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Adolescent Idiopathic Scoliosis Treated with Simultaneous Translation on Two Rods (ST2R) Involving Preoperative, Postoperative, and Follow-Up Evaluation by EOS 3D Imaging: A Case Series

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Abstract

Objective: To evaluate preoperative, postoperative, and follow-up of spinal and pelvic parameters using EOS 3D imaging in adolescent idiopathic scoliosis (AIS) patients who underwent simultaneous translation on two rods (ST2R) technique for corrective posterior spinal surgery.

Methods: Five patients had surgical correction of Lenke type 1 or 2 AIS using the ST2R technique. The preoperative average Cobb angle was 72.4° ± 19.4. Low-dose standing biplanar radiographs were obtained to evaluate several spinal and pelvic parameters preoperatively (five patients), immediately postoperatively (four patients), and at follow-up (four patients). Three-dimensional reconstructions were performed (a total of 13 reconstructions).

Results: The mean number of levels fused was 11.2° ± 2.0. The number of pedicle screws used for constructs averaged 19.2° ± 3.06 (1.75 density screw per vertebra). The Cobb angle values were significantly changed by the operation (75° ± 21 to 28° ± 7, p = 0.009), but no other parameters were altered. The maximal apical axial change at the junctional region was 32.8° (absolute value), and the minimal apical axial change at the apical region was 4.8° (absolute value). The intervertebral rotation difference in the axial plane was larger near the apical region (T8-T9), from 2.1° ± 2.7 to -14° ± 6.9, and smaller near the junctional region (T12-L1), from -2.6° ± 2.9 to -1.1° ± 8.4.

Conclusion: This case series suggests that corrective posterior spinal surgery for AIS using ST2R can achieve both 3D correction of the spine and additional intervertebral axial rotation, with minimal deterioration during follow-up. Preoperative, postoperative, and follow-up evaluation can be accurately evaluated with EOS low-dose 3D imaging.

Keywords

Simultaneous Translation on Two Rods, Adolescent Idiopathic Scoliosis, 3D Spinal Reconstruction, EOS Imaging, Scoliosis

Introduction

Adolescent idiopathic scoliosis (AIS) is a structural spinal deformity with an unknown etiopathogenesis, affecting about 1% to 3% of children between 10 and 16 years old [1-4]. Severe morphologic changes, such as rib cage and pelvic asymmetry, may develop in affected individuals [5,6]. Although conventionally diagnosed and classified based on two-dimensional X-ray projections of the spine, AIS is a three-dimensional deformity that affects all three vertebral planes (coronal, sagittal, and transverse) [6-9]. The simultaneous translation on two rods (ST2R) technique was designed to achieve three-dimensional correction of spinal deformities, including scoliosis and kyphosis. ST2R pulls the spine toward the pre-contoured rods rather than pushing down or levering the spine. Clement et al. demonstrated superior sagittal correction with ST2R reduction compared to cantilever reduction [13,14].

Traditionally, the Cobb method has been the standard for quantifying the degree of deformity [10]. This angle is based on sagittal and coronal radiographic views but does not adequately portray the 3D nature of scoliosis because it overlooks the rotational component [11]. Thus, 3D models have been used to better evaluate spinal deformities [9]. Magnetic resonance imaging (MRI) and computerized tomography (CT) show the full 3D geometry of the spine, but they are performed in a supine position, which modifies the curvature [12,9]. Additionally, CT exposes young patients to high radiation.

EOS (EOS Imaging, Paris, France) is a relatively new development that can avoid some of the problems associated with other imaging methods. It is a low-dose X-ray device that creates a 3D reconstruction of the spine from biplanar (lateral and posteroanterior) images taken simultaneously (**Fig-1**) [1,12]. Because it automatically records many different spinal and pelvic parameters, EOS is particularly helpful for evaluating changes in spinal deformity after surgery.

The objective of this study was to compare preoperative, postoperative, and follow-up 3D spinal and pelvic parameters using EOS imaging in patients who had corrective (ST2R) instrumentation and fusion for AIS.

Fig-1: EOS Imaging System

Methods

Patients:

Following institutional review board approval, five consecutive patients with AIS (Lenke type 1 or 2) who underwent surgical correction using the ST2R technique were retrospectively studied. Four patients with a minimum follow-up of 8 months were included. Patients were evaluated preoperatively, in the early postoperative period (within six weeks), and at the latest follow-up. None of the patients had prior spinal surgery.

Surgical Technique:

For the ST2R reduction maneuver, two 6.0-mm titanium rods are first bent according to the desired sagittal profile and then attached to the anchors with threaded polyaxial screw extensions and claws. Two proximal nuts are tightened on the threaded extension to lock the rotation of the rods. Gradual and alternating tightening of the nuts on the threaded rods pulls the vertebrae back toward the rods (translation maneuver), reducing the coronal plane and restoring kyphosis. Unlike other techniques that bring the rod toward the anchorages, ST2R pulls the vertebrae back toward the rods, distributing the forces among all vertebrae with anchorages. No distraction techniques were used.

Reconstruction Process:

Full 3D images of the spine were reconstructed (a total of 13 reconstructions) by a trained observer. The preliminary step involved identifying a segment on the sacral endplate and two spheres around the femoral heads in the acetabulum, which allowed for the creation of a 'patient frame' compatible with the reference axis used by the SRS for AIS classification [15]. In the spinal curve, the T1 upper endplate and the L5 lower endplate were digitized and used as predictors to statistically estimate the other parametric spine 3D-model descriptors. A highly detailed 3D model was generated and then projected onto both X-rays so that the operator could verify and, if necessary, make fine adjustments to the position and shape of each reconstructed vertebra (T1–L5) [16].

Method of Evaluation:

Several spinal and pelvic parameters were measured preoperatively, postoperatively, and at the latest follow-up. Although all five patients had preoperative measurements, only four had immediate postoperative and latest follow-up measurements. The parameters measured included major and minor Cobb angles, T1/T12 and T4/T12 kyphosis, L1/L5 and L1/S1 lordosis, apical vertebral rotation (AVR), pelvic incidence, sacral slope, and sagittal pelvic tilt. Additionally, intervertebral axial rotation was measured.

Kyphosis was defined as the angle between vectors normal to the endplates when projected onto the local sagittal (xz) plane. Similarly, the local coronal Cobb angle for each vertebra and disc was defined as the angle between vectors normal to the endplates when projected onto the local coronal (yz) plane [17]. Apical vertebral rotation was defined as the angle between the projections of the apical vertebra's x-axis and the global spinal reference frame onto the XY plane of the global spinal reference frame. The intervertebral axial rotation used the same projection concept. Clockwise rotation was defined as positive, using the anteroposterior view [17]. Intervertebral rotation in the axial plane between adjacent vertebrae was defined as the angle between adjacent y-axes projected onto the subjacent local coordinate x–y plane [7].

Statistical Analysis:

A two-tailed paired t-test was used to compare 1) preoperative and postoperative measurements and 2) postoperative and latest follow-up measurements. A p-value of <0.05 was considered significant. All statistical analyses were conducted using SAS version 9.3 (SAS Institute Inc, Cary, NC, USA).

Results

Population:

The average age of the two female and three male patients was 15 years and 6 months (range: 13–19 years); three had Lenke type 1 curves, and two had Lenke type 2 curves. Frontal and lateral EOS 3D images were captured for each of the five patients preoperatively, four patients immediately postoperatively (images were unavailable for patient #2), and four patients at the latest postoperative follow-up (images were unavailable for patient #5), providing complete sets of images for three patients.

All patients had structural thoracic curves, and two had structural thoracolumbar curvature based on bending criteria. Three patients had preoperative Cobb angles between 50° and 65°, and two had severe curves with Cobb angles greater than 65°.

The average time between the first examination and surgery was 56 days; between surgery and the immediate postoperative examination, 25 days; and between surgery and the latest follow-up, 328 days.

All five patients included in this study had routine clinical courses without any complications or complaints, and their progress was considered satisfactory.

Operative Procedure:

The mean number of levels fused was 11.2° ± 2.0. The number of pedicle screws used for constructs averaged 19.2° ± 3.06 (1.75 screws per vertebra). Polyaxial screw constructs were used for all five patients. The apical vertebra was instrumented with two pedicle screws in all cases.

a) b) c)

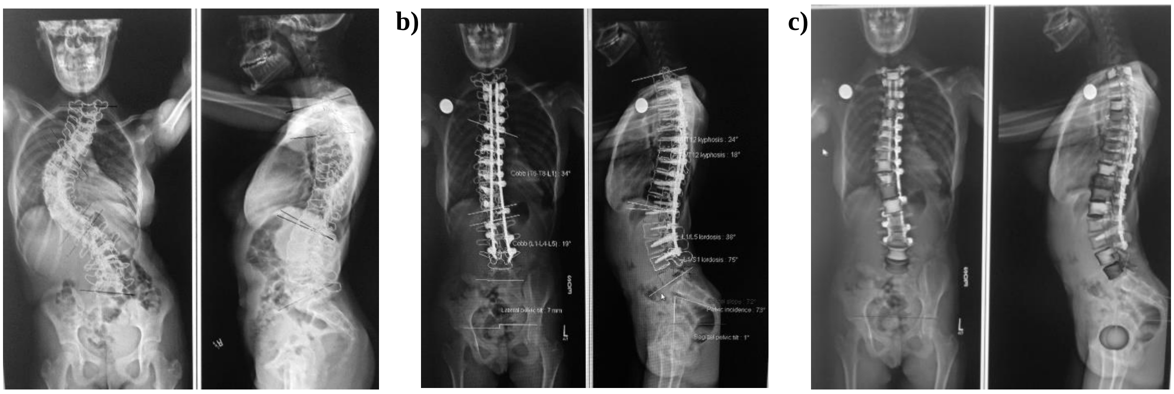

Fig-2:

Illustrative Case Preoperative (a) and postoperative posteroanterior reconstruction (b)(c) radiographs of a 12-year-old patient operated using simultaneous translation on 2 rods (ST2R).

Table-1: Mean values (in degrees) of the 10 parameters (4 patients) of preoperative and postoperative immediate

	Preoperative (Mean ±SD)	**Postoperative Immediate (Mean ±SD)**	**p**
Major Cobb(°)	**75 ± 21**	**28 ± 7**	**0.009**
Minor Cobb(°)	35 ± 18	25 ± 3	0.22
Kyphosis (T1/T12) (°)	32 ± 7.5	28 ± 7	0.56
Kyphosis (T4/T12) (°)	31 ± 30	22 ± 8	0.52
Lordosis (L1/L5) (°)	48 ± 22	41 ± 8	0.6
Lordosis (L1/S1) (°)	77 ± 25	81 ± 10	0.76
Apical Vertebral Rotation (AVR) (°)	-5.4 ± 17	6.5 ± 25	0.31
Pelvic Incidence(°)	76 ± 4	82 ± 6	0.16
Sacral Slope(°)	71 ± 5	73 ± 4	0.65
Sagittal Pelvic Tilt(°)	4.9 ± 4	8.5 ± 7	0.33

Table-2: Mean values (in degrees) of the 10 parameters (3 patients) of postoperative immediate and postoperative latest

	Postoperative Immediate (Mean ±SD)	**Postoperative Latest (Mean ±SD)**	**P**
Major Cobb(°)	**29 ± 7**	**38 ± 7**	**0.16**
Minor Cobb(°)	25 ± 3	27 ± 6	0.76
Kyphosis (T1/T12)(°)	27 ± 8	30 ± 6	0.12
Kyphosis (T4/T12)(°)	22 ± 10	24 ± 10	0.67
Lordosis (L1/L5)(°)	41 ± 10	40 ± 5	0.91
Lordosis (L1/S1)(°)	81 ± 12	77 ± 3	0.76
Apical Vertebral Rotation (AVR)(°)	13 ± 26	-3 ± 43	0.25
Pelvic Incidence(°)	83 ± 7	81 ± 2	0.65
Sacral Slope(°)	73 ± 5	69 ± 5	0.4
Sagittal Pelvic Tilt(°)	10 ± 8	12 ± 6	0.19

Spinal and Pelvic Parameters:

The anatomic landmarks were clearly distinguishable by varying the luminosity and contrast to optimally reveal the vertebrae and pelvis. In particular, the superior endplate of T1 and the femoral heads were visible in all cases. Consequently, the 10 radiologic parameters were measurable in all five patients. We compared preoperative and immediate postoperative measurements in 4 subjects [1,3-5], and immediate postoperative and latest follow-up measurements in 3 subjects [1,3,4]. The mean values of the spinal and pelvic parameters of the series are summarized in **Table-1** and **Table-2,** separated by moments. The Cobb angle values were significantly changed by the operation (75° ± 21 to 28°± 7, p = 0.009), but no significant changes occurred at the latest follow-up (**Fig-2**).

Intervertebral Axial Rotation:

The change in the intervertebral rotation due to the axial plane was larger near the apical region (T8-T9),) 2.1° ± 2.7 to -14° ± 6.9, and smaller near the junctional region (T12-L1), -2.6° ± 2.9 to -1.1° ± 8.4. The maximal apical axial change at the junctional region was 32.8° (absolute value), and the minimal apical axial change at the apical region was 4.8° (absolute value) (**Fig-3**).

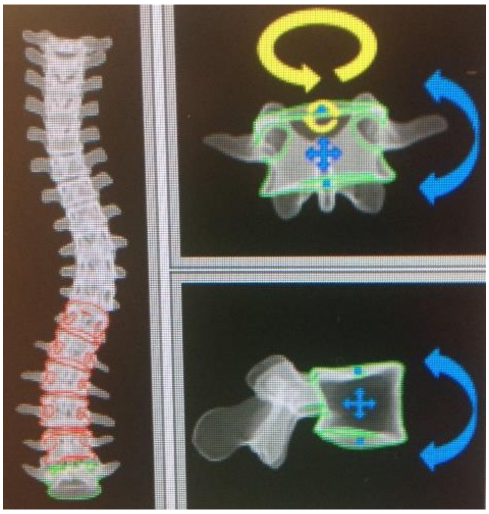

Fig-3: 3D measurements

The magnitude of changes between adjacent vertebral axial rotation of three representative cases (Subjects 1, 3, and 4 (left curve)) are shown in **Fig-4**.

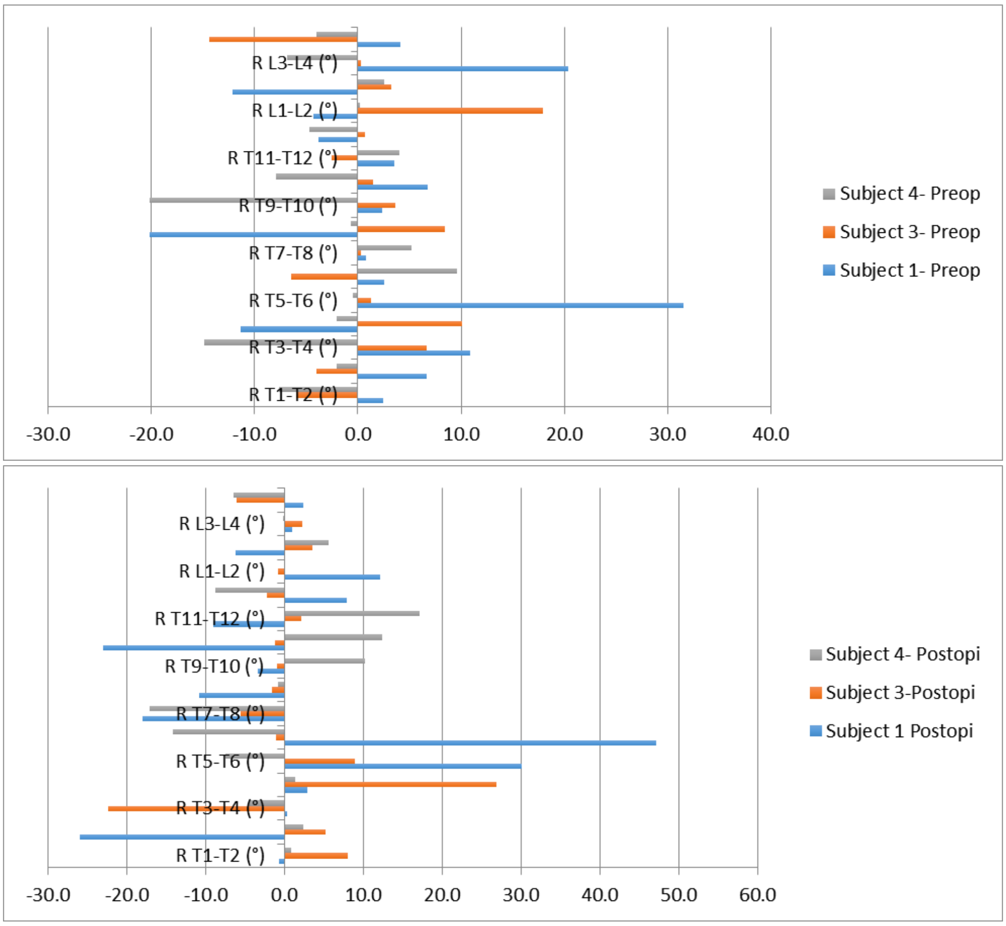

Fig-4: Intervertebral axial rotation graphs for different periods

Discussion

With this study, we attempted to quantify the multi-planar correction capabilities of the ST2R spinal system using EOS imaging and SterEOS reconstruction software. Although the results are projection interpretations, they provided interesting information to warrant further studies.

The number of levels fused (11.2° ± 2.0) compared with thoracic and lumbar curves was similar to the average published. All patients in this study required fusion at least to the level of L2 to stabilize the curves and avoid distal junctional kyphosis [18].

A significant decrease in Cobb angle was observed between preoperative and immediate postoperative measurements but not in kyphosis and lordosis (L1-L5). There was a non-significant increase in Cobb angle at the latest follow-up, probably caused by biomechanical adjustments during the healing process [18]. Winter et al. expressed concern about over-correction in the attempt to obtain a few supplemental degrees of coronal reduction and suggested that it is critical to obtain a balanced fusion [19]. The pelvic parameters showed the same relation during follow-up with no significant difference. According to Shakeri, 2024, spinopelvic parameters such as thoracic kyphosis (TK), lumbar lordosis (LL), pelvic incidence (PI), sacral slope (SS), sacral pelvic tilt (SPT) were comparable to those in conventional lateral upright C1S1 radiographs in the literature, and we found in our sample as well. The pelvic Incidence values were the same for each patient, with no significant difference [20].

In the present study, reconstructed models from images obtained by an EOS imaging system enabled accurate measurement of the axial profile (apical vertebral rotation). Furthermore, it was possible to measure not only the axial AVR but also that of each intervertebral segment [21].

Our study had some limitations. This case series did not include nonscoliotic patients. The corrections obtained with PASS LP instrumentation MEDICREA® simultaneous translation on 2 rods (ST2R) will need to be compared in the future to other reduction techniques assessed with low-dose stereoradiography [18,22]. Although the follow-up period was short (9 months), it is generally accepted that loss of correction after fusion in AIS primarily occurs during the first postoperative year. The results of the spine surgery can be reliably evaluated radiologically after a minimum follow-up of 2 years [23]. The measurements obtained with the EOS system were not compared to other imaging methods since the purpose of the study was not to evaluate the reliability of stereoradiography, which has already been reported previously in AIS [24]. Finally, this was a purely radiographic study; no functional score was used to evaluate the clinical outcome of these patients.

Conclusions

This case series suggests that corrective ST2R spinal surgery for AIS can achieve 3D correction of the spine and additional correction of intervertebral axial rotation with minimal deterioration during the follow-up period and that EOS imaging is adequate for evaluating this 3D correction.

Acknowledgments

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Conflict of Interest

The authors have read and approved the final version of the manuscript. The authors have no conflicts of interest to declare.

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Keywords: Simultaneous Translation on Two Rods, Adolescent Idiopathic Scoliosis, 3D Spinal Reconstruction, EOS Imaging, Scoliosis