Original Article

Computer Simulation of Two-level Pedicle Subtraction Osteotomy for Severe Thoracolumbar Kyphosis in Ankylosing Spondylitis

Abstract

Background: Advanced ankylosing spondylitis is often associated with thoracolumbar kyphosis, resulting in an abnormal spinopelvic balance and pelvic morphology. Different osteotomy techniques have been used to correct AS deformities, unfortunnaly, not all AS patients can gain spinal sagittal balance and good horizontal vision after osteotomy. **Materials and Methods:** Fourteen consecutive AS patients with severe thoracolumbar kyphosis who were treated with two-level PSO were studied retrospectively. All were male with a mean age of 34.9 ± 9.6 years. The followup ranged from 1–5 years. Preoperative computer simulations using the Surgimap Spinal software were performed for all patients, and the osteotomy level and angle determined from the computer simulation were used surgically. Spinal sagittal parameters were measured preoperatively, after the computer simulation, and postoperatively and included thoracic kyphosis (TK), lumbar lordosis (LL), sagittal vertical axis (SVA), pelvic incidence, pelvic tilt (PT), and sacral slope (SS). The level of correlation between the computer simulation and postoperative parameters was evaluated, and the differences between preoperative and postoperative parameters were compared. The visual analog scale (VAS) for back pain and clinical outcome was also assessed. **Results:** Six cases underwent PSO at L1 and L3, five cases at L2 and T12, and three cases at L3 and T12. TK was corrected from 57.8 ± 15.2° preoperatively to 45.3 ± 7.7° postoperatively ($P < 0.05$), LL from 9.3 ± 17.5° to −52.3 ± 3.9° ($P < 0.001$), SVA from 154.5 ± 36.7 to 37.8 ± 8.4 mm ($P < 0.001$), PT from 43.3 ± 6.1° to 18.0 ± 0.9° ($P < 0.001$), and SS from 0.8 ± 7.0° to 26.5 ± 10.6° ($P < 0.001$). The LL, VAS, and PT of the simulated two-level PSO were highly consistent with, or almost the same as, the postoperative parameters. The correlations between the computer simulations and postoperative parameters were significant. The VAS decreased significantly from 6.1 ± 1.9 to 2.0 ± 1.1 ($P < 0.001$). In terms of clinical outcome, 10 cases were graded "excellent" and 4 cases were graded "good." **Conclusion:** Two-level PSO using a preoperative computer simulation is a feasible, safe, and effective technique for the treatment of severe thoracolumbar kyphosis in AS patients with normal cervical motion.

Keywords: *Ankylosing spondylitis, computer simulation, osteotomy, spinal kyphosis*
MeSH terms: *Osteotomy, kyphosis, spondylitis, ankylosing, visual analogue pain scale*

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Introduction

Ankylosing spondylitis (AS) is a chronic inflammatory disease that mainly affects the spine and sacroiliac joints.[1] Thoracolumbar kyphosis secondary to advanced AS often causes spinal sagittal imbalance and poor horizontal vision, and these adversely affect the patient's physiological, psychological, and chest and abdominal organ functions.[2-4] Different osteotomy techniques have been used to correct AS deformities, but pedicle subtraction osteotomy (PSO) is the most commonly used method.[5-8] However, not all AS patients can gain spinal sagittal balance and good horizontal vision after PSO due to insufficient, excessive, or improper osteotomy segment selection.[9,10] Therefore, good preoperative planning is important to achieve a more physiologic spinal sagittal balance.[9,11] The Surgimap Spine (Nemaris Inc., New York, NY, USA) software, a free computer program for the surgical planning of osteotomies, has been successfully applied in single-level PSO. Many studies have shown there to be great consistency between the postoperative spine and pelvis sagittal parameters and the preoperative and planning parameters.[11] In addition, Surgimap Spine's planning method is much simpler and quicker than comparable methods. Single-level PSO may also be insufficient for correcting severe and rigid thoracolumbar kyphosis in some cases, and therefore, some researchers have applied two-level PSO in these cases.[12,13] However, good preoperative

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planning remains important even for two-level PSO. The main purpose of this study, therefore, was to investigate the efficacy of computer simulations of two-level PSO in severe and rigid thoracolumbar kyphosis secondary to advanced AS.

Materials and Methods

14 consecutive AS patients with severe thoracolumbar kyphosis underwent two-level PSO at our hospital between January 2010 and January 2014 were included in this retrospective study. The diagnosis of AS was made by radiographical features, laboratory tests, and clinical features according to the New York criteria for diagnosing AS. All cases were male with an average age of 34.9 ± 9.6 (range 22–58 years) years. Two-level PSO was planned for all patients using the Surgimap Spine software. Cervical ankylosis was considered an exclusion index because the main goal for the treatment of these patients was to recover the chin-brow vertical angle (CBVA).[14]

Pre- and postoperative full-length anteroposterior and lateral spine radiographs and flexion extension stress lateral cervical radiographs were measured in all patients. The sagittal C0-7 Cobb's angle was measured on flexion extension stress lateral radiographs, and the difference was defined as cervical motion.[15]

According to the measurement methods recommended by the Scoliosis Research Society,[16] we measured the thoracic kyphosis (TK) (T5–T12 Cobb's angle), lumbar lordosis (LL; T12–S1 Cobb's angle), and sagittal vertical axis (SVA; the distance between the C7 plumb line and the posterior endplate of the S1 vertebral body, where the C7 plumb line located in front of the posterior endplate of the S1 vertebral body is defined as positive, and when located behind the posterior endplate of the S1 vertebral body is defined as negative). We also measured pelvic parameters such as pelvic incidence (PI; the angle between the line perpendicular to the S1 endplate at its midpoint and the line connecting this point to another line bisecting the center of the femoral heads), sacral slope (SS; the angle between the horizontal and upper sacral endplate), and pelvic tilt (PT; the angle between the vertical and the line through the midpoint of the sacral plate to the femoral head axis).

Clinical data, including the back pain visual analog scale (VAS) score and clinical efficacy rate,[5] were also obtained. Clinical efficacy was defined as excellent if the patient was restored to an upright posture and horizontal vision; good if the patient was left with residual mild deformity but no pain; moderate if the patient was left with residual obvious deformity or back pain; and poor if the patient's symptoms were worse than the preoperative conditions.

Use of the Surgimap Spine software for pedicle subtraction osteotomy planning

First, we used the Surgimap Spine software to measure TK, LL, SVA, PI, PT, and SS.[11] Then, we simulated single-level osteotomy. When selecting osteotomy segments, one should aim to include the largest SVA restoration, minimize the incidence of neurological complications, and get close to the apical vertebrae of the kyphosis. Therefore, we usually chose L3 or L2 as the osteotomy segment in single-level PSO. Second, as isosceles triangle osteotomy can achieve a greater degree of correction than right triangle osteotomy, we usually performed the former.[11] Third, the largest single-level osteotomy angle is set to 40°. When a single-level osteotomy could not achieve a physiological sagittal spinal profile, such as SVA ≤50 mm, PT <20°, and LL = PI ± 9°,[17] we chose two-level PSO to obtain a physiological sagittal spinal profile [Figures 1 and 2]. The principle of osteotomy segment selection is the same as for single-level PSO. We do not advocate two consecutive segmental osteotomies because it is difficult to perform correction without causing greater disturbance of the nerves. Finally, we performed two-level PSO with the planned osteotomy segment and angle according to the simulation results.

Statistics

The SPSS 16.0 (SPSS Inc., Chicago, IL, USA) statistical software was used to analyze the data. Pre- and postoperative parameters were compared using a paired *t*-test, and the consistency of preoperative computer simulation osteotomy parameters and postoperative parameters was analyzed by a Kappa test. Kappa values of 0.81–1.0 were considered to be very good and 0.61–0.80 as good. The level of significance was set at $\alpha = 0.05$.

Results

The average followup is 3.2 years (range 1–5 years). The cervical range of all patients is more than 50°. The osteotomies were performed at L1 and L3 in 6 cases, T12 and L2 in 5 cases, and T12 and L3 in 3 cases. The operation time was 240–390 min, with an average of 303 ± 45 min. The intraoperative average blood loss was 1453 ± 907 mL (range 700–3500 mL) [Table 1]. Two cases experienced unilateral lower limb weakness (with a quadriceps muscle

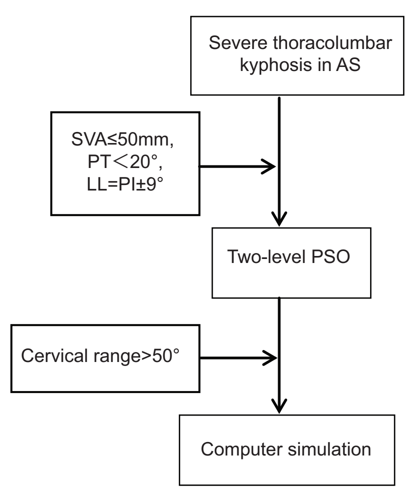

Figure 1: Algorithm for treatment of severe thoracolumbar kyphosis in ankylosing spondylitis

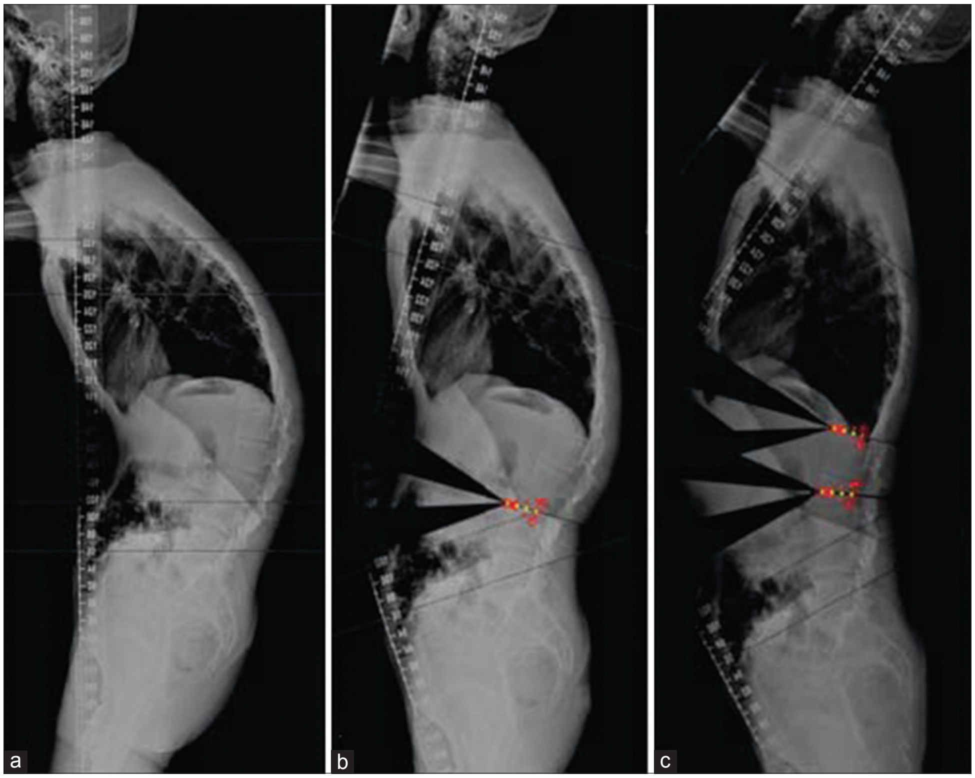

Figure 2: Two-level pedicle subtraction osteotomy is performed when single level pedicle subtraction osteotomy cannot restore the physiological sagittal spinal profile. (a) Preoperative thoracic kyphosis was 47°, lumbar lordosis was 14°, sagittal vertical axis was 169 mm, pelvic incidence was 38°, pelvic tilt was 42°, sacral slope was −4°; (b) The simulating L3 single segment pedicle subtraction osteotomy cannot restore sagittal spinal balance; (c) The simulating L1 and L3 two-level pedicle subtraction osteotomy restore sagittal spinal balance: pelvic incidence 38°, lumbar lordosis 42°, pelvic tilt 8.7°, sagittal vertical axis 48 mm

Table 1: Patient demographics

Patients	Sex	Age	Blood loss (ml)	Operative time (min)	Osteotomy levels
1	Male	30	855	330	L1, L3
2	Male	58	2900	360	T12, L2
3	Male	41	840	240	L1, L3
4	Male	32	1000	260	T12, L3
5	Male	29	700	260	L1, L3
6	Male	46	750	300	T12, L2
7	Male	22	900	270	T12, L3
8	Male	29	850	350	L1, L3
9	Male	33	2200	310	L1, L3
10	Male	45	800	335	T12, L2
11	Male	32	1900	390	T12, L2
12	Male	30	3500	250	L1, L3
13	Male	37	750	290	T12, L3
14	Male	25	2400	300	T12, L2

strength of grade 3 out of 5) postoperatively, which had fully recovered at 1 and 3 months postoperatively. Cerebrospinal fluid leakage occurred in one patient, and this healed after continuous drainage for 4 days plus focal oppression.

All patients regained a physiological sagittal spinal profile, with an average osteotomy angle of 59.1 ± 5.3°. The average TK was 57.8 ± 15.2° preoperatively and 45.3 ± 7.7° postoperatively, but the difference was not statistically significant. The average LL was 9.3 ± 17.5° preoperatively and −52.3 ± 3.9° postoperatively, and the difference was statistically significant. The average SVA was 154.5 ± 36.7 mm preoperatively and 37.8 ± 8.4 mm postoperatively, with a significant difference. The average PT was 43.3 ± 6.1° preoperatively and 18.0 ± 0.9° postoperatively, and the difference was statistically significant. The average SS was 0.8 ± 7.0° preoperatively and 26.5 ± 10.6° postoperatively and was significantly different [Table 2 and Figure 3].

The LL, SVA, and PT of the simulated two-level PSOs were highly consistent with, or almost the same as, the postoperative parameters. The kappa values of the pre- and postoperative data were 0.91, 0.76, and 0.83, respectively [Figure 4].

All patients retained horizontal vision and regained flat lying. The average lower back pain VAS score was 6.1 ± 1.9 preoperatively and 2.0 ± 1.1 postoperatively, with a significant difference. The clinical efficacy was excellent in 10 cases and good in 4 cases, and the combined excellent and good rate was 100%.

Discussion

Advantages of the Surgimap Spine software for preoperative planning

Patients with advanced AS usually have reduced LL, kyphosis, or increased TK, causing sagittal spinal imbalance

Table 2: Comparison of the preoperative and postoperative spine and pelvis parameters

Preoperative and postoperative parameters	TK (°)	LL (°)	SVA (mm)	PT (°)	SS (°)
Preoperative	57.8±15.2	9.3±17.5	154.5±36.7	43.3±6.1	0.8±7.0
Postoperative	45.3±7.7	−52.3±3.9	37.8±8.4	18.0±0.9	26.5±10.6
P	<0.05	<0.001	<0.001	<0.001	<0.001

TK=Thoracic kyphosis, LL=Lumbar lordosis, SVA=Sagittal vertical axis, PT=Pelvic tilt, SS=Sacral slope

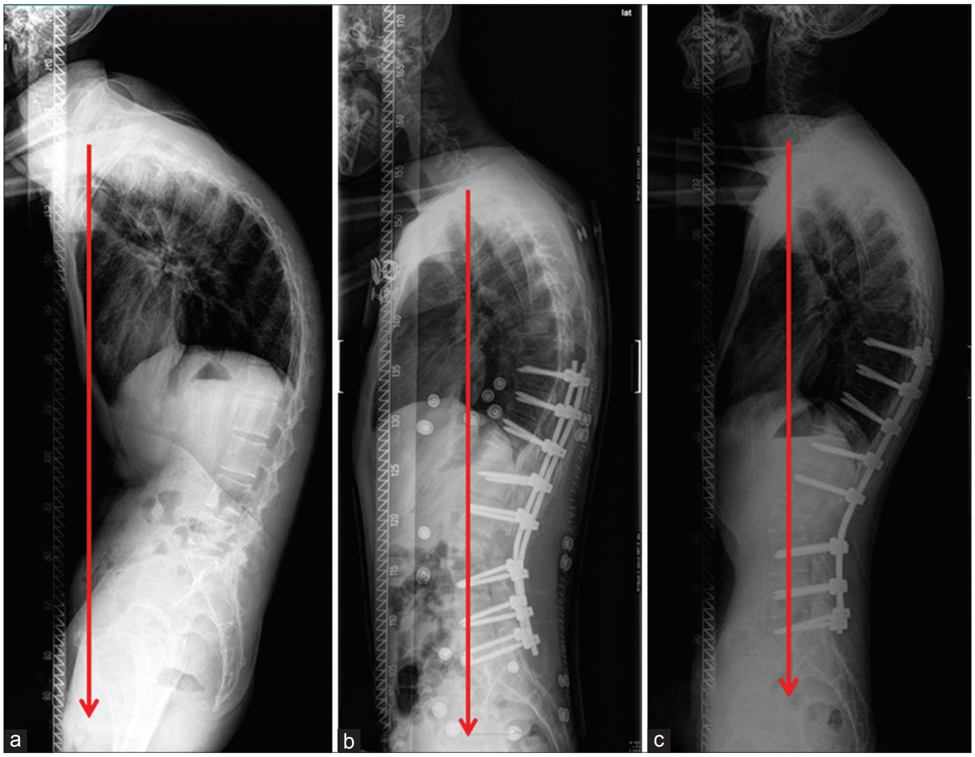

Figure 3: A case of 41-year-old male patient underwent two-level pedicle subtraction osteotomy and restored the physiological sagittal spinal profile postoperatively. (a) Preoperative thoracic kyphosis was 73°, lumbar lordosis was 11°, sagittal vertical axis was 175 mm, pelvic incidence was 36°, pelvic tilt was 44°, sacral slope was −8°; (b) One week postoperatively, thoracic kyphosis was 49°, lumbar lordosis was −53°, sagittal vertical axis was 37.6 mm, pelvic incidence was 38°, pelvic tilt was 20°, sacral slope was 18°. (c) One year postoperatively, sagittal spine maintains overall balance, and there was no significant change in all parameters

which severely affects the patient's quality of life. The sagittal profile of the thoracic spine is related to that of the cervical spine.[18-22] Such patients have lumbar back pain and difficulty in flat vision, flat lying, upright standing, and walking.[1-4] Thoracolumbar PSO technology has been widely used in the surgical treatment of these patients, and this can effectively improve the patient's thoracolumbar kyphosis, restore the sagittal spinal profile, and alleviate lower back pain so that patients are able to regain normal flat vision, upright walking, and flat lying.[1,3-6,11] Shin *et al*.[23] showed that the restoration of the spine and pelvis sagittal profile is closely related to clinical symptoms and function. To enable patients to obtain a physiological sagittal spinal profile, preoperative planning, including the osteotomy segment and osteotomy angle, is of great importance. Currently, the most commonly used preoperative planning methods include the paper-cut method,[24] the mathematical calculation method,[25] and the CBVA method.[14] However, these methods are all highly cumbersome and cannot simultaneously obtain sagittal parameters for both spine and pelvis. Park *et al*.[11] used the Surgimap Spine software to simulate single-level PSO osteotomy in 18 cases of AS with thoracolumbar kyphosis. The results demonstrated that the planning was simple and fast and that the software simultaneously provided the postoperative LL, TK, and SVA, which were all highly consistent with the actual postoperative parameters. In this study, we used the same software to plan two-level PSO for patients with kyphosis deformity secondary to advanced AS. All patients regained a physiological sagittal spinal profile because the average LL was −52.3 ± 3.9°, the SVA was 37.8 ± 8.4 mm, and the PT was 18.0 ± 0.9° postoperatively. We also found that the planning sagittal parameters of both spine and pelvis were also highly consistent with the postoperative parameters. Therefore, this software can be effectively applied to plan two-level PSO for patients with severe kyphosis deformity secondary to advanced AS.

However, it is worth noting that we excluded AS patients with cervical ankylosis in this study because the restoration of the CBVA has a greater impact on quality of life than

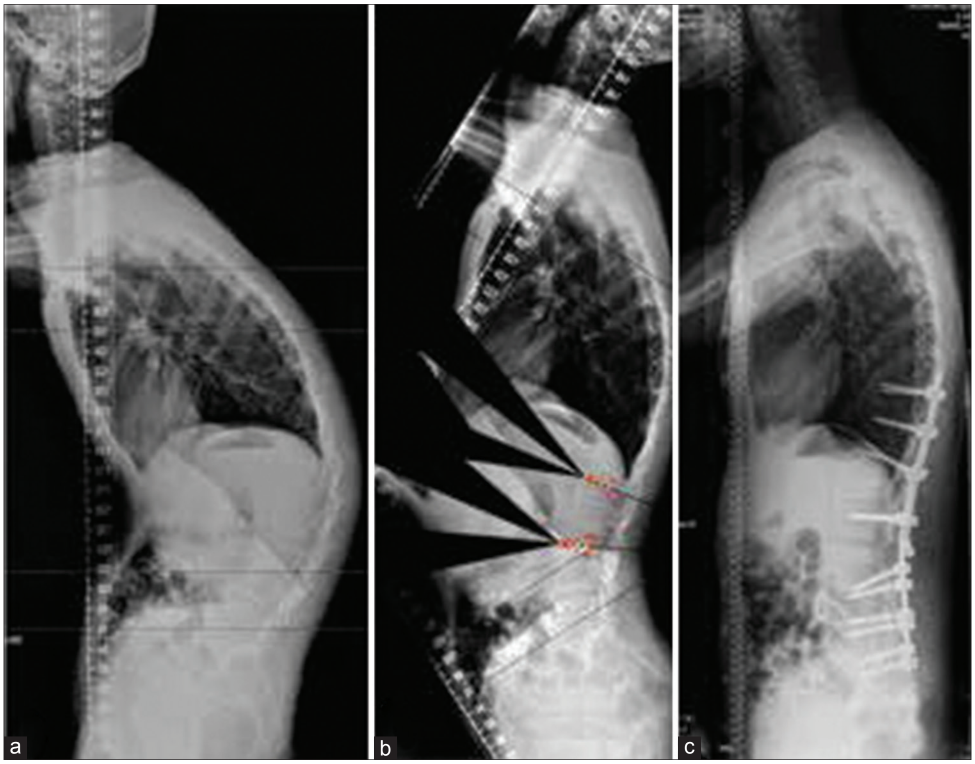

Figure 4: The result of computer simulation was highly consistent with the postoperative parameters. (a) Preoperative spine; (b) The simulating L1 and L3 two-level pedicle subtraction osteotomy; (c) The spine and pelvic parameters after L1, L3 two-level pedicle subtraction osteotomy, which were highly consistent with results of preoperative computer simulation

the other sagittal spinal parameters for these patients.[14] In addition, it is very difficult to measure the CBVA in patients with normal cervical motion. CBVA also has little clinical value because it is difficult to determine the true cervical neutral position in these patients, and the difference is greater between individuals. In view of this, we did not assess the CVBA in these patients but paid more attention to the patient's sagittal parameters for the spine and pelvis.

Indications for two-level pedicle subtraction osteotomy

Usually, patients with severe thoracolumbar kyphosis who undergo single-level PSO may still have kyphosis and spinal sagittal imbalance, which could seriously affect clinical efficacy. Schwab *et al*.[10] found that only 77% patients who underwent single-level PSO were able to gain sagittal balance postoperatively with the reasons for failure given as inadequate osteotomy segment selection and osteotomy angle. Qian *et al.*[26] also showed that for patients with large PI (>50°) and SVA, single-level PSO is often inadequate and an additional osteotomy is required to restore the sagittal spinal profile. Chen *et al.*[5] performed PSO osteotomies in 78 AS patients and found 14 cases with a thoracolumbar kyphosis angle larger than 70° that required two-level PSO. Zheng *et al.*[13] also proposed that two-level PSO is indicated for patients with thoracolumbar and lumbar kyphosis. In summary, for patients with severe kyphosis deformity, there is currently a lack of clear indications for two-segment or multiple-segment osteotomy. In our 14 patients, a preoperative computer-simulated osteotomy was conducted; as it is difficult to achieve a good physical spinal sagittal balance in single-level PSO, two-segment osteotomy was performed. Therefore, in this study, two-level PSO was indicated for patients with severe thoracolumbar kyphosis because single-level PSO cannot restore or nearly restore the spinal sagittal balance.

Theoretically, osteotomy segment selection and osteotomy angle both affect the restoration of the sagittal spinal profile. Most researchers have found that when the osteotomy segment is much further from the apical vertebrae and the osteotomy angle is much greater, the sagittal spinal profile will be restored more significantly.[11,13,26] We also confirmed this observation in the simulated osteotomy plan as the osteotomy segment and angle have a significant impact on LL, SVA, PT, and SS. To obtain the ideal sagittal spinal profile, we conducted several simulations of different osteotomy segments and angles.

In addition, neurological complications need to be considered when choosing the osteotomy segment. For this reason, we did not perform thoracic PSO surgery. Furthermore, the postoperative appearance is also an important factor that needs to be considered preoperatively. To obtain a more satisfactory appearance, we chose an osteotomy segment as close as possible to the apical vertebrae of the kyphosis after complying with the above mentioned two main principles.

The limitations of the current study include its retrospective nature posing problems of possible bias. Moreover, our study was limited in that we did not investigate the correlation between the restoration of sagittal spinal parameters and clinical symptoms. We also did not study the effects of osteotomy segment and osteotomy angle on the pelvic sagittal parameters. In addition, this study is only suitable for patients with normal cervical motion, and consideration of the importance of restoring, the CBVA is needed for patients with poor cervical motion or cervical ankylosis. If we only paid attention to the restoration of the sagittal spinal profile, an inadequate CBVA may affect patients' horizontal vision.

Conclusion

Preoperative computer simulation of two-level PSO is an effective procedure for treatment of severe thoracolumbar kyphosis in AS patients. It achieves good functional outcome on midterm follow up. However, this procedure is only suitable for the AS patients with normal cervical motion.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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