Corrective Osteotomies in Spine Surgery

J. Brian Gill, Andrew Levin, Tim Burd and Michael Longley


This information is current as of November 1, 2008

Reprints and Permissions

Click here to order reprints or request permission to use material from this article, or locate the article citation on jbjs.org and click on the [Reprints and Permissions] link.

Publisher Information

The Journal of Bone and Joint Surgery
20 Pickering Street, Needham, MA 02492-3157
www.jbjs.org
Spinal deformities can result in increasing thoracic kyphosis or loss of lumbar lordosis, leading to imbalance in the sagittal plane. Such deformities can be functionally and psychologically debilitating.

The Smith-Petersen osteotomy can achieve approximately 10° of correction in the sagittal plane at each spinal level at which it is performed. This osteotomy is beneficial for patients who have a degenerative imbalance in the sagittal plane.

The pedicle subtraction osteotomy can achieve approximately 30° to 40° of correction in the sagittal plane at each spinal level at which it is performed. It is the preferred osteotomy for patients with ankylosing spondylitis who have an imbalance of the spine in the sagittal plane.

The cervical extension osteotomy is performed in the cervical spine, at the cervicothoracic junction, in patients who have a cervical flexion deformity that impedes their ability to look straight ahead while walking or who have difficulty swallowing.

The vertebral column resection is used when the imbalance is severe enough that the other osteotomies cannot correct the deformity, especially in patients who have a combined sagittal and coronal spinal imbalance.

Neurologic problems, whether transient or permanent, are the most commonly encountered complications following these procedures.

Recent results have shown a high patient satisfaction rate and good functional outcomes after spinal osteotomies done to treat a variety of disorders.

Adult spinal deformity poses many challenges to the spine surgeon. In particular, a substantial imbalance in the sagittal plane sometimes cannot be corrected solely with an arthrodesis with instrumentation, especially when the deformity is inflexible. In these unique cases, spinal osteotomies must be performed to achieve balance in both the sagittal and the coronal plane. There are several conditions for which osteotomies are a viable treatment option. These disorders include, but are not limited to, fixed adult scoliosis, imbalance of the spine in the sagittal plane, and spondyloarthopathies (ankylosing spondylitis and psoriatic arthritis). These disabling deformities may result in flattening of normal lumbar lordosis, in thoracic hyperkyphosis, and in forward translation (positive sagittal balance) of the head and cervical spine. Such postures are functionally and psychologically disabling. In addition to understanding these spinal conditions, a detailed review of the major spinal osteotomies is necessary to better understand the advantages and disadvantages of each technique and to determine which osteotomy is best for a particular deformity. In this review, the types of sagittal deformities that can occur will be discussed to improve the readers’ understanding of the importance of restoring so-called normal spinal alignment. We will also describe how sagittal deformities affect the horizontal gaze of an individual and the effect on the pelvic and hip orientation to the spine. Horizontal gaze refers to an orientation in which a patient is looking straight ahead with the horizontal plane of the head and eyes parallel to the floor. A patient with a decompensated spine with loss of sagittal balance may no longer be able to maintain a gaze that is parallel to the floor.

Disclosure: The authors did not receive any outside funding or grants in support of their research for or preparation of this work. Neither they nor a member of their immediate families received payments or other benefits or a commitment or agreement to provide such benefits from a commercial entity. No commercial entity paid or directed, or agreed to pay or direct, any benefits to any research fund, foundation, division, center, clinical practice, or other charitable or nonprofit organization with which the authors, or a member of their immediate families, are affiliated or associated.
Sagittal and Coronal Imbalances
There are two general types of spinal imbalance in the sagittal plane: type 1 and type 2. A type-1 imbalance refers to a condition in which the patient has a segmental or regional imbalance in the sagittal plane of the spine but still has a balanced spine as defined by a plumbline from C7 that falls over the L5-S1 disc (Fig. 1). These patients typically have a short segment (two or three vertebrae) that is hyperkyphotic and results in the more cephalad or caudal vertebrae having to compensate with lordosis. For example, in patients who sustain a fracture of the vertebral body at the thoracolumbar junction that results in kyphosis, the more mobile cephalad lumbar levels will try to compensate for the kyphosis with hyperlordosis to maintain proper sagittal balance of the spine. With kyphosis at the L3 vertebra, the lumbar vertebrae cephalad and caudal to L3 would try to compensate for the kyphosis. The thoracic spine is fairly rigid and maintains its normal kyphosis.

A type-2 imbalance refers to a global imbalance whereby the plumbline falls >5 cm in front of the L5-S1 disc. A spine with a type-2 imbalance is unable to compensate for the deformity, and the patient tends to flex the hips and knees to maintain a proper balance and horizontal gaze (Fig. 2). Therefore, during an examination, it is important for these patients to stand with the hips and knees straight so that the uncompensated spinal deformity can be assessed. An imbalance in the sagittal plane of the spine can also be combined with an imbalance in the coronal plane to produce inequality in the shoulder heights in relation to the pelvis (Fig. 3).

The overall sagittal alignment of the spine is influenced by contributions from the cervical, thoracic, and lumbar levels. These segments, when functioning correctly, allow the head to be positioned over the pelvis. However, disruption of the normal sagittal alignment can impair walking and cause pain as a result of the imbalance. Increased stress is placed on the spinal dynamic stabilizers, resulting in muscle fatigue and increased energy consumption during walking. Many different factors need to be addressed to determine the treatment of imbalance of the spine in the sagittal plane, including the degree of imbalance, the flexibility of the curve, whether the deformity is segmental or global, and whether it is at the cervical, thoracic, or lumbar level.

Corrective Osteotomies
Treating imbalance of the spine in the sagittal plane typically involves one or more osteotomies that manipulate the position of the spine by either lengthening or shortening a particular spinal column (anterior or posterior), resulting in a specific amount of correction. Several types of osteotomies are available, including the Smith-Petersen osteotomy, pedicle subtraction osteotomy, cervical extension osteotomy, and vertebral column resection.

Smith-Petersen Osteotomy (Posterior Element Wedge Resection)
History
This osteotomy was first described by Smith-Petersen et al. as an operative technique for the treatment of kyphotic deformity caused by ankylosing spondylitis. Smith-Petersen et al. recommended a single-stage posterior wedge resection of the mid lumbar spine in a chevron arrangement with controlled fracturing of the ossified anterior longitudinal ligament (Fig. 4).

Operative Technique
Like all osteotomies, the Smith-Petersen osteotomy can be performed on an open-frame spine table and should take advantage of any flexibility in the deformity. The hips of the patient may need to be flexed initially and then extended to help close the osteotomy site. Once the appropriate level for the Smith-Petersen osteotomy is identified, the lamina, ligamentum flavum, and superior and inferior articular processes are removed bilaterally. Typically, the width of the osteotomy is 7 to 10 mm. A rough guideline to follow is that every 1 mm of resection results in 1° of correction, resulting in approximately 10° of correction at each level at which the Smith-Petersen osteotomy is performed. An open disc space is a prerequisite for closure of the Smith-Petersen osteotomy site. If the disc is collapsed, then it may limit the amount of correction that can be obtained. Additionally, a Smith-Petersen osteotomy cannot be done at a level at which a spinal arthrodesis has been previously performed, since the disc is no longer mobile. Once the osteotomy site has been closed with the aid of rods and pedicle screws, through gradual compression, it is important to ensure that the neural elements are free and not compressed in the osteotomy site.

Pedicle Subtraction Osteotomy (Posterior Three-Column Wedge Resection)
History
In 1985, Thomasen first described the three-column posterior osteotomy for the management of fixed sagittal plane deformities in patients with ankylosing spondylitis. The pedicle subtraction osteotomy is typically performed at either L2 or L3, as these vertebrae are the normal apex of lumbar lordosis. It is also safer to perform the osteotomy at one of these levels, as they are caudad to the conus medullaris. The technique involves a transpedicular vertebral wedge resection extending from the posterior elements through the pedicles and into the anterior cortex of the vertebral body. When the middle and posterior column bone defects are closed, the length of the anterior vertebral cortex remains unchanged (Fig. 4). A substantial surface area for osseous union is provided by closure of the anterior, middle, and posterior bone surfaces of the osteotomy.

Operative Technique
Preoperative preparations are similar to those used for the Smith-Petersen osteotomy. With the Smith-Petersen method, the posterior column is shortened and the anterior column is lengthened. With the pedicle subtraction osteotomy, the posterior column is shortened without lengthening of the anterior column, thus shortening the spinal canal. On the average, the pedicle subtraction osteotomy can achieve approximately 30° to 40° of lordosis at each level at which the osteotomy is performed.
Sagittal Balance

Lateral C7 to Sacrum
(Sagittal Balance = B - A)

Line A is drawn from the posterior-superior corner of S1 and is perpendicular to the vertical edge of the radiograph. Its length is measured in mm from the left hand edge of the radiograph.

Line B is drawn from the center of C7 and is perpendicular to the vertical edge of the radiograph. Its length is measured in mm from the left hand edge of the radiograph.

Neutral Balance: B = A
Negative Balance: B < A
Positive Balance: B > A

Fig. 1
Before the osteotomy is begun, pedicle screws should be placed cephalad and caudal to the intended osteotomy site as they will be used to help secure and stabilize the spine after the osteotomy. The pedicle subtraction osteotomy technique requires that all of the posterior elements (spinous process and lamina) at the level of the osteotomy be removed. Once the pedicles are isolated, bone from the vertebral body can be removed through the pedicles while protecting the dura and nerve roots. Bleeding from the vertebral body will occur, so the use of a hemostatic agent such as thrombin is useful. The thrombin can be used in combination with a collagen sponge to pack the pedicles to help control blood loss. Additionally, working through one pedicle at a time helps to control blood loss while the contralateral pedicle is packed with the collagen sponge soaked with thrombin to assist with hemostasis. Once adequate bone has been removed from the vertebral body through the pedicles, the dorsal cortex of the vertebral body is removed. An osteotomy is then done circumferentially through the lateral walls of the vertebral body without violating its ventral aspect. Careful attention is needed to ensure that the removal of bone is uniform throughout the vertebral body. This will produce a symmetric closure of the osteotomy site, correcting the sagittal deformity. If the bone removal is not uniform—i.e., if more bone is removed from one side than from the other—the closure will be asymmetric. The ventral aspect of the vertebral body acts as a hinge by which the osteotomy site is closed in a manner similar to a closing wedge osteotomy of the proximal part of the tibia. Disruption of the ventral cortex of the vertebral body will destabilize the spinal column. Bridwell et al. suggested creating a central enlargement in the lamina cephalad and caudal to the osteotomy so that when the osteotomy site is closed the thecal sac and nerve roots can be inspected to make sure that nothing impinges on them (Fig. 5). The osteotomy site can be closed with use of temporary rods cantilevering the spine and also by hyperextending the chest and legs with the operating table or with the manual help of an assistant.

Fig. 2
Cervical Extension Osteotomy

History

The goal of a corrective osteotomy is not only to correct sagittal balance, but also to correct horizontal gaze. Inspired by the work of Smith-Petersen et al., Urist reported his experience with the use of the cervical extension osteotomy in a patient with severe flexion deformity secondary to ankylosing spondylitis. The difference between the concepts of sagittal balance correction and visual angle correction was not recognized until van Royen and Slot and Lazennec et al. reported on their work. Those authors found that the level of the osteotomy affects each parameter differently. Thus, a cervical extension osteotomy is indicated for correction of horizontal gaze. The conventional operative technique involves a standard posterior approach to the cervical spine and the performance of the osteotomy at C7-T1.

Operative Technique

Preoperative preparation prior to the cervical extension osteotomy includes measuring the chin-brow to vertical angle (Fig. 6). This measurement is used to determine the degree of flexion deformity of the cervical spine. On the basis of the chin-brow to vertical angle, the size of the wedge to be removed from the posterior aspect of the cervical spine can be determined. A general rule is that each millimeter of bone resection will allow approximately $1^\circ$ to $2^\circ$ of correction. Magnetic resonance imaging and computed tomography scans of the cervical spine can be performed before the operation to determine the diameter of the spinal canal at the osteotomy site. This allows appropriate planning of the osteotomy so that when the osteotomy gap is closed the neural elements are not compressed by the bone posteriorly or by a herniated intervertebral disc. Preoperative imaging also helps to define the position of the vertebral artery in relation to the proposed osteotomy site.

The cervical extension osteotomy can be performed in one of two ways. The technique described by Simmons et al. requires removal of the posterior elements (spinous process and lamina) and the pedicles. However, an osteotomy of the vertebral body is not performed. Another technique is the transpedicular osteotomy, which is similar to the pedicle subtraction osteotomy in that an osteotomy of the vertebral body is performed. In the lumbar spine, the thecal sac can be retracted below L2. However, in the cervical spine, care must be taken to avoid retraction of the sac. The osteotomy is performed at C7, where a generous lamina resection is done. This provides ample space in which to avoid impingement on the dura or C8 nerve roots once the space is closed down. Lateral mass screws are used in the cervical spine, whereas pedicle screws are not.
Fig. 4
A: Comparison of the pedicle subtraction osteotomy (PSO) with the Smith-Petersen osteotomy (SPO). The shading indicates the bone to be resected. B: The pedicle subtraction osteotomy involves resection of a vertebral wedge with a fulcrum in the anterior aspect of the spine (Point B), whereas the Smith-Petersen osteotomy involves resection of only posterior elements and a fulcrum in the middle column (Point A). Thus, pedicle subtraction osteotomy can provide a greater degree of kyphosis correction at each treated level. (Reprinted, with permission, from: Wang MY, Berven SH. Lumbar pedicle subtraction osteotomy. Neurosurgery. 2007;60[2 Suppl 1]:ONS140-6.)
screws can be used in the thoracic spine. The length of the instrumentation should be sufficient to support the osteotomy site. Our preference is to secure the osteotomy site three levels cephalad and three levels caudad to the osteotomy site, but particular care must be taken for each patient.

Vertebral Column Resection

History

Vertebral column resection has been described for the treatment of spinal column tumors, spondyloptosis, and congenital kyphosis as well as for hemivertebrae excision. It is defined as a resection of one or more vertebral segments, including the posterior elements (spinous process and lamina), pedicles, vertebral body, and discs cephalad and caudal to the vertebral body. Vertebral column resection has been suggested for use in deformity-correcting operations when the deformity is not amenable to other osteotomy techniques such as the Smith-Petersen osteotomy or the pedicle subtraction osteotomy. The vertebral column resection is performed either through a combined anterior and posterior approach or through a posterior approach only.

Operative Technique

This discussion will be limited to the operative technique through the posterior approach only. First, the posterior elements (spinous process and lamina), including the pedicles, are removed. A wide lateral dissection to the transverse processes is done to facilitate the vertebral body resection. This wide lateral resection will avoid violation of the thecal sac when it is performed more cephalad than L2 and prevent excessive retraction on the thecal sac when it is performed caudad to L2. In the thoracic spine, costotransversectomies are performed to facilitate removal of the vertebral body. Unlike the previously discussed osteotomies, bone-on-bone contact is not achieved, as the vertebral body is completely removed. Therefore, reconstruction of the spinal column is needed after the deformity is corrected. A metal cage, structural autograft, or allograft may be used to reconstruct the vertebral column after correction of the deformity. This reconstruction of the vertebral column is supplemented with pedicle screws and rods. The instrumentation also helps to achieve the desired deformity correction once the vertebral column resection is done. Finally, an arthrodesis of the spine that is equal to the
Selection of the Appropriate Osteotomy and Spinal Level

Selecting the appropriate osteotomy and level at which to perform it is critical to the success of the procedure. The osteotomies are typically performed in the region of the relative kyphosis and maximal deformity, which can be in the cervical, thoracic, or lumbar spine. The amount of correction needed can be estimated from the preoperative radiographic measurements indicating the degree of curvature in the sagittal plane. A Smith-Petersen osteotomy can be used if <30° of correction is needed. Otherwise, a pedicle subtraction osteotomy is typically performed. An algorithm that can serve as a general guideline for the selection of the appropriate osteotomy is depicted in Figure 8. A sagittal deformity that is combined with coronal imbalance is better treated with an asymmetric pedicle subtraction osteotomy or even a vertebral column resection so that the coronal deformity is corrected rather than exacerbated. The Smith-Petersen osteotomy or a symmetric pedicle subtraction osteotomy would correct the sagittal deformity and allow the coronal deformity to decompensate as these osteotomies cannot correct a coronal deformity. The level of the osteotomy is also important in that the more caudad the osteotomy, the fewer vertebrae there are for fixation, placing greater stress on the instrumentation and potentially leading to hardware failure prior to osseous union.

Once the selected osteotomy is done, an adequate number of vertebrae needs to be included in the instrumentation and arthrodesis. Instrumentation that is too short (encompassing two or three vertebrae) may result in junctional kyphosis cephalad or caudal to the operative construct. Additionally, the operative construct should not end at the apex of the curve as this may exacerbate the curve or lead to loss of fixation. The caudal end of the construct should end, if possible, cephalad to the L5 vertebra, with the L4-L5 and L5-S1 disc spaces left open. A construct that ends at L5 may accelerate degeneration of the L5-S1 disc.

Indications for Specific Osteotomies

Smith-Petersen Osteotomy

Indications for the Smith-Petersen osteotomy depend on the extent of the deformity, the degree of functional impairment of the patient, the age and condition of the patient, and the feasibility of correction. The Smith-Petersen osteotomy is typically performed in the thoracic spine. In addition, multiple Smith-Petersen osteotomies can be done throughout the thoracic spine, and even the lumbar spine, to achieve the desired correction.

Multiple Smith-Petersen osteotomies are very useful for treating a fixed imbalance in the sagittal plane of the spine.
caused by a loss of lumbar lordosis following operative treatment of spinal deformities, particularly idiopathic scoliosis. These patients were typically treated with a posterior distraction instrumentation system such as the Harrington rods.

Smith-Petersen osteotomies are also beneficial for patients with a degenerative imbalance in the sagittal plane of the spine. This condition typically occurs in the lumbar spine in older individuals (more than fifty years of age). These patients typically have substantial intervertebral disc collapse, facet arthropathy, and vertebral end plate osteophytes causing the deformity.

Pedicle Subtraction Osteotomy
The pedicle subtraction osteotomy is useful for treating patients with ankylosing spondylitis and an imbalance in the sagittal plane of the spine. Unlike the Smith-Petersen osteotomy, the pedicle subtraction osteotomy is mainly useful for deformities with an apex in the lumbar spine. The pedicle subtraction osteotomy is historically performed at L2 or L3, and an ideal candidate for the procedure typically has a positive sagittal imbalance of >12 cm. The pedicle subtraction osteotomy is also indicated for patients who have had a circumferential fusion along multiple vertebrae, which prevents the performance of a Smith-Petersen osteotomy since osteoclasis cannot be done through a fused intervertebral disc.

Cervical Extension Osteotomy
Indications for a cervical extension osteotomy include impairment of the visual field to see ahead (horizontal gaze) and difficulties with attending to personal hygiene, with function, and with swallowing due to the cervical flexion deformity. Most patients requiring a cervical extension osteotomy have had a long-standing history of ankylosing spondylitis leading to the flexion deformity. Besides ankylosing spondylitis, prior trauma to the cervical spine (especially at the cervicothoracic junction) can lead to a cervical flexion deformity.

Vertebral Column Resection
Patients with a severe and rigid imbalance in the sagittal plane of the spine that is not amenable to treatment with a Smith-Petersen osteotomy or a pedicle subtraction osteotomy are candidates for a vertebral column resection. A type-2 sagittal deformity with coronal imbalance of the spine requires a vertebral column resection, as an asymmetric pedicle subtraction osteotomy would not fully correct the coronal deformity. Additional indications for a vertebral column resection include congenital kyphosis, a hemi-vertebra, L5 spondyloptosis, and resection of a spinal tumor.
Clinical Outcomes of Osteotomies

The advantages of using a Smith-Petersen osteotomy to treat an imbalance in the sagittal plane of the spine are that it can be performed relatively rapidly, it involves less blood loss than does a pedicle subtraction osteotomy, it does not necessitate neural element manipulation, and it is performed safely at the cord, conus, or caudal levels. Using a variety of statistical analyses, Cho et al. prospectively compared Smith-Petersen osteotomies with pedicle subtraction osteotomies for the treatment of imbalances in the sagittal plane of the spine in seventy-one patients. They found that the Smith-Petersen osteotomy achieved an average overall correction of 24.9° ± 10.6°, corresponding to 10.7° ± 3.2° per segment. A subgroup of patients who had had three or more Smith-Petersen osteotomies had an average overall correction of 33.0° ± 9.2°. The group treated with a pedicle subtraction osteotomy had an average correction of 31.7° ± 9.0°. This difference was not significant (p > 0.05). In terms of the functional outcome, the mean Oswestry Disability Index improved from 42.3 ± 14.2 points before the Smith-Petersen osteotomies to 21.3 ± 14.8 points after them and improved from 47.9 ± 15.8 points before the pedicle subtraction osteotomies to 29.7 ± 18.3 points after them; the difference in improvement between the two treatment groups was not significant (p = 0.35). Although Cho et al. noted that the amount of sagittal correction resulting from three or more Smith-Petersen osteotomies was equivalent to the amount produced by one pedicle subtraction osteotomy, the Smith-Petersen osteotomy may exaggerate the concavity of a coronal curve if one is present. Therefore, a Smith-Petersen osteotomy should not be used in spines with curvature in the coronal plane.

A variation of the Smith-Petersen osteotomy is the osteotomy of Ponte, a multilevel thoracic procedure used to treat flexible thoracic kyphosis. It is an aggressive resection of the unfused facet joints, lamina, interspinous ligaments, and lamina mentum flavum at each level. This osteotomy is advantageous in that it is simple and may be performed at multiple levels, and the osteotomies can be substantially smaller. Substantial curves may be treated effectively with this osteotomy, and the procedure can provide a smooth transition between areas of maximum and minimum kyphosis. In a level-IV study by Geck et al., seventeen consecutive patients with Scheuermann kyphosis underwent the osteotomy of Ponte. Correction of the kyphosis averaged 61%. The average correction across the apex of the kyphosis was 9.3° (range, 5.9° to 15°) per osteotomy. There were no neurologic complications. One patient with a solid fusion had a late infection twenty-four months after the procedure. The infection was treated with removal of the instrumentation and intravenous antibiotics. Two patients had junctional kyphosis cephalad and caudal to the instrumentation. The authors concluded that this osteotomy was an acceptable alternative to a combined anterior and posterior approach to the spine since it is not associated with the morbidity and extended operative time attributed to the anterior approach.

The pedicle subtraction osteotomy is advantageous in that it can produce substantial correction at a single level, it results in successful bone union due to the three columns of bone contact, and it can be done without the use of a supplemental anterior approach. In a prospective study in which thirty patients underwent a Smith-Petersen osteotomy and forty-one patients underwent a pedicle subtraction osteotomy, only 39% of the patients treated with the pedicle subtraction osteotomy required a concomitant anterior arthrodesis compared with 87% of those treated with the Smith-Petersen osteotomy. Kim et al. retrospectively analyzed their results at a minimum of five years following pedicle subtraction osteotomies in thirty-five patients. Between two and five years postoperatively, the authors did not see any significant radiographic changes in thoracic kyphosis or lumbar lordosis (p = 0.38 and 0.84, respectively). Eight patients subsequently underwent revision procedures for treatment of pseudarthrosis. The Oswestry Disability Index and Scoliosis Research Society outcome scores between two and five years postoperatively also did not change significantly. A sagittal vertical axis of <8 cm at the time of final follow-up was significantly associated with a better Scoliosis Research Society outcome score (p = 0.038). The authors concluded that pedicle subtraction osteotomy can provide satisfactory clinical and radiographic outcomes at a minimum of five years postoperatively.

In a retrospective study comparing circumferential fusion to pedicle subtraction osteotomy in twenty-six patients with posttraumatic kyphosis who were followed for a mean of 3.5 years, Suk et al. found that the pedicle subtraction osteotomy had a shorter operative time (215 minutes compared with 351 minutes), less intraoperative bleeding, and more correction of the kyphosis between the preoperative and postoperative examinations (25.7° compared with 11.2°). The cervical extension osteotomy allows the patient to see straight ahead and provides major functional and psychological benefits. In the largest series of which we are aware, Simmons et al. retrospectively reviewed the results of cervical extension osteotomy in 114 patients. On the average, 37° of correction was obtained, with a fusion rate of 95%. Two patients had neurologic complications resulting from impingement on the spinal cord on closure of the osteotomy site; one of them had transient paraplegia, which resolved after a reoperation, and the other had permanent paraplegia. Pseudarthrosis was noted radiographically and required additional procedures in 5% (six) of the 114 patients. Belanger et al. reported achievement of an average of 38° of correction in their series of twenty-three patients. They concluded that a cervical extension osteotomy not only improves horizontal gaze but also can help to alleviate neck pain, eating difficulties, and neurologic abnormalities such as radiculopathy. Furthermore, they found that internal fixation is necessary to stabilize the osteotomy site to reduce the risk of nonunion, prevent subluxation, prevent loss of correction, and minimize the risk of neurologic injury.

Although vertebral column resections are extensive procedures, correction of the deformity is achievable. In a study by Suk et al., sagittal curves were reduced, on the average, from 111° preoperatively to 50° postoperatively in patients with adult scoliosis and from 68° preoperatively to 12° postoperatively in...
those with postinfectious kyphosis\textsuperscript{31}. In another study by Suk et al., twenty-five patients with a lumbosacral deformity were treated with a vertebral column resection with removal of more than two vertebrae on the average\textsuperscript{27}. The patients obtained approximately 60\% correction (from 38\textdegree{} to 15\textdegree{}) of the coronal deformity and 40\textdegree{} of correction of the kyphosis.

**Complications with Osteotomies**

Spinal osteotomies are extensive and complex procedures. As the level of complexity increases, so does the risk of complications. As in any spinal procedure, major neurologic problems can occur, especially when there is manipulation of the foraminial space, retraction of the thecal sac and nerve roots, and shortening of spinal columns and segments. Therefore, it is important to perform proper spinal cord monitoring. A wake-up test after the osteotomy site has been closed may be the most accurate way to assess spinal cord and nerve root function\textsuperscript{1}.

A Smith-Petersen osteotomy shortens the posterior column while lengthening the anterior column. There is a concern that this could result in injury of the major vessels, particularly the abdominal aorta, although we are not aware of any reported case of an aortic injury. Specific to the Smith-Petersen osteotomy are complications such as intraspinal hematoma and intestinal obstruction or superior mesenteric artery syndrome\textsuperscript{6,25}. Cho et al. found that the most frequent complications after a Smith-Petersen osteotomy were superficial wound infections and substantial coronal imbalance of >4 cm when three or more Smith-Petersen osteotomies had been done\textsuperscript{26}.

Pedicle subtraction osteotomies are technically demanding and involve substantial mobilization of the dura, and the blood loss is greater than that associated with the Smith-Petersen osteotomy\textsuperscript{6,25}. A retrospective analysis of data obtained prospectively in a study of forty-six patients who were sixty years of age or older showed that patients who underwent a pedicle subtraction osteotomy were seven times more likely to have at least one major complication compared with patients who underwent a different spinal procedure (odds ratio, 6.96; 95\% confidence interval, 1.10 to 79)\textsuperscript{11}. Major complications included neurologic deficits, deep wound infection, pulmonary embolus, pneumonia, and myocardial infarction. Increasing age was a significant predictor of a complication (p < 0.05). The investigators concluded that the age at which patients are able to tolerate a major procedure such as a pedicle subtraction osteotomy may be lower than the age at which they can tolerate other common spinal procedures.

Buchowski et al. reported the prevalence of intraoperative and postoperative neurologic deficits to be 11.1\% and the prevalence of permanent deficits to be 2.8\% in a study of 108 patients who had undergone a pedicle subtraction osteotomy\textsuperscript{1}. In a study by Bridwell et al., five (15\%) of thirty-three patients who had undergone a pedicle subtraction osteotomy for the treatment of an imbalance in the sagittal plane experienced a transient neurologic deficit\textsuperscript{26}. In a recent retrospective study, Yang et al. found the prevalence of intraoperative or postoperative neurologic deficits to be 4\% (one of twenty-eight patients) after lumbar or thoracic pedicle subtraction osteotomy for the treatment of an imbalance in the sagittal plane\textsuperscript{32}. This single deficit was thought to be most likely due to nerve root compression.

In a cervical extension osteotomy, neurologic complications can arise from a variety of causes. When the osteotomy site is closed, neural elements including the spinal cord and nerve roots may be compressed if enough bone was not removed from the posterior elements (spinosus process and lamina). Also, the C8 nerve roots may be compressed in their intervertebral foramen if not enough bone was removed from the pedicles cephalad and caudal to the osteotomy. In addition, instability and subluxation at the osteotomy site may lead to neurologic complications. If subluxation occurs, there is a high probability that it will lead to nonunion at the osteotomy site, which may require an anterior spine arthrodesis\textsuperscript{3}.

Suk et al. retrospectively evaluated the complication rate following a vertebral column resection in sixteen patients with rigid scoliosis\textsuperscript{38}. Complications, including one complete paralysis, one hematoma, one hemopneumothorax, and one proximal junctional kyphosis, developed in four of these patients. In another retrospective study, a complication developed in 20\% (five of twenty-five patients who had had a vertebral column resection to treat a fixed lumbosacral deformity\textsuperscript{39}). The complications included two cases of radicular pain that resolved in six months, two compression fractures, and one pseudarthrosis. The investigators reported a mean blood loss of 2810 mL (range, 320 to 5460 mL), indicating that a substantial amount of blood loss can occur in association with this procedure.

**Overview**

Corrective osteotomies are used to treat sagittal and coronal imbal-ances of the spine in patients with a variety of spinal deformities. It is important to be able to recognize the type and underlying cause of the deformity so that the most appropriate osteotomy can be chosen. The Smith-Petersen osteotomy is relatively simple compared with the other osteotomies and can typically be used to treat type-1 deformities. Also, curves that have a relatively smooth kyphosis instead of a sharp angular kyphosis can be treated with a Smith-Petersen osteotomy. Multiple Smith-Petersen osteotomies can be used to achieve the necessary amount of correction. Pedicle subtraction osteotomies are typically used in patients with greater imbalances in the sagittal plane of the spine and when a minimum of 30\textdegree{} of correction is needed. Vertebral column resections are reserved for deformities, such as those in both the sagittal and the coronal plane, that are not amenable to treatment with either a Smith-Petersen osteotomy or a pedicle subtraction osteotomy, or a combination of the two. The cervical extension osteotomy is performed in patients with a history of ankylosing spondylitis, but it is specifically used to correct the horizontal gaze by directing the visual field forward. As the level of complexity of the osteotomy increases, so does the potential for complications.\[\textcopyright\] J. Brian Gill, MD, MBA

Tim Burd, MD
References


