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Original Article

Comparison of efficacy for ankylosing spondylitis kyphosis with preoperative osteotomy designs using the Photoshop software or papercut/splice

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Abstract: Objective: Thoracolumbar kyphotic deformity is a common complication in the late stage of ankylosing spondylitis. The aim of this study was to compare the correction efficacy for ankylosing spondylitis kyphosis using preoperative osteotomy designs of papercut (PC)/splice and Photoshop (PS). Methods: This was a retrospective study of 35 patients with ankylosing spondylitis and thoracolumbar kyphotic deformity that underwent correction osteotomy at the Department of Spinal Surgery, Affiliated Hospital of Yan'an University between May 2009 and November 2014. The preoperative osteotomy design using PC/splice was applied in 17 patients and preoperative osteotomy design using PS was applied in 18 patients. The patients were followed-up for 18-30 months. The postoperative osteotomy angle error and correction efficacy at the last follow-up were compared between the two groups. Results: There were significant differences in the errors between postoperative actual and preoperative planned osteotomy angle of the PS group and PC/splice group ($P<0.01$). The spinal sagittal global kyphosis and sagittal vertical axis in the PS group were 29.3±11.1° and 3.1±1.6 cm, respectively, while those in the PC/splice group were 38.9±13.1° and 5.7±2.1 cm, respectively ($P<0.01$). The Oswestry Disability index and Scoliosis Research Society (SRS)-22 questionnaire score in the PS group were significantly higher to those in the PC/splice group ($P<0.05$). PS was independently associated with improvements in SRS-22 scores (OR=63.0; 95% CI: 1.73-2298.19; P=0.02). Conclusion: Compared with osteotomy design using traditional PC/splice, osteotomy design using the PS software could achieve a smaller osteotomy angle error and a better postoperative spinal balance in the sagittal plane.

Keywords: Photoshop software, thoracolumbarkyphotic deformity, correction for ankylosing spondylitis, osteotomy design, papercut/splice

Introduction

Thoracolumbar kyphotic deformity (TKLD) is a commonly complication of late-stage ankylosing spondylitis (AS) and can cause typical spinal round-shouldered or angular kyphotic deformity. In TKLD, the normal angle of lumbar lordosis decreased or even retroflexed, while the angle of thoracolumbar kyphosis is increased, resulting in forward leaning of the head and neck. Eventually, the full spine will generate bony ankylosis in a kyphosis posture, which directly causes spinal sagittal imbalance, deficiency of horizontal view angle, and physiological activity limitation, severely affecting the daily life of the patients [1, 2].

Surgical osteotomy and correction is the main method for treating this kind of deformity due to limited efficacy of traditional physiotherapy or orthopedic therapy. Presently, methods for preoperative osteotomy design mainly include: operator's experience, papercut (PC)/splice, 3D models, and professional software [3-7], but all of these methodsare not widely used due to a certain degrees of deviation and limitations. The limitations and deviations can be costly and make difficult to correct rotational misalignment, which is difficult to assess despite the use of a repositioning device. The other limitation of computer-assisted correction with manipulator-fixator system is that no minimally invasive fixation method is available instead of the fracture-fixation plate and screws.

We have developed a method for preoperative calculation of the osteotomy angle and osteotomy simulation by using the Photoshop (PS) software, and applied this method in the preoperative osteotomy design for patients with ASkyphosis (ASK), which showed satisfactory results. This study introduced this osteotomy

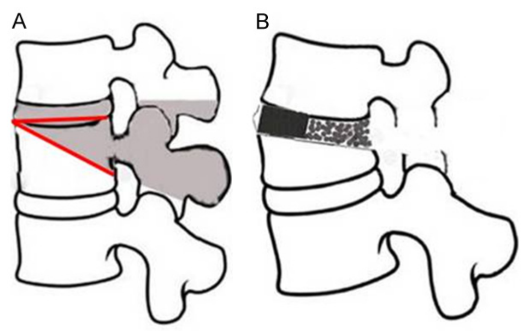

Figure 1. Patients received correction osteotomy using the modified pedicle subtraction closing wedge osteotomy (PSO) method by the same group of surgeons. The osteotomy was performed in the single segment of L1-L4 levels. (A and B) represent pre- and post-operation, respectively.

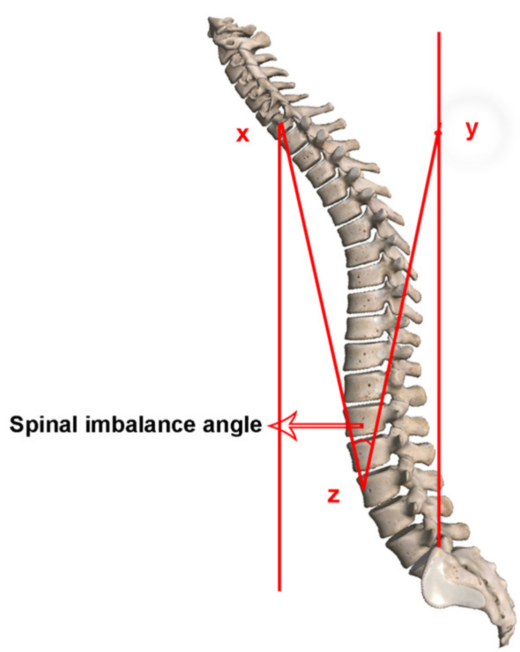

Figure 2. Calculation principle of the spinal imbalance angle. Point z is the apex of the osteotomy vertebra, the center of the C7 vertebral body (x) was migrated to cross the plumb line of the posterior edge of the sacrum (y) to ensure xz=yz.

design using the PS software, and compared its efficacy with the traditional PC/splice method.

Materials and methods

General information

This was a retrospective study of 35 patients with ankylosing spondylitis and thoracolumbar kyphotic deformity that underwent correction osteotomy at the Department of Spinal Surgery, Affiliated Hospital of Yan'an University between May 2009 and November 2014. All patients received correction osteotomy using modified pedicle subtraction closing wedge osteotomy (PSO) by the same group of surgeons (**Figure 1**). The osteotomy was performed in the single segment of L1-L4 levels. The patients were followed-up for 8-36 months (mean, 18 months) except two patients who were lost to follow-up and one patient who died of another disease. Preoperative osteotomy design using PC/splice was applied in 17 cases (13 males and four females; 22-53 years of age, mean of 32.6 years). Preoperative osteotomy design using PS was applied in 18 patients (14 males and four females; 23-50 years of age, mean of 34.2 years).

Inclusion/exclusion criteria

Inclusion criteria: (1) lower lumbago and morning stiffness for more than 3 months, which was improved after activitiesbut was not alleviated at rest and accompanied by sacroiliitis; (2) limited activities in lumbar flexion, extension, and lateral bending, accompanied by sacroiliitis; (3) thoracic mobilitylower than normal for people of the same age and gender, and accompanied by sacroiliitis; and (4) significant thoracolumbar kyphotic deformity, forward leaning of the head and neck, and incapability of horizontal viewing; bamboo form spine was visible on X-ray, accompanied by decreased lumbar lordosis, and even retroflex as well as increased thoracickyphosis.

Exclusion criteria: (1) spinalkyphotic deformity caused by any other reasons; or (2) thoracolumbar and lower limb disorderscaused by lumber disc herniation, trauma, or any other reasons.

Methods

The patients were grouped according to the preoperative planning they underwent (PS vs. PC/splice). The preoperative planning osteotomy angle, postoperative actual osteotomy angle, and sagittal parameters before and after the surgery were collected.

Preoperative osteotomy design in the PS group

Prior to surgery, lateral X-ray films of the full spine in the standing position, as well as X-ray

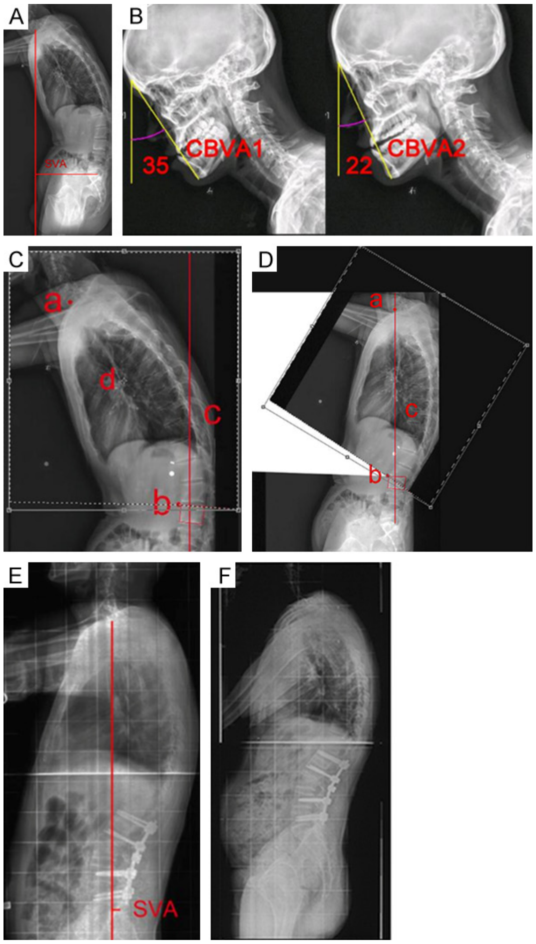

Figure 3. A 34-year-old male patient with thoracolumbar kyphotic deformity. A: Lateral X-ray of the full spine before operation, showing that the C7 plumb line was far away from the posterior edge of the sacrum (S1), which resulted in severe spinal deformity. B: The cervical extension and flexion X-ray of the CBVA including head and neck, showing the determination of the osteotomy angle to recover the CBVA (=CBVA1-10° to CBVA2+10°=12°-45°). C and D: The SIA measured by PS was 30.81°, which was decided as the ultimate osteotomy angle since it was in the range of the osteotomy angle for CBVA recovery. Then we could determine directly the location and scope of the osteotomy using the ruler tools of PS. E: Lateral X-ray of full spine 1 week after surgery: the preoperative osteotomy line was very close to the postoperative actual osteotomy line, and the postoperative C7 plumb line was near to the posterior edge of the sacrum (S1), leading to excellent spinal sagittal balance. F: Lateral X-ray of the full spine 2 years after surgery, showing fusion of the osteotomy segment, without loss of deformity correction.

films of the cervical spine in hyperextension and hyperflexion were taken, during which the patients' bilateral knee and hip joints were maintained at full extension. The raw data of the X-ray films were exported as. Img format and transformed to standard .jpg pictures with a ratio of 1:1. A measurement template was developed using the measurement tools in PS, which was used to measure the following sagittal parameters of the spine and pelvis: global kyphosis (GK), lumbar lordosis (LL), sagittal vertical axis (SVA), pelvic incidence (PI), pelvic tilt (PT), Cobb angle of osteotomy segment, and chin brow-vertical angles (CBVA) of the cervical spine in hyperextension and hyperflexion. Data were exported and saved in Microsoft Excel.

Theoretical osteotomy angle

The ideal spinal sagittal balance means that the C7 plumb line runs across the posterosuperior edge of the sacrum, which refers to a SVA value of 0. The osteotomy angle was calculated and simulated using the PS software according to the calculation principal of spinal imbalance angle (SIA) (**Figure 2**), as proposed by Yang *et al.* [8]. It should be noted that the osteotomy apex was located at the anterosuperior edge of the vertebra since the pedicle subtraction closing wedge osteotomy (PSO) was selected in this study. The operational procedures are illustrated in **Figure 3C-F**: (1) the center of C7 vertebral body (a), osteotomy apex of the vertebra (b), plumb line crossing the posterior edge of sacrum (c), a line passing through the superior endplate of the osteotomy vertebra as well as the contour of the osteotomy vertebra were marked preoperatively in the lateral X-ray films using PS. (2) The images above the osteotomy line of the osteotomy vertebra were selected, and the pivot of the PS software (d) was migrated to the osteotomy apex of the osteotomy vertebra. (3) The osteotomy vertebra was rotated around the pivot until the C7 center coincided with the plumb line crossing the posterior edge of the sacrum, in which the theoretical osteotomy angle to recover the spinal imbalance was automatically measured in PS. The surgical osteotomy location and scope were also determined. If it was needed to further obtain the accurate osteotomy location, the distances between the osteotomy point (e) and the superior/inferior endplates or pedicle could be measured using the ruler tools in PS, hereby providing guidance for intraoperative osteotomy location. In osteotomy simulation, if the planned osteotomy angle was unlikely to be obtained using a single vertebra, dual segmental osteotomy would be selected, where the osteotomy angle and scope were determined using the methods mentioned above.

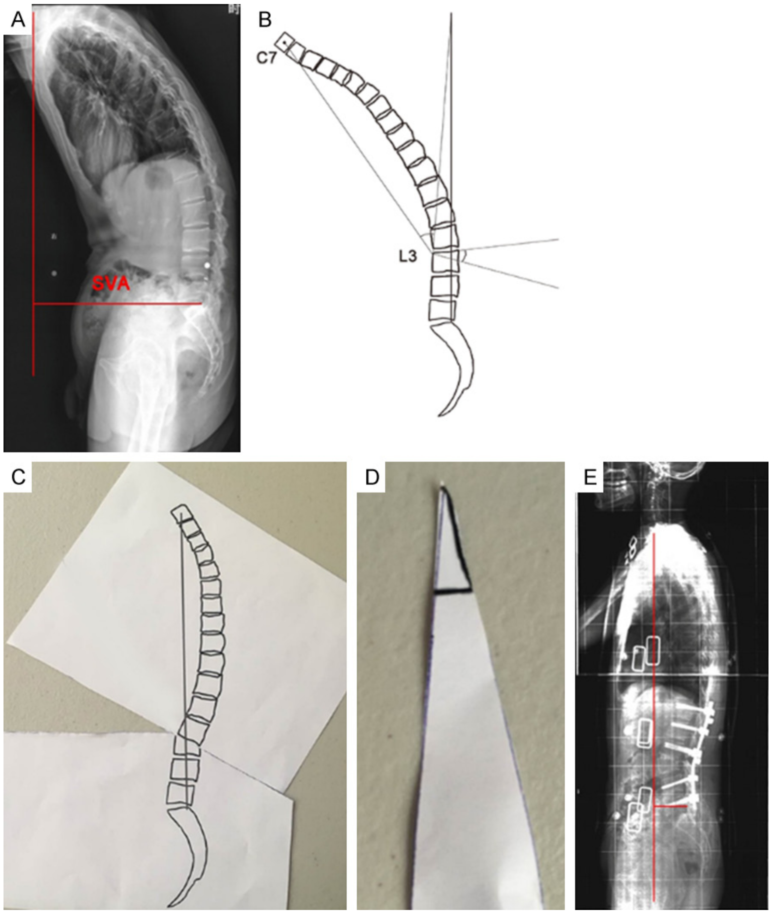

Figure 4. A 26-year-old male patient with thoracolumbar kyphotic deformity. A: Lateral X-ray of full spine before operation, showing that the C7 plumb line was far away from the posterior edge of the sacrum (S1), resulting in severe spinal deformity. B: The X-ray was copied on paper with a 1:1 ratio, and the spinal imbalance angle was measured. C: The paper was cut at L3 and the pieces were spliced to achieve SVA=0. D: The angle of the wedge-shaped paper piece was measured to ensure the best osteotomy position and range. E: Spinal imbalance was improved after operation.

Determination of osteotomy plane

After calculating the osteotomy angle using PS, the osteotomy was simulated by placing the osteotomy apexat the L1-L4 separately, where a vertebra returning a minimum osteotomy angle to recover sagittal balance was selected as the osteotomy plane.

Determination of actual osteotomy angle

The actual osteotomy angle had to be corrected according to individual CBVA. Suk *et al.* [9] believed that a CVBA ranging from -10° to 10° after osteotomy was preferable, while an angle >10° was referred to under correction and an angle <-10° was referred to overcorrection. Meanwhile, the change of CBVA caused by spinal kyphosis osteotomy was basically equal to the osteotomy angle. Therefore, the ultimate osteotomy angle should be corrected referring to the CBVA. Given that the vertical spine in patients with ASK has a certain range of activities, the osteotomy angle for recovering CBVA was determined to range from cervical hyperextension CBVA (CBVA1) -10° to cervical hyperflexion CVBA (CBVA2)+10°, where theosteotomy angle was corrected as CBVA1+10° for a case with a SIA larger than CBVA1+10°, while it was not necessary to correct for a case with a SIA ranging from CBVA1-10° to CBVA2+10°. Subsequently, the osteotomy angle was appropriately reduced or increased according to the patient's daily work and life. For example, a certain CBVA could be retained in a patient who needed to drop the head and study by a desk, in which the osteotomy angle could be corrected as CBVA2-10°.

Preoperative osteotomy design in the PC/splice group

The preoperative spinal and pelvic sagittal parameters were routinely measured using the X-ray films. The preoperative lateral X-ray film of the full spine in the standing position was 1:1 monotyped on paper, on which the Cobb angles of each part on the spinal sagittal plane were measured. The osteotomy correction was simulated on paper to dynamically observe the correction efficacy, hereby to determine the best osteotomy location and angle. Meanwhile, the surgical osteotomy location and scope were determined by measuring the width of the posterior part of the osteotomy segment (**Figure 4**).

Surgical method

Patients received general anesthesia, and transnasal incubation guided by optical fiber in the awakened status was performed to prevent spinal fractures and spinal cord injury when changing the postures. The patients were placed in prone the position, and the operating table was folded into a proper angle according to the kyphosis extent. A sponge mats was blocked under the abdomen to avoid floating of the abdomen. During surgery, the spine was monitored using somatosensory evoked potentials. Firstly, the vertebral body was positioned using a C-arm X-ray machine, and the Cobb angle between the superior and inferior endplates of the head side vertebra of the osteotomy segment was measured on the lateral images using the measurement tools that come with the X-ray machine. Then, a median incision of the posterior lumbar vertebra was made to expose subperiosteally the posterior structure of the vertebra for fusion. Pedicle screws were implanted separately in at least two segments at the head and tail sides of the osteotomy vertebra. After that, the vertebral spinous process, lamina, superior articular process, and other posterior structures were removed, and the vertebra and intervertebral disc above the osteotomy line were chiseled using a bone knife according to the preoperative osteotomy location and scope. The endplate of the upper vertebra was worked into a rough surface, during which the nerve and spinal cord were protected. An appropriate interbody infusion or humeral ring allograft (Bone bank, Xijing Hospital of No.4 Military Medical University) was inserted to guarantee support in front of the vertebral body. Finally, the folded operating table was slowly reset, the abdominal mat was removed, where closure of part of the osteotomy space was visible, and bone fragments obtained by trimming the lamina were inserted into the back part of the interbody infusion. Two pre-bent titanium rods of appropriate length were intercepted and implanted using the cantilever technique, followed by further closure of the osteotomy space. The osteotomy space was gradually closed using instrument pressurization, and the actual osteotomy angle (intraoperative Cobb angle-preoperative Cobb angle) was measured under fluoroscopy until the planned osteotomy angle was achieved. After surgery, patients were wakened up to confirm that they had normal functionality of the lower limbs. The bone bed was made, and the posterolateral fusion was performed after crunching the posterior structure of the resected vertebra, followed by drainage indwelling and wound closure layer by layer.

Postoperative treatment

Patients received routine anti-infection treatment and were given anti-osteoporosis drugs. They started activity with the help aid of a holder after the drainage tube was removed 3-5 days after the surgery. Lateral X-ray films of the full spine in the standing position were taken 1 week after surgery and at the last follow-up. The Cobb angle of the osteotomy vertebra was measured on the images obtained 1 week after surgery to calculate the actual osteotomy angle (=postoperative Cobb angle of osteotomy vertebra minus the preoperative Cobb angle of osteotomy vertebra). The sagittal parameters of the spine and pelvis (SVA, GK, LL, PT, and PI) as well as CBVA were measured using the images obtained 1 week after surgery and at the last follow-up.

Functional assessment

Preoperative and postoperative functions of patients with ASK were mainly assessed using a visual analogue scale (VAS), Oswestry disability index (ODI), and Scoliosis Research Society-22 (SRS-22) questionnaire [10-13]. All patients filled these forms before operation, 1 week after operation, and at the last follow-up.

Statistical analysis

Data were expressed as mean ± standard deviation ($\overline{x}$±s) and analyzed using paired *t*-test and independent sample *t*-test, as appropriate. Categorical data were presented as frequencies and analyzed using the chi-square test. The differences of the SRS-22 score (△SRS-22) before operation and at the last follow-up was calculated. The median △SRS-22 was 20, which was set as the cutoff value of efficacy outcome of operation. To analyze which variables were related with the surgical outcome, △SRS-22>20 was set as effective outcome (dependent variable), and SVA, GK, LL, PT, CBA, and ODI were set as independent variables for multiple logistic regression. Results were reported as odds ratios (OR) and 95% confidence intervals (95% CI). All the statistical analyses were performed using SPSS 16.0 (IBM, Armonk, NY, USA). A difference with P<0.05 was considered statistically significant.

Table 1. Comparison of imaging measurement and functional indexes between the experimental and control groups ($\bar{x}\pm s$)

	PS (18)	PC/splice (17)	*P*
Age (years)	32.3±6.7	31.8±6.9	1.000
Male, n	15	14	0.829
SVA (°)			
Preoperative[a]	12.8±4.9	11.9±4.7	0.583
One week after operation[b]	3.1±1.6	6.1±2.2	<0.001
Last follow-up[c]	3.4±1.5	6.0±1.9	<0.001
P value	$P^{a,b}<0.001$ $P^{a,c}<0.001$	$P^{a,b}<0.001$ $P^{a,c}<0.001$	
GK (°)			
Preoperative[a]	60.2±14.9	62.5±15.6	0.658
One week after operation[b]	29.3±11.1	38.4±12.9	0.032
Last follow-up[c]	30.2±11.5	39.6±12.8	0.029
P value	$P^{a,b}<0.001$ $P^{a,c}<0.001$	$P^{a,b}<0.001$ $P^{a,c}<0.001$	
LL (°)			
Preoperative[a]	4.3±12.7	5.4±13.1	0.802
One week after operation[b]	-43.1±8.5	-37.2±6.3	0.026
Last follow-up[c]	-42.2±8.3	-36.8±6.2	0.037
P value	$P^{a,b}<0.001$ $P^{a,c}<0.001$	$P^{a,b}<0.001$ $P^{a,c}<0.001$	
PI (°)			
Preoperative[a]	48.5±7.1	46.5±6.9	0.404
One week after operation[b]	46.7±7.6	47.7±7.8	0.703
Last follow-up[c]	48.1±8.1	47.9±7.9	0.941
P value	$P^{a,b}=0.468$ $P^{a,c}=0.876$	$P^{a,b}=0.638$ $P^{a,c}=0.586$	
PT (°)			
Preoperative[a]	23.4±9.1	24.8±9.2	0.653
One week after operation[b]	13.1±4.3	16.3±5.3	0.026
Last follow-up[c]	14.2±4.1	17.8±5.5	0.037
P value	$P^{a,b}<0.001$ $P^{a,c}<0.001$	$P^{a,b}=0.002$ $P^{a,c}=0.011$	
CBVA (°)			
Preoperative[a]	33.6±8.9	35.1±9.0	0.802
One week after operation[b]	6.3±3.6	9.8±3.8	0.026
Last follow-up[c]	6.7±3.5	10.1±3.9	0.037
P value	$P^{a,b}<0.001$ $P^{a,c}<0.001$	$P^{a,b}<0.001$ $P^{a,c}<0.001$	
VAS			
Preoperative[a]	7.4±1.1	7.6±1.1	0.594
One week after operation[b]	2.6±0.8	2.9±0.9	0.304
Last follow-up[c]	2.7±0.8	3.0±0.8	0.275
P value	$P^{a,b}<0.001$ $P^{a,c}<0.001$	$P^{a,b}<0.001$ $P^{a,c}<0.001$	
ODI			
Preoperative[a]	59.4±13.3	62.4±15.1	0.536
One week after operation[b]	13.9±4.2	17.8±4.4	0.011
Last follow-up[c]	14.5±4.4	18.2±4.3	0.016
P value	$P^{a,b}<0.001$ $P^{a,c}<0.001$	$P^{a,b}<0.001$ $P^{a,c}<0.001$	
SRS-22			
Preoperative[a]	57.4±9.7	59.6±10.1	0.516
One week after operation[b]	80.1±13.1	71.9±9.8	0.045
Last follow-up[c]	79.5±12.8	70.4±10.2	0.037
P value	$P^{a,b}<0.001$ $P^{a,c}<0.001$	$P^{a,b}<0.001$ $P^{a,c}<0.001$	

Preoperative planned osteotomy angle (°)[a]	30.0±6.5	32.7±7.1	-
Postoperative actual osteotomy angle (°)[b]	30.3±5.9	26.6±6.4	-
P value	$P^{a,b}$=0.550	$P^{a,b}$=0.013	-
Osteotomy angle error (°)	1.68±0.92	5.49±2.14	<0.001

Abbreviations: Photoshop (PS), papercut (PC), global kyphosis (GK), lumbar lordosis (LL), sagittal vertical axis (SVA), pelvic incidence (PI), pelvic tilt (PT), Cobb angle of osteotomy segment as well as the chin brow-vertical angles (CBVA), visual analogue scale (VAS), Oswestry disability index (ODI), Preoperative value (a), Postoperative value (b), Last follow-up value (c), Scoliosis Research Society-22 (SRS-22).

Results

Generation results

All the patients in the PS group underwent osteotomy of a single vertebra (L3, L4, and L2 in 12, two, and four patients, respectively), among whom thetheoretical osteotomy angle (SIA), cervical hyperflexion CBVA (CBVA1)+10°, and cervical hypertension CBVA (CBVA2)-10° were implemented in 13, four, and one patients, respectively. The 17 patients in the PC/splice group also underwent osteotomy of a single vertebra (L1, L2, L3, and L4 in two, five, seven, and three patients, respectively), among whom the osteotomy angle was determined using the PC/splice of the monotyped x-ray films as well as the surgeons' experience.

Age, gender, SVA, and GK are shown in **Table 1**, which revealed that the preoperative general characteristics as well as the kyphosis extent were similar between the two groups (all P> 0.05). In the PS group, the preoperative planned osteotomy angle was very close to the postoperative actual osteotomy angle (P>0.05). On the other hand, the difference between the preoperatively planned osteotomy angle and postoperative actual osteotomy angle was significant in the PC/splice group (P<0.05). Meanwhile, the osteotomy angle error (the absolute value of the difference between the preoperative planned osteotomy angle and the postoperative actual osteotomy angle) was significantly smaller in the PS group compared with the PC/splice group (*P*<0.05) (**Table 1**).

Imaging measurement and evaluation of clinical functions

Key sagittal parameters (SVA, GK, and PT) of the spine and pelvis as well as CBVA at 1 week after operation and at the last follow-up were significantly different compared with those before the operation in both groups (all P<0.0001), while these parameters measured 1 week after surgery did not show significant difference compared with those at the last follow-up (all P>0.05), suggesting that a certain correction efficacy was obtained in both groups. Meanwhile, SVA, GK, and PT were smaller in the PS group at the last follow-up compared with the PC/splice group (all P<0.05) and were closer to the ideal sagittal parameters of the spine and pelvis (PT<20°, SVA<5 cm) [14]. In addition, the CBVA at the last follow-up were all in the ideal range of -10° to 10° in the PS group [9].

In both groups, the VAS, ODI scores, and SRS-22 scores at 1 week after operation and at the last follow-up showed significant differences compared with preoperative values (all P<0.001), while those at 1 week after surgery were similar to those observed at the last follow-up (all P>0.05), indicating that the function was improved significantly in both groups. Furthermore, the ODI and SRS-22 scores at the last follow-up in the PS group were significantly superior to those in the PC/splice group (*P*<0.05), while the VAS score was similar between the two groups (*P*>0.05).

Thirteen patients were found to be with a △SRS-22 value >20. The multivariate analysis showed that the preoperative osteotomy design method (OR=63.0; 95% CI: 1.73-2298.19; P=0.02) and ODI (OR=0.86; 95% CI: 0.75-0.98; P=0.03) were independently associated with operation efficacy, i.e. that the use of PS and patients with lower baseline ODI had better outcomes at the last follow-up (**Table 2**).

Discussion

Correction of spinal deformity aims to reconstruct the sagittal balance, restore normal gait, supine, and horizontal view as well as improve appearance [15]. In the present study, osteotomy location was selected in the lumbar vertebra since we believed that better sagittal balance could be achieved by compensating thoracic kyphosis with lumbar lordosis because of

Table 2. Multiple logistic regression analysis for the effect of using PS on the errors between postoperative actual and preoperative planned osteotomy angle

Variables	OR	95% CI	*P* value
PS vs. PC	62.964	1.73, 2298.19	0.024
SVA	1.250	0.94, 1.66	0.124
GK	1.075	0.97, 1.20	0.190
LL	0.998	0.91, 1.09	0.967
PT	1.118	0.94, 1.33	0.208
CBA	1.135	0.93, 1.39	0.215
ODI	0.859	0.75, 0.98	0.028

Photoshop (PS), papercut (PC), global kyphosis (GK), lumbar lordosis (LL), sagittal vertical axis (SVA), pelvic incidence (PI), pelvic tilt (PT), Cobb angle of osteotomy segment as well as the chin brow-vertical angles (CBVA), visual analogue scale (VAS), Oswestry disability index (ODI), odds ratio (OR), 95% confidence interval (95% CI).

the following reasons: (1) the lumbar osteotomy was conducted below the spinal conus level, having wide spinal canal and free from the effects of the ribs and thorax, hereby a bigger correction angle could be achieved using the same osteotomy procedure, and avoid to a larger extent the risk of spinal cord and nerve root injuries; (2) a larger sagittal correction could be achieved by conducting osteotomy of the spinal coccygeal body [6, 16, 17]. In a previous study, we randomly measured the osteotomy angles at different osteotomy planes (T6-L5) in 40 patients with ASK using PS, and found that the required osteotomy angle was gradually decreased with descending osteotomy plane. (3) some studies reported that LL was associated with PT, PI, and SS, while thoracic kyphosis was not significantly correlated with PT, PI, and SS [18-21]. Therefore, restoring the physiological lumbar lordosis tended to recover the pelvic compensatory status, hereby enabling the spinal curvature to be a most stable status with minimum energy consumption. Although this study took into account many aspects of spinal kyphosis, still a variety factors were excluded from the osteotomy design. Patients with advanced ankylosing spondylitis may show decreased lumbar lordosis or increased thoracic kyphosis, which lead to forward leaning of their body, hereby requiring the hypertension of the adjacent cervical and thoracic segments and hip joints, pelvic tilt and knee flexion and other compensatory means in order to maintain gravity balance and horizontal viewwhen walking. Therefore, persistent tension and contraction of muscles, increased articular surface pressure and other factors may lead to fatigue and pain of the neck, waist, hip, and knee after activities. However, when we measure the osteotomy angle for spinal kyphotic deformity, we often consider only spinal imbalance alone while neglecting the compensation for the pelvis, hip, and knee joints, hereby prone to under-correction. The angles for compensation of hip and knee joints may be counteracted by knee joint extension, while the angle for compensation of the pelvis can only be determined by the surgeon's experience [22]. Thus, further studies are required to quantify the osteotomy angle for pelvic compensation.

The commonly used Mimics software is a highly integrated software for generating and editing 3D images, allows constructing and editing 3D modelsafter importing various scanning data (CT and MRI), and has been widely applied in preoperative osteotomy design for different indications, including ASK [4]. However, Mimics simulates osteotomy using 3D CT data, which are obtained under non-weight-bearing conditions, hereby resulting in a certain bias between the acquired osteotomy angle and simulated osteotomy. In addition, Mimics tends to simulate the osteotomy in 3D images, with complicated operation, which requires professional treatment and is not applicable in surgery intuitively. On the other hand, PS is a large-scale image processing software, and is mainly used for processing digital images composed of pixels.In the present study, calculation of the osteotomy angle and osteotomy simulation were successfully implemented using PS based on the principle of ASK osteotomy, in which multistage osteotomy simulation and angle calculation could also be performed for severe kyphosis. Furthermore, if a general X-ray system is available, it is possible to simulate the osteotomy using PS as well as dynamically measure the changes of CBVA, hereby enabling to select the best balance between recovering the sagittalbalance and CBVA. In the present study, PS was used to determine the osteotomy plane, angle, location, and scope preoperatively. The postoperative sagittal parameters of the spine and pelvis (GK, SVA, CBVA, and PT) were restored to the ideal ranges, and remained stable at the last follow-up compared with the 1-week examination, suggesting that there is no loss of the correction effect. Furthermore, the postoperative ODI and SRS-22 scores were significantly improved compared with preoperative scores, indicating that patients recovered well on the psychological and physiological points of view. In addition, the multivariate analysis showed that surgery design using PS was independently associated with the surgical outcome (based on SRS-22 improvement) and that the baseline ODI score also played a role in the outcomes.

Limitations

The limitations of this study are the small sample size, and that PS could only be applied to simulate the improved PSO osteotomy rather than to simulate other osteotomy procedures. Therefore, further refinement and comparative validation are necessary.

Conclusion

Different osteotomy apexes can be determined for different osteotomy methods using PS, hereby calculating the osteotomy angle to recover spinal sagittal balance accurately. This method can dynamically simulate the osteotomy process, identify the osteotomy location and scope, allowing guiding the surgery directly and achieve an accurate osteotomy angle. It also allows determining the best osteotomy angle while balancing the restoration of the spinal sagittal balance and horizontal view angle. Therefore, compared with traditional osteotomy design using PC/splice, this method could have superior advantages in terms of recovering the spinal sagittal balance and horizontal view angle more accurately.

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Disclosure of conflict of interest

None.

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