PREDICTION OF SPINAL DEFORMITY IN SCOLIOSIS FROM TORSO SURFACE CROSS-SECTIONS

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INTRODUCTION: Scoliosis is currently followed by multiple X-rays which increase cancer risk [1]. It would be preferable to assess scoliosis noninvasively via the associated torso surface deformity, but studies to date have shown only moderate correlations between torso and spinal deformity [2,3]. Improved correlations may be possible through analysis of the entire torso and use of an artificial neural network (ANN) for pattern-recognition. In this study we assessed whether full-torso surface laser scan images could be effectively used to predict spinal deformity with the aid of an ANN.

METHODS: Torso Laser Imaging: Each patient stood within a calibrated positioning apparatus during a series of three torso scans and two X-rays (one postero-anterior (PA-0) and one at 20° to horizontal (PA-20)). During each 15 s scan, four laser scanners each acquired 3-D coordinates of part of the patient’s torso surface, which were transformed into a single bicubic-spline torso surface model using data from a calibration object and a custom computer algorithm (Figure 1). Contours were cut through the torso model at each vertebral level (estimated from skin marker locations), and the line joining the centroids of area of the torso contours was generated. Indices were computed including lateral deviations and the maximum Cobb angle of the torso centroid line, relative rotation of the principal axes of area of each contour (Figure 2a), and the range of contour rotation (the angle of rotation between the most left-rotated and most right-rotated contours). Inter-scan reliability of these torso indices was tested using three scans of a mannequin.

Stereo-Radiographic Technique: Anatomic landmarks (6 points per vertebra) from the PA-0 and PA-20 X-rays were used to create a three-dimensional reconstruction of the spine and rib cage [4] (Figure 1). Curves were defined as lying between points of inflection of the smoothed line joining centroids of vertebral bodies. For each spinal curve, the computer Cobb angle, the apex location, and the maximum value of vertebral axial rotation were recorded.

RESULTS: Index Reliability: Inter-scan variability was 3 mm for torso centroidal deviation, 2° for the torso Cobb angle, and 1° for torso contour rotation.

Correlation of Torso and Spinal Indices: The torso estimate of T1-L5 height correlated well with the actual T1-L5 height (r = 0.89). The torso centroid line (maximal torso Cobb angle ±5°) was much straighter than the vertebral body line (maximal Cobb angle ±13°) (Figure 2b). Maximal torso rotation was two thirds of the maximal vertebral rotation (±4° vs. ±137°, r = 0.43). The range of torso rotation was the best estimator of both the maximal Cobb angle (r = 0.64) and vertebral axial rotation (r = 0.49).

Prediction of Spinal Deformity: The best model used 10 indices describing torso centroidal lateral deviation, torso Cobb angle, and torso rotation. This model predicted the Cobb angle within ±6.3° (0.5 S.D.) in 44% (regression) to 63% (ANN) of the test set, and within ±12.7° (1 S.D.) in 69% (regression) to 94% (ANN). The ANN was able to identify patients with maximal Cobb angles greater than 30° in the test set (prevalence: 0.50) with SN = 1.0, SP = 0.75, PPV = 0.80, NPV = 1.0. Results were similar in the training set.

DISCUSSION: The torso centroid line was remarkably straight despite significant torso contour rotation in the patients studied. The range of torso rotation related moderately well to the maximum Cobb angle (r = 0.64). Despite this moderate level of linear correlation, the ANN was able to predict the maximal Cobb angle within 6° in 63% of the test data set and within 13° in 94%. These results indicate that neural-network analysis of full-torso scan imaging shows promise to accurately predict scoliotic spinal deformity in a variety of patients. We now intend to refine these predictions using additional indices of spinal deformity in a larger patient group.


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Figure 1(a) Torso surface mesh superimposed on 3-D spine and rib cage model. (b) Same patient, showing the torso centroid line.

Patient Database: The study had appropriate ethics approval and all subjects gave informed consent. Sixty-five scan-X-ray pairs were generated during 18 months in 40 patients (30 female), aged 8-17 yr, with a mean maximal spinal Cobb angle of 33° (Cobb angles 0°-58°). Sixteen (25%) were randomly selected to form a "test set," whose indices did not differ significantly from those in the remaining "training set" (n = 49, p<0.05).

Statistical and Neural Network Evaluation: Pearson correlation coefficients between spinal indices and torso indices were computed. Groups of torso inputs were selected for prediction of the Cobb angle. For each group of inputs, a multiple linear regression model and a three-layer back-propagation ANN were both trained to predict the maximal Cobb angles in the training set, then used to predict the maximal Cobb angles in the test set. The percentage of predictions that lay within 0.5 and 1.0 standard deviations of the actual Cobb angle and the sensitivity (SN), specificity (SP), and positive and negative predictive values (PPV, NPV) of model predictions of the spinal Cobb angle were computed.

Figure 2(a) Contour principal axis (X*, Z*) rotation, relative to axis joining posterior superior iliac spine (PSIS) markers. (b) Typical result: the torso centroid line is nearly straight despite substantial spinal curvature.