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Accuracy and reliability of coronal and sagittal spinal curvature data based on patient-specific three-dimensional models created by the EOS 2D/3D imaging system

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Abstract

BACKGROUND CONTEXT: Three-dimensional (3D) deformations of the spine are predominantly characterized by two-dimensional (2D) angulation measurements in coronal and sagittal planes, using anteroposterior and lateral X-ray images. For coronal curves, a method originally described by Cobb and for sagittal curves a modified Cobb method are most widely used in practice, and these methods have been shown to exhibit good-to-excellent reliability and reproducibility, carried out either manually or by computer-based tools. Recently, an ultralow radiation dose–integrated radioimaging solution was introduced with special software for realistic 3D visualization and parametric characterization of the spinal column.

PURPOSE: Comparison of accuracy, correlation of measurement values, intraobserver and interrater reliability of methods by conventional manual 2D and sterEOS 3D measurements in a routine clinical setting.

STUDY DESIGN/SETTING: Retrospective nonrandomized study of diagnostic X-ray images created as part of a routine clinical protocol of eligible patients examined at our clinic during a 30-month period between July 2007 and December 2009.

PATIENT SAMPLE: In total, 201 individuals (170 females, 31 males; mean age, 19.88 years) including 10 healthy athletes with normal spine and patients with adolescent idiopathic scoliosis (175 cases), adult degenerative scoliosis (11 cases), and Scheuermann hyperkyphosis (5 cases). Overall range of coronal curves was between 2.4° and 117.5°. Analysis of accuracy and reliability of measurements were carried out on a group of all patients and in subgroups based on coronal plane deviation: 0° to 10° (Group 1, n=36), 10° to 25° (Group 2, n=25), 25° to 50° (Group 3, n=69), 50° to 75° (Group 4, n=49), and more than 75° (Group 5, n=22).

METHODS: Coronal and sagittal curvature measurements were determined by three experienced examiners, using either traditional 2D methods or automatic measurements based on sterEOS 3D reconstructions. Manual measurements were performed three times, and sterEOS 3D reconstructions and automatic measurements were performed two times by each examiner. Means comparison *t* test, Pearson bivariate correlation analysis, reliability analysis by intraclass correlation coefficients for intraobserver reproducibility and interrater reliability were performed using SPSS v16.0 software (IBM Corp., Armonk, NY, USA). No funds were received in support of this work. No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of this article.

RESULTS: In comparison with manual 2D methods, only small and nonsignificant differences were detectable in sterEOS 3D–based curvature data. Intraobserver reliability was excellent for

FDA device/drug status: Approved for these indications (EOS 2D/3D orthopedic imaging system and sterEOS 3D workstation software for surface 3D reconstruction of the spine in adults, adolescents, and children).

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both methods, and interrater reproducibility was consistently higher for sterEOS 3D methods that was found to be unaffected by the magnitude of coronal curves or sagittal plane deviations.
CONCLUSIONS: This is the first clinical report on EOS 2D/3D system (EOS Imaging, Paris, France) and its sterEOS 3D software, documenting an excellent capability for accurate, reliable, and reproducible spinal curvature measurements.

Keywords: EOS 2D/3D; 3D reconstruction; Interrater reliability; Coronal and sagittal curve measurements

Introduction

The normal spinal column shows physiological curves only in sagittal plane, whereas scoliotic spinal deformities always include deviations in all three dimensions: lateral (LAT) translation in coronal plane, (mainly lordotic) deviations in sagittal plane, and very characteristically vertebral axial rotation in transverse (horizontal) plane. Clinical diagnosis, quantitative evaluation, treatment planning, and progression monitoring of spine deformities usually rely on conventional X-ray images, performed in anteroposterior (AP)/posteroanterior and LAT directions. Spinal curves are routinely quantified by measurements performed on these X-ray images, mostly carried out manually or assisted by computer-based tools, resulting in parameters of two-dimensional (2D) values. These 2D values are then used to evaluate and interpret spinal geometry, a complex three-dimensional (3D) entity. Numerous alternative measurement methods exist for the same purpose, but the most widely used are based on the original Cobb method for coronal curves and the modified Cobb method for sagittal kyphosis and lordosis [1]. Because of their simplicity, these methods became standard in clinical practice, and they were shown to exhibit a good intraobserver reliability and a good-to-excellent interrater reproducibility by some authors [2] although disputed by others for their error originating from interobserver variability in definitions of the end vertebrae of spinal curves and pitfalls stemming from problems of interpreting measurements for 3D objects like vertebral end plates based on projections in 2D planes [3]. In spite of the widely accepted view of scoliotic spinal deformities having an intricate 3D nature, routine clinical diagnosis and classification prominently remained 2D. Computed tomography (CT) and CT-based spinal 3D reconstructions are rarely used for standard scoliosis diagnosis because of their prohibitively high radiation dose and to some extent, to the documented ambiguous effect of supine position on spinal curvature data during imaging [4–6]. Consequently, routine visualization and evaluation of spinal deformities in 3D remained a goal to be achieved for many years after introduction of surgical correction techniques of spinal deformities based on 3D principles in 1984 [7].

In the last few years, the EOS 2D/3D imaging system (EOS Imaging, Paris, France), a new low radiation dose X-ray device, became available for orthopedic applications, based on an ultrasensitive X-ray detection technology awarded by the 1992 Nobel Prize in Physics [8,9]. This device is able to simultaneously capture full-body standing orthogonal digital biplanar images in a weightbearing upright position at a fraction of the radiation dose used for conventional radiography [10]. Typical radiation dose reduction values were reported recently on dosimetry measurements of entrance skin dose ratios between 2.9 and 9.2, depending on the anatomic location—all favorable to the EOS system versus a conventional computed radiography system. Average dose values by the EOS system were 0.11 to 0.30 mGy, whereas the value range by a computed radiography system for identical images was 0.59 to 2.47 mGy [11]. Distorsion-free and 1:1 scale AP/posteroanterior and LAT images created by the system were shown to exhibit a wide dynamic range with fine pixel resolution, optimizable for visualization of osseous or soft-tissue structures. A special 3D reconstruction software named sterEOS 3D was developed to accompany the system, enabling creation of realistic 3D models based on a combination of geometric and statistic modeling by a parametric surface 3D reconstruction procedure, with high precision for spinal vertebrae as shown in comparison with CT-based spinal 3D reconstructions as a gold standard [12,13]. Clinically relevant, 2D and 3D parameters for the spine and pelvis are automatically computed by the software from the 3D model obtained. Since its first introduction at our university clinic in May 2007, the system shows a growing adoption by scoliosis centers in Europe and North America.

Accuracy and reliability studies of 3D reconstructions based on a similar stereoradiography system and EOS prototype units involving small groups of patients with normal spine or mild scoliotic deviations were published earlier [14–16]. However, there are no reports on the reliability of a commercial EOS 2D/3D system and its sterEOS 3D software under routine clinical circumstances involving larger groups of patients with moderate-to-severe spinal deformities. The purpose of this study was to report on clinical validation of the system, focusing on accuracy and reliability of coronal and sagittal spinal curve measurements obtained by the full sterEOS 3D reconstruction procedure, as compared with manual 2D measurements performed on AP and LAT EOS 2D images.

Materials and methods

In total, 201 patients (170 females, 31 males; mean age, 19.88 years) were selected for this nonrandomized