Comparison of Three Noninvasive Methods for Measuring Scoliosis
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Research Report

Comparison of Three Noninvasive Methods for Measuring Scoliosis

The premise behind most noninvasive techniques for the measurement of scoliotic conditions of the spine is that the lateral distortion of the spine relates directly to transverse rib cage deformity within the transverse plane. The focus of this study was to examine this assumption by comparing different noninvasive methods for the assessment of scoliotic curves. The three techniques examined were (1) use of the Scoliometer® (SCOL), (2) use of the back-contour device (BCD), and (3) use of moiré topographic imaging (MTI). Fourteen subjects (10 female, 4 male) with idiopathic adolescent scoliosis were measured. Posterior-anterior radiographs were obtained for the clinical assessment of all subjects and were subsequently used to determine Cobb angles. Significant correlations between axial trunk rotation and Cobb-angle measurements were observed in the thoracic region (MTI, r=.80, df=10, P<.005; BCD, r=.70, df=10, P<.025; SCOL, r=.59, df=10, P<.025) but were not found within the lumbar region (MTI, r=.42; BCD, r=.17; SCOL, r=.20). Factors other than trunk deformity, such as the posture assumed by the subject during measurement, may have influenced axial trunk rotation. Hence, the techniques appear to provide valid estimations of lateral curvature of the spine in the thoracic region of the trunk but not the lumbar region. The results suggest that the measurement techniques cannot be used interchangeably in clinical recording.

Key Words: Back measurement, Moiré, Scoliosis, Spinal curvature

Idiopathic adolescent scoliosis, a pathologic lateral curvature of the spine, has been reported to affect from 0.13% to 13% of the population. Although both boys and girls may be affected, the condition is more prevalent in girls. Severe scoliotic deformities can cause chronic back pain, the need for constant medical attention, social and emotional distress, severe disability, and premature death. These lateral curvatures are detectable from 10 years of age through the early teens and may become progressively worse during puberty. Small curves initially deemed inconsequential should be monitored for further deterioration.

To accurately evaluate a patient’s scoliosis requires an erect posterior-anterior (PA) radiograph of the full spine. From the PA image, the internal bony configuration and the extent of lateral deviation of the spine can be determined. Various measurements such as those of pedicle rotation, may be taken from the radiograph; however, the technique most advocated by the Scoliosis Research Society has been the Cobb method. When using the Cobb method, an angle that quantifies the extent of...
lateral curvature within the affected region of the spine is calculated. Measurements obtained with the Cobb method do not fully describe the three-dimensional geometry of the spine and associated deviations, such as axial rotation and kyphosis. The Cobb method has nonetheless come to represent the standard means of clinically evaluating scoliosis because it measures the most extreme features of scoliosis.

Estimates of the number of persons affected by scoliosis are dependent on the criterion used to define the degree of severity of the scoliotic curve. Some researchers have suggested that patients with Cobb-angle curves of greater than 20 degrees are in need of treatment and those with Cobb-angle curves of between 5 and 10 degrees are "at risk" and should be monitored carefully. Other investigators, however, have recommended that curves between 20 and 30 degrees need not be treated until definite signs of progression are observed. Thus, identification of the scoliotic conditions needing physical intervention requires the precise quantification and monitoring of the severity of scoliosis.

The development of accurate noninvasive techniques to complement or to replace existing scoliosis measurement procedures has been pursued for several reasons. Noninvasive techniques may provide reliable and discriminative measurements of scoliosis that would ultimately reduce the number of false-positive and false-negative findings. A nonradiographic technique could be used more frequently, enabling practitioners to better document changes in scoliotic curves. This information would enhance not only the patient's treatment, but the understanding of the progression of scoliosis. Noninvasive techniques may drastically reduce the number of radiographs needed over the patient's treatment period. Alternatives to radiographic techniques would be desirable because repeated exposures to x-ray radiation involves health risks to the patient as well as increased cost to the health care system.

Several noninvasive techniques have evolved that attempt to relate external deformity, particularly observed by rib cage humps, with lateral curvature of the spine. These techniques are designed on the premise that the extent of lateral curvature of the spine within the frontal plane will be directly related to the amount of axial rotation of the spine and rib cage. The ability of devices to be used to identify and measure scoliotic conditions based on axial rotation, however, has been variable. The focus of this study, therefore, was to compare the validity of different noninvasive methods for the estimation of scoliotic curves. Specifically, the three techniques examined were (1) use of the Scoliometer® (SCOL), (2) use of the back-contour device® (BCD), and (3) use of moiré topographic imaging (MTI). Measurements obtained with each technique were compared with Cobb-angle measurements taken from PA radiographs of the thoracic and lumbar regions of the back.

**Literature Review**

Scoliosis is a pathological condition of the spine marked by abnormal lateral curvature. Depending on the etiology, there may be only one primary curve or a primary curve and a compensatory secondary curve. Scoliosis may be chronic as a result of muscle or bone deformation, such as with idiopathic scoliosis, or transient as a result of unequal muscle contraction. Individuals with scoliosis may exhibit markedly altered standing postures and rib cage deformity. It is the association of rib humps with lateral curvature of the spine that has prompted the development of instruments and procedures that attempt to relate the extent of rib cage deformity observed externally to the internal severity of spinal distortion.

The detection of scoliotic curves has usually taken the form of screening programs initiated in the school system. These programs have been reported to lead to the early identification of scoliotic curves that can be treated before they become severe. The results from these programs are quite variable, and the number of persons assessed having scoliosis can range from 1% to 21%. This variability may be due, in part, to the differences in the expertise or experience of those involved in the evaluation and to the criterion used to define a scoliotic curve.

The forward-bending test has been used as a simple and effective means of detecting scoliosis. Subjects exhibiting abnormal rib humps usually have been referred to a specialist for a more detailed examination. The severity of rib hump deformity justifying further examination is difficult to define, given that a rib hump is normally present. Some research has shown no relationship among specific indexes concerned with the rib hump and the degree of the Cobb angle. Furthermore, the forward-bending test has been shown to be insensitive to the most common form of scoliosis, which occurs in the thoracolumbar region of the vertebral column.

To provide a means for scoliosis screening, several clinical measurement methods have been introduced. The possible advantage of such measures are that they provide a quantitative record that may be used to track the progression or regression of the curve. They also help standardize the screening procedure. The Scoliometer®, for example, has been proposed as a simple and reliable instrument for detecting scoliosis. This specially designed inclinometer is said to be sensitive to rotational deformities that are often present in patients with scoliosis who assume a standard forward-bending position (Fig. 1). Bunnell suggested that the minimum...
significant deformity justifying referral for orthopedic evaluation was a 5-degree angle of axial trunk rotation (ATR) at any level of the spine. This criterion has been reported to be very sensitive to false-negative results. Unfortunately, over one half of the patients with minor scoliosis, defined as a Cobb angle of less than 20 degrees, were evaluated with the SCOL method as having positive (ie, false-positive) results. Amendt et al determined that the use of the SCOL method led to measurements that had good reproducibility; however, the correlation of these measurements with measurements of lateral curvature was low, indicating that measurements obtained with the SCOL method were not sufficiently accurate for diagnostic purposes.

The inadequacies of the forward-bending and SCOL methods have led to the development of various other indexes and the application of more sophisticated measurement techniques of back surface characteristics such as the use of BCDs. The BCD consists of a level frame through which pass a series of movable rods (Fig. 2). These rods may be locked in position to record the contour of the opposing back surface of the patient in the forward-bending position. Thulbourne and Gillespie used this device to record the rib hump deformity features of hump height and rib depression and the corresponding hump height and rib depression gradients. No clear linear relationship between lateral curvature and these measurements, however, was evident. Burwell et al also used the BCD method and calculated a trunk asymmetry score (TAS) to evaluate the shape discrepancies of transverse contours of the back. With this quantitative approach, they were able to demonstrate significant correlations between TAS measured at the apex of the primary spinal curve and the Cobb-angle measurements. In addition, lateral curves of 20 degrees or more were found to have considerably greater TAS values than did normal curves.

More elaborate systems have evolved to record the surface topography of the entire back; examples are Raster stereography, the integrated shape imaging system (ISIS), and moiré topography. The moiré method involves superimposing dark and light fringes on an object by illuminating and viewing the object through a
Figure 3. Moire topographic image of subject with scoliosis.

The accuracy of the MTI method for predicting the location of the scoliotic curvature has been found to vary between back regions. Daruwalla and Balasubramaniam19 for instance, stated that only 68% of thoracic, 54% of thoracolumbar, and 15% of lumbar scoliotic curves could be calculated by the MTI method.

The SCOL, BCD, and MTI methods may be effective in screening programs to assess the degree of scoliosis. Ideally, screening procedures should be based on reliable and valid measurements and should identify only those individuals who have scoliosis needing intervention. If a screening program produces a large number of false-positive results, there will be an increased burden on the health care system as specialists deal with unnecessary referrals. With a large number of false-negative results, however, there is the possibility that the persons not identified early enough will need more extensive and costly treatment in the future such as extensive bracing or spinal surgery. Hence, the cost effectiveness in financial and human terms of any screening program depends on appropriate evaluations being made such that only those people with clinically significant scoliosis are identified.7,17,22

Method

Subjects

Fourteen subjects (10 girls, 4 boys) with idiopathic adolescent scoliosis, who were under clinical observation, participated in this study. Full trunk PA radiographs were taken of all subjects as part of their clinical assessment to determine the form and extent of lateral curvature as defined by the Cobb-angle method. The sample had a mean age of 13.9 years (SD=3.3, range=8-19), a mean height of 157.8 cm (SD=15.2, range=127.0-179.7), and a mean body mass of 53.3 kg (SD=14.6, range=26.4-75.5). The scoliotic curves of the subjects consisted of 10 thoracolumbar, 2 thoracic, and 2 lumbar scoliotic curves. Further anthropometric and descriptive data are detailed in Table 1. All subjects gave informed consent prior to participation in the study.

Procedure

Following each subject’s PA radiographic assessment, the three noninvasive scoliotic measuring methods (SCOL, BCD, MTI) were used to measure transverse surface deformity features. A single examiner experienced in anthropometric measurements and postural evaluation recorded all measurements. Each subject was given a gown and shorts to wear during testing, with the back clearly visible at all times during measurement. In addition, no shoes were worn by the subjects during testing.

For the SCOL measurement, each subject assumed a forward-bending posture with the trunk approximately perpendicular to the legs and the feet spaced shoulder width apart. The subject’s arms were allowed to hang vertically from the trunk with the palms of the hands placed together. The examiner placed the Scoliometer® on the subject’s back such that the device’s center corresponded to the center of the contour of the trunk, that is, the palpable spine. The examiner viewed the Scoliometer® from behind the subject and at the same height of the device. The Scoliometer® was placed at all vertebral levels, but only those vertebral levels showing the maximum ATR in the thoracic and lumbar regions were recorded.

The BCD was used in essentially the same manner as the Scoliometer®. A similar forward-bending position was assumed by the subject. The examiner placed the device on the subject’s back such that the BCD’s center corresponded to the center of the contour of the trunk. The BCD frame also was balanced horizontally by the examiner, as determined from the spirit level affixed to the device’s frame, to prevent measuring erroneous asymmetric profiles relative to the horizontal plane. The examiner viewed the BCD from behind the subject and at the same vertical level of the device. The BCD was placed at
all vertebral levels, but only those vertebral levels showing the maximum asymmetric profile in the thoracic and lumbar regions were recorded. The maximum asymmetric profiles then were traced on graph paper for later evaluation.

The MTI for each subject was obtained using an Ota Contourgraph (MS 20 40) and recorded onto 35-mm film. Reflective markers were placed on the back of the subject by the examiner. These markers corresponded to the palpable spinous processes beginning at C-7 and alternating through L-5 and the posterior superior iliac spines (PSISs). The reflective markers were necessary for subsequent identification of the back regions in the MTI. The entire back region and buttocks were uncovered during MTI recording. Each subject's pelvis was aligned parallel to the screen of the Ota Contourgraph to ensure that equivalent fringe patterns were produced on left and right gluteal checks and that the left and right PSIS markers were contained in the same fringe plane. Parallel alignment was necessary to prevent the formation of erroneous asymmetrical fringe contours. Each subject was told to stand in a relaxed upright position in front of the apparatus. While photographing the moiré pattern created on the subject's back, the subject was asked to hold her or his breath at the end of a normal exhalation. The MTI was then used to obtain the desired quantitative data for each subject.

**Experimental Measures**

To enable comparisons among the measurement techniques, ATR was chosen as a common variable to correlate. The presumption that a measure such as ATR can be used as an estimator of scoliosis is based on the assumption that the degree of lateral curvature within the spine tends to be associated with rib cage deformation in the transverse plane. Other quantitative measures such as the TAS, rib hump height and depth discrepancies, or rib hump contour amplitude differences could have been recorded; however, only ATR measurements could be derived from all three methods under examination.

The measurements obtained with the SCOL technique were directly equivalent to the ATR measurements. For the BCD and MTI methods, however, the ATR values were calculated from the transverse trunk profiles following the method presented by Hefti et al. The maximum ATR values from the thoracic and lumbar regions were recorded for each of the three techniques.

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To obtain an ATR value with the BCD method, a subject's trunk profile at a specific vertebral level was first recorded on graph paper, then digitized using a Summagraphics 1201 tablet. A computer program calculated the ATR for each profile data file in the following manner. To derive ATR values from transverse profiles, the mean difference (d) between the left and right halves of each transverse profile (about the spinous process) was divided by the horizontal distance (l) over which the profile was examined (Fig. 4). The arctan of this value represented the degree of ATR within the transverse profile.

The ATR was calculated from the MTI in a manner similar to the BCD method of calculation. Several additional intermediate steps, however, were required. The film image of the MTI was projected onto the Summagraphics 1201 digitizing tablet from which the fringe levels were traced, and depth transformations were determined as described by Pekelsky. The irregularly spaced data file was then transformed by nearest-point interpolation into a square grid data file (Fig. 5). The ATR values were calculated at all transverse levels from C-7 to L-5 by retrieving transverse trunk profiles from the grid data file and using the calculation procedure described by Hefti et al.

**Figure 4.** Axial trunk rotation (ATR) calculation from transverse profile of the back: (a) The sum of differences between left and right profiles was measured at increments from the profile's center. (b) The mean difference (d) was the sum of differences divided by the distance (l) over which the profile was measured. This value effectively represented the average slope of the profile's difference. (c) Axial trunk rotation was the arctan of d.

Cobb angles were derived from the PA radiographs of the vertebral column, as defined by Keim. In addition, the vertebrae involved, the direction of curvature (convex left or convex right), and the nature of the curvature (primary or secondary) were identified (Tab. 1).

**Data Analysis**

The comparison of the noninvasive scoliosis measurement techniques was accomplished by calculating the Pearson Product-Moment Correlation Coefficient matrix for ATR measurements obtained with the three techniques. Similarly, the relationships between ATR and Cobb-angle mea-
Results

The degree of interrelation for measurements obtained with the three measuring techniques varied depending on the region of the back for which they were compared (Tab. 2). Comparison of measurements derived from the thoracic and lumbar regions revealed that the ATR values obtained with the SCOL and BCD methods were highly correlated \( (r = .87, df = 22, P < .005) \). The SCOL and BCD measurements, however, did not relate well to the MTI measurements \( (r = .02, \text{SCOL-MTI}; r = .28, \text{BCD-MTI}) \).

When comparison of measurements was limited to the thoracic region, greater correlation was observed between the SCOL and BCD measurements \( (r = .91, df = 10, P < .005) \) than previously noted for those in the thoracic and lumbar regions. Low, but significant, correlations between the MTI and SCOL measurements \( (r = .58, df = 10, P < .025) \) and between the MTI and BCD measurements \( (r = .71, df = 10, P < .005) \) were observed.

When limiting comparisons to the lumbar region, the relationship between the SCOL and BCD measurements was less \( (r = .62, df = 10, P < .025) \) than that determined for the thoracic region. Furthermore, the correlation of MTI measurements with either SCOL or BCD measurements was low and not statistically significant within the lumbar region.

The Cobb-angle measurements derived from radiographic analysis were compared with the ATR values obtained with the three different techniques (Tab. 3). The ATR measurements from the thoracic and lumbar regions revealed low correlations to the Cobb-angle measurements except for the MTI values \( (r = .58, df = 22, P < .005) \). When limited to the thoracic region, correlations between ATR measurements and Cobb-angle values were statistically significant for the SCOL \( (r = .59, df = 10, P < .025) \), BCD \( (r = .70, df = 10, P < .005) \), and MTI \( (r = .80, df = 10, P < .005) \) methods. Within the lumbar region, however, significant correlations between the

Figure 5. Topographic image of square grid \((x, y, z)\) derived by moiré topographic imaging technique.
Table 2. Pearson Product-Moment Coefficient Correlation Matrices of Axial Trunk Rotation Measurements Obtained by Scoliometer® (SCOL), Back-Contour Device (BCD), and Moiré Topographic Imaging (MTI) Methods from the Thoracic and Lumbar Regions, the Thoracic Region Only, and the Lumbar Region Only

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<th>SCOL</th>
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*df=22, P<.005.
*df=10, P<.005.
*df=10, P<.025.

ATR and Cobb-angle measurements were not found.

Discussion

The comparison of ATR measurements obtained by the three different techniques revealed that the SCOL and BCD measurements were in close agreement, particularly in the thoracic region. The relationship between the MTI measurements and the SCOL or BCD measurements, however, was not as great. Only when comparing ATR measurements in the thoracic region were the three techniques significantly correlated. Two conclusions may be drawn from these findings: (1) The ATR measurements obtained with the SCOL and BCD methods were very similar, indicating that the BCD method for calculating ATR values from transverse profiles was essentially the same as the direct measurement of ATR (SCOL method); and (2) the ATR discrepancy between the MTI method and the SCOL and BCD techniques suggests that the transverse profile of the back as measured in the forward-bending posture was different from that in the upright position, particularly in the lumbar region. This latter conclusion is in agreement with the findings of Stokes and Moreland, who compared back measurements obtained in the standing and forward-bending positions. They found that ATR measurements in these two postures were slightly different in the thoracic region, but significantly dissimilar in the lumbar region.

The relationship of the three techniques for evaluation of lateral curvature depended on the region of the back analyzed. Comparison of Cobb-angle measurements with ATR values within the thoracic and lumbar regions revealed that only the ATR values obtained with the MTI method provided a significant relationship \( r = .58, df=22, P<.005 \). When comparison was limited to the thoracic region of the back, the relationship was observed to improve substantially. In increasing order of relation to the known Cobb angles were the SCOL \( (r=.59, df=10, P<.025) \), BCD \( (r=.70, df=10, P<.005) \), and MTI \( (r=.80, df=10, P<.005) \) ATR measurements. Conversely, when limiting the analysis to the lumbar region, no significant correlations with Cobb angles were shown. These findings agree with those of Daruwalla and Balasubramaniam.

The correlation between ATR values and Cobb-angle measurements for the three techniques were statistically

Table 3. Pearson Product-Moment Correlation Coefficients for Comparison of Cobb-Angle and Axial Trunk Rotation Measurements Obtained by Scoliometer® (SCOL), Back-Contour Device (BCD), and Moiré Topographic Imaging (MTI) Methods from the Thoracic and Lumbar Regions, the Thoracic Region Only, and the Lumbar Region Only

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*df=22, P<.005.
*df=10, P<.025.
*df=10, P<.005.
significant in the thoracic region; however, at best (ie, MTI, r = .80, df = 10, P < .005) only 64% of the measurement variation could be addressed. The residual variance not accounted for by the correlations may have been due to differences in the subjects’ posture during the radiographic and noninvasive measurement procedures. The posture differences between the radiographic and forward-bending positions is obvious. In addition, a more subtle difference between the unconstrained upright stance as measured by the MTI method and the fixed posture required during radiography may contribute to the remaining variance between ATR and Cobb-angle measurements.

Conclusions

The results of this study have several clinical implications regarding the use of noninvasive devices for estimation of lateral curvature of the spine attributable to scoliosis. For instance, the relation of scoliotic curvature to ATR was shown to vary with the technique used and the regions of the back appraised. More specifically, Cobb-angle measurements acquired from radiographs were best related to the ATR measurements obtained with the MTI method and, to a lesser extent, to the ATR measurements obtained with the BCD and SCOL methods. Furthermore, the three noninvasive techniques examined were found to be significantly correlated to Cobb-angle measurements within the thoracic region. The poor relationship of lumbar ATR measurements to lateral curvature of the spine, however, represented a major deficiency of these noninvasive techniques for addressing the scoliotic condition of the whole spine.

Comparison of these techniques revealed that measurements obtained with the SCOL and BCD methods were similar (ie, as determined from statistical analysis); however, these measurements were not well related to measurements obtained with the MTI method. These differences suggest that, in addition to scoliosis, other factors may confound or influence ATR measurements. For instance, the posture assumed by the subject during measurement may prejudice the extent of rib cage deformity and thus alter ATR values. Therefore, actual variations in posture when subjects were measured with the Scolimeter® and the BCD relative to MTI may account for the poor correlation among the measurement techniques. The implications of these observations suggest that the measurement techniques cannot be used interchangeably in clinical recording if posture is not standardized.

The three noninvasive techniques examined were able to relate back surface characteristics to the underlying vertebral structure with varying degrees of accuracy; therefore, measurements obtained with these methods should be interpreted with discretion. These noninvasive measuring techniques could be utilized as part of an objective physical evaluation program for the early detection of scoliosis because they were shown to be sensitive to deformities in the thoracic region of the spine, where scoliotic conditions commonly occur. Measurements obtained by noninvasive methods from the lumbar region of the spine are not as clinically valuable, however, because these measurements were shown not to be significantly related to lateral deformity of the spine. Consequently, the results of this study suggest that these noninvasive methods are reasonable indicators of upper-spine scoliotic conditions; however, for an accurate clinical diagnosis of the scoliotic state of the whole spine, radiographic investigation is still necessary.

References


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