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ESSENTIAL SURGICAL TECHNIQUES

SUBSPECIALTY PROCEDURES

Pedicle Subtraction Osteotomy

Munish C. Gupta, MD, Sachin Gupta, MD, Michael P. Kelly, MD, MS, Keith H. Bridwell, MD

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Abstract

Background: Pedicle subtraction osteotomy (PSO) was originally performed in cases of ankylosing spondylitis. This procedure was invented because it was safer than trying to lengthen the anterior column via osteoclasis, which risked vascular injury and death[1-4]. PSO involves the removal of the posterior elements and the use of a vertebral body wedge to shorten the spine posteriorly and achieve sagittal-plane correction[5,6]. PSO has been used to correct sagittal-plane deformities not only in patients with ankylosing spondylitis but also in those with degenerative conditions or those who have previously undergone surgical procedures resulting in a loss of lumbar lordosis[7,8].

Description: The fixation points are placed with pedicle screws above and below the planned osteotomy level. The posterior elements are decompressed at the level of the osteotomy and at 1 level proximally. In addition to the use of straight and angled curets, a high-speed burr is used to decancellate the vertebral body. Pedicle osteotomes are used to remove the pedicle. Temporary rods are placed. The posterior wall of the body is then impacted into the vertebral body, and the temporary rods are loosened. To close the osteotomy, the bed is extended or the spine is pushed manually, resulting in correction of the lordosis. The temporary rods are tightened. The main rods, independent of the short rods, are used to connect multiple segments several levels above and below the osteotomy site to provide final stabilization.

Alternatives: The alternatives to PSO depend on the surgical history of the patients, as well as the flexibility and alignment of the spine. In a spine with mobile disc spaces, Smith-Petersen osteotomies can be performed posteriorly to shorten the posterior column over multiple segments to gain lordosis. A formal anterior or lateral approach can be performed to release the disc spaces and restore the disc height. A posterior release through the facet joints with segmental compression can achieve desired lumbar lordosis. A vertebral column resection can also be performed to achieve lordosis.

Rationale: PSO is ideal for patients who have undergone multiple spinal fusions and who have a very rigid, flat lumbar spine. A single posterior approach can be used to provide adequate correction of the flat lumbar spine up to 40°. Asymmetric PSO can also be performed to allow for correction in the coronal

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plane. Recently, PSO has been performed more frequently because of the improved osteotomy instrumentation, exposure to resection techniques, and improved positioning tables that allow correction of the osteotomy.

Introductory Statement

Pedicle subtraction osteotomy (PSO) can be used to achieve sagittal-plane correction and restoration of lumbar lordosis with a single posterior approach. This procedure was invented because it was safer than trying to lengthen the anterior column via osteoclasis, which risked vascular injury and death.[1-4]

Indications & Contraindications

Indications

- Need for >25° of lordosis correction.
- Sagittal imbalance of >10 cm that is rigid from the deformity itself or from a previous surgical procedure.
- A stiff spine that does not achieve any correction on either supine or extension radiographs.
- A previously posteriorly fused spine with very collapsed and stiff disc spaces.
- A spine that has been circumferentially over multiple segments.
- Both coronal and sagittal malalignment.

Contraindications

- Inability of the patient to tolerate the procedure because of medical comorbidities.
- Patients with poor bone quality who are at risk for failure of osteotomy closure and poor healing potential across the osteotomy site.
- Patients with open disc spaces who can be managed with combined anterior and posterior or posterior-only Smith-Petersen osteotomies.
- Patients who require >40° of correction may benefit from an extended PSO that involves removing the adjacent disc space, 2 nonadjacent PSOs, or a vertebral column resection.
- Patients with normal sagittal and coronal alignment.

Step-by-Step Description of Procedure

Step 1: Introduction and Preoperative Planning (Video 1)

Use preoperative planning to assess the deformity and plan the correction needed with the PSO.

- Start preoperative planning by performing the patient history and physical.
- Patients with flat-back postures compensate with pelvic retroversion and knee flexion to maintain forward gaze.
- If available, use preoperative, full-length standing radiographs and EOS imaging (www.eos-imaging.com) to assess the spinal deformity in the coronal and sagittal planes. The radiographs in the present article did not show the typical advanced stages of ankylosing spondylitis. The early stages were more apparent on the computed tomography (CT) scan, with changes in the sacroiliac joint, multilevel posterior element fusion, and syndesmophytes. This patient had the diagnosis confirmed by a rheumatologist.
- It is very important to assess the flexibility of the spine using supine radiographs. The bending and supine radiographic images demonstrate the severity and rigidity of the kyphotic deformity. If supine radiographs are not available, use a CT scan scout view or a sagittal reconstruction as a surrogate for assessing flexibility. The CT scan can also be used to assess the mobility of the disc spaces that appear collapsed or auto-fused in the standing radiographs. Preoperative CT scans are also helpful to study the pedicles when planning screw placement.
- The correction that can be achieved with a PSO can be simulated in multiple software programs to plan the level and extent of the osteotomy. These simulations can also be used to study the potential postoperative compensatory changes in the sagittal plane of the thoracic spine as a result of the dramatic changes in lumbar lordosis. The amount of correction needed in the present case was approximately 36°, as calculated by the difference between pelvic incidence and lumbar lordosis. The level of osteotomy was L3, which was assessed to be the apex of the lordosis, but L4 could easily have been used to gain more correction in the sagittal vertical axis . In cases of previously fused spines, carefully perform preoperative assessment of the position, placement, and trajectory of previous instrumentation, including pedicle screws, with use of radiographs and CT scans.
- PSO is usually performed in the lumbar spine at the level of the conus medullaris and cauda equina. It is safer to perform PSO in the lumbar spine than at the level of the thoracic spinal cord because of the risk of substantial shortening and angular correction; however, there have been reports of PSOs performed in the thoracic spine[9,10]. We prefer performing a vertebral column resection in the thoracic spine. Vascular injuries have been reported with Smith-Petersen osteotomies, with acute rupture of the great vessels as a result of the lengthening of the anterior column with osteoclasis, which can be avoided with the shortening procedure of PSO[1,3].

Video 1 Introduction to PSO and preoperative planning.

Step 2: Positioning and Approaching the Spine (Video 2)

Position the patient on the operating table and expose the spine.

Positioning

- Placed the head in Gardner-Wells tongs to prevent any pressure on the eyes or face of the patient.
- Positioned the patient on an open-frame table or a table that allows extension, which aids in the correction of the osteotomy. The abdomen must be free in order to allow venous drainage away from the spinal canal.
- Pad all pressure points to avoid pressure injury.
- Extend the thighs and bend the knees. Place padding beneath and between the feet to prevent them from touching each other and to prevent pressure sores.
- Position the arms in a relaxed "90-90" position and pad and support the shoulders.
- The open frame allows the C-arm and radiographs to be used during the surgical procedure to assess insertion of instrumentation, correction of the osteotomy, and overall alignment of the deformity.
- Maintain the mean blood pressure at ≥80 mm Hg at the time of the osteotomy in cases of 3-column osteotomy. The mean blood pressure is kept high to ensure there is adequate spinal cord perfusion.
- Neuromonitoring is routinely used with multiple modalities, such as transcranial motor evoked potentials, somatosensory evoked potentials, and electromyography. These modalities provide an early warning system for changes in the neural function so that timely intraoperative adjustments may be made. Perform a Stagnara wakeup test only if there is a change in the neuromonitoring. Examine the patient after the procedure but before extubation.

Approaching the Spine

- Perform a subperiosteal dissection of the posterior spinal elements with meticulous hemostasis.
- Use radiographs to ensure that the correct levels, including adequate levels above and below the osteotomy, have been exposed.
- Remove any prior instrumentation. After the screws have been removed, thoroughly explore the fusion and debride and decorticate any pseudarthrosis.

Video 2 Patient positioning and posterior approach to the spine.

Step 3: Placement of Fixation (Video 3)

Place the pedicle screws and Iliac screws.

Placement of Pedicle Screws

- Use pedicle screws in fixation of the thoracolumbar and lumbar spine.
- Decorticate the transverse process and define the entry point with a burr.
- Use a pedicle probe to cannulate the pedicle and a ball-tipped probe to make sure the pedicle wall is intact.
- Insert a screw with the appropriate diameter and length.
- In cases in which prior instrumentation was removed, the same entry points for pedicle screw placement can be utilized if the prior trajectory and position were deemed adequate on the preoperative CT scan. Screws found to be loose on removal or by preoperative imaging should be upsized to gain adequate pedicle fixation.
- Place at least 2 pairs of pedicle screws above and below the level of the pedicle subtraction osteotomy. Multiple points of fixation above and below the osteotomy allow for distribution of the mechanical load over multiple segments, leading to increased stability and improved fusion rates.

Placement of Iliac Screws

- Use iliac screws for pelvic fixation in patients who require a large correction with PSO. It is even more critical to obtain multiple points of distal fixation with pelvic fixation for lower lumbar osteotomies. Sacral-2 alar-iliac screws and iliac screws can both be utilized to gain pelvic fixation. Sacral-2 alar-iliac screws are being used more often recently. There are advantages and disadvantages to both methods of pelvic fixation. The iliac screws can be more prominent, but this can be helped by removing the posterior superior iliac spine before placing the screw, to recess it. Iliac screws also require more soft-tissue dissection.
- Dissect the posterior superior iliac spine through a separate fascial incision and palpate the outer table of the ilium.
- Remove the posterior superior iliac spine with a rongeur to recess the head of the screw.
- Use a probe to cannulate the iliac wing and place a large screw in the iliac wing. Place the iliac screws 1 cm above the greater sciatic notch in the iliac wing. Aim the screw toward the anterior inferior iliac spine.
- In cases of poor bone quality, increasing the length of fusion from the thoracolumbar junction to the ilium is recommended.

Video 3 Placement of pedicle screws and iliac screws.

Step 4: Decompression (Video 4)

Decompress the spine in preparation for the PSO.

- Perform posterior laminectomies at the level of the PSO and the level above. Totally remove both laminae and the facet joints to expose the pedicles above, at, and below the level of the osteotomy. For example, for an L3 PSO, remove the laminae of L2 and L3. Completely decompress the nerve roots of L2 and L3, not only around the pedicles but also into the soft tissue outside the canal.
- This decompression is extremely important to prevent any soft-tissue or osseous compression of the nerve roots following closure of the osteotomy.
- If the patient has had a previous decompression, peel the scar from the dura as completely as possible because the dura must be soft enough to accept shortening and produce multiple buckles (rather than a single buckle). If the dura is thick with scar, a single buckle may form that could create compression of the cauda equina and lead to a neurologic deficit.
- After the decompression is complete, the pedicles of L2, L3, and L4 (in the example of an L3 PSO) and the nerve roots of L2 and L3 can be completely visualized from the dural tube, exiting into the soft tissue.
- Circumferentially isolate the L3 pedicle with the transverse process intact.

Video 4 Decompression, laminectomy, and exposure of nerve roots.

Step 5: Pedicle and Vertebral Body Resection (Video 5)

Perform the PSO.

Exposure of the Vertebral Body

- Strip the transverse process of any soft tissue that connects to it, then remove the transverse process, exposing the lateral portion of the pedicle.
- Isolate the pedicle and visualize the lateral portion of the body. In line with the lateral portion of the pedicle, use a Cobb elevator to expose the lateral portion of the vertebral body, anterior enough to see the curve of the anterior part of the body.
- If the segmental vessels are encountered, use bipolar electrocautery to coagulate them.
- Use a sponge to protect the soft tissues lateral to the body before placing a spoon-type retractor. The spoon retractor lateral to the body protects the soft tissue during the resection of the vertebral body.
- Pay careful attention to protecting the L2 nerve root, which will be in danger when using the spoon retractor and retracting laterally. To avoid nerve compression, minimize the time the spoon retractor is left in position.

Pedicle and Vertebral Body Resection

- Enter the pedicle with use of a pedicle probe. Using a circular motion, enlarge the hole in the pedicle. Place a thin rongeur in the hole and remove the lateral portion of the pedicle. Leave the medial portion of the pedicle intact to serve as a retractor for the dura and the nerve root.
- Use a diamond-tip burr to enter the lateral portion of the pedicle and the body. Using the burr, decancellate the lateral portion of the body and the inside of the vertebral body as much as possible. A diamond-tip burr prevents excessive bleeding from the cancellous bone of the vertebral body. Use straight and curved curets to remove more of the cancellous bone and to further decancellate the body without removing the anterior cortex of the vertebral body. The anterior cortex can be visualized after decancellation; a radiograph can be made at this time to determine the extent of the decancellation, but this is not routinely done. The procedure described in the present article is a decancellation technique rather than a precision-cut technique with osteotomes. In our patients, the use of this decancellation technique has not led to a higher rate of pseudarthrosis.
- Following complete decancellation of the vertebral body, remove the pedicle with use of a pedicle osteotome. Perform the resection performed superiorly and inferiorly, removing the entire pedicle. Preserve the anterior vertebral wall and the posterior body wall.
- Prior to removal of the posterior body wall, place a temporary rod to connect the adjacent segments. For example, when performing an L3 PSO, the temporary rod would connect the L2 and L4 pedicle screws, preventing sudden collapse of the spinal column and possible translation. If there is a sudden shift and translation has occurred, use the small rods across the osteotomy to control and correct the translation.
- Place an impactor in the plane developed between the dura and the posterior body wall. Impact the posterior body wall into the decancellated vertebral body, which is hollow. Remove all soft tissue and osseous elements from the anterior portion of the dura to prevent any compression of the neural elements anteriorly.

Video 5 Exposure of the vertebral body and pedicle and resection of the vertebral body.

Step 6: Closure of the Osteotomy (Video 6)

Close the PSO to correct the spinal deformity.

- Leave the temporary rods in position but loosen the set screws to allow for gliding of the rods inside the screws.
- Adjust the bed to correct and close the osteotomy, or push the spine down manually. Some operating room tables have an ability to flex and extend, with the function on the remote control often labeled as “reflex.” Using this function, bring up the trunk and legs of the patient at the same time. This maneuver not only closes the osteotomy but allows greater correction of the sagittal-plane deformity through the osteotomy. The axis of rotation is the foramen, around which the trunk and the legs rotate. Pay careful attention to the neural elements while the correction is being performed.
- If necessary, perform additional decompression prior to complete closure of the osteotomy site. After adequate closure is achieved, inspect the dura to ensure there is no dural buckling.
- Check radiographs and perform neuromonitoring to prevent neurologic injury. If there are changes in the neuromonitoring as a result of excessive correction, simply open the osteotomy site and perform additional decompression. After achieving satisfactory correction through the osteotomy, tighten the temporary small rods. These rods then become permanent at this point and are left alone for the remainder of the procedure.
- Place long rods to connect multiple segments proximal and distal to the osteotomy site. Because the osteotomy site is already held securely with the satellite rods, it should be possible to place long rods with ease. In the present case, we used titanium rods with a diameter of 6.35 mm because of the higher fatigue strength; however, cobalt-chromium rods with a diameter of 5.5 mm may also be utilized. We used no crosslinks because the spine was fused, and multiple points of fixation above and below the osteotomy can provide adequate fixation. For this procedure, do not connect the long rods to the short rods. The long rods can also allow for additional correction via posterior-column osteotomies above and below the level of the PSO in a patient with a more mobile spine. The advantage to not connecting both sets of rods is that the smaller rods maintain correction at the osteotomy site and allow for decreased stress on the long rods at the osteotomy site. After placing the main rods, perform final tightening.

Video 6 Closure of the PSO.

Step 7: Decortication and Bone-Grafting (Video 7)

Decorticate and place bone graft on the spine for fusion.

- Perform decortication of all of the posterior elements. PSOs have been found to have high rates of nonunion and subsequent instrumentation failure[11].
- PSOs require removal of all of the posterior elements, which leads to less osseous surface area for a fusion. In difficult cases, a large amount of local bone allograft can be placed in the lateral gutter, with additional off-label use of bone morphogenetic protein (BMP)[12-14].
- A collagen-based protective barrier can be used to avoid direct contact of the bone graft and recombinant human BMP-2 with the neural elements. Some publications have implicated BMP-2 as a cause of neural inflammation[15-17].
- The use of multiple rods across the osteotomy helps avoid early rod failure[18]. The designations of "satellite" and "accessory" rods were given in order to classify and communicate uniformly among spine surgeons[19]. For the PSO, the short rods that are not connected to the main longitudinal members are called satellite rods. If additional rods are added with side-to-side connectors to the main longitudinal members, such rods would be called accessory rods. The use of multiple rods has been reported to protect against early rod failure and loss of correction[11].
- Posterior lumbar interbody fusion of the disc space adjacent to the PSO with cages has also been described, with studies showing decreased risk of nonunion across the PSO[8,19,20]. In a finite-element study, Luca et al. found that anterior support reduced the stresses on the posterior instrumentation following PSO[20].
- Subfascial drains are always used in PSOs. These drains are deemed necessary to prevent the formation of hematomas and, possibly, compression of the cauda equina because of the exposed dura and large area of osseous decortication that bleeds.

Video 7 Decortication and bone-grafting.

Step 8: Radiographic and Clinical Result (Video 8)

Assess radiographic and clinical results of the PSO.

- Make long-cassette radiographs to assess the correction achieved. In the present case, 48° of correction was achieved across the L3 PSO.
- A blood recovery system (e.g., Cell Saver [Haemonetics]) is typically used. However, also perform blood typing and prepare 2 units of cross-matched red blood cells to be used as necessary. The use of fresh frozen plasma and platelets is determined by the anesthesiologist. We use rotational thromboelastometry to determine whether fresh frozen plasma or cryoprecipitate is necessary during PSO.
- In the present case, the patient was mobilized out of bed on postoperative day 1. During the hospital stay, the patient was seen by physical and occupational therapists for training in ambulation and activities of daily living. The patient was asked to walk up to 30 minutes per day after being discharged home.

Video 8 Summary and radiographic and clinical results.

Results

PSOs performed for ankylosing spondylitis and flat-back deformity resulting from previous surgical procedures or degenerative conditions have been reported to achieve correction in the sagittal plane[5,7] ranging from 25° to 40°[6]. The average correction reported by Gupta et al. was 39° across the osteotomy[18]. PSOs usually involve the removal of the pedicle and part of the vertebral body. If additional angular correction is needed, the disc above can also be removed, which is called an extended PSO. The PSO is classified as a Schwab type-4 procedure, whereas the extended PSO is a Schwab 5[21]. The correction that is achievable with a PSO can be simulated in multiple software programs to plan the level and extent of the osteotomy. These simulations can also be used to study the potential postoperative compensatory changes in the sagittal plane of the thoracic spine as a result of the dramatic changes in lumbar lordosis. The amount of correction needed in the present case was approximately 36°, as calculated by the difference between pelvic incidence and lumbar lordosis. The level of osteotomy was L3, which was assessed to be the apex of the lordosis, but L4 could easily have been used to gain more correction in the sagittal vertical axis. However, more postoperative motor deficits and revisions have been reported with more distal levels of PSO[22].

The rate of rod failure following PSO has been reported to be as high as 15.8%[23]. The use of multiple rods has been reported to aid in the prevention of early rod failure and to contribute to successful union compared with the use of just 2 longitudinal members across the pedicle subtraction [18]. The rate of rod failure when using 4 rods with a satellite configuration was dramatically less than when using 2 rods[18]. Buchowski et al. reported a rate of neurologic deficit of 11%[24], with dural buckling and dorsal impingement being the most common causes for the neurologic problems. Studies have also been conducted comparing PSOs performed as the primary procedure with those performed as a revision procedure in patients with sagittal deformity; in those studies, the major difference between populations was that the fractional lumbosacral lordosis was not corrected as well in the revision setting[11].

In general, PSO using a single posterior approach provides a large correction of a lumbar flat-back deformity. However, there are some risks to the procedure such as failure of instrumentation, failure of fusion, and nerve deficits around the osteotomy as a result of manipulation.

Pitfalls & Challenges

- Inadequate decompression around the osteotomy.
- Poor and inadequate fixation around the osteotomy.
- Inadequate osseous resection resulting in poor correction.
- Dural buckling if the dural scar is not removed.
- Failure of fusion and of instrumentation.
- Neurologic injury involving the nerves around the osteotomy.
- Excessive bleeding.

Munish C. Gupta, MD[1]
Sachin Gupta, MD[2]
Michael P. Kelly, MD, MS[1]
Keith H. Bridwell, MD[1]
[1]Washington University School of Medicine, Saint Louis, Missouri
[2]Perelman School of Medicine at the University of Pennsylvania, Philadelphia, Pennsylvania

Email address for M.C. Gupta: munishgupta@wustl.edu

ORCID iD for M.C. Gupta: 0000-0002-4711-4377
ORCID iD for S. Gupta: 0000-0002-7899-6800
ORCID iD for M.P. Kelly: 0000-0001-6221-7406
ORCID iD for K.H. Bridwell: 0000-0001-9228-8782

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