CLINICAL ARTICLE

Pedicle Subtraction Osteotomy in Lateral Position: A New Strategy for Correcting Severe Thoracolumbar Kyphosis Combined with Hip Flexion Contracture in Ankylosing Spondylitis

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Objective: To describe spinal osteotomy in lateral position, which might be a new strategy for correcting thoracolumbar kyphotic deformity combined with severe hip flexion contracture, and to present two cases in which this method was successfully performed.

Methods: Spinal osteotomies in lateral position were performed in two patients with severe thoracolumbar kyphosis combined with hip flexion contracture, which was not suitable for operation in the prone position. Case 1: a 33-year-old female AS patient still had severe hip flexion contracture due to poor rehabilitation after total hip replacement (THR). The range of movement of the hip was only about 15° in right and 10° in left. Pre-operativethoracic kyphosis (TK), thoracolumbar kyphosis (TLK), lumbar lordosis (LL), and sagittal vertical axis (SVA) were 52.4°, 49.1°, 42.7°, and 315 mm, respectively. Pedicle subtraction osteotomy (PSO) at L3 was performed in the lateral position. The eggshell procedure was used during osteotomy. Case 2: a 45-year-old male AS patient presented coexisting rigid thoracolumbar kyphosis and hip flexion contracture. The range of movement of the hip was only about 20° in right and 25° in left. Pre-operativeTK, TLK, LL and SVA were 34.9°, 66.8°, 58.8° and 290.8 mm, respectively. PSO at L_2 was performed in lateral position. The eggshell procedure was also used.

Results: Sagittal malalignments of both patients were greatly improved. For case 1, the total operation time was 5.5 h. The blood loss was 1500 mL and the amount of allogeneic blood transfusion was 1580 mL during the operation. SVA was reduced to 127 mm and LL decreased from preoperative 42.7° to −28.4°. The correction angle through L_3 was 34.7° and the correction angle through the osteotomy segment was 62.9°. For case 2, the duration of surgery was 6.5 h. The operative blood loss was 2000 mL and the total amount of blood transfusion was 2020 mL. SVA was reduced to 209.8 mm and LL decreased from preoperative 58.8° to 9.2°.The correction angle through L_2 was 37.1° and the correction angle through the osteotomy segment was 55°. No intra-operative or post-operative complications were observed. Six months after PSO, case 1 had good posture for standing and sitting. The case 2 underwent bilateral THRs nine months after PSO.

Conclusion: PSO could be performed in the lateral position successfully. For AS patients who cannot be placed in the prone position due to coexisting severe thoracolumbar kyphosis and hip flexion contracture, performing spinal osteotomy in the lateral position as the first step is an alternative.

Key words: Ankylosing spondylitis; Pedicle subtraction osteotomy; Spinal osteotomy; Thoracolumbar kyphosis; Total hip replacement

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Introduction

Ankylosing spondylitis (AS) is a chronic, inflammatory rheumatic disease that primarily involves the sacroiliac joints, axial skeleton and hips[1,2]. Radiographic evidence of spinal fusion can be observed in approximately 18.5%–20% of AS patients[3]. A rigid thoracolumbar kyphosis may be the characteristic deformity in the AS latter stage, leading to sagittal spinopelvic imbalance and impairing the patient's horizontal gaze and activities of daily living[1,4]. The hip joints may be involved in about 30%–50% of AS patients[5]. Hip involvement ranges from flexion contractures to complete ankylosis, which is often in a disabling flexed position and affects the mobility of patients[2].

Surgical treatment of those AS patients who have rigid thoracolumbar kyphotic deformity combined with hip flexion contracture is still a formidable challenge. For such patients, spinal osteotomy and total hip replacement (THR) are usually both needed to correct sagittal imbalance and improve function of the hip[2,6]. However, there is still no consensus on the order of these two operations. Some authors recommended that the THR should be performed before the spinal osteotomy, because the pain relief and the improvement in range of movement of the hip might help in evaluating the residual sagittal spinal deformity more accurately in kyphotic AS patients combined with severe hip flexion deformity[7–9]. Other authors hold the opposite opinion[6,10,11]. Zheng *et al.*[6] proposed that primary spinal osteotomy would achieve satisfactory spinopelvic alignment and allow better acetabular component position and safer nursing during the operation.

Various spinal osteotomy techniques, including Smith–Petersen osteotomy (SPO), pedicle subtraction osteotomy (PSO), vertebral column resection (VCR) and vertebral column decancellation (VCD), have been described to correct AS thoracolumbar kyphosis deformity[12–17]. To our knowledge, all these spinal osteotomies reported in the literature are carried out in prone position. However, if AS patients with thoracolumbar kyphosis who have had THR previously still have severe hip flexion contracture due to poor rehabilitation and they are not able to lie in the prone position, how should we deal with such cases? We proposed spinal osteotomy would be able to be performed in the lateral position, which might be a new strategy for correcting severe thoracolumbar kyphosis combined with hip flexion contracture. The purpose of this study was to describe our method and to present two cases in which this method was performed successfully.

Materials and Methods

Patients Information

Patient 1 was a 33-year-old female AS patient with severe thoracolumbar kyphosis combined with hip flexionankylosis. She presented a "chin-on-thigh" deformity (Fig. 1A), which greatly restricted her daily activities. Radiography showed thoracolumbar, bilateral sacroiliac and hip joints were complete bony ankylosis (Fig. 1B,C). Prone position for spinal osteotomy was not able to be achieved due to the patient's trunk and thighs fixed in a serious deformity. Therefore, we determined that bilateral THRs were performed prior to spinal osteotomy. Immediately after THR, the range of movement of the bilateral hips reached 90°. However, when spinal osteotomy was ready to be carried out 3 months after THRs, the hips came back to a condition of severe flexion contracture due to poor rehabilitation (Fig. 1D). The position of hip prothesis was good and there was no dislocation of hips (Fig. 1F). The range of movement of the hip was only about 15° in the right and 10° in the left.

Patient 2 was a 45-year-old male AS patient with coexisting severe thoracolumbar kyphosis and hip flexion contracture (Fig. 2A). Radiography showed complete bony ankylosis in the whole spine and bilateral sacroiliac, and narrowing joint space and damage of articular surface in bilateral hip joints (Fig. 2B,C).The range of movement of the hip was only about 20° in right and 25° in left.

Radiographic Measurement

The preoperative and postoperative full-length spine radiographs of AS patients that included the whole spine and pelvis were taken. The following radiographical parameters were measured: pelvic incidence (PI), the angle between the line perpendicular to the sacral endplate at its midpoint and the line connecting this point to the center of the femoral heads; pelvic tilt (PT), the angle between the vertical axis and the line drawn from the midpoint of the sacral endplate to the center of the femoral heads; sacral slope (SS), the angle between the horizontal line and the line along the sacral endplate; thoracic kyphosis (TK), the angle between the upper endplate of T_4 and the lower endplate of T_{12}; thoracolumbar kyphosis (TLK), the angle between the upper endplate of T_{11} and the lower endplate of L_2; lumbar lordosis (LL), the angle between the upper endplate of L_1 and the upper endplate of S_1; sagittal vertical axis (SVA), the distance between the C_7 plumb line (C_7PL) and the superior posterior corner of S_1. The angle was positive if the curve was kyphotic and negative if the curve was lordoticfor TK, TLK and LL. Surgimapsoftware (New York, NY, USA) was used to measure all the parameters.

After spinal osteotomy, the local radiological parameters at the osteotomy including the correction angle through osteotomy vertebrae or segment were also assessed. The correction angle through osteotomy vertebrae was defined as the angle between the upper endplate and the lower endplate of the osteotomy vertebrae, and the correction angle through the osteotomy segment was defined as the angle between the upper endplate of one vertebrae superior to the osteotomy vertebrae and the lower endplate of one vertebrae inferior to the osteotomy vertebrae.

For patient 1, pre-operative PI, PT, SS, TK, TLK, LL, and SVA were 68°, 65.7°, 2.3°, 52.4°, 49.1°, 42.7° and 315 mm, respectively. For patient 2, pre-operative PI, PT, SS,

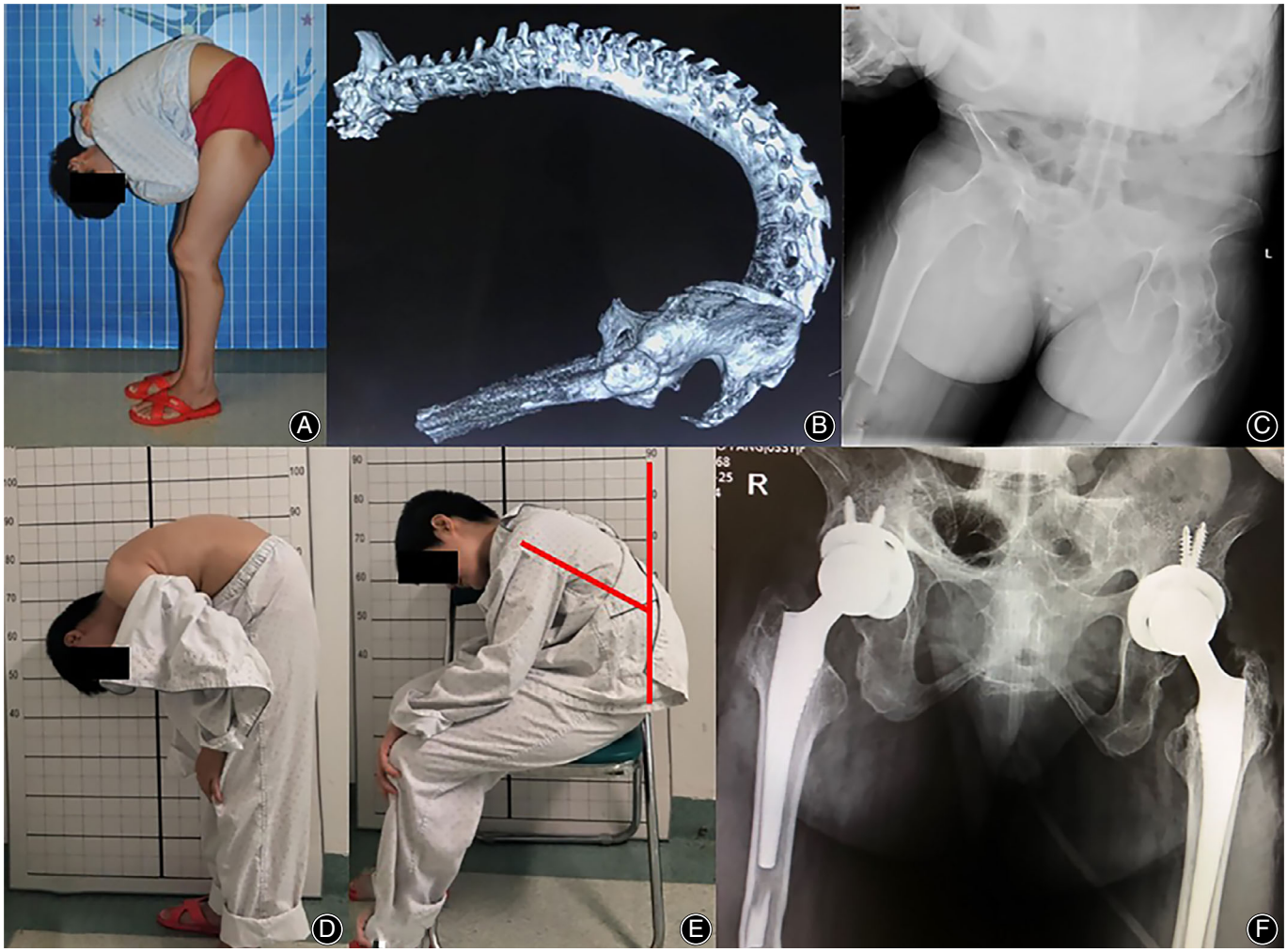

Fig. 1 (A) Preoperative clinical photograph showed the AS patient 1 with severe thoracolumbar kyphosis combined with hip flexion ankylosis. (B, C) CT three-dimensional reconstruction and X-ray revealed thoracolumbar, both sacroiliac and hip joints were complete bony ankylosis. (D) Photograph of the patient three months after THRs. The hips were still in a condition of severe flexion contracture. (E) Photograph of the patient sitting with extreme hip flexion. The correction angle should be smaller than the angle between the line drawn from L_3 to the should and the vertical axis. (F) Anteroposterior X-ray showed there was no dislocation after THRs.

TK, TLK, LL, and SVA were 50.8°, 53.0°, −2.2°, 34.9°, 66.8°, 58.8° and 290.8 mm, respectively.

Surgical Strategy

Because these two patients had coexisting severe thoracolumbar kyphosis deformity and hip flexion contracture, which was not suitable for operation in prone position, we decided to perform spinal osteotomy in the lateral position.

The spinal deformity of these two patients were both divided into Type IIB according Wang's classification system[18]. Reconstruction of the lumbar lordosis was the primary consideration and L_3 was the ideal osteotomy level. For patient 1, provided the hips were normal, the required correction angle was 120° according to Song's methods[1]. However, if the osteotomy was performed as calculated, the patient could not sit well because severe hip flexion contracture would not compensate for the restored sagittal alignment. So the correction angle should be smaller than the angle between the line drawn from L_3 to the shoulder and the vertical axis when the patient sat with extreme hip flexion, which was about 65° (Fig. 1E). Therefore we determined to make a one-level PSO at L_3 in patient 1.

For patient 2, the apex of kyphosis was L_2 and the Cobb angle between L_1 and L_3 was dominant for the whole kyphosis, thus L_2 was chosen as the osteotomy level. Similarly, the correction angle should be smaller than the angle between the line drawn from L_2 to the shoulder and the vertical axis when the patient sat with extreme hip flexion, which was about 55° (Fig. 2D). Therefore, one-level PSO at L_2 was performed on patient 2.

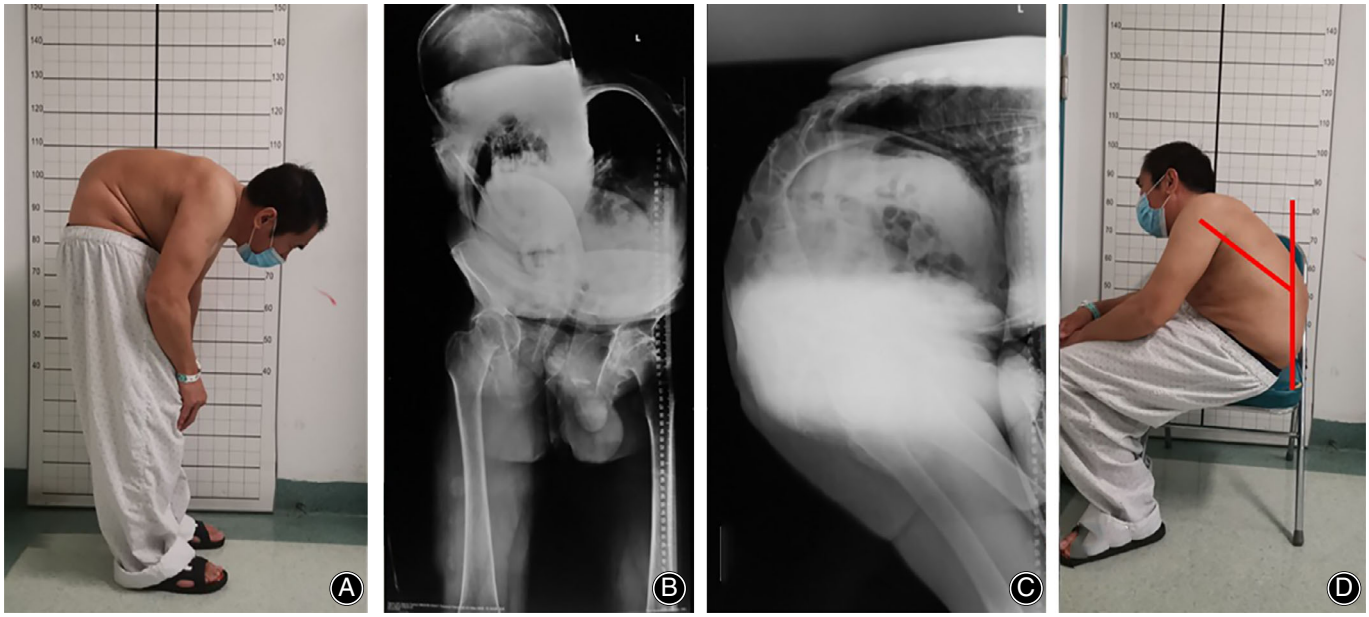

Fig. 2 (A) Preoperative clinical photograph showed the AS patient 2 with coexisting severe thoracolumbar kyphosis and hip flexion contracture. (B, C) Anteroposterior and lateral standing X-ray revealed complete bony ankylosis in the whole spine and bilateral sacroiliac, and narrowing joint space and damage of articular surface in bilateral hip joints. (D) Photograph of the patient sitting with extreme hip flexion. The correction angle should be smaller than the angle between the line drawn from L_2 to the should and the vertical axis.

The main concern about pedicel subtraction osteotomy in the lateral position was the influence of position on operative vision and surgical operation of osteotomy. The eggshell procedure was recommended and is useful in such situations[19]. We also performed osteotomy with gradually enlarged and triangular cone-shaped taps, which made osteotomy convenient and safe. As well as manipulation through the internal instruments and the strength of pushing on shoulders and pelvis by off-table staff might be the primary corrective forces in the lateral position.

Technique of Spinal Osteotomy in the Lateral Position

Under general endotracheal anesthesia, the patient was placed in a left lateral position (Figs 3A,B,4B,C). The operating table was flat and did not need any flexion to accommodate the kyphosis. Electrophysiological monitoring of somatosensory-evoked potentials (SEPs) and motor-evoked potentials (MEPs) were performed during the whole operation.

A standard posterior midline skin incision was made and subperiosteal dissection was carried out to expose the posterior bony elements. For patient 1, pedicle screws were inserted into T_{11}, T_{12}, L_1, L_2, L_4, L_5, and S_1 by a free-hand technique. For patient 2, pedicle screws were placed at both sides of T_{11}, T_{12}, L_1, L_3 and L_4, and the right side of L5 (Fig. 4A). The positions of the screws were confirmed by intraoperative radiograph. After both pedicles of osteotomy level (L_3 for patient 1 and L_2 for patient 2) were identified, holes were made through them into the vertebral body with probe. Then three progressively larger triangular cone-shaped taps were used to dilate the pedicle holes until the lateral cortex wall of pedicles was fractured. Through the pedicle holes the posterior cancellous bone of vertebral body was pushed anteriorly into the body to create a "V" shaped cavity with triangular cone-shaped taps and angled curettes. With small osteotome and angled curettes the bilateral cortex of the vertebral body was fractured and the anterior cortex was thinned. Care was taken to keep the medial wall of pedicles intact and to avoid injury to the nerve roots and dura, especially when the down side of the osteotomy level (left side) was handled. Gelfoams were placed into the pedicle holes and the osteotomy space to control the bleeding.

Then laminectomy and facetectomy of L_3 or L_2 were performed. The residual pedicles were removed. With Kerrison rongeur and angular forceps, the posterior cortex of L_3 or L_2 vertebral body was pushed down into the "V" shaped cavity. Two precontoured titanium rods of appropriate lordosis were separately connected to the cranial and caudal pedicle screws. With firm grasping and controlling the rods by clamps, the off-table staff slowly and simultaneously pushed the shoulders and pelvis of the patient to extend the lumbar. The osteotomy gap was gradually closed under direct and continuous vision (Fig. 3C,D).The rods were temporally tightened. After the dura and nerve roots were closely inspected to ensure that there were no compression, the pedicle screw and rod stabilization was ultimately performed. Two satellite rods were also placed bilaterally. No change of SEPs and MEPs was detected during the whole operation.

Fig. 3 (A, B) Photographs of positioning. Patient 1 was placed in a left lateral position and the operation table was flat. (C, D) Intraoperative photographs of PSO at L_3 showed the osteotomy gap was closed.

Results

Intraoperative Clinical Data

For patient 1, the total operation time was 5.5 h. During the operation, the blood loss was 1500 mL and the amount of allogeneic blood transfusion was 1580 mL. For patient 2, the duration of surgery was 6.5 h. The operative blood loss was 2000 mL and the total amount of blood transfusion was 2020 mL, including 1000 mL autologous blood transfusion.

Radiographic Outcomes

Global sagittal alignment was resorted after PSO at L3 in patient 1 (Fig. 5A,B). SVA were reduced to 127 mm and LL decreased from preoperative 42.7° to −28.4°. Post-operative PI, PT, SS, TK and TLK were 68.6°, 55.4°, 13.2°, 55.2° and 43.7° respectively. The correction angle through L_3 was 34.7° and the correction angle through the osteotomy segment, the angle between the upper endplate of L_2 and the lower endplate of L_4 was 62.9°.

Spinopelvic sagittal malalignment was also improved after PSO at L_2 in patient 2 (Fig. 4D,E). SVA were reduced to 209.8 mm and LL decreased from preoperative 58.8° to 9.2°. Post-operative PI, PT, SS, TK and TLK were 51.2°, 57.6°, −6.5°, 35.9° and 20.4° respectively. The correction angle through L_2 was 37.1° and the correction angle through the osteotomy segment, the angle between the upper endplate of L_1 and the lower endplate of L_3 was 55°.

Complications and Follow-up

Intra-operative or post-operative complications, such as sagittal translation, leakage of cerebrospinal fluid, neurological deficit and vascular injury, were not observed in these two patients. Six months after PSO, patient 1 had good posture for standing and sitting (Fig. 5C,D). The osteotomy site also showed bone fusion at 6 months follow up (Fig. 5E). Patient 2 underwent bilateral THRs nine months after PSO (Fig. 4F).

Discussion

Current Situation of Spinal Osteotomy Position

Spinal osteotomies including SPO, PSO, VCR and VCD are the most common and effective surgical interventions for AStho racolumbar kyphotic deformity，which are performed in prone position for all cases as reported in the literature[2,4,12,14–17,20]. Operation in the prone position is convenient for exposure, placing pedicle screws, and manipulation

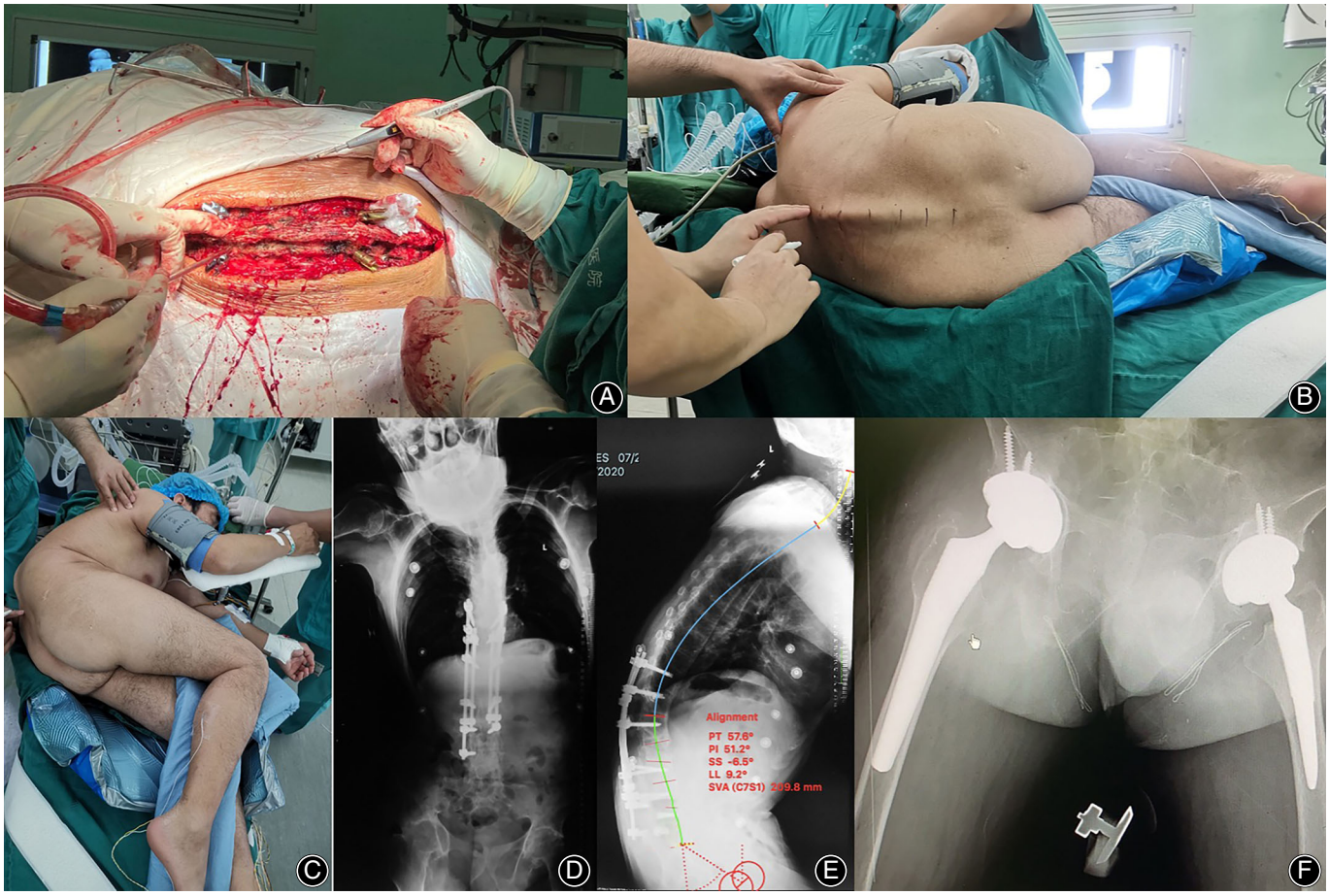

Fig. 4 (A) For patient 2, pedicle screws were inserted in a left lateral position. (B, C) Patient 2 was placed in a left lateral position and the operation table was flat. (D, E) Anteroposterior and lateral standing X-ray of patient 2 after PSO at L_2. LL, PT and SVA were 9.2°, 57.6° and 209.8 mm respectively. (F) Anteroposterior X-ray of the patient 2 after THRs.

of osteotomy. In addition, the gravity of patient and extension of the operation table can facilitate correction of kyphosis in the prone position[12]. To our knowledge，spinal osteotomies in lateral position have not previously been reported. Our study showed that PSO was able to be performed in the lateral position with satisfactory result. No intra-operative or post-operative complications were observed in this patient. We believe that PSO in the lateral position might enlighten us with a new strategy for correcting rigid thoracolumbar kyphosis combined with severe hip flexion contracture in AS patients.

The Order of Spinal Osteotomy and THR for AS Patients

For those AS patients who have coexisting rigid thoracolumbar kyphosis and hip flexion contracture, which operation should be performed first，spinal osteotomy or total hip replacement, is still under debate. In 1963, Lee[7] first recommended that THR should be carried out before corrective spinal osteotomy to assess the residual sagittal spinal deformity more accurately. Since then, some authors also contended that a prior THR should be performed，which would contribute to better evaluation of disability caused by spinal deformity and formulation of proper spinal osteotomy plan[8,9,21]. However, others stated that spinal osteotomy should be performed before THR[6,10,11]. These authors confirmed that it was difficult to decide the positions of acetabular component and prone to component malposition and anterior dislocation if THR was performed before spinal correction. In addition, for spinal osteotomy performed first, the corrective angle of spinal osteotomy can be accurately calculated according to pelvic incidence (PI), which is a position-independent and anatomical parameter[1,6]. Zheng *et al.*[6] suggested that spinal correction should be performed prior to THR for these AS patients, except that the intraoperative positioning was not achieved due to the severe coexisting deformity of hip and spine.

However, there are still few AS patients whose deformity of kyphosis and hips are so severe that the head and trunk almost contact with lower extremities. For these patients, it is impossible to be placed in the prone position for spine surgery. To date there are two possible surgical strategies. One strategy is to perform THR first and

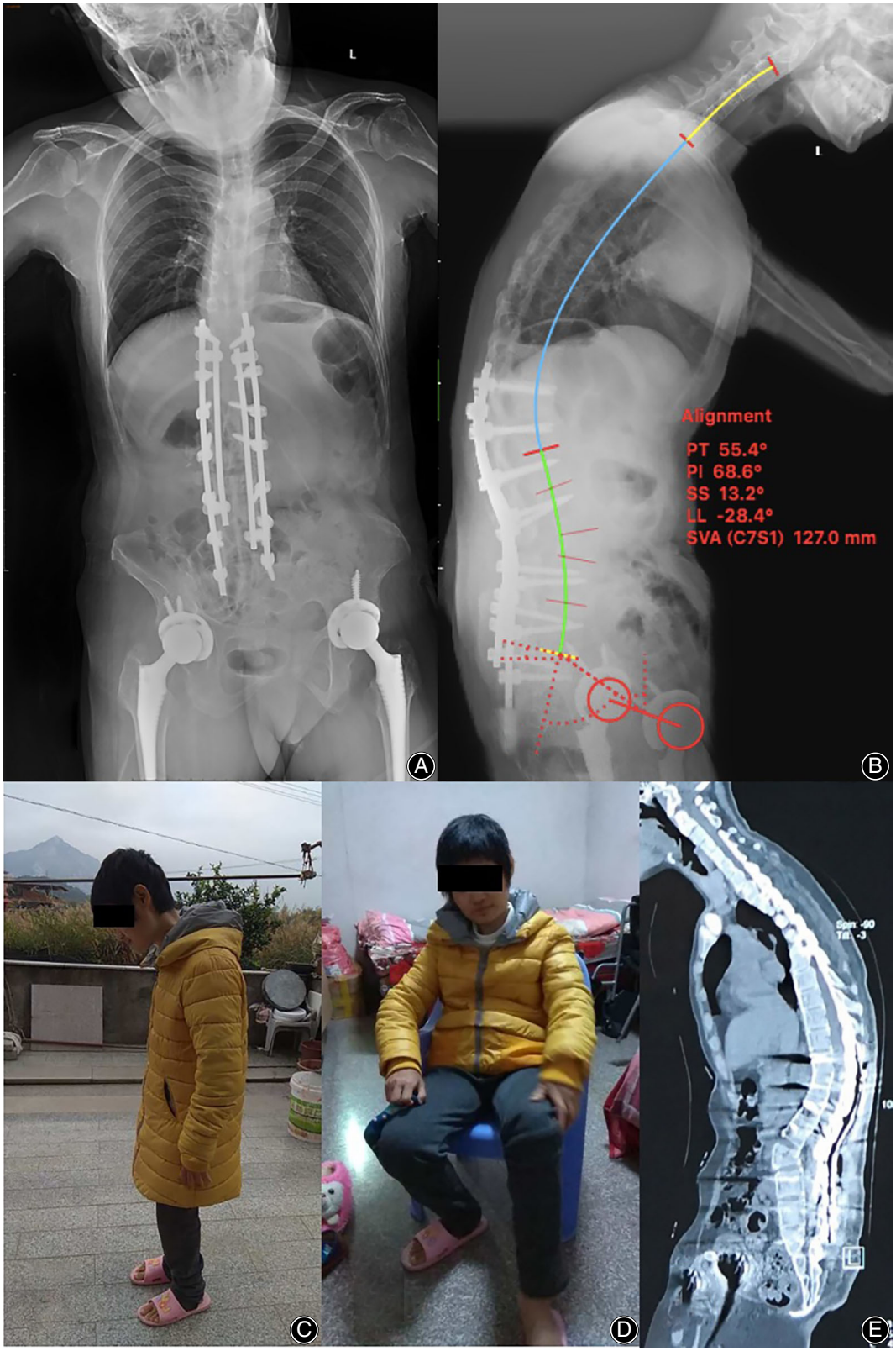

Fig. 5 (A, B) Anteroposterior and lateral standing X-ray of patient 1 after PSO at L_3. LL, PT and SVA were − 28.4°, 55.4° and 127 mm respectively. (C, D) Six months after PSO, the photographs showed good posture for standing and sitting in patient 1. (E) The CT scan of the spine revealed bone fusion of the osteotomy site at six months follow-up.

subsequently spinal osteotomy. When THR is performed first, patients might be exposed to the risks mentioned above. In addition, we propose that there would be some difficulties in the postoperative rehabilitation of hip joints as severe spinal sagittal imbalance still causes a forward and downward shift of the patient's gravity and retroversion of the pelvis, which affects the movement of hip and walking. Patient 1 in our study might be a case who still could not be placed on operation table in the prone position due to poor function of hip after THR. The other strategy is resection arthroplasties first which improves the range of movement of hip and enables patients to lie in the prone position, subsequently spinal osteotomy and lastly THR[15]. While resection arthroplasties is performed first, the patients may feel more uncomfortable after surgery, such as pain in hips, as well as needing one more operation. Therefore, we suggest performing spinal osteotomy in lateral position first and subsequentlyTHR, which is a new surgical strategy, for those AS patients who present with coexisting severe thoracolumbar kyphosis and hip flexion contracture. Sagittal malalignment could also be restored by spinal osteotomy in the lateral position, which is useful for subsequent THR to access the position of acetabular component.

Spinal Osteotomy in Lateral Position

With regards to spinal osteotomy in the lateral position, we prefer PSO or VCD as a larger corrective angle is usually needed in these AS kyphotic patients with severe coexisting hip flexion contracture. Although the mean correction of VCR is reported to be approximately 51° to 58.9° in kyphosis[22,23], the technique is more complex and the risk of complication is higher[23,24]. Therefore, VCR is unsuited to be performed in the lateral position.

During the manipulation of osteotomy in lateral position, there might be some difficulties due to the special position, which are different from those in the conventional operation. Firstly, spinal canal decompression and osteotomy are more difficult and the risk of dura sac and nerve injury is also increased, especially when the down side of operative level is manipulated. Therefore, the eggshell procedure is recommended. In our study, three gradually enlarged and triangular cone-shaped taps might facilitate the decancellation of the vertebral body through pedicel, which is relatively rapid and safe. By using this method, most cancellous bone of the vertebral body is pushed or pressed to create a "V" shaped cavity instead of being removed. The bilateral cortex of the vertebral body only needs to be fractured rather than resected. Through these improvements of operation, osteotomy in the lateral position can be performed safely. In addition , ultrasonic osteotome can also be used to improve the efficiency and safety of operation. In order to improve the visual field of surgery, the operation table or patients might be tilted slightly to the opposite side. Secondly, the corrective forces of osteotomy are different between the lateral position and the prone position. In the prone position, corrective forces of osteotomy are mainly applied by manipulation through the internal fixation device, gravity of patient, and gradual straightening or reversal of the flex in the operation table[4,12]. However, manipulation through the internal fixation device combined with the strength of pushing on shoulders and pelvis by off-table staff are the main corrective forces in the lateral position. Thus, in order to facilitate the operation of osteotomy, titanium rods need to be shaped as precisely as possible according to the designed correction angle. Furthermore, loser cooperation between surgeons and off-table staff is also needed and more attention should be paid to control the hinge when the osteotomy gap is gradually closed, since the strength exerted by off-table staff might not be well controlled. Finally, it should be noted that the amount of blood loss in operation would be more than usual. Therefore, more allogeneic blood needs to be prepared before operation. Intraoperative autologous blood transfusion is also an alternative.

Conclusions

This study showed that PSO was satisfactorily performed in lateral position. For AS patients with coexisting severe thoracolumbar kyphotic deformity and hip flexion contracture who cannot be placed in prone position, spinal osteotomy in lateral position first is a new surgical strategy. However, this is a new attempt and more investigation is needed to confirm the validity and security of this strategy.

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Availability of data and material

The patients' data were collected in the Chinese PLA General Hospital. The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request

Consent for publication

We have obtained consent to publish from the participants.

Ethics approval and consent to participate

This study was conducted with approval from the Ethics Committee of Chinese PLA General Hospital. Written informed consent to participate was obtained from all participants.

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