Pedicle Subtraction Osteotomies for Correcting Sagittal Imbalance

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Abstract

Background Data: Restoration of sagittal balance typically involves Smith Peterson osteotomy (SPO) or pedicle subtraction osteotomy (PSO). Since 2008, PSO was used for patients with kyphosis at our centers.

Purpose: The aim of this study is to report the results of PSO for correcting fixed sagittal imbalance at a minimum follow up of 24 months.

Study Design: Prospective descriptive study.

Methods: Twenty four consecutive patients with sagittal imbalance (9 females/15 males), with a mean age at surgery of 33.4 years, were treated with 25 PSOs and prospectively followed for a mean of 36 months. The etiology for imbalance was post-traumatic (n=9), Scheuermann disease (n=6), congenital (n=5), Post-tuberculous (n=3), and post-laminectomy (n=1). PSO was performed at T7 (n=1), T8 (n=1), T9 (n=2), T10 (n=1), T11 (n=3), T12 (n=4), and at L1 (n=6), L2 (n=5), and at L3 (n=2). Radiographic and clinical outcomes analysis was performed.

Results: The mean operative time was 5.6±3.2 hours and the mean blood loss was 1,319±1,416 ml. Patients reported very good satisfaction (86%) and good function (79%) at final follow-up. The mean correction of the kyphotic angle at the osteotomy site was 32.3°±5.0°. No permanent neurological deficits were encountered. Postoperative complications included pulling out of screws (n=1) and recurrence of deformity within 48 hours after surgery requiring revision and longer fixation, transient lower limb paraesthesia (n=2), superficial infection (n=1), and significant wound hematoma requiring drainage (n=2). Progressive distal junctional kyphosis occurring in a patient with Scheuermann’s disease was managed 6 months later with vertebral column resection and distal fixation. One patient developed pseudarthrosis and implant failure 9 months postoperatively. He was revised by graft augmentation and rods exchange.

Conclusion: PSO can provide satisfactory clinical and radiographic outcomes with acceptable risk and morbidity. (2012ESJ016)

Key Words: Sagittal Imbalance, Kyphosis, PSO, SPO, Ponte Osteotomy, Pseudarthrosis.
Introduction

Sagittal balance is defined as the alignment of C7 to the posterior superior aspect of S1 on an upright long cassette radiograph. This line is drawn from the center of C7 and should be plus or minus 2 - 4 cm from the sacral postero-superior aspect1.

Two types of sagittal imbalance have been described. Type 1 (segmental) sagittal imbalance describes segmental kyphosis but with maintained global balance (through remaining mobile segments); C7 plumb line remains within 2-4 cm from the postero-superior aspect of S1 body. Type 2 (global) sagittal imbalance represents global imbalance in which the plumb line from C7 falls more than 5 cm anterior to the postero-superior aspect of S1 body6.

Patients with sagittal imbalance cannot stand erect without decreased pelvic tilt, compensatory hip extension, knee flexion, and overwork of the erector spinal musculature. This crouched posture is inefficient and results in early fatigue of paraspinal musculature and quadriceps, decreased ambulatory tolerance, progressive degenerative changes at cephalad and caudad transition levels, and intractable pain2,6. Furthermore, with advancing age, muscular weakness, adjacent disc degeneration, and hip and pelvic disease may decrease compensation and increase disability. Restoration of normal sagittal balance reduces the work of erector spinae and hamstring muscles to achieve balance during normal activity2,4.

Restoration of sagittal balance typically involves Smith Peterson osteotomy (SPO), its modification by Ponti18, or pedicle subtraction osteotomy (PSO). PSO was first described by Thomasen28 in 1985. The technique involves removal of the posterior ligaments and facets followed by resection of the pedicles and decancellation of a wedge of the vertebral body via a transpedicular corridor. Closure of the wedge-shaped osteotomy through posterior shortening creates a large contact area of cancellous bone. PSO permits correction through all 3 columns from a posterior approach without lengthening the anterior column, thereby maximizing the healing potential while avoiding the risk of stretch or injury on the major vessels and viscera anterior to the spine11.

Typically, PSO is used for patients with sharp or angular kyphosis, as well as at levels lacking anterior flexibility at which effective SPOs/Ponte Osteotomies would be precluded11. Furthermore, patients with greater than 10 cm of sagittal imbalance would be more likely to benefit from a PSO than SPOs11,14.

We started using PSO in our centers since 2008. The purpose of this study is to report the radiographic and clinical results of the newly adopted PSO technique for treating patients with sagittal imbalance, to define factors that contribute to successful results, and to discuss complications.

Methods

This is a prospective multicenter study of all patients treated with PSO for sagittal imbalance from January 2008 to December 2009 who have completed a minimum of 24 months follow-up. The study protocol was approved by the institutional ethics committees and all patients signed an informed consent.

A total of 24 patients who underwent 25 PSOs are included in this study; one patient had 2 PSOs in one session because of very rigid deformity. There were 9 females and 15 males. The mean age at surgery was 33.4 years (range=15-53 years). The etiology for imbalance was post-traumatic (n=9), Scheuermann’s disease (n=6), congenital (n=5), Post-tuberculous (n=3), and post-laminectomy (n = 1). PSO was performed at T7 (n=1), T8 (n=1), T9 (n=2), T10 (n=1), T11 (n=3), T12 (n=4), and at L1 (n=6), L2 (n=5), and at L3 (n=2). The osteotomy was always performed at the apex of the deformity.

Measurements were made on radiographs taken preoperatively, immediate postoperatively, and at final follow-up. The kyphotic angle at the osteotomy site was measured from the upper and lower endplates of the apical vertebra. Sagittal balance was assessed on a standing lateral radiograph taken with the arms at 45° forward flexion and the hips and knees fully extended, measuring the horizontal distance between a C7 plumb line and the posterosuperior aspect of the sacrum at the L5–S1 disc (sagittal vertical axis). Clinical assessment relied on VAS for pain, patient satisfaction and their return to previous work or activity level.

Operative technique:

We used the same operative technique as described by Bridwell et al9, 10 with only one
We do not use curettes to decancellate the pedicle and vertebral body first, but rather we directly osteotomise the pedicle on each side together with the lateral cortex of the vertebral body with a fine osteotome, and then we excise it intact. We believe, this modification significantly shortens the operative time and decreases the amount of blood loss. We then use the curettes to remove the remaining cancellous bone from the vertebral body just in front of the central piece of the posterior vertebral cortex, which is then pushed forward and removed.

PSO was used for Type 1 sagittal imbalance (n=9 patients) and at the apex of Type 2 sagittal imbalance (n=15 patients) in conjunction with many Ponte osteotomies in adjoining levels. A wake up test was routinely used for neurologic monitoring. The operative time and the amount of blood loss were recorded. All patients were allowed out of bed on the first postoperative day. No cast or brace were used after surgery.

Results

The mean follow up was 36 months (range = 24–72 months). The mean estimated blood loss was 1319±1416 ml and the mean operative time was 5.6±3.2 hours. It was, however, difficult to differentiate between the time necessary for nor the amount of blood loss during the PSO step from the rest of the procedure, especially in type II imbalance with long constructs and many Ponte osteotomies also performed. The mean correction of the kyphotic angle at the osteotomy site was 32.3°±5.0°. The mean improvement in sagittal imbalance was 5.3±2.7 cm (Figure 1).

There were no permanent neurological deficits, no vascular injury, thrombo-embolic events or death. Three dural tears with transient cerebrospinal fluid leakage were recognized intraoperatively and were successfully repaired without further complication. Two patients suffered from transient lower limb paraesthesia that resolved spontaneously within a week. One patient, who had rigid Scheuermann’s kyphosis, developed haemo-pneumothorax during double level PSOs (at T7 and T11) that was managed by the insertion of an intercostal tube for 4 days (Figure 2). One patient with post-traumatic kyphosis had implant failure (pedicular screw pull out) within 48 hours after surgery, which led to the recurrence of the deformity and required revision with longer fixation. One patient had superficial wound infection, which resolved with repeated dressings and required no further surgical interference. Two patients developed significant wound hematoma, which required drainage. Progressive distal junctional kyphosis (DJK) leading to lower limbs weakness and sphincteric disturbance occurred in a patient with Scheuermann’s disease due to short distal fixation points. He was successfully managed with vertebral column resection and more distal fixation 6 months later (Figure 3). Another patient developed pseudarthrosis with rods breakage at a site distant from the PSO. He was revised after nine months with changing the rods and graft augmentation.

According to Denis scale of pain and work status at 6 months follow-up, 19 patients (79.2%) reported no or minimal pain (P1-P2), 2 patients (8.3%) reported moderate pain with occasional medication (P3), and 3 patients (12.5%) reported severe pain with frequent medication (P4). These included the patient who was revised for DJK and the one who was later revised for pseudarthrosis. Both patients showed significant reduction of their pain and marked functional improvement thereafter. Nineteen patients (79.2%) returned to their work and normal activity (W1-W2), 3 patient (12.5%), who was heavy manual workers and had a post-traumatic kyphosis, changed their job into a lighter one (W3), and 2 patients (8.3%) with DJK and pseudarthrosis were completely disabled (W5) until they were revised.

In answer to the question “If you could go back in time and make decisions again, would you choose the same treatment for your musculoskeletal condition or problem?”, 20 patients (83.3%) replied definitely yes, and 3 (12.5%) was not sure, and 1 (4.2%) replied by no.
**Figure 1.** A 15 years old girl suffered at the age of 9 from ependymoma that was successfully treated in another hospital by surgical resection followed by radiotherapy. a. & b. $T_1$-Gd and $T_2$-weighted sagittal MR images show the tumor. c. This 3-D CT picture demonstrates the T9-L1 laminectomy. d. & e. Whole spine reformatted coronal and sagittal CT show severe lower thoracic kyphosis, severe compensatory lumbar lordosis and upper thoracic lordosis. Mild right thoracolumbar scoliosis is also seen. f. & g. AP and Lateral erect X-rays show mild coronal shift and 6 cm anterior translation (red line) of sagittal plumb line (blue line). The white arrow points to the apex of the deformity at T11. h. & i. Preoperative and postoperative clinical pictures. j., k. & l. Two years follow-up X-rays show almost full correction of the scoliosis and kyphosis and restoration of sagittal plumb line to pass through the sacral posterosuperior corner. The white arrow points to the site of PSO at T1.
Figure 2. A 16 years old girl with rigid thoracolumbar Scheuermann kyphosis was corrected with 2 PSOs and multiple Ponte osteotomies. 

a. & b. Preoperative clinical pictures. c. & d. Preoperative erect X-rays show marked thoracic kyphosis and compensatory lumbar hyperlordosis with sagittal plumb line passing 4 cm behind the posterosuperior corner of S1. e. & f. Postoperative clinical pictures. g. & h. Two years follow-up erect X-rays show restoration of sagittal balance. The two white arrows point to the PSOs sites at T7 and T11.
Figure 3. A 20 years old male patient with Scheuermann kyphosis managed with T9 PSO and T4-T11 fixation developed junctional kyphosis, difficulty in walking and mild lower limbs weakness. He was revised 6 months later with posterior vertebral column resection (VCR).

a. Preoperative picture.
b. Preoperative erect lateral X-ray. c. Preoperative sagittal MRI. d. Six months post-PSO picture with marked junctional kyphosis. e. Six months post-PSO lateral x-ray with marked junctional kyphosis. The white arrow points to the site of PSO at T9. f. Six months post-PSO sagittal MRI with marked junctional kyphosis. g. Nine months follow-up after VCR at the junctional zone with T5-L3 fixation. h. Nine months follow-up after VCR done at the junctional zone with T5-L3 fixation. The white arrow points to the healed PSO site and the red arrow to the VCR site.
i. & j. Nine months sagittal reformatted CT confirming healing at the PSO and VCR (blue arrow) sites.
Discussion

Correction of sagittal imbalance remains one of the most difficult of all spinal reconstructive procedures. Reported major complications, including paraplegia, rupture of the abdominal aorta, and mortality limited the use of SPOs. Anterior release and fusion followed by posterior compression instrumentation, as a more successful and less morbid alternative, was widely accepted and used by many authors for managing sagittal plane deformity of various etiologies.

More recently, pedicle subtraction osteotomy has been introduced and widely accepted as the most powerful single technique in the correction of a fixed sagittal plane deformity. This technique can achieve 30°-40° of correction at a single osteotomy site. This accomplishes approximately as much correction as can be achieved with three Smith-Petersen or Ponte osteotomies, but has the advantage of achieving bone-on-bone contact throughout all three columns of the spine.

The present study analyzed the clinical and radiographic results for the first 24 patients undergoing PSO for sagittal deformity in our institute. Excellent deformity correction was initially achieved in all patients. The mean correction of the kyphotic angle at the osteotomy site was 32.3°±5.0°. This is comparable to the mean correction of 34.5° achieved by Bridwell et al in their series, and the 38° reported by Wu et al analyzing their series of post-traumatic kyphosis. This is also significantly better than the mean correction of 22.5° achieved by Böhm et al and the mean correction of 19° by Berven et al. Both groups used a combined dorsal decompression and fixation and ventral osteotomy and grafting. On the other hand, although the mean improvement in global sagittal imbalance of 5.3±2.7 cm in our series seems lower than the 10-16 cm reported in most series in the literature, it should be noted that the global balance in our patients was only little affected preoperatively and that it has been restored to normal in all of them. Our patients mean age was significantly younger than that reported in the largest series on PSO by Bridwell et al (33.4 versus 53.4 years) that many of our patients had preoperative negative sagittal balance. Compensatory mechanisms are more effective in the mobile spine and in younger age group.

Successful treatment of sagittal imbalance requires restoration of neutral sagittal balance while maintaining coronal balance. Most patients in our study reported improvement in terms of pain and self-image as well as overall satisfaction with the procedure. Achieving and maintaining sagittal realignment were repeatedly found to be associated with improved satisfaction and positive clinical outcomes. One patient (7%) in our series was somewhat dissatisfied with his treatment and would not undergo the procedure again because he failed to resume his work as a heavy manual worker, despite having excellent deformity correction.

There are inherent dangers with reconstructive procedures needed to restore sagittal balance. Most of the complications encountered in our study were minimal and self-limiting. Although 2 of our patients suffered from temporary lower limb numbness, which could be explained by the dural retraction during the resection of the central posterior cortex during the osteotomy, none had permanent neurological deficit. It is important to keep a central window, through which a fine dissector can be passed to exclude the possibility of iatrogenic canal stenosis. Some form of neurological monitoring is also mandatory. We routinely use Stagnara wake-up test, which is considered by many authors to be the most accurate way to assess spinal cord and nerve root function. Others have recommended the use of Somato-Sensory Evoked Potential (SSEP). It should be noted, however, that SSEP has been associated with both false positive and false negative results and that it does not prevent the occurrence of neural damage, but rather alarms the surgeon of its occurrence earlier than the wake-up test.

We also observed one case (4.2%) of pseudarthrosis in our study, occurring in the lumbar spine distal to the PSO site, which was identified by instrumentation failure and localized pain. Pseudarthrosis has been repeatedly reported in all similar series, but only rarely at the PSO site. Bridwell et al reported pseudarthrosis in 7 (26%) of 27 patients undergoing pedicle subtraction osteotomy for fixed sagittal imbalance. However, only 1 patient developed pseudarthrosis at the PSO level. Booth et al reported three (10.7%) pseudarthroses in 28 patients treated with various osteotomies for flat-back deformity. In their study of 25 consecutive
patients treated with combined anterior-posterior surgery for fixed sagittal imbalance, Berven et al reported five (20%) pseudarthrosis. In fact, because PSO is the only osteotomy that accomplishes three columns primary bony contact, it is associated with the lowest pseudarthrosis rate compared to all other anterior and posterior deformity correction techniques.

Junctional kyphosis has been repeatedly reported to occur either proximally or distally. DJK has been related to many factors including a low apex of the deformity (T7-T12), a very long curve, poor selection of distal fixation segment. In our study, DJK was observed in one patient who had Scheuermann kyphosis, although as recommended, his fusion extended to the lower end vertebra. Most recently, Cho et al in 2009 introduced the concept of extending fusion to the sagittal stable vertebra (SSV), which is defined as the most proximal lumbar vertebral body touched by the sagittal vertical axis to prevent the development of DJK. In our single case of DJK, the sagittal vertical axis did not contact the last instrumented vertebrae. Had we fused him during the first surgery to the SSV, DJK could have possibly been avoided.

Proximal Junctional Kyphosis (PJK) is also a risk of these procedures and has been reported in multiple series. It has been blamed on ligamentous disruption and balance parameters. In a recent series of PJK in Scheuermann kyphosis, the rate was 27% (12/45) with ligamentous disruption and incorrect upper instrumented vertebrae being risk factors. Although every effort was made intraoperatively to maintain the integrity of the most proximal facet joints and ligaments, some degree of PJK was occasionally observed in our patients postoperatively. Fortunately, none of them was symptomatic and none progressed during the follow-up. A more proximal instrumentation level (to T1 or T2) in all patients has been suggested by some authors to avoid PJK, but there is no data to support this.

The limitations of the current study are the small number of the patients having mixed types of sagittal imbalance with heterogeneous etiologies, and the absence of a control group, which makes an accurate statistical analysis of the data impossible to perform and present an obstacle against drawing solid conclusions and making recommendations. However, the aim of the current study is to demonstrate the PSO as an effective and safe technique that can be reliably used for surgical correction of various types of sagittal imbalance and would encourage the execution of a bigger and controlled clinical trials dedicated to a single type of deformity.

**Conclusion**

PSO can provide satisfactory clinical and radiographic outcomes with acceptable risk and morbidity. It provides single-stage decompression and correction using a more familiar posterior approach. PSO, however, is a technically demanding surgery, requiring strict attention to detail to avoid neurologic complications and to ensure sound fusion at the osteotomy site. Although several surgical options exist for correction of positive sagittal imbalance, it is believed that this single-staged posterior approach can reach the goals of decompression, correction, and rigid fixation in the same approach, and therefore it is a good alternative for the management of fixed sagittal imbalance.

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