Change in Cobb angle of each segment of the major curve after posterior vertebral column resection (PVCR): a preliminary discussion of correction mechanisms of PVCR

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Abstract

Introduction Posterior vertebral column resection (PVCR) is an effective technique for treating severe rigid spinal deformities, and no other osteotomy is capable for such an excellent corrective effects. The purpose of this study was to discuss the correction mechanisms of PVCR.

Materials and methods Forty-six patients with severe rigid spinal deformities undergoing PVCR were retrospectively analyzed. According to a routine posteroanterior supine entire spine radiograph performed before and after surgery, the major curve at coronal plane was divided into three segments factitiously: upper segment (from the superior endplate of the upper vertebra of the major curve to the inferior endplate of the upper vertebra adjacent to the resected vertebra), middle segment (from the inferior endplate of the upper vertebra adjacent to the resected vertebra to the superior endplate of the lower vertebra of the resected vertebra), and lower segment (from the superior endplate of the lower vertebra of the resected vertebra to the inferior endplate of the lower end vertebra of the major curve). Cobb method was used to measure the curvature of the major curve and each segment. We analyzed the changes of the Cobb angle in the major curve and each segment. We also analyzed the correlation between the placement of pedicle screws and deformity correction.

Results The Cobb angle of the major curve decreased from $110.1 \pm 18.1^\circ$ to $51.0 \pm 17.3^\circ$ ($p < 0.05$) after surgery (decreased by $59.1 \pm 16.4^\circ$), the mean correction rate was $54.1 \pm 12.2\%$ ($p < 0.05$). The Cobb angle of the middle segment decreased by $28.1 \pm 14.7^\circ$ ($p < 0.05$), the

contribution rate was $49.1 \pm 27.3\%$. The upper and lower segments decreased by $15.7 \pm 13.1^\circ$ and $15.3 \pm 12.4^\circ$, respectively ($p < 0.05$). There were no significant differences in the contribution rate between upper and lower segments ($25.2 \pm 16.6\%$ vs. $26.3 \pm 22.6\%$) ($p > 0.05$). 22 patients were instrumented with at least one pedicle screw in the adjacent upper and lower vertebrae of the resected vertebra and gained a better corrective effect in comparison with the others ($p < 0.05$). The data also indicated that deformity correction was closely related to the numbers of the pedicle screws ($r = 0.82$, $p < 0.05$).

Conclusion In conclusion, the middle segment offered the highest contribution rate to the deformity correction of the major curve, but at the same time the spinal cord was angulated in this segment. So, it is dangerous to gain too much deformity correction in the middle segment. Because spine would shorten and the tension in spinal cord would decrease after vertebral column resection, a better correction effect could be gained in upper and lower segments at a low risk of spinal cord injury. But it was actually too hard for such rigid spinal deformity. It could gain a better corrective effect and stability by placing more pedicle screws at major curve, especially at the upper and lower vertebrae adjacent to the resected vertebra, but sometimes it was difficult to place enough pedicle screws in severe rigid spinal deformities.

Keywords Spinal deformity · Posterior vertebral column resection · Major curve · Cobb angle

Introduction

The treatment of spinal deformity has been a major problem for orthopedic surgeons so far. Even now orthopedic

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devices and technique have got a great development, it remains a obstacle to get a satisfied curative effect for those with severe rigid spinal deformity.

Vertebrectomy was first reported in 1922 by MacLennan [1]. In 1987, Bradford performed a circumferential VCR (vertebral column resection) for severe rigid spinal deformity. In 2002, Suk [2] first reported a posterior-only VCR (PVCr) technique through a single posterior approach for severe deformities with limited flexibility that offers excellent surgical correction and minimal long-term complications over the anterior–posterior vertebral column resection. Since then, Lenke [3] and Xie [4] also have performed the PVCr for the treatment of severe rigid spinal deformity.

For severe rigid spinal deformity, PVCr provides the better deformity correction and rebalancing of the trunk than other techniques. The stiffness major curve could be turned into two free segments only connected with spinal cord after vertebral column resection, and the two segments can be controlled freely and safely by the instrumentation. Thus, in this study, the major curve at coronal plane was divided into three segments factitiously: upper segment, middle segment, and lower segment (Fig. 1).

The purpose of this study was to compare the changes in pre- and post-operative Cobb angles in the major curve and each segment and to analyze the correlation between the placement of pedicle screw and changes in Cobb angle, then further discuss: (1) The contribution rate of each segment to the major curve correction; (2) The interaction of the correction and spinal cord at middle segment; (3) The correlation between the placement of pedicle screw

in major curve and correction effect, as well as the reconstruction of the spine stability. Finally, we discuss the correction mechanisms of PVCr.

Materials and methods

Retrospective analysis of 46 patients with severe rigid spinal deformities from 2005 to 2010 (25 male and 21 female, with age range 11–45 years old). The diagnoses included severe scoliosis and scoliosis-dominated kyphoscoliosis, the apical vertebra was located in T5–L2, and all patients received a PVCr exclusively. All patients took a routine posteroanterior entire spine radiograph before surgery and 3 months after surgery.

The major curve at coronal plane was divided into three segments factitiously: upper segment, middle segment, and lower segment. Cobb method was used to measure the Cobb angle of the major curve and each segment. We compared the pre- and post-operative Cobb angles of the major curve and each segment to investigate the correction rate and the contribution rate of each segment to the major curve correction. We also analyzed the placement of pedicle screw at the major curve, in particular the relativity between the correction effect and the placements of pedicle screw at the upper and lower vertebral adjacent to the resected vertebral body.

$$\text{Correction rate} = (\text{preoperative Cobb angle} - \text{postoperative Cobb angle}) / \text{preoperative Cobb angle} \times 100\%$$

Fig. 1 **a** Schematic diagram of preoperative spinal deformity at coronal plane, the main curve at coronal plane was divided into three segments factitiously: *upper segment* (from the superior endplate of the upper end vertebra of the major curve to the inferior endplate of the upper vertebra adjacent to the resected vertebra), *middle segment* (from the inferior endplate of the upper vertebra adjacent to the resected vertebra to the superior endplate of the lower vertebra of the

resected vertebra), *lower segment* (from the superior endplate of the lower vertebra of the resected vertebra to the inferior endplate of the lower end vertebra of the major curve). **b** Schematic diagram of postoperative spine, PVCr created a factitious space, in which surgery was able to be accomplished, including instrumental deformity correction, titanium mesh and bone grafting to obtain excellent results

Contribution rate of each segment = (preoperative Cobb angle of the segment – its postoperative Cobb angle)/ (preoperative Cobb angle of major curve – postoperative Cobb angle of major curve) $\times$ 100%

SPSS 17.0 was used to perform statistical analyses. Values were presented as mean $\pm$ SD. Mean values between groups were compared by Student's *t* test. The linear correlation analysis was to analyze the correlation, $p < 0.05$ was statistically significant.

Results

The Cobb angle of major curve decreased from $110.1 \pm 18.1^\circ$ to $51.0 \pm 17.3^\circ$ ($p < 0.05$) after surgery, decreased by $59.1 \pm 16.4^\circ$, the mean correction rate was $54.1 \pm 12.2\%$. Among them, the Cobb angle of the middle segment decreased by $28.1 \pm 14.7^\circ$ ($p < 0.05$), the contribution rate was $49.1 \pm 27.3\%$. The upper and lower segments decreased by $15.7 \pm 13.1^\circ$ and $15.3 \pm 12.4^\circ$, respectively, ($p < 0.05$). There were no significant differences in contribution rate between upper and lower segments ($25.2 \pm 16.6\%$ vs. $26.3 \pm 22.6\%$), ($p > 0.05$) (Table 1). The correction rate and contribution rate of middle segment to the major curve deformity correction were higher than those in upper or lower segments, respectively, ($p < 0.05$). 22 patients who were instrumented at least one pedicle screw in the upper and lower vertebra adjacent to the resected vertebra earned a better correction effect in middle segment in comparison with the others ($p < 0.05$). The data also indicated that deformity correction was closely related to the numbers of the pedicle screws ($r = 0.82$, $p < 0.05$).

Discussion

PVCR technique

The treatment of severe rigid spinal deformity has been a daunting challenge for orthopedic surgeon, and extended efforts have been devoted to find a more effective treatment. Vertebrectomy was first reported in 1922 by MacLennan [1]. In 80s of last century, Bradford was the

first to describe the use of a circumferential vertebrectomy on 13 scoliosis patients with severe structural spinal deformities, who underwent vertebrectomy with a preoperative curve averaging 117° , correcting to an average 55° [3]. Bradford et al. [5] later reported 24 patients with rigid coronal decompensation who underwent a circumferential VCR. The average preoperative scoliosis was 103° corrected by 52%. Importantly, however, this technology can correct the patient's coronary and sagittal trunk imbalance commodiously. Suk et al. [2] first promoted a PVCR for severe spinal deformity in 2002. In 2005, Suk et al. [6] reported 16 patients with severe rigid spinal deformity who underwent a posterior VCR. The mean preoperative scoliosis of 109° was corrected to 46° (59% correction). In 2009, Lenke et al. [3] also reported a PVCR for severe spinal deformity, in which, scoliosis correction was 51, and 60% in kyphoscoliosis patients. This study included 46 patients with a mean preoperative scoliosis of 110° , and the flexibility was very poor. The mean scoliosis after PVCR decreased by 59° , mean correction rate was 54%. Those patients with severe rigid deformity all received a satisfactory correction by only PVCR. As an effective alternative for severe rigid scoliosis, PVCR can get a better correction than other surgery.

Patients with rigid spinal deformity often combine with severe pulmonary function impairment, and many researches have shown that anterior spinal surgery had great impact on pulmonary function [7]. PVCR, however, could not only correct the deformities as good as or better than other surgery, but also could avoid anterior approach-related complications, particularly to pulmonary function impairment.

However, as Suk [6] warned, PVCR was a highly technical procedure and should only be performed by an experienced surgical team. PVCR as a potent treatment for severe rigid spinal deformity has gradually been recognized by orthopedic surgeons, and the following sections will discuss its mechanism, in particular those about the role of spinal cord in the spinal deformity correction.

Correction mechanisms of PVCR

In severe rigid spinal deformity, due to poor flexibility, it is very untoward to obtain satisfactory results only by convex

Table 1 Pre–postoperative Cobb angle, Cobb angle reduction, correction rate and contribution rate

	Preoperative Cobb angle	Postoperative Cobb angle	Cobb angle reduction	Correction rate (%)	Contribution rate (%)
Major curve	$110.1 \pm 18.1^\circ$	$51.0 \pm 17.3^\circ$	$59.1 \pm 16.3^\circ$	54.1 ± 12.2	
Upper segment	$38.2 \pm 17.9^\circ$	$22.5 \pm 12.4^\circ$	$15.7 \pm 13.1^\circ$		25.2 ± 16.6
Middle segment	$34.3 \pm 14.2^\circ$	$6.4 \pm 9.8^\circ$	$28.1 \pm 14.7^\circ$		49.1 ± 27.3
Lower segment	$37.5 \pm 19.1^\circ$	$22.2 \pm 13.7^\circ$	$15.3 \pm 12.4^\circ$		26.3 ± 22.6

compressing or concave distracting between vertebrae. In most stiffness segment: the major curve, PVCR could create a wide-open space by vertebral column resection, then the major curve was divided into upper and lower free segments and most flexible middle segment only connected with spinal cord. We could impose various orthopedic forces such as compression, distraction, rotation, close, and open in this space and gain excellent correction effect due to the super flexible of the spinal cord.

In this study, the middle segment of the major curve got an average of 28° correction through the space factitiously created by PVCR, which offered the contribution rate of up to 50% to the major curve correction. PVCR provided preferable results mainly from the space factitiously created by vertebral column resection at middle segment of the major curve. However, correction in this space is by no means random without any limits, because the free upper and lower segments were connected only by the spinal cord after the resected vertebrae removed. The spinal cord here is imposed to act as a hinge point, in which any orthopedic force would put the spinal cord at great risk. One patient in this study even displayed reverse angulation at middle segment after surgery, which meant inevitable serious angulation of the spinal cord during correction (Fig. 2). Namely, it was actually at the cost of angulation of the spinal cord even spinal cord injury that the best corrections could achieve at the middle segment. And, the more spinal deformity was corrected, the more angulation of the spinal cord was to tolerate. Therefore, the spinal cord was subject to great risk if we blindly pursue too much correction effect at the middle segment. According to our experience, the angulation of the spinal cord was no more than 20° in sagittal or coronal plan, and 10° in rotation. Correction of

spinal deformity is usually accompanied by increased tension of the spinal cord, however, PVCR could create enough wide-open space to fulfill the compression or crimpation to spinal cord to release spinal tensions, and thus reduces the risk of spinal cord injury.

Our study showed that the Cobb angle at upper and lower segments was reduced by $15.7 \pm 13.1^\circ$ and $15.3 \pm 12.4^\circ$, respectively, the contribution rate of these two segments was about 50% to the major curve correction together. During surgery, orthopedic forces imposed by equipments to each deformed vertebra could also achieve certain correction. Furthermore, tiny correction effect in each deformed inter-vertebrae space would cumulate to offer a considerable contribution to the major curve correction. The vertebral numbers and the deformity in upper and lower segments were approximate, this might lead to that there were no significant differences in the contribution rate or Cobb angle reduction between these two segments. With the appropriate correction at the middle segment, the following correction procedure at the upper and lower segments would further improve the deformity. However, the spinal deformity which needs PVCR was usually extremely rigid, thus, it was extremely difficult to get too much correction only at the upper and lower segments.

In the treatments of severe rigid spinal deformity, in fact, PVCR created a wide-open space at the middle segment by vertebral column resection to perform excellent correction, namely, to enforce the spinal cord in middle segment as a hinge point. Meanwhile the shortening of the spinal cord can increase the safety of the corrective surgery. Conclusively, the core of PVCR technique depends on whether or not the “floating” spinal cord at the middle segment of major curve should be utilized fully and safely.

Fig. 2 Radiographs of a 12-year-old patient before surgery (a) and after surgery (b) showing reverse angulation at middle segment after surgery

PVCR issues related to the placement of pedicle screws

In PVCR, one or more intact vertebrae and adjacent intervertebral disks were removed with the destruction of spinal stability, resulting in the upper and lower spines to be completely separate from each other, and the spinal cord “floating” in the complete instable middle segment. A large number of studies have shown that pedicle screws can provide stronger fixation than the other devices because of its longer force arm [8]. It is only through the pedicle screw rod system that surgeons are able to control the free upper and lower segments and “floating” spinal cord freely and safely, and then rebuild the spinal stability. As in the internal fixation process, the screws placed adjacent to fracture line provide the most stability. In PVCR, the pedicle screws, which may be called “key screws”, inserted into upper or lower vertebrae adjacent to the resected vertebrae can provide the most dependable stability as well as safety to the middle segment and the “floating” spinal cord. Meanwhile, these “key screws” were also conducive to impose a variety of orthopedic forces at the space to get the maximum deformities correction.

In this study, 22 patients were instrumented at least one pedicle screw in the upper and lower vertebra adjacent to the resected vertebra earned a better correction effects of middle segment in comparison with others without screws inserted there. The preferable correction effect in the middle segment contributed a fine correction to the major curve. And, these “key screws” were also conducive to offer a stable environment for anterior interbody bone graft fusion through posterior approach.

With the continuous development of pedicle screw technology and popularity, many scholars have pointed out that the effects of all pedicle screws technique were superior to mixed fixation in spinal deformity correction [9, 10]. Yasser et al. [11] reported that all pedicle screws technique got better correction results with less correction loss at final follow-up in the therapy of scoliosis in Marfan syndrome. Koptan et al. [12] considered that all pedicle screws technique surpass other technique in the treatment of osteochondrosis-related spinal deformity. Other scholars, however, have put forward a different point of view about it, Quan et al. [13] pointed out that the inserting proportion of pedicle screws had no correlation with the degree of correction on a group of adolescent idiopathic scoliosis patients study.

In this study, the proportion of pedicle screws at major curve was closely related to the correction rate of the major curve, namely, the more pedicle screws were inserted into the major curve, the more corrections were able to be gotten. In this study, orthopedic forces such as compression, distraction across multiple vertebrae were unable to

fully transmitted to each anomaly vertebrae because the patients in this study all suffered from severe rigid spinal deformity with extremely poor flexibility. Therefore, orthopedic forces have to be exerted to each vertebrae by sufficient pedicle screws, especially these “key screws”, to get the preferable deformity correction. Pedicle screw is the site of action for a variety of orthopedic force, and so, placing sufficient pedicle screw is crucial for preferable deformities corrections. Meanwhile, more screws can also avoid stress concentration which may cause implant failure.

Thoracic pedicle screw technology has the potential risks because of the maximum permissible translational error of less than 1 mm and rotational error of less than 5° at the normal midthoracic spine due to small pedicle diameter [14], meanwhile its inner wall is close to the spinal cord [15]. In spinal deformity, the pedicle is often combined with congenital deformity with smaller pedicle diameter, especially in the apical region of the concave side [16]. The pedicle diameter was significantly reduced with the pedicle inner wall close to the spinal cord, which will greatly increase the risk of pedicle screws placement. In severe spinal deformity, it is even hard to find a pedicle with enough canal to insert pedicle screw. PVCR is designed for the treatment of severe rigid spinal deformity with high complex and risks, which requires a high successful rate of pedicle screws placement to get good correction and strong fixation. But for patients with severe rigid spinal deformity, the pedicle itself is combined with congenital deformation, resulting in a low successful rate of pedicle screw placement. This contradiction is particularly prominent when inserting screws into the upper and lower vertebrae adjacent to resected vertebra. In summary, PVCR needs top screw technique and experience [17], otherwise it would bring catastrophic consequences.

Conclusion

The middle segment offered the most contribution rate to the deformity correction of the major curve, with deformation of the spinal cord. It suggested that it should not gain too much deformity correction in spite of the risk of spinal cord distortions. There were no significant differences in correction rate or contribution rate to the major curve correction between upper and lower segments. However, a better correction effects could be gained here, because the spine would shorten and tension in spinal cord would decrease to allow increase correction effect with the lower risk of spinal cord injury. But it was actually too hard for such rigid spinal deformity. Placement of pedicle screws in the upper and lower vertebra adjacent to the resected vertebra was crucial to gain a better correction rate

and was also vital to reconstruct spinal stability with less risk of spinal cord injury. It could gain a better corrective effect by placing more pedicle screws at major curve, but sometimes it was difficult to place enough pedicle screws in severe rigid spinal deformities.

Conflict of interest None of the authors has any potential conflict of interest.

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