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Spine and back-shape changes in scoliosis

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Thirty-five untreated patients with scoliosis were studied by Cobb radiography and back-surface photogrammetry on each of at least two clinic visits. Also, the maximum vertebral axial rotation was measured. Each pair of patient visits was classified as showing either a progression, improvement, or no change in the scoliosis using a threshold of 5° change in the Cobb angle. The computer Cobb measurement was the most precise measurement, and the back-surface measurements were the least precise. The Cobb measurement of scoliosis is the most precise for detecting small changes, but can be improved by a computerized analysis of digitized radiographs.

In adolescent idiopathic scoliosis, radiography is traditionally used to document the spinal curvature and to assess progression. Three-dimensional measurements have also been proposed to show changes in the spinal curve in other planes (DeSmet et al. 1983, 1984). Recently, interest in noninvasive methods for measuring the clinically apparent back asymmetry has increased. Each radiographically defined curve is usually associated with a corresponding region of asymmetry of the back surface (Stokes et al. 1988). Therefore, it is possible that monitoring the surface manifestation of the scoliosis curve might permit detection of changes in these patients.

In this study the following two questions were addressed: *1.* Can changes in back-surface shape be distinguished from measurement errors to detect progression in the spinal deformity and reduce the need for sequential radiography? *2.* Can the conventional radiographic Cobb method be improved?

Patients and methods

Thirty-five patients (33 females, 2 males) with a mean age of 13 (9–20) years who were attending a scoliosis clinic, but not undergoing treatment, were studied by radiography and surface topography on two or more consecutive visits over a period of 4 years. The mean follow-up interval was 9 (2–22) months. Twenty-five patients were seen on two visits, 7 on three visits, and 3 on four visits for a total of 83 visits giving 48 comparable visit pairs.

For the purpose of this study, the largest spinal curve in each patient was considered in the analyses. The mean Cobb angle was 22° (5–50°). There were 13 thoracic curves, 10 thoracolumbar curves, and 12 lumbar curves.

Measurement techniques. Posterior-anterior radiographs were made with the patient standing with a 4-m tube-to-film distance and using 36×14-inch films (low-dose method of Ardran et al. 1980). Back-surface topograms were made by the projected raster stereophotographic method (Stokes et al. 1988). Five measurements (three from the radiographs and two from the back-surface topogram) were made of each curve:

1) *Conventional Cobb angle.* This was measured from the radiographs by the usual clinical method.

2) *Computer Cobb angle.* Landmarks (centers of end-plate images and the top and base of each pedicle image) were marked on the films. The positions of these points were then digitized and the coordinates were stored in a computer file. The coordinates were divided by a scaling factor (1.075) to correct for the magnification resulting from the spine-to-film distance (about 300 mm).

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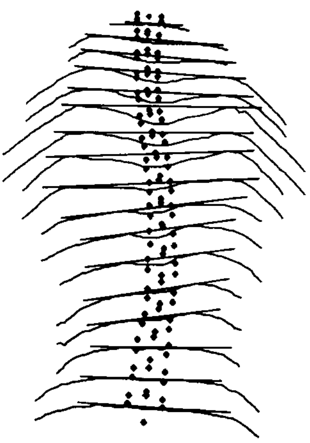

	V. ROTN	S. ROTN
T1	-2.4	-2.5
2	-2.8	-4.0
3	-4.0	-4.4
4	-2.4	-3.0
5	-0.0	-1.9
6	-2.3	0.1
7	-0.1	0.7
8	1.9	2.1
9	-0.3	3.2
10	0.5	5.6
11	5.1	7.1
T12	2.5	7.4
13	1.8	8.5
14	-1.4	6.9
15	-2.3	0.8
16	-0.6	-0.9
17	1.1	-3.2

Figure 1. Digitized landmarks on each vertebra T1 through L5 with superimposed horizontal-plane cross sections through the back surface. The magnification of the radiograph has been compensated for to give it the same scale as the back surface. The axial rotation of each vertebra was calculated from the landmark positions. Double tangent lines drawn across both posterior prominences of the back surface provided angular measurements of the axial rotation of the back surface at each anatomic level of the trunk. V. ROTN vertebral rotation, S. ROTN back-surface rotation. Units in degrees.

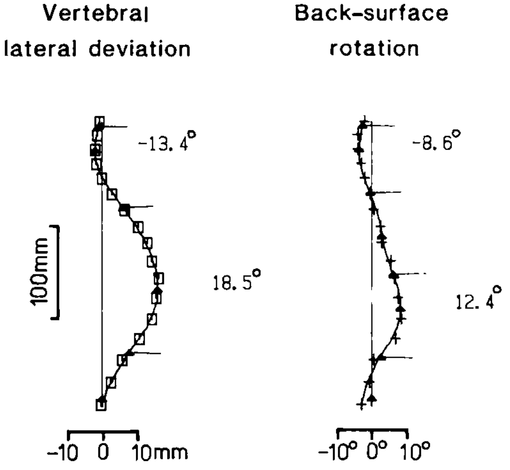

Figure 2. Lateral deviation of the spine and back-surface rotation each plotted as a function of anatomic level, along with computerized measurements of the Cobb angle. These plots are for the same patient, as is illustrated in Figure 1. The horizontal scale of the spinal plot has been magnified. The Surface Cobb angle was calculated from the surface rotation plot by the same method as the Computer Cobb angle measurement of the spinal curve.

Note: Because the units of measurement in the surface rotation plot are mm on the horizontal axis and degrees on the vertical axis, the units of the Surface Cobb angle are arbitrary, but consistent for all the cases in this study.

Then, an automatic curve-fitting method (Stokes et al. 1987) was used to locate curves and to calculate Cobb angles by first finding inflection points (points of zero curvature and greatest inclination to the spinal axis), which defined the end points of a scoliosis curve. Then, the angle formed between perpendiculars to the curve at these inflection points was measured as the Computer Cobb angle. The mean Computer Cobb angle was 1.13 times the mean value of the Conventional Cobb measurement, but was highly correlated with it (r=0.99) (Stokes et al. 1987).

3) *Maximum back-surface rotation*. The greatest axial rotation in that region of the back defined by the radiographically determined curve was measured by the double tangent technique (Stokes et al. in press). This maximum rotation was normally found close to the spinal curve apex (Figure 1).

4) *Surface Cobb angle*. This was measured from the back-surface double-tangent angles (Figure 2). The same computer program that calculated Computer Cobb angles was used, except that the double tangent angles at each vertebral level of the spine were used in place of the lateral deviation of the vertebra.

5) *Maximum vertebral axial rotation*. This was measured from the digitized landmarks on the radiographs by the method of Stokes et al. (1986).

Precision of measurements. Each of the measurements was characterized by a 95 percent confidence interval based on repeated measurements. This was calculated as twice the standard deviation of differences between the repeated measurements. This confidence interval was then used to define the threshold for determination of significant changes by the corresponding measurement technique. It was expected that the measurements would be less variable if both measurements were taken on the same clinic visit, than on visits several weeks or months later, especially because the children were growing during the study. Therefore, we studied both the "within" and the "between" visits variability of the measurements.

The within clinic visits variability of the back-surface measurements was studied in 6 twice-photographed patients who were randomly selected from the study population. The precision of the radiographic measurements was not determined in this way because these measurements could not, on ethical grounds, be repeated. Between clinics variability of both radiographic and topographic measurements was estimated by examining measurements made on sequential clinic visits of patients whose scoliosis was judged not to have increased. A change (increase or decrease) of 5° by the computerized Cobb measurement was used to select these "nonchanging" patients. There were 41 pairs of Computer Cobb angle measurements in 29 patients that did not change by more than 5°.

Precision (variability) of measurements. The standard deviations of differences between successive measurements of the Cobb angles were 4.5° and 3.0° for the Conventional and Computer Cobb measurements, respectively, in the "nonchanging" group of patients, giving confidence limits of the Cobb angle measurements at ± 9° and ± 6°, respectively (Table 1). Because the Cobb angle was the basis for determining whether a change had occurred or not, we adopted threshold values for change of the Cobb angle of 5° to conform with normal clinical practice. Repeated measurements (with repeat markings) of radiographs of 6 randomly selected patients gave a 95 percent confidence limit (due to film marking and measurement alone) of ± 2.5° for the Computer Cobb angle.

Table 1. Measurements (degrees) of spinal and back-surface asymmetry, together with the precision estimates of each measurement, defined as twice the standard deviation of differences between repeated measurements

	Computer Cobb	Conventional Cobb	Maximum surface rotation	Surface Cobb	Maximum vertebral axial rotation
Mean	24.0	22.0	5.6	10.4	7.3
Standard Deviation	11.4	10.3	3.1	4.1	5.0
Range	6.1–58	4–50	0.2–16	2.4–23	0.2–25
Within visits precision	[a]	[a]	3.6	4	7.1
Between visits precision	6	9	6.3	9	8.1

[a] Not measured, for ethical reasons.

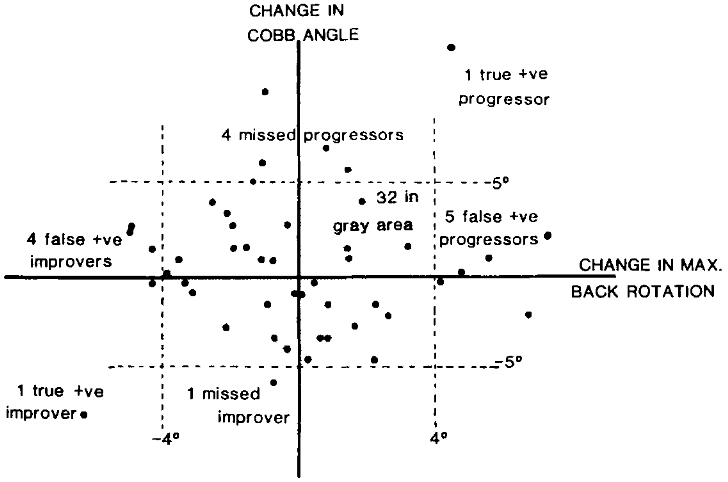

Figure 3. Changes in maximum back-surface rotation (horizontal axis) and in the Computer Cobb angle (vertical axis) for 48 visit pairs of 35 patients. The gray area represents a region where neither measurement exceeded the threshold of significant change. For other terminology, see the text.

The accuracy of measurement of vertebral axial rotation has been determined experimentally as ± 7.1° (Stokes et al. 1986). The between clinics variability of the maximum vertebral axial rotation in the "nonchanging" group of patients was ± 8.1° (Table 1).

Changes in the Cobb angle were plotted against changes in the maximum back-surface rotation (Figure 3). A gray area has been defined in which the changes in the spinal and surface measurements were less than those considered significant (± 5° for Computer Cobb angle; the 95 percent confidence limit in the case of the surface measurement). Values outside this error range were considered to represent real changes. If there was a change in both the spinal shape and the back-surface shape, then it was considered as a change correctly identified by the surface measurement. Changes in the surface shape that did not correspond to changes in spinal shape were considered to be false-positive findings. Similarly, absence of change in back-surface shape in a case with a change in spinal shape was considered as a false negative. Increase in the magnitude of the curve represented progression, and decrease in the magnitude was improvement.

Results

Changes in the patients. Of the 35 patients (48 visit pairs), 4 were observed on sequential visits to undergo an increase of 5° or more by the Computer Cobb measurement of their major curve. Two other patients had a decrease of scoliosis of more than 5° Computer Cobb. By Conventional Cobb measurement, seven visit pairs showed an increase of more than 5°, and 8 showed a decrease greater than 5°. There was 1 case of a large decrease followed by a large increase.

Because most patients in this group did not have a changing Cobb angle by the criterion of a 5° change, it was also expected that other measurements would not change. The best correspondence between the spinal and surface measurements was obtained between the Computer Cobb angle changes and changes of the maximum back-surface rotation.

There were two significant increases in the spinal curvature correctly identified (Figure 3). There were 33 cases of no significant change in the spinal curve also showing as no significant change in the back surface. However, 3 cases of a significant progression were not detected; one improvement was not detected. There were nine falsely identified changes in the spinal curve (five false progressions and four false improvements). There were no cases of a change in the opposite direction to the actual change. Thus, in terms of the diagnostic accuracy of the surface measurement for detecting spinal change, there were 35 correct correspondences and 13 incorrect, but the specificity was low.

Most patients were growing during the period of study. The average increase in spine length (projected on to the coronal plane) between visit pairs was 10.4 mm, or about 3 percent of the total thoracic and lumbar spine length.

Correlations between magnitudes of changes. Correlation analyses showed that the magnitudes of changes in the measurements of spinal and back asymmetry were related to each other with positive correlation coefficients (Table 2). However, because the correlations were low, it was not possible to obtain accurate regression relationships to define the relative magnitudes of the changes in the measurements. Therefore, the correlations between the original measurements (as opposed to changes in them) were used to estimate these magnitude relationships (Table 3). The "magnitude ratio" of a surface measurement and a skeletal measurement was defined as the ratio between the mean values of those two measurements in this population of patients. Because linear regression lines pass through the means of the two variables in a regression, the

Table 2. Correlation between changes on successive visits in measurements of truncal asymmetry

	Computer Cobb	Conventional Cobb	Max surface rotation	Surface Cobb
Conventional. Cobb	0.53			
Max surface rotation	ns	ns		
Surface Cobb	ns	ns	0.48	
Max. Vertebral axial rotation	0.40	ns	0.37	ns

Table 3. Magnitude ratios (ratios between mean absolute values) and correlation coefficients in parentheses between measurements of spinal and back-surface shape, based on measurements of 35 patients[a]

	Computer Cobb	Conventional Cobb	Max. surface rotation	Surface Cobb
Conventional Cobb	1.12 (0.95)			
Max surface rotation	4.24 (0.25)	3.78 (0.33)		
Surface Cobb	2.10 (0.54)	1.87 (0.56)	0.49 (0.70)	
Max vertebral axial rotation	3.17 (0.61)	2.83 (0.51)	0.75 (0.40)	1.51 (0.55)

[a] The first clinic visit of each patient was used. The absolute values of all measurements were used in these analyses, thus pooling measurements from right- and left-sided curves and assigning positive values to all measurements.

"magnitude ratio" represents the "slope" of such a regression, but ignoring the (probably spurious) intercept term in such an analysis. For an individual patient who changed with time according to the relationships found in the group of patients as a whole, a change of 10° Cobb would be expected to produce a change of vertebral rotation of 3.4°, and a change of back-surface rotation of 2.6°. These estimates are based on reciprocals of the magnitude ratios given in Table 3.

Discussion

This study has emphasized the problem of measurement in the clinical follow-up of patients with small, potentially progressive curves. Among the measurements we studied, the Cobb angle had the highest precision of measurement when expressed as a percentage of both the mean value of this measurement and the change considered clinically significant. However, even when improved by the computerized method of digitization and automatic curve measurement, the random variability of this measurement was 6° (95 percent confidence interval). This implies that about 5 percent, or one in 20 measurements, could give a false indication of the need for a change in treatment plan based on this Computer Cobb measurement alone.

There is a high correlation between back-surface rotation and spinal lateral deviation (Stokes et al. 1988). Therefore, a method analogous to the Cobb angle measurement of the spine was used to give a measure (Surface Cobb angle) of the magnitude of the back-surface manifestation of the curve. The level of the maximum axial rotation was usually found to be within one anatomic level of the apex of the curve.

There was a positive correlation between changes in the vertebral axial rotation and changes in the Cobb angle, indicating that both were an integral part of the etiology of progression or improvement of scoliosis. Similarly, there was a significant positive correlation between the changes in the axial rotation of the vertebra and of the back surface. However, the back-surface rotation was on an average less than the maximum vertebral rotation by a factor of 0.76 in this population of patients (Table 3). The axial rotation of the back surface did not prove to have a sufficiently close relationship to the Cobb angle to be an indicator of change of the spinal lateral curvature. The measurement of back-surface symmetry we used (the rotation of the surface double tangent) was a noncontacting optical technique that produces measurements similar to the angular measurements obtained by means of inclinometers (e.g., Bunnell 1984). It is not known whether other methodologies (e.g., Moiré fringe photography) might provide data more sensitive to small changes in the backs of these patients. However, the relationships between the measurements show that in absolute terms the axial rotation of the back surface is less than the axial rotation of the vertebrae, which in turn is less than the Cobb angle. This is probably the major reason why surface measurement techniques have not been effective in quantifying spinal deformity, although they document an aspect of the scoliosis deformity not seen radiographically, and without ionizing radiation.

There was an average increase in spine length of about 3 percent between clinic visits. To maintain the same angular Cobb angle, as most of these patients did, the lateral deviation of the spine would have to increase by a similar percentage. Thus, the Cobb method actually ignores an increase in the lateral deviation of the spine if the Cobb angle remains constant during a period of spinal longitudinal growth.

Both the Conventional and Computer Cobb

angle measurements had greater precision in repeated measurement than the back-surface measurements used here, and they had greater precision than expected, based on previously published reports (Oda et al. 1982, Sevastikoglou and Bergquist 1969) of interobserver and intraobserver errors. The Conventional Cobb angles were measured by 1 observer (MSM) and were made with consistent positioning of both the patient and the x-ray equipment, which probably reduced the variability. The Computer Cobb had slightly higher precision than the Conventional method. Jeffries et al. (1980) also found that repeated measurements of the same film could be done more accurately with computerized calculation of the Cobb angle than by manual marking and measurement. In this study and in that of Jeffries et al. (1980), the Computer Cobb method gave measurements about 11 percent greater than the traditional manual method. This small, systematic difference should be compensated for before making a comparison with Conventional Cobb angle measurements. The computerized version of Cobb's method appears to be the most accurate method for detecting changes in the coronal plane spinal deformity.

References

Ardran G M, Coates R, Dickson R A, Dixon-Brown A, Harding F M. Assessment of scoliosis in children: low dose radiographic technique. Br J Radiol 1980; 53(626):146–7.

Bunnell W P. An objective criterion for scoliosis screening. J Bone Joint Surg (Am) 1984;66(9):1381–7.

De Smet A A, Tarlton M A, Cook L T, Berridge A S, Asher M A. The top view for analysis of scoliosis progression. Radiology 1983;147(2):369–72.

De Smet A A, Asher M A, Cook L T, Goin J E, Scheuch H G, Orrick J M. Three dimensional analysis of right thoracic idiopathic scoliosis. Spine 1984;9(4):377–81.

Jeffries B F, Tarlton M, De Smet A A, Dwyer S J, Brower A C. Computerized measurement and analysis of scoliosis: a more accurate representation of the shape of the curve. Radiology 1980;134(2):381–5.

Oda M, Rauh S, Gregory P B, Silverman F N, Bleck E E. The significance of roentgenographic measurement in scoliosis. J Pediatr Orthop 1982;2(4):378–82.

Sevastikoglou J A, Bergquist E. Evaluation of the reliability of radiological methods for registration of scoliosis. Acta Orthop Scand 1969;40(5):608–13.

Stokes I A F, Armstrong J G, Moreland M S. Spinal deformity and back surface asymmetry in idiopathic scoliosis. J Orthop Res 1988;6(1):129–137.

Stokes I A, Bigalow L C, Moreland M S. Measurement of axial rotation of vertebrae in scoliosis. Spine 1986; 11(3):213–8.

Stokes I A, Bigalow L C, Moreland M S. Three dimensional spinal curvature in idiopathic scoliosis. J Orthop Res 1987;5(1):102–13.

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