

Review Paper

Tips and Pearls in Spinal Osteotomy



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ABSTRACT

Background and Aim: Spinal osteotomy is a general term for techniques applied to correct spinal deformity. The aims of osteotomy are to create a normal range of spine curvature, pain relief, and to improve the quality of life. In the cases where spinal deformities cannot be corrected using instrumentation alone or by facet or ligament release, the osteotomy is indicated. In spinal osteotomies, spinal alignment is corrected by removing part of the spinal bone. Osteotomies can be performed as anteroposterior or posterior-only procedures with a greater predilection for posterior-only procedures. Different types of osteotomy are available, including the Smith-Petersen osteotomy (SPO), Ponte osteotomy (PO), pedicle subtraction osteotomy (PSO), corner osteotomy (CO) or bone-disc-bone osteotomy (BDBO), vertebral column decancellation (VCD) and vertebral column resection (VCR).

Methods and Materials/Patients: In this narrative study, to provide up-to-date information, we precisely reviewed articles in the osteotomies context. Using the keywords spinal osteotomy, spinal deformity, Smith-Petersen osteotomy (SPO), pedicle subtraction osteotomy (PSO), vertebral column resection (VCR), vertebral column decancellation (VCD), Ponte osteotomy (PO), corner osteotomy (CO), all the relevant articles were retrieved from PubMed, Google Scholar, Medline, and critically reviewed and analyzed.

Results: In the spine surgery, osteotomy is performed to correct the deformity in uncorrectable spinal deformity. The suitable type of osteotomy is selected based on the etiology, type, and apex of deformity, surgeon's experience, availability of blood and bleeding control agents, and availability of intensive care. A wider acceptance of posterior-only procedures exists in osteotomy.

Conclusion: In spinal deformity surgery, more degrees of correction are needed for better cosmetic results, and for this purpose, spinal osteotomy has a central role. For this reason, all spine surgeons should be familiar with these osteotomy techniques.

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Highlights

- Osteotomy creates a normal range of spine curvature, relieves pain, and improves the patients' quality of life.
- In the cases where spinal deformities cannot be corrected using instrumentation alone or by facet or ligament release, the osteotomy is indicated.
- In spinal osteotomies, spinal alignment is corrected by removing part of the spinal bone and can be performed as anteroposterior or posterior-only procedures with a greater predilection for posterior-only procedures.

Plain Language Summary

Osteotomy has a central role in correcting the spinal deformity. More degrees of correction are needed for better cosmetic results in spinal deformity surgery and the osteotomy is essential to correct the deformity. Familiarity with osteotomy techniques is obligatory for all surgeons dealing with spine surgery.

1. Introduction

Spinal osteotomy corrects spinal deformity. Osteotomy is aimed at creating a normal range of spinal curvature and improving patient's quality of life by reducing pain. These osteotomy techniques are classified as posterior column osteotomy (PCO) (including Ponte osteotomy (PO) and Smith-Petersen osteotomy (SPO)), pedicle subtraction osteotomy (PSO), vertebral column decancellation (VCD), and vertebral column resection (VCR). To perform these posterior approach osteotomies, it is crucial to be familiar with spinal anatomy and a 3-dimensional anatomical component of the deformity [1-3]. In PCO, posterior elements are resected and the correction line is via the disc space with the lengthening of the anterior column. Recently, Schwab et al. [4], based on the extent of bone removal, classified spinal osteotomies into six grades:

- Grades 1 and 2 correspond to partial/complete removal of facet (SPO is grade 1 and PO is grade 2).
- Grades 3 and 4 correspond to PSO with or without resection of the neighboring discs.
- Grades 5 and 6 correspond to VCR (extended version of VCR into the adjacent disc space is grade 6).

From a nomenclature viewpoint, PO addresses the thoracic spine, generally for kyphosis with aggressive posterior resection, and SPO historically addresses the lumbar spine for ankylosing spondylitis. PSO is a SRS (scoliosis research society)-Schwab classification 3 in which the pedicles and wedged shape part of the body

are resected by shortening and compressing the posterior spine in its final stages in association with or without resection of the adjacent discs. In VCR, aggressive resection of the body of the spine is performed while preserving the anterior thin rim of bone to protect the great vasculature. In the cases with a sagittal imbalance to perform a good gradual correction of deformity, PCO can be used over multiple levels, or in cases with more complex deformity, PCO can be performed as a supplement at extra levels to acquire an appropriate correction. The amount of correction with a PCO level is about 10 degrees and for each 1 mm of bone removal, 1 degree of deformity correction is acquired. This is suitable for smooth gradual correction of deformity, such as Scheuermann Kyphosis. The best cases for PSO are the cases with a remarkable inflexible sagittal imbalance, and the best effect of PSO is at the apex of a sharp deformity. With each PSO level, about 30 degrees of deformity correction is acquired. The best candidates for VCR are cases with fixed multiplanar deformity, rigid coronal imbalance, hemi vertebra resections, and sharp angular deformities. VCR can obtain 35-60-degree deformity correction [5-7].

In cases with significant rigid deformity, a three-column osteotomy is effective, and in these cases, the patient's functional status, quality of bone, underlying disorders, and quality-of-life goals should be considered. For a safe and uncomplicated spinal osteotomy, the following can help neuromonitoring, somatosensory evoked potential, and spontaneous and triggered electromyography (EMG). The following complications can occur with osteotomy, including iatrogenic injury to the spinal cord and nerves, durotomy, infection, pseudomeningocele,



injury to the adjacent structures (such as pneumothorax, pleural effusion, large vessel injury, abdominal visceral injury), or medical complications (such as deep vein thrombosis, myocardial infarction, or pneumonia). Revision spinal operation increases these risks. After the operation, the patient should be followed up in terms of instrumentation failure and evolution of proximal junctional kyphosis [8-10].

2. Methods and Materials/Patients

To conduct this narrative study and provide up-to-date information on osteotomies, we precisely reviewed articles on osteotomies. Using the keywords of spinal osteotomy, spinal deformity, SPO, PSO, VCR, VCD, PO, corner osteotomy (CO), all the relevant articles were retrieved from PubMed, Google Scholar, Medline, and critically reviewed and analyzed.

3. Results

Different types of osteotomy and the major types are SPO, PO, PSO, CO or bone-disc-bone osteotomy (BDBO), VCD, and VCR. The results of the study on each osteotomy type in terms of indications, limitations, and pitfalls viewpoint are as follows.

Smith-Petersen osteotomy (SPO)

Smith-Petersen described SPO in 1945 as a monosegmental chevron or V-shaped osteotomy for the lumbar spine. The SPO is a type of PCO by removing posterior elements, such as posterior ligaments (supraspinatus, intra-spinous ligaments, and ligamentum flavum), bilateral facet joints, the inferior portion of the lamina, and the inferior portion of spinous process. In SPO, the correction line is through the disc space. SPO is indicated if the surgeon is not familiar with the more complex osteotomy types and is the least complicated procedure. If C7 plumb-line is positive in the range of 6 cm to 8 cm, SPO is applicable. In cases with the ossified anterior vertebral column that cannot be fractured by light pressure, osteoclasts is performed at the anterior disc space with the usage of a blunt tip osteotomy which is placed through the disc space at the level of osteotomy under the guidance of fluoroscope. After an assured osteoclasts, correction of the deformity is acquired by closing the posterior wedge and opening the anterior disc space. In an extensive SPO with more than 10 mm of anterior disc space opening with substantial correction, grafting of anterior disc space may be necessary. The amount of deformity correction with a SPO level is about 10° or with each 1 mm of bone removal, 1° of deformity cor-

rection is acquired (1° correction/1 mm bone removal). Sometimes surgeons consider modified SPO with more radical posterior column removal and anterior osteoclasts to create 30° of correction, especially in ankylosing spondylitis with the major risk of spine kinking and vascular complications. A gradual restoration of sagittal balance with less disruption of the anterior column can be performed in multilevel SPO, such as in ankylosing spondylitis, or in cases with more complex deformity, SPO can be performed as a supplement at extra levels to acquire an appropriate deformity correction [11-18].

Pitfalls can occur during Smith-Petersen osteotomy (SPO) as follows

- Epidural bleeding: This can occur during the resection of ligaments or facets, especially during superior facet resection. To stop bleeding, bipolar cautery is effective, if not, gelatin sponges packing usually stop bleeding but do not pack too much in the sponge to prevent cord compression.

- Nerve root impingement: Following facet resection, the height of compression foramina decreases, and nerve root impingement may occur. In this situation, in the presence of any neuro-monitoring abnormality, a wide facetectomy is the solution.

- Vascular injury: Risk of vascular injury following anterior column lengthening especially in cases with calcified major vessels, such as in elderly cases and ankylosing spondylitis cases.

- Superior mesenteric artery syndrome and consequent gastrointestinal complications

- Coronal decompensation: A trapezoidal wedge-type removal or performance of SPO at neutral and stable vertebra can cause future complications [11-18].

Ponte osteotomy (PO)

Alberto Ponte described PO in 1987, as a multilevel thoracic procedure for the treatment of non-rigid thoracic kyphosis or kyphoscoliosis patients. In PO, as a type of PCO, unfused facet joints, lamina, intraspinal ligaments, and ligamentum flavum are resected. PO is not a true osteotomy because it is performed in the unfused spine, but PO requires significant and specific bony removal to be effective so the fused versus the unfused status of the spinal segment is probably irrelevant. In PO, two types of osseous resection exist, narrow resection as an aggressive facetectomy and radical resection from

the pedicle to the pedicle. To create a smooth gradual transition between areas of maximum and minimum kyphosis, performing PO above and below more aggressive osteotomies may be useful [19, 20]. The following differences are present between PO and SPO:

- PO is routinely performed on the unfused spine with a mobile disc at each level and can be useful with a mobile anterior and middle column. PO is feasible in cases without any anterior bony bridge. In cases with a fine anterior bony bridge, osteoclasis should be performed with the breaking of the bony bridge, and in patients with a thick solid bony bridge, it should be released and PO converted to SPO.

- PO is routinely performed at multiple levels and creates a few degrees of correction for each level of osteotomy; therefore, multi-level osteotomies will be required for significant deformity correction. SPO can be performed as a single level or multiple levels.

- In PO, anterior column physiologic structures remain supported and undisturbed in contrast with the SPO, anterior column opening wedge effect [19, 20].

Disadvantages of multilevel PO are increased operative time, increased blood loss during operation, and increased blood transfusion [21].

Pedicle subtraction osteotomy (PSO)

Thomassen et al. described PSO in 1985. Heining's proposal was the 'eggshell' technique for bony resection and Thomassen's suggested the removal of the bone with an osteotomy. In PSO posterior elements, pedicles, and a triangular wedge through the pedicles are removed. In PSO, shortening of the posterior spine occurs and the anterior cortex acts as a hinge [22-25].

The suitable cases for PSO are the following cases [22-25]:

- Type 2 sagittal deformity and a significant sagittal imbalance of more than 12 cm (sagittal vertical axis >12 cm) with a sharp, angular kyphosis

- Multiple segments circumferential fusion, which prevents SPOs

- In rotation areas and prior laminectomy

- Asymmetric PSO can be done in type 1 coronal and type 2 sagittal imbalances which categorize osteotomy between PSO and VCR with an extensive removal on the convex side of the deformity.

The most useful region to perform PSO is at the apex of the deformity. PSO can be performed in all spine regions [25-27]. The real aim of PSO is to place the center of the C7 vertebral body on the posterosuperior aspect of the S1 vertebral body so that a plumb line passes through both [25-31].

PSO is performed in a prone position on a four-poster frame and in cases with severe kyphosis, two separate posters are used. To prevent pressure injuries on bony prominences, standard pressure injury facilities can be used. In ankylosing spondylitis cases with a completely fused spine, due to the risk of cervical spine fractures, do not exert pressure on the chin or forehead. Before any osteotomy attempt, instrumentation should be performed to prevent cord buckling. Pedicle screws are placed at three levels above and below the level of osteotomy and in cases with a thick fusion mass and obscuration of normal anatomy, one level above and below the osteotomy level can be placed in the fusion mass. A transient rod is placed to prevent sudden spinal collapse during the following steps. Buckling is a more severe problem in cases with prior laminectomy or laminotomy with peridural fibrosis due to the prevention of gliding movement of the dura during the closure of osteotomy gap. After instrumentation laminectomy is performed. For each level of laminectomy about 5 to 6 cm of exposure to dural and neural elements exposure is obtained. To widen the spinal canal from the inside and prevent ligamentum flavum and bony surfaces from infolding laminar undercutting, it should be done along with an extensive laminectomy. After the laminectomy is completed, the transverse processes are removed. Then half of the inferior and superior articular processes of the upper and lower vertebra are removed, respectively. Pedicles are bilaterally removed using an osteotome or a burr with precise protection of the nerve roots with their perineural fat tissue with a dural retractor and a single foramen is created. Then resection of the body in a wedge-shaped fashion is performed using the 'egg-shell' technique or an osteotome. To prevent sudden spinal collapse during these maneuvers, a transient unilateral rod is placed other than in severe angular kyphotic or kyphoscoliotic deformities where bilateral rods are placed to prevent spinal subluxation. In the final stage, the posterior and lateral wall of the vertebral body is removed. To close the osteotomy site, the nuts holding is loosened and the operating table bent opposite the deformity. The rods are acutely angulated as the spine at the level of osteotomy and should freely sit in the grooves of the screw heads. If the rod is not as acutely angulated as the spine in the cases with fused

spine above and below the osteotomy line (in ankylosing spondylitis or in previous fusion cases) loss of deformity correction occurs because the rod does not sit into the grooves and pulls the screws just above and below the osteotomy line [25-31].

Pedicle subtraction osteotomy (PSO) Has the following limitations:

-Regional lumbar lordosis increases about 30° up to 60° with PSO and 30° to 40° of correction of deformity can occur with single-level PSO.

-Restoration of global sagittal balance about 9-19 cm with a PSO level at L3 and for more correction L4 or to two-level osteotomy can be planned.

-VCR is a better choice than PSO in cases with kyphotic deformity more than 40° with a coronal imbalance (>6 to 8 cm).

The following pitfalls can occur with pedicle subtraction osteotomy (PSO):

-Bleeding: During PSO about 2 liters of blood may be lost, and the amount of bleeding in single-level PSO is about twice the amount of bleeding in three-level SPO.

-Transient neurological deficits: These deficits can occur in about 20% of patients with PSO. Strict adherence to the osteotomy technique, prevention of vertebral translation at the osteotomy level, and neuro-monitoring during the procedure, especially during osteotomy closure, can prevent these deficits [25-28].

-Pseudoarthrosis: This is a delayed complication. The chance of anterior fusion is higher than posterior mid-line fusion because in the anterior part, the osteotomy line is through the cancellous bone but in the posterior, laminectomy site and bony defect are observed. To prevent pseudoarthrosis in the cases of PSO with anterior fusion, interbody arthrodesis above and below the osteotomy as either a transforaminal lumbar interbody fusion (TLIF) or an anterior lumbar interbody fusion (ALIF) procedure is effective and in the cases of PSO with posterior fusion, closure of laminectomy sites with a cortical strut allograft is effective. In all cases with PSO, postrolateral fusion following transverse processes decortication should be performed [28-31].

-Infection: It occurs in 4% to 7% of cases. The number of prior surgeries, prior infection, amount of blood loss, increased operative time, and underlying diseases, such as insulin-dependent diabetes mellitus, chronic steroid

usage, and the use of TNF alpha-blockers, are effective factors in the occurrence of infection [28-31].

Bone-disc-bone osteotomy (BDBO) or corner osteotomy (CO)

In BDBO or CO, the disc with its adjacent end-plate(s) is removed with a correction rate of 35° to 60°. Instrumentation is performed two levels below and three levels above the planned osteotomy level. Above and below the disc space planned for removal, wide laminectomies are performed. This is followed by a wedge osteotomy is performed as the removal of the disc end-plate(s) with or without the pedicle(s). If desired anterior column lengthening is required, placing the anterior titanium mesh cage is effective and at the end, bone-to-bone closure of the osteotomy site is performed. CO has three types, type 1 CO-the wedge includes from the inferior border of the pedicle to the anteroinferior corner of the superior vertebra (at osteotomy site) plus disc plus superior end plate of the inferior vertebra, type 2 CO-the wedge includes from pedicle (all pedicle is removed) to anterosuperior border of the inferior vertebra plus disc plus inferior end plate of the superior vertebra, type 3 CO-the wedge includes from the inferior border of the pedicle to anteroinferior corner of the superior vertebra plus disc plus wedge from pedicle (all pedicle is removed) to the anterosuperior corner of the inferior vertebra. CO is indicated in deformities where the disc space is at the apex of deformity or the center of the rotational axis (CORA) and in severe sagittal plane deformities that need correction rates more than a simple PSO correction.

The advantages of corner osteotomy (CO) include:

- Deformity correction at its apex, especially if disc space is situated at the deformity apex.

- Pseudoarthrosis rate decreases due to disc removal and bone-to-bone closure of the osteotomy site.

- Better stability in type 1 CO due to the four pedicle screws placed in the vicinity of the osteotomy site.

- Comparable correction rates compared to other osteotomy types.

CO has the following limitations:

-In CO, you may need nerve sacrifice; however, the rate of nerve sacrifice is lower than posterior vertebral column resection (PVCR).

- Average correction in the sagittal plane after BDBO (CO) is between 38 to 49 degrees.
- In cases with ankylosing spondylitis and a calcified or ossified anterior annulus, CO is impossible or hard.
- Theoretical vascular damage can occur [31-33].

Vertebral column resection (VCR)

MacLennan described vertebrectomy as a posterior apical resection with post-operative casting for correction of severe scoliosis in 1922. Bradford described circumferential VCR in the late 1980s for severe non-flexible spinal deformity. The 1st investigator to perform PVCR was Suk with the idea that PVCR decreases total operation time and blood loss.

VCR indications are:

- Fixed multi-planar deformities
- Sharp angular deformities
- Hemivertebra resections
- Respectable spinal tumors
- Post-traumatic deformities
- Grade 5 spondylolisthesis

In the cases where the fixed coronal plane deformity is not adequately corrected with a posterior-based PSO, or anteroposterior procedure VCR is indicated. VCR is the only viable way in the hyperkyphosis deformity greater than 100 degrees of kyphosis [34-48].

The following pitfalls can occur with VCR:

- Difficulty in placing the cord: In VCR, it is difficult to identify the location and direction of the cord due to spinal rotation at the apex of deformity identification.
- Buckling of posterior longitudinal ligament (PLL): To prevent PLL buckling and following anterior cord compression, all bone anterior to PLL should be removed.
- Neurological deficit: Neurological deficit can occur due to spinal subluxation (most common cause), anterior column over-shortening and cord buckling, and dural buckling and cord compression. Supporting and lengthening of anterior column with a cage or changing the cage with a longer cage is effective in preventing an-

terior column over-shortening and subsequent neurological deficit. The risk of neurological deficits is higher in kyphotic deformities.

- Spinal instability before reduction: To prevent this, the temporary use of a rod is effective [34-48].

Vertebral column decancellation (VCD)

A research group described VCD as an operative procedure for deformity treatment in patients with a sharp angular deformity in 2011 [49]. VCD has many advantages and is an effective and excellent osteotomy technique for kyphotic deformities in AS or Potts disease. Angular spinal deformities have two main curve types, sharp angular deformity, and round angular deformity. In sharp angular kyphotic deformity, the anterior elements of the spine fail under compression and posterior elements fail under tension, after this increased eccentric loads, increased wedging, and deformity can occur with the appearance of pain and probable neurologic deficit [50].

In VCD, all pedicle screws were inserted 1st and after this probing and dilation on both sides of pedicles of the osteotomies vertebrae, the pedicle probe or drill was performed. Then to enlarge the pedicle holes, a special spacer was inserted. After this partial removal of the cancellous bone of the middle column, thinning of the anterior cortex, and thinning of lateral walls are performed via bilateral pedicle holes using a curette or high-speed drilling. After all of this laminectomy is done and the rods were bent and placed. Then with forceps or a Kerrison rongeur, the posterior wall of the vertebral body and the pedicle residual medial wall is resected. A "Y"-shaped osteotomy rather than a "V"-shaped osteotomy is performed by this point. After this, to close the osteotomy site, the operating table was gradually extended in association with the exertion of continuous pressure on the pedicle screws above and below the osteotomy and as a result, the middle column was closed. In the beginning, the hinge is located on the anterior column, and at the end, it is displaced to the middle column.

In sharp angular deformity after pedicle screw insertion above and below the level of the deformed vertebra, multilevel VCD must be performed and in kyphoscoliosis cases, the basic techniques are similar to those in sharp angular kyphosis other than for more coronal plane correction in the convex side in the same fashion. In round angular deformity, the anterior and middle columns are resected as less as possible for minimal shortening of the cord, and the osteotomy gap is resected as Y-shape rather than V-shape, if correction is not suf-

ficient following middle column gap closure, open the anterior column with an assistant of the operation table or spinal rod. The following pitfalls can occur in VCD, such as CSF leaks, transient neurological deficits, vascular laceration bleeding, infections, postoperative low back pain, spinal rod breakage, pedicle screws pull out and non-fusion [51-53].

5. Conclusion

In today's spine surgery, osteotomy has a central role in correcting spinal deformity. In spinal deformity surgery, more degrees of correction is needed for more reasonable cosmetic results and osteotomy is essential to correct the deformity. Familiarity with osteotomy techniques is obligatory for all surgeons dealing with spine surgery.

Ethical Considerations

Compliance with ethical guidelines

This article is a review with no human or animal sample.

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Authors' contributions

All authors cooperated equally in all stages of this review.

Conflict of interest

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