

Efficacy Comparison of Multiplanar Deformity Reducer System and Direct Vertebral Rotation in Adolescent Idiopathic Scoliosis Corrective Surgery

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Objective : This study aims to evaluate the efficacy of the multiplanar deformity reducer (MDR) and direct vertebral rotation (DVR) techniques in surgically treating adolescent idiopathic scoliosis (AIS), focusing on surgical and radiographic outcomes.

Methods : A retrospective analysis was conducted on AIS patients who underwent surgery between December 2017 and August 2019, comparing the outcomes of those treated with MDR system and DVR technique. Data on demographics and surgical characteristics were collected, while radiographic parameters were measured manually by three spine surgeons and by EOS 3D analysis (EOS imaging, Paris, France).

Results : Nine patients were surgically corrected with the MDR system and 13 with DVR, who were predominantly females with an average age in their late teens. Despite more fusion levels in the MDR group (12.3±1.0) compared to the DVR group (10.0±3.2), operation time, blood loss, overall radiographic correction, and patient-reported outcome was comparable. Moreover, only the interrater reliability for manual apical vertebral rotation measurements was below good, which necessitates the use of EOS 3D analysis.

Conclusion : The MDR technique is effective and safe for AIS surgery, offering comparable corrective efficacy to the DVR technique. Furthermore, EOS 3D imaging was more reliable for assessing rotational deformities, which incorporates pelvic position.

Key Words : Adolescent idiopathic scoliosis · Apical vertebral rotation · EOS imaging · Direct vertebral rotation · Multiplanar deformity reducer.

INTRODUCTION

Adolescent idiopathic scoliosis (AIS) is a complex three-dimensional spinal deformity of unknown etiology, character-

ized by lateral curvature in the coronal plane, thoracic hypokyphosis in the sagittal plane, and axial rotation³⁰. Given the limited understanding of the pathogenesis, the primary focus has been on early detection, prevention of progression, and sur-

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gical correction following diagnosis as necessary. Surgical intervention aims to correct the deformity, achieve trunk balance, and preserve motion segments through strategic spinal fusion. Over time, various surgical approaches have been developed to address these deformities.

The pioneering surgical technique for AIS correction, introduced by Paul Harrington in 1962, was widely adopted for over two decades¹⁰. This method, focusing exclusively on distractive forces, failed to address spinal rotation and rib hump deformities adequately. The evolution of posterior scoliosis surgery in the 1980s, spearheaded by Cotrel and Dubousset, introduced a method for intraoperative curve correction using multihook segmental instrumentation. Then, the introduction of pedicle screws led to significant modifications of the original Cotrel-Dubousset method, establishing a new standard in scoliosis corrective surgery^{11,15,27}. Subsequent technical advancements in scoliosis surgery have primarily focused on optimizing curve correction techniques and fusion level selection firmly based on pedicle screw-only, or hybrid constructs²⁶. And to address the rotational malalignment in AIS, the direct vertebral rotation (DVR) technique was introduced by Suk in 2004¹⁸. This surgical technique applies a direct rotational force to the apical vertebrae.

More recently, the multiplanar deformity reducer (MDR) system was developed to facilitate scoliosis correction by facilitating gradual rod derotation. However, the safety and efficacy of the MDR system in terms of surgical outcomes have yet to be thoroughly investigated. While very few studies, focusing on the “simultaneous translation on two rods” maneuver—similar to the MDR technique—have reported efficacy particularly in correcting thoracic hypokyphosis, comprehensive evaluations are still required^{16,24}. In this context, this study aims to share our experiences using the MDR system for AIS corrective surgery and to evaluate its impact on radiographic and surgical outcomes in comparison to the established DVR technique.

MATERIALS AND METHODS

We conducted a retrospective analysis of consecutive posterior scoliosis corrective surgeries performed by a single experienced spine surgeon from December 2017 to August 2019. This study was approved by the Institutional Review Board of Seoul National University Bundang Hospital (B-2404-892-108). Eligible patients were selected from our institution’s electronic

health records based on the following criteria : 1) who underwent deformity corrective surgery for AIS using either the MDR system or DVR technique, 2) who possessed pre- and postoperative whole-body standing radiographs using the EOS imaging system along with the EOS 3D analysis for radiographic parameters, and 3) who had pre- and postoperative computed tomography (CT) scans. Patients were excluded if they 1) had syndromic scoliosis or 2) had undergone previous spinal surgery.

Demographic data, scoliosis characteristics, and operative characteristics were analyzed. Radiographic parameters were measured using the last follow-up imagings and measured by three independent spine surgeons manually with the average value used for analysis, along with the interrater reliability analyzed by intraclass correlation coefficient (ICC). Central sacral vertical line (CSVL), Cobb angle (CA), thoracic kyphosis (TK), lumbar lordosis (LL), and radiographic shoulder height (RSH) defined by the difference between bilateral acromioclavicular joints were measured from whole-body standing EOS radiograph, and apical vertebral rotation (AVR) was measured from CT. Radiographic parameters were also acquired using EOS 3D analysis, with interrater reliability between manual measurements assessed through ICC. The CSVL was deemed positive for deviations to the right and negative for deviations to the left. AVR was deemed positive for clockwise rotation and negative for counterclockwise rotation. Postoperative shoulder imbalance (PSI) was deemed present for RSH over 15 mm as per previous study¹⁶. Furthermore, the Scoliosis research society-22 (SRS-22) score was analyzed as a patient-reported outcome measure.

Regarding surgical procedures, patients were positioned prone on the Jackson spine table with Gardner-Wells tong axial traction. Intraoperative monitoring was done with somatosensory evoked potential and transcranial motor evoked potential. The surgical technique was consistent across cases, involving posterior subperiosteal dissection, facet release, and freehand insertion of all pedicle screws. The randomly predetermined scoliosis correction technique of either MDR or DVR was followed by lamina decortication and posterior onlay fusion. The MDR system utilized in our study was the Multi Deformity ReducerTM, manufactured by CGBio in Korea. Strategies to minimize intraoperative bleeding was also uniform including cell salvage system and administration of intraoperative tranexamic acid^{4,5}.

The use of MDR system functions similarly to reduction screw heads, facilitating gradual and controlled derotation of rod. Upon insertion of polyaxial pedicle screws and facet release, the MDR system is mounted on top of the screw heads (Fig. 1A), then the precontoured rod is inserted (Fig. 1B). In pace with the gradual derotation, the precontoured rod can be incrementally tightened. This is achievable due to the screw-mounted system's design, which is sufficiently elongated to accommodate a floating rod positioned above the screw heads. Additionally, the system includes a tightener specifically engineered for this purpose (Fig. 1C and D). This system facilitates the intentional conversion of scoliotic curve into normal ky-

photic alignment via reductional traction of vertebral bodies toward the rods. Such curvature conversion is theoretically challenging to achieve with the DVR technique, which corrects the major curve only through rotational force. Following rod tightening, set-screws are inserted, tightened, then locked after the removal of the MDR system (Fig. 1E and F).

Statistical analyses were executed using R software (version 4.2.2; www.r-project.org), with the t-test applied for quantitative data and the chi-squared test for binary data. A *p*-value of less than 0.05 was considered statistically significant. Interrater reliability for the radiographic parameters was assessed using the ICC.

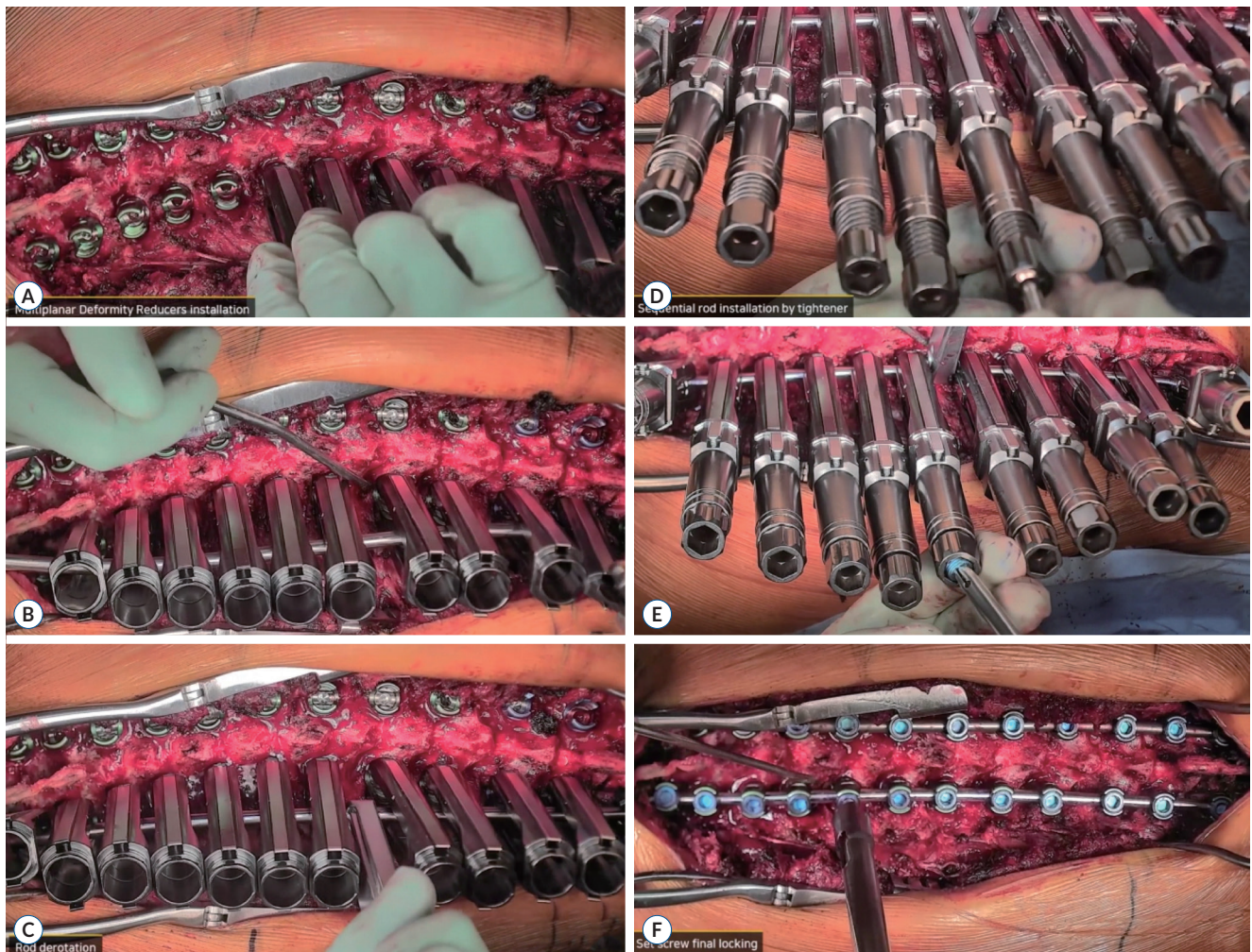


Fig. 1. The procedural steps of scoliosis curve correction for main thoracic curve of an adolescent idiopathic scoliosis patient using multiplanar deformity reducer (MDR) system. A : Installation of MDR system on the concave aspect of the main thoracic curve following midline skin incision and periosteal dissection of the fusion levels. B : Insertion of a precontoured rod into the MDR system. C : Derotation of the inserted rod for curve correction. D : Sequential rod installation by tightener. E : Set screw insertion and gradual tightening. F : Set screw final locking following removal of the MDR system and further scoliosis correction using *in situ*-bender and L-bender.

RESULTS

Demographics, scoliosis characteristics, and operative characteristics

The study included 22 patients, divided into two groups : nine in the MDR group and 13 in the DVR group. Both groups had a mean age in the 18-year range and exhibited a predominance of female patients (Table 1). In terms of the Lenke classification, type 2 curves exclusively presented in the MDR group (3 vs. 0, $p=0.025$), while type 5 curves exclusively presented in the DVR group (0 vs. 5, $p=0.034$). No significant difference was observed in the apex level category between the two groups. However, the number of fused vertebrae differed significantly between groups, with the MDR group having 2.3 more levels fused than the DVR group in average, (12.3 ± 1.00 vs. 10.0 ± 3.23 , $p=0.031$) possibly reflecting different fusion level requirement from curve type difference. Screw density, estimated blood loss, and operation time were similar across both groups. There was

no reoperations until last follow-up.

Radiographic parameters with interrater reliability analysis, and patient-reported outcome scores

The study observed no significant differences between the MDR and DVR group concerning preoperative and postoperative values and the degree/percentage of correction for the CSVL, CA of the major curve, TK, LL (Table 2). RSH and PSI ratio immediately postoperatively and at the 2-year follow-up also showed no significant differences. Both groups exhibited significant CSVL correction, ranging from 80% to 90% which is quite large, attributable to the initially centered vertebral column with small preoperative CSVL values (-38.4 mm to 27.4 mm). The correction of CA was substantial in both groups, with an average reduction of approximately 35 degrees from preoperative values. TK increased in both groups, with a notably high average correction percentage in the MDR group, pri-

Table 1. Patient demographics, scoliosis characteristics, and operative characteristics

	MDR (n=9)	DVR (n=13)	p-value
Demographics			
Age (years)	18.7 $\pm$ 2.6	18.6 $\pm$ 5.9	0.978
Sex, female	6 (66.7)	11 (84.6)	0.323
Follow-up (months)	30.8 $\pm$ 23.4	39.2 $\pm$ 26.7	0.454
Reoperation	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	1.000
Lenke classification			
1	3	5	0.805
2	3	0	0.025*
3	1	1	0.784
4	1	0	0.218
5	0	5	0.034*
6	1	2	0.773
Apex vertebra of major curve			
Thoracic (T2-T11/12 disc)	7	4	0.301
Thoracolumbar (T12-L1)	2	6	0.251
Lumbar (L1/2 disc-L4)	0	3	0.120
Operative characteristics			
Fusion level	12.3 $\pm$ 1.0	10.0 $\pm$ 3.2	0.031*
Screw density	1.84 $\pm$ 0.17	1.93 $\pm$ 0.12	0.222
Blood loss (mL)	422 $\pm$ 164	408 $\pm$ 328	0.892
Operation time (minutes)	236 $\pm$ 48	230 $\pm$ 104	0.855

Values are presented as mean $\pm$ standard deviation or number (%). *Statistically significant, $p<0.05$. MDR : multiplanar deformity reducer, DVR : direct vertebral rotation

Table 2. Radiographic parameters and patient-reported outcome scores

	MDR (n=9)	DVR (n=13)	p-value
CSVL			
Pre	4.1±20.5	-2.5±13.3	0.413
Post	-1.8±6.2	-4.7±7.6	0.344
Correction (degree)	14.6±9.4	7.2±6.1	0.056
Correction (%)	91.3±42.7	80.0±62.1	0.667
Cobb angle			
Pre	56.8±10.0	56.9±13.9	0.991
Post	21.4±9.7	22.3±7.3	0.817
Correction (degree)	35.4±8.6	34.5±9.3	0.829
Correction (%)	62.9±14.0	60.6±8.0	0.660
TK			
Pre	25.1±18.0	24.3±12.0	0.906
Post	31.5±12.9	31.4±10.9	0.992
Correction (degree)	8.08±6.07	9.22±5.88	0.666
Correction (%)	97.7±137	49.2±42.5	0.330
LL			
Pre	44.8±13.3	41.6±12.4	0.580
Post	47.6±9.9	41.8±7.9	0.166
Correction (degree)	5.43±5.15	6.55±5.21	0.623
Correction (%)	14.6±16.2	18.9±23.7	0.621
Shoulder balance			
Post (immediate) RSH (mm)	9.30±5.07	8.98±8.30	0.911
Post (immediate) PSI	1 (11.1)	3 (23.1)	0.474
Post (2 year) RSH (mm)	4.78±2.51	5.74±4.86	0.552
Post (2 year) PSI	0 (0.0)	1 (7.7)	0.394
AVR (CT)			
Pre	-13.7±18.1	11.3±25.1	0.013*
Pre [†]	20.4±8.3	25.1±9.2	0.227
Post	-9.3±15.4	8.4±18.6	0.025*
Post [†]	15.2±8.6	18.1±8.1	0.441
Correction (degree) [‡]	5.21±2.77	7.04±5.06	0.290
Correction (%) [‡]	30.1±22.5	29.7±18.7	0.970
AVR (EOS)			
Pre	-0.4±23.9	9.5±21.2	0.462
Pre [†]	18.6±11.9	20.6±8.4	0.745
Post	-0.3±13.2	2.6±9.2	0.646
Post [†]	10.3±6.9	8.0±4.7	0.482
Correction (degree) [‡]	11.7±4.4	12.7±8.9	0.796
Correction (%) [‡]	91.5±96.6	56.8±29.0	0.472
SRS-22			
Pre	3.52±0.17	3.95±0.45	0.231
Post	3.98±0.47	4.42±0.37	0.307

Values are presented as mean±standard deviation or number (%). *Statistically significant, $p<0.05$. [†]Data presented as absolute values. [‡]Data calculated with original values, not absolute values. MDR : multiplanar deformity reducer, DVR : direct vertebral rotation, CSVL : central sacral vertical line, TK : thoracic kyphosis, LL : lumbar lordosis, RSH : radiographic shoulder height, PSI : postoperative shoulder imbalance, AVR : axial vertebral rotation, CT : computed tomography, pre : preoperative, post : postoperative, SRS-22 : Scoliosis research society-22

Table 3. Interrater reliability analysis for radiographic parameter measurement between three spine surgeons, and between surgeons and EOS 3D imaging analysis (EOS imaging, Paris, France)

	Between three spine surgeons					Between surgeons and EOS 3D imaging			
	ICC	p-value	Surgeon 1	Surgeon 2	Surgeon 3	ICC	p-value	Surgeons	EOS 3D
Cobb angle (pre)	0.867	<0.001	56.7±11.9	48.9±12.9	50.2±13.5	0.959	<0.001	51.7±13.3	54.5±15.6
TK (pre)	0.906	<0.001	24.2±14.1	21.6±13.4	24.5±13.3	0.897	<0.001	23.3±11.6	20.0±14.6
LL (pre)	0.887	<0.001	41.9±12.0	41.7±14.3	37.5±11.7	0.916	<0.001	39.2±10.1	41.1±13.5
AVR (CT) (pre)	0.731*	<0.001	22.7±8.1	16.7±13.8	17.6±10.2	0.499 [†]	0.113	19.9±10.8	19.8±9.4
Cobb angle (post)	0.832	<0.001	21.1±7.0	17.1±8.2	15.7±8.3	0.862	<0.001	16.5±6.1	21.3±9.7
TK (post)	0.921	<0.001	30.0±11.3	24.8±10.1	26.7±12.5	0.906	<0.001	25.7±8.8	27.0±11.9
LL (post)	0.850	<0.001	44.9±9.1	42.7±8.5	37.8±10.2	0.872	0.001	40.9±6.3	43.3±8.3
AVR (CT) (post)	0.690*	0.001	16.4±7.9	14.6±9.6	15.7±9.0	0.712*	0.016	15.7±6.9	8.9±5.8

Values are presented as mean±standard deviation. *0.5< ICC <0.75, indicating moderate reliability. [†]ICC <0.5, indicating poor reliability. ICC : intraclass correlation coefficient, TK : thoracic kyphosis, pre : preoperative, LL : lumbar lordosis, AVR : apical vertebral rotation, CT : computed tomography, post : postoperative

marily due to three patients who had initially less than 10 degrees of hypokyphosis corrected to normal range. The shoulder balance, as indicated by the RSH, was corrected to approximately 5 mm in both groups, with only one case of PSI observed in the DVR group at the 2-year follow-up.

To avoid dilution of data from averaging contralateral rotational values, absolute values were also measured and analyzed for AVR, revealing no significant differences between groups for both preoperative and postoperative values. However, unlike other radiographic parameters which demonstrated good interrater reliability in ICC analysis, the pre- and postoperative AVR measurements from CT exhibited only moderate reliability across the three spine surgeons' assessments (Table 3). Similarly, the ICC between EOS 3D analysis and measurements by surgeons indicated below-good reliability. The discussion section further explores the implications of these findings on the reliability of AVR and EOS 3D measurements.

Lastly, the SRS-22 score improved postoperatively, without significant differences between groups.

DISCUSSION

AIS predominantly affects otherwise healthy children, with a prevalence rate of approximately 1% to 3% among the at-risk population aged 10 to 16 years. Despite extensive research, the pathogenesis of AIS remains elusive, with studies on genetic and epigenetic factors providing inconclusive results^{1,3,30}. Con-

sequently, current treatment strategies post-diagnosis, whether conservative or surgical, are the primary focus for clinicians.

In this context, many studies aim to identify the least invasive yet most efficient surgical method for correcting the scoliosis curve, when surgery is deemed necessary. The prevailing approach to scoliosis corrective surgery involves segment fixation after careful fusion level selection to mitigate and prevent progression of scoliosis. Additionally, it is crucial to address accompanying thoracic hypokyphosis to ensure the overall spinal balance is appropriately corrected. In achieving these surgical objectives, attention must also be given to perioperative complications, including bleeding, operative time, surgical technique complexity, and potential surgical complications. While AIS corrective surgery recipients are typically healthy with favorable outcomes, the cumulative impact of these complications can lead to unsatisfactory clinical results or postoperative care challenges. Large-scale studies have indicated medical and surgical complication rate of approximately 6% for non-syndromic pediatric scoliosis surgery, with common complications including surgical site infection, pulmonary, neurologic, and implant-related issues^{7,22}.

In the current era, where pedicle screw constructs have become the standard for fusion constructs, simple rod derotation and DVR are the two principal techniques for scoliosis curve correction, with many studies comparing their effectiveness. The debate continues, as some studies suggest that DVR achieves greater curve correction or offers additional corrective capabilities beyond simple rod derotation^{8,18,21,25}. However,

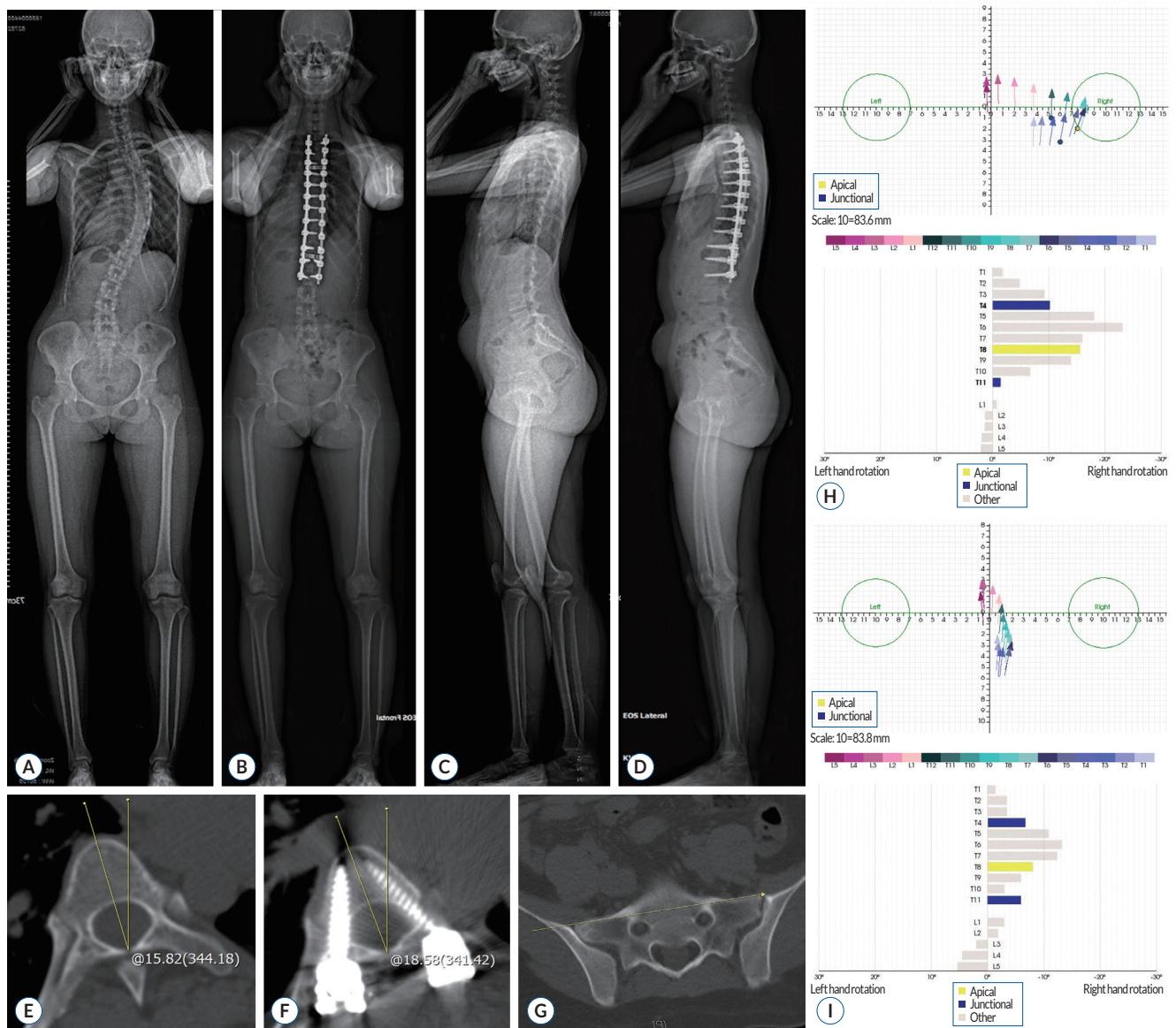


Fig. 2. The example of a 22-year-old female adolescent idiopathic scoliosis patient who underwent surgical deformity correction using multiplanar deformity reducer (MDR) system. A and C : Preoperative EOS radiographs. Lenke type 1A- curve with the apex at T8, 56.6° Cobb angle, and 3.6° thoracic hypokyphosis. B and D : Postoperative EOS radiographs. Following T2 to L2 posterior instrumented fusion, scoliosis corrected to 12.1° Cobb angle and 17.4° thoracic kyphosis. E : Preoperative CT with apical vertebral rotation (AVR) of -15.8° on radiographic plane. F : Postoperative CT with AVR of -18.5° on radiographic plane. G : Postoperative computed tomography (CT) showing pelvic obliquity, which is not taken into account in the radiographic plane. H : Preoperative EOS 3D analysis (EOS imaging, Paris, France) showing AVR of -15.5° on patient plane. I : Postoperative EOS 3D analysis showing AVR of -5.9° on patient plane. Notably, there exists a discrepancy of 12.6° in the postoperative AVR when compared with CT measurement, attributable to the consideration of pelvic obliquity in the EOS 3D analysis.

some studies argue that DVR does not significantly enhance curve correction^{14,23)}, or that it may be associated with increased bleeding, operative time²⁸⁾, and exacerbation of pre-existing thoracic hypokyphosis in AIS patients^{20,29)}. Furthermore, the DVR technique requires insertion of segmental monoaxial

screws complicating rod assembly and utilizes dramatic corrective force carrying higher risk of screw pullouts. On the other hand, the MDR system employs a more gradual correction at multiple and bilateral fixation points, enhancing convenience—a benefit that is difficult to quantify and safety. Con-

sidering these debates, this study presents data from our single-center experience comparing the MDR system with the DVR technique in terms of surgical and radiographic outcomes.

It should be acknowledged that defining the success of surgical treatment of AIS is difficult¹²⁾. Radiographic indicators like vertebral rotation or CA are commonly used, yet there is no consensus on specific thresholds for determining successful outcomes. Furthermore, while functional parameters and health-related quality of life measures are considered, they present their own set of challenges due to the variability of functional impairments among AIS patients and the inherent limitations of questionnaires which relies on Likert item responses²⁾. And in this study, outcomes are presented using various measures including radiographic outcomes, perioperative complications, and the SRS-22 score.

Despite the MDR group requiring more fusion levels, both groups exhibited similar blood loss and operation times, highlighting the technical feasibility of the MDR technique. However, the small sample size and uneven distribution of curve types caution against drawing definitive conclusions (Table 1). As there was no CSVL deviation beyond 4 cm and had CA ranging from 45.5° to 71.3°, there was no so-called severe surgical curve in the study group, which is considered to cause functional impairment, although there lacks definite criteria^{9,17)}. The CA of major curve was corrected to around 20°, or 60% for both groups, acceptable based on previous studies^{15,19)}. Regarding AIS-associated thoracic hypokyphosis, four out of nine patients in MDR group and six out of 13 patients in DVR group had TK of below 20°, with all of them corrected into TK of above 20° except for one patient in MDR group corrected from 3.6° to 17.4°, and one patient in DVR group corrected from 17.6° to 17.5°. Overall, the concern that DVR may exacerbate thoracic hypokyphosis was not evidenced from our study, and patients were corrected into around 30° of TK by surgical correction^{20,29)}. Regarding vertebral rotation measurement, previous studies with the AVR measured from EOS 3D analysis presents around 10° as the usual postoperative outcomes, which is consistent with our results (Table 2)^{13,32)}. However, the manual measurements from CT by three spine surgeons showed higher degrees of AVR (Table 2) with below-good reliability of ICC value of 0.731 and 0.690 for pre- and postoperative measurements (Table 3). This discrepancy may stem from individual differences in considering the patient's positioning and pelvic obliquity, highlighting the importance of accounting for patient

plane in measurement (Fig. 2). Previous study has pointed out that by considering patient position, asymmetry, and pelvic obliquity, more accurate sagittal and rotational parameters can be acquired than by radiographic plane³¹⁾. This is also evidenced from our data of relatively low interrater reliability values for the AVR between EOS 3D analysis and manual measurements.

Overall, our study demonstrated that the MDR system is comparably effective in various aspects of AIS corrective surgery, including operative blood loss, operation time, complications, reoperation rates, radiographic correction, and clinical outcome. Although the theoretical advantages of the MDR system motivated our study, its superiority over other technique was not empirically demonstrated. Furthermore, the DVR group also did not show obvious surgical complications such as screw pullouts, likely due to the small sample size and the absence of cases with extreme curvature. Thus, the value of this study lies in providing surgeons with additional evidence when considering the use of the MDR system. Additionally, this study highlights the advantages of using EOS 3D analysis for rotational parameters. Unlike CT scans which primarily focus on the radiographic plane, EOS 3D analysis takes into account the patient plane by considering the position of the pelvis.

Our study is not without limitations. Firstly, this is a retrospective study with small sample size and uneven distribution of curve types between groups. The challenge in enrolling sufficient number of cases was largely due to the study's focus on a relatively novel instrument-employing technique. Consequently, our conclusion that the MDR system is non-inferior to the DVR technique could be subject to further scrutiny in larger studies. However, it is noteworthy that a few studies focusing on surgical techniques nearly identical to the MDR system have also demonstrated benefits in curve correction and TK restoration, which lend support to the potential advantages of the MDR system^{6,24)}. Secondly, the study did not account for the rigidity of the scoliosis curves or include patients with severe category of surgical curves that typically present more complex surgical challenges. The variability in curve rigidity and severity is known to impact the effectiveness of corrective techniques, suggesting that our results might have differed had these factors been considered. Lastly, rib hump, another common measurement used in the outcome assessment of AIS corrective surgery, was not measured and therefore could not be included in the analysis due to the retrospective nature of this study.

CONCLUSION

Our study demonstrated that the MDR system was not inferior to the conventional DVR technique in AIS rotational deformity corrective surgery. Future studies with larger, more diverse cohorts and a more comprehensive analysis of outcomes are required to validate our findings. Furthermore, EOS 3D analysis, which considers pelvis position, proved beneficial for assessing scoliosis curves.

AUTHORS' DECLARATION

Conflicts of interest

No potential conflict of interest relevant to this article was reported.

Informed consent

This type of study does not require informed consent.

Author Contributions

Conceptualization : SJH, KJK; Data curation : SJH, JMA; Formal analysis : SA, SJH, JMA, BJP, SHW; Funding acquisition : SJH; Methodology : SJH, JMA, BJP, SHW, KJK; Project administration : SJH; Visualization : SA, SJH; Writing - original draft : SA, JMA; Writing - review & editing : SJH

Data sharing

None

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