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Multicenter Comparison of 3D Spinal Measurements Using Surface Topography With Those From Conventional Radiography

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Abstract

Introduction: In pediatric spinal deformity the gold standard for curve surveillance remains standing full-column radiographs, but repeated exposure to ionizing radiation motivates us to look for nonradiographic solutions. This study tests a modern system of surface topography (ST) to determine whether it is reliable and reproducible.

Methods: Patients from 6 pediatric spinal deformity clinics were recruited for enrollment. Inclusion criteria were age 8-18; diagnosis of scoliosis measuring ⩾10 and <50 degrees or increased kyphosis of ⩾45 degrees. Standing radiographs and ST scans (DIERS Formetric, Diers Medical Systems, Chicago, IL) were obtained on all patients and then measured and compared. A single investigator using a validated electronic measurement tool performed all radiographic measurements. Analysis of reproducibility and comparison of ST and radiographs were done.

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This research project was approved by the IRB committee at Rosalind Franklin University of Medicine and Science, and then subsequently approved by cooperative agreement at each of the participating medical centers.

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Results: A total of 193 patients were enrolled (148 F [77%]). The mean age was 13.25 years (range 8−18). The scoliosis magnitude was as follows: thoracic average 22.7 ± 10 degrees; lumbar average 19.6 ± 9 degrees. The kyphosis magnitude was 54.0 ± 11 degrees. The reproducibility for each ST parameter for 3 repeated scans was strong (interclass correlation = 0.855−0.944). Comparison to radiographic measurements was strong in the thoracic (r = 0.7) and moderate in the lumbar curve (r = 0.5). There was an average difference of 5.8 degrees in the thoracic spine and 8.8 degrees in the lumbar spine between ST Cobb angle estimates and radiographs. Thoracic kyphosis also had a strong correlation (r = 0.8) with radiographs.

Conclusions: Although the results are intended to measure similar aspects of deformity as the traditional Cobb angle, the measurement is not intended to be an exact estimation. The utility of ST is in the reproducible quantification of deformity after the initial radiograph has been taken. This has the potential to make longitudinal assessment of change in deformity without serial radiographs.

Keywords: Surface topography; Scoliosis; Reproducibility; Reliability; Curve surveillance

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Introduction

Adolescent idiopathic scoliosis (AIS) is a structural spinal deformity in the coronal plane that affects 1%−3% of children in the United States [1]. When the deformity is minor, less than 20°, treatment for this condition typically includes observation and surveillance to assess for curve progression [2]. Bracing and surgery are the treatments indicated for larger curves, though management in these patients also includes radiographic surveillance for evidence of a change in the deformity. The gold standard for diagnosis and subsequent curve surveillance remains standing full-column radiographs of the spine [3].

Radiographic images allows for assessment of the magnitude of the deformity in both the coronal and sagittal planes, and quantifying the spinal curvatures by deriving Cobb angle measurements. The disadvantage of radiographs, however, particularly in young patients, is that repeated exposure to ionizing radiation causes a significant increase in the risk of malignancies later in life [4,5]. The relative risk of breast cancer, for example, is nearly four times greater in these patients [6]. Nash et al. reported in 1979 that the average teenage girl with scoliosis received 22 radiographs over 3 years of surveillance for AIS [7]. The frequency of radiographs has undoubtedly gone down since then, but there are no current studies measuring how many radiographs the average patient receives. The radiation dose for standard x-rays has also improved significantly over the years [8], but nonradiographic methods to image the spine and predict spinal deformity are still needed. Although no patient can avoid radiographs completely, there should be an effort to reduce radiation exposure whenever possible.

Surface topography (ST) has been used as an alternative to plain radiographs, beginning with the use of the inclinometer to measure the rotational deformity associated with scoliosis [9]. Many systems using surface topography have since been developed [10-25], but there has not yet been a system that has gained widespread acceptance, as prior research on ST has shown it to be inconsistent as a method of measuring spinal deformity [18]. The goal of this study was to test a modern system of surface topography measurement and to determine whether it was reliable and reproducible across multiple users. The correlation between ST-estimated curvature measurements and radiographic Cobb angles were compared to determine the suitability of ST as a replacement for some radiographs during AIS surveillance.

Methods

Patients treated for juvenile idiopathic scoliosis (JIS) or AIS from six North American institutions and one German institution were prospectively enrolled. Inclusion criteria for the analysis of the coronal plane deformity (CD) patients were as follows: age between 8 and 18 years with JIS or AIS measuring $\geqslant$10° and $<$50°. A second cohort of patients whose primary deformity was kyphotic (KD) were studied. Inclusion criteria for this group were defined as a sagittal Cobb angle measuring $\geqslant$45°.

Standing posteroanterior and lateral radiographs were obtained at each visit. There were no additional radiographs taken for the purpose of this research study. Surface topography measurements were obtained using an ST scanner (DIERS Formetric, Diers Medical Systems, Chicago, IL) during the same visit (Fig. 1). The ST scan was taken three times for each patient within a 5-minute period so that repeated scans could be analyzed for reproducibility. To obtain the scan, the patient stands in an upright position at a distance of 2 meters in front of the ST scanner. The scanner projects lines of white light (raster lines) onto the back of standing patients. A digital image of this is obtained by the computer, and surface asymmetry is assessed using computer algorithms. The ST device measures patients over a 6-second interval, taking 2 pictures per second. The 12 images acquired are evaluated and averaged by the machine's software, correcting for any subject movement during the data acquisition period. In the case of obese patients, external markers are placed over the posterior-superior iliac spine, and these markers serve as reference points for the computer algorithm as it determines surface topography. A three-dimensional (3D) image of the spine is created from surface topography results (Fig. 2). Recent literature has shown that the accuracy of the mathematical

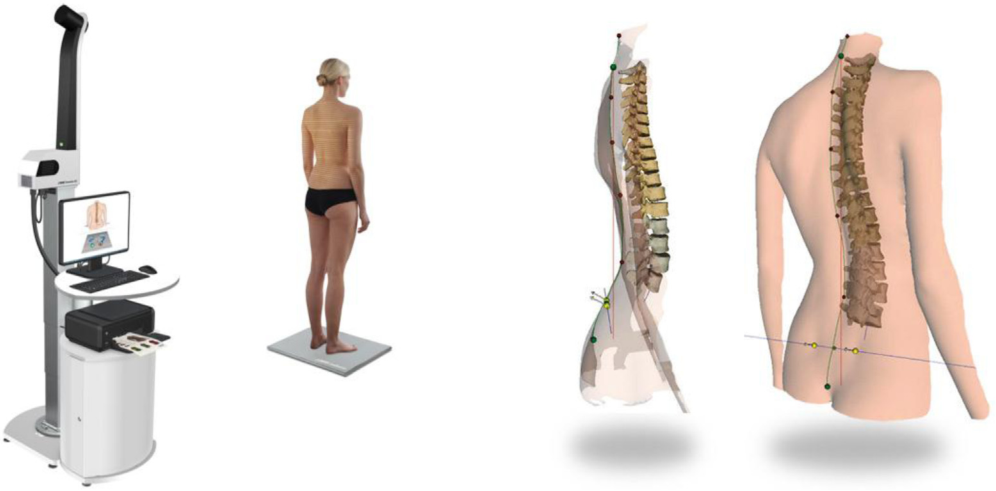

Fig. 1. DIERS Formetric system, and resulting 3D spinal reconstruction.

models that correlate topography with internal 3D spinal shape has been improving with the use of more powerful computers and more sophisticated formulas [25,26].

Demographic data collected included gender and age. Radiographic data collected included main thoracic and thoracolumbar/lumbar maximal Cobb angle values. Coronal alignment was measured by the C7 plumb line and the midsacral line and was expressed in degrees. Sagittal alignment was measured similarly, using C7 and the posterior S1 endplate, and expressed in degrees. Pelvic obliquity, thoracic kyphosis, and lumbar lordosis were measured as well using standard techniques. A single investigator,

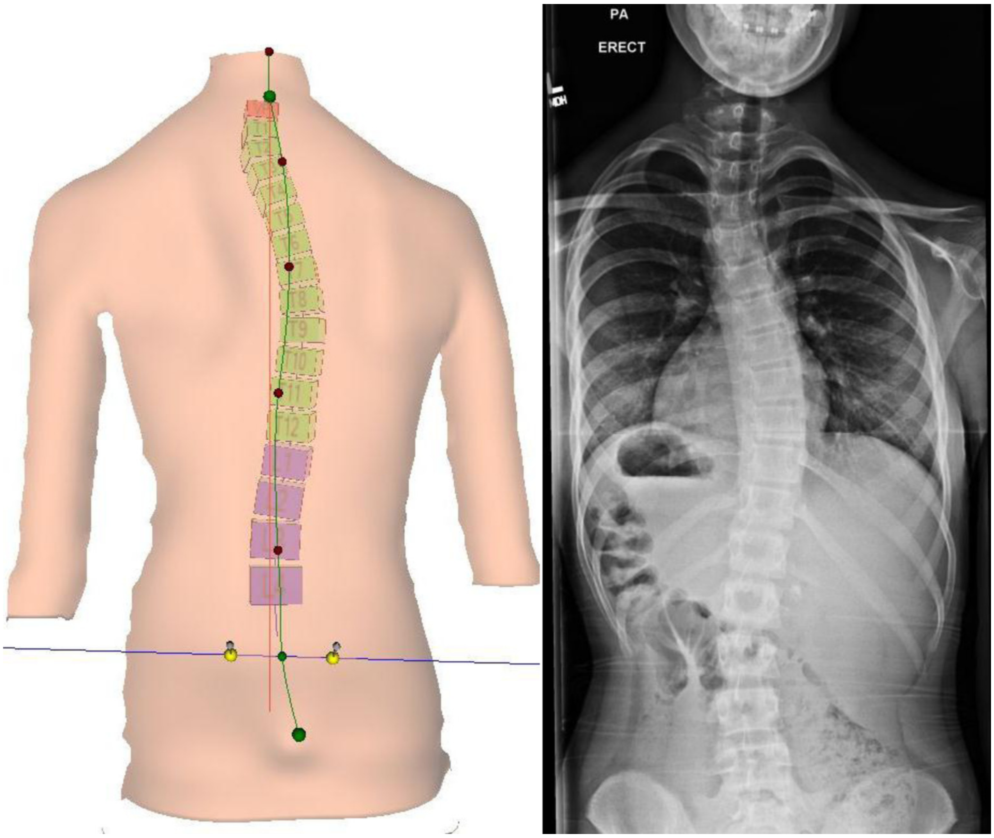

Fig. 2. Example of a 3D reconstruction next to a corresponding x-ray.

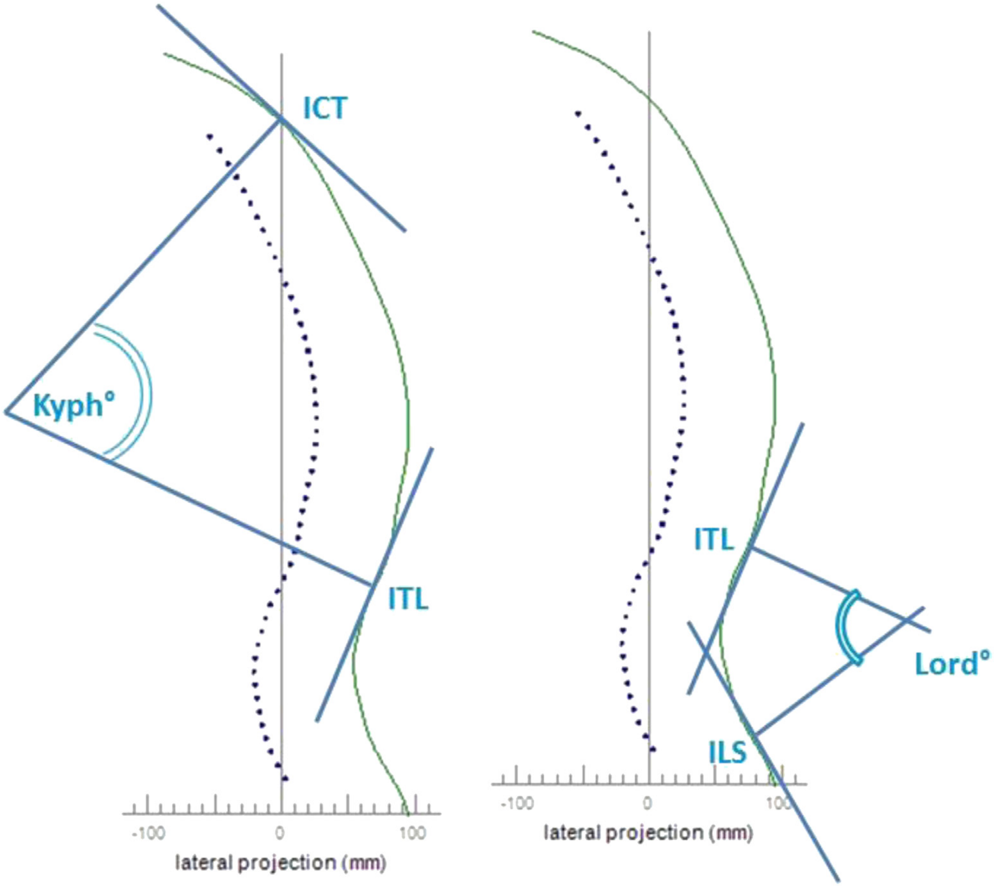

Fig. 3. Measurement of kyphosis and lordosis using surface tangents.

using a validated, electronic measurement tool (Surgimap, Nemaris, Inc, New York, NY), performed all radiographic measurements. Computer-generated approximations of these values were collected from the algorithmic calculations.

ST measurements differ from radiographic ones in technique. Kyphosis and lordosis are measured using the surface tangents of the inflection points of the convex and concave curves (Fig. 3). Coronal vertical axis (CVA), sagittal vertical axis (SVA), and pelvic obliquity are measured using topographical landmarks such as the vertebral prominence of C7 and the dimples of the posterior sacrum. These are all produced automatically by the computer software.

Descriptive data were calculated with mean and standard deviation for continuous variables. Approximated ST measurements were correlated with radiographic measurements using Pearson correlation coefficients. Statistical calculations were performed using IBM SPSS Statistics Package V21.0. Significance was defined as $p < .05$.

Results

One hundred ninety-three patients were enrolled between 2012 and 2014. There were 170 that met the criteria for the coronal plane group (scoliosis > 10 degrees), 29 that met the criteria for the sagittal plane group (kyphosis >45 degrees), and 6 that were in both groups. The demographics of each group are listed below in Table 1.

The reliability and comparison to x-ray for each ST parameter are represented in Table 2. The reproducibility for each ST parameter for 3 repeated scans was strong (ICC = 0.855 to 0.944).

Comparison to radiographic measurements was strong in the thoracic ($r = 0.7$) and moderate in the lumbar curve

Table 1
Subject demographics.

Plane of deformity	Number of subjects	Mean age (years)	Age range (years)	Gender (Female), %	Thoracic scoliosis, degree	Lumbar scoliosis, degree	Thoracic kyphosis, degree
Coronal	170	13.25	8–18	81	23.0 ± 10	19.8 ± 9	
Sagittal	29	13.54	8–17	59			55.2 ± 8

Table 2
Results showing the reliability of ST measurements and their comparison to x-ray.

Measurement	Reliability		Comparison to X-ray	
	Average SD, degree	Interclass correlation coefficient	Average difference, degree	Pearson correlation coefficient (ST vs. X-ray)
Thoracic scoliosis curve	±2.5	0.951	±5.8	0.733
Lumbar scoliosis curve	±2.6	0.855	±8.8	0.492
Pelvic obliquity	±1.1	0.894	±2.3	0.223
Coronal vertebral axis	±0.6	0.950	±1.3	0.623
Thoracic kyphosis	±2.1	0.984	±9.3	0.867
Lumbar lordosis	±2.1	0.977	±9.7	0.817
Sagittal vertebral axis	±1.1	0.906	±3.7	0.489

SD, standard deviation; ST, surface topography.

($r = 0.5$). There was an average difference of 5.8 degrees in the thoracic spine and 8.8 degrees in the lumbar spine between ST coronal angle estimates and radiographs. In the thoracic spine, 12% of comparisons differed by more than 10 degrees and 3% of comparisons differed by more than 15 degrees. This can occur with patients who have very flat thoracic spines. In these patients, the computer model for coronal plane deformity can be inaccurate, but can be improved with the use of reflector markers at the curve apex. Markers were not used in this study, however, to improve the outcomes of these patients.

Thoracic kyphosis also had a strong correlation ($r = 0.8$) with radiographs.

Discussion

This multicenter study was conducted to test surface topography in the evaluation of spinal deformity. A similar paper by the lead author was done at a single site with a single examiner and had results that were almost identical [27]. This study utilized six different centers and multiple examiners, demonstrating the reproducibility of the Formetric surface topography scanner across many venues. The average standard deviation of repeated measurements of less than three degrees across all parameters measured meets the requirement for a reliable measurement tool. This implies that longitudinal assessments over time in evaluating patients will yield valuable clinical information. If no significant changes in surface topography are noted in sequential examinations, then a reduction in radiographs should be possible. If changes in surface topography are noted over time, then radiographic confirmation could be performed. This approach will require prospective longitudinal study, which is now in progress.

Although the differences between scoliosis angle and Cobb angle were between 5 and 10 degrees, which is larger than the measurement error for a radiographic measurement of Cobb angle [28], this does not negate the utility of Formetric surface topography. The measurements quantify similar but not identical aspects of spinal deformity. The Cobb angle is a 2D measurement from a single plane, whereas the scoliosis angle is a 3D quantification of deformity.

Surface topography produces a 3D spinal model and measures kyphosis, lordosis, and scoliosis curves in the plane of greatest deformity. As such, the larger value seen for the scoliosis angle is not surprising. As long as both radiographs and surface topography are done during the initial patient visit, the comparison can be made of the two methods, and if the 3D topography model does not match the radiographs, the clinician will be alerted to this failure of the system. In this study, there were between 10% and 15% of patients where the 3D model for lumbar curvature did not match the radiographs well. This resulted in an overall lower correlation for lumbar curves in the study group.

For measurements that are not so dependent on the exact plane, the differences were much closer. Pelvic obliquity, CVA, and SVA were 2.3, 1.3, and 3.7 degrees different, respectively. This shows that direct measurements obtained from surface topography are more similar to radiographs than calculated Cobb angles are.

In terms of its clinical usefulness, the Formetric surface topography scanner is able to produce a 3D spinal model showing deformity in all planes that is reliable and reproducible in most patients. Ongoing investigation includes a longitudinal analysis to examine the Formetric system's responsiveness to changes in deformity over time. The benefits of this evaluation method in reducing x-ray exposure in children and adolescents are readily apparent. Occasional radiographs will still be required to assess morphology of the vertebrae. The utility of this scanner may be in its use as an initial measurement tool when the need for radiographs is uncertain; for repeated assessments to determine whether or not a deformity has progressed; and in quantifying the magnitude, 3D shape, and rate of progression of a spinal deformity.

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