Spinal Osteotomies for Rigid Deformities

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KEYWORDS

• Rigid spinal deformities • Wide posterior release • Smith-Petersen • Osteotomy • Ponte osteotomy • Pedicle subtraction osteotomy • Vertebral column resection

KEY POINTS

- Rigid deformities of the spine pose a significant challenge to the even the most experienced spine surgeon.
- The definition of a rigid deformity is one that does not correct more than 50% on bending or traction radiographs.
- There are many surgical options for the treatment of rigid spinal deformity.
- Understanding the character of the curve can help surgeons choose the most appropriate surgical corrective.

INTRODUCTION: NATURE OF THE PROBLEM

Rigid deformities of the spine pose a challenge to the most experienced spine surgeons. Rigid deformities can be encountered in primary or revision spinal procedures. Rigid deformity denotes a deformity that does not correct more than 50% on bending or traction radiographs. The deformity can be large or small, but rigid (eg, a flat lumbar spine that has been previously operated on from anteriorly and posteriorly). The other scenario is a sharp angular deformity that is rigid and causes cord compression. Usually, the deformity is not only rigid but also severe in the coronal plane, sagittal plane, or both. The definition of an osteotomy is cutting of bone. A rigid spine that is almost ankylosed often requires a thorough release or an osteotomy. The choice is to either accept the deformity or use osteotomies to make the spine flexible enough to be corrected to a balanced coronal and sagittal plane.

PREOPERATIVE PLANNING

The type of release or osteotomy chosen depends on the type of deformity, location of the deformity, presence of spinal cord compression, and previous surgical procedures that have already been performed on the spine.

There are rigid deformities that are round and smooth and others that are sharp and angular. Large round and smooth deformities are more amenable to a release at multiple segments to give a correction that is smooth and harmonious over several levels. This strategy avoids correction at the middle of the round smooth curve, creating 2 semicircles with a kink in the middle. Sharp angular deformities can be in the coronal as well as the sagittal plane. Sharp angular deformities are more amenable to a resection procedure regardless whether the resection is performed via an anterior or a posterior approach. Large sharp angular deformities are the easiest to

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approach from a posterior-only approach than from an anterior and posterior approach. It is difficult to reach the posterior part of the vertebral body and the canal through the anterior approach in such cases.

The location of the deformity also determines the approach, which might be more facile and less morbid. For example, a high thoracic deformity is more difficult to approach anteriorly than posteriorly. The thoracic, thoracolumbar, and lumbar spine can easily be approached anteriorly. The anterior approach is useful in performing a release in a rigid smooth curve, which can be scoliotic or kyphotic. Multiple disk spaces can be released by removing the annulus and disk in almost its entirety. In addition, support of the anterior column can be addressed by providing strut grafting for either disk space or vertebral body deficiencies. The anterior approach has recently been used less, because of more powerful instrumentation systems and techniques such as preoperative traction and intraoperative temporary distraction.

Previous surgery may limit the options for correcting a deformity. Previous multiple decompressions may limit the amount of posterior elements for obtaining a solid arthrodesis. An anterior arthrodesis may be helpful in ensuring a successful fusion. Previous fusion from the posterior approach only can still be approached anteriorly for either enhancing the ability to fuse or trying to achieve correction with a release or resection procedure. A previously fused spine that has had a previous anterior approach cannot be easily approached from the same side and certainly not from the opposite side, endangering the vascular supply to the spinal cord. In these cases, a posterior-only approach is the most useful in achieving correction using a pedicle subtraction osteotomy (PSO) or a vertebral column resection (VCR).

Spinal cord or cauda equina compression in the presence of a rigid deformity necessitates decompression in addition to the spinal realignment procedure. If the compression is posterior-only, the approach for deformity correction is seldom influenced. But if the compression is anterior or circumferential, then a formal anterior approach, posterolateral approach such as a costotransversectomy or a posterior VCR, enters the decision making for choosing the surgical procedure.

The available hospital facilities and resources also influence the procedure that is chosen. An advanced anesthesia team with neuromonitoring and an intensive care unit with ventilators are mandatory in the care of these complex patients. The surgeon's experience and comfort level are also paramount in deciding the nature of the procedure.

PREPARATION AND PATIENT POSITIONING

The patient is usually placed in a right lateral decubitus position for a thoracic, thoracolumbar, and lumbar left-sided anterior approach. The table can be flexed to open the interval between the pelvis and the ribs in the flank. An axillary roll is always placed in the axilla of the right shoulder. A pillow is placed below the right knee and between the legs. The patient can be held with the help of a beanbag or tape. The left arm is placed in a 90/90 position, with the help of a universal arm holder. It is important to pad all the pressure points. The draping for the preparation includes a midline-to-midline drape at the umbilicus and the posterior spinous processes.

Posterior positioning is usually performed on a 4-poster frame either on a regular operating table or a Jackson frame. It is important to place bolsters underneath the thighs to gain hip extension, which helps achieve better lumbar lordosis. All the pressure points should be well padded, especially when a 4-poster similar to a Relton-Hall frame is used, to prevent pressure damage to the chest and anterior iliac crest area. Reflexing the bed can assist with closure of a PSO. A regular operating table or adjustable Jackson frame can be used.

After positioning, the patient is prepared with an alcohol scrub followed by a ChloraPrep solution (care fusion corporation, San Diego, CA). The perioperative prophylactic antibiotics used are vancomycin and cefazolin. The flora of every hospital have different sensitivities. The sensitivities of a particular hospital have to be assessed to decide which antibiotics should be used for prophylaxis. Use of fibrinolytics such as tranexamic acid and aminocaproic acid have been shown to decrease operative blood loss in spine surgery.[1] A Cochrane review[2] showed safety and efficacy of antifibrinolytics in pediatric patients with idiopathic scoliosis.

SURGICAL APPROACH

Wide Posterior Release

Shufflebarger and Clark described wide posterior release.[3] They first described wide posterior release in patients with idiopathic scoliosis in whom partial resection of the spinous process, ligamentum flavum, facet capsule, and facet joint is performed. The release helped correction in both coronal and sagittal planes of the lumbar deformity. This release was then applied in a situation in which the adult degenerative lumbar spine was usually flat and rigid. A 3-stage sequential same-day procedure using a posterior, anterior, and then posterior approach was described. The first

approach included placement of pedicle screws in the lumbar spine, followed by wide posterior release. An anterior release was then performed by diskectomies and placement of mesh cages in the disk space for disk height restoration. The posterior part of the spine was again approached to achieve the final correction by shortening the posterior column and realigning the spine in both the coronal and sagittal planes (**Fig. 1**).

Wide posterior release involves removing the interspinous ligament and inferior and superior portion of the spinous process to expose the interlaminar space, ligamentum flavum and facet capsule and a partial removal of the facet joint. A distracter is used to distract the posterior elements between the spinous processes or the lamina to help visualize the resection of the ligamentum flavum as well as the facet capsule through to the foramen. Partial facet joint resection is enough to release the level so that the facet joint can be separated with a simple distracter rather than a Ponte osteotomy. While performing the Ponte osteotomy, a large part of the superior and inferior facet is resected, creating a large gap that is closed for a posterior shortening procedure. Wide posterior release is commonly performed to disengage all the soft tissues between segments to correct deformity in the coronal and sagittal

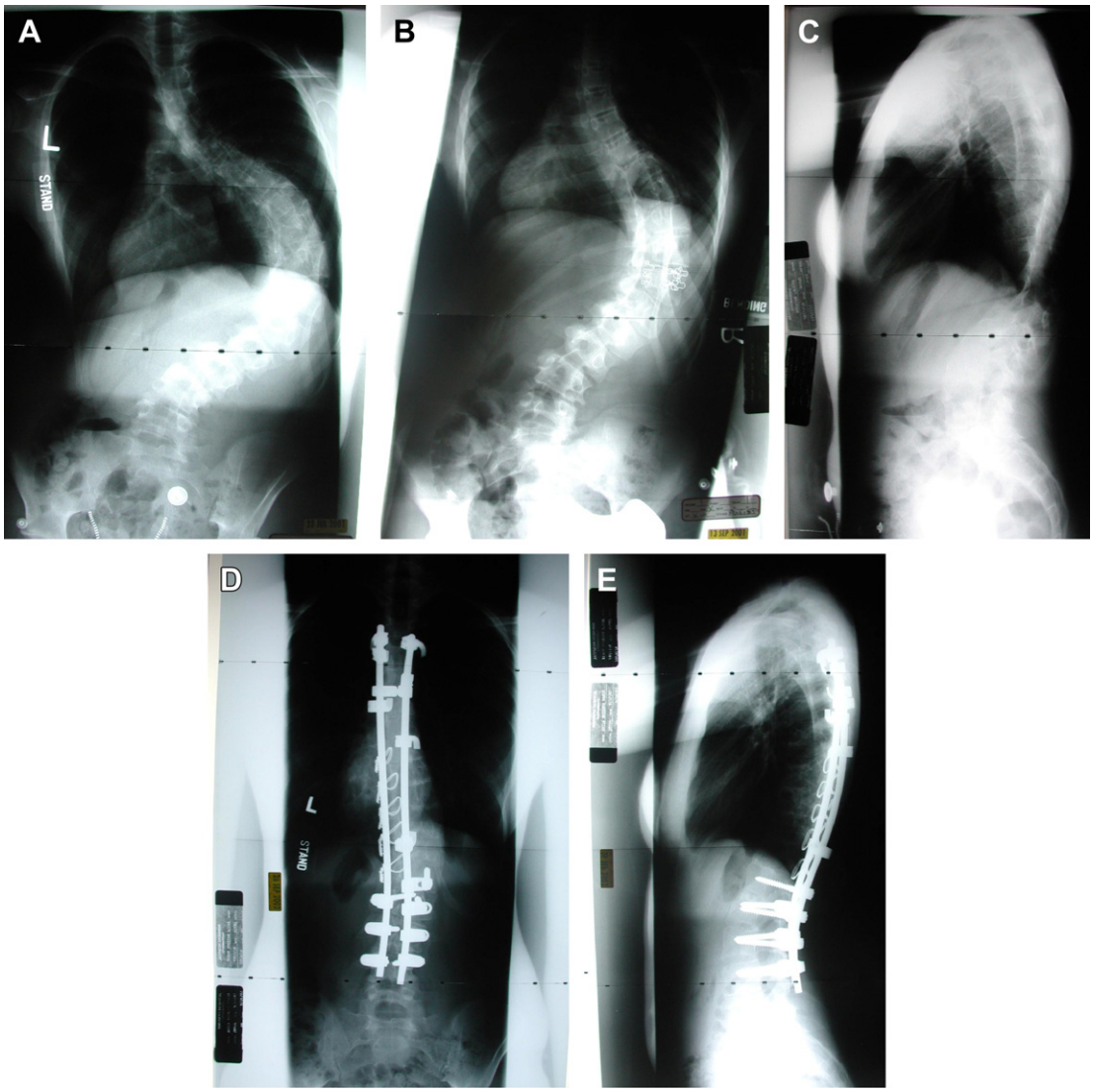

Fig. 1. (*A*) Large round rigid adolescent idiopathic scoliosis. (*B*) The curve is rigid on bending radiographs. (*C*) Preoperative lateral radiographs. (*D*) Postoperative correction obtained by anterior release, wide posterior release, and spinal instrumentation. (*E*) Postoperative lateral radiograph.

planes. This release can facilitate correction in rigid curves, especially in combination with segment instrumentation, when in previous years, an anterior release may have been performed.

Smith-Petersen Osteotomy

Smith-Petersen osteotomies (SPOs) were first described in 1945[4] for correcting sagittal plane deformities in the already fused spine either surgically or with an ankylosing condition such as ankylosing spondylitis. From Smith-Petersen's first reports, the technique improved with modifications such as foraminotomies and addition of rigid internal fixation.[5] The osteotomy relies on a mobile disk space for correction. The spinous process, lamina, and facet joints are resected. The foramen is fully exposed and the soft tissue is removed to prevent impingement of the nerve root when the osteotomy is closed. If the disk is ankylosed, the osteotomy produces a fracture through the disk space or the end plate of the vertebral body. The separation that can occur anteriorly has been reported with rare devastating injury to the large vessels, such as a tear of the aorta, which was deadly.[6] The term SPO has been used loosely to describe any posterior release. The major difference between the SPO and wide posterior release or Ponte osteotomy is that the SPO was described for already fused spines.

Ponte Osteotomy

Alberto Ponte described the Ponte osteotomy for treatment of Scheuermann kyphosis.[7] The vertebral end plates in Scheuermann disease have growth plates that are abnormal and weak. The disk material goes through these weak end plates, giving rise to the classic picture on magnetic resonance imaging (MRI) of a Schmorl node. Scheuermann disease with kyphosis results in elongated posterior elements compared with the anterior column consisting of the abnormal vertebral bodies and disks. The Ponte osteotomy involved removal of the inferior part of the spinous process, lamina, and facet joints. The superior and the inferior facets are resected in their entirety. After removal, the kyphosis is corrected with posterior column shortening. The main maneuver is a cantilever moment and compression across the apex of the kyphosis. Ponte described this procedure for Scheuermann disease and kyphosis in mostly the thoracic spine. The main difference between the Ponte osteotomy and the wide posterior release is the amount of facet resection. In the Ponte osteotomy, the entire superior and inferior facet is removed. The main difference between the SPO and the Ponte osteotomy is that the SPO was described for treatment of already fused spines.

Pedicle Subtraction Osteotomy

Fixed sagittal imbalance or fixed kyphotic deformities have been treated with SPO and PSO. Osteotomies such as SPO as well as PSO have been described and used for more than 5 decades.[4,5,8,9] PSOs have been used mainly to correct the sagittal plane, but, in addition, has been used recently to correct coronal plane deformities as well. PSO is performed from a posterior-only approach, avoiding anterior release in many cases. Pedicle subtraction has been mostly used in revision surgeries in the past but this technique is often used in primary as well as revision deformity corrections.[10,11]

The limitation of the Smith-Petersen technique is the lengthening of the anterior column, which may lead to stretching of the cauda equina and possible vascular complications, such as aortic rupture.[6] Thomasen[8] in 1985 described a 3-column posterior wedge osteotomy in 11 patients with ankylosing spondylitis. The anterior column did not lengthen as in SPO.[4] No complications such as stretching of the cauda equina or vascular complications were noted by performing the posterior compression or wedging through the L2 vertebral body.

Several clinical studies have attempted to document the efficacy of both SPO and PSO. Van Royen[9] reported on 856 patients with ankylosing spondylitis who underwent lumbar osteotomies. No difference was reported between SPO versus PSO for treating fixed sagittal plane deformity.

Recently, Cho and colleagues[10] assessed the clinical and radiographic outcomes between PSO and SPO in a total of 71 patients. Although there was greater blood loss with the PSO group compared with the SPO, no significant difference was noted in the clinical outcome measures. However, when more than 3 levels of osteotomies were compared, there was a statistically significant difference with correction of the sagittal and coronal planes of PSO versus SPO.[10] PSO is an excellent tool for the orthopedic spine surgeon to tackle the difficulty of fixed sagittal plan deformities.

Indications

The indications for a PSO keep widening. Pedicle subtraction was and still is used for treating a fixed sagittal deformity. PSO has been used to treat not only the iatrogenic flatback but also sagittal plane deformities that have other causes in combination with coronal deformities. The simplest example is

degenerative scoliosis with significant loss of lumbar lordosis. Using wide releases and, if needed, a PSO can help correct these deformities from a posterior-only approach. We have primarily used PSO in patients who are undergoing revision surgery with fixed sagittal plane deformities. This technique has been used less frequently in revision surgeries of a combined coronal and sagittal plane deformity.

Preoperative planning

Long films for posteroanterior and lateral radiographs are mandatory. Supine anteroposterior and lateral radiographs are helpful. Supine radiographs help define the flexibility of the deformity in the sagittal and coronal planes. The amount of correction necessary can be reevaluated if the spine corrects significantly in the supine position. The rigid parts of the spine and the more flexible or compensatory parts of the spine can be identified in this manner. Bending radiographs also are performed in a supine position to gain the help of removing gravity and access any flexibility of the coronal deformities. In addition, a lateral radiograph while the patient is in supine hyperextension over a bolster is helpful in assessing the flexibility of the focal kyphotic segment of the spine. The hyperextension radiograph frequently reveals areas of nonunion in a patient with a previous attempt at arthrodesis, such as air in the disk space or angular correction between erect and supine radiographs. The preoperative planning includes measuring all the sagittal and coronal parameters. The sagittal parameters have to include the sagittal vertical axis, thoracic kyphosis, lumbar lordosis, pelvic incidence, pelvic tilt, and sacral slope. The analysis of these parameters helps determine the amount of correction needed in order to achieve sagittal balance.

Having MRI as well as computed tomography (CT) scans preoperatively allows the surgeon to be prepared for the complexity of revision surgery. Arachnoiditis can be found after spinal surgery with clumping of the cauda equina. The presence of arachnoiditis may be a prognostic indicator of subtotal improvement in lower extremity symptoms after decompression and should be discussed with the patient preoperatively. Stenosis, whether central or foraminal, can be defined properly and decompressed during surgery before performing the PSO. CT is helpful in outlining the bony landmarks and elucidating the extent of the fusion mass. The CT scan can be used for planning the placement of the spinal instrumentation such as pedicle screws. A CT scan after a myelogram is a useful tool in cases, for example, in which a patient who has claustrophobia cannot have MRI because of a pacemaker. In revision cases, it is essential to define the neural elements and the canal.

Surgical Technique

Patient positioning

PSO requires the patient to be in the prone position with bony prominences well padded and the abdomen free during surgery. The abdomen hanging free helps increase venous drainage away from the epidural plexus. The procedure lends itself to large blood loss because of the cancellous bone of the vertebral body as well as the disrupted epidural vessels during the procedure. A bed that reflexes is useful not only in the initial accommodation or positioning of the patient with kyphotic deformity but closing the wedge osteotomy in a controlled manner using the bed can be a useful technique. Using temporary rods and a bed that reflexes helps guide the closure safely and effectively.

Operative technique

First, adequate exposure is performed exposing all the previous instrumentation. Then, new pedicle screws are placed before performing PSO. Once instrumentation is in place, we proceed with laminectomy and removal of the posterior elements. The decompression laminectomy is performed from pedicles above and below the proposed pedicle resection. The nerve roots above and below are followed all the way out to the paraspinal muscles. Attention is then turned to removal of the pedicles. It is helpful to keep the medial part of the pedicle intact initially to protect the neural elements. The medial part of the pedicle acts as a nerve root retractor while the pedicles are removed and the resection of the body is performed.

The transverse process is removed. The lateral portion of the vertebral body is dissected with a Cobb elevator and a malleable retractor is placed on the lateral portion of the vertebral body. The pedicle is then cannulated as if a pedicle screw was being placed. Once adequate exposure of the lateral wall has been achieved, Leksell rongeurs are used to remove the lateral wall of the vertebral body to the level of the anterior cortex. The vertebral body is decancelled through the partially resected pedicles and lateral wall of the body by serially using larger curettes.

The next step requires resecting the posterior wall of the vertebral body. Often, it is necessary to use reversed angled curettes to thin the cortex enough to create a controlled fracture. Care must be taken to protect the anterior aspect of the dura and the posterior aspect of the vertebral body. Bipolar cautery can be used to coagulate

the epidural vessels before removal of the posterior wall of the vertebral body. Hemostasis is critical at this junction, using topical hemostatic agents such as Gelfoam, bone wax, and thrombin-soaked Cottonoids (particularly if there is bleeding form the epidural vessels). Remnants of the posterior cortex are then removed.

The next step involves closing the osteotomy in a controlled manner. Using a bed that has ability to reflex can assist. If a bed that reflexes is not available, hyperextension of the patient's chest and pelvis also aids in closing the osteotomy. In preoperative planning, we decide to correct for coronal plane deformities by adjusting the asymmetric closure of the osteotomy. Short rods to control our correction in a gradual manner are placed and tightened once the PSO is complete. The short rods help to stop the osteotomy from shifting and provide additional stability to the highest stress region around the pedicle subtraction site (**Figs. 2** and **3**).

VCR

VCR was performed first in cases of hemivertebrae resection. The resection was performed via an anterior approach followed by posterior resection of the posterior elements.[12] VCR was also described in treatment of rigid deformities with removal of the vertebral bodies from the anterior approach. Gelfoam was left on the dura and loose bone graft anteriorly. The posterior elements were then resected before achieving any correction.[13–15] Suk[16] recently described using the posterior-only approach for performing a VCR. Posterior VCR (PVCR) is being performed with more frequency than ever before.

Indications

The indications of VCR or PVCR are severe rigid deformities that are not amenable to correction with an anterior and posterior release alone. Disk space release is not adequate in achieving correction, and more shortening is needed for correction. Thus, a vertebral body has to be removed anteriorly and from the corresponding posterior elements to gain correction, to avoid residual deformity. Severe rigid scoliosis with a previous fusion posteriorly can be treated with an anterior and posterior VCR. However, there are circumstances in which the anterior approach is not possible (eg, in a patient with previous anterior and posterior fusion). In such cases, PVCR is a viable option. A severe sharp angular kyphosis is also easier to treat with PVCR, because it is difficult to reach the canal at the apex with an anterior approach (**Fig. 4**).

Preoperative planning

Preoperative planning includes a thorough medical workup to evaluate the cardiac and pulmonary status. Patients with severe curves can have associated pulmonary restrictive disease from the scoliosis as well as obstructive disease, which

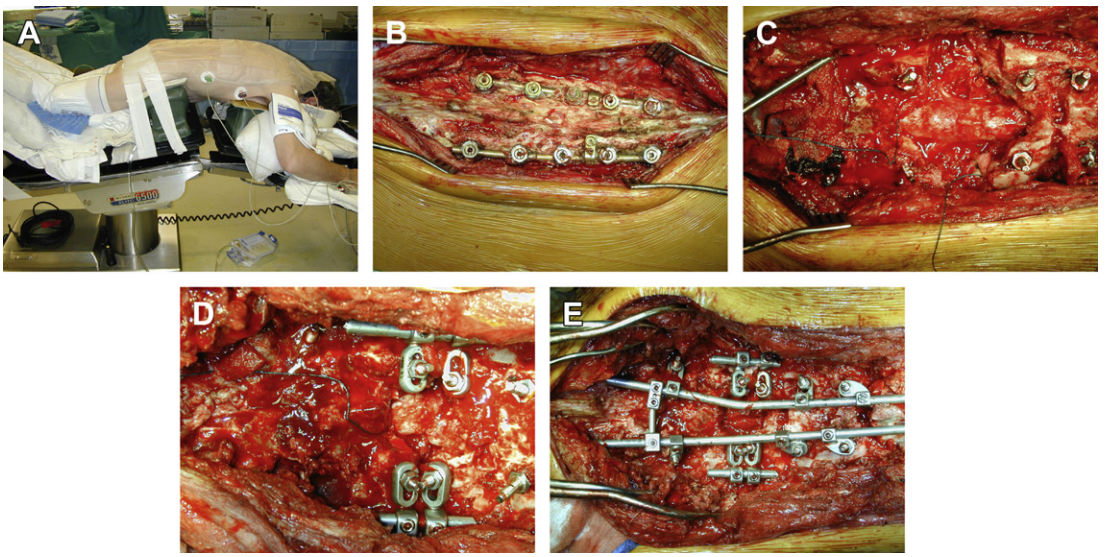

Fig. 2. (*A*) Positioning for PSO. (*B*) An example of an exposure of previous instrumentation and fusion. (*C*) After removal and reinstrumentation, wide decompression is performed from pedicle to pedicle, delineating 4 nerve roots. (*D*) After correction using the help of the operating room table and short rods. Notice the redundancy of the dural sac. (*E*) The longitudinal members are placed without disturbing the correction already obtained and secured with the short rods.

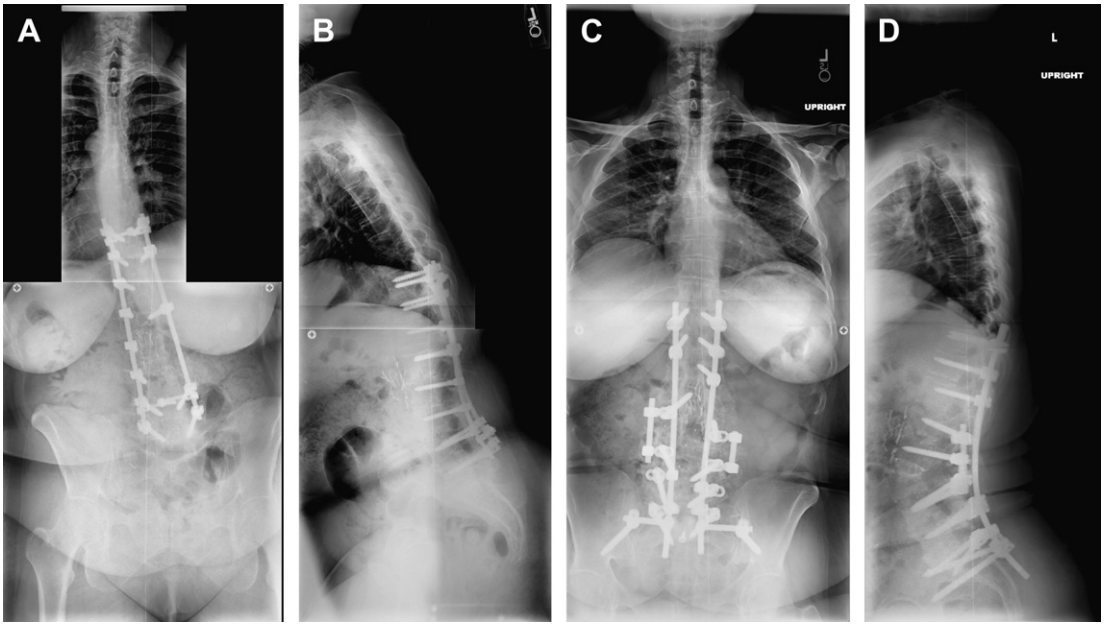

Fig. 3. (*A*) A rigid fusion after anterior and posterior fusion with instrumentation in coronal imbalance. (*B*) The patient has a severe positive sagittal imbalance after instrumentation and fusion. (*C*) Coronal balance obtained after PSO and extension to the pelvis. (*D*) Sagittal balance has markedly improved after PSO and extension to the pelvis.

is treatable. Beside the normal radiographs, as described for PSO, the use of additional studies such as MRI and CT can further delineate the anatomy and help in planning the resection and instrumentation. It is also possible to make a three-dimensional (3D) model in resin before the surgery. These models are helpful not only in operative planning of the resection but also in

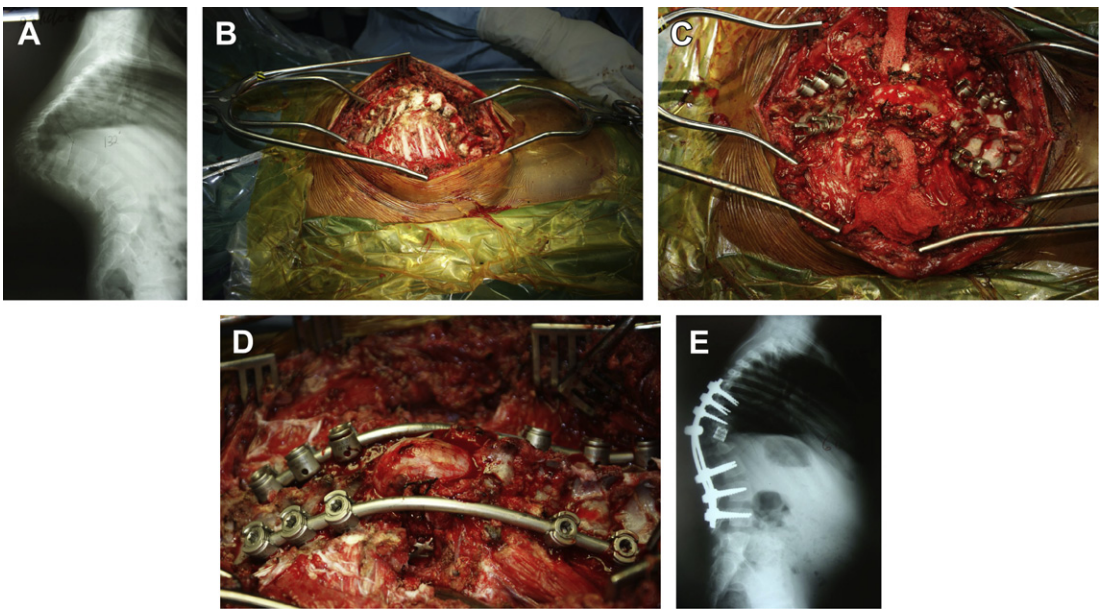

Fig. 4. (*A*) Posttuberculosis kyphosis resulting in a severe rigid deformity. (*B*) Exposure of the spine and rib cage for posterior VCR. (*C*) Ribs have been removed. Nerve roots had to be ligated. Anterior exposure has been performed, and vital structures protected with a sponge. (*D*) Correction of the kyphosis after resection and shortening. A cage has been placed anteriorly. (*E*) Correction of the kyphosis after PVCR kyphosis; improved but not perfect.

placing instrumentation. The models also help define the patient's congenital anomalies, which would be difficult to visualize from a CT scan. Anterior vertebral anomalies are sometimes not at the same level as posterior elements. For example, a hemivertebra at T4 in the thoracic spine may have redundant hemilamina of the posterior elements at the T5 level. The mismatch can occur anywhere in the spine. The 3D model not only makes it easy to visualize the anomalies clearly but also helps avoid resection of the unplanned levels.

Neuromonitoring is essential in performing these cases. Neuromonitoring is an early warning system that points out if there is a problem with spinal cord function. The warning can lead to adjustments to the correction and also to spinal cord perfusion parameters to prevent a devastating spinal cord injury. There are large savings in terms of the time if several wake-up tests are performed. The wake-up test is not as accurate as the neuromonitoring in testing spinal cord function.

Patient positioning

Positioning is lateral decubitus for an anterior approach if a VCR is being performed for the anterior portion of the resection, then prone for the posterior approach and resection. PVCR, which is all posterior, requires a regular operating table with a 4-poster frame or Jackson table. The table does not require a reflex function, as in PSO, because the correction is obtained from resection and sequential rod contouring.

Operative technique

PVCR is the most challenging osteotomy. The dissection of the spine requires not only a thorough posterior approach but also an anterior approach exposing the vertebral bodies that are to be removed. After the exposure is complete, the transverse process and ribs have to be removed. The more lateral the ribs are removed, the easier it is to reach the front of the spine safely. Usually, the ribs that are removed are above and below the vertebral body that is to be removed. For example, if a T4 vertebra has to be removed, the T4 rib is articulated with the T3 and T4 vertebrae or a high-speed burr. After the body has been mostly removed except the posterior cortex, temporary rods are used to stabilize the construct. The posterior cortex is then removed by using either a Kerrison or a reverse-angle curette.

The size of the cage to be put in place of the vertebral body is determined. The cage is then placed with local bone and allograft. The deformity is then corrected using compression, distraction, and in situ contouring. The rods are replaced sequentially as the correction is dialed into the rods. The spinal cord is assessed manually each time a correction maneuver is completed to ensure that there is no compression of the spinal cord or the nerve roots. After the final correction, the radiographs as well as the neuromonitoring are checked for transcranial motor-evoked potentials and somatosensory potentials from the upper and lower extremities. If there are any changes in neuromonitoring, a Stagnara wake-up test is performed. The hemodynamic parameters can be adjusted to ensure proper spinal cord perfusion.

After all the correction is achieved, the spinal cord is assessed to see if it is vulnerable by lying supine from the muscle and fascia. If the spinal cord is above the level of the instrumentation, a cross-link or a cage can be placed on top of the rod to protect the spinal cord.

IMMEDIATE POSTOPERATIVE CARE

Postoperative care usually requires admission to the intensive care unit. The patient may require blood products and ventilator support, as well as intravenous analgesia. If there were any neuromonitoring changes during surgery, the mean blood pressure should be kept higher than 80. Sometimes a dopamine drip is used to increase the blood pressure artificially for spinal cord perfusion. There have been reports of spinal cord compromise in the next few days after surgery as a result of lack of adequate perfusion of the spinal cord.

Mobilization of the patient is important to prevent deep venous thrombosis and pneumonia. An orthosis is seldom required for mobilization because of the pedicle screw segmental instrumentation.

REHABILITATION AND RECOVERY

The rehabilitation required is not different from other long segment spinal construct. The patient is usually asked to ambulate daily for 20 to 30 minutes. The precautions are: no driving for 6 weeks, no tub baths for 6 weeks, no repetitive bending and stooping, and refraining from lifting more than 13.6 kg (30 pounds). Children usually fare better than adults. Elderly patients usually require a transitional stay at a skilled nursing facility for 2 weeks before they can go home. After 4 to 6 weeks, children can go back to school. Adults feel better after about 3 months and feel much better about 1 year postoperatively.

COMPLICATIONS

PSOs have a significant complication rate of 35%, as reported by Auerbach and colleagues.[18] The

PSO complication rate was 38% and VCR, 22%.[13,16]

Transient neurologic deficit has been reported to range from 11.1 to 9.2% and major permanent neurologic deficit from 5.7 to 2.8%.[16,17] The VCR neurologic injury rate was 5.6%. Suk reported a neurologic deficit rate of 17%. There were only 2 complete cord deficits.

SUMMARY

Rigid deformities of the spine pose a challenge in achieving correction. The type of deformity, location of the deformity, presence of cord compression, hospital facilities, and surgeon experience help determine the approach used to correct that particular deformity. PSO and VCR should be used only when other simpler approaches are not possible.

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