Flat Back and Sagittal Plane Deformity

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HISTORY, ETIOLOGY, INCIDENCE, AND RATE OF PROGRESSION

Sagittal plane deformity as described by Doherty in 1973 is a fixed forward inclination of the trunk because of loss of normal lumbar lordosis after posterior spinal fusion for scoliosis. The term flat back syndrome is also known as kyphotic decompensation syndrome and flat buttock syndrome.¹ There are other causes of sagittal plane deformity as defined by Errico and colleagues, such as ankylosing spondylitis, diffuse idiopathic skeletal hyperostosis, Scheuermann’s disease, congenital kyphosis, postamputation kyphosis, and kyphosis secondary to radiation therapy and trauma.²

Sagittal balance is present when a plumb line dropped from C2 or C7 on a lateral radiograph falls within approximately 2.5 to 4 cm of the posterosuperior corner of S1. Lines that fall more anterior are said to exhibit “positive” sagittal balance; those more posterior exhibit “negative” sagittal balance. In most clinical situations such as those discussed here (e.g., flat back deformity), the problem is positive sagittal balance.

Iatrogenic flat back syndrome is classified into two types. Type 1 is segmental (previous fusion levels) hypolordosis or kyphosis of the lumbar spine with the body of the C7 vertebral body remaining centered over the lumbosacral disk (i.e., a compensated deformity). A defining characteristic of type 1 on standing lateral radiographs is that anterior disk height is 5 mm greater than posterior disk height because of compensatory hyperextension to maintain sagittal balance. A noteworthy goal on postoperative radiographic assessment is to have the anterior disk height be reduced to less than 2 mm greater than posterior height on standing radiographs.³ Type 2 flat back syndrome is present when the plumb line from C7 falls more than 5 cm anterior to the lumbosacral disk.⁴

CLINICAL FINDINGS

On clinical examination, patients literally look like they have a “flat back,” hence the term flat back deformity. With time, these patients progress and tilt more forward as their center of gravity is shifted anterior to the sacrum.

When evaluating a patient with a kyphotic deformity, it is important to determine which area is contributing to the sagittal imbalance. For instance, in ankylosing spondylitis it is sometimes difficult to establish whether the cervicothoracic junction, the thoracolumbar junction, the lumbar region, or the hips are contributing to the kyphotic deformity. This may be determined clinically by obtaining dynamic films and evaluating the patient standing, sitting, and lying supine. When sitting, if the deformity is not very pronounced, it is probably predominantly located in the thoracic and lumbar region. If the deformity appears to be severe on sitting films and the patient has difficulty looking up to the ceiling, it probably involves the cervicothoracic region. If the posterior aspect of the patient’s thigh does not touch the table when lying down, a hip flexion deformity may be associated.

Forward inclination of the trunk because of loss of lumbar lordosis and difficulty extending the knees when standing erect subject most patients to pain in the lower part of the back. (Patients with flat back deformity have pain in the lower part of their backs because of muscle fatigue resulting from forward inclination of the trunk secondary to loss of lumbar lordosis. This sagittally imbalanced posture results in the need for continual hip and knee flexion to maintain an upright stance.)

Lee and colleague and Hasday and associates discussed the significance of hip contractures in these patients leading to an abnormal pelvic tilt. This abnormal tilt increases the chance for a suboptimal postoperative result despite correction of the lordosis and should therefore be assessed preoperatively.

Accelerated degenerative changes from a chronically abnormal posture can also increase the incidence of radicular and claudication symptoms as a result of stenosis, so evidence for these concomitant problems must be assessed.

Positive sagittal balance is the most reliable predictor of clinical symptoms in patients with spinal deformity.⁵ Sagittal imbalance greater than 4 cm results in deterioration of pain and function scores over time in most unoperated patients. Restoration of normal sagittal balance should therefore be one of the main goals of any deformity reconstruction procedure.⁶

These patients also exhibit decreased step, stride length, and gait velocity. Sarwahi and coworkers prospectively analyzed the gait function of 21 patients with postsurgical flat back deformity.⁷ The authors concluded that the patients’ gait was slower than that of normal controls and that several compensatory mechanisms were used by the patients. The compensatory mechanisms adversely affected the hip and knee joints.⁸

PREVENTION OF FLAT BACK AND SAGITTAL PLANE DEFORMITY

A common cause of flat back syndrome is previous spinal fusion. Potter and associates mentioned four essential methods for prevention of this iatrogenic condition: (1) thorough preoperative assessment of sagittal alignment, (2) limitation of the caudal extent of fusion when possible, (3) use of segmental instrumentation and avoidance of distraction with preservation or improvement of physiologic lumbar lordosis and sagittal balance, and (4) intraoperative positioning of the hips in an extended fashion.

Preoperatively, the surgeon must thoroughly evaluate the patient’s deformity and its overall impact. Multiple clinic visits are recommended to fully evaluate gait, pain levels, the severity of the deformity, and radiographic evidence. Maintaining the current normal curves of the patient while addressing correction of the deformity should be a leading consideration in formulating the surgical plan. For degenerative short-segment fusion in the lumbar spine, increasing lordosis in anticipation of loss of lordosis over time as a result of ongoing degenerative changes is a preferred strategy.¹⁰

Limitation of caudal fusion levels to L3 or lower to avoid decompensation or progression of the curve during scoliosis surgery and thus prevent flat back syndrome should be evaluated on a case-by-case basis. Although several studies have indicated...
benefit, it must be noted that these studies were undertaken with nonsegmental and currently rarely used Harrington rod instrumentation.

Most early cases of flat back syndrome secondary to loss of lumbar lordosis arose from the use of distraction via Harrington instrumentation and Luque segmental wiring has produced greater correction of curves with better construct rigidity and has thus decreased the incidence of sagittal plane deformity.

Intraoperative positioning is vital in preventing sagittal plane deformity during long-segment spinal fusion. In a study of 13 anesthetized patients, Benfanti and Geissele demonstrated that 95% of lordosis was maintained on a Wilson frame when the patients were positioned with the hips in full extension. With the use of a Jackson table (our preferred choice for instrumented fusion), Stephens and colleagues proved that positioning patients in hip extension resulted in a minor increase in lumbar lordosis. It is therefore prudent to position patients for prone posterior lumbar fusion with the hips in extension to preserve physiologic lumbar lordosis.

RADIOGRAPHIC FINDINGS

Global assessment of spinal balance is required in all patients with deformity, particularly if any surgical intervention is anticipated. This radiographic work-up begins with upright full-length 36- by 14-inch posteroanterior and lateral scoliosis films to determine coronal and sagittal balance. This may be complemented with additional studies, including supine, flexion, extension, and side-bending radiographs, which can be used to better evaluate dynamic pathologies such as degenerative spondylolisthesis. The “clavicle position” should optimize visualization of the entire spine on the lateral scoliosis radiograph. In this position, the patient fully flexes the elbows with the hands in a relaxed fist, wrists flexed, and the proximal interphalangeal joints placed comfortably up into the supraclavicular fossa while passively flexing the humerus forward. This maneuver produces an overall visualization of critical vertebral landmarks that is significantly better than that achieved with positions in which the arm is either positioned straight out or partially flexed. Ideally, on the lateral radiograph one should be able to visualize C2 to the pelvis, including the femoral heads, to assess the global sagittal balance of the spinal column (Fig. 288-1A to D). Similarly, on the posteroanterior view, the margins of the rib cage and the pelvis along with the femoral heads can be clearly visualized. Assessment of the hips helps determine whether a leg length discrepancy, hip arthritis, or pelvic pathology is present. Visualization of the ribs helps in diagnosing the presence of any associated thoracic cage deformity. Either congenital fusion of the ribs or a significant chest wall deformity can be associated with rigid or fused spinal segments. After assessing spinal balance in the sagittal and coronal planes, Cobb’s measurements are obtained for each area of the spine, including the cervical, proximal thoracic, main thoracic, thoracolumbar, and lumbar areas. Vertebral body rotation at the apex of the coronal plane is a factor in determining the rigidity of the curve. The greater the vertebral body rotation, the greater the rigidity of the coronal curve. If the curve and clinical characteristics warrant serious consideration of surgical intervention, the flexibility of the curve can be further assessed with dynamic side-bending radiographs.

Sagittal balance is determined by examining the vertical axis with a line drawn through the middle of the C7 vertebral body and projecting inferiorly to intersect a horizontal line through the L5-S1 disk space. In a balanced spine, this line passes through the posterior third of the L5-S1 disk space, although a line up to 4 cm anterior to the L5-S1 disk space may be considered relatively normal in elderly patients. Computed tomographic (CT) myelography is frequently used for the evaluation of adults with scoliosis when surgery is planned. The CT myelogram provides intimate details of bone anatomy and is helpful in identifying areas of lateral recess and far lateral stenosis. The greater the spinal deformity, degenerative changes, or number of previous surgeries, the greater the diagnostic value of the CT myelography. The bone anatomy will dictate the instrumentation options available for the patient.

Magnetic resonance imaging of the spine can provide additional detailed information about the neural elements, vascular, and soft tissues, such as hydration of the disks. The degenerative status of the lower lumbar disks is a factor to be considered when deciding the lowest segment to be instrumented.

NONOPERATIVE TREATMENT

The first line of management includes exercises to increase hip and back extension, nonsteroidal anti-inflammatory medications, and bracing. It is important that patients be evaluated for the presence of hip contractures because in this case more aggressive treatment is mandated. Bracing can cause significant deconditioning and is of minimal benefit in patients with fixed deformity over the long term. In some elderly patients, however, it may be a more suitable alternative to an extensive operative intervention. Progressive sagittal imbalance during conservative therapy is an indication for surgery. Expectations with surgical correction of the deformity and any risk for significant morbidity and possible mortality from the procedure should be discussed at great length with the patient and designated family members before surgery.

Farcy and Schwab reported poor outcomes in symptomatic patients initially managed with intensive conservative therapy. Only 27% were considered to have long-term success (13 of 48 patients). Overall, conservative management has been disappointing in the treatment of flat back and sagittal plane deformity.

OPERATIVE TREATMENT OF SAGITTAL PLANE DEFORMITY

The goal of surgery for correction of deformity is to achieve a stable, well-balanced spine centered over the pelvis by fusing as few motion segments as possible. A balanced spine is created by a close interplay of the patient’s spinal anatomy, the biomechanical properties of the spine, and the corrective capabilities of surgical techniques and instrumentation.

The goals of surgery are (1) to restore sagittal balance so that the patient can stand erect without having to flex the hips or knees and (2) to reduce pain. Frequently, patients who have previously undergone surgical procedures have multiple abnormalities that are contributing to both the pain and the sagittal imbalance. An error is to treat a portion of the global condition and neglect to fully address the sagittal imbalance. For instance, if a patient has pseudoarthrosis and significant sagittal imbalance, simply repairing the pseudoarthrosis will not improve the patient’s posture and will rarely improve the pain. In this case, the lumbar pain is related in part to fatigue of the spinal extensor muscles and to coexistent pseudoarthrosis.

A patient with decompensated sagittal balance stands with the knees flexed and the hips in extension to maintain an upright posture. The sagittal and coronal profiles demonstrate the true extent of the sagittal imbalance, pelvic obliquity, and coronal plane deformity. Any neurological deficit, truncal deformity, and muscle contractures should be carefully noted, as well as the patient’s overall posture. Previous surgical scars or a scar over the
mimize the anterior column. Another viable option is to perform PSO, which usually achieves greater angular correction by removing a posterior wedge of corticocancellous bone from the vertebral body. This procedure is highly effective in restoring sagittal balance in patients with a fixed sagittal plane deformity.

Pedicle Subtraction Osteotomy

Pedicle resection plus transpedicular wedge resection of the vertebral body to restore sagittal balance was first reported in patients with ankylosing spondylitis in 1985. Since Thomsen's initial description, the procedure has been used for the management of flat back deformity and lumbar kyphosis secondary to other causes. PSO directly involves performing two Smith-Petersen–type (extension) osteotomies, as well as resection of the intervening pedicles and a portion of the vertebral body from a posterior approach. It accomplishes approximately

Surgical Options

Lumbar pedicle subtraction osteotomy (PSO) has been used with increasing frequency for the management of either sagittal plane deformity or a combination of coronal and sagittal plane deformity. Treatment of fixed sagittal imbalance involves performing osteotomies to shorten the posterior elements of the spine or performing anterior column osteotomy to release or lengthen the anterior column. Surgical options include performing one or more Smith-Petersen osteotomy (SPO) procedures, one or more polysegmental osteotomy procedures, or PSO. Both SPO and polysegmental osteotomy do not require the surgeon to osteotomize the anterior column. Another viable option is to perform PSO, which usually achieves greater angular correction by removing a posterior wedge of corticocancellous bone from the vertebral body. This procedure is highly effective in restoring sagittal balance in patients with a fixed sagittal plane deformity.

**FIGURE 288-1**  
as much correction as three SPO procedures. This aggressive osteotomy results in removal of the posterior elements, including the pedicle and transverse process. With this technique, removal of up to 6 cm of bone is possible with resultant sagittal plane correction of up to 60 degrees. By performing asymmetric removal of the posterior elements, correction of both sagittal and coronal plane deformities can be achieved. PSO is a technically demanding procedure, and substantial blood loss can occur from the epidural venous plexus or from cancellous bone. With removal of the posterior elements bilaterally, two nerve roots exit through the reconstructed neural foramina at the level of the osteotomy and are at risk for injury. During closure of the osteotomy, care must be taken so that impingement of the thecal sac or nerve roots does not occur.

**Smith-Petersen (Extension) Osteotomy**

Smith-Petersen and associates were the first to describe a posterior osteotomy for correction of fixed sagittal deformity in patients with rheumatoid arthritis. The osteotomy involves removing the posterior elements, undercutting the adjacent spinous processes, and then closing the osteotomy to create an opening in the spine (extension) anteriorly through the disk space. The posterior aspect of the disk space is the axis of rotation. Sagittal correction is then achieved by posterior compression with instrumentation, which results in anterior osteoclasis through the vertebral body or distraction through rupture of the anterior longitudinal ligament and disk space. The extension osteotomy creates hyperextension by closing the posterior elements and opening the anterior elements. SPO achieves correction by creating a sharply lordotic angle and elongation of the anterior elements, which may result in the development of superior mesenteric artery syndrome. This technique may result in decompensation of the spine if the instrumentation fails before fusion. As a general rule, approximately 1 degree of correction can be expected for each millimeter of posterior bone resected during the procedure. LaGrone and coauthors reported an average initial correction of 22 degrees in lumbar lordosis and 9 degrees in kyphosis at the thoracolumbar junction and an 8.1-cm improvement in the sagittal vertical axis when using this technique. A number of complications were reported, including pseudarthrosis, implant failure, inadequate initial correction, loss of correction, and a need for further surgical intervention.

**Polysegmental Osteotomies**

In 1949, Wilson and Turkell reported on the use of multiple osteotomies to correct sagittal balance in a patient with ankylosing spondylitis. Sagittal balance was achieved through polysegmental posterior lumbar osteotomies. This technique involves removing the facet joints at several levels and then compressing the posterior elements to create lordosis. The correction is achieved through deformation of the disk spaces without rupture of the anterior longitudinal ligament with the use of transpedicular instrumentation. Polysegmental osteotomies achieve less correction per level but permit more gradual correction of sagittal plane deformity than possible with either PSO or SPO, both of which cause an abrupt angular correction. Currently, this technique may be used for the correction of milder forms of sagittal imbalance or in conjunction with PSO for additional correction in patients with severe sagittal imbalance. The amount of correction achieved with polysegmental osteotomies is less than that achieved with the other methods described. One series found an average correction of 9.5 degrees per level with this technique.

**Advantages and Disadvantages of Pedicle Subtraction Osteotomy**

An advantage of PSO is its ability to restore lumbar lordosis with the fulcrum at the anterior apex of the vertebral body; it does not result in distraction of the anterior column, which can cause vascular injury. The other advantage of performing PSO is that when the osteotomy is completed, there is bone-on-bone contact throughout all three columns of the spine. Theoretically, because of the potential for three-point fixation, PSO provides much more stability and reduces the risk for pseudarthrosis. The major disadvantage of PSO is that it is a very technically demanding procedure, particularly in patients who have previously undergone surgical procedures at the level of correction. Other disadvantages of PSO include a risk for neurological injury, the possibility of significant perioperative blood loss, inability to achieve complete correction of a deformity with a single-level procedure, and the possibility of nonunion despite using spinal instrumentation.

**Indications and Contraindications**

PSO is indicated when significant correction is needed because of prominent sagittal imbalance. Patients who require approximately 30 degrees of additional lumbar lordosis will need to undergo PSO to restore sagittal balance. Bridwell and colleagues found an average increase of 34 degrees and an average improvement in the sagittal plumb line of 13.5 cm after PSO in patients with fixed sagittal plane deformity. Numerous other studies have reported angular correction in the range of 32 to 38.8 degrees. Clinical conditions for which PSO is an effective procedure include ankylosing spondylitis, progressive adult lumbar idiopathic scoliosis, degenerative scoliosis, infectious deformity, and progressive kyphosis after fracture or iatrogenic flat back syndrome. It may also be beneficial in the group of patients who have already undergone anterior surgery, which increases the risk for vascular injury with a repeat anterior procedure or classic SPO.

**Preoperative Planning**

Preoperative planning involves detailed evaluation of the patient’s overall clinical status, ability to undergo major spinal surgery, and extent of surgical intervention required to achieve the goals of correction. The goal of surgery is to restore sagittal balance such that the plumb line intersects the posterosuperior corner of the S1 vertebra, in other words, to end up with the head centered over the sacrum. This will enable the patient to stand without knee flexion and hip hyperextension, thereby diminishing the overall pain. The decision where to place the osteotomy depends on the site of the deformity. Patients with flattening of the lumbar spine but without thoracolumbar kyphosis can be treated by osteotomies below the level of the conus medullaris. This provides adequate lordosis without jeopardizing the spinal cord. Any coexisting thoracolumbar kyphosis also needs to be addressed. If it is flexible and correction can be seen on hyperextension radiographs, osteotomies can be performed in the lumbar spine and the fusion extended proximally into the thoracic spine. If it is not flexible, either an osteotomy can be performed at the apex of the kyphosis, or an osteotomy of larger magnitude or multiple osteotomies can be performed at other levels. Bernhardt and Bridwell have shown that the average thoracic kyphosis is 30 degrees, or roughly 2.5 degrees per segment, whereas the average lumbar lordosis is 60 degrees. Sagittal alignment dictates that there should be 30 degrees more lumbar lordosis than thoracic kyphosis. The angle of osteotomy is the total angular correction achieved to restore sagittal balance. The angle at which the spine is redirected at the osteotomy site (the osteo-
imbalance. Another indication for anterior release would be deformity and when PSO alone may not restore spinal balance.

Anterior surgery can be planned as a staged or same-day procedure. An anterior procedure may involve anterior release with interbody bone grafting to reduce the risk for pseudarthrosis. The apex of the lumbar lordosis in a sagittally balanced spine should be at the level of the L3–4 disk space. Thus, the maximum physiologic lordotic curvature that can be achieved will be in this area. Asymmetrical osteotomy can also be performed to address any coronal plane deformity.

The selected lumbar PSO level should generally be below the level of the conus medullaris to minimize the risk for injury to the spinal cord. It also facilitates retraction of the thecal sac to perform the osteotomy safely. The level chosen is approximately at L2, L3, and occasionally L4. It is preferable to perform pedicle subtraction through areas of previous fusion to reduce the risk for pseudarthrosis. The apex of the lumbar lordosis in a sagittally balanced spine should be at the level of the L3–4 disk space. Thus, the maximum physiologic lordotic curvature that can be achieved will be in this area. Asymmetrical osteotomy can also be performed to address any coronal plane deformity.

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In elderly patients, the postoperative course can be complicated by deep venous thrombosis (DVT), which can lead to pulmonary embolism. It may also be difficult to start DVT prophylaxis (e.g., low-molecular-weight heparin) in the immediate postoperative period because of the prolonged oozing from the bony surface that persists after an osteotomy and fusion procedure. Preoperative placement of removable inferior vena cava filters may be judicious to avoid serious complications, particularly in patients who are at high risk for the development of blood clots or who cannot take low-molecular-weight heparin because of chronic renal insufficiency.

Proper surgical setup is crucial for performing this complex surgery. Neuroradiology can be used to detect any possible intraoperative neurological injury while correcting the deformity. The risk for neurological injury is highest during the correction of junctional kyphosis. During the performance of lumbar PSO, we monitor patients with free-flowing electromyography and somatosensory evoked potentials while performing the correction. Immediately after correction of the deformity, motor evoked potentials should be checked. If there is any change in response, the correction is reversed immediately.

Close attention should be paid to positioning of the patient during spinal deformity surgery because the patient will be prone for an extended period. A Jackson table is suitable because it allows for an extended period of spinal surgery. It facilitates sequential progression of the events. The first step involves meticulous exposure of the bony anatomy. A significant number of patients undergoing PSO have had multiple previous surgeries. It is critical that thorough exposure of the bony anatomy and fusion mass be achieved. The area involving a pseudoarthrosis or floating fusion mass needs to be carefully exposed and the bony anatomy carefully delineated. A preoperative CT scan and intermittent use of intraoperative fluoroscopy may be used to aid in this process.

After exposure, pedicle screw fixation points are prepared. The goal should be “harmonious” placement of pedicle screws to facilitate application of the contoured rod. Careful attention should be paid to localization of the pedicle and determination of its angulation, especially in patients with associated coronal plane deformity and a residual fusion mass, which may distort the normal anatomic landmarks. Intraoperative fluoroscopy or image guidance may be used to place the pedicle screws; however, careful attention must be directed to proper alignment of the fluoroscope for the images, especially when associated coronal plane deformity is present.
We always perform a generous laminectomy at the level of the osteotomy and even at times perform a partial or total facetectomy above and below the level of the osteotomy (Fig. 288-2A). In some cases, partial laminectomies are also performed at the levels above and below the planned osteotomy. The bone surrounding each pedicle is then removed completely to expose the nerve roots running inferior and superior to the pedicle to be removed for the PSO (Fig. 288-B). In essence, circumferential bone removal involves excising the superior facet, inferior facet, and pars interarticularis and disconnecting the transverse process at the level of the PSO. Thus, an SPO is performed cephalad and caudal to the pedicle, and bone removal is performed from the level of the pars above and below.

After isolation of the pedicles, space between the soft tissue and the lateral vertebral wall is created with a small Cobb elevator. The Cobb elevator is used subperiosteally while hugging the bone to gently reflect the soft tissue off the lateral bony wall without injuring the segmental vessels, the exiting nerve roots, and the traversing sympathetic chain during the wedge osteotomy. This exposes the vertebral bony anatomy and reflects the soft tissue laterally.

Before initiation of the decancellation procedure, the medial pedicle wall is delineated and the thecal sac is protected with a nerve root retractor. Gentle traction may be applied with the retractor on the thecal sac if the level of the osteotomy is below the conus. The nerve root above the pedicle is also protected with a retractor or a No. 4 Penfield instrument (Fig. 292-IC).

After circumscribing the pedicle, decancellation is performed through the residual pedicle stump (Fig. 288-2D). The residual pedicle stump is removed with a Leksell rongeur, and both sides are now made flush with the level of the vertebral body (Fig. 288-2E). The extent of decancellation depends on the amount of bone to be removed as determined during preoperative planning. Straight and curved curets are then used to perform decancellation through the pedicles and extended in wedge fashion into the vertebral body with the apex at the anterior cortex. The decancellation is performed until one side connects to the other. The extent of vertebral body removal should include the inferior dimension of the pedicle while not violating the anterior cortical wall. Use of the curet should be controlled and meticulous with close attention paid to the surrounding neural structures. Bleeding during the decancellation procedure is managed with the intermittent use of hemostatic agents and tamponade with cottonoids. The cancellous bone behind the posterior vertebral cortical wall is removed thoroughly to make the wall as thin as possible. This cancellous bone should be saved for the future posterolateral fusion portion of the procedure.

The osteotomy remains stable because of the intact lateral vertebral body wall. The lateral bony wall is removed with an
osteotome or Leksell rongeur in wedge fashion without violating the anterior cortical wall. The final step in completing the osteotomy involves developing the epidural space between the posterior cortex and anterior dura with a Woodson elevator. Epidural bleeding is addressed by careful bipolar cautery and judicious use of hemostatic agents. A reversed-angle curet is placed between the posterior cortex and the dura. The posterior cortex is pushed down with the reversed-angle curet into the potential space created by the decancellation procedure to produce a greterectomy. Symmetrical removal of the posterior cortical wall is performed along with meticulous removal of all residual bone fragments or spicules.

Before closure of the osteotomy, a Kerrison rongeur is used to further enlarge the central canal and remove any bone fragments that may interfere with the exiting nerve roots. The opposing bone surfaces are also made symmetrical with a Leksell or Kerrison rongeur. On one side an appropriately sized rod is contoured and fixed to the screws loosely with caps. The compressor is placed along the head of the pedicle screws on each side and gently compressed to close the osteotomy defect. While maintaining compressive force, the caps are tightened and the rod is secured to the screw. Multiple sequential compression steps may be required for complete bone apposition (Fig. 288-2F). If the osteotomy is not completely closed, one should check for interlocking residual bone fragments. However, in many cases, a small metallic artifact that may conceal small bone fragments or subluxation of the proximal elements. Bone fragments may be removed with a curet or Kerrison rongeur. In situ benders may be used to recontour the rod and compressive forces then reapplied. The proximal spinal elements may sublux dorsally with respect to the distal elements. Such subluxation needs to be reduced to achieve anatomic alignment before final tightening of the implant (Fig. 288-2G). Finally, a Woodson elevator is used to facilitate inspection of the thecal sac and the nerve roots to make certain that there is no bone compression or any compromise of the neural structures. Midline buckling of the thecal sac is expected after closure of the osteotomy. The procedure is completed by posterolateral decortication with a drill and placement of the bone graft harvested from the osteotomy procedure. A subfascial drain is placed and the wound is closed in standard multilayer fashion.

**POSTOPERATIVE CARE**

Monitoring in the intensive care unit for the first 24 hours postoperatively is recommended. Postoperative pain is best managed with patient-controlled analgesics. However, certain patients with high preoperative narcotic use may require an epidural catheter for analgesia. The epidural catheter may be placed intrathecally and adds a minimal amount of extra operating room time to the procedure.

If the procedure is staged, consideration should be given to central hyperalimentation between the staged procedures. Close monitoring of overall drain output and maintenance of hemoglobin and hematocrit levels to prevent cardiac stress are mandatory, as well as close vigilance for possible DVT, which can lead to pulmonary embolism. Antibiotic prophylaxis is administered until the drain is removed.

Any postoperative neurological deficit should be vigorously investigated. An immediate CT scan is performed to locate any compression of neural structures by bone. There may be significant metallic artifacts that may conceal small bone fragments causing compromise of the thecal sac or nerve roots, especially at the osteotomy site. Surgical exploration performed in an expedient manner may reverse the neurological deficits. The surgical procedure is highly demanding but, when conducted in meticulous fashion, is able to restore significant function with a high degree of patient satisfaction.

**SUMMARY**

Several types of osteotomies can be used to correct sagittal imbalance. Smith-Petersen (extension), polysegmental, and pedicle subtraction osteotomies have all been used to treat fixed sagittal deformities. Many of these types of osteotomies were initially devised for the treatment of deformity secondary to ankylosing spondylitis and have been adapted to treat a variety of sagittal plane abnormalities, including flat back syndrome. PSO has several key advantages. The technique allows correction in both the sagittal and coronal planes of the spine. 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 biomechanics of the osteotomy. The hardware is therefore used to maintain spinal alignment, as opposed to actually creating the desired alignment, and it decreases the risk for neurological and vascular injury.

**CONCLUSION**

Management of flat back and sagittal plane deformity is complex and difficult, even by experienced surgeons. Prevention of this deformity by vigorous and thorough assessment of the patient before any fusion intervention is paramount. The exact technique used to restore sagittal balance and minimize the high but short-term complication rate is highly dependent on the surgeon's experience. PSO appears to be the most optimal technique, and it can also be used to restore coronal alignment without additional complications.

**SUGGESTED READINGS**


Case Study

Brief History

Idiopathic scoliosis was diagnosed in a 61-year-old woman with a complicated medical history at the age of 14. In 1998 she experienced progressively worsening lower back pain and lower extremity radicular pain and underwent circumferential spinal fusion from T5 through S1. The patient initially did well, but new back pain and worsening lower extremity radicular pain soon began developing. The patient had her hardware removed in May 2007 because of misplaced instrumentation. Since that time, she has experienced progressively worsening sagittal imbalance and coronal scoliosis. Because of this history, the patient underwent thorough evaluation, including CT myelography, and was found to have a relatively dense fusion, except for the T12-L1 level, where possible pseudoarthrosis was noted. She had 32 degrees of left-sided scoliosis, severe (23 cm) positive sagittal imbalance, and 6 cm of coronal imbalance. An extensive discussion was held with the patient regarding the benefits and risks associated with surgical intervention, as well as the alternatives to surgery. Because of the history of misplaced screws and the fact that the patient had almost no anatomic landmarks, the plan was to perform a stage 1 procedure to insert posterior segmental anchors. A CT scan was planned for final adjustment of screw position, followed by subsequent L1 and L3 PSO procedures.

Stage 1 of a Planned Two-Stage Procedure

Stage 1 included posterior segmental instrumentation of T4 through S1 with 5.5-mm titanium Medtronic instrumentation. The second-stage procedure was to be a two-level PSO procedure.

Stage 2 of a Planned Two-Stage Procedure

The stage 2 procedure was planned to include posterior re-exposure of the thoracic and lumbar spine, irrigation and debridement, removal of the left-sided T9 and S1 pedicle screws, replacement of the T9 and S1 pedicle screws and repositioning, placement of a new left-sided T10 pedicle screw, asymmetrical L1 and L3 PSO procedures for correction of severe kyphoscoliosis, fusion of T4 through S1 with a local fusion mass and bone harvested from the PSO procedure, L1 and L3 interbody fusion with the use of recombinant human bone morphogenetic protein-2 (rhBMP-2) for anterior fusion of L1 and L3, and placement of T4 through S1 rods during correction of the kyphoscoliosis.
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