they were allowed to sit up in bed 24 h after the surgery. The drain was removed when the output decreased to <50 ml/24 h, which was usually 3–5 days after surgery. The patients were allowed to ambulate with a custom-made plastic thoracolumbosacral orthosis (TLSO) after 3 days. If there was cerebrospinal fluid (CSF) leakage, the drainage time and in bed time should be prolonged. The TLSO was used during the first 3 to 6 months after surgery.

Radiologic and clinical parameters

The standard radiographic measurements included global kyphosis (GK) [21], which was measured from the superior end plate of the T5 thoracic vertebra to the superior end plate of the S1 vertebra. Local kyphosis (LK) [22], was defined as the cobb angle between the superior endplate of one vertebra above the osteotomy and the inferior endplate of one vertebra below the osteotomy (LK1: superior osteotomy vertebra; LK2: inferior osteotomy vertebra). The sagittal vertical axis (SVA) [23], was the distance between the C7 plumb line and the posterior superior corner of S1. The clinical records were reviewed for operative time, blood loss, complications, and chin-brow vertical angle (CBVA) [24], which was defined as the angle measured between a line from the brow to the chin to the vertical, while the patient stood with the hips and knees extended.

Statistical analysis

Statistical analyses were performed using SPSS (version 18.0; SPSS, Inc., Chicago, IL, USA). Comparisons of the pre- and post-operative spinal sagittal parameters and CBVA were performed with a paired sample t-test. The patients were also divided into two groups according to the number of osteotomy segments, and the operative time, the blood loss volume, and the rate of complications were compared. Values for $P < 0.05$ were considered statistically significant.

RESULTS

All patients could walk with horizontal vision and lie on their backs post-operatively. One-level osteotomy was performed in 339 patients, and two-level osteotomy was performed in the remaining 89 patients (Table 1). Neither mortalities nor any major neurologic complications were occurred during the follow-up; however, 32 patients suffered one or two complications have been encountered, including CSF leaks (n=21, 9 in two-level group and 12 in one-level group), transient neurological deficits (n=3, in the two-level group), vascular laceration bleeding (n=1, in the two-level group), infections (n=2, 1 in the two-level group and 1 in the one-level group), post-operatively low back pain (n=5, 2 in the two-level group and 3 in the one-level group), spinal rod broken (n=3, 2 in the two-level group and 1 in the one-level group), distally pedicle screws pull out (n=4, 2 in the two-level group and 2 in the one-level group), and non-fusion at osteotomy site (n=4, 3 patients associated with Andersson's lesion pre-operatively), as shown in Table 2.

Table 2. Frequency of complications in 2 groups

Complication	Frequency	
	one-level group (n=339)	two-level group (n=89)
CSF leaks	12	9
Neurologic deficit	0	3
Vascular laceration bleeding	0	1
Surgical site infection	1	1
Low back pain	3	2
Rod broken	1	2
Pedicle screws loosening	2	2
Pseudarthrosis	3	1

Pre- and 2-year follow-up radiological and clinical outcomes of the 428 patients are shown in Table 3. All patients demonstrated changes in pre- and post-operative radiological parameters and the CBVA. The pre- and post-operative average GK were corrected from 82.6° to 12.7° ($p<0.05$) in the two-level group and from 55.8° to 9.6° ($p<0.05$) in the one-level group. The CBVA improved from 68.3° to 8.2° ($p<0.05$) in the two-level group and from 46.2° to 4.2° ($p<0.05$) in the one-level group. The mean SVA improved from 29.4 cm to 8 cm ($p<0.05$) in the two-level group and from 18.0 cm to 4.3 cm ($p<0.05$) in the one-level group. The operative time, blood loss, and complication rate is shown in Table 3. The average operative time of the one-level group was 253 min versus 331 min for the two-level group, the average operative-related blood loss was 537 ml in the one-level group and 1132 ml in the two-level group, and the complication rate was 6.5% in the one-level group (22 of 339 patients) and 23.6% in the two-level group (21 of 89 patients). The results demonstrated that the operative time, blood loss, and frequency of complications was significantly higher in patients who underwent two-level osteotomy than in patients who underwent one-level osteotomy ($p<0.05$; Table 3).

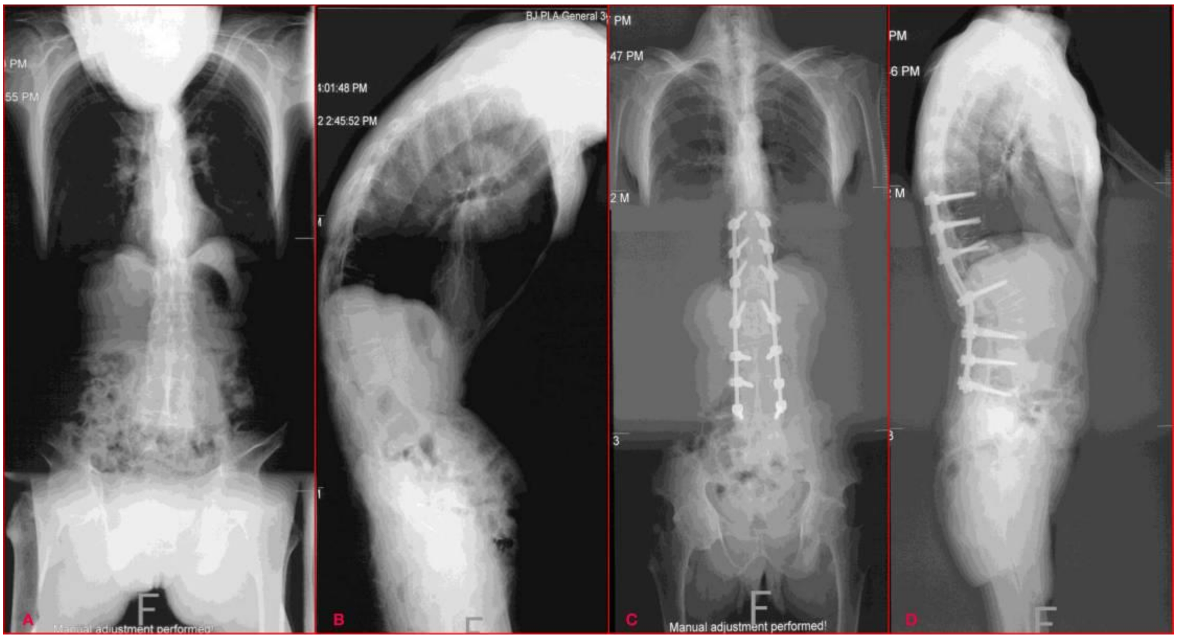
Table 3. Pre-, intra-, and post-operative clinical and radiologic parameters of the patients.

Variable	one-level osteotomy (n=339)	two-level osteotomy (n=89)
Operation time (min)	253±51.2	331±85.3*
Blood loss (ml)	537±121.3	1132±417.2*
Complication rate (%)	6.5%	23.6%*
GK (°)		
Pre-op	55.8±21.3	82.6±29.2
Post-op	9.6±6.2#	12.7±12.1#
LK1 correction (°)	46.2±12.9	27.8±10.5
LK2 correction (°)		42.1±13.2
SVA (cm)		
Pre-op	18.0±8.9	29.4±8.5
Post-op	4.3±5.1#	8±4.6#
CBVA (°)		
Pre-op	46.2±10.9	68.3±21.5
Post-op	4.2±3.3#	8.2±7.9#

Note: * Compared with one-level osteotomy group, P < 0.05 and statistically significant; # Compared with pre-operation, P < 0.05 and statistically significant; GK: global kyphosis; LK: local kyphosis; SVA: sagittal vertical axis; CBVA: chin-brow vertical angle;

Discussion

Surgical correction, such as spinal osteotomy, may be the appropriate option for the treatment of AS patients with sever kyphosis deformity [8, 9, 25]. Spinal osteotomy, which has been proven by us, did not just corrected the sagittal deformity, but also significantly increased the pulmonary function (Figure 10) [26, 27], digestive function by relieving abdominal viscera compression [21, 28], cardiac function [29], and sexual activity [30] of patients with AS.



➤**Figure 10** [26]**.** Changes of lung volume before and after spinal osteotomy. Radiographs of 1 male patient with AS, A and B, 41-year old man with 74 ° thoracolumbar kyphosis preoperatively. C and D, the postoperative lung volume increased from 4017 to 4798 mL, 781 mL (19.4%) more than preoperative value.

Adequate pre-operative planning of the surgery is critical for sagittal plane corrective osteotomies of the spine in AS. Suk [24] and Van Royen [31] used the CBVA and biomechanical and mathematical method for planning the correction angle and the osteotomy site, while these methods carry some limitations [11, 32]. Thus, we have explored a new osteotomy angle calculation method according to an analysis of the center of gravity (CG) of the trunk [11, 16]. Based on our extensive clinical experience, we found that the hilus pulmonis (HP) is located over the hip axis (HA) in normal subjects, so we chose HP as the marker of the center of CG of the trunk. Thus, if we shifted the HP over the hip axis, the exact angle required for spinal osteotomy in patients with AS kyphosis can be calculated.

Theoretically, an osteotomy at the apex vertebra should achieve a better corrective effect [29, 33, 34]. With the same correction angle, osteotomy at the lower level vertebra can achieve higher safety [35]. Therefore, we prefer to perform osteotomy at the lumbar or thoracolumbar spine. Usually, we do not perform osteotomy at L4 or L5 because L4 and L5 are not the apex vertebrae of lumbar lordosis [11], and the fusion to the sacrum and the short lever arm of the distal part of fusion will result in discomfort or an inability to sit on the floor [34]. In view of these above-mentioned considerations, we suggest that most of the osteotomy sites are located at the second and third lumbar vertebra because the third vertebra is the apex of the lumbar spine and the second vertebra is usually near the thoracolumbar kyphosis. In addition, the second and third vertebrae are usually located below the conus medullaris, which means osteotomy can be performed more safely. For thoracic hyperkyphosis, T12 or L1 will also be accepted as the osteotomy site because T12 or L1 are near to the apex vertebra.

In our opinion, a two-level spinal osteotomy at the spinal cord region is not recommended. First, satisfactory reconstruction of lumbar lordosis is necessary, because the loss of lumbar lordosis is usually co-existent with hyperkyphosis of the thoracolumbar and thoracic spine. Second, spinal osteotomy in non-spinal cord regions is relatively safety, and osteotomy at the lumbar region could achieve a relatively large operating space and correction angle [25]. At the same time, a continuous two-level spinal osteotomy will not be recommend because the excessive shortening of the area may result in buckling of the dura and spinal cord, which is very dangerous [36]. Thus, with respect to severe thoracolumbar kyphotic deformities, the ideal combination of osteotomy sites is L1 and L3. If the apex of the kyphosis is located above T12, we may choose T12 and L2 as osteotomy sites [25].

Several spinal osteotomy techniques include the Smith-Petersen osteotomy (SPO) [37], PSO [17], and VCD [14, 19], have been applied for the AS kyphotic deformity. However, the most effective and safe surgical procedure for AS-related kyphosis deformity is still controversial [2, 9, 38]. A SPO is more suitable for flexible kyphosis and without ossification of the anterior column of the spine [39-41]. PSO is a technically demanding procedure with relatively great surgical trauma and high risk of complications [41, 42]. VCD osteotomy, which first described in 2011 by us as an operative technique for the treatment of patients with sharp angular spinal deformity [19]. It has been performed as an effective and excellent treatment option for kyphotic deformity in patients with AS [14, 15].

In the current study, the total complication rate was 10.1% (43 complications in 32 patients) for all 428 patients, and there were no major acute complications, such as death or complete paralysis occurred. The patients were also divided into 2 groups according to the number of osteotomy segments (one- and two-level osteotomy groups), and the significantly high complication rate of the two-level osteotomy group (23.6%) when compared with the one-level osteotomy group (6.5%). Therefore, a two-level osteotomy can provide more extensive correction than a one-level osteotomy, at the same time, it brings a higher complication rates.

To our experience, CSF leak, as the most common complication in the literatures [14, 25], is difficult to avoid when the dura is extremely thin due to the chronic inflammation adherent to the surroundings, especially to the ossified ligamentum flavum [1, 9]. If a dural tear occurrs intra-operatively, prompt management of the leak with a gel sponge or muscle and myofascia should be made, and a drainage tube should be left until the output fell to <50 ml/24 h, and the time for drainage and bedrest should be prolonged if needed. To avoid neurological damage, it is safer to perform a creeping expansion laminectomy. Many investigators have reported there is a potential for pseudarthrosis or rod breakage when the osteotomy is performed through an area that is not previously fused at the time of osteotomy [40, 43]. Thus, we suggested that a sufficient bone graft must be achieved to facilitate better bony fusion and better stability in the corrected position at the time of osteotomy. For infection and vascular laceration bleeding, to strengthen the principle of asepsis during and after surgery and gentle manipulation during surgery can avoid vascular damage. There are some other complications that have been reported, such as paralytic ileus [44], which resolved after a Levin tube insertion and oral intake restriction, and blindness, possibly caused by local extrusion during the operation, which may be avoided by paying more attention to protect the eyes, usually by the non-operative personnel [45]. Because of the complication rate of spinal osteotomy, the indication should be carefully assessed, and should be performed by experienced spine surgeons who have mastered various types of deformity correction techniques, and the role of non-operative assistants is also of importance, especially when positioning patients and during reduction [25].

Based on the great series of AS-related kyphotic deformity treated by spinal osteotomies in our single spine center, we recommend many key points that should be conscious in order to ensure the successful performance of the several spinal osteotomy techniques:

(1) Pre-operative detailed surgical plan base on radiological and clinical evaluation is critical. An understanding of neural structures and deformity types of the spine will be clearer. The method, location, and range of the osteotomy can be determined, and the length and fixation point of the internal fixation can be selected.

(2) Bleeding can be controlled with bipolar electrocautery or with the application of absorbable hemostatic gauze and gelatin sponge, and/or with controlled hypotension during the operation. At the same time, three methods are used to replenish blood loss: 1) cell saver, which re-transfuses the patient’s own blood; 2) blood from the blood bank is given to the patient when necessary; 3) and for the first 6 h, blood from the suction drains is collected and remains fused using a postoperative cell saver [19].

(3) Accurate fixation of the pedicle screws, sufficient length fixed of the spine (at least two segments above and below the designated osteotomy site), and a high successful rate of disposable nailing should be ensured to provide sufficient and reliable fixation strength.

(4) Extended central laminectomy should be performed to the adjacent lamina above and below the osteotomy level to ensure that there is no impingement on the dural sac and nerve roots, then the neurologic elements are visualized directly during closure.

(5) Optimal prebending of the spinal rod and sufficient paste to the spinal curve, so as to avoid the occurrence of broken rods or pedicle screws pull out.

(6) For severe deformity, gentle and continuous bilateral symmetrical compression forces were applied on the rods (one proximal and one distal) to the osteotomy at the same time during closure, and supplemented by the gradual extension of the folding operating table to achieve position reduction.

Conclusion

In this study, we reported the results of a large series of two types of spinal osteotomies for AS kyphosis, focusing on the surgical strategy, technical aspects, complications, correction outcomes, and compared the results of one-level osteotomy with the results of two-level osteotomy. The results demonstrate that both PSO and VCD are effective osteotomies in correcting kyphotic deformity in AS. Among them, VCD osteotomy, as a simple and effective procedure with number of advantages, include the higher fusion rates, lower complication rate, acceptable operation time and bleeding, should be mastered by spine surgeons.

In addition, a personalized surgical plan should be made according to the type of deformity and the characteristics of the surgeon, and an intra-operative careful operation is also needed for the successful process of the surgery, and the role of non-operative assistants is also important.

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