Osteotomies in the posterior-only treatment of complex adult spinal deformity: a comparative review

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In addressing adult spinal deformities through a posterior approach, the surgeon now may choose from among a variety of osteotomy techniques. The Ponte or Smith-Petersen osteotomy provides the least correction, but it can be used at multiple levels with minimal blood loss and a lower operative risk. Pedicle subtraction osteotomies provide nearly 3 times the per-level correction of Ponte/Smith-Petersen osteotomies but carry increased technical demands, longer operative time, and greater blood loss and associated morbidity. Vertebral column resections serve as the most powerful method, providing the most correction in the coronal and sagittal planes, but posing both the greatest technical challenge and the greatest risk to the patient in terms of possible neurological injury, operative time, and potential morbidity. The authors reviewed the literature relating to these osteotomy methods. They also provided case illustrations and suggestions for their proper application. (DOI: 10.3171/2009.12.FOCUS09259)

Key Words • spinal osteotomy • pedicle subtraction • vertebral column resection • Ponte • Smith-Petersen • adult deformity • posterior-only approach • kyphosis correction

Abbreviations used in this paper: PSO = pedicle subtraction osteotomy; pVCR = posterior vertebral column resection; SPO = Smith-Petersen osteotomy; SRS = Scoliosis Research Society; VB = vertebral body.

P eleterio-only approaches for the correction of adult kyphotic or kyphoscoliotic deformities have become increasingly common in recent years. The reason for this change in practice has been the advent of polysegmental 3-column fixation through the use of pedicle screws, as well as the use of posterior osteotomies to effect greater curve correction without the need for anterior releases or corpectomies. The status of surgical techniques and technology in adult deformity surgery is now such that essentially any kyphotic deformity can be addressed through a posterior-only approach, which obviates the morbidity of an anterior approach while obtaining equivalent correction to what a combined anterior-posterior approach can provide.

The surgeon treating patients with kyphotic deformities must be versed in the relative merits of the various osteotomy techniques. Three major techniques are currently used for the posterior-only correction of kyphotic deformities in adults as follows: Ponte or Smith-Petersen osteotomy (SPO), PSO, or pVCR. The indications, surgical techniques, anatomical characteristics, kyphotic correction afforded, complications, outcomes, and relative benefits of each osteotomy technique will be described in turn, with an illustrative case provided for each.

Ponte or Smith-Petersen Osteotomy

Although it is a commonly used osteotomy technique, much confusion surrounds the nomenclature and technique of the Ponte or Smith-Petersen osteotomy. Smith-Petersen and colleagues first described the technique of posterior element osteotomy and posterior compression. In this technique, they used the disc space as a fulcrum to effect anterior column lengthening and posterior column shortening in the treatment of flexion deformities in individuals with “rheumatoid arthritis” and autofused (that is, ankylosed) spines. This method involved violation of the anterior longitudinal ligament and entailed significant risk of injury to vascular structures anterior to the spine. Hehne et al. also described a “polysegmental lordosis osteotomy” with resection of a portion of the posterior elements at each level, producing a per-segment correction of about 10°. More recently, Ponte et al. further elaborated on the use of wide segmental osteotomies and posterior compression along unfused regions of the kyphotic deformity in patients with Scheuermann kyphosis. Although the description by Ponte et al. more directly captures the technique most commonly used today for...
### TABLE 1: Osteotomy techniques for treatment of deformity*

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>No. of Patients</th>
<th>Average OR Time (minutes)</th>
<th>Mean EBL (ml)</th>
<th>Neurological/Overall Complication Rate (%)</th>
<th>Kyphosis Correction at Final Follow-Up (°)</th>
<th>Sagittal Balance Correction at Final Follow-Up (cm)</th>
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<td></td>
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<td></td>
<td>SPO (per level)</td>
<td>PSO (per level)</td>
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<tr>
<td>SPO (per level)</td>
<td>PSO (per level)</td>
<td>VCR (coronal/ sagittal plane)</td>
<td>SPO</td>
<td>PSO</td>
<td>VCR</td>
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<tr>
<td>Cho et al., 2005</td>
<td>30 SPO, 41 PSO</td>
<td>756 726</td>
<td>1392 2617</td>
<td>3.3/46.6†</td>
<td>7.3/58.5†</td>
<td>10.7 31.7</td>
</tr>
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<td>Geck et al., 2007</td>
<td>17 SPO</td>
<td>270 808</td>
<td>0/29.4</td>
<td>9.3</td>
<td></td>
<td></td>
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<tr>
<td>Lehmer et al., 1994</td>
<td>38 PSO</td>
<td>294 1850</td>
<td></td>
<td>19.5/51.2†</td>
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<tr>
<td>Danisa et al., 2000</td>
<td>11 PSO</td>
<td>36.4/54.5</td>
<td></td>
<td>40.1</td>
<td></td>
<td></td>
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<tr>
<td>Berven et al., 2001</td>
<td>13 PSO</td>
<td>30.8/69.2†</td>
<td></td>
<td>29.9</td>
<td></td>
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<tr>
<td>Chen et al., 2001</td>
<td>78 PSO</td>
<td>225 1150</td>
<td>1.3/14.1</td>
<td>34.5</td>
<td></td>
<td></td>
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<tr>
<td>Kim et al., 2002</td>
<td>45 PSO</td>
<td></td>
<td></td>
<td>11.1/NR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Murrey et al., 2002</td>
<td>37 PSO</td>
<td>2874</td>
<td>NR/16.9</td>
<td>25</td>
<td></td>
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<tr>
<td>Bridwell et al., 2003‡</td>
<td>27 PSO</td>
<td>744‡ 2396‡</td>
<td>3.6/14.5</td>
<td>34.5</td>
<td></td>
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<tr>
<td>Bridwell et al., 2003‡</td>
<td>66 PSO</td>
<td>732 2386</td>
<td>7.6/48.5†</td>
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<td>Lazenec et al., 2006</td>
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<td>1850</td>
<td>15.4/61.5†</td>
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<td>250 3800</td>
<td>0/18.1</td>
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<td>35 PSO</td>
<td>948 5800</td>
<td>3.6/14.5</td>
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<td>Buchowski et al., 2007</td>
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<td>2874</td>
<td>NR/16.9</td>
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<td>Ikenaga et al., 2007</td>
<td>67 PSO</td>
<td>277 1988</td>
<td>8.9/40</td>
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<td>Mummaneni et al., 2008</td>
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<td>180 2450</td>
<td>5.5/25†</td>
<td>4.9</td>
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<td>Klaer &amp; Gehrchen, 2009</td>
<td>36 PSO</td>
<td></td>
<td></td>
<td>10/70</td>
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<td>Kawahara et al., 2001</td>
<td>7 VCR**</td>
<td>576 2386</td>
<td>0/NR</td>
<td>NR/49</td>
<td></td>
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<tr>
<td>Suk et al., 2002</td>
<td>70 VCR</td>
<td>27† † † 2604† † †</td>
<td>17/34</td>
<td>61.9/45.2</td>
<td></td>
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</tr>
<tr>
<td>Suk et al., 2005</td>
<td>25 VCR</td>
<td>280 2810</td>
<td>23.40</td>
<td>4.7</td>
<td></td>
<td></td>
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<tr>
<td>Lenke et al., 2009‡</td>
<td>35 VCR (peds)</td>
<td>460 691</td>
<td>11.4/40</td>
<td>36/36</td>
<td></td>
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</tr>
<tr>
<td>Lenke et al., 2009‡</td>
<td>43 VCR</td>
<td>577 1103</td>
<td>NR/48.8</td>
<td>50/59</td>
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<td>Wang et al., 2008</td>
<td>13 multi-VCR</td>
<td>266 2411</td>
<td>15.3/30.7</td>
<td>33.7/53.9</td>
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<td></td>
<td>580 341 385 1181 1831 1928</td>
<td>2.1/40.4</td>
<td>9.1/38.5</td>
<td>14.3/39</td>
<td>10.2 32.6</td>
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</table>

* EBL = estimated blood loss; NR = not reported; peds = pediatric patients.
† This value represents total complications divided by total number of patients; some patients experienced multiple complications.
‡ Some procedures involved 2 stages.
§ Estimated.
¶ Includes thoracic and lumbar PSOs.
** “Closing-opening wedge osteotomy.”
†† Average extrapolated from data in paper.
posterior column osteotomies, the name Smith-Petersen osteotomy seems to have taken hold to describe the spectrum of posterior column osteotomies and will be used in this manuscript.

Surgical Technique

The technique typically involves removal of the posterior ligaments (supraspinous, intraspinous, and ligamentum flavum) and facets to produce a posterior release, thereby aiding in coronal correction and sagittal plane realignment. Compression of the osteotomy brings about kyphosis correction, although it does require a mobile disc space anteriorly. Additionally, compression leads to contraction of the neural foramina to prevent nerve root impingement. As previously noted, although some descriptions depict the method as resulting in correction through rupture of the anterior tension band and resultant profound anterior lengthening, this is not how the procedure is commonly used; rather, the disc space typically compresses posteriorly and expands anteriorly with a fulcrum between. Anything more would present a significant risk of vascular or gastrointestinal complications, as noted in the literature on extension osteotomies.

Indications for Surgery

The classic indication for an SPO would be a long, gradual, rounded kyphosis as in Scheuermann kyphosis. The degree of kyphotic correction afforded by an SPO has been reported to be in the range of 9.3–10.7° per level, with another general guideline being 1°/mm of bone resected. Because these osteotomies could practically be used at every level within a fusion construct, they lend themselves to powerful correction globally across a kyphotic segment; for focal regions of kyphosis, however, other osteotomies may be more appropriate. Other common indications for the technique include application along the apex of a rigid coronal curve to enhance curve flexibility and correction. Furthermore, the technique may contribute to greater technical ease and speed when
used in conjunction with thoracic pedicle screw placement, as the osteotomy creates a window through which the pedicles can be palpated for more confident screw insertion.\textsuperscript{44}

With respect to safety and efficacy, SPOS compare favorably with other osteotomy techniques. Blood loss tends to be less with SPOS. Cho et al.\textsuperscript{9} found that using at least 3 SPOS (to achieve a comparable degree of correction with a single PSO) resulted in an average blood loss of 1392 ml, versus nearly twice as much for a PSO (2617 ml). In that same study, no difference was noted in fusion rates or the ODI, although patients undergoing PSO experienced greater sagittal plane imbalance correction ($\equiv$ 3 SPOS 5.49 $\pm$ 4.5 vs PSO 11.19 $\pm$ 7.2 [p < 0.01]) and reduced risk of coronal decompenstation. Further data on the safety and efficacy of the technique came from a study by Geck et al.,\textsuperscript{24} in which the authors successfully treated 17 patients using a posterior-only approach and Ponte osteotomy, achieving an average correction of 61\% of kyphosis across instrumented levels and 49\% for the largest Cobb angle, with no reoperations for pseudarthrosis/instrumentation failure; they reported 1 proximal junctional kyphosis and 1 distal junctional kyphosis that were essentially asymptomatic, 1 late wound infection, and 2 minor, transient, nonneurological complications.

Overall, the SPO is a versatile technique that can be performed safely and rapidly to aid in the correction of gradual kyphotic or scoliotic curves. Compared with the PSO, the SPO offers a reduction in operative time, blood loss, and risk of neurological complications, but it has the drawbacks of reduced sagittal plane correction, possibly a greater likelihood for coronal decompensation, reduced effectiveness for sharp, angular kyphoses, and inapplicability when the disc space lacks flexibility. A collection of recent published findings relating to the SPO can be found in Table 1.

Illustrative Case

Case 1. This 17-year-old boy had a history of Scheuermann kyphosis with an 84° thoracic kyphosis. At the age of 15 years, he underwent a T4–L1 video-assisted thoracoscopic fusion with a hybrid hook/rod construct. He suffered instrumentation failure with screw pullout at the distal end, which was revised with laminar wiring; this construct also failed, and he developed an infection requiring instrumentation removal. He then was referred with a progressing 115° of thoracic kyphosis that bent out to 90° when he was lying supine over a hyperextension bolster (Figs. 1 and 2A and B). He underwent a T2–L2 instrumented fusion with a posterior-only, pedicle screw construct as well as a total of 9 apical SPOS. Five years postoperatively, he has maintained correction at 47° of thoracic kyphosis with evidence of solid fusion at all levels (Figs. 2C and D and 3).

Pedicle Subtraction Osteotomy

Surgical Technique

Pedicle subtraction osteotomy was first described by Thomasen in 1985.\textsuperscript{22} Like the SPO, the PSO has been called by various names, including transpedicular wedge procedure, closing wedge osteotomy, and eggshell osteotomy, which are used more or less interchangeably throughout the literature. The technique involves removal of the posterior ligaments and facets—as though one were performing an SPO—followed by resection of the pedicles and decancellation of a wedge of the VB via a transpedicular corridor. More aggressive resections include the disc space above the decancellated segment. Following the osteotomy, closure occurs in a wedge fashion, which brings about kyphosis correction through posterior shortening. This closure also creates a large contact area of cancellous bone, which proves beneficial for fusion of the PSO body (although the effect on fusion at neighboring levels remains less clear). If performed in an asymmetric fashion, the osteotomy can also lead to significant coronal correction.

Indications for Surgery

The indications for a PSO overlap somewhat with the use of multiple SPOS, but they diverge in key ways. Typically, the PSO is used for patients with sharp or angular kyphosis, as well as at levels lacking anterior flexibility at which effective SPOS would be precluded.\textsuperscript{4} Furthermore, patients with greater than 10 cm of sagittal imbalance would be more likely to benefit from a PSO than SPOS.\textsuperscript{4,9} A PSO may be of particular use in the treatment of lumbar flat-back syndrome in which significant lumbar kyphosis can be safely treated, and because of the long moment arm of the resultant sagittal rotation, a tremendous degree of correction in sagittal balance can be obtained.

Numerous recent cadaveric, radiographic, and clinical studies have evaluated the degree of deformity correction one can produce with a PSO. In a cadaveric model, Li et al.\textsuperscript{28} obtained 36.4° of kyphotic correction with a standard decancellation closing wedge osteotomy, versus 48.5° for modified closing wedge osteotomy involving resection of part of the superior endplate of the decancellat-
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Clinical studies to date have shown relative uniformity for the degree of kyphosis correction obtained at the osteotomized level, ranging from 26.2° to 40.1° with an average of 32° across recent studies, although the expected correction is likely less for the thoracic spine. Additionally, Ondra et al. have created a mathematical model to determine the degrees of correction needed via PSO in the lumbar spine to bring a patient back into proper sagittal balance.

Outcomes After Surgery

Several recent studies have also highlighted outcomes from PSO procedures. A study by Bridwell et al. in 27 patients who underwent PSOs for fixed sagittal imbalance showed highly significant improvements in final postoperative sagittal balance (from 17.74 ± 7.95 cm to 4.23 ± 6.73 cm, p < 0.0001), thoracic kyphosis (from 21.59 ± 18.37° to 31.70 ± 16.58°, p < 0.0001), lumbar lordosis (from −14.52 ± 21.82° to −48.63 ± 19.01°, p < 0.0001), and height (from 156.87 ± 8.18 cm to 160.30 ± 7.09 cm, p < 0.0001). Patients also experienced significant improvements in pain scale scores (from 6.96 to 4.41, p = 0.0002) and the ODI (from 51.21 to 35.75, p < 0.0001). Early complications varied in severity and were associated with patient comorbidities. Late complications included 1 case of neurogenic urinary retention and 7 pseudarthroses (all but 1 occurred either cephalad or caudal to the site of the PSO procedure, and none when a PSO was used through the site of a previous fusion mass). The neurological complication rate was 3.7%, with no permanent deficits. In expanding this group of patients who had undergone PSO to 66 patients (33 with 2 or more years of follow-up), Bridwell et al. found a 7.6% rate of transient neurological complications, all of which improved; meanwhile these patients had significant improvements in pain scale, ODI, and SRS score outcomes. When follow-up was extended to 5 years in 35 patients, SRS scores and the ODI remained statistically unchanged, as did radiographic measures such as proximal junctional change, thoracic kyphosis, lumbar lordosis, and global sagittal balance—although a trend toward an increasingly anterior sagittal vertical axis was noted. A more extensive complication review by the same group in 2007 showed that, in 108 adults treated with PSO for kyphotic deformity, the rate of intraoperative and postoperative neurological deficits was 11.1%, with a 2.8% rate of permanent deficits. However, the ODI still improved in the study population (from 51.5 ± 16.2 to 29.5 ± 18.7, p < 0.001), as did SRS-22 scores (from 48.4 ± 15.3 to 71.2 ± 15.3, p < 0.001). Of note, none of the neurological complications were predicted by intraoperative monitoring, thus emphasizing the importance of performing a wake-up test before leaving the operating room.

Other centers have noted similar effectiveness and complication rates with PSOs. An early report by Lehner et al. in 38 patients with either posttraumatic or iatrogenic deformity showed a 19.5% rate of new neurological deficits, including a case of permanent paraplegia, although 76% of patients were satisfied enough to state that they would repeat the surgery. In a more recent study of PSO in 45 patients with ankylosing spondylitis and a minimum 5-year follow-up, neurological complications occurred in 11.1% while sagittal imbalance improved from 9.4 to 0.8 cm, and the modified Abnormal Involuntary Movement Scale (AIMS) assessment improved significantly. Another review of 59 transpedicular “eggshell” osteotomies (37 for deformity) showed a 16.9% overall complication rate but no cases of neurological worsening. Significant improvement was noted in pooled 36-Item Short Form

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Health Survey scores, and 74.1% of patients were “completely satisfied” with the surgery. A somewhat higher rate of complications was noted by Ikenaga et al.18 of 67 patients who underwent PSO for thoracolumbar kyphosis, 27 (40%) had some type of complication. There were 48 total complications, including 7 pseudarthroses and 6 neurological complications (2 hematomas requiring re-operation) for a neurological complication rate of 8.96%. High complication rates were also found in a study by Mummaneni et al.,32 with 70% of those in a 10-patient PSO cohort experiencing some major or minor perioperative complication; this study highlights an important point, however, which is that this subset of patients carries many medical comorbidities (90% in this cohort) and frequently has undergone multiple revision surgeries (80% in this cohort), both of which can contribute to worse operative outcomes.

Although the aforementioned studies focused largely on the use of PSOs in the lumbar spine, the technique may also be effective in the thoracic region. A study by Yang et al.48 compared lumbar and thoracic PSOs for fixed sagittal imbalance and found no difference in outcomes between the 2 groups for modified Prolo scale scores or SRS-22 scores. Here again, there is a fairly high early and late complication rate ranging between 10 and 30% for the thoracic and lumbar cohorts.

Overall, PSO offers several benefits with respect to other osteotomy choices. First, it addresses focal kyphosis more effectively than SPO, although not as effectively as a VCR.19,44 Furthermore, the ability to perform an asymmetric bone resection may aid in the attainment of coronal correction. A PSO may also be particularly useful in addressing sagittal imbalance, especially when used in the lumbar spine to recreate lordosis and restore the C-7 plumbline over the sacrum. However, these benefits do not come without associated drawbacks. Most notably, the PSO procedure is more technically demanding and carries with it greater operative time and blood loss than the SPO. Multiple studies have also shown a rather high complication rate following PSO procedures, which, although they may not result directly from the technique itself, highlight the medical fragility of this subset of patients in whom prior procedures and a multiplicity of comorbidities lead to a propensity for perioperative difficulties. Please refer to Table 1 for a collection of recent published findings relating to PSO.

Illustrative Case

Case 2. At the age of 23 years, this 42-year-old woman suffered a flexion-distraction injury that resulted in an 88° thoracolumbar kyphosis. At that time she underwent an instrumented fusion via an anteroposterior approach, with correction to 59° of thoracolumbar kyphosis. In the intervening years, she underwent implant removal and ultimately had progression of her kyphosis to 105° with a sagittal balance of +5 cm (Fig. 4A). Meanwhile she complained of symptoms of neurogenic claudication, and an MR imaging study (Fig. 5) demonstrated her lumbar nerve roots draped anteriorly over the posterior aspect of the vertebrae at the apex of the curve. Because her kyphosis was focal and largely centered over the L-2 VB, she underwent posterior spinal fusion with an L-2 PSO. This was followed by a second-stage anterior spinal fusion due to extension of the fusion to her sacrum. At the 5-year follow-up, her thoracolumbar kyphosis was reduced to
40°, and her sagittal balance was restored to 0 cm (Fig. 4B). Preoperative and postoperative clinical photographs are depicted in Fig. 6.

Vertebral Column Resection

Surgical Technique

Although vertebral corpectomy has been used for the treatment of scoliosis for many years, the procedure known currently as pVCR has only recently been promoted by Suk et al. as an option for posterior-only deformity correction. The procedure involves the resection of all posterior elements, the facet joints at the levels above and below, and essentially the entire VB and supra-adjacent/subjacent discs. The spine is then disarticulated, and the proximal and distal limbs are slowly brought together. In most cases, an anterior fusion is performed with structural support via an anterior cage in all cases; this allows

Fig. 7. Case 3. Preoperative standing anteroposterior (A), preoperative standing lateral (B), postoperative standing anteroposterior (C), and postoperative standing lateral (D) 36-inch radiographs. A 2-level VCR enabled profound correction of a very severe kyphoscoliosis. sac = sacrum.

Fig. 8. Case 3. Preoperative (A and B) and postoperative (C and D) clinical photographs.
for relative anterior lengthening, perhaps through the use of an expandable cage implant, which enhances the degree of correction. Kawahara et al. have also described essentially the same technique as involving a closing-opening wedge osteotomy, which is to say that a kyphotic deformity is reduced by resection of the vertebra through a costotransverse approach, followed by “closing” of the gap with posterior compression and then “opening” of the anterior column with cage insertion. In any case, the aggressive VCR technique provides tremendous potential for deformity correction.

Posterior VCR primarily finds use in the thoracic and thoracolumbar spine for the treatment of sharp, angular kyphotic deformity. Other indications include the resection of hemivertebrae or intravertebral spinal tumors, or even, as has recently been described, the shortening of the spine proximal to a tethered region as a novel method of treating tethered spinal cord without the risks of dissection around adhesed nerve roots.

Outcomes After Surgery

Studies of pVCR to date have demonstrated it to be a powerful method of focal deformity correction. Suk et al. noted a correction of 61.9° in the coronal plane and 45.2° in the sagittal plane in their series of 70 patients with adult scoliosis, congenital kyphoscoliosis, and postinfectious kyphosis. In a series of 35 children, Lenke et al. noted major curve improvements that averaged 61° (51%) in scoliosis cases, 56° (55%) in global kyphosis cases, 51° (58%) in angular kyphosis cases, and 24° (60%) in congenital scoliosis cases; in a slightly larger series of adults and children, the average major curve improvements were 57° (69%) for scoliosis, 45° (54%) for global kyphosis, 49° (63%) for angular kyphosis, and a combined 109° (56%) for kyphoscoliosis.

Despite its effectiveness, however, pVCR poses significant operative times and blood loss, and its use can be fraught with complications. Reported operative times have ranged from 266 to 577 minutes, and blood loss has ranged from 691 to 2810 ml for this technique. Regarding complications, in a series of 70 patients, Suk et al. found a 34.3% overall rate of complications and a 17.1% rate of neurological complications; however, half occurred intraoperatively and were noted during osteotomy closure with loss of monitoring data, allowing for reparative measures that

Fig. 9. General algorithm for decision making in osteotomy selection. Surgeon experience and good medical status of the patient are 2 prerequisites to proceeding with advanced osteotomy techniques. A gradual, sweeping kyphosis favors an SPO or PSO, with the latter preferable in cases with severe positive sagittal balance. A mobile disc space is required for SPOs. For sharp or focal kyphoses, VCRs are typically used in the thoracic spine and PSOs in the lumbar spine. However, individual patient characteristics and surgeon judgment must supersede any general algorithmic approach.
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prevented subsequent deficits, thereby highlighting the importance of neuromonitoring during these cases. Finally, a recent study by Wang et al.\textsuperscript{45} reported on 13 adults with severe rigid kyphoscoliosis who underwent a modified combined multilevel eggshell osteotomy and pVCR. These authors found a 30.7\% rate of complications and a 15\% rate of temporary neurological complications. They did, however, note substantial improvements in postoperative pain and SRS-24 scores at 2-year follow-up.

Overall, pVCR appears to be the most powerful posterior osteotomy method, but it carries a significant risk of complications, including potentially permanent neurological lesions. It also likely entails longer operating room time and blood loss than less invasive osteotomy techniques. This method, as emphasized by multiple authors, should be used at high-volume centers by surgeons highly experienced with the technique, and even then patients and families must be counseled to expect a difficult perioperative course. That being said, success with vertebral column resection can be optimized by following several key principles: There is no reason for a circumferential approach; more severe sagittal deformities thrust the anterior portions of the spine further posteriorly, thereby optimizing the anatomy for a posterior VCR approach. Stable pedicle screw fixation above and below is vital. A posterior VCR allows 360° access to the spinal cord to confirm/obtain decompression. From the standpoint of neurological risk, pVCR is safer for severe scoliosis than kyphosis/kyphoscoliosis. It is imperative to use somatosensory evoked potential or motor evoked potential monitoring throughout the period of correction, as well as to maintain normotension with mean arterial pressures of at least 75 to 80 mm Hg during osteotomy closure. Temporary rod placement must precede a pVCR to avoid potential catastrophic intraoperative subluxation. Placement of an anterior structural cage prevents buckling of the spinal cord and excessive segmental shortening. Extensive laminectomy one level above and below the VCR area is necessary to avoid spinal cord impingement. Rib struts can serve as “bridge grafts” to provide a bony surface for fusion over the laminectomized region following osteotomy closure. Table 1 contains a collection of recent published findings relating to VCR.

Illustrative Case

Case 3. This 20-year-old man had a history of congenital kyphoscoliosis for which he had undergone fusion in situ as a child. He presented many years later with a severe, progressive deformity with a rigid main thoracic curve with 124° of scoliosis in the coronal plane and 144° of kyphosis in the sagittal plane. He underwent VCR at T-8 and T-9 with posterior spinal fusion from T-2 to L-4. On the 2-year follow-up radiographs, reductions were noted in the main thoracic coronal curve to 62° and sagittal curve to 65° (Fig. 7). Preoperative and postoperative photographs are shown in Fig. 8.

Conclusions

The addition of several osteotomy techniques to the surgeon’s armamentarium, along with the advent of 3-column posterior pedicle screw fixation, have made it such that essentially all kyphotic deformities can be treated via a posterior-only approach. A general algorithm for the selection of osteotomy techniques is provided in Fig. 9.

An understanding of the relative merits of each of the osteotomy techniques is imperative so that the deformity surgeon can use these methods to greatest effect. It is equally imperative, however, to respect the great potential for complications, even catastrophic neurological events, when these techniques are used.

Disclosure

The senior author (L.G.L.) maintains financial relationships with Medtronic (consulting, royalties, and research), DePuy (research), and Medtronic (consulting, royalties, and research), and Axial Biotech (research).

Author contributions to the study and manuscript preparation included the following: Conception and design: IG Dorward, LG Lenke. Drafting the article: IG Dorward. Critically revising the article: IG Dorward, LG Lenke. Reviewed final version of the manuscript and approved it for submission: LG Lenke. Administrative/technical/material support: IG Dorward. Study supervision: LG Lenke.

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