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Research Article

Modified Compact-Contact Pedicle Subtraction Osteotomy: Technique Description and Outcomes in a Retrospective Case Series

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Abstract

Background: Pedicle subtraction osteotomy (PSO) is an established technique for correcting fixed sagittal plane deformities (FSPD), but it is associated with substantial blood loss and a risk of pseudarthrosis. This study aims to develop a modified PSO technique to treat FSPD and assess its technical efficacy and safety.
Methods: A retrospective review was conducted on patients with FSPD who underwent the modified PSO technique between 2004 and 2021. Radiographic outcomes were assessed using kyphotic angle and sagittal vertical axis (SVA), while clinical outcomes were evaluated using the visual analog scale (VAS) for back pain and the Oswestry Disability Index (ODI). Postoperative complications were assessed to evaluate the safety of the technique.
Results: Fifty-three patients (54.7% men) with a mean age of 34.5 years were included in the study, with a mean follow-up of 54.8 months. The mean intraoperative blood loss was 466.9 ± 252.9 ml. Postoperatively, the mean kyphotic angle improved significantly from 37.2° to 8.5° ($P < 0.0001$). At the final follow-up, a mean loss of correction of 6.4° was observed compared with the immediate postoperative measurement. Statistically significant improvements were observed in the SVA, ODI, and VAS between the preoperative and postoperative assessments ($P < 0.0001$ for all). Postoperative complications occurred in five patients (9.4%), including pseudarthrosis with rod breakage in two patients (3.8%). No intraoperative or early postoperative neurological complications were observed.
Conclusion: The modified compact-contact PSO technique was feasible and demonstrated favorable radiographic and clinical outcomes, with relatively limited estimated blood loss (EBL) in primary procedures and a low rate of pseudarthrosis. Prospective comparative studies are warranted.

Keywords: Deformities; Osteotomy; Surgical Technique; Outcomes

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Background

Spinal deformity is a term that defines pathological curvatures of the spine in the coronal and sagittal planes. Pedicle subtraction osteotomy (PSO) is a posterior-based three-column osteotomy for the correction of fixed sagittal plane deformities (FSPD) of the spine (1, 2). The etiologies of these deformities are diverse and include degenerative, posttraumatic, neoplastic, infectious, metabolic, and congenital disorders (1, 3).

PSO is an effective surgical approach for restoring normal sagittal balance while providing biomechanical stability (1, 2). With advances in instrumentation and neuromonitoring supported by improved anesthetic care, the PSO technique has greatly developed in recent years (4). Despite its benefits, PSO is a technically demanding procedure, which may increase the risk of intraoperative and postoperative complications, including substantial blood loss, pseudarthrosis, implant failure, and loss of correction. Pseudarthrosis and implant failure are among the most frequent complications observed during follow-up in patients undergoing PSO, often resulting in loss of correction, the need for revision surgery, and considerable morbidity for both patients and clinicians. Pseudarthrosis rates associated with the standard PSO technique have been reported from 9.8% to 31.0% at the treated level (2, 5-8). PSO is also associated with significant blood loss from the epidural venous plexus and cancellous bone, often requiring intraoperative transfusion and posing elevated clinical risks, especially in older patients (2, 9-11). Both excessive intraoperative blood loss and the need for blood transfusion have been associated with prolonged hospital stays, increased rates of cardiovascular events, and higher mortality. In the literature, average blood loss ranges from 500 ml to 6000 ml among patients undergoing the PSO for the treatment of spinal deformity (2, 9-11). Therefore, it is of utmost importance to discuss the potential risks and advantages of applying the PSO technique, especially considering methods to reduce pseudarthrosis rate and blood loss.

This study aimed to describe a modified compact-contact PSO technique and report the radiographic, clinical, and perioperative outcomes observed in a retrospective case series.

Methods

A retrospective study was conducted on patients who underwent surgical correction of sagittal imbalance using the modified PSO technique employed in the present study, with a minimum postoperative follow-up of 2 years. Patients were eligible for inclusion if they had FSPD requiring surgical correction with PSO, underwent surgery using the modified PSO technique described in the present study, had adequate preoperative clinical and radiographic documentation, and completed at least 2 years of postoperative follow-up. Patients were excluded from the final analysis if a minimum 2-year postoperative follow-up was unavailable, or if the available clinical or radiographic records were insufficient to assess the predefined clinical or radiographic outcomes. All surgeries were performed at the referral hospital in Tehran City, Iran, by an experienced spine surgeon with 17 years of experience, from 2004 to 2021. The radiological parameters were assessed before and after the surgery. Kyphotic angle (angle between the superior endplate and inferior endplate of the vertebrae above and below the osteotomy site, respectively) and global sagittal vertical axis (SVA) (distance from the C7 plumb line to the posterior superior corner of the sacrum) were measured preoperatively and on postoperative spine radiographs. Radiographic measurements were also assessed at the final follow-up to evaluate maintenance of correction. Clinical outcomes were assessed using the visual analog scale (VAS; rated on a scale from 0 to 10) for back pain and the Oswestry Disability Index (ODI; ranging from 0, no disability to 100, maximum disability possible) preoperatively and at the 6-month postoperative follow-up.

Surgical Procedure: The modified compact-contact PSO follows the fundamental principles of a conventional three-column PSO but incorporates specific modifications in vertebral body preparation, cancellous bone handling, and osteotomy closure. The surgical procedure consisted of the following five steps:

Step 1: Under neurophysiologic monitoring and standard posterior approach, the pedicle screws were inserted at least two levels above and below the osteotomy level. For L3 osteotomy, 1/3 of the spinous process and lamina of L2 and 1/3 of the spinous process and lamina of L3 were removed (Figure 1).

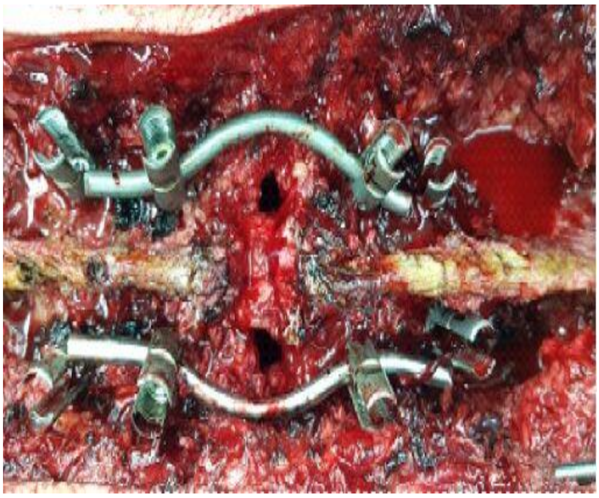

Figure 1. Modified compact-contact pedicle subtraction osteotomy (PSO) technique. Following pedicle screw insertion, partial resection of the spinous processes and laminae of L2 and L3, along with bilateral facetectomy at the osteotomy level, is performed. Temporary bent rods are subsequently placed to maintain spinal stability throughout the osteotomy, facilitate exposure of the vertebral body, and avoid repeated insertion and removal of conventional temporary rods.

Step 2: Facetectomy was performed by resection of the L3 facet joints. The pedicle entry hole was marked by an awl (Figure 2).

The temporary bent rods were placed (Figure 1). The temporary screw or tapper with a diameter of 4.5 mm was inserted in the pedicle and then replaced with larger diameters of 5.5 mm, 6.5 mm, and 7.5 mm, respectively (Figure 3).

Figure 2. Identification of the pedicle entry point. The pedicle entry hole is marked using an awl under fluoroscopic (C-arm) guidance before sequential pedicle preparation and vertebral body compaction.

The tapper was used at different angles - 15°, 30°, and 45° from lateral to medial for each side (Figure 4).

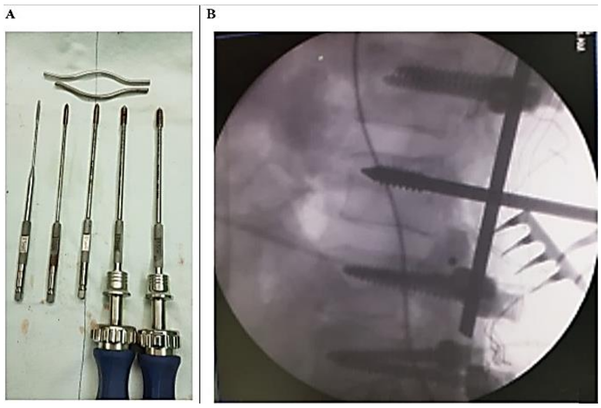

Figure 3. Sequential vertebral body compaction through the pedicle. A) Tappers of progressively increasing diameters together with the temporary bent rod used during the procedure; B) The smallest tapper is initially inserted through the pedicle and is sequentially replaced with larger-diameter tappers to progressively compact the cancellous bone within the vertebral body before wedge resection.

By repeatedly applying tappers of maximal diameter at these specific angles, the cancellous bone and intraosseous vascular channels were compacted. This technique served to mitigate intraoperative bleeding from the vertebral body during osteotomy.

Figure 4. Vertebral body compaction before osteotomy. The tapper is advanced through the pedicle at approximately 15°, 30°, and 45° from lateral to medial on each side to compact the cancellous bone within the vertebral body before osteotomy. This maneuver compresses the blood vessels within the vertebral body and may help reduce intraoperative bleeding during vertebral body resection.

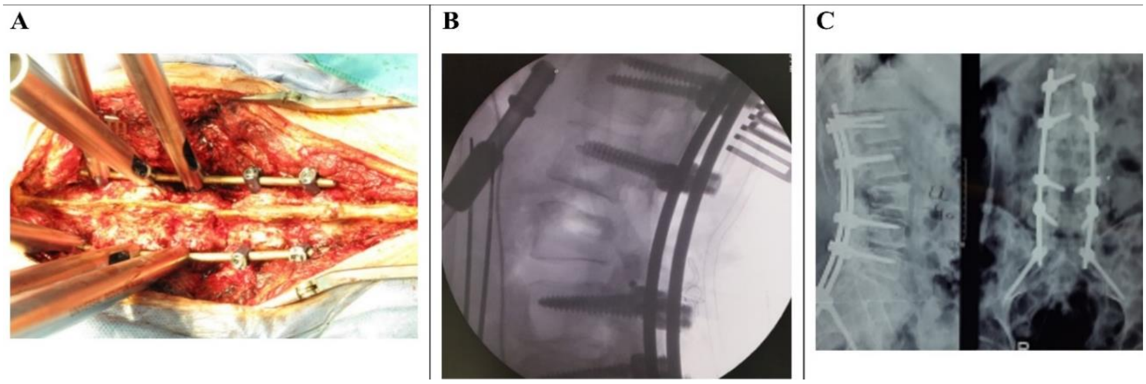

Figure 5. Closure of the osteotomy and restoration of posterior bony contact. A, B) After wedge resection, the osteotomy is gradually closed by controlled compression until the remaining laminae and spinous processes come into direct contact without a residual posterior gap, promoting contact between the posterior spinal elements; C) Standing anteroposterior (AP) and lateral radiographs obtained one year after surgery demonstrate maintenance of sagittal correction and stable instrumentation.

Step 3: From inside the pedicle hole, the lateral wall of the vertebral body was thinned to the size of the osteotomy wedge and removed by Kerrison rongeur and curette, instead of using the osteotome. The posterior wall of the vertebral body was also removed by the abovementioned method. Osteotomy was performed 5 to 6 mm below the superior endplate of the L3 vertebral body to avoid entering the disc. During surgery, the base of the osteotomy wedge was removed as much as the height of the pedicle.

Step 4: The edges of the remaining laminas were undercut by Kerrison rongeur to avoid compression of the dural sac during osteotomy closure. Efforts should be made to preserve the L3/L4 facet capsule as it maintains the viability of the remaining L3 lamina and contributes to stability. The posterior gap was closed by pushing down the spine and bending the operating table as usual until the spinous processes and the laminae came into contact. Following closure, the spinal canal and neural elements were carefully inspected to ensure the absence of dural buckling or nerve root kinking. Permanent rods were then placed to connect the proximal and distal segments of the osteotomy site. The remaining spinous processes were tightened with wire or suture to increase stability (Figure 5).

Step 5: Spinal decortication and posterolateral autograft fusion were performed using bone graft from the surgical site or, where indicated (particularly in revision or iatrogenic cases), from the iliac crest. Wound closure was executed according to the conventional surgical technique.

Key modifications from the conventional PSO technique: The modified compact-contact technique differs from the conventional PSO primarily in the method of vertebral body preparation and osteotomy closure. In the present technique, cancellous bone was progressively compacted using sequentially larger tappers introduced through multiple trajectories, rather than being primarily removed to create the osteotomy cavity. In addition, the lateral and posterior vertebral body walls were thinned and removed in a controlled manner using Kerrison rongeurs and curettes instead of an osteotome. The technique also emphasizes preservation of the remaining posterior elements and the L3/L4 facet capsule, followed by controlled closure until the remaining laminae and spinous processes were approximated. These modifications define the compact-contact approach while maintaining the fundamental three-column closing-wedge principle of PSO.

Estimated blood loss (EBL) was calculated from the volume collected in the suction canisters after subtraction of the irrigation fluid together with the estimated blood volume absorbed by blood-soaked surgical sponges. Tranexamic acid and intraoperative cell salvage (cell saver) were not routinely used. Blood transfusion was administered according to the patient's hemodynamic status and perioperative hemoglobin (Hb) level at the discretion of the anesthesiologist and surgeon.

Fusion status was assessed at follow-up using serial standing radiographs. Computed tomography (CT) was performed selectively when pseudarthrosis was clinically or radiographically suspected rather than routinely in all patients. Patients with confirmed pseudarthrosis and symptomatic implant failure were considered for revision surgery.

Assessment and Definitions of Postoperative Complications: Postoperative complications were assessed clinically and radiographically throughout the follow-up period. Pseudarthrosis was defined as failure to achieve solid bony fusion across the osteotomy and posterolateral fusion site, based on persistent absence of bridging bone on serial follow-up radiographs, with supportive CT findings when CT was obtained because of clinical or radiographic suspicion. Rod breakage was defined as radiographic evidence of mechanical discontinuity or fracture of the spinal instrumentation. Wound infection was defined as a postoperative surgical site infection (SSI) requiring antibiotic treatment and/or surgical intervention. Proximal junctional kyphosis (PJK) was defined as a postoperative increase in the proximal junctional angle of ≥10° compared with the preoperative measurement. Distal junctional kyphosis (DJK) was assessed using the same radiographic principle at the distal end of the fusion construct. Bony union was considered achieved when bridging bone across the osteotomy site was present without evidence of implant loosening, progressive deformity, or other radiographic signs of nonunion. Neurological complications were assessed based on the clinical neurological examination and documented postoperative neurological deterioration.

Statistical Analysis: Statistical analysis was performed using Microsoft Excel 2016 and IBM SPSS Statistics (version 22, IBM Corporation, Armonk, NY, USA). The Wilcoxon signed-rank test was used to compare paired preoperative and postoperative clinical and radiographic outcomes, as well as postoperative and final follow-up radiographic measurements. The difference between preoperative and postoperative sagittal kyphotic angles was considered the kyphosis correction, whereas the difference between postoperative and final follow-up angles was considered the loss of correction. Patients with spinal deformities were asked to respond to the questionnaires at two time points: preoperatively and at the 6-month postoperative follow-up. Furthermore, spinal radiography was assessed at the final follow-up.

Ethics: This was a retrospective observational study based on the review of previously recorded clinical and radiographic data from patients treated at a tertiary referral center in Tehran City, between 2004 and 2021. No additional diagnostic or therapeutic interventions were undertaken for the purposes of this study. The study was conducted in accordance with applicable institutional and ethical standards for retrospective analysis of clinical records.

Results

Nine patients were excluded from the study due to a lack of follow-up, and only 53 patients were analyzed. The mean age of patients was 34.5 ± 19.3 years (range: 8.0-65.0 years), with 54.7% of patients being men and 45.3% being women. The mean follow-up was 54.8 ± 31.3 months (range: 24.0-142.0 months). PSO was performed in cases of ankylosing spondylitis (AS) (n = 15), congenital kyphosis (n = 21), failed back surgery syndrome (FBSS) (n = 15), and old fracture (n = 2).

Regarding the apex location, 2 cases (3.8%) were thoracic, 23 (43.4%) were thoracolumbar, and 28 (52.8%) were lumbar. The osteotomy sites included: T10 (n = 2), T11 (n = 7), T12 (n = 8), L1 (n = 8), L2 (n = 2), L3 (n = 21), L4 (n = 4), and L5 (n = 1). The mean level of fusion was 7.6 ± 3.5, and the mean operative time was 5.3 ± 1.3 hours (range: 3.5-8.0 hours). The mean blood loss was 466.9 ± 252.9 ml (range: 200-1000 ml). EBL differed between primary (n = 38) and revision (n = 15) procedures. The mean EBL was 318.4 ± 76.6 ml (range: 200-500 ml) in primary cases and 843.3 ± 101.5 ml (range: 650–1000 ml) in revision cases. Overall, 12 of the 53 patients (22.6%) required intraoperative blood transfusion, all of whom underwent revision surgery for FBSS. The mean hospital stay was 6.3 days (range: 4-9 days).

The SVA improved from a mean preoperative value of 101.6 ± 65.2 mm (range: 10.0-244.0 mm) to 49.5 ± 42.4 mm (range: -35.0 to 150.0 mm) at the final follow-up. The mean preoperative kyphotic angle was 37.2° ± 29.7° (range: -18.0° to 100.0°), and the mean postoperative kyphotic angle was 8.5° ± 27.1° (range: -40.0° to 60.0°), showing a mean correction of 28.7° with statistically significant differences ($P < 0.0001$). Spinal radiography at the final follow-up presented a mean angle of 14.8° ± 27.4° (range: -30.0° to 71.0°), indicating a correction loss of 6.4° ($P = 0.236$). However, the overall correction was 22.4° with statistically significant differences ($P = 0.0001$).

The mean preoperative ODI and VAS scores were 40.1 ± 4.5 and 6.8 ± 1.3, respectively, while the mean ODI and VAS scores at 6-month follow-up were 14.5 ± 5.1 and 2.1 ± 0.98, with statistically significant differences ($P < 0.0001$ for all).

Among the 53 patients, five (9.4%) developed postoperative complications, including pseudarthrosis with rod breakage (n = 2), wound infection (n = 1), and PJK (n = 2). No cases of DJK were observed. Rod breakage occurred in two patients at 15 and 18 months after surgery, and both cases underwent revision surgery. The two patients with PJK also required revision surgery. Successful bony union was achieved in all patients at the final follow-up. Figure 6 illustrates a patient with AS who underwent the modified PSO at L1 and demonstrated satisfactory contact and fusion at the osteotomy site.

Discussion

This study describes a modified compact-contact PSO technique and reports the radiographic, clinical, and perioperative outcomes observed in a retrospective case series of spinal deformities. The technique demonstrated clinical efficacy and was associated with satisfactory deformity correction, improved functional outcomes, minimal EBL, and a low incidence of pseudarthrosis.

Spinal deformity surgery aims to attain balance, relieve pain, and prevent recurrence or deterioration of the deformity. PSO has been widely presented as an effective procedure for correcting spinal deformities. Postoperative corrections of 30° to 45° can be achieved by performing conventional one-level PSO (12-14), which were comparable to the values obtained with the modified PSO technique in the present study. Moreover, in the modified PSO technique, the average corrections of SVA and the kyphotic angle at the last follow-up were 5.2 cm and 22.4°, respectively, which was similar to the values in the standard PSO group and those documented in previous studies (14-17).

In this study, we found that patients' ODI and VAS scores significantly improved after treatment with the modified PSO technique, indicating that the technique was effective for FSPD; this is in line with other studies based on the conventional method (17, 18).

Complication rates for adult spinal deformity surgery are notably broad, with reported incidences ranging from 10.5% to 96% (19). Specifically, PSO-related neurologic deficits remain a significant clinical concern, occurring in 7.0% to 14.3% of cases (20, 21). Hyun and Rhim reported that 61% (8/13) of patients who underwent PSO were associated with complications such as massive bleeding, dural tear, spinal cord compression, cerebrospinal fluid (CSF) leakage, and hypotension (18). Our complication rate of 9.4% — with a total absence of neurological deficit — is significantly lower than that reported in existing literature, suggesting that this modified approach is a safe and reliable option for the treatment of these patients.

A pseudarthrosis rate of 9.8% to 31% has been reported in the literature for the standard PSO. In our study, the rate of pseudarthrosis was 3.8%, significantly lower than the standard PSO rate. Researchers are trying to find ways to reduce the rates of pseudarthrosis. Clinical studies presented lower pseudarthrosis and instrumentation failure rates with multi-rod constructs and interbody cage implantation (8, 22). Gupta et al. found that the pseudarthrosis rate with 2 rods was 25% (5/20) and with 4 rods was 3.4% (1/129) in patients receiving a PSO stratified by rod configuration across the osteotomy site. Although a significant reduction in pseudarthrosis rate was observed in the 4-rod technique, there was a trend toward a higher rate of infection in this construct (22). The most important advantage of the modified PSO technique compared to other techniques is the potential decrease in the postoperative pseudarthrosis rate due to the bony union between two laminae at the PSO site (Figure 6).

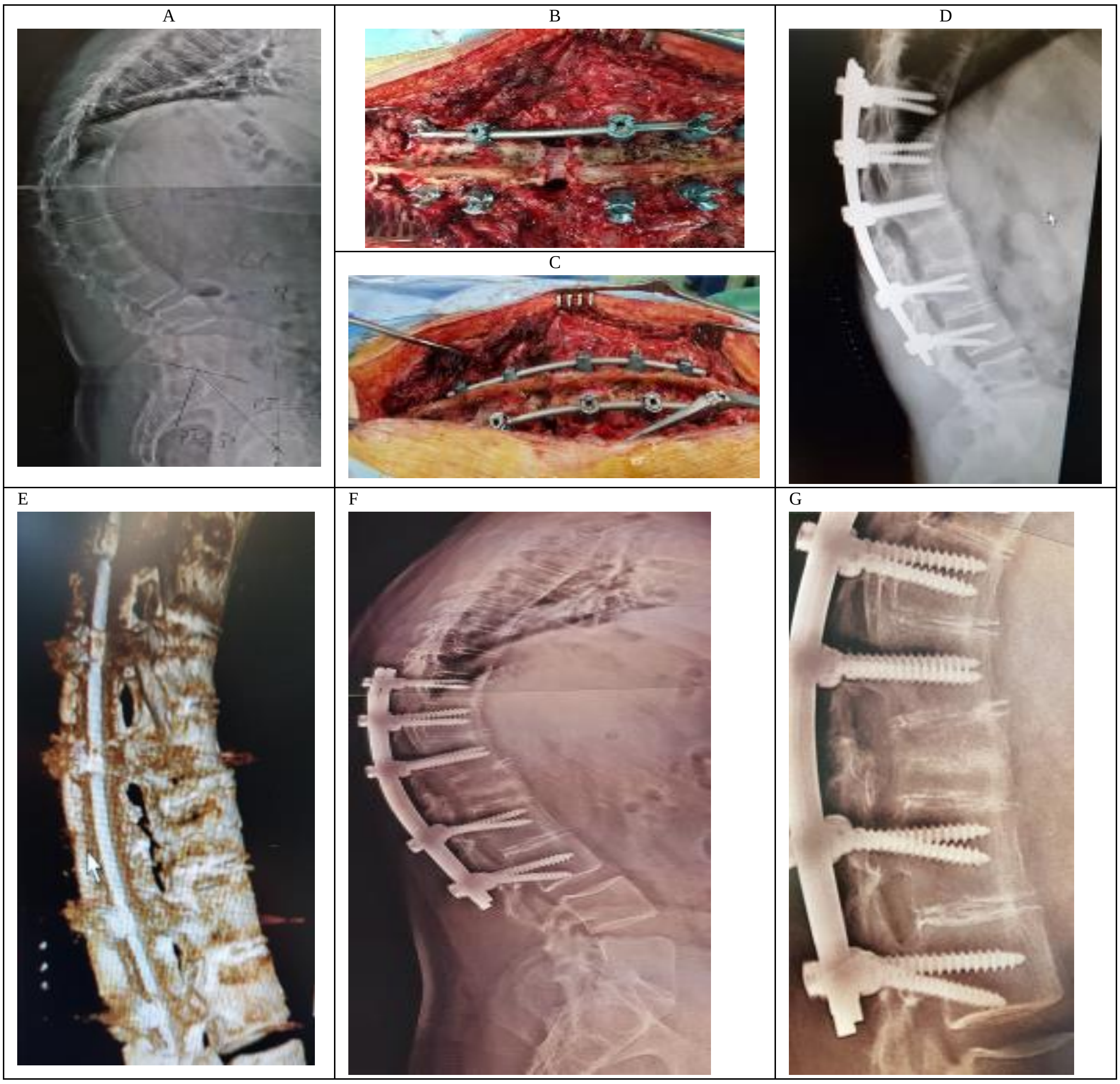

Figure 6. Representative case of ankylosing spondylitis (AS) treated with the modified compact-contact pedicle subtraction osteotomy (PSO) technique. A) Preoperative standing radiograph of a 39-year-old man with AS and fixed sagittal plane deformity (FSPD); B, C) Intraoperative photographs of the L1 osteotomy showing direct contact between the preserved laminae and spinous processes after closure of the osteotomy; D, E) Standing radiograph and computed tomography (CT) images obtained six months postoperatively demonstrating satisfactory bony fusion at the osteotomy site; F, G) Standing anteroposterior (AP) and lateral radiographs obtained three years after surgery showing maintained sagittal alignment, stable instrumentation, and solid fusion across the osteotomy site

Moreover, by using a bent rod in the modified technique, stability is maintained during surgery, and there is no need to insert and remove the rod repeatedly (Figure 1). The osteotomy site, located at the apex of the deformity, serves as a primary locus of stress concentration, rendering it the most biomechanically vulnerable region within the long-segment construct. However, the modified PSO is performed to create a bony union between posterior spinal elements at the osteotomy site, in order to stabilize the spine. Further, in the conventional PSO technique, the lamina, spinous process, and facet joints are completely removed at the osteotomy level (1, 23). This leads to a large bony gap in the posterior spinal elements (24), which remains unbridged and increases the possibility of pseudarthrosis. In our technique, only part of the lamina and spinous process is removed. Hence, the posterior spinal structures get close to each other and can achieve contact; this increases bony fusion and decreases the risks of pseudarthrosis and instrumentation breakage. In other words, unlike the standard PSO technique, most posterior spinal structures are well preserved in order to minimize postoperative weakening of the spine. It is noted that the observed pseudarthrosis rate in our series was lower than that reported in previous studies of conventional PSO; however, absence of a control group necessitates caution when interpreting direct comparative findings.

Previous studies have reported substantial blood loss with conventional PSO, with mean values ranging from approximately 500 to 6000 ml (2, 9-11). In the present series, the mean EBL was 466.9 ml (range: 200–1000 ml), with a marked difference between primary and revision procedures (318.4 ml vs. 843.3 ml, respectively). Thus, EBL was relatively limited in primary procedures but substantially higher in revision cases. Direct comparisons with previous studies should be interpreted cautiously because of differences in patient characteristics, deformity severity, surgical complexity, revision status, and methods used to estimate blood loss. In the present series, all 12 patients who required intraoperative blood transfusion had undergone revision surgery for FBSS, which may reflect the greater surgical complexity and more extensive adhesiolysis typically associated with revision procedures. Overall, although substantial blood loss remains an important consideration in PSO, the present findings suggest that blood loss may be relatively limited in primary procedures using the modified technique. However, the retrospective design and absence of a control group preclude definitive conclusions regarding any reduction in blood loss compared with conventional PSO.

There were some limitations in this study. First, this was a retrospective study with a small sample size and single-center data. More research is needed to further verify the safety and efficacy of the modified PSO technique. Second, this technique shares similar limitations with standard PSO for the correction of rigid deformities. Finally, the clinical assessment was primarily based on pre- to postoperative comparisons, lacking a concurrent control group treated with conventional techniques. Despite these limitations, our findings demonstrate the effectiveness and applicability of the modified PSO technique, offering insights that may inform future surgical strategies for spinal deformity correction. Studies with a larger sample of patients undergoing this modified PSO technique and a long-term follow-up period are warranted to clarify the rate of loss of correction and other complications.

Conclusion

The modified compact-contact PSO technique was feasible in this retrospective case series and was associated with satisfactory radiographic correction, improved clinical outcomes, relatively limited EBL in primary procedures, and a low incidence of pseudarthrosis. Because this was a single-center retrospective study without a comparison group, these findings should be interpreted cautiously. Prospective comparative studies are required to determine whether this technique offers advantages over conventional PSO.

Conflict of Interest

The authors declare no conflict of interest in this study.

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