Decision Making Regarding Smith-Petersen *vs.* Pedicle Subtraction Osteotomy *vs.* Vertebral Column Resection for Spinal Deformity

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Study Design. Author experience and literature review.

Objectives. To investigate and discuss decision-making on when to perform a Smith-Petersen osteotomy as opposed to a pedicle subtraction procedure and/or a vertebral column resection.

Summary of Background Data. Articles have been published regarding Smith-Petersen osteotomies, pedicle subtraction procedures, and vertebral column resections. Expectations and complications have been reviewed. However, decision-making regarding which of the 3 procedures is most useful for a particular spinal deformity case is not clearly investigated.

Methods. Discussed in this manuscript is the author's experience and the literature regarding the operative options for a fixed coronal or sagittal deformity.

Results. There are roles for Smith-Petersen osteotomy, pedicle subtraction, and vertebral column resection. Each has specific applications and potential complications.

Conclusion. As the magnitude of resection increases, the ability to correct deformity improves, but also the risk of complication increases. Therein, an understanding of potential applications and complications is helpful.

Key words: Smith-Petersen osteotomy, pedicle subtraction osteotomy, vertebral column resection. **Spine 2006; 31:S171–S178**

For the purpose of this manuscript, a Smith-Petersen osteotomy (SPO) will be described as one in which the posterior column is resected between the facet joints at one or multiple levels to accomplish, in most cases, additional lordosis. The middle and anterior columns are such that the anterior column opens through the disc space. Many are confused by the terminology and consider this a Chevron osteotomy. Some consider the SPO to be a radical posterior column resection followed by an anterior osteoclasis to achieve approximately 30° of correction at 1 level as in an ankylosing spondylitis patient. The SPO referred to in this manuscript is the Chevron variety (Figure 1). A pedicle subtraction osteotomy (PSO) refers to doing a V-shaped resection through the posterior elements, pedicles, and vertebral body. The hinge is anterior through bone. In most cases, the resection is entirely through bone. A variant of this is to also resect the disc space above. The osteotomy is then closed in such a way to accomplish bone-on-bone in the posterior, middle, and anterior columns (Figures 2, 3). A vertebral column resection (VCR) refers to completely resecting 1 or more vertebral segments. At a minimum, this means the posterior elements, pedicles, and the entire vertebral body with the discs above and below. Closure usually does not imply bone-on-bone throughout. Reconstruction of both the posterior and frequently the anterior column is usually necessary with a VCR (Figure 4).

Indications for Osteotomies

When a patient has a substantial deformity, the initial workup always includes an assessment of flexibility of the spine. This can be determined both clinically and radiographically. At times, if a patient stands with a sagittal imbalance, the surgeon may find that if the patient lies supine or prone, this imbalance corrects to some extent through mobile segments. Therein, part of the assessment is to compare standing long-cassette anteroposterior and lateral radiographs to either long-cassette anteroposterior and lateral supine or prone radiographs. The patient's spine will fall into one of three categories: 1) totally flexible, meaning that the spinal deformity corrects simply by being in a supine or prone unweighted position; 2) a deformity that partially corrects through mobile segments, but not entirely; and 3) a totally inflexible deformity with no correction in the recumbent position, meaning that the spine is entirely fused throughout the thoracic and lumbar spine.

Literature Review

SPOs were first described in 1945 and were used principally for ankylosing spondylitis.[1–3] Subsequently, the concept of doing multiple SPOs has been useful for treatment of ankylosing spondylitis and iatrogenic fixed sagittal imbalance.[4–6] More recently, PSOs have been described for ankylosing spondylitis and iatrogenic fixed sagittal imbalance.[7–10] VCR has been suggested for tumors[11] and spondyloptosis.[12,13] Also, VCR has been described for severe rigid deformities, either performed through combined anterior and posterior approaches[14] or through a posterior approach.[15,16] Hemivertebra excision is a form of VCR as the posterior elements, vertebral body, and discs above and below are completely resected at 1 segment.[17]

Smith-Petersen Osteotomy
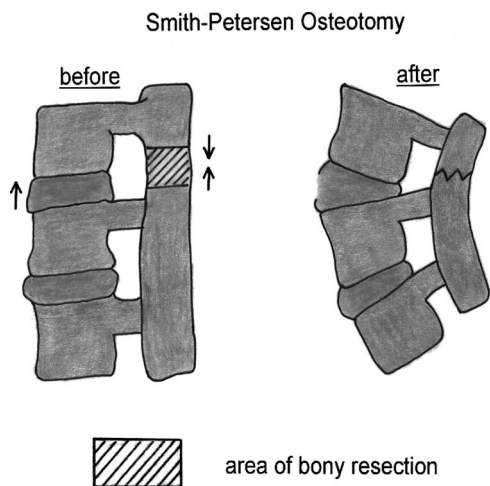
before   after

area of bony resection

Figure 1. Smith-Petersen osteotomy. Correction of sagittal deformity usually involves performing multiple Smith-Petersen osteotomies as depicted in this figure. Smith-Petersen osteotomies shorten the posterior column and lengthen the anterior column. They either hinge or slightly shorten the middle column.

Sagittal Imbalance

We prefer to classify sagittal imbalance as both Type I and Type II.[18] In Type I imbalance, the patient has a segmental problem. A portion of the spine is substantially hyperkyphotic, but the patient is able to maintain balance by hyperextending segments above and below. An example of this is a young adult who has been treated with Harrington rod instrumentation from T4 to L4 but has not yet degenerated discs at L4–L5 and L5–S1 and is able to maintain balance by hyperextending those 2 segments. Another common example is a post-traumatic kyphosis in which there is a regional kyphosis, but the patient is able to maintain balance by hyperextending segments above and below. Certain congenital kyphoses and many Scheuermann's kyphoses may fall into this category as well, where there is a regional hyperkyphosis

Three Column Pedicle Subtraction Osteotomy

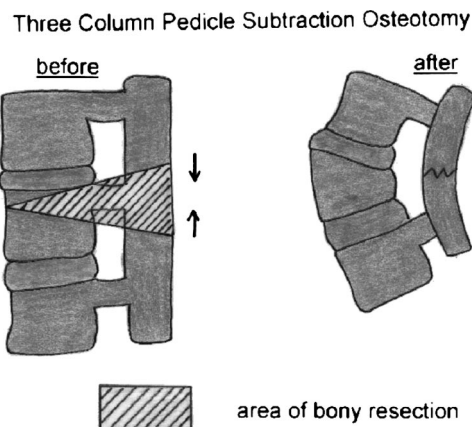before   after

area of bony resection

Figure 2. Pedicle subtraction osteotomy. Pedicle subtraction osteotomy resects a V from the spine. That V widens from anterior to posterior. The posterior element, pedicle, and vertebral body are resected and closed bone-on-bone from anterior to posterior.

but the patient is able to hyperextend segments above and below enough that sagittal balance is maintained and on a standing sagittal radiograph the C7 plumb does fall over the sacrum.

A Type II imbalance is one in which the regional hyperkyphosis is such that the patient cannot balance by hyperextending segments above and below. Examples frequently include ankylosing spondylitis patients and the middle-aged or older patient with a Harrington fusion from T4 to L4 with severe disc degeneration at L4–L5 and L5–S1 such that he/she is not able to hyperextend those distal segments to maintain balance. Another common problem is that of a middle-aged or older patient who has had surgeries in the distal lumbar spine where the fusion heals in a hypolordotic position and segments above in the upper lumbar spine or distal thoracic spine degenerate and fall into kyphosis. Therein, the patient is not able to stand straight and is pitched

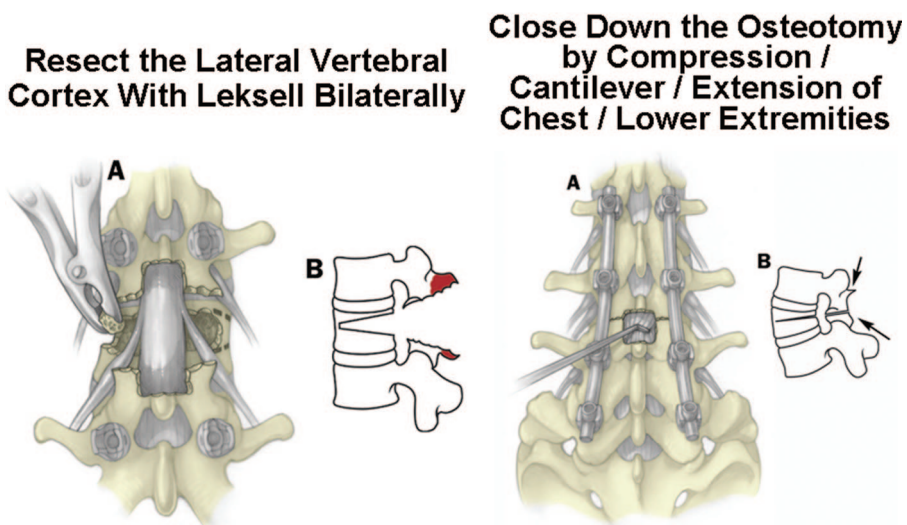## Resection And Closure Of Pedicle Subtraction Osteotomy

Resect the Lateral Vertebral Cortex With Leksell Bilaterally

Close Down the Osteotomy by Compression / Cantilever / Extension of Chest / Lower Extremities

Figure 3. Resection and closure of pedicle subtraction osteotomy. (**A**) The spine at the point where the lateral vertebral wall is being resected with a pedicle subtraction osteotomy. (**B**) Closure of the pedicle subtraction osteotomy.

**Vertebral Column Resection.
Depiction of a Sharp Angular Kyphosis
In the Thoracic Spine**

A
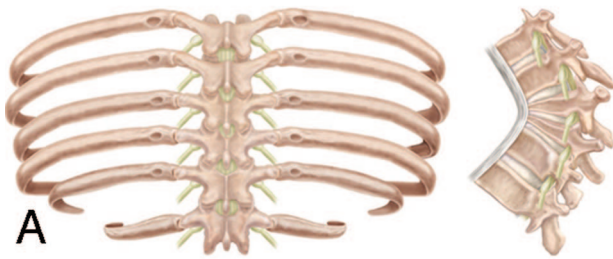
**Vertebral Column Resection.
Resection of Two Vertebral Segments and
Three Discs, Anteriorly and Posteriorly**

B
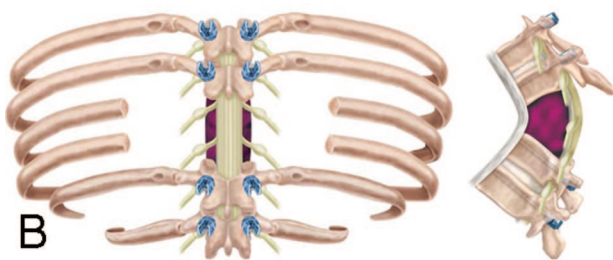
**Vertebral Column Resection.
Closure of the Vertebral Column Resection
With Reconstruction of the anterior Column
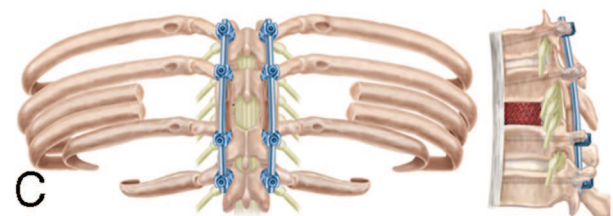With Cage and Posterior Column With Pedicle
Screw Instrumentation**

C

Figure 4. (**A**) Vertebral column resection. Depiction of a sharp angular kyphosis in the thoracic spine. (**B**) Vertebral column resection. Resection of two vertebral segments and three discs. (**C**) Vertebral column resection. Closure of the vertebral column resection. Reconstruction of the anterior column with a cage and the posterior column with pedicle screw instrumentation. Note the anterior and posterior columns are not closed bone-on-bone. A generous posterior central enlargement is maintained to observe the thecal sac. Performance of the vertebral column resection was preceded by resection of the transverse processes and ribs at these levels.

forward. Most define radiographic sagittal balance as a C7 plumb falling either through the sacrum or within 2 cm anterior to the sacrum. So radiographic sagittal imbalance is commonly defined as a C7 plumb falling 2 cm or more in front of the sacrum. Another way of stating this is the C7 plumb is 6 cm or more in front of the posterior aspect of the L5–S1 disc space. This assumes that the patient is standing in a natural position without knee flexion or hip hyperextension.

Further characterization of the kyphosis includes whether the kyphosis is based in the thoracic or lumbar spine. The critical point is whether the pathology is in spinal cord or cauda equina territory. Another important feature is whether the kyphosis is more of a rounded, long sweeping kyphosis or a short, angular one. A long sweeping kyphosis, such as a Scheuermann's, is more amenable to multiple SPOs, in part because of its multisegmental nature and in part because the pathology is in the thoracic spine/spinal cord territory. A short, angular kyphosis, such as seen with post-traumatic kyphosis, is more amenable to a PSO. Usually, a PSO in the lumbar spine will accomplish approximately 35° of lordosis. In the thoracic spine a PSO will accomplish approximately 25° of lordosis. A SPO will usually accomplish approximately 10° of lordosis. SPOs are rarely performed at one level and are usually performed at 2 or more levels. It is necessary to have a potentially mobile disc space to achieve correction with an SPO. For a PSO, this is not necessary.

At times, sagittal imbalance will be coupled with coronal imbalance. There are 2 types of coronal imbalance. For the first type, the right shoulder will be high and the right pelvis low. In this circumstance, the coronal deformity can be corrected by simply shortening the right-hand side of the spine. An example of the second type is one in which the association of the shoulders to the pelvis is such that it cannot be corrected simply by shortening one side of the spine (Figure 5). In this circumstance (Type 2), a VCR is necessary. In the first type (Type 1), an asymmetric PSO will potentially accomplish the correction.

Indications for SPO
A long, rounded, smooth kyphosis, such as Scheuermann's, especially with a previous fusion and malunion, is often an ideal candidate for multiple SPOs (Figure 6).

**Type 1 and 2 Coronal Decompensation.
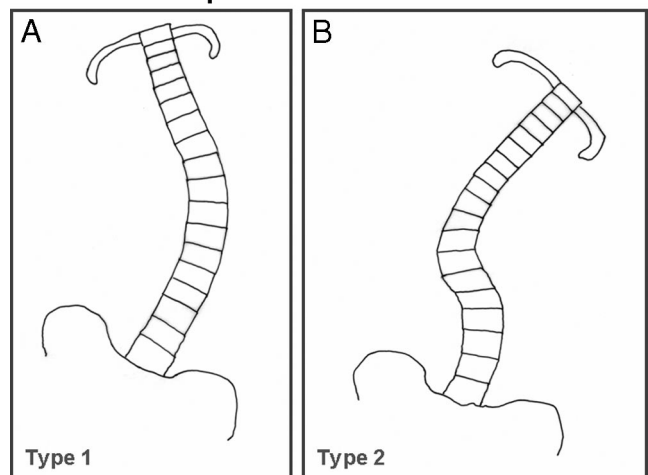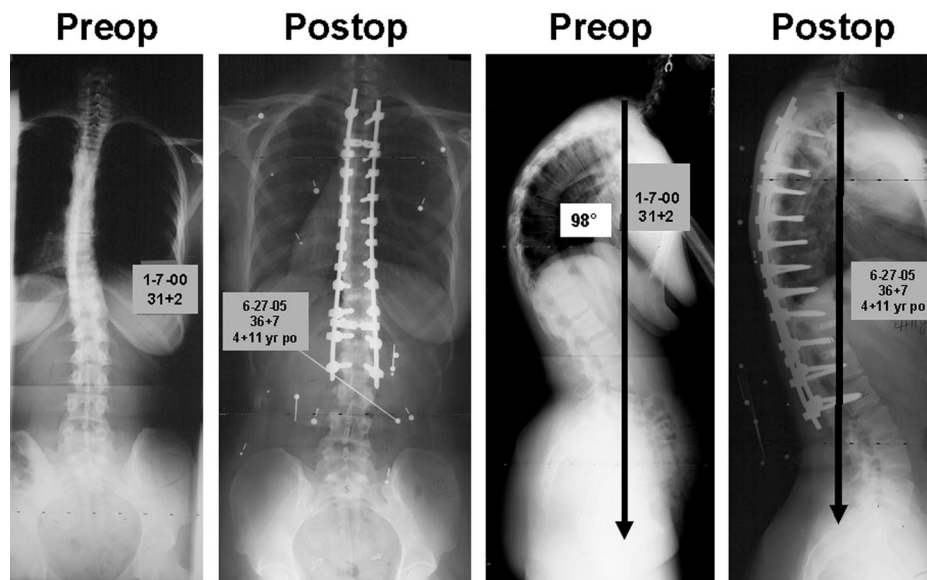Relationship Of Shoulders To The Pelvis**

A   **B**

Type 1   **Type 2**

Figure 5. Type 1 and 2 coronal decompensation. (**A**) Depiction of Type 1 coronal deformity. With Type 1, shortening the spine on the right side will rebalance the spine. (**B**) Depiction of Type 2 coronal deformity. With Type 2, shortening one side of the spine will not accomplish coronal rebalancing.
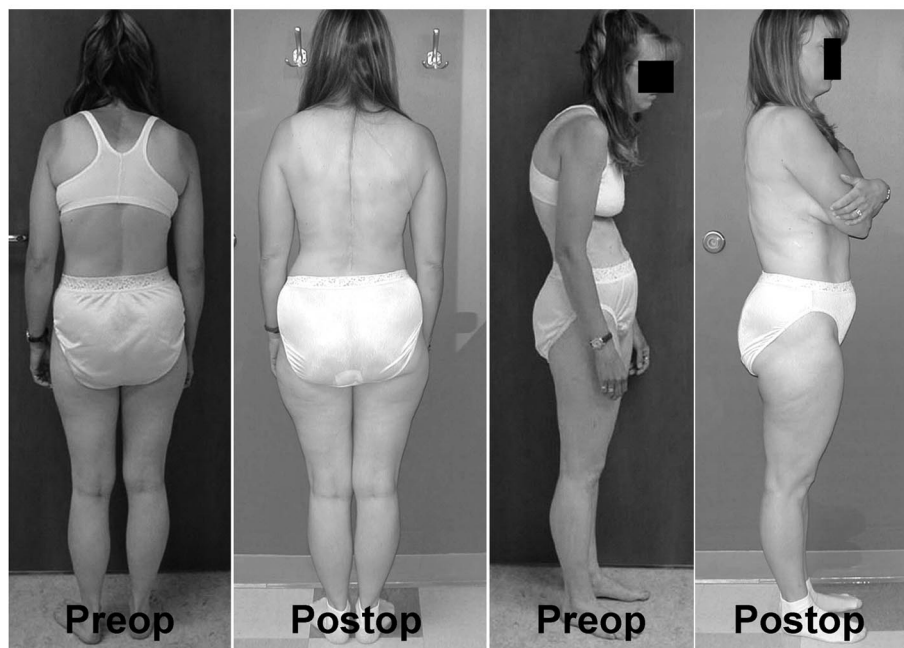
Figure 6. (**A**) Correction of kyphosis with multiple SPOs. Composite long cassette coronal and sagittal radiographs before and after treatment. A patient with Scheuermann's kyphosis with failed prior anterior and posterior surgery and 98° of kyphosis, which corrected to only 95° on supine hyperextension. This long sweeping rounded fixed kyphosis in the thoracic spine was treated with multiple Smith-Petersen osteotomies to accomplish correction. (**B**) Correction of kyphosis with multiple SPOs. The clinical appearance of the patient before and after surgical treatment with multiple Smith-Petersen osteotomies.

In most circumstances, surgeons feel that ankylosing spondylitis is best treated with a PSO. Sometimes a single PSO will not afford enough correction; therein, one might considering coupling this with 2 or 3 SPOs. The other 2 considerations for ankylosing spondylitis are to perform a large SPO either at the cervicothoracic junction or in the lumbar spine, making an effort to achieve a large amount of correction at 1 segment. The other option is the Zielke technique of performing SPOs at all levels from T10 to the sacrum.[4]
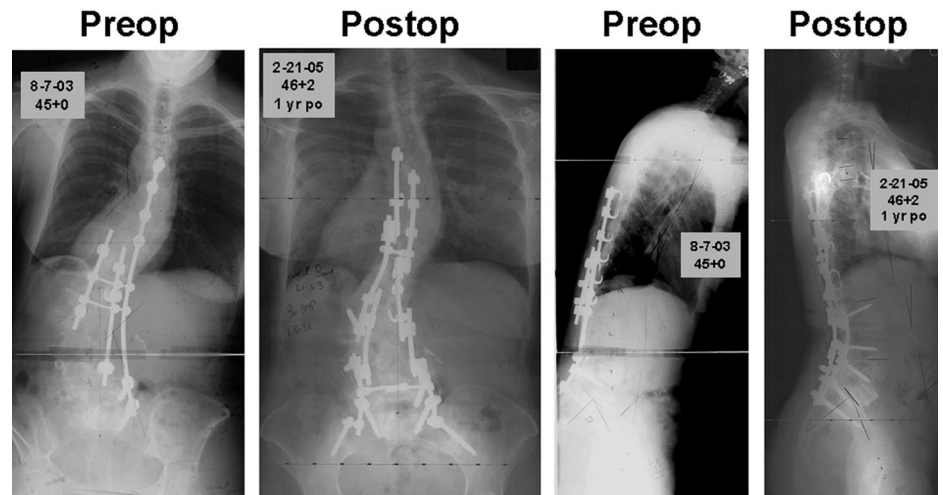
The degree of sagittal imbalance in a patient who has had a prior idiopathic scoliosis fusion to L4 with subsequent degeneration of L4–L5 and L5–S1 varies quite a bit from patient to patient. If the patient has a substantial imbalance of 12 cm of more, this is best treated with a PSO. On the other hand, if the imbalance is more minor (in the range of 6–8 cm), then treat this by achieving additional lordosis with a cage or structural graft placement at L4–L5 and L5–S1 and also 2 SPOs through the prior fusion mass in the lumbar spine. In this circumstance, doing a PSO might be excessive and performing 2 SPOs is ideal. If one can accomplish bone-on-bone correction with an SPO, then an anterior reconstruction is usually not needed.

Indications for PSO

This procedure is feasible in both the lumbar and thoracic spine. If it is performed in the thoracic spine, it is
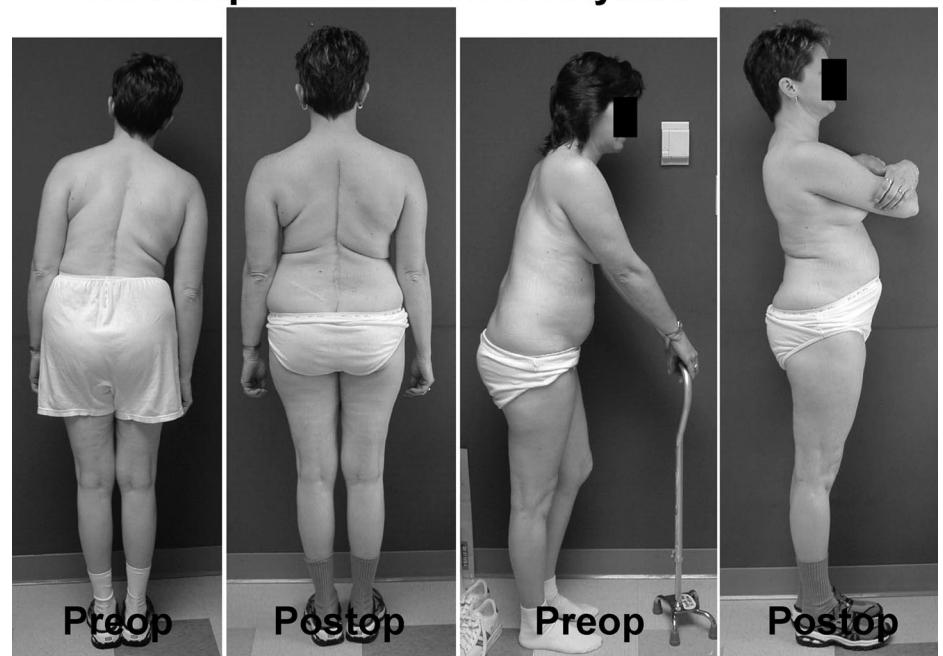
Figure 7. (**A**) Correction of coronal and sagittal decompensation with asymmetric PSO. Composite long cassette coronal and sagittal radiographs before and after revision surgery. This patient had multiple anterior and posterior surgeries and presented with a fixed deformity. The patient had very positive sagittal balance and is decompensated to the right side. The coronal decompensation was Type I with the left shoulder high and the left pelvis low. She was treated with an asymmetric pedicle subtraction osteotomy at L2 and a revision instrumented fusion. (**B**) Correction of coronal and sagittal decompensation with asymmetric PSO. The clinical appearance of the patient before and after reconstruction.

important to not retract the thecal sac, and it is therein necessary to resect portions of ribs on both sides in an effort to approach the vertebral body more laterally. Surgeons are most comfortable performing PSOs at L2 or L3 and do not have as wide an experience performing PSOs in the thoracic spine. Surgeons prefer not to perform PSOs in the distal lumbar spine as the neurologic risk seems somewhat greater and there are fewer fixation points achievable distally.

The ideal candidates for PSO are those patients with a substantial sagittal imbalance >10 to 12 cm, those patients with a sharp, angular kyphosis, and those patients who have circumferential fusion along multiple segments, which would preclude performing SPOs. It is feasible to perform a PSO through areas of rotation and prior laminectomy, but this does increase the complication rate and makes the procedure more technically demanding.

For most patients with ankylosing spondylitis, a PSO is ideal. If the patient has a Type 1 coronal and Type 2 sagittal imbalance, the PSO can be performed somewhat asymmetrically but requires reaching around the front somewhat more and doing a more aggressive resection on one side, which categorizes it between a standard PSO and a VCR (Figure 7).

Indications for VCR

Common indications include Type 1 congenital kyphosis, a hemivertebra, a sagittal decompensation with a Type 2

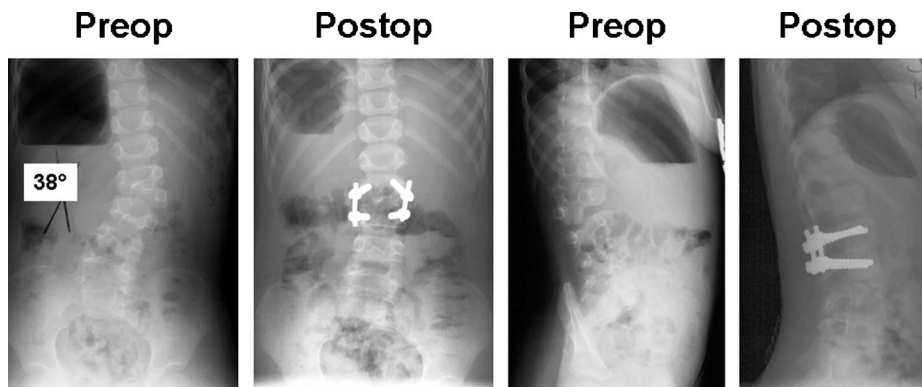**Preop**   **Postop**   **Preop**   **Postop**

Figure 8. Hemivertebra resection through a posterior approach. Composite 14 × 17 inches coronal and sagittal radiographs before and after treatment. A 4-year-old child with a hemivertebra at L2 unsegmented and nonincarcerated. She was treated with a posterior vertebral column resection, which involved resection of the posterior elements, pedicle, vertebral body, and discs above and below through a posterior approach and closure with pedicle screw implants, one above and one below, and reconstruction of the anterior column with morselized bone graft. This is a circumstance in which posterior vertebral column resection may not require an anterior reconstruction with cage(s).

coronal malalignment, a sharp angular thoracic deformity, a spondyloptosis at L5, and a resectable spinal tumor. For the thoracic resections, it is necessary to perform costotransversectomies, namely, resection of the transverse processes and ribs, at the segments being resected in order to approach the anterior column laterally. This is necessary to limit retraction of the neural elements in spinal cord territory. The more sharp and angular the thoracic kyphosis is, the easier the VCR is through an all posterior approach. VCRs at times are very helpful in very large thoracic scoliosis deformities as well in which halo traction; anterior releases and posterior facetectomies are not adequate to achieve correction of the deformity. For the unsegmented nonincarcerated hemivertebra, the most common locations that benefit from VCR are at the lumbosacral junction and the upper lumbar spine (Figures 8, 9).

Limitations of SPO/PSO/VCR
Usually, with an SPO, correction is approximately 10° per level. It does require a mobile disc space anteriorly, which

may at times be difficult to discern. If there is no bony bridge anteriorly, then it is feasible. If there is a fine bony bridge, it can potentially be broken with closed osteoclasis. If there is a thick, solid bony bridge, it will not budge without anterior release. In some cases, if substantial correction is achieved with an SPO, it may be necessary to graft the disc space anteriorly. In most cases, if a moderate correction is achieved at each level and the posterior column is closed bone-on-bone centrally and laterally, the SPO is likely to heal and anterior grafting and reconstruction is not needed.

With a PSO, when closing the osteotomy, it is necessary to observe the spine for subluxation. This does not commonly occur with an SPO but often occurs when closing a PSO. With PSOs, we find about an 8% incidence of neurologic deficit (usually a single root, L4 or L5), identified either intraoperatively or after surgery. It is related to either a mild subluxation of the spine and/or dural buckling and/or dorsal compression of nerve roots and/or traction particularly on distal roots that have had

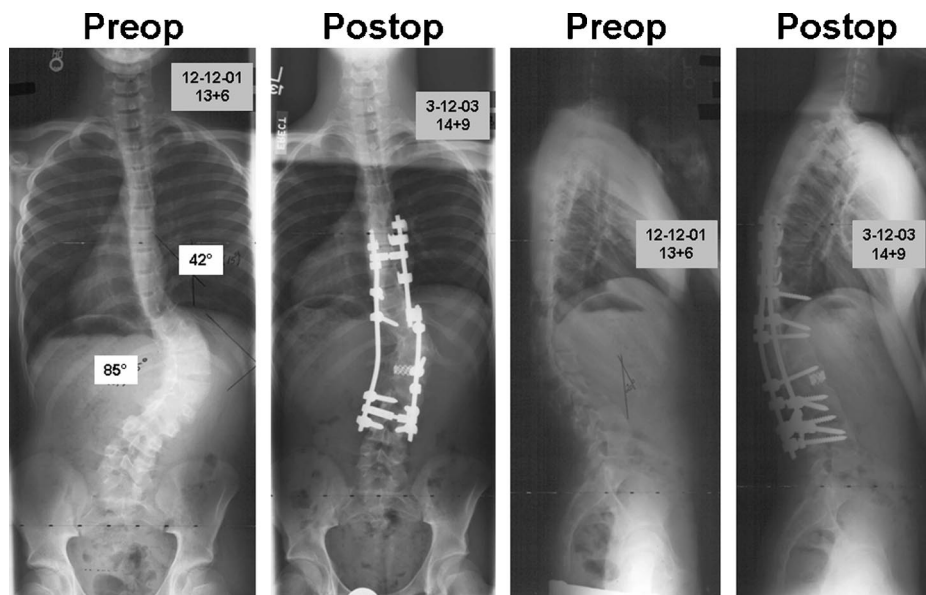**Preop**   **Postop**   **Preop**   **Postop**


Figure 9. This teenage boy presented with a congenital scoliosis that demonstrated no correction on flexibility maneuvers. He was treated with a vertebral column resection of T12. The reconstruction was performed with a cage and bone graft anteriorly and with segmental spinal instrumentation posteriorly. Cantilever and compression forces were used to close the vertebral column resection.
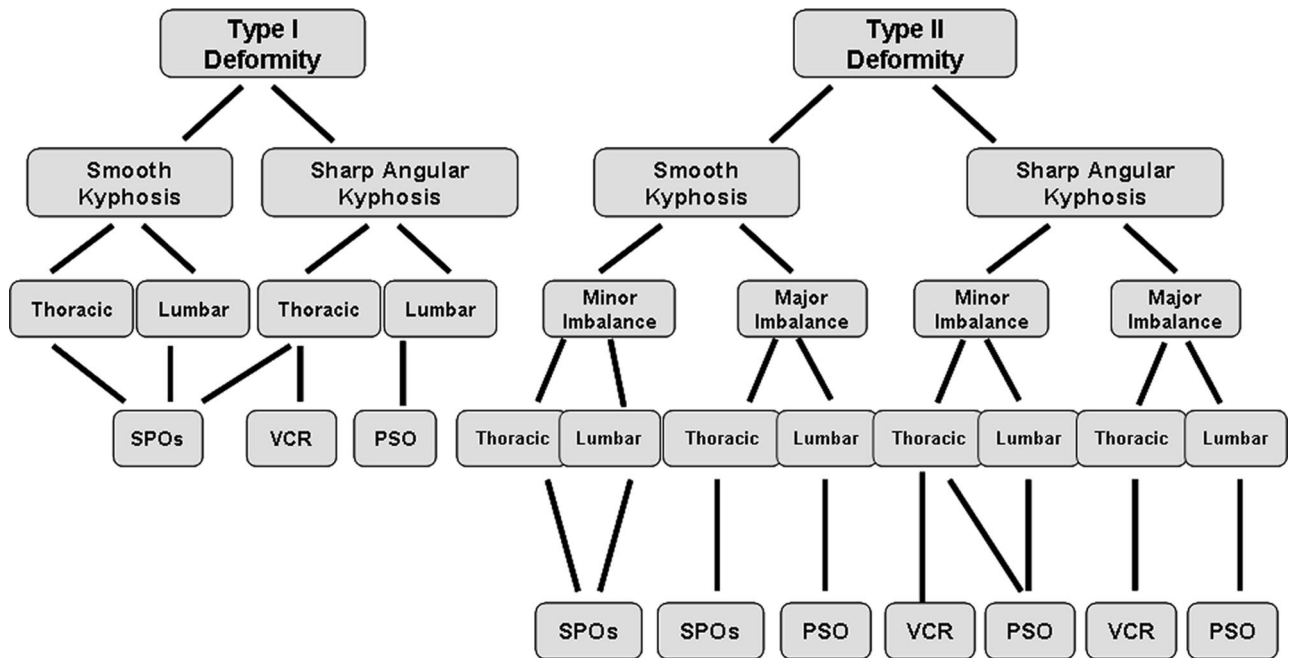
PSO = pedicle subtraction osteotomy; SPO = Smith-Petersen osteotomy; VCR=vertebral column resection

Figure 10. Algorithm for osteotomy type based on the character of the sagittal deformity.

prior surgeries. Therein, my personal preference is to keep the canal somewhat enlarged centrally with a PSO so I can inspect the dura and spinal canal after the osteotomy is closed. Realize though that the potential for neurologic deficit is greater for a PSO than an SPO. It seems to be somewhat higher at L4 and L5 than at L2 or L3.[19]

A VCR performed in the thoracic spine will have greater risk than a lumbar PSO, as the spine will be rendered more unstable, there is more manipulation, and it is performed in cord territory. Further, more blood loss should be anticipated.

Surgical Planning and Decision-Making

To decide the appropriate surgery for a fixed deformity, the following questions should be answered: 1) How many osteotomies should be performed? 2) What are the fusion levels? 3) After the osteotomy(ies), how many fixation points are needed above and below? 4) What is the ideal location for the osteotomy(ies)? Considerations are anatomic: is the pathology more in the thoracic spine or the lumbar spine? What is the risk of surgery around the spinal cord *versus* the cauda equina? How many fixation points are achievable above and below? Also, what prior surgeries have been performed and where was the prior laminectomy? For PSO in particular, it is most useful to perform the osteotomy through a prior fusion mass. Although it is feasible to perform it through an area of prior laminectomy, it is best to avoid that if possible (Figure 10).

■ Conclusion

Smith-Petersen osteotomies, pedicle subtraction procedures, and vertebral column resections all have a potential role in patients with severe inflexible spinal deformities. In most cases, there will be a fixed component of sagittal deformity and potentially a component of fixed coronal deformity. In this manuscript, broad guidelines are given. If you think of these 3 procedures as Venn diagrams, there is some overlap among the three circles. Therein for certain pathologies, one may have the option of doing either SPOs or a PSO for an ankylosing spondylitis patient, for instance. For sharp, angular kyphosis, one may have the option of either PSO or VCR depending on many factors. All 3 procedures are technically demanding and have inherent risks. The more substantial the resection, the greater the risk of blood loss, neurologic deficit, and complications.

■ Key Points

● Smith-Petersen osteotomy, pedicle subtraction procedure, and vertebral column resection may be indicated in patients with fixed coronal and sagittal deformities.
● Smith-Petersen osteotomies are most helpful for long-sweeping thoracic kyphotic deformities and mild to moderate sagittal imbalances.
● Pedicle subtraction osteotomies are most helpful for major sagittal imbalances, sharp angular lumbar kyphosis, and coexistent Type 1 coronal imbalances.
● Vertebral column resections are most useful for spondyloptosis, resectable spinal tumors, sharp angular thoracic deformities, and sagittal imbalances with Type 2 coexistent coronal imbalances.

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