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Validation Study

Correlation Between a Novel Surface Topography Asymmetry Analysis and Radiographic Data in Scoliosis

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Abstract

Study Design: Cross-sectional study.

Objective: To investigate the correlation between parameters extracted from a three-dimensional (3D) asymmetry analysis of the torso and the internal deformities of the spine presented on radiographs, including 1) curve number, direction and location; 2) location of the apical vertebra; and 3) curve severity.

Summary of Background Data: Surface topography (ST) is used to assess external torso deformities and may predict important characteristics of the underlying spinal curves. ST does not expose patients to radiation and could safely be used clinically for scoliosis patients. Most ST indices rely on anatomical landmarks on the torso and 2D measurements.

Methods: The ability of a 3D markerless asymmetry technique to predict radiographic characteristics was assessed for 100 scoliosis patients with full torso ST scans. Twenty-four additional patients were used for validation. The number, direction, and location of curves were determined by three examiners using ST deviation color maps. The inter-method percentage of agreement and Kappa coefficient were estimated for each measure. Linear regression predicted the vertical location of the apical vertebra from ST. Curve severity (mild, moderate, severe) was predicted with a decision tree analysis using ST parameters.

Results: The average percentage of agreement was 62%, 66%, and 23% for single, double, and triple curves, respectively. Curve direction was always correctly identified. The average percentages of agreement for curve location were 63%, 92%, and 62% for proximal thoracic, thoracic/thoracolumbar (T-TL), and lumbar (L) curves, respectively. Apical vertebra location was predicted with $R^2 = 0.89$ for T-TL and $R^2 = 0.58$ for L curves. ST parameters classified curve severity for T-TL and L curves with 73% and 59% accuracy, respectively.

Conclusions: The method presented here improves upon current ST techniques by using the entire torso surface and both a visual and quantitative representation of the asymmetry to better capture the torso deformity.

Keywords: Surface topography; Asymmetry analysis; Adolescent idiopathic; Scoliosis; Radiography

Introduction

Spinal deformities such as scoliosis affect both internal and external alignment and vary among patients [1]. It is important to monitor the scoliosis deformity with regular clinical visits in order to identify progression and prescribe appropriate treatments. The Cobb angle measured on posterior-anterior (PA) radiographs is the standard to monitor scoliosis [2-5].

Mild curves (Cobb angle <25°) typically do not require treatment. Moderate curves (Cobb angle between 25° and 40°) are treated using noninvasive methods such as bracing. Severe curves (Cobb angle >40° or 50°) may require spinal fusion and instrumentation surgery to correct the curve [6].

Using the Cobb angle in monitoring scoliosis is problematic because of the long-term effects of radiation [7-10], including an increase in the risk for breast cancer [11].

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Additionally, because the Cobb angle is measured from two-dimensional radiographs, it has a limited ability to fully describe the three-dimensional (3D) spinal deformities associated with scoliosis. Moreover, the cosmetic appearance of the torso is a major concern of patients, which cannot be captured with radiographs [12,13].

Surface topography (ST) has been suggested to assess the deformities associated with scoliosis [12,14-20]. Attempts have been made to use ST to predict the Cobb angle and the geometry of the underlying spine in order to replace or decrease the periodic radiographic evaluations [12,16,20-27]. However, most of the current ST methods assess the torso deformities by measuring indices from manually placed markers [12,14,26,28]. Marker placement requires a trained operator and can introduce measurement error and uncertainties. Additionally, the number and location of anatomical landmarks are limited, and the 3D torso surface cannot be fully represented by so few points.

A novel 3D markerless ST technique has been recently developed to identify areas and patterns of asymmetry using the "best plane of symmetry" [29]. Torso asymmetries are illustrated using a deviation color map (DCM) on the 3D model of the patient's torso. Because the indices are extracted without human intervention, the issues with marker placement are avoided. The proposed asymmetry measures are universal and independent of the scanning technology employed. Previously, patients have been reliably classified into various groups according to their DCM [29]. In the present study, the clinical relevance and relation of the DCMs to radiographic measures of scoliosis is studied.

The objectives of this study are to determine the ability of the asymmetry analysis to 1) identify the number, direction, and location of scoliosis curves; 2) predict the vertical height of the curve apex; and 3) predict the curve severity, defined as mild (Cobb angle $<25°$), moderate ($25° <$ Cobb angle $<40°$), and severe (Cobb angle $>40°$). The long-term objective of this work is to develop noninvasive methods based on ST analysis to accurately quantify and monitor scoliosis deformities with the aim of reducing the number of required x-rays.

Materials and Methods

Torso scans from 100 patients with adolescent idiopathic scoliosis (AIS) were selected randomly from scans collected in an ongoing study on full-torso ST (Table 1a). All subjects had no surgical treatment and had an ST scan with a corresponding radiograph. Data were collected from consenting volunteers during routine clinical visits. Ethics approval from the human research ethics board was obtained.

Torso scans of 24 additional patients with AIS (Table 1b) meeting the same selection criteria were employed as a validation sample to assess the accuracy of the model developed for predicting the location of the curve apex from ST data.

Table 1
Description of subjects (a) test subjects (b) validation sample.

(a) Test subjects		(b) Validation sample	
Total subjects	100	Total subjects	24
Age, years	10−18	Age, years	10−18
Cobb angle, °	10°−69°	Cobb angle, °	12°−63°
Gender, n		Gender, n (%)	
Male	22	Male	5 (20.8)
Female	78	Female	19 (79.2)
Curve type, n		Curve type, n (%)	
Lenke 1	32	Lenke 1	8 (33.3)
Lenke 2	3	Lenke 2	0
Lenke 3	13	Lenke 3	3 (12.5)
Lenke 4	0	Lenke 4	2 (8.3)
Lenke 5	46	Lenke 5	9 (37.5)
Lenke 6	6	Lenke 6	2 (8.3)

Data Collection

ST data were collected using four Minolta scanners to capture the front, back, and side views of the torso surface [30], which were merged to reconstruct the 3D model of the torso. Asymmetry was investigated using our previously developed 3D markerless asymmetry analysis [29]. The torso was reflected about the best plane of symmetry and was compared with its reflection to identify the areas of asymmetry in the form of a DCM. Based on our previous work, deviation <3 mm was considered normal [29]. Any deviation >3 mm was shown with a red or blue color depending on whether the asymmetry was convex (blue) or concave (red) relative to the other side of the torso. When viewing the DCM from the back of the patient, the pattern of color patches is symmetric about the best plane of symmetry (approximately midsagittal), with each blue-colored patch having a corresponding red-colored patch on the other side of the torso (Fig. 1A). To quantify the local deformities, the color patches were automatically isolated from the DCM. Because of symmetry, only one side of the torso was used to calculate the quantitative parameters from the DCM. Figure 1 shows an example of the DCM and the isolated color patches.

All subjects received a PA radiograph as part of their routine clinical visit. Radiographs were taken the same day and in a similar position as the ST images, and served as the gold standard to assess the performance of the predictions from the ST data.

Number, direction, and location of curves

Three novice observers determined the number, direction, and location of the curve(s) from the DCM. The novice observers were graduate and undergraduate engineering students conducting research in our institution. Standard instructions were provided by the author. The observers first counted the number of color patches in the DCM. To determine the direction of the curve, observers simply determined if the blue color was on the right or left side of