Pedicle subtraction osteotomy in the treatment of chronic, posttraumatic kyphotic deformity

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Object. Thoracolumbar fractures, treated operatively or nonoperatively, may cause painful kyphotic deformities over time. A pedicle subtraction osteotomy (PSO) is a single-stage posterior procedure designed to correct sagittal plane deformity. Although it was initially used to treat nontraumatic conditions, a PSO can be highly effective in chronic, posttraumatic fractures of the lumbar spine. In this report the authors review details obtained in the treatment of three patients with severe, posttraumatic spinal deformities. They describe the surgical technique used to correct the sagittal malalignments.

Methods. All three patients were middle aged, and good bone mineral density had been demonstrated in each case preoperatively. After PSO, a mean 51° improvement in sagittal alignment was achieved and maintained until a solid arthrodesis was documented in each case. Substantial improvements in pain relief and functional outcome were observed. A detailed, procedure-specific literature review was undertaken.

Conclusions. A PSO is a valuable tool to add to the armamentarium of neurosurgeons who treat patients suffering from painful posttraumatic deformity following fractures of the upper lumbar spine.

KEY WORDS • kyphosis • sagittal imbalance • posttraumatic kyphosis • burst fracture • spinal osteotomy

The optimal initial treatment of thoracolumbar burst fractures continues to be strongly debated.8,26,27 Following both surgical and nonsurgical treatments, some degree of kyphosis at the injured level is present in many patients.1,19,25 In some patients, significant kyphosis can be functionally limiting and associated with severe chronic pain despite the absence of neurological involvement. The treatment of such patients with chronic, painful, posttraumatic kyphosis can be quite challenging.11,20

Surgery to correct kyphosis can take several forms. Conceptually, the procedure must be “lordogenic”—that is, it must produce lordosis. This can be achieved by lengthening the anterior elements, shortening the posterior elements, or a combination of the two.

Pedicle subtraction osteotomy was developed to achieve significant deformity correction. In a single-stage, posterior-approach procedure, portions of the VB and posterior neural arch are resected.2,5,14,24 Conceptually the procedure entails a shortening of the posterior elements but, in reality, it involves shortening of portions of the anterior elements as well. Deformity correction relies on maintaining an intact anterior VB cortex “hinge” that represents the apex of a wedge-like bone resection.

Originally used to treat VB abscesses, PSO was first described in the orthopedic literature.16 Since its earliest application, PSO has also been conducted to correct sagittal plane deformities associated with AS, degenerative deformities, idiopathic scoliosis, and postsurgical iatrogenic flat-back syndrome.2–7,13,14,17 Few authors have reported using the procedure to manage posttraumatic kyphosis.3,14 In an extensive review, we found that the PSO-based management of posttraumatic kyphotic deformity has not been described in the neurosurgical literature.

The present report represents our experience in the treatment of patients with healed upper-region lumbar burst fractures associated with chronic intractable pain and kyphotic deformity. In addition to providing clinical data obtained in three cases, we describe the technical aspects of the surgical procedure and evaluate the available peer-reviewed literature.

Case Presentations

Study Overview

During a 1-year period, we treated three patients with painful posttraumatic kyphosis associated with healed upper lumbar (L-1 or L-2) burst fractures. All patients had suffered traumatic burst fractures in the distant past. One patient had undergone prior surgery whereas the other two patients had been initially treated nonoperatively. None of the patients had initially undergone treatment at our institutions. The hospital records—including operative re-
ports, radiographs, and follow-up examination data—were reviewed for the present study. An integer-based (score range 0–10) VAS was used to assess pain levels both preoperatively and at follow-up evaluations.

**Case 1**

*History.* This 32-year-old woman had sustained an L-2 burst fracture 3 years previously. Despite undergoing various nonoperative treatments, she continued to suffer severe, intractable low-back pain. At the time of the initial injury, she had been treated with a short period of bed rest and subsequent mobilization while wearing a custom-molded thoracolumbosacral orthosis for 3 months. She was compliant with the prescribed treatment regimen.

*Examination.* When evaluated 3 years after the injury, she rated her back pain as greater than 10 on the 10-point VAS. She did not have significant leg pain, numbness, or weakness. Physical examination demonstrated a forward truncal shift and a palpable prominence of one spinous process in the upper lumbar spine. She was neurologically intact. She was an unemployed waitress receiving disability payments because she was unable to stand or sit upright for any prolonged period.

Plain radiography revealed a healed L-2 burst fracture in which there was a substantial amount of anterior VB height loss and wedging. Sagittal Cobb angle measurements demonstrated 26° of focal kyphosis from the superior L-2 endplate to the inferior L-3 endplate (Fig. 1). The sagittal balance measured $-19.7$ cm. Dynamic flexion-extension radiography showed no pathological motion. Preoperative CT scanning of the canal demonstrated minimal compromise at the fracture site and no other levels of spinal stenosis.

*Operation.* A PSO was undertaken at L-2, and T12–L4 PS fixation and fusion were performed. There were no intra- or perioperative complications, and the patient tolerated the procedure well.

*Postoperative Course.* Initial postoperative plain radiography demonstrated 7° of lordosis between the superior L-2 endplate and the inferior L-3 endplate. This represented 33° of sagittal plane correction. In addition, the sagittal balance now measured $-1.9$ cm. At the 2-year follow-up evaluation, a solid fusion was apparent and there was no evidence of hardware failure. The measured correction remained unchanged. The 2-year VAS score was 1 and she remained neurologically intact. She had resumed gainful employment. Pain and functional assessments were performed by a clinical nurse practitioner for the Department of Neurosurgery.

**Case 2**

*History.* This 47-year-old man presented with severe low-back pain that inhibited him from standing in a normal position. His medical history included an L-1 burst fracture suffered 31 years prior to presentation. At the time of the initial injury, he had sustained a neurological deficit, which included bilateral foot drops and numbness, that had never recovered. He retained clinically normal bowel and bladder functions. The initial treatment was a laminectomy without fusion and, subsequently, a prolonged period of bed rest. By the patient’s own account, his foot drops were unimproved after surgery. With continued complaints of intractable back pain, he underwent an uninstrumented thoracolumbar posterior fusion 2 years later. He reported that his pain did not substantially improve after the fusion, and he remained in this condition for the next 29 years.

*Examination.* On initial presentation, the patient’s pri-

![Fig. 1. Case 1. Radiographic studies. A: Preoperative lateral standing radiograph demonstrating a 26° focal kyphosis from the superior aspect of L-2 to the inferior aspect of L-3. B: Preoperative three-dimensional CT scan. C: Postoperative lateral standing 36-in radiograph taken 2 years after an L-2 PSO, showing an improvement in the sagittal alignment to 7° of lordosis (from the top of L-2 to bottom of L-3), representing a 33° overall correction.](image-url)
mary symptom was constant back pain. His pain was great, reflected by a VAS score of 10, and he regularly used high doses of narcotic agents. Physical examination demonstrated a forward stooped posture, which he attempted to compensate for by flexing his knees and extending his hips. Neurological examination revealed absent (Grade 0/5) dorsiflexion of both feet. The remainder of lower-extremity power was normal on isolated muscle group testing, and sensation was diminished to pinprick testing in the L-5 and S-1 intact dermatomes.

Plain radiography revealed a healed L-1 burst fracture in which there was severe wedging and anterior VB height loss. The sagittal Cobb angle measured 49˚ from the superior T-12 endplate to the inferior L-2 endplate. The sagittal balance measured +6.8 cm (Fig. 2).

**Operation.** An L-1 PSO with an instrumented posterior T11–L3 fusion was conducted.

**Postoperative Course.** The surgery resulted in an improvement to 5˚ of kyphosis (as measured from the top of T-12 to the bottom of L-2) on postoperative lateral radiographs (representing 44˚ of sagittal plane correction). The sagittal balance improved to −0.9 cm. The patient tolerated the procedure well, and he remained neurologically unchanged, his bilateral foot drop persisting. At 2 years postoperatively, he stated he was pain free (VAS Score 0). He required no pain medications after the initial 3-month postoperative period. Interestingly, although his foot drops had not changed, he reported significant improvement in his foot sensation bilaterally. Radiography at 2 years revealed a solid fusion, maintenance of sagittal correction, and no evidence of rod or PS failure.

**Case 3**

**History.** This 32-year-old man presented with a history of an L-2 burst fracture that he had sustained as a teenager while living in South America. At that time, he had undergone a 3-month period of bed rest and no brace therapy, after which he was progressively allowed to ambulate.

**Examination.** The patient was unable to stand fully upright and he suffered severe, intractable back pain. These symptoms prevented him from seeking employment. His initial VAS score was 10. Physical examination revealed a marked gibbus deformity in the upper lumbar region, point tenderness over the L-2 spinous process, and a forward shift of the trunk over the pelvis. Neurological examination demonstrated no deficits.

Radiography revealed a 54˚ kyphotic angle, measured from the superior endplate of L-1 to the inferior endplate of L-3 (Fig. 3). The sagittal balance was +12.8 cm.

**Operation.** We performed an L-2 PSO that included removal of all of the posterior elements at L-2 and partial laminotomies of the inferior aspect of L-1 and the superior aspect of L-3.

**Postoperative Course.** The patient tolerated this surgery well in the immediate postoperative period. The initial postsurgical radiographs revealed 23˚ of lordosis from the superior and inferior endplates of L-1 and L-3, respectively, representing a sagittal plane correction of 77˚. The postoperative sagittal balance measured +1.0 cm.

Although the patient’s neurological status was normal.
for the first 2 days after surgery, an incomplete lower-extremity motor deficit developed on Day 3. This occurred when the patient left his bed and sat upright in a thoracolumbosacral orthosis. An emergency myelogram, along with a postmyelography CT scan, demonstrated a nearly complete dye occlusion at the L-2 level despite no change in alignment or instrumentation position, compared with the immediate postoperative studies.

Second Surgery. The patient was taken to the operating room where bilateral L-1 and L-3 laminectomies were performed without revision of the instrumentation.

Second Postoperative Course. The deficit began to resolve immediately after surgery and, at the 2-year follow-up examination, the patient was neurologically intact with normal muscle strength and bowel/bladder function. Radiography revealed a solid fusion and maintenance of the deformity correction. The VAS score was 2. The patient was unemployed, but he was actively pursuing employment opportunities.

Surgical Technique

A uniform preoperative evaluation and surgical technique were used in all three cases.

Perioperative Considerations. Because of the significant corrective forces imparted and maintained through the PS instrumentation, assessment of BMD is crucial. All patients had undergone dual-absorption x-ray absorptiometry scanning to assess vertebral BMD. Importantly, this was performed in the lower lumbar spine at a level other than the fracture site because sclerotic bone at the injury site can erroneously lead to higher BMD measurements.

In addition to evaluation of medical comorbidities, detailed radiographic studies were performed. These assessments included standing lumbar plain radiographs with flexion-extension views, standing 36-in AP and lateral radiographs, and CT scans with sagittal reconstructions. Sagittal plane Cobb angle measurements were made above and below the kyphotic segment, and these were compared with postoperative same-level measurements. Sagittal balance was determined by dropping a vertical plumb line from the center of the C-7 vertebra inferiorly to the sacrum. The reference point used inferiorly was the posterior aspect of the L5–S1 interspace. By convention, when the plumb line is in front of the inferior reference point, this represents kyphosis and a positive value is assigned. To obtain a true determination of sagittal balance, it is essential that the patient be instructed to extend the hips and knees as much as possible. Otherwise, because knee flexion is nearly uniform in this painful kyphotic condition, inaccurate sagittal-balance values would be obtained. Donated autologous blood was utilized in all three cases. We routinely use an intraoperative blood salvage (cell-saver) technique to minimize the need for postoperative homologous blood transfusions.

Intraoperative Positioning. Following endotracheal intubation, the patient was positioned prone on a radiolucent frame. Use of a transverse chest pad and hip/thigh pads enabled maximal extension of the lumbar spine. This facilitates intraoperative osteoclasis through the osteotomy. Prior to beginning the surgery, AP and lateral fluoroscopic (C-arm) images were obtained at the intended operative levels to ensure that all osseous landmarks could be adequately visualized. All osseous prominences were padded and the eyes were protected. The patient’s arms

Fig. 3. Case 3. A: Lateral preoperative radiograph showing a 54° kyphosis from the top of L-1 to the bottom of L-3. B: Intraoperative photograph obtained following the removal of all L-2 posterior elements including the spinous process, bilateral laminae, the pars interarticularis, superior and inferior facet joints, and the transverse processes bilaterally. The inferior aspect of the L-1 lamina and the superior aspect of the L-3 lamina have been removed, and the L-2 pedicles have been resected. The thecal sac and L-2 nerves are widely decompressed. The distance between the L-1 PSs and the L-3 PSs is 6.5 cm. The compressor is positioned between the L-1 and L-3 PSs. C: Intraoperative photograph acquired after compression was created with a contralateral temporary plate to maintain the correction. Note that the distance between the L-1 and L-3 PSs is now 3 cm, and the spinous processes of L-1 and L-3 are nearly in contact. D: Intraoperative photograph obtained following placement of bilateral rods, implantable bone stimulator, superior and inferior cross-connectors, and a generous quantity of autologous bone graft. Note that additional L-1 and L-3 resection has been performed and the redundant dura mater is visible. E: Lateral standing 36-in plain radiograph taken 2 years postoperatively of a 23° lordotic curvature from L-1 to L-3 representing a 77° correction in sagittal alignment compared with the preoperative view (A).
Pedicle subtraction osteotomy

were placed on arm boards, allowing free movement of the C-arm over the involved region of the spine.

Surgical Approach. A standard midline approach was followed. A subperiosteal exposure was performed from two levels above to two levels below the intended vertebrae to be instrumented. Care was taken to avoid disruption of the interspinous ligaments and facet joint capsules at levels not included in the fusion. After the exposure was completed, the spinous process and lamina of the level to be osteotomized were removed, as were the inferior and superior halves of the superior and inferior adjacent spinous processes and laminae. At the osteotomy level, the pars interarticularis, superior and inferior articular processes, and the transverse processes were excised in their entirety. Care should be taken to protect the exiting nerve roots at all times. This is best achieved by circumferential subperiosteal dissection in which a Penfield elevator and small angled curettes are used. At the completion of the posterior element resection, the cauda equina, exiting nerve roots, and descending nerve roots should be clearly visualized. The exiting nerve root should be seen descending below the pedicle of the osteotomy level, which at this point, should appear as an “ant-hill” emerging from the VB with its cancellous inner core facing posteriorly.

Preosteotomy Instrumentation. Using C-arm guidance, PSs were inserted bilaterally into the vertebrae two levels above and two levels below the osteotomized segment. We use posted screws, rather than polyaxial screws, which enable more control during osteoclasis. We prefer screws with a 6.25-mm diameter. A 5.5-mm-diameter screw is the smallest acceptable size that we consider. If more than 40° of correction is to be attempted, we recommend a more aggressive midline resection of the lamina above and below to avoid impingement of the thecal sac after closure of the osteotomy. This may help to prevent the postoperative neurological deterioration that occurred in Case 3.

Vertebral Body Osteotomy. Careful, preemptive bipolar coagulation of the epidural venous plexus was performed. The epidural veins often appeared as “lakes” of vessels along the posterior VB.

Next, the lateral walls of the pedicles were resected down to the level of the posterior VB. We have found it useful to maintain the medial pedicle wall to protect the dural sac. A high-speed air drill with a large, round (5- or 6-mm) cutting bit was advanced through the remaining pedicle and into the VB to create a working void within the bone. In general, an attempt was made to create a wedge-shaped void that has a greater height posteriorly than anteriorly. This entails drilling a greater rostrocaudal extent of bone in the posterior aspect of the vertebra while removing less bone as one progresses anteriorly. The air drill can be “wanded” through the VB to allow for removal of medial and lateral bone. Caution should be taken to avoid penetration of any of the osseous cortices, at any time, to prevent iatrogenic injury to surrounding structures.

At this point, the depth of bone resection can be checked by inserting a Penfield dissector into the VB. Anterior resection was considered complete if a lateral fluoroscopic view revealed approximately 5 mm of bone between the instrument and the anterior VB cortex. Care was taken to avoid violating the anterior cortex as well as the inferior and superior osseous endplates. The intervertebral discs above and below the osteotomy were left intact.

The next step involved excision of the remainder of the pedicle and the posterior VB cortex. The medial pedicle wall was taken down until flush with the VB. From this point forward, the exiting nerve root and thecal sac must be continuously observed and protected with gentle retraction. By placing the air drill through the defect of the resected pedicle and angling it medially, we could excise the remaining cancellous bone in the posterior VB. After the posterior bone has been satisfactorily thinned, the posterior cortex of the VB was carefully resected using Kerrison rongeurs, working medially from the pedicle defect. During this maneuver, gentle retraction and protection of the dura were required bilaterally, progressing to, but not across, the midline. Significant EBL may occur during this maneuver. Attempts at coagulating the epidural venous plexus prior to this maneuver can help minimize EBL. If appreciable epidural bleeding is encountered on one side, the area can be temporarily packed with Gel-foam and cotton patties, and work can be shifted to the contralateral side.

At this point, the lateral cortical bone at the osteotomized segment was also partially resected with rongeurs. Next, the most midline portion of the VB cortex was pushed anteriorly, into the defect, using down-angled curettes. This method of resection is preferred over the use of a Kerrison rongeur to avoid inadvertent injury to the anterior dural sac. In a similar manner, the lateral portion of the thinned VB cortex was resected bilaterally in a wedge configuration by using down-angled curettes. The anterior VB cortex should be maintained because it will act as the axis of rotation, or hinge, of the osteotomy.

Lordotic Maneuver. The osteotomy was now ready to be closed. This was accomplished by using a compressor device placed on the posted screws immediately above and below. Gentle, continuous force was applied to achieve a controlled correction. The dura and neural elements must be visualized at all times during this maneuver. Although dural redundancy is inevitable at the osteotomy level, osseous impingement of the adjacent lamina borders onto the dura mater must not be left unaddressed. If needed, additional bone resection should be performed. Final inspection of the dura included probing its anterior and posterior aspects with an angled (Hockey-stick or Woodson) dissector. In addition, in viewing a lateral fluoroscopic C-arm image, one should ensure that there has not been any inadvertent AP translation through the osteotomy, which can occur if the anterior VB cortex was violated.

Postosteotomy Instrumentation and Bone Grafting. Because the osteotomy can be quite springy, full closure was temporarily maintained using an uncontoured plate fixed to the PSs on the contralateral side. The compressor on the ipsilateral side was then removed without sacrificing deformity correction. A 0.25-in titanium rod was then contoured and secured to the four PSs. The temporary plate was removed from the contralateral side, and a second rod was contoured and secured to the screws.

Because the procedure was a highly destabilizing maneuver, we used cross-connectors to increase the overall torsional stability. One connector was placed above
and a second connector below the osteotomy. An implantable bone growth stimulator can be inserted in cases in which there may be a particular risk of nonunion. Finally, a generous amount of iliac crest autograft bone was placed over the decorticated lateral gutters (transverse processes), laminae, and facet joints to promote fusion. Large-bore suction drains were then placed, and a standard layered closure was completed.

Postoperative Protocol and Follow-Up Course. Plain radiographs were obtained immediately and a detailed neurological examination was performed in the recovery room. If there was any concern that neurological function had been compromised, an emergency CT study was obtained. Alternatively, the patient may be brought to the operating room. Notwithstanding any urgent postoperative events, postoperative CT scanning was routinely performed once the drains were removed. The patient was allowed out of bed, but the use of a custom-fitted thoracolumbar orthosis was required for 3 months postoperatively. Physical therapy was initiated in the hospital and continued for 6 weeks on an outpatient basis. After hospital discharge, clinical and radiographic follow-up evaluations were scheduled at 1.5, 3, 6, 12, and 24 months. The criteria for a solid fusion included continuous, bilateral trabecular bone bridging along the intertransverse and/or posterior elements. The VAS scores were recorded at initial presentation and all follow-up visits.

Results

The same surgical procedure was performed in all three patients. At the final follow-up examination after a minimum of 2 years, the VAS score was reduced by a mean of 9 (range 8–10). Despite one case of delayed postoperative neurological deterioration in which the patient was returned to the operating room, we observed that findings at the most recent neurological examinations were equivalent to those recorded at the initial examinations in all three cases. The mean operative time was 420 minutes and the mean EBL was 883.3 ml. No homologous blood transfusions were necessary. Radiography demonstrated solid fusions in all three cases. A mean of 51˚ of sagittal plane correction was achieved and maintained at the final follow-up of two years. The mean sagittal balance improved from +13.1 cm preoperatively to −0.6 cm postoperatively as measured from the center of C-7 to the posterior edge of the L5–S1 disc space (Table 1).

Discussion

Many authors have reported their results of PSO for the treatment of sagittal deformities caused by a variety of underlying disorders of the thoracolumbar and lumbar spine. The origins of the technique stem from its first description in 1949 by Michele and Krueger as does its first moniker, the eggshell procedure. Interestingly, the procedure was developed as a method of accessing and debriding an infected VB via an all-posterior approach. Since 1949, the procedure has been adapted and modified for the treatment of spinal deformities, and these changes have been facilitated by the development of rigid internal spinal fixation. During the time of these evolutionary technical/mechanical changes, this procedure has been referred to by many different names, such as transpedicular wedge osteotomy, monosegmental transpedicular subtraction osteotomy, transpedicular decancellation closed wedge osteotomy, and posterior transvertebral osteotomy.

Recently, Bridwell and colleagues reported results obtained in 27 patients consecutively treated with PSO for fixed sagittal imbalance due to varying pathological entities. Most of the cases were idiopathic scoliosis (14) or degenerative disease (eight). The mean correction was 34.1˚. Significant improvements in pain and Oswestry Disability Index scores were reported. Complications included one pseudarthrosis at the osteotomy level and six cases of pseudarthroses in the thoracic spine.

In a subsequent report from the same group, the authors analyzed complications in 66 patients who had undergone a PSO. New-onset, but temporary, neurological deficits occurred in five patients (8%), thoracic pseudarthrosis in six (9%), and lumbar pseudarthrosis in two (3%). The mean EBL was 2386 mm and the mean operative time was 12.2 hours.

Murray and associates retrospectively analyzed the results of the so-called eggshell procedure in 59 patients. Thirty-seven of the procedures were performed for deformity correction and could be considered to represent a PSO; however, the specifics of the cause of the underlying deformities were not reported. The mean postoperative correction was 26.2˚ (range 14–43˚). The mean EBL was 2874 mm and was significantly greater in men than in women. In five patients the authors documented a new-onset nerve root injury, which resolved completely in three patients. Instrumentation failure occurred in three (8%) of 37 cases, although the overall fusion rate was reported to be 100%.

### TABLE 1
Summary of pre- and postoperative data obtained in three patients with chronic, posttraumatic kyphotic deformity*

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* + = kyphosis; − = lordosis.
† The patient’s subjective response was that her pain was greater than indicated by the highest score.
Pedicle subtraction osteotomy

The results of PSO in patients with AS have been extensively reported. Kim et al., prospectively analyzed the results acquired in 45 patients who underwent PSO to treat AS-related kyphotic deformity. The mean correction was 34°. Pain scores, function, and activity evaluations significantly improved. In five patients transient neurological deficits occurred, four of which were radicular. Fusion rates were not reported. In another dedicated series of patients with AS, Chen and coworkers reported a mean of 34.5° of correction per osteotomy level. Interestingly, they performed staged, two-level osteotomies in 14 patients with severe deformities. In one such patient, 100° of correction was achieved. No neurological complications were documented. In one of the earliest reports of PSO for AS, Thiranont and Netrawichien reported a mean of 33° of correction in six patients.

Berven, et al. retrospectively reviewed their results after undertaking PSO in 13 consecutive patients with various disorders. The mean improvement in lumbar lordosis was 30° (range 8–62°). Approximately 90% of patients were satisfied with their postoperative results. Surgery-related complications included dural tears in three patients and transient nerve root paresthesia in four. Although fusion rates were not reported, one patient underwent a subsequent operation to treat proximal adjacent-level kyphosis.

Few authors have reported the results of PSO for posttraumatic kyphosis. In fact, in our literature search we found only one dedicated case series in which PSO was performed in patients with posttraumatic kyphosis. Some authors have included postfracture cases within a larger series of patients. Consecutive cases, Lehmer and colleagues treated 21 patients with PSO for kyphosis associated with a previous fracture. Although not specific to this subgroup of patients, a high rate of neurological deficits was noted. A new-onset neurological deficit occurred in eight patients (19.5%); three were temporary or minor, but one was an unresolved case of paraplegia.

Various other types of osteotomies have been used to treat posttraumatic kyphosis. Chang utilized a so-called single-stage oligosegmental osteotomy in 17 patients with prior fractures or dislocations. According to his description, this included an anterior disectomy and posterior closing-wedge osteotomy that is similar to a Smith-Petersen technique. A mean correction of 37.8° was documented, and no neurological complications developed. Jodoin, et al., reported results derived from using many different types of surgery, one of which included a simple posterior osteotomy and fusion that they performed in four patients. In one of the earliest reports of surgical treatment of posttraumatic kyphosis, Roberson and Whitesides used varying combinations of anterior and posterior surgery.

To produce lordosis, the anterior column needs to be lengthened and/or the posterior column needs to be shortened. Preoperative decision making should include consideration of all types of osteotomies. Selection of one osteotomy technique over another can be influenced by a number of factors, including the extent of deformity correction desired, the preoperative medical condition, and the type(s) of prior surgery performed in the targeted region. In our practices, this decision-making process involves a frank discussion of the risks, benefits, alternatives, and goals of each procedure with the patient and family. A strong family support system has a significant impact on an individual’s good outcome.

It has been purported that a PSO allows the maximal amount of segmental correction via a single-approach, single-stage procedure. In human cadavers, Li and associates found that a standard PSO resulted in comparable amounts of correction (mean 36°) as a combined anterior discectomy–posterior closing osteotomy (mean 38°, Smith-Petersen technique). Of note, they indicated that additional resection of the posterosuperior endplate of the osteotomized VB resulted in an additional 10 to 13° of correction (total 47–49°), a modification similar to those clinically used by Lehmer, et al., Gertzbein and Harris, and Thiranont and Netrawichien. Interestingly, these correction values are similar to those achieved in our present three cases (mean 51°). Using rigid, posted screws in combination with aggressive bone resection, we produced a greater degree of kyphotic correction than is typically reported. It is our belief that the dramatic degree of correction in Case 3 led to symptomatic neural element compression when the patient was assisted in assuming the upright position. As a result, in scenarios in which we are attempting to obtain greater than 30° of correction at a single level, we have been more aggressive in removing laminar bone from the levels above and below the osteotomized vertebrae.

It should be noted that in all of the present cases the BMD was considered to be within normal limits. The strength of PS fixation, it has been shown, is directly affected by BMD. As large corrective forces are applied through and maintained with PSs during a PSO, the strength of fixation is a critical element in the overall technical success of the procedure. Therefore, osteoporosis is considered to be a relative contraindication to performing the osteotomy.

Medical optimization of the patient’s condition prior to undergoing a PSO is beneficial. Due to the substantial EBL and long operative times associated with the surgery, patients with significant medical comorbidities (such as cardiac or pulmonary disease) may not be optimal candidates for the procedure. Because of poor bone quality as well as medical comorbidities, advanced age may also be a relative contraindication. Patients at significant risk for nonunion (such as those with diabetes and those who are smokers) may be better treated with other methods.

Permanent neurological injury after a PSO is a rare event. In fact, we found only one case in the literature. Most postoperative deficits are nerve root injuries, The nerve roots are most at risk during closure of the osteotomy if insufficient bone has been resected from the posterior neural arch at the levels above and below. Intraoperatively, this can be detected by using an angled dissector to probe the epidural space to ensure adequate decompression. Postoperatively, if a new-onset neurological deficit arises, the patient should be immediately returned to the operating room to undergo additional decompression. In our experience, this emergency decompression can be achieved without removing the instrumentation or reversing the correction. Ultimately, adequate bone resection results in a seemingly “giant foramen” through which two adjacent nerve roots exit.

Because the maneuver entails shortening of the posterior elements, traction is not considered to pose a significant
risk of neural injury. This is in contrast to combined ante-
rior column lengthening–posterior stabilization tech-
niques which can effectively distract the neural elements. 
Furthermore, we have not utilized intraoperative evoked 
potential monitoring with this decompressive or shorten-
ing procedure. When correcting coronal plane deformity, 
or scoliosis, where distraction of the osseous elements 
causes a lengthening of the spinal canal, intraoperative 
monitoring is routinely used. Performing the surgery be-
low the level of the conus medullaris is also thought to 
help minimize the incidence of permanent neurological 
deficits.

Conclusions

Pedicle subtraction osteotomy is a powerful technique 
for the correction of sagittal plane deformity. Although the 
initial reports of this procedure were for nontraumatic 
conditions, we have found this single-stage, single-ap-
proach operation to be highly effective in correcting 
chronic posttraumatic deformity. We have not attempted, 
nor would we recommend, the use of this procedure for 
the treatment of an acute thoracolumbar burst fracture. 
The improvements in pain status and function have been 
both dramatic and gratifying.

Disclaimer

Neither author has a financial interest in the subject discussed in 
this report.

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