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Effect of thoracic kyphosis formation and rotational correction by direct vertebral rotation after the simultaneous double rod rotation technique for idiopathic scoliosis

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ABSTRACT

Objective: The objective of the present study was to evaluate the effect of thoracic kyphosis formation and rotational correction by direct vertebral rotation (DVR) after the simultaneous double-rod rotation technique (SDRRT) for idiopathic scoliosis (IS).

Patients and methods: The present study included twelve patients with IS who received SDRRT (SDRRT group) and twelve patients with IS who received DVR after SDRRT (SDRRT + DVR group). We investigated the following parameters preoperatively, postoperatively, and at postoperative 2 years: Cobb angle (PT, MT, T/L, C7-CSVL, AVT, TK (T5-12), LL(L1-S1) RSH, the angle of rotation (RAsag), percent change of RAsag and SRS22 (at postoperative 2 years only).

Results: Preoperatively, the mean main thoracic curve was 58.9 ± 12.4° for the SDRRT group and 59.9 ± 16.0° for the SDRRT + DVR group, which was corrected to 14.6 ± 6.7° and 13.4 ± 4.9° postoperatively. and 14.9 ± 7.1° and 14.3 ± 4.1° at postoperative 2-year follow-up, respectively. Correction rates were 75.4 ± 10.4% and 77.2 ± 8.0 % postoperatively. Thoracic kyphosis increased postoperatively and at postoperative 2-year follow-up in both the SDRRT group and the SDRRT + DVR group. The mean preoperative TK was 11.4 ± 7.3° in the SDRRT group, and 12.8 ± 11.5° in the SDRRT + DVR group, which improved significantly to 24.8 ± 5.2° and 23.6 ± 3.5° postoperatively and 23.3 ± 3.9° and 24.2 ± 6.0° at postoperative 2-year follow-up, respectively. Correction of vertebral rotation as RAsag was significantly better in the SDRRT + DVR group than in the SDRRT group. The mean preoperative RAsag was 19.1 ± 6.7° in the SDRRT group, and 18.3 ± 7.5° in the SDRRT + DVR group, which improved to 13.3 ± 4.3° and 10.1 ± 2.9° postoperatively ($P = 0.04$) and 13.9 ± 4.0° and 10.6 ± 2.8° at postoperative 2-year follow-up ($P = 0.02$), respectively.

Conclusion: DVR after SDRRT for idiopathic scoliosis allowed for rotation correction without compromising kyphosis formation.

1. Introduction

Idiopathic scoliosis (IS) represents a complex spine deformity with different grades of involvement of the frontal, sagittal, and axial planes. Posterior spinal correction and fusion with segmental pedicle screw (PS) instrumentation is generally used for the correction of many types of IS, because of their high correction rates in the coronal plane [1–3]. However, all-screw constructs have been associated with a significant decrease in thoracic kyphosis after surgery [4–6]. Since thoracic IS patients are typically hypokyphotic [7], restoring and maintaining a normal sagittal contour is an important surgical outcome [7–9]. To overcome further lordosis of the thoracic spine secondary to PS constructs, several attempts were developed to effectively create thoracic kyphosis during surgery. One popular method of creating thoracic kyphosis is an in situ bending technique, in which surgeons bend inserted rods manually with rod benders after connecting the rods to screw heads [10]. On the other hand, Ito et al developed a surgical technique called the simultaneous double-rod rotation technique (SDRRT) for

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correcting IS [11], which includes upward pushing and lateral translation of the spinal column with simultaneous double-rod rotation maneuvers, and achieves thoracic kyphosis as well as favorable coronal correction of scoliosis [12,13]. Although SDRRT provides significant sagittal correction of the main thoracic curve while maintaining sagittal profiles and correcting coronal deformities, there is still room for improvement of the correction of vertebral rotation in axial deformity.

Di Silvestre et al. [14] documented that a direct vertebral rotation (DVR) maneuver using a vertebral column manipulator after a concave rod rotation maneuver showed a significantly better final correction of apical vertebral rotation. They reported that DVR can achieve more than 60% axial rotation. However, the T5–T12 kyphosis angle was lower at final follow-up evaluation in the DVR group than in the simple concave rod rotation group. There is a possibility that DVR induces a decrease in thoracic kyphosis after surgery, and this phenomenon may occur because the DVR maneuver pushes the vertebra on the hump side during rotation correction.

We believe that after SDRRT provides sagittal and coronal correction, *en bloc* DVR with the de-rotation device might lift the main thoracic apical area, and correct vertebral rotation without compromising kyphosis formation. Therefore, the aim of the present study was to evaluate an effect of the thoracic kyphosis formation and rotational correction by DVR after SDRRT for IS.

2. Materials and methods

2.1. Patient population

The study design was a comparative review of 2 cohorts with retrospective data collection on patients operated using SDRRT without (n = 12) or with DVR (n = 12) for structural thoracic idiopathic scoliosis (Lenke type 1, 2, lumbar curve modifier A or B). We corrected data from medical and radiological records of 24 patients affected by IS, who were performed SDRRT between 2011 and 2016. The first 12 consecutive patients operated on using SDRRT without DVR between 2011 and 2014, served as the SDRRT group, and the following 12 consecutive patients operated on using SDRRT with DVR between 2014 and 2016, served as SDRRT + DVR group (Table 1). Same surgeon (M.M.) performed all 24 cases, using two different techniques (SDRRT or SDRRT + DVR). Inclusion criteria were: patients with IS (Lenke type 1, 2) who had lumbar curve modifier A or B and a minimum of 2 years follow-up; a complete pre- and post-surgical radiological and clinical evaluation. Exclusion criteria were: Lenke 1 or Lenke 2 AIS curves with lumbar curve modifier C, Lenke 3–6 AIS curves, and scoliosis of the syndromic, neuromuscular, and congenital types. In all patients, standing long-cassette posteroanterior and lateral radiographs were evaluated for multiple parameters before and immediately after surgery and on postoperative two year follow-up. Coronal and sagittal Cobb measurements of the proximal thoracic (PT), main thoracic (MT), and thoracolumbar/lumbar (TL/L) curves were obtained. Sagittal measurements included thoracic kyphosis TK (T5–T12) and lumbar lordosis LL (L1–S1). Global coronal balance was measured by the lateral displacement of the C7 coronal plumb line from the center sacral vertical line (CSVL). For regional alignment, the MT apical vertebral translation (AVT) was measured as the distance between the geometric center of the apical vertebrae and the C7 plumb line. Radiographic shoulder height (RSH) was measured to assess shoulder balance [15]. A positive RSH was defined as left shoulder up and right shoulder down. The rotation angle of thoracic apical vertebrae was measured on computed tomography (CT) images before and after surgery. The angle of rotation (RAsag) of the vertebra was measured using the angle between the junction of the laminae, the dorsal central aspect of the vertebral foramen and the middle of the vertebral body, and the sagittal plane [16]. The percent changes of RAsag were calculated with the following formula: The percent changes of RAsag (postoperative) = ((preoperative RAsag) – (postoperative RAsag))/ (preoperative RAsag)*100, the percent changes of RAsag (postoperative 2 years) = ((preoperative RAsag) – (postoperative 2 years RAsag))/ (preoperative RAsag)*100.

Table 1
Patient Demographic Data.

Parameter	SDRRT (n = 12)	SDRRT + DVR (n = 12)
Age at surgery (yrs)	16.0 ± 4.1	17.0 ± 3.7
Sex (male/female)	1/11	2/10
Number of levels fused (n)	10.8 ± 2.0	10.3 ± 1.9
Operation time (min)	394.3 ± 134.4	370.0 ± 122.2
Blood loss (ml)	431.5 ± 294.0	339.2 ± 172.3
Lenke type (n)		
1	8	9
2	4	3

SDRRT: simultaneous double-rod rotation technique.
DVR: direct vertebral rotation.
Values are means ± standard deviation.

The Scoliosis Research Society questionnaire score (SRS-22) was used to measure patient outcomes during follow-up and the average score for each of the five domains was used for analysis. In the present prospective project, we obtained preoperative and postoperative 2 years follow-up status.

The data were analyzed separately for SDRRT and SDRRT + DVR group. The patients in the SDRRT group were corrected by side-loading pedicle screw system (USS II Polyaxial, DePuy Synthes, Raynham, MA, USA). The patients in the SDRRT + DVR group were corrected by top-loading pedicle screw system (CD HORIZON SOLERA, Medtronics Spinal and Biplogics, Memphis, TN, USA).

2.2. Surgical technique for SDRRT and DVR

In principle, the instrumentation levels were initially determined on standing films to include end-to-end vertebrae. Next, the upper instrumented vertebra (UIV) was determined based on the postoperative shoulder balance and anatomical TK; T2 was selected when RSH was positive or for Lenke type 2 cases, T3 was selected when RSH was > −5 mm to 0 mm, and T4 or T5 was selected when RSH was ≤ −5 mm. As for the lower instrumented vertebra (LIV), the last vertebra touching the CSVL was selected [17].

All patients underwent posterior spinal fusion with only all screw constructs and 70–90% screw density. After exposure of the posterior spinal elements, PS instruments were placed. After facetectomy at the apical lesion, two titanium alloy rods measuring 6 mm or 6.35 mm in diameter were identically bent to guide the postoperative anatomical TK. For the postoperative anatomical TK, the apex was anticipated to be located at T6–T8. After connecting the two rods to all screw heads, the two rods were simultaneously rotated (Fig. 1). After SDRRT, compression on convex side and distraction on concave side were performed. Patients received apical DVR (SDRRT + DVR group), performed with Vertebral Column Manipulator device (VCM, Medtronic Medtronics Spinal and Biplogics, Memphis, TN, USA). VCM was mounted over apex screws, the level above and below (3 levels). In order to get an efficient axial de-rotation, uniplanar screws were used at the levels undergoing DVR. Once VCM construct was assembled, forceful de-rotation was done in en bloc manner—three levels connected in one stiff construct, resulting in a de-rotation force being applied evenly to the whole apex. The device was used to de-rotate the thoracic spine by lifting up the apical major thoracic concave area and in this manner providing DVR (Fig. 2). An *in situ* rod-bending maneuver was conducted at the end of the surgery. Local bone grafting followed decortication of the laminae. Intraoperative monitoring of the patients regarding motor evoked potentials was performed in all cases. A brace was required six months after surgery.

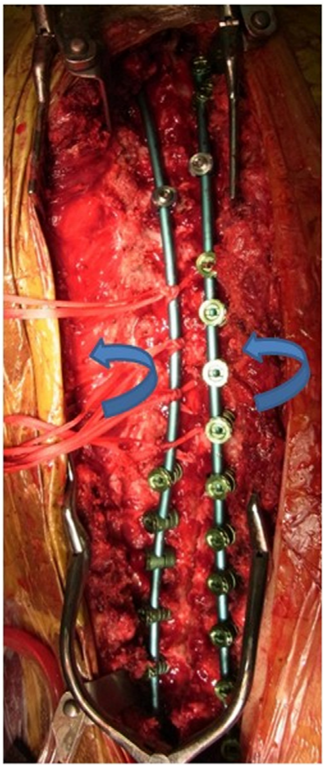

Fig. 1. Simultaneous double-rod rotation technique (SDRRT): Intraoperative photograph shows that after two titanium alloy rods were connected, the two rods were simultaneously rotated.

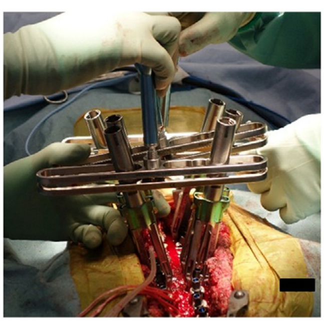

Fig. 2. Direct vertebral rotation (DVR) performed with a Vertebral Column Manipulator (VCM) device: Forceful de-rotation was done in an en bloc manner—three levels connected in one stiff construct, resulting in a de-rotation force being applied evenly to the whole apex. The device was used to de-rotate the thoracic spine by lifting up the apical major thoracic concave area and in this manner providing DVR.

2.3. Statistical analysis

Our internal studies of inter- and intra-rater reliability have shown excellent kappa statistics for all continuous measures (kappa > 0.80). Values are given as means, standard deviations (SD). Mann-Whitney's U test was used to calculate the level of significance for continuous variables. *P* values below 0.05 were considered statistically significant.

3. Results

3.1. Radiographical outcomes

The radiographical parameters are summarized in Table 2. The preoperative curve flexibility of the major thoracic curve was similar in both groups in the bending radiographs (37.2 ± 22.4% for the SDRRT group and 36.6 ± 20.3% for the SDRRT + DVR group, respectively, *P* = 0.95). Preoperatively, the mean main thoracic curve was 58.9 ± 12.4° for the SDRRT group and 59.9 ± 16.0° for the SDRRT + DVR group, which was corrected to 14.6 ± 6.7°and 13.4 ± 4.9 postoperatively and correction rates were 75.4 ± 10.4% and 77.2 ± 8.0%, respectively and 14.9 ± 7.1°and 14.3 ± 4.1 at 2-year follow-up and correction rates were 74.0 ± 7.1% and 75.9 ± 5.4%, respectively (not significant). No statistical difference was observed in the proximal thoracic or thoracolumbar/lumbar curve correction postoperatively and at postoperative 2-year follow-up between the study groups (Table 2).

Thoracic kyphosis increased postoperatively and at the postoperative 2-year follow-up in both the SDRRT group and the SDRRT + DVR group. The mean preoperative TK was 11.4 ± 7.3° in the SDRRT group, and 12.8 ± 11.5° in the SDRRT + DVR group, which improved significantly to 24.8 ± 5.2° and 23.6 ± 3.5° postoperatively and 23.3 ± 3.9° and 24.2 ± 6.0° at the postoperative 2-year follow-up, respectively. No statistical difference was observed in the C7-CSVL, AVT and LL preoperatively, postoperatively or at postoperative 2-year follow-up between the study groups (Table 3).

RSH increased postoperatively and decreased at postoperative 2-

Table 2
Radiographical Outcomes.

Parameter	SDRRT	SDRRT + DVR	P-value
Proximal thoracic curve			
Preoperative (°)	23.3 ± 9.6	30.6 ± 10.6	0.11
Postoperative (°)	9.2 ± 7.0	14.4 ± 6.1	0.07
Correction rate (%)	59.7 ± 23.6	51.4 ± 18.6	0.50
Postoperative 2 years (°)	8.7 ± 6.7	13.3 ± 8.5	0.08
Correction rate (%)	61.2 ± 26.2	59.5 ± 15.8	0.66
Main thoracic curve			
Preoperative (°)	58.9 ± 12.4	59.9 ± 16.0	0.94
Postoperative (°)	14.6 ± 6.7	13.4 ± 4.9	0.62
Correction rate (%)	75.4 ± 10.4	77.2 ± 8.0	0.74
Postoperative 2 years (°)	14.9 ± 7.1	14.3 ± 4.1	0.83
Correction rate (%)	74.0 ± 7.1	75.9 ± 5.4	0.79
Thoracolumbar/Lumbar curve			
Preoperative (°)	26.8 ± 8.7	31.8 ± 14.6	0.49
Postoperative (°)	7.8 ± 7.2	9.8 ± 6.9	0.35
Correction rate (%)	73.2 ± 20.6	65.7 ± 24.1	0.41
Postoperative 2 years (°)	8.8 ± 6.2	8.8 ± 4.9	0.98
Correction rate (%)	68.2 ± 22.5	69.8 ± 16.3	0.83

SDRRT: simultaneous double-rod rotation technique.
DVR: direct vertebral rotation.
Values are means ± standard deviation.

Table 3
Radiographical Outcomes.

Parameter	SDRRT	SDRRT + DVR	P-value
C7-CSVL			
Preoperative (mm)	3.6 ± 7.9	2.2 ± 11.2	0.45
Postoperative (mm)	1.2 ± 8.4	−0.9 ± 5.7	0.48
Postoperative 2 years(mm)	−2.7 ± 10.1	−1.4 ± 7.1	0.54
AVT			
Preoperative (mm)	48.7 ± 24.0	50.4 ± 19.3	0.79
Postoperative(mm)	6.4 ± 7.3	3.2 ± 15.8	0.74
Postoperative 2 years(mm)	3.8 ± 11.5	6.4 ± 15.4	0.96
TK			
Preoperative (°)	11.4 ± 7.3	12.8 ± 11.5	0.70
Postoperative (°)	24.8 ± 5.2	23.6 ± 3.5	0.76
Postoperative 2 years (°)	23.3 ± 3.9	24.2 ± 6.0	0.72
LL			
Preoperative (°)	40.2 ± 10.7	45.6 ± 8.76	0.18
Postoperative (°)	38.2 ± 10.2	43.9 ± 6.29	0.15
Postoperative 2 years (°)	40.4 ± 8.1	44.6 ± 6.7	0.25

SDRRT: simultaneous double-rod rotation technique.
DVR: direct vertebral rotation.
Values are means ± standard deviation.

Table 4
Radiographical Outcomes.

Parameter	SDRRT	SDRRT + DVR	P-value
RSH			
Preoperative (mm)	−8.6 ± 9.6	−13.5 ± 8.9	0.51
Postoperative(mm)	9.2 ± 5.5	14.3 ± 7.3	0.53
Postoperative 2 years(mm)	4.4 ± 8.6	4.7 ± 6.1	0.72
RAsag			
Preoperative (°)	19.1 ± 6.7	18.3 ± 7.5	0.66
Postoperative (°)	13.3 ± 4.3	10.1 ± 2.9	0.04
Postoperative 2 years (°)	13.9 ± 4.0	10.6 ± 2.8	0.02
Percent change of RAsag			
Postoperative (%)	28.2 ± 15.2	41.1 ± 15.8	0.05
Postoperative 2 years (%)	25.0 ± 12.7	38.5 ± 14.1	0.03

SDRRT: simultaneous double-rod rotation technique.
DVR: direct vertebral rotation.
Values are means ± standard deviation.

year follow-up in both the SDRRT group and the SDRRT + DVR group. The mean preoperative RSH was -8.6 ± 9.6 mm in the SDRRT group, and -13.5 ± 8.9 mm in the SDRRT + DVR group, which increased to 9.2 ± 5.5 mm and 14.3 ± 7.3 mm postoperatively and decreased to 4.4 ± 8.6 mm and 4.7 ± 6.1 mm at the postoperative 2-year follow-up, respectively.

Correction of vertebral rotation as RAsag was significantly better in the SDRRT + DVR group than in the SDRRT group. Correction of vertebral rotation did not change in either groups during the 2-year follow-up. The mean preoperative RAsag was 19.1 ± 6.7° in the SDRRT group, and 18.3 ± 7.5° in the SDRRT + DVR group, which improved to 13.3 ± 4.3° and 10.1 ± 2.9° postoperatively (P = 0.04) and 13.9 ± 4.0° and 10.6 ± 2.8° at postoperative 2-year follow-up (P = 0.02), respectively. The mean percent change RAsag (postoperative) was 28.2 ± 15.2% in the SDRRT group, and 41.1 ± 15.8° in the SDRRT + DVR group (P = 0.05), and the mean percent change RAsag (postoperative 2 years) was 25.0 ± 12.7% and 38.5 ± 14.1°, respectively (P = 0.03) (Table 4).

3.2. SRS clinical outcomes data

The SRS total and individual domain scores are shown in Table 5. The mean preoperative total score of 3.5 ± 0.5 in the SDRRT group and 3.6 ± 0.6 in the SDRRT + DVR group significantly increased to 4.6 ± 0.2, and 4.6 ± 0.3 on final follow-up, respectively.

Table 5
Five domains of Scoliosis Research Society-22 questionnaire.

Parameter	SDRRT	SDRRT + DVR	P-value
Function/ Activity			
Preoperative	4.2 ± 0.4	4.3 ± 0.5	0.30
Postoperative 2 years	4.7 ± 0.5	4.7 ± 0.5	0.96
Pain			
Preoperative	3.9 ± 0.3	3.4 ± 0.8	0.10
Postoperative 2 years	4.9 ± 0.4	4.7 ± 0.6	0.51
Self image/ Appearance			
Preoperative	3.1 ± 1.0	3.5 ± 0.7	0.30
Postoperative 2 years	4.4 ± 0.5	4.5 ± 0.5	0.80
Mental heal			
Preoperative	3.4 ± 0.8	3.4 ± 0.7	0.97
Postoperative 2 years	4.4 ± 0.5	4.7 ± 0.6	0.51
Satisfaction with management			
Preoperative	3.2 ± 0.9	3.2 ± 0.9	0.89
Postoperative 2 years	4.7 ± 0.5	4.7 ± 0.6	0.89
Total			
Preoperative	3.5 ± 0.5	3.6 ± 0.6	0.65
Postoperative 2 years	4.6 ± 0.2	4.6 ± 0.3	0.90

SDRRT: simultaneous double-rod rotation technique.
DVR: direct vertebral rotation.
Values are means ± standard deviation.

3.3. Surgical revisions and complications

There were no implant breakages or vascular and neurologic complications on final follow-up, with all patients demonstrating solid fusion.

3.3.1. Case presentation

3.3.1.1. Case 1. SDRRT group. A 12-year-old girl presented with AIS and a single right-sided convex thoracic curve (Figs. 3A-3D). The MT curve from T5 to T12 was 54° and the TK from T5 to T12 was 4°. Her curve pattern was Lenke type 1 A-. Postoperative radiographs obtained two years after surgery showed that the MT curve and the TK were 6° and 26°, respectively. Preoperative CT showed that vertebral rotation at the apex was 21° and postoperative CT obtained two years after surgery showed that vertebral rotation at apex was 15° (Figs. 3E, 3 F).

3.3.1.2. Case 2. SDRRT + DVR group. A 14-year-old girl presented with AIS and a single right-sided convex thoracic curve (Fig. 4A- 4D). The MT curve from T5 to T12 was 50° and the TK from T5 to T12 was 6°. Her curve pattern was Lenke type 1B-. Postoperative radiographs obtained two years after surgery showed that the MT curve and the TK were 6° and 25°, respectively. Preoperative CT showed that vertebral rotation at the apex was 21° and postoperative CT obtained two years after surgery showed that vertebral rotation at the apex was 9°.

4. Discussion

Most patients with IS are primary hypokyphotic in the thoracic region. The sagittal deformity remains critical because a flat back may lead to progressive decompensation and anterior imbalance [7,18]. Although an ideal surgical correction in thoracic IS patients should address reduction of a pre-existing hypokyphotic thoracic spine, conventional segmental PS fixation has decreased ability to restore TK [4–6]. Lowenstein et al. [4] reported that the PS system decreased TK by an average of 10°, and Kim et al [5] also reported an average decrease of 9°. Clements et al. [19] concluded that increasing implant density with pedicle screws was correlated with decreasing thoracic kyphosis.

Some surgical techniques have been reported to address this issue. One is an *in situ* rod-bending procedure after single-rod rotation [10]. However, a much greater load would be applied to the PSs around the area of rod bending, and this may increase the possibility of vertebral fractures or screw loosening because of the higher concentration of mechanical force around the screws. Vallespir et al. [21] also reported the vertebral coplanar alignment technique for the relocation of vertebral axis in a single plane. This technique uses slotted tubes attached to each pedicle screw to convex side on the thoracic curve. Two longitudinal rods were inserted through the end of tubes. Then, they were separated along the slots, driving the tubes into one plane, making the axis of the vertebrae coplanar and thus correcting transverse rotation and coronal translation. To obtain kyphosis, distal ends of the tubes were spread in thoracic spine. They reported that the curve correction rate in the main thoracic curve was 73% on average, and the average preoperative thoracic kyphosis of 18° remained unchanged after surgery. Another procedure using polyaxial PSs and polyaxial claws comprising a pedicle hook and an opposing transverse counterhook is reported by Clement et al. [20]. In this technique, 2 pre-bent rods are inserted and the deformity is reduced by tightening the nuts on both rods, allowing the vertebrae to gradually approach the rods. In their technique, the average preoperative TK of 17.3° improved to 33.1°. The SDRRT is a much simpler procedure. Once the 2 rods are connected to the screw heads, they are simply rotated simultaneously. During the double rod rotation maneuver, the forces of upward pushing and lateral translation of the spinal column were applied. As a result, thoracic kyphosis formation occurred. Sudo et al. [12] reported that the preoperative TK of 12° increased significantly to 20° using the SDRRT. In

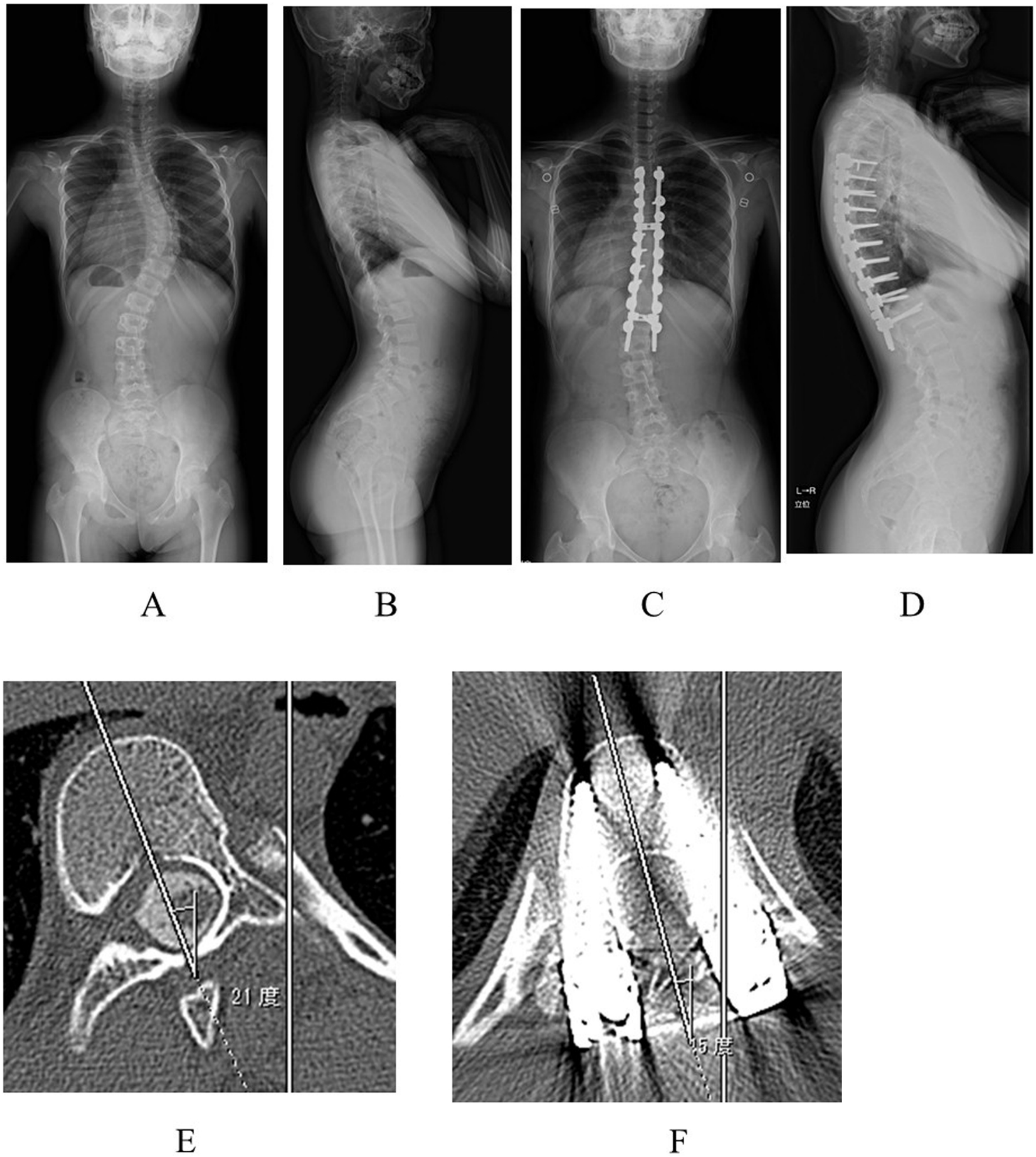

Fig. 3. Case 1. SDRRT group: Preoperative posteroanterior (A) and lateral (B) radiographs obtained in a 12-year-old female with Lenke 1 A- scoliosis. The MT curve from T5 to T12 was 54° and the TK from T5 to T12 was 4°. Posteroanterior (C) and lateral (D) radiographs obtained 2 years after surgery. The MT curve and the TK were 6° and 26°, respectively. Preoperative CT (E) showed that vertebral rotation at apex was 21° and postoperative CT obtained two years after surgery (F) showed vertebral rotation at the apex was 15°.

the fact, the present study showed that the preoperative TK of 12° increased significantly to 20° at 2 years postoperative follow-up.

Although the aforementioned techniques can maintain or restore TK, next-generation surgical strategies for thoracic AIS should include corrections in three anatomical planes. In particular, for the axial plane, the DVR obtained significantly better correction of apical vertebral rotation when compared to simple concave rod rotation [14,22,23]. Di Silvestre et al. [14] documented that a DVR maneuver using a vertebral column manipulator after a concave rod rotation maneuver showed a significantly better final correction of apical vertebral rotation. In our series, we found an average de-rotation rate of 39% in the SDRRT + DVR group and 25% in the SDRRT group. Furthermore, DVR provides a good clinical result on rib-hump prominence, avoiding additional procedures like thoracoplasty and related complications [14]. However, DVR induced a significant decrease in thoracic kyphosis after surgery. When using the DVR technique to decrease rotational deformity around the apex of the thoracic curve, the major applied force pushes the thoracic hump downward to decrease vertebral rotation deformity, which eventually causes dekyphosis of the thoracic spine [11]. In addition, according to Dickson's theory of IS development [24,25], anterior column overgrowth leads to lordotization and concomitant lateral "buckling" of the spine. Based on this theory, axial correction by DVR will inevitably result in further decrease of thoracic kyphosis [26]. In fact, Hwang et al [27] reported that the DVR group experienced a mean decrease in thoracic kyphosis as compared to in the non-DVR group. Di Silvestre et al. [14] and Mladenov et al. [28] also reported the loss of

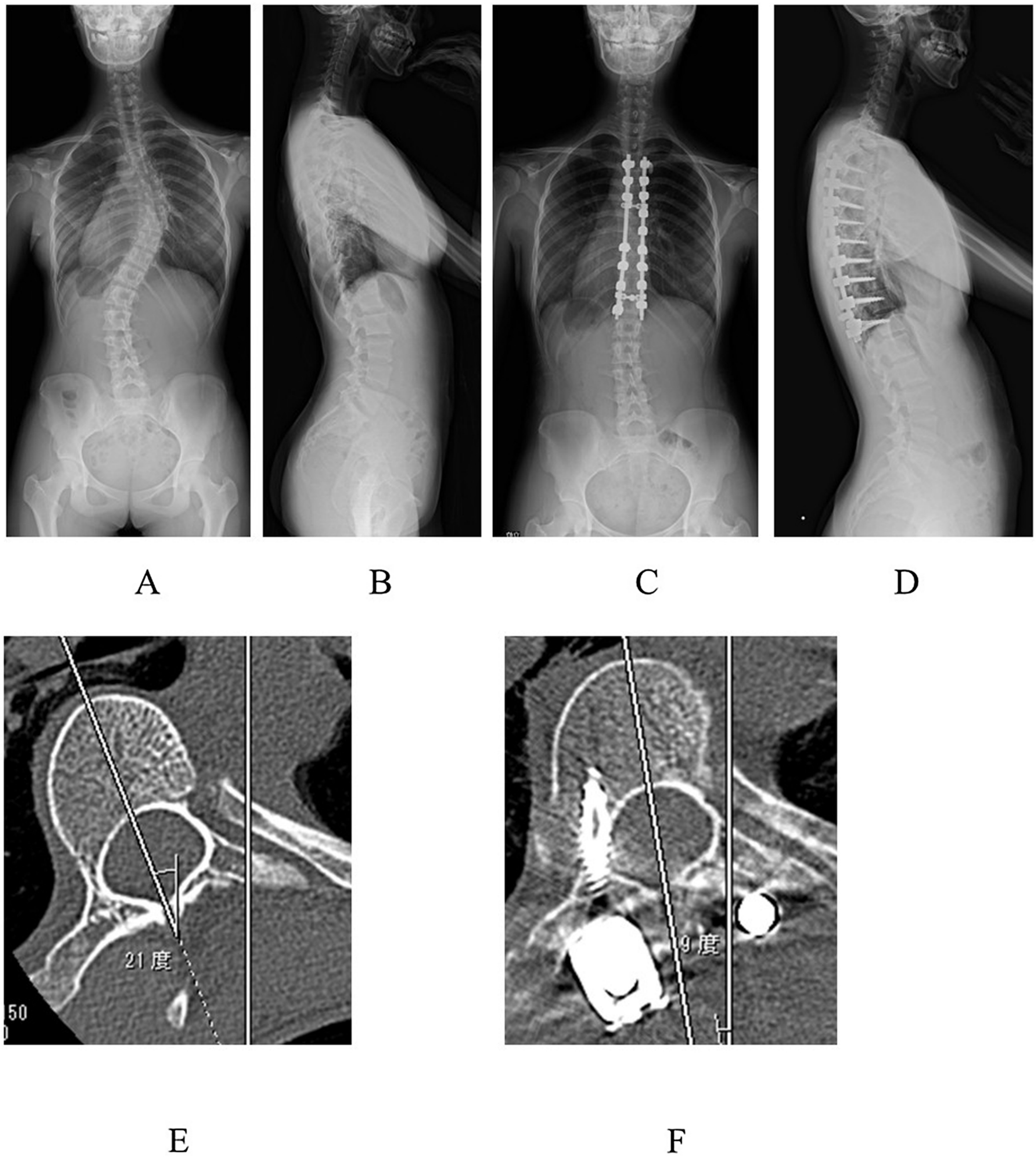

Fig. 4. Case 2. SDRRT + DVR group: Preoperative posteroanterior (A) and lateral (B) radiographs obtained in a 14-year-old female with Lenke 1B- scoliosis. The MT curve from T5 to T12 was 50° and the TK from T5 to T12 was 6°. Posteroanterior (C) and lateral (D) radiographs obtained 2 years after surgery. the MT curve and the TK were TK were 6° and 25°, respectively. Preoperative CT (E) showed that vertebral rotation at apex was 21° and postoperative CT obtained two years after surgery (F) showed vertebral rotation at apex was 9°.

thoracic kyphosis after DVR. In contrast, Faldini et al. [29] described the corrective maneuver using two differently contoured rods simultaneously in combination with direct vertebral rotation can provide a good sagittal alignment restoration. Demura et al. [30] also reported that a combination of segmental uniplanar screws, ultra high-strength 5.5-mm steel rods, aggressive differential rod contouring, periapical ponte osteotomies, and segmental direct vertebral derotation increased the TK in patients with hypokyphotic thoracic spine. In the present study, using DVR with VCM after SDRRT for IS, rotational correction was obtained without compromising kyphosis formation. The merits of this procedure are thoracic kyhosis formation by SDRRT and lifting up the low-lying main thoracic apical area by *en bloc* DVR with the derotation device, without pushing the thoracic hump downward.

Our study has some limitations. The present study is a retrospective design. Additionally, the sample size was small and we did not evaluate data for clinical correction of the rib hump. Therefore, it was not possible to compare improvement of cosmetic appearance between both groups. Although there were significant differences in vertebral rotation between the SDRRT group and SDRRT + DVR group, there are slight difference (only 3.8° difference between SDRRT and SDRRT + DVR groups 2 years after operation) and no significant differences for SRS-22. Still, there is no clear evidence that application of DVR benefits in terms of clinical outcome and patient's self-assessment [31]. It would be ideal to increase the sample size and evaluate the thoracic kyphosis formation of the SDRRT + DVR maneuver and the clinical relevance of the DVR maneuver. Future studies are required to address these issues.

5. Conclusion

We evaluated the effect of the thoracic kyphosis formation and rotational correction by DVR after SDRRT for IS. Although previous papers reported that pedicle screw constructs appear to decrease the amount of thoracic kyphosis, our results suggest that the addition of DVR after SDRRT does not compound the adverse impact on the sagittal profile. In addition, in the SDRRT + DVR group, there were no significant differences between any other radiographic parameters and clinical outcomes, compared with the SDRRT group.

Conflict of interests

None.

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