Delayed treatment of adolescent idiopathic scoliosis is a common condition in mainland China because of the lack of public education, medical insurance, or reluctance to undergo surgery, which leads to more severe and rigid deformity. In addition, scoliosis caused by a hemivertebra, Marfan syndrome, and neuromuscular lesions progresses fast and usually develops into severe scoliosis. However, the surgical treatment of severe and rigid scoliosis is currently challenging. Pathologically, the rigid segment is often located in the anterior and middle spinal columns, thus many scholars recommend performing the anterior release operation first so as to improve spinal flexibility, and then performing the posterior correction and bone fusion, which has achieved satisfactory results. However, anterior procedures are not ideal as they may increase operative time and estimated blood loss, as well as compromise pulmonary function. With a greater understanding of this disease, some scholars...
have suggested that contraction of the posterior spinal structures and fusion of the costotransverse, intercostal, and intratransverse joints may also play important roles in the rigid spinal deformity; thus, a posterior-only approach is advocated.4,20 Using segmental pedicle screw spinal instrumentation and vertebral derotation, many authors have reported a loss of thoracic kyphosis postoperatively, but segmental sagittal imbalance correction has been achieved by in situ contouring.2-3 Therefore, we adopted a posterior release operation combined with derotation, translation, segmental correction, and an in situ rod-contouring technique to alleviate severe and rigid scoliosis.

Methods

Patient Population

All study participants provided written informed consent prior to their inclusion in the study, and all human studies were approved by the China Ethics Committee and performed in accordance with ethical standards. Twenty-eight patients with severe and rigid scoliosis (Cobb angle > 70° and flexibility < 30%) who underwent posterior spinal release combined with derotation, translation, segmental correction, and an in situ rod-contouring technique were retrospectively enrolled between June 2008 and June 2010. The average age of the patients at surgery was 17.1 years (range 12–22 years) and the female/male ratio was 9/5. Etiological diagnoses were idiopathic scoliosis in 24 patients, neuromuscular scoliosis in 2 patients, and scoliosis associated with Marfan syndrome in 2 patients. The average scoliosis Cobb angle in the coronal plane was 85.7° (range 77°–94°), the average kyphosis Cobb angle in the sagittal plane was 64.5° (59°–83°), and the average flexibility was 22.1% (range 7%–27.8%). Seven patients had a thoracic scoliosis, 13 had thoracolumbar scoliosis, and 8 had lumbar deformation (Tables 1 and 2). The surgery for each patient was performed by the first author (F.S.).

Surgical Procedure

Preoperatively, all patients underwent the pulmonary function test and balloon-blowing exercise to improve lung capacity. A suspension exercise was also performed to improve the flexibility of scoliosis segments. All patients underwent general anesthesia and were placed

<table>
<thead>
<tr>
<th>Parameter</th>
<th>No. of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (female/male)</td>
<td>18/10</td>
</tr>
<tr>
<td>Mean age in yrs (range)</td>
<td>17.1 (12–22)</td>
</tr>
<tr>
<td>Etiological diagnosis</td>
<td></td>
</tr>
<tr>
<td>Idiopathic scoliosis</td>
<td>24</td>
</tr>
<tr>
<td>Neuromuscular scoliosis</td>
<td>2</td>
</tr>
<tr>
<td>Scoliosis associated w/ Marfan syndrome</td>
<td>2</td>
</tr>
<tr>
<td>Scoliosis curve type</td>
<td></td>
</tr>
<tr>
<td>Thoracic major curve</td>
<td>7</td>
</tr>
<tr>
<td>Thoracolumbar major curve</td>
<td>13</td>
</tr>
<tr>
<td>Lumbar major curves</td>
<td>8</td>
</tr>
</tbody>
</table>

### TABLE 2. Spinal deformity correction outcome

<table>
<thead>
<tr>
<th>Clinical Index</th>
<th>Preop</th>
<th>Immediately Postop</th>
<th>Postop</th>
<th>Correction at Last Follow-Up</th>
<th>p Value</th>
<th>t Score*</th>
<th>p Value</th>
<th>t Score†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Cobb angle (range)</td>
<td>85.7° (77°–94°)</td>
<td>33.1° (20°–52°)</td>
<td>61.3° (33.7°–72.4°)</td>
<td>3.047</td>
<td>0.0037</td>
<td>60.7% (46.8%–71.2%)</td>
<td>3.039</td>
<td>0.0045</td>
</tr>
<tr>
<td>Sagittal plane</td>
<td>64.5° (59°–83°)</td>
<td>42.6° (34°–59°)</td>
<td>33.9° (23.2°–41.6°)</td>
<td>2.879</td>
<td>0.0067</td>
<td>31.6% (26.4%–49.6%)</td>
<td>2.883</td>
<td>0.0071</td>
</tr>
<tr>
<td>Mean AVT in mm (range)</td>
<td>81 (35–108)</td>
<td>44 (15–85)</td>
<td>37 (14–48)</td>
<td>3.056</td>
<td>0.0035</td>
<td>35 (15–41)</td>
<td>3.072</td>
<td>0.0031</td>
</tr>
<tr>
<td>Mean TS in mm (range)</td>
<td>23 (2–33)</td>
<td>10 (1–20)</td>
<td>13 (1–18)</td>
<td>2.767</td>
<td>0.0077</td>
<td>12 (1–19)</td>
<td>2.779</td>
<td>0.0075</td>
</tr>
</tbody>
</table>

AVT = apex vertebral translation; TS = trunk shift.
*Comparison between preoperative and immediately postoperative.
†Comparison between preoperative and the last follow-up visit.
The contractural soft tissues in the concave side were resected and the intertransverse ligament and costotransverse joint ligament in the rigid segment—including the ribs and transverse process in some cases—were excised followed by placement of a rigid rod. Correction of the curve was performed by rod derotation. Another new rod was then placed and locked in the convex side, and the rod in the concave side was removed. Two force application sites were selected in the convex rod to link the in situ rod-bending device. Compression in the coronal and sagittal planes was performed to correct the spinal deformity. After satisfactory results were achieved, the rod in the concave side was replaced, followed by segmental distraction of locking screws. Finally, the in situ rod-bending device was removed and 2 rods were connected by transverse connectors at both ends of the construct. Autogenous bone or allograft was then selected for posterior fusion at the segments. An antibiotic was used 1 day before the operation and every day after the operation for 8–10 days. Active motion with a brace was performed from the third week after the operation. The brace protection was removed at 3 months after the operation.

Outcome Measures

The radiograph was examined in all patients every 3 months after the operations so as to observe the bone union and correction effect. The following indices were recorded: 1) the scoliosis Cobb angle in the coronal plane; 2) the kyphosis Cobb angle in the sagittal plane; 3) the apex vertebral translation, which was measured as the distance from the perpendicular line drawn from the center of the S-1 vertebral body (center sacral vertical line) to the midpoint of the apical vertebral body of the curve; and 4) the trunk shift, which was determined as the distance between the vertical line drawn from the C-7 spinous process and the center sacral line. Neurological function was evaluated by the Frankel grade: A, complete motor and sensory loss; B, has sensation but has lost all motor function; C, motor function present, but no practical use (nonambulatory); D, ambulatory; and E, completely normal. The Scoliosis Research Society-22 questionnaire (SRS-22) was used for the assessment of health-related quality of life in patients preoperatively and at the final follow-up evaluation. Total scores as well as individual domain scores for pain, self-image, function, mental health, and satisfaction parameters were calculated and analyzed for each patient.

Statistical Analysis

All data were analyzed by SPSS statistical analysis software (version 13.0, SPSS Inc.). The difference between each preoperative and postoperative index was analyzed by a t-test. The correction ratio was calculated using the formula:

\[
\text{Correction ratio} = \frac{\text{postoperative index} - \text{preoperative index}}{\text{preoperative index}} \times 100\%
\]

A p value < 0.05 was considered statistically significant.

Results

All patients were successfully treated by the posterior spinal release combined with derotation, translation, segmental correction, and an in situ rod-contouring technique, with an average operative time of 241.8 ± 32.1 minutes and estimated blood loss of 780.5 ± 132.6 ml. The average scoliosis Cobb angle in the coronal plane was corrected from 85.7° (range 77°–94°) preoperatively to 33.1° (range 21°–52°) postoperatively, resulting in the correction ratio of 61.3% (Table 2). The average kyphosis Cobb angle in the sagittal plane was corrected from 64.5° (range 59°–83°) preoperatively to 42.6° (range 34°–58°) postoperatively (Table 2). After the average 24-month follow-up (range 13–30 months), we only found a few screw-related complications, including screw pullout of the upper thoracic vertebrae in 2 patients and screw penetration into the apical vertebrae in 1 patient. In addition, 1 patient appeared to have numbness and muscle weakness in both lower limbs (Frankel C), which recovered to Frankel Grade E 1 month after the operation. All fixed segments were completely fused and no wound infection or pseudarthrosis was present in these 28 patients. The SRS-22 scores were significantly improved at the last follow-up evaluation compared with that present during the preoperative period (Table 3). A typical case is shown in Fig. 1.

Discussion

According to the theory of 3D scoliosis correction, spinal deformity and flexibility can be well corrected by concave rod derotation, segment distraction, and convex rod support. The corrective ability of this approach is associated with 2 main factors: the solidity between the internal fixation and the bone, and the metal rod strength. The precontoured titanium rod used at present cannot provide a satisfactory stiffness to overcome the rigid deformity of scoliosis. Thus, the excellent correction effect may not be obtained for severe and rigid scoliosis using traditional precontoured rod derotation. In contrast, the in situ rod-contouring technique can provide greater strength to directly correct the scoliosis rigid deformity. As expected, our results indicated that a good correction ratio was obtained in the scoliosis Cobb angle in the coronal plane, from 85.7° (range 77°–94°) preoperatively to 33.1° (range 21°–52°) postoperatively.

The in situ rod-contouring technique is not usually used because it may lead to bone fracture and neurologi-
operative treatment for severe and rigid scoliosis

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...cal complications. The above risks come from the use of vertebral pedicle hooks and vertebral plate hooks. But with the development of pedicle screws, especially pedicle screws for the upper thoracic spine, the in situ rod-contouring technique has attracted more attention from investigators. The pedicle screws not only can increase the immobility between the internal fixation and the bone, but also can control the vertebra effectively. However, pedicle screw penetration and pullout occasionally occur with the in situ rod-contouring technique, especially on the convex side. This may be attributable to the correction role of the convex rod, but also the supporting and maintaining effect of the concave rod. To decrease the operative complications we placed the rod in the concave side twice so as to disperse the strength of the convex vertebra pedicle screws. It has been reported that the more internal fixation points there are, the more the strength is dispersed, which leads to a reduced possibility of pedicle screw penetration and pullout phenomena.

In addition, Kubo et al. reported that the release of the posterior contractural tissues could improve spinal flexibility. Thus, in this study, the contractual soft tissues in the concave side were released and the intertransverse ligament and costotransverse joint ligament in the rigid segment were cut, which may improve the flexibility of the spinal posterior rigid deformity segments and lead to a good correction effect after the operation. This indirectly demonstrates that the anterior release operation is unnecessary.

However, there are still some limitations in this study. Only 2 patients with scoliosis caused by Marfan syndrome and 2 with scoliosis caused by a neuromuscular disease were included, which are different from idiopathic scoliosis. The anterior release operation not only can improve...
spinal flexibility but also prevent occurrence of the crankshaft phenomenon in the treatment of the scoliosis. Kioschos et al.\textsuperscript{3} used posterior pedicle screw internal fixation in the lumbar vertebrae of the canine and found that the posterior pedicle screw internal fixation system could control the anterior growth center of the spine and prevent the crankshaft phenomenon, even if no anterior release and fusion operation were performed. However, the crankshaft phenomenon was not recorded because of the short follow-up period in this study.

Conclusions

Posterior spinal release combined with derotation, translation, segmental correction, and an in situ rod-contouring technique has proved to be a promising new technique for rigid scoliosis, significantly correcting the scoliosis and accompanied by fewer complications. However, further multicenter studies with a large sample size and a long-term follow-up period are needed before definitive conclusions can be made.

References

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