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Reliability of Three-Dimensional Spinal Modeling of Patients With Idiopathic Scoliosis Using EOS System

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Abstract

Study Design: Three-dimensional (3D) spinal models of children with idiopathic scoliosis (IS) were created using the EOS imaging system (EOS) and sterEOS software.
Objective: To determine the inter- or intraobserver reproducibility of the 3D spinal models in children with IS of different apex locations.
Summary of Background Data: 3D spinal model measurements include the Cobb angle, kyphosis, lordosis, and axial vertebral rotation (AVR). Variation of these measurements between two investigators and two different trials by the same investigator were analyzed by inter- and intraclass correlation coefficients (ICCs).
Methods: Biplanar radiographic images of 15 patients (age: 6–15 years) with IS were uploaded into the sterEOS software. Spinal and pelvic markers were manually identified to construct a 3D spinal model and measure spinal parameters. Two trained examiners independently performed modeling and performed modeling in spaced out trials. The ICC between inter- and intraobservers were calculated.
Results: ICCs between inter- and intraobservers were significant for all parameters ($p < .05$). Both the inter- and intraobservers showed excellent agreement for the Cobb angles in the thoracic segment, kyphosis and lordosis. Substantial interobserver agreement and excellent intraobserver agreement were determined for the Cobb angle in the thoracolumbar or lumbar (TL/L) segment, with less than 6° difference between two raters and less than 2° difference between two trials. Substantial interobserver agreement for the AVR in the TL/L region and substantial interobserver agreement for the AVR in the thoracic region were found, with less than 4° difference between raters. One rater had substantial intraobserver agreement for the AVR in the TL/L region whereas another rater reported moderate to substantial intraobserver agreement in both the thoracic and TL/L regions, with less than 3° difference between trials.
Conclusion: The EOS system shows reliable and repeatable results in 3D spinal modeling of children with IS.
Level of Evidence: Level III.

Keywords: Scoliosis; EOS; 3D spinal reconstruction; ICC; Reproducibility

Introduction

Recent studies show that a two-dimensional (2D) analysis of spinal deformities oversimplifies the disorders [1-3]. For decades, the 2D Cobb angle, which quantifies the deviation of the spine in the coronal plane, has been the standard for the assessment and classification of spinal deformities [4]. Recently, several organizations such as the Scoliosis Research Society have agreed that the Cobb angle is insufficient for measuring deformities because the transverse plane is completely ignored [2,3,5]. In fact, a recent publication by the Scoliosis Research Society showed that two patients with similar main thoracic Cobb angles can have very different three-dimensional (3D) morphologies, showing that the Cobb angle does not provide a complete picture [2].

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Even though the importance of 3D analysis of the spine has been known, clinicians have struggled to find an efficient, convenient, and safe way to view a patient's spine in 3D [6]. As a result, standard analysis and treatment of spinal deformities has relied on radiographic images taken from anteroposterior and lateral points of view. These 2D images are further quantified by computer-assisted measurements, resulting in the use of 2D measurements to describe a 3D deformity. Computed tomographic (CT) imaging, a popular alternative to common radiographic scanning, can create accurate 3D reconstructions of spines. However, this process exposes patients to a harmful dosage of radiation, forcing the clinicians to avoid CT scans and rely on 2D representations of the spine to analyze spinal deformities [7,8].

In the year 2000, the EOS Imaging System was developed (EOS imaging, Paris, France), which revolutionized the way clinicians could view and diagnose spinal deformities. A unique attribute of the EOS imaging system is that it simultaneously captures images from the posteroanterior and lateral points of view using two orthogonal x-ray sources, removing the need for manual reconstruction/orientation of multiple images [9]. Moreover, the biplanar EOS imaging system scans the patients' spine while they are standing in an upright, weight-bearing stance. This is exceptionally advantageous, as some multiplanar correction of the spine will occur when a patient assumes the supine position, as is the case with CT imaging [10]. For the best representation of the actual spine and most accurate 3D reconstruction, a patient stands with both feet on the same alignment with 20–25 cm distance between the two feet and the upper arm perpendicular to the body with fingertips on the clavicle [11].

The greatest benefit of the EOS imaging system is the reduction of the x-ray exposure to patients. In fact, the EOS imaging system exposes patients to 80% to 90% less radiation compared with computed topography or conventional radiographs [11,12]. The reduction in radiation is due to Charpak's new x-ray detection method, which is unaffected by scattered radiation, meaning that less radiation is needed to acquire the images [13,14]. Considering that patients with spinal deformities receive many imaging sessions during their lifetime, the EOS system causes a drastic reduction in lifetime radiation exposure.

Before a new technology is incorporated into daily clinical practices, the new system's accuracy and consistency must be validated by comparing it to standard methods. Several studies have shown that the reconstructions produced by the EOS imaging system are comparable to conventional radiography techniques such as CT scan [8,9,15-19]. In these studies, the authors measured several parameters including the Cobb angle, T4–T12 kyphosis, L1–L5 lordosis, spinal penetration index, and point-to-surface distance using the EOS system, conventional radiography, and CT scans and determined that the EOS system produces accurate 3D reconstructions [8,9,15-19]. However, these studies have limited their measurements to the anteroposterior plane of references and have excluded the transverse plane. Glaser et al. found a EOS vertebral body root mean square accuracy of 1.1 mm, with a maximum of 4.7 mm [19]. Additionally, the Cobb angle was found have an accuracy of 1.6° [19]. Axial vertebral rotation (AVR) had an accuracy of 1.9° whereas the sagittal kyphosis was within less than 1° [19]. The aims of this study were to (1) determine the intraclass correlation coefficients (ICCs) for both the interobserver and the intraobserver in the measurements of the kyphosis and lordosis angles, AVR of the apex vertebra, and the thoracic and TL/L Cobb angles; and (2) determine the 3D reconstruction time of the spine.

Materials and Methods

Image collection

Ethical approval was obtained from the Children's Hospital of Wisconsin institutional review board. Biplanar radiographic images of 15 deidentified pediatric patients with idiopathic scoliosis (averaged age: 11.9 years; range: 6–15 years) were retrospectively drawn from a collected database. These EOS images were uploaded into the sterEOS computer program.

3D reconstruction

Within the sterEOS software, pelvic parameters are identified on the radiographic images (Fig. 1A). Next, the entire thoracolumbar spine is manually identified (Fig. 1B). The EOS software uses this labeling as a predictor to automatically identify and create an approximated outline of each vertebra. The examiner then manipulates the vertebral bodies by moving them, rotating them, and adjusting their shapes until the model closely resembles what is shown on the radiograph (Fig. 1C). The examiner then adjusts the pedicles, spinous processes, transverse processes, and facets of the model to best match the radiograph (Fig. 1C). All these manipulations are performed on both the anteroposterior and lateral radiographs. Once the adjustments are completed, the EOS software creates a 3D model of the spine (Fig. 1D). Once the modeling is complete, the sterEOS software automatically calculates the Cobb angles, angles of lordosis, angles of kyphosis, and the AVRs of the apex vertebra of the model. Because most patients held a double curve, which were composed of a thoracic segment (average apex: ~T6) and a lumbar segment (L) (average apex: ~L1), these were analyzed separately. Patients with a single curve have their curve classified as thoracic if the apex is