Partial pedicle subtraction osteotomy: a modification for PSO in the treatment of sagittal deformities

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Background
Pedicle subtraction osteotomy is one of the most common spinal osteotomies used for correcting kyphotic deformities. The main disadvantage of this osteotomy is the complete dissociation between the vertebral body and the posterior elements, which creates an anterior displacement of the involved segment. There is also a reduction of the vertical dimension of the neural foramen. A new modification is to perform partial subtraction to avoid both complications.

Purpose
The aim of the study was to introduce a new modification of the traditional pedicle subtraction osteotomy, in which we perform partial pedicle osteotomy, preserving the inferior third of the pedicle. This allows smoother correction of the deformity, minimizes the injury or irritation to the nerve root below this pedicle, and decreases the incidence of subluxation and dorsal impingement. As the correction occurs with theoretically smaller wedges, better closure and union of the osteotomy site is expected.

Patients and methods
Our study included 33 patients with sagittal plan deformity (16 patients with ankylosing spondylitis, eight with old fractures, five with congenital kyphosis, and four with postlaminectomy kyphosis after cord tumor resection). All patients were treated by our modifications of the pedicle subtraction osteotomy technique. Radiographic analysis included assessment of kyphosis by the regional Cobb angle and the C7 sagittal plumb line in preplain and postplain radiographs. Clinically, the patients were assessed by the Oswestry functional score.

Results
Our series included 23 men and 10 women. The mean age of the group was 42.3 years. The vertical plumb line distance from the first sacral segment improved to 3.4 cm compared with a mean of 9.3 preoperatively. The degree of correction for single osteotomy was a mean of 22.4°. The intervertebral foramen below the osteotomized pedicle showed an unchanged vertical dimension after the osteotomy. Complications included four patients with dural tears, one with massive bleeding (2500 ml), three with superficial wound infection, and one patient with transient postoperative paraparesis. There was no single case of root injury. The mean follow-up period of the patients was 27.4 months. At the end of the follow-up period, radiological examination showed a loss of correction of a mean of 2° with no appearance of pseudoarthrosis or metal failure. According to the Oswestry disability score, 88% of patients were able to return to normal to moderate daily activities confidently and with overall satisfaction.

Conclusion
Although our new technique is technically demanding, it has a lower rate of neurological complication, with better chances of union compared with traditional osteotomy.

Keywords:
kyphosis, osteotomy, pedicle subtraction osteotomy, sagittal deformity

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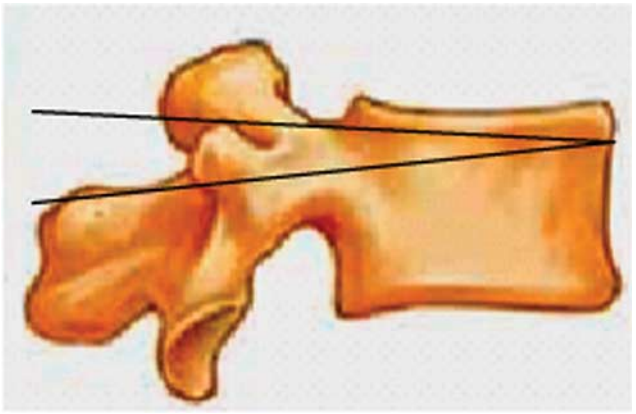
Introduction

Spine imbalance because of sagittal deformities leads to compensatory postures that place the body at a biomechanical disadvantage and results in inefficient use of muscle energy, causing strain, fatigue, and pain. Traditionally, this deformity has been treated with extension osteotomies at the level of the deformity. Pedicle subtraction osteotomy (PSO) has the advantage of being accomplished completely through a posterior approach without the need for an anterior procedure. Neurological deficits that accompany the procedure are believed to be the result of a combination of subluxation, residual dorsal impingement, and dural buckling.

The spine curves, with their alternating concavities between lordosis and kyphosis, should result in a balanced head over the sacrum to maximize the efficiency of ambulation and posture with the least expenditure of muscle energy. The disturbance in the magnitude of these curves will result in sagittal imbalance and excessive energy expenditure, which will result in muscle fatigue and pain. Moreover, sagittal imbalance may disturb the forward gaze, besides being cosmetically unacceptable to the patients.

PSO had been proposed and is a widely used surgical technique for the treatment of sagittal imbalance because of kyphotic situations. However, this technique has complications. We introduce a new modification of this widely accepted technique that we believe may decrease its complications, especially the neurological deficits.

Figure 1



Lateral view of lumbar vertebra with the lines of partial pedicle subtraction osteotomy. Notice that the inferior line is through the pedicle, leaving the inferior third of the pedicle intact to protect the underlying exiting nerve root.

Patients and methods

This was a retrospective study that included 33 patients who had been operated upon between January 2004 and December 2007. Among the patients included, 16 had ankylosing spondylitis, eight had old fractures, five had congenital kyphosis, and four had postlaminectomy kyphosis after cord tumor resection. Nine patients in our study presented with neurological deficits. The patients were evaluated with both plain radiography and MRI preoperatively. Plain radiographs were used to quantify the degree of kyphosis using the regional Cobb angle and the distance from the posterior superior endplate of the S1 vertebral body and the vertical plumb line. The anteroposterior view serves to detect any associated coronal deformity.

Our technique of partial PSO consists of the same steps as those used in traditional PSO for exposing the desired pedicle for osteotomy after fixation of the planed levels without assembling the construct, pedicle screws in all patients, to the rods. Once the pedicle is exposed after deroofing the intervertebral foramen above and below it, the osteotomy is performed preserving the inferior third of the pedicle. We performed our first line of the wedge osteotomy using a sharp osteotome above the superior wall of the pedicle through the vertebral body up to the anterior cortex. The second line of osteotomy was performed by introducing the osteotome through the pedicle, preserving its inferior one-third, which protects the underlying nerve root (Fig. 1). The nerve root is mildly retracted for protection as it passes medial to the pedicle. The inferior line of osteotomy is inclined to meet the first line just posterior to the anterior cortex of the vertebral body, preserving this cortex to act as a hinge during closure of this wedge. The two osteotomes remain in place and the position is verified by a lateral view using an image intensifier. Once the position of both osteotomes is accepted, the same maneuver is repeated in the contralateral pedicle of the same vertebra. The resultant bony wedge is removed, including its posterior cortex, using curved curettes to prevent posterior buckling against the dura. Once we are sure that the entire circumference of the dura is free and the posterior cortex of the wedge is totally removed, we extend the operating table and our construct is assembled to the rod with compression at the site of osteotomy to close our wedge hinging over the intact anterior cortex of the vertebral body. As a final step, we recheck the anterior dural surface and the roots exiting near the osteotomy in order to ensure their freedom and absence of any compression.

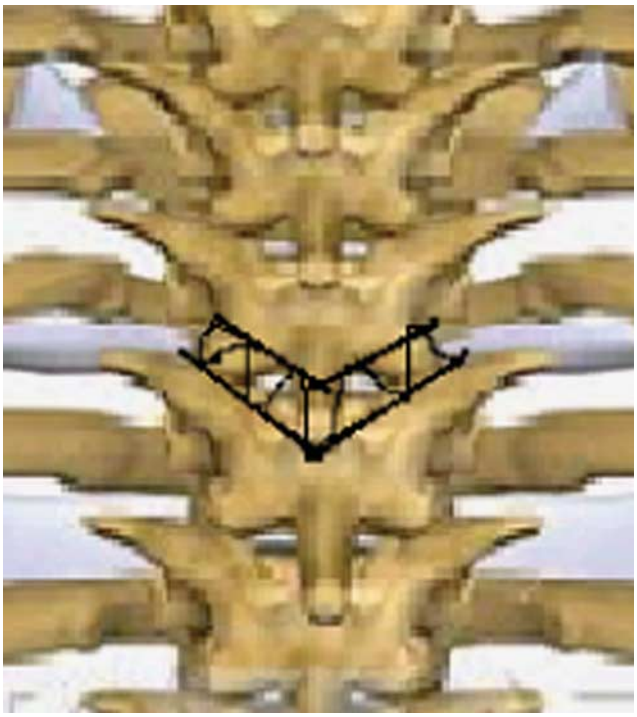
In patients with global loss of the lumbar lordosis, the 16 patients with ankylosing spondylitis, we preferred to perform a double-level osteotomy (usually at L2 and L4) with the same technique to produce smoother correction of the lumbar curve. In patients with ankylosing spondylitis, thoracic hyperkyphosis was a component of the deformity. We prefer to perform posterior V-shaped osteotomy at the dorsal spine to achieve additive dorsal correction. This is accomplished by removal of the adjacent parts of two successive laminae, spinous processes, ligamentum flavum, and facet joints (Figs 2–4). The number and levels of this osteotomy are individualized to every patient on the preoperative scanogram plane depending on the degree of the deformity, the degree of correction of the vertical plumb line distance after the lumbar osteotomies, and the whole sagittal balance required.

All patients were evaluated by the Oswestry functional score for clinical assessment and follow-up. The postoperative radiographs were evaluated for the correction of the regional Cobb angle and the distance from the plumb line to S1. The patient was allowed weight bearing using support on the second day postoperatively and when discharged. The patient was scheduled for follow-up at 2, 6, 3 months, then at every 3-month interval until fusion occurred, and annual follow-up thereafter.

Results

Our series included 23 men and 10 women. The age group varied from 5 to 65 years, with a mean age of 42.3

Figure 2



The V-shaped osteotomy of the dorsal spine. The shaded area is removed from the posterior elements to allow closure of the osteotomy achieved by posterior compression of the adjacent pedicle screws.

years. The mean intraoperative bleeding was 1350 ml and operative time was 235 min. The vertical plumb line distance from the first sacral segment was a mean of 9.3 cm. The average regional Cobb angle ranged from 7 to 115°, with a mean of 49.8°. The postoperative plumb line improved to 3.4 cm and there was a mean correction of 45.3° for the regional Cobb angle. In our study, the degree of correction in patients who underwent single osteotomy varied between 19 and 31°, with a mean of 22.4°. The intervertebral foramen below the osteotomized pedicle showed an unchanged vertical dimension after the osteotomy owing to the preservation of the inferior wall of the pedicle, whereas the foramen above the pedicle was enlarged distally.

The intraoperative complications included four patients with dural tears that were managed by direct repair and one patient with massive bleeding (2500 ml). No patient had root injury. The postoperative complications included three patients with a superficial wound infection that required debridement and four patients with prolonged serous discharge for more than 5 days. The infection subsided and the patients received antibiotic treatment for at least 3 weeks. Only one patient developed postoperative paraparesis, but recovered completely within 3 months. Six patients with preoperative neurological deficits improved by at least one grade on the Frankel grading system. One patient with postlaminectomy kyphosis after cord tumor resection developed unexplained neurological deterioration 6 weeks postoperatively that was attributed by neurosurgeons to the pre-existing cord pathology. One patient had postoperative cerebrovascular stroke because of diabetes and atherosclerosis.

The follow-up ranged from 25-66 months. The minimum follow-up is 25 months at time of editing this paper in November 2009. The maximum was 66 months. At the end of the follow-up, radiologically, there was a mean loss of correction of 2°, with no case of pseudoarthrosis or metal failure. According to the Oswestry functional score, 88% of patients were able to return to their normal to moderate daily activities confidently and with overall satisfaction.

Discussion

The development of osteotomy techniques has led to advancements in the ability of spine surgeons to treat spinal deformities [1]. The shift away from simple compression/distraction or cantilever maneuvers as a means of realigning the spine in favor of vertebral column osteotomies and resections with posterior column shortening has been an important philosophical and practical paradigm shift away from combined anterior–posterior procedures [2,3].

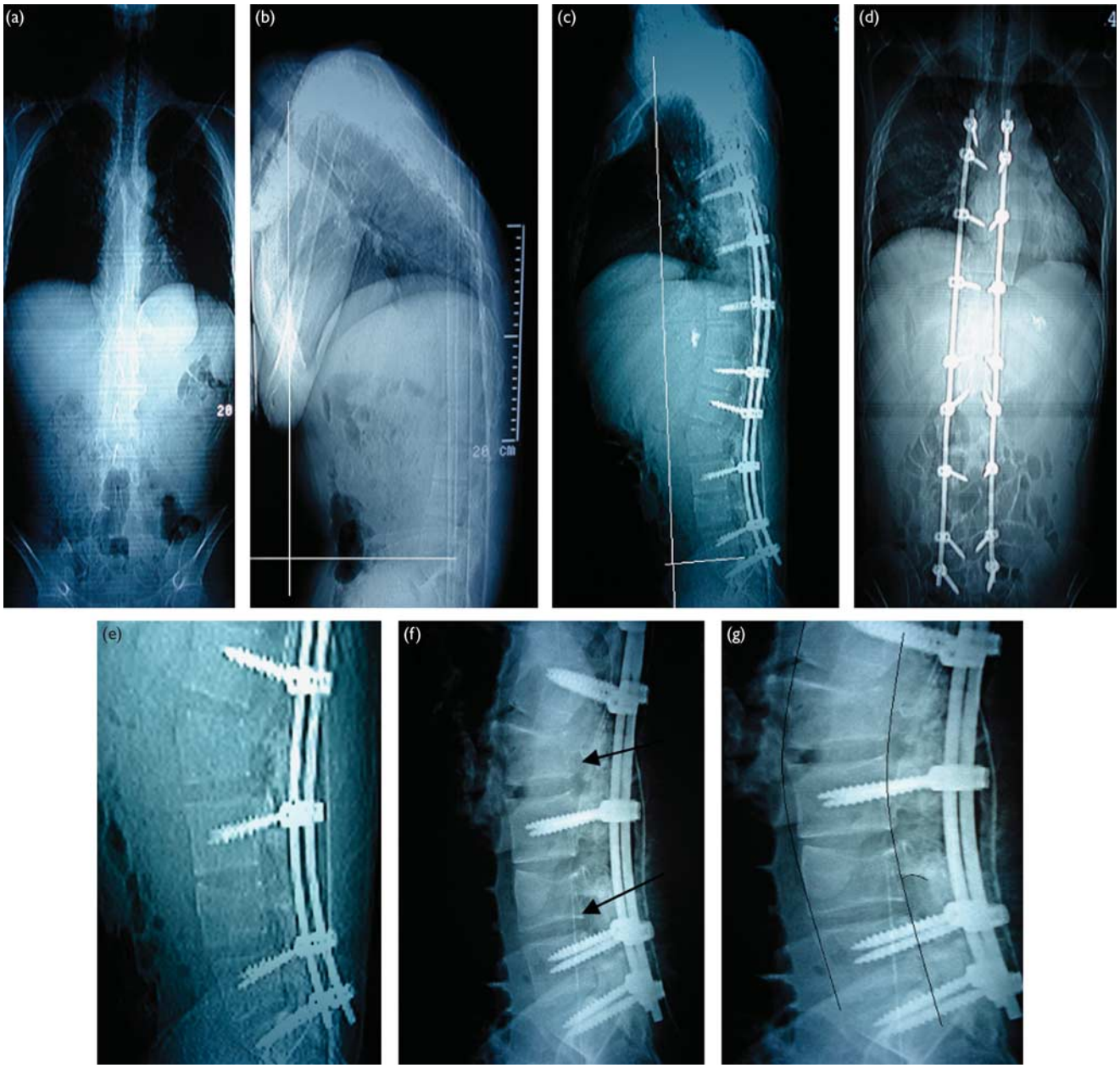
A unifying feature of Smith-Peterson osteotomy is shortening of the posterior column accompanied by elongation of the anterior column. Although there are many reports of successful Smith-Petersen osteotomies [4–7], lengthening of the anterior column has been associated with major complications, such as fatal aortic rupture, superior mesenteric artery syndrome, cauda equina syndrome, paraplegia, and paralytic ileus [8–11].

PSO is a relatively aggressive resection of a wedge of bone, including posterior elements, the pedicles, and the vertebral body [12]. There are several advantages of pedicle subtraction closing wedge osteotomy. Correction is achieved through all three columns of the spine. This allows for correction in both the sagittal and the coronal plane. In addition, the spine is not lengthened, thereby avoiding the vascular and abdominal complications associated with extension osteotomies. The bone surface for fusion is large and placed under compression by the mechanics of the osteotomy. The instrumentation is therefore used to maintain the alignment as opposed to creating the desired alignment. Cho *et al.* [13] reported that the corrections per segment were 10.7 for Smith-Peterson osteotomy and 31.7 for PSO.

Many authors have reported good and satisfactory results with this technique in the treatment of sagittal plane deformities [8,14,15]. Closing wedge osteotomy appears to provide satisfactory sagittal plane correction with superior results and a relatively low rate of major complications in comparison with opening-wedge osteotomy and polysegmental wedge osteotomy in patients with ankylosing spondylitis [8].

However, PSO is technically demanding and neurological complications may occur. Buchowski *et al.* [16] reviewed all 110 patients treated with a PSO at their institution

Figure 3



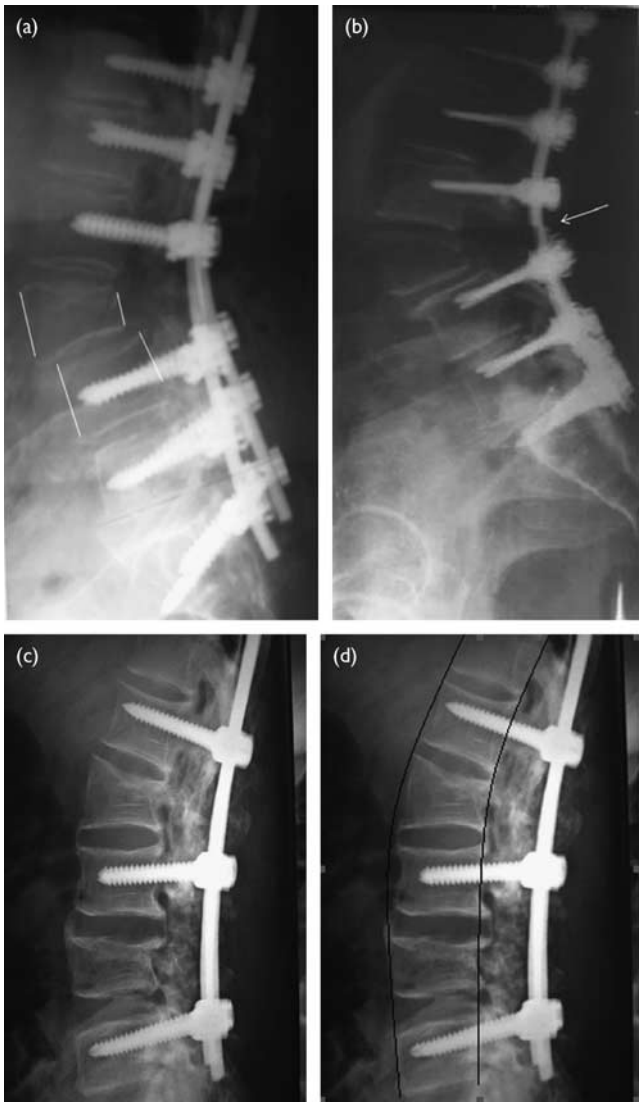
Male patient, 38 years old, with ankylosing spondylitis with sagittal imbalance. (a, b) Preoperative long film spine scanogram with the vertical plumb line in white color, (c, d) Postoperative spine scanogram with an improvement in the vertical plumb line distance, (e–g) Postoperative lumbar spine showing osteotomy at L2, L4, with smooth correction of lumbar spine with no evidence of subluxation at the level of osteotomy [black lines in (g)]. The inferior smooth pedicle wall is preserved with an unchanged vertical dimension of the intervertebral foramen (black arrows) and complete closure of the wedge osteotomy.

over a recent 10-year period and found that intraoperative and postoperative deficits were observed in 12 (10.9%) patients and permanent deficits in three (2.8%) patients. Deficits were believed to be the result of a combination of subluxation, residual dorsal impingement, and dural buckling [16]. Van Royen [8] listed postoperative nerve root compression requiring reoperation among the complications in his series.

As we believe that PSO provides very satisfactory results for the treatment of sagittal imbalance, we developed our modification as a trial to decrease its complications. Although the exiting nerve root occupies the upper third of the intervertebral foramen, in our modification, we preserve the inferior wall of the pedicle with its smooth cortex to protect the exiting nerve root during cutting through the pedicle and closure of the osteotomy. The vertical diameter of the foramen was not altered postoperatively; thus, there was no root compression or injury.

Our technique of partial PSO provides a smaller wedge, which we believe to be advantageous. The closure of this wedge is easier, with no need for excessive compressive

Figure 4



(a) A case of traditional pedicle subtraction osteotomy complicated by subluxation (spondylolisthesis) of L3 (white lines). (b) Another case complicated by both subluxation metal failure (white arrow). This may be attributed to a large degree of correction through only one osteotomy at L3. Moreover, L3 is connected to the spinal column only by the intervertebral disc and anterior longitudinal ligament, with considerable stress placed on the metal implants until intertransverse fusion occurs. (c, d) A case of partial pedicle subtraction osteotomy performed at L2, L4 at the end of follow-up shows no evidence of any subluxation, smooth correction of lumbar lordosis (black lines), maintenance of intervertebral foramen, and union of the osteotomy sites. Near-normal anatomy of L2, L4 because of the union of the remaining lower one-third of the pedicle with the posterior fusion mass.

forces, which stresses the fixation and endangers its stability in both the short and the long term. Moreover, this smaller wedge allows better apposition and compression of the osteotomy surfaces and therefore better healing, with lower chances for pseudoarthrosis at the osteotomy site. Being a smaller wedge, it decreases the incidence of anterior subluxation that resulted because of the closing of large wedges, which endangers the neural elements posteriorly because of kinking at the osteotomy sites. This is very beneficial in high degrees of deformity or in cases where the deformity is global to the entire region as in ankylosing spondylitis. For this, we prefer to perform double-level osteotomy, above and below the apex of deformity, with our technique rather than a single large osteotomy at the apex. This provides smoother correction of the deformity rather than the sharp correction at one level, with better chances of proper closure of the wedges, with a low incidence of subluxations. Although double osteotomies increase the surface needed to fuse, the small wedges are usually compressed perfectly, which markedly decreases the incidence of non union. Finally, the remaining part of the pedicle may give the surgeon a landmark after disturbance of the anatomy in this region in cases of revision surgeries. Fortunately, it may adhere to the posterior fusion mass when fusion is accomplished to connect the osteotomized vertebra to the posterior element again.

We are aware that this operation has complications. However, all the complications we encountered were those that are associated with any extensive spine operation (multilevel pedicle fixation, extensive decompression, and posterior handling of anterior structures) and not because of the technique described. Multiple-level osteotomies may be more time consuming than single osteotomy. However, we believe that the advantages can justify this disadvantage.

Conclusion

Our technique, partial PSO, is a modification to the traditional PSO, which has already yielded highly satisfactory results in the treatment of sagittal plan deformities. Our aim was to decrease the incidence of complications that may result from this technically demanding procedure. Our data represent an optimistic guide toward making this technique safer.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

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