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The Relationship Between Apical Vertebral Rotation and Truncal Rotation in Adolescent Idiopathic Scoliosis Using 3D Reconstructions

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Abstract

Study Design: Retrospective review of prospective data.
Objectives: To evaluate the relationship between absolute apical vertebral rotation (AVR) evaluated with upright 3D imaging and angle of trunk rotation (ATR) before and after surgery for thoracic and lumbar curves in adolescent idiopathic scoliosis (AIS).
Summary of Background Data: New imaging technology allows for improved radiographic assessment of the degree of AVR pre- and postoperatively through 3D spine models created from biplanar, simultaneous spine radiographs.
Methods: A prospective registry was queried and identified 55 AIS patients with major thoracic or major thoracolumbar/lumbar curves who underwent posterior spinal fusion. All patients had biplanar upright imaging of their spine and ATR measurements assessed via scoliometer pre- and postoperatively.
Results: There were 33 major thoracic and 22 major lumbar curves. The mean Cobb angles for thoracic and thoracolumbar/lumbar curves were 54° ± 10° and 47° ± 8° preoperatively, and 11 ± 6° and 12 ± 7° postoperatively. The differences in the mean preoperative ATR measurements for both major curve types was not statistically significant; however, the difference in AVR between thoracic curves (13 ± 6°) and lumbar curves (22 ± 7°) was significant ($p < .001$). There was a significant decrease in the ATR and AVR for both thoracic and thoracolumbar/lumbar curves ($p < .001$) postoperatively. A significant correlation between ATR and AVR was found only for the major thoracolumbar/lumbar curves ($p < .001$). The relationship between ATR and AVR changes for both curves was not statistically significant.
Conclusion: ATR measured via scoliometer strongly correlates with 3D measurements of AVR in both thoracic and lumbar curves before and after surgery for AIS. No significant relationship was found between the changes in ATR and AVR due to surgery. Postoperatively, greater clinical rotational deformity remains in the thoracic spine compared to the lumbar spine, despite greater apical vertebra axial plane correction in thoracic curves.
Level of Evidence: Level II, diagnostic.

Keywords: Adolescent idiopathic scoliosis; 3D reconstructions; Truncal rotation; Apical vertebral rotation

IRB Statement: This study was approved from the Institutional Review Board at University of California, San Diego.

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This study was conducted at Rady Children's Hospital, San Diego, CA.

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Introduction

Adolescent idiopathic scoliosis (AIS) is a three-dimensional (3D) deformity with changes in the shape of the spine in the sagittal, coronal, and transverse planes [1,2]. The overall deformity consists of lateral deviation in the coronal plane, frequent thoracic hypokyphosis in the sagittal plane, and rotation in the axial plane that is greatest at the apex of the curve [3,4]. The axial plane deformity has been the most difficult to appreciate on standard two-dimensional (2D) posteroanterior (PA) and lateral radiographs. The axial rotation must be inferred based on the out-of-plane appearance of the apical vertebrae. Using the Nash-Moe grading system to quantify the magnitude of axial deformity is of limited reliability [5]. Despite the difficulty in measuring axial deformity, vertebral rotation is known to be an important aspect of the global spinal alignment [4,6] and clinically manifests itself as the thoracic rib hump and lumbar prominence accentuated by the forward bend test [3].

In AIS, the apical vertebral rotation (AVR) that remains after correction of the deformity has been shown to be associated with less than satisfactory outcomes and poorer cosmetic satisfaction [7-9]. Recent studies have shown that although surgeons place an emphasis on improving the radiographic appearance of the spine in the coronal and sagittal planes, adolescent patients and their parents are concerned about cosmetic improvements in trunk shape that may be addressed via transverse plane correction [10-12]. Thoracoplasty, via multiple rib resections, has been the traditional treatment for clinically significant rib cage deformity in thoracic idiopathic scoliosis [12-15]. Since the more routine use of pedicle screw instrumentation, new surgical techniques such as direct vertebral rotation have been added to rod derotation [16,17] and translation [18] methods to improve deformity correction, particularly in the transverse plane.

Despite the 3D nature of the scoliotic deformity and efforts at achieving correction based on 3D principles, the ability to routinely assess the spine in three dimensions, especially vertebral rotation correction in the axial plane, has largely been limited by technology. More specifically, a major limitation lies in the inability to obtain 3D reconstructions quickly, accurately, and with low radiation exposure to the patient [19-21]. This, however, has been circumvented in large part through the development of the EOS imaging system (EOS Imaging, Paris), which can create 3D renditions of the spine based on biplanar radiographs without the radiation typically associated with a 3D CT reconstruction [22,23]. This technology permits analysis of the transverse plane with the patient imaged in the upright position, an additional benefit as supine positioning has been shown to spontaneously reduce deformity in both the transverse and coronal planes [24,25].

This technology has allowed for improved radiographic assessment of the degree of AVR pre- and postoperatively, which can now be calculated from the 3D reconstruction. The purpose of this study was to evaluate the relationship between scoliometer readings of trunk rotation and the 3D radiographic AVR before and after surgery for thoracic and thoracolumbar/lumbar curves in surgically treated patients with AIS.

Material and Methods

A prospective registry of AIS patients was queried to identify those who (1) underwent posterior spinal fusion and instrumentation without thoracoplasty to correct their scoliosis; (2) underwent upright biplanar imaging of their spine pre- and postoperatively; and (3) had pre- and postoperative angle of trunk rotation (ATR) measurements. This was a nonconsecutive series of patients. Not all of the patients received bilplanar imaging because of lack of availability of the EOS machine at different facilities where images were obtained.

Image acquisition

Images were obtained with the EOS Imaging system, a slot-scanning radiologic device that scans the PA and lateral planes simultaneously. The simultaneous acquisition allows for the creation of 3D shell reconstruction of the spine. Scan times vary from 8 to 15 seconds depending on patient height [26]. All images were obtained as part of the patient's routine care.

3D software reconstruction

Using sterEOS software (EOS Imaging, Paris), a single trained operator created pre- and postoperative 3D spine reconstructions of each patient's spine (Fig. 1). This was done by first defining the pelvic parameters (femoral heads, sacral slope) on both the PA and lateral 2D images. Next, a digital spline was drawn down the center of the patient's spine in both planes from T1 to L5. The computerized