Differential rod contouring is essential for improving vertebral rotation in patients with adolescent idiopathic scoliosis: thoracic curves assessed with intraoperative CT

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Abstract

Study design Case series

Objective We investigated the contributions of rod contouring and of differential rod contouring (DRC) to the reduction of apicalaxial vertebral body rotation in patients with adolescent idiopathic scoliosis (AIS).

Summary of Background Data DRC is used for posterior spinal correction and fusion. The contribution of DRC to vertebral body derotation is unclear.

Methods We analyzed the results of intraoperative computed tomography (CT) in 40 consecutive AIS patients with thoracic curves (Lenke type I or II, 35; type III or IV, 5). Rod contour before initial rod rotation was analyzed by x-ray. Periapical rod contour between concave and convex rod rotation (RR) were analyzed by cone-beam CT imaging. To analyze the reduction of vertebral body rotation with DRC, intraoperative cone-beam CT scans of the three apical vertebrae of the major curve of the scoliosis (120 vertebrae) were taken post-concave RR and post-convex DRC in all patients. The angle of vertebral body rotation was measured. Additionally, the contribution of rod contouring to apical vertebral body derotation was analyzed. Rib hump indices (RHi) were measured by pre- and postoperative CT.

Results The mean vertebral body rotation angles post-concave rod rotation and post-convex DRC were 15.3° and 9.3°, respectively, for a mean reduction of vertebral rotation in convex DRC after concave rod rotation of 6.0° for thoracic curves (P < 0.001). The RHi was significantly improved by DRC (P < 0.05). Improved apical vertebral rotation was significantly correlated with the difference of apical rod curvature between concave and convex. Vertebral derotation was significantly higher in curves with > 10° difference between concave and convex rod curvature than differences < 10°.
Conclusion: DRC contributed substantially to axial derotation and reducing rib hump in thoracic scoliosis. The degree of apical rod curvature correlated with the degree of apical vertebral derotation.

Key Words: Scoliosis/SU; Adolescent; rod contour; differential rod contouring; Spine/AB; Computed Tomography; axial vertebral rotation

Level of Evidence: 4
INTRODUCTION

Adolescent idiopathic scoliosis (AIS) is a three-dimensional deformity of the spine. The goal of surgical correction is a healthy well-balanced spinal curvature. Surgical techniques have evolved over many years. Rod rotation methodology was introduced in 1988 in the form of the Cotrel-Dubousset (CD) technique, and Suk et al. reported that segmental pedicle screw fixation technique with rod rotation was useful for surgical correction in patients with AIS. Lee et al. reported that direct vertebral rotation (DVR) was effective for the correction of vertebral body rotation using the segmental pedicle screw insertion technique in 2004. Assessing with postoperative computed tomographic (CT) scans, they were able to achieve 43% axial plane correction using DVR as compared with only 2.5% without it. Matilla reported that DVR technique significantly decreased vertebral body rotation, but they did not recognize significant improvement in the rib hump. While there is a report that DVR is more effective at improving apical vertebral rotation than rod rotation alone in Lenke type I or II curves, Hwang et al. reported that posterior spinal fusion without DVR using pedicle screws was more effective in correcting the lumbar prominence than fusion with DVR in Lenke type V curves. Our data suggested that DVR showed significant reduction of vertebral rotation in thoracic curves with intraoperative computed tomography. However, rod rotation and differential rod contouring (DRC) resulted in more significant reduction of apical vertebral rotation than those of DVR. It is still unclear whether there is an additive effect of DRC with a flattened convex rod in the further reduction of vertebral body rotation in the axial plane following concave rod rotation in patients with AIS.

Cotrel and Dobbouset al. described a convex rod that was prebent into a flatter shape at the apex to give posteroanterior pressure at the apex and improve the derotation. Cidambi and Newton et al. described postoperative flattening of concave rods with a resulting decrease in deflection of 13 mm and reduction in angle of 21°, in contrast to postoperative convex rods, which increased deflection 1.5 mm and 2° in angle. They concluded that rod overcontouring resulted in a high degree of correction
without loss of sagittal alignment. Le Navéaux et al\textsuperscript{9} reported that the differences in initial rod deflection between concave and convex correlated with apical vertebral rotation pre- and post-surgery. However, it is still unclear how much apical rod bending and DRC each contributes to periapical vertebral derotation. We investigated the effect of rod contouring on the reduction of apical vertebral body rotation and whether there was an additive effect of DRC in patients with AIS.

METHODS

Subjects

The study included 40 patients with AIS (37 females, 3 males; mean patient age 14 years), who underwent concave RR and convex DRC followed by DVR using uniplanar screws at our institution from August 1\textsuperscript{st}, 2014 through December 31\textsuperscript{st}, 2016. Based on the classification of Lenke et al\textsuperscript{10}, 18 patients were Type I, 17 were type II, and 5 were Type III or IV. Patients were evaluated by x-ray before and after surgery for scoliosis, and both concave and convex rod curvatures were evaluated by x-ray before implantation. Informed consent to participate in this study and consent to instrumentation was obtained before surgery. This study was approved by the Ethical Review Board of our hospital (No. 28-30).

Surgical Methods and rod contouring

Surgery was performed under general anesthesia in the prone position in all patients, using techniques we have described previously.\textsuperscript{7} All surgeries were performed by one surgeon (S.S.). With the patient prone, both buttocks were stabilized with tape to ensure close contact with the operating table, and were tightly secured to prevent slipping. A standard posterior incision was extended from the uppermost to the lowest vertebra designated for instrumentation. The facet joints included in the fusion and their articular cartilages were removed to promote intra-articular arthrodesis. After performing a Ponte procedure\textsuperscript{11} on the three apical intervertebral segment, uniplanar screws were inserted into every
vertebra by the free hand technique according to the method of Kim et al. After all pedicle screws were inserted, a concave 5.5 mm CoCr rod was rotated 90° to straighten the scoliosis in the coronal plane and to forma thoracic kyphosis in the sagittal plane, and we tightened the setscrew of the most caudal pedicle screw to maintain the correction. Next, a different bending convex rod was inserted, and the rib hump was reduced using a differential bending rod, and we tightened the lowest setscrew of the convex side in the same way. The concave rod was bent 25–30° to form a thoracic kyphosis, but the curvature of the convex rod was more flattened than that of the concave rod. After bending the rods, a radiograph of both rods was taken. We measured the difference in curvature between concave and convex. The rod bending was performed by operating surgeon with French style rod benders. Lastly, we performed DVR on each vertebra from the most caudal vertebra to the most cranial neutral vertebra. Global spinal balance was checked under fluoroscopic guidance. We did not perform a thoracoplasty in any patient. Spinal cord monitoring with motor-evoked and somatosensory-evoked potentials was performed during all operations.

**Cone-beam CT analysis**

A cone-beam CT scanner (ARCADIS Orbic 3D, SIEMENS, Bayern, Munich, Germany) with a C-arm with an isocentric design and 190° orbital movement was used to acquire images. A total of two intraoperative cone-beam CT scans of the three apical vertebrae (120 vertebrae in total) were taken: [1] after concave RR; and [2] after convex DRC. Three surgeons interpreted all CT images.

The angle of vertebral body rotation in the three apical vertebrae was calculated after each technique and the results were compared. The angle to the floor of the operating room was used as reference for the angle of vertebral body rotation. The measurement of vertebral body rotation was performed as previously described. Full-length rod curvatures were measured using x-rays of pre-implantation and post-operative images (Figure 1). Apical rod curvatures were measured four times at pre-implantation, post-concave RR, post-convex DRC, and post-operation. The apex was used for
measuring the rod curvature of the three apical vertebrae (Figure 1). The results of full-length rod curvature were measured by comparing preoperative x-ray to postoperative CT scans. We measured pre- and postoperative rib hump index (RHi) from pre- and postoperative CTs based on the method reported by Aaro et al. The differences between pre- and postoperative RHIs were compared with the difference between preoperative concave and convex full length rod curvature. Full-length and apical rod curvature were analyzed by each technique. During the CT scan, ventilation was temporarily suspended to minimize respiratory motion. Radiation dose from this cone-beam CT scan was approximately 1.58 mGy per image. We looked for any association between the improvement in vertebral body rotation in thoracic curves and age, Risser’s grade, Cobb angle, sagittal alignment, apical vertebral translation, and full-length and apical rod curvature.

**Inter-rater and intra-rater reliability**

We determined inter-rater and intra-rater reliability of the measurement of CT images by calculating the Fleiss’ Kappa coefficient using a dedicated program (MATLAB Mathworks, Paris, France). Kappa values of 0.00–0.20 were interpreted as slight agreement, 0.21–0.40 were interpreted as fair agreement, 0.41–0.60 were interpreted as moderate agreement, 0.61–0.80 were interpreted as substantial agreement, and 0.81–1.00 were interpreted as almost perfect agreement. We also determined inter-rater and intra-rater percent agreement.

**Statistical analysis**

Data are presented as the mean ± standard deviation. Mann Whitney’s U-test was used for the statistical analysis of the differences in degrees of apical rod curvature between preoperative baseline and post-concave rod rotation, post-convex DRC, and post-operation. Commercial software (JMP®, version 9, SAS Institute Inc., Cary NC, USA) was used for the analysis, with $P < 0.05$ considered statistically significant.
RESULTS

The mean preoperative Cobb angle was 53.8° (Table 1). Lenke type I, II, and other groups did not significantly differ with regard to age, height, weight, flexibility, or Risser sign. There was a significant difference in Cobb angle between Lenke type I and II. Full-length concave rod curvature post-operation was significantly decreased compared to that of pre-implantation. Full-length convex rod curvature was not significantly changed between pre-implantation and post-operation (Figure 2A). Periapical concave rod curvature decreased post-concave RR and decreased further post-convex DRC compared to preimplantation, while the postoperative concave rod curvature was increased to a greater extent than that of post-convex DRC. It seemed that DVR was involved in the increase of concave rod curvature at the post-operation. On the other hand, the convex rod curvature did not change so much between each technique. The rod curvature difference between concave and convex was the most significantly increased post-convex DRC (Figure 2B). The difference between preoperative concave and convex full length rod curvature significantly correlated with improvement in RHi (Figure 3).

Figure 4 shows the mean vertebral body rotation after each technique. The mean apical vertebral rotation angle was 15.3° after concave RR, and further reduced to 9.3° after subsequent convex DRC (P<0.001) (Figure 4A). Figure 4B shows the mean vertebral rotation angle of each periapical and apical vertebra. There were significant differences between post-concave RR and post-convex DRC at each apical vertebra (P<0.001), with no significant difference between the rotation angles on the vertebrae caudal and cranial to the apical vertebra. The averaged Fleiss’ Kappa coefficient of inter-rater reliability for the measurement of intraoperative CT images was 0.84 ± 0.01 for the three observers. The intra-rater reliability for the measurement of intraoperative CT was 92.5% (95% CI 90.7–94.7), and 91.8% (95% CI 90.5–95.0).7

Our data demonstrate that apical vertebral rotation improved a mean of 6° between concave RR and convex DRC. We investigated the factors associated with this. A difference between apical
concave and convex rod curvature correlated with improved apical vertebral rotation ($R=0.67, P<0.0001$) (Figure 5A). If the difference between apical concave and convex rod curvature was $>10^\circ$, vertebral rotation improved significantly ($P<0.01$) (Figure 5B).

**Representative case presentation**

A 13-year-old girl had a Lenke type I scoliosis of 55° (Figure 6A, B). On intraoperative cone-beam CT, the rotation angles of the apical (T9) vertebral body post-concave RR and post-convex DRC were 15° and 9°, respectively (Figure 6C, D). Postoperative x-rays (Figure 6E, F) showed that the scoliosis had been corrected by 11°. Convex DRC following rod rotation showed a definite additive effect to vertebral derotation.

**DISCUSSION**

Our results show that DRC technique substantially contributed to reducing vertebral body rotation and reducing rib hump in thoracic curve scolioses. Even though other surgical methods (RR and DVR) were affected by RHii, the reduction of rib hump suggests that apical vertebral derotation depends on the contribution DRC makes towards reducing apical rib hump. The thoracic curve groups did not significantly differ by patient age, flexibility, Risser sign grade or degree of rotation. The difference between apical concave and convex rod contour with 5.5mm CoCr rods correlated with the degree of improvement in apical vertebral rotation. Various rod materials have been used for AIS patients, such as CoCr, titanium, and ultrahigh-strength steel, and our data and other reported data indicate almost the same deformation between pre-implantation and post-operation for all materials.\(^8,9,18\) Periapical rod concave curvature showed a change with each successive technique as compared to little change in apical convex rod curvature. Periapical concave rod curvature post-convex DRC showed additional flattening to that of post-concave RR. This finding suggests that a convex rod pushes the apical scoliotic spine and the concave rod is more flattened because of the opposing force of reduced vertebral body.
rotation. In order to prevent this phenomenon, the concave rod might need more strength than the convex rod for reducing apical vertebral derotation. Post-operative concave rod curvature showed more increase than that of post-concave DRC after DVR. This finding suggests that DVR might reduce the load against bilateral rods because of reducing vertebral body rotation using bilateral uniplanar screws. There have been no detailed reports on rod contour after each technique or reports of vertebral body derotation with DRC alone using cone-beam CT scans.

Our data suggested that a difference between concave and convex apical rod curvature of > 10° predicts substantial derotation. Cidambi et al. suggested rod overcontouring resulted in high degrees of correction without loss of sagittal alignment. They recommended an overcontour with a difference of 20° between preimplantation concave and convex rods. Le Navéaux et al. reported an association between the amount of kyphosis change and the relative concave rod-to-spine contour (rod curvature - preoperative kyphosis), as well as between initial differential concave/convex rod deflection and apical vertebral derotation that was seen in analysis of pre- and post-operative 3D reconstructions of the spine from bi-planar radiographs. Our data show how much the degree of vertebral body derotation improved with the addition of DRC using intraoperative cone-beam CT scans, with a mean improvement of 6°. The difference in apical rod contour between concave and convex is predictive of the degree of derotation, with a cutoff of 10° predicting substantial derotation. The more severe the scoliosis, the greater the difference in apical rod contour between concave and convex rods may be necessary for substantial apical vertebral derotation and reduction of the rib hump. In patients with mild or flexible scoliosis, the difference in apical rod contour between concave and convex may not need to be increased.

We have reported how much concave RR with DRC or DVR contributes to the derotation of the apical vertebral bodies in analysis using intraoperative CT (Figure 7). DVR additionally improved vertebral body rotation by about 3° in thoracic curves in our previous study. However, we did not
know how much DRC contributed to reducing vertebral body rotation. This new study shows the additive effect of DRC after RR. We chose this cone-beam CT scanning protocol because we wanted to know how much the DRC technique itself contributed to reducing vertebral body rotation in this study. At first we thought concave RR itself may have a greater effect; however, our data showed that the vertebral body rotation of convex DRC was improved by a mean of 6°. These findings also suggest that concave RR contributes little to reducing vertebral body rotation but is effective for apical vertebral translation \(^{19, 20}\) and normalizing thoracic kyphosis. \(^{8, 9}\)

Cone-beam CT involves a relatively low radiation dose. The dose in this study was 1.58 mGy per scan, which is markedly low compared to the exposure from a chest CT scan. The total radiation exposure to patients from C-arm scanning is between that from posterior-anterior chest radiography and that from spine CT scanning using the O-arm. \(^{21-23}\) A limitation of this study was using the angle to the floor of the operating room as a reference. Because this C-arm CT scanner covers a volume equivalent to only approximately three vertebral bodies, the pelvis or sacrum could not be used as a reference.

**CONCLUSIONS**

DRC contributed a substantial reduction in vertebral body rotation within thoracic curves in patients with AIS. The improvement in RH\(_i\) was significantly correlated with the difference between preoperative concave and convex full length rod curvature. The difference between apical concave and convex rod curvature was correlated with the degree of improvement in apical vertebral rotation, with a > 10° difference predicting substantial derotation. DRC technique is an important technique in improving vertebral body rotation in thoracic curve scolioses.

**Acknowledgements**

The authors thank the radiation technologists at our hospital.
References


4) Mattila M, Jalanko T, Helenius I. En bloc vertebral column derotation provides spinal derotation but no additional effect on thoracic rib hump correction as compared with no derotation in adolescents undergoing surgery for idiopathic scoliosis with total pedicle screw instrumentation. 


Figure Legends

Figure 1. The methods of rod curvature of both full-length and apical rods. indicates full-length rod curvature, and indicates apical rod curvature. Full-length rod curvature ( ) was measured at pre-implantation and post-operation. Periapical rod curvature( ) was measured at pre-implantation, post-concave rod rotation (RR), post-convex differential rod contouring (DRC), and post-operation.

Periapical rod curvature ( ) was measured along the three apical vertebrae.
Figure 2. Transitional change in the curvature of both full-length (A) and apical rods (B). Change in full-length rod curvature between pre-implantation and post-operation. (B) Time course of the change in apical rod curvature from pre-implantation to post-operation.
Figure 3. Improvement in rib hump index (RHi) depending on differential rod contouring (DRC). The difference between preoperative concave and convex full length rod curvature correlated with preoperative minus postoperative RHi (R=0.36, P < 0.05).
Figure 4. Improvement in periapical vertebral rotation depending on convex differential rod contouring (DRC). (A) Degree of apical vertebral body rotation both post-concave rod rotation (RR) and post-convex DRC (overall data). (B) Degree of apical vertebral body rotation between post-concave rod rotation (RR) and post-convex DRC at each vertebra. Apex-1 indicates the vertebra cranial to the apical vertebra, and Apex+1 indicates the vertebra caudal to the apical vertebra.
Figure 5. Association between the difference in apical concave and convex rod curvatures and amount of apical vertebral derotation. (A) Improved apical vertebral derotation between post-RR and post-DRC correlated with apical concave minus convex rod curvature. (B) There were significant differences in amount of derotation between apical concave minus convex rod curvatures > 10° and < 10°.
Figure 6. Pre- and post-operative x-rays and intraoperative cone-beam CT images of thoracic curve. The patient was a 13-year-old girl, and had a Lenke type 1 scoliosis of 55°. (A, B) Preoperative x-rays. (C) Apical vertebral body rotation after concave rod rotation (RR), 15°; (D) post-differential rod contouring (DRC), 9°. (E, F) Post-operative x-ray.
Figure 7. Dynamic schema of apical vertebral body rotation with each surgical method. Estimated additional improvement in apical vertebral rotation was 6° after DRC, and 3° at DVR.
Table 1. Background of AIS patients

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<td>(n = 18)</td>
<td>(n = 17)</td>
<td>(n = 5)</td>
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<td>age (years)</td>
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<td>height (cm)</td>
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<td>flexibility (bending test)</td>
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* indicates statistically significant difference between Lenke type I and II.