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Classification of Scoliosis Deformity Three-Dimensional Spinal Shape by Cluster Analysis

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Study Design. Cluster analysis of existing database of spinal shape of patients attending a scoliosis clinic.

Objective. To determine whether patients with scoliosis can be classified into distinct groups by 3-dimensional curve shape.

Summary of Background Data. Subjective or semi-quantitative methods can be used to classify curve types in scoliosis, with the goal of rationalizing surgical planning. There are very few reports of using objective methods such as cluster analysis to improve this process.

Methods. One hundred ten patients who underwent radiography of the spine by a stereo technique, at a scoliosis clinic in the period between 1982 and 1990, were studied. Fifty-six were studied longitudinally (average 3.4 clinic visits each), providing 245 total observations. Selected patients had 2 scoliosis curves with apex between T4 and L3, and both Cobb angles >9° by an automated measurement. The 3-dimensional spinal shape was reconstructed from stereo-radiographs. Each curve was quantified by its Cobb angle, apex level, apex vertebra rotation, and rotation of the plane of maximum curvature (PMC) (8 variables). Cluster analysis classified each patient at each visit by these variables.

Results. When the analysis searched for 4 clusters, the largest cluster (148 of 245 observations) was the pattern having counterclockwise rotation of the PMC of both curves (typically, a right upper scoliosis curve with kyphosis and left lower scoliosis curve with lordosis). The other 3 clusters (48, 34, and 15 observations) were the other permutations of these variables. Substantial overlap of all the other variables between groups was observed. Of the 56 patients seen longitudinally, 25 were consistently grouped at all clinic visits.

Conclusion. Spinal shape of patients in a clinic population with 2 scoliosis curves form distinct groups according to the 4 permutations of the signs of the rotations of the PMC in 2 curve regions. The pattern can change with repeated observation, often because a slight curvature in the sagittal plane can change because of postural variation and measurement errors. Overlap of the other curve-shape variables between groups suggests that these spinal deformity classifications alone should not determine treatment strategy.

Key words: scoliosis, classification, spinal shape, cluster analysis, plane of maximum curvature. **Spine 2009;34: 584–590**

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Classification of patients according to their clinical presentation is used to assist in planning their management. Grouping of patients according to a classification scheme provides guidelines as to the appropriateness of different treatment interventions. The information that is used in the classification process may be categorical or binary (*e.g.*, gender), ordinal (*e.g.*, anatomic level of a scoliosis curve apex), or continuous (*e.g.*, Cobb angle). To be effective, a classification should be exhaustive (no patient excluded) and mutually exclusive (each patient assigned to 1 group only), patients should be assigned to their group consistently, and the classification should be useful in guiding management. Also, classification should be easily applicable (*i.e.*, "user-friendly").

Classification of patients with thoracolumbar scoliosis was proposed by King *et al*[1] to assist in decisions concerning the length of surgical arthrodesis, and providing criteria for "selective fusion" of the thoracic curve. This classification was extended by Lenke *et al*.[2] The King *et al* classification employed measurements of relative magnitudes of Cobb angles, proportion of curve correction on lateral bending, presence of vertebral tilt (binary), and position of the neutral vertebra relative to the center-sacral line (ordinal). This classification has relatively poor reliability associated with difficulty in distinguishing between patients whose curve shape lies very close to one of the classification boundaries.[3] Accurate classification requires that there is a distinct boundary between the groups – *i.e.*, few patients lie at or close to the classification boundaries.

Cluster analysis is an objective method to identify groupings of individuals according to a set of measurements or observations. With this statistical tool, it is possible to analyze a dataset that combines several grouping variables, and to search for clusters of patients having similar characteristics. Further, it is possible to determine whether the groupings are statistically significant. Duong *et al*[4] presented the use of cluster analysis to identify groupings of patients with scoliosis according to measurements of spinal shape made by stereoradiography. They studied 409 sets of spinal shape data of patients with adolescent idiopathic scoliosis aged between 10 and 18 years, with a Cobb angle (main curve) >40°. The parameters of curve spinal shape were 3 curvatures (frontal, sagittal planes, and plane of maximum curvature [PMC]) for each of 2 curve regions. It was found that 5 groupings could be reliably identified, and these resembled the 5 major curve types in the Lenke *et al*[2] classification. However, these analyses did not include

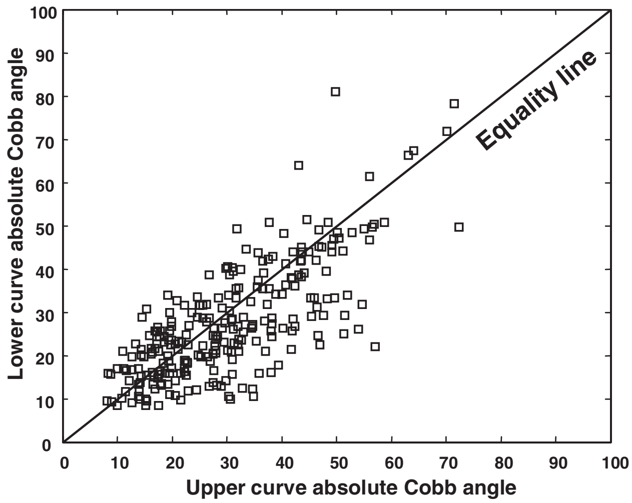

Figure 1. Scatter plot of the lower *versus* the upper Cobb angles (absolute values). In the King *et al* classification, the relative magnitudes of the Cobb angles can be used to distinguish between Type 1 and Type 2 (King 1 requires lower curve Cobb angle >thoracic – *i.e.,* above the equality line in the scatterplot).

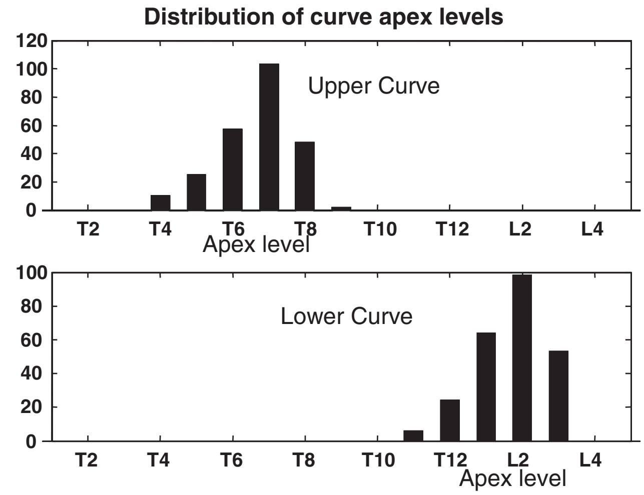

Figure 2. Histogram of the distribution of levels of scoliosis curve apices.

curve-shape measurements in the transverse plane, and only considered large magnitude deformities.

The purpose of this study was to employ cluster analysis of spinal shape measurements of a diverse group of patients with idiopathic scoliosis to determine whether distinct groupings existed. The curve shape included measurements from the frontal, sagittal, and transverse planes. A secondary objective was to determine whether patients seen more than once retained the same group assignment (longitudinal study). The patients' spinal shape had been recorded by stereoradiography during a visit to a scoliosis clinic.

■ Methods

The dataset consisted of stereoradiographic reconstructions of the spines of 110 patients with adolescent idiopathic scoliosis whose radiographs indicated that they had 2 scoliosis curves with apex between T4 and L3, and both Cobb angles larger than 9° by automatic measurement.[5] The range of Cobb angles was 9 to 81 in the upper curves and 9 to 72 in the lower curves (Figures 1, 2). Fifty-six patients had repeat measurements from multiple clinic visits. Each of these patients had an average of 3.4 observations, for a total of 245 observations. Patients were standing at the time of radiography, with their clavicle and anterior superior iliac spine regions in contact with 4 adjustable pads that helped maintain a constant position and posture while the stereo pair of radiographs was made.

Four shape parameters of each of the 2 curves were measured (Figure 3). The shape parameters were calculated from the 3-dimensional coordinates of 6 landmarks on each vertebra from T1 to L5 (total 102 landmarks) as defined by Stokes *et al*.[5] These coordinates were determined by stereoradiographic reconstructions of digitized landmarks in the stereoradiographic film pairs. Marking and digitizing the films took about 25 minutes per film pair. The spinal shape measurements used in the cluster analysis were the automatically determined Cobb angle,[5] the anatomic level of the apical vertebra, the axial rotation of the apical vertebra,[6] and the axial rotation of the PMC,[5,7] relative to the sagittal plane of a spinal axis system.[8] The PMC was defined as the plane passing through the vertebral body centers of the 2 end vertebrae and the apical vertebrae of the curve.[7,8] These 4 parameters were recorded for each of the 2 curves; hence, there was a total of 8 measurements per patient visit.

Each of the variables had either positive or negative sign. By convention here, positive indicated the Cobb angle of a scoliosis curve that was to the right, and the rotation of the apical vertebra or PMC that was counterclockwise as seen from above. The rotation of the PMC was calculated in the range −90° to +90°, with zero degrees indicating that the PMC lay in the sagittal plane (no scoliosis, only lordosis or kyphosis present). Positive rotation of both planes of maximum curvature occurs with the typical pattern having right thoracic scoliosis in a kyphotic region and left lumbar or thoracolumbar scoliosis in a lordotic region (Figure 3). Other comple-

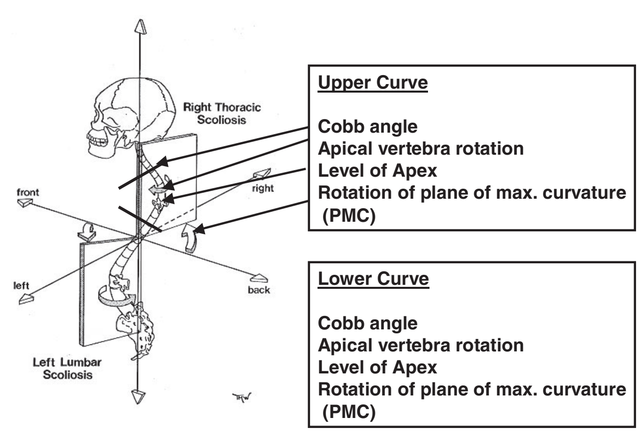

Figure 3. Spinal shape measurements of each patient that were used in the cluster analysis. The Figure shows the classic pattern having right thoracic scoliosis in a kyphotic region and left lower scoliosis curve in a lordotic region. This produces a PMC in the curve region that is rotated from the sagittal plane in a direction counterclockwise as viewed from above. This was considered as a positive rotation in the present study. The normally observed rotation of the apical vertebra is clockwise (negative) in the upper curve region (counter to the PMC rotation) and counterclockwise (positive) in the lower curve region (Adapted from Stokes *et al*[5]).

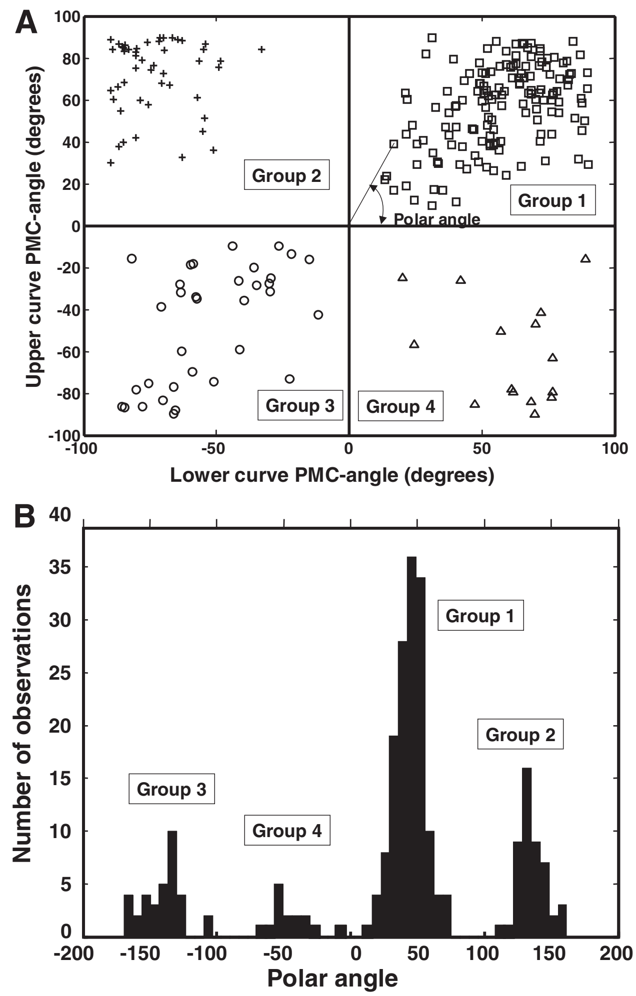

Figure 4. **A,** Scatter plot of the angle of PMC of the upper curve, *versus* the angle of PMC of the lower curve. The cluster analysis identified distinct groups in each of the 4 quadrants of this graph. The location of any observation on this graph can be identified by the "polar angle." **B,** Histogram of the polar angles, demonstrating distinct differences between the 4 groups.

mentary permutations can produce rotation of the PMC in the opposite sense.

The cluster analysis was performed in the SPSS version 12.0.1 for Windows (SPSS Inc., Chicago, IL), using the K-means cluster analysis routine. In the K-means method, unsupervised clustering was performed in which there were no prior assumptions about grouping tendencies, except that the number of clusters (groups) must be predefined. The analyses were performed for each of the values 3, 4, and 5 for the number of clusters sought, and the resulting groupings were then examined to determine whether they were distinct (statistically significant differences between groups), and which variables used in the cluster analysis were the important ones in establishing the group-wise differences.

Results

The cluster analysis identified distinct groupings within the entire dataset when it searched for 4 groups. The rotations of the PMC of the 2 curve regions were the variables that distinguished between groups (Figure 4). The mean values of each parameter for each of the 4 groups (Table 1) followed a different pattern whereby each group included 1 of the 4 permutations of positive or negative mean values of the rotations of the PMC. Further, the group assignments were consistent according to the sign of the PMC rotations (Figure 4). The group assignment could be uniquely determined by the signs of the PMC rotations – each group corresponded to 1 of the 4 quadrants in the scatterplot of the rotations of the upper and lower curve PMC. There were group-wise differences in the other parameters (apex levels, Cobb angles, and apical vertebral axial rotation) between groups by analysis of variance, but with substantial overlap of values. These other variables were not required in the cluster analysis to identify the distinct groups. When the curve shapes were examined in the frontal, sagittal, and axial planes (Figures 5–8), there was substantial variability in the shapes — the figures are for illustrative cases that demonstrate curve features producing the 4 characteristic combinations of PMC rotation.

There were different numbers of patients in each group. Group 1 was the largest group (148 observations), and 144 had the "typical" right upper curve and left lower curve pattern in regions having kyphosis and lordosis, respectively (Figure 5), such that both curve regions had a PMC rotated counterclockwise when viewed from above (Figure 3).

Group 3 (34 observations) had a pattern that was the reverse of this norm, with both PMC rotations negative.

Table 1. Characteristics of the 4 Groups Identified by Cluster Analysis (Mean Values and Standard Deviations of the 8 Parameters)

	Group 1 Mean (SD)	Group 2 Mean (SD)	Group 3 Mean (SD)	Group 4 Mean (SD)
Apex level (upper curve)	6.9 (0.9)	6.5 (1.0)	6.4 (1.0)	5.73 (1.5)
Apex level (lower curve)	13.9 (0.9)	13.4 (1.0)	13.6 (1.0)	13.0 (1.5)
Cobb angle (upper curve)	26.9 (14.0)	33.5 (16.1)	2.4 (24.2)	4.55 (24.5)
Cobb angle (lower curve)	−30.6 (15.9)	−33.3 (14.6)	1.7 (27.0)	−7.75 (26.7)
Apex vertebra rotation (upper curve)	5.0 (7.0)	6.7 (6.8)	2.9 (7.7)	4.30 (7.4)
Apex vertebra rotation (lower curve)	−3.6 (6.2)	−7.9 (8.6)	3.1 (6.9)	2.84 (8.4)
Rotation of PMC (upper curve) (degrees)	57.0 (19.6)	71.7 (17.6)	−46.7 (27.9)	−60.3 (24.8)
Rotation of PMC (lower curve) (degrees)	57.1 (18.9)	−73.0 (13.8)	−52.5 (21.2)	60.9 (19.7)
No. observations in group	148	48	34	15

Cobb angles are for signed values (left curve has a negative Cobb angle).

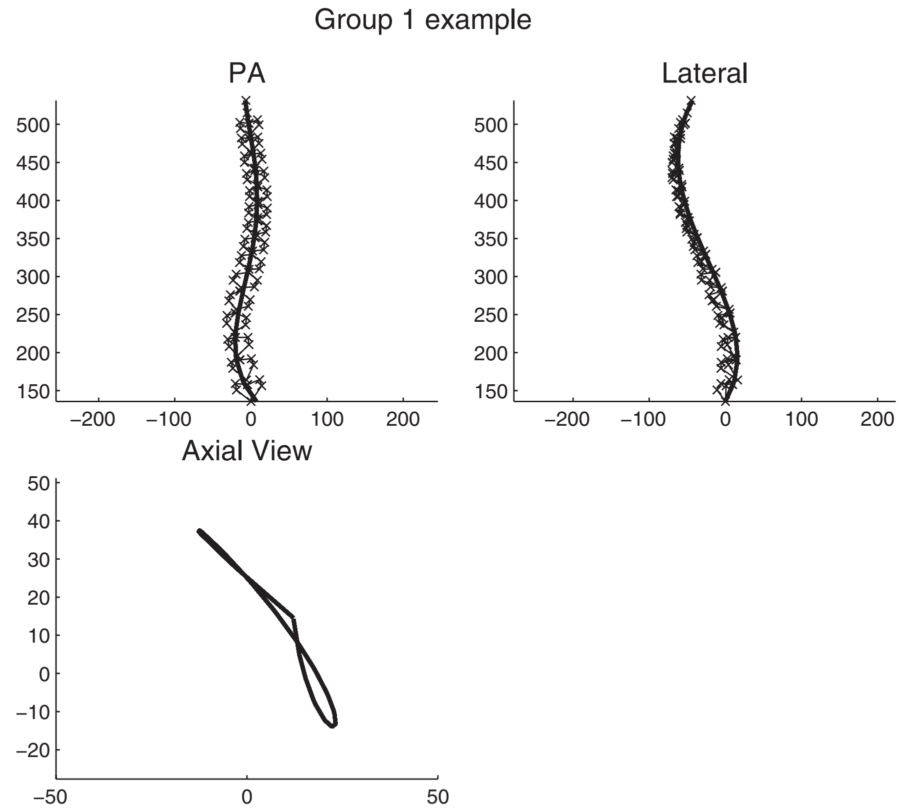

Figure 5. Illustrative example of a patient's spinal shape in Group 1. "x" = each of 6 landmarks (vertebral endplate centers and bases of pedicles) on each of 17 vertebrae (omitted from axial view for clarity). Solid line: a smoothed line fitted to the positions of landmarks at vertebral endplate centers. This spinal shape was classified as group 1 because the combination of right upper scoliosis curve with kyphosis, and left lower curve with lordosis provided the positive rotations of both planes of maximum curvature in the 2 respective scoliosis curve regions.

In 14 of these cases, the right upper curve and left lower scoliosis curve pattern was present, but the sagittal plane curvatures in the curve regions were reversed. The other 20 cases had reversed pattern of side of the scoliosis.

Group 2 (48 observations) had negative (clockwise) rotation of the PMC in the lower curve region. In all cases, the curve pattern was right upper curve and left lower curve with kyphosis in both curve regions. Group 4 was the smallest group (15 observations) with negative rotation of the PMC in the upper curve region. These had either the right upper and left lower curve pattern with lordosis in both curve regions (8 cases), or a left upper

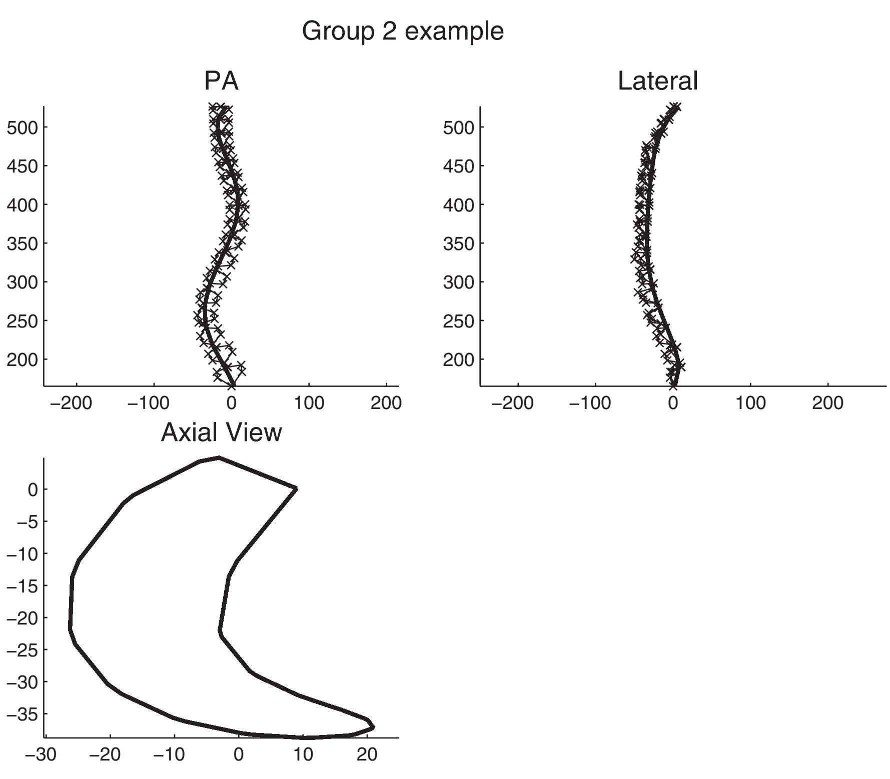

Figure 6. Illustrative example of a patient's spinal shape in group 2. "x" = each of 6 landmarks (vertebral endplate centers and bases of pedicles) on each of 17 vertebrae (omitted from axial view for clarity). Solid line: a smoothed line fitted to the positions of landmarks at vertebral endplate centers. This spinal shape was classified as group 2 because the combination of right upper scoliosis curve with kyphosis, and left lower curve with kyphosis provided the positive and negative rotations of the 2 planes of maximum curvature in the 2 respective scoliosis curve regions.

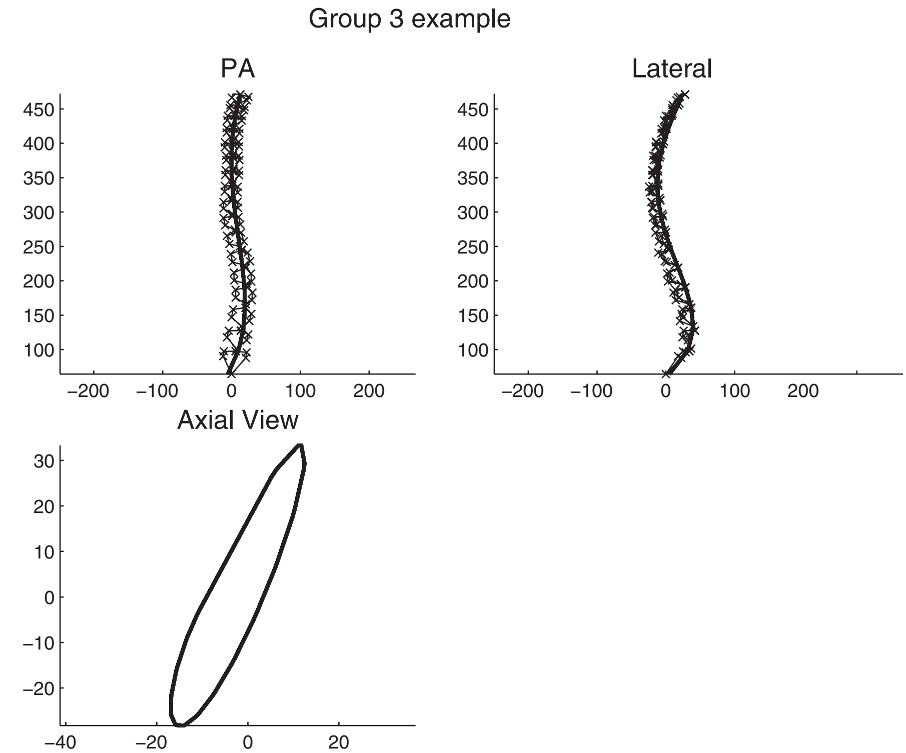

Figure 7. Illustrative example of a patient's spinal shape in group 3. "x" = each of 6 landmarks (vertebral endplate centers and bases of pedicles) on each of 17 vertebrae (omitted from axial view for clarity). Solid line: a smoothed line fitted to the positions of landmarks at vertebral endplate centers. This spinal shape was classified as group 3 because the combination of left upper scoliosis curve with kyphosis, and right lower curve with lordosis provided the negative rotations of both planes of maximum curvature in the 2 respective scoliosis curve regions.

and right lower curve pattern with kyphosis in both curve regions (7 cases).

When the number of clusters was set to 3, the 2 smallest groups of the 4-group analysis (groups 3 and 4) were combined, except that 1 member of group 4 was combined with group 1. When the number of clusters was set to 5, groups 1 and 2 remained unchanged; and 1 observation in group 4 together with 20 observations in group 3 created a new group. These additional analyses of 3 and 5 groups did not appear useful relative to the 4-group analysis.

In the 4-group analysis, the groupings were consistent when 2 subsets of observations with larger curves (>18°,

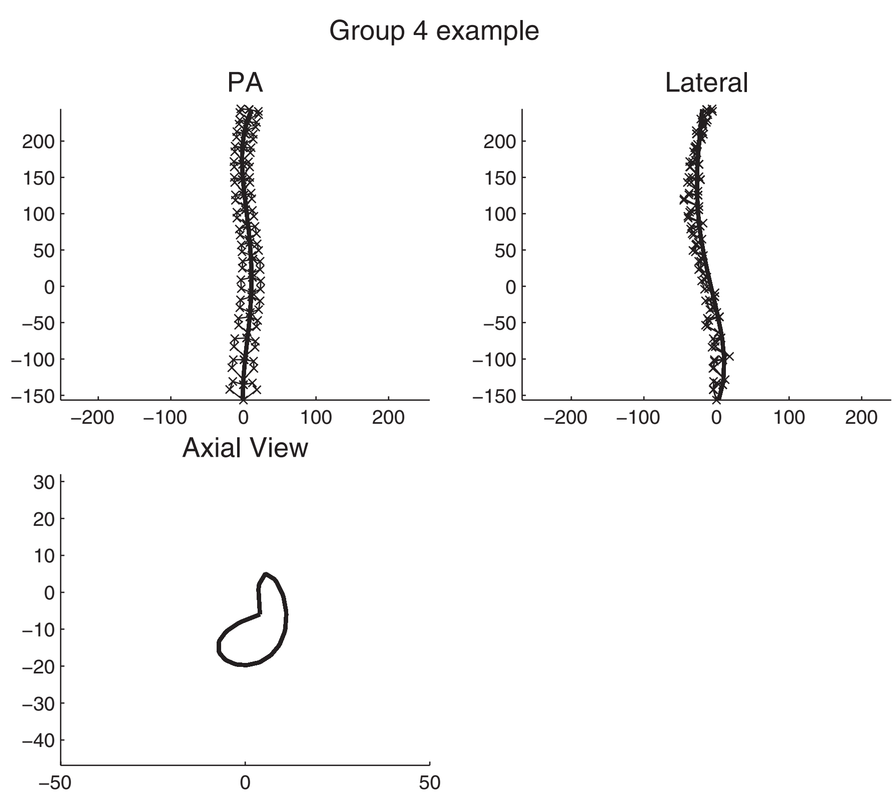

Figure 8. Illustrative example of a patient's spinal shape in group 4. "x" = each of 6 landmarks (vertebral endplate centers and bases of pedicles) on each of 17 vertebrae (omitted from axial view for clarity). Solid line: a smoothed line fitted to the positions of landmarks at vertebral endplate centers. This spinal shape was classified as group 4 because the combination of left upper scoliosis curve with kyphosis, and right lower curve with kyphosis provided the negative and positive rotations of the 2 planes of maximum curvature in the 2 respective scoliosis curve regions.

then >27° by automated[5] Cobb measurement) were selected and a cluster analysis was performed again. In these analyses, the group assignments were identical to those determined in the analysis of the full dataset.

Among the 56 patients observed longitudinally, there were 25 who remained in the same group (same quadrant of the upper and lower curve PMC rotation scatterplot in Figure 4). The 31 who did not remain in the same group on repeat examination were not different on average with respect to scoliosis curve magnitude or change in curve magnitude. The mean (SD) Cobb angles for those who did not and those who did change grouping were 32 (4.8) and 30 (4.2) degrees, respectively. Instead, the grouping changes were most commonly associated with a large change in the angle of the PMC of the upper curve, and this resulted from a change in sagittal plane curvature, not the Cobb angle. Among the patients who did not remain in the same group, the mean sagittal curvature was 24% less, and the standard deviation (between examination variability) was 5 times greater than patients who remained in the same group.

The single variable "curve apex" (Figure 2) indicated that there was a bimodal distribution of the levels of apical vertebrae, indicating that curves (not patients) can be reliably grouped as "upper" or "lower" (with a level of T10 [no observations]) identifying the boundary value between the groups. Conversely, in the plot of the absolute (unsigned) values of the 2 variables "upper Cobb angle" and "lower Cobb angle" (Figure 1), there was no evidence of any groupings, indicating that there is no clear distinction between the King-1 and King-2 groups if Cobb angle alone is used as the grouping criterion.

Discussion

It was found that the spinal shape of patients with idiopathic scoliosis in a clinic population could be divided into 4 groups, according to the direction of the rotation of the PMC in each of 2 curve regions. The direction of this rotation depends on the relative magnitudes and signs of the scoliotic and sagittal curvatures. It should be noted that the groupings identified here were very different from those that are commonly used in treatment planning. The present study was based on different curve shape parameters. The PMC is not used in any other existing classifications, but it was the key variable in determining the groupings identified here. The present study did not employ any measures of curve flexibility or of spinal alignment relative to the vertical axis.

The cluster analysis of Duong *et al*[4] had different findings in a less diverse group of patients with large (>40° Cobb) scoliosis. They performed a cluster analysis using curvatures in frontal, sagittal, and maximum curvature planes, but did not include transverse plane rotation measurements, and the PMC rotation here was found to be the key parameter in determining group assignment.

The changes in group assignments of individual patients over multiple clinic visits (longitudinal study) were not associated with differing magnitudes of scoliosis, or changes in curve magnitude. The changed (inconsistent) group assignments were not more likely in either small or large curves, or with larger changes in curve magnitude (the standard deviations of the Cobb angles did not differ between those who did and did not retain consistent group assignment). Instead, the changes in group assignments resulted from changes in measurements of the rotation of the PMC, associated with larger changes in sagittal plane curvature in patients having lesser sagittal plane curvature. The rotation of the PMC is very sensitive to small changes in the sagittal profile when the sagittal plane curvature in the curve region is small, which was observed frequently. Small changes in the sagittal curvature could result from errors in measurements of vertebral landmark positions and from small postural changes. Both were probably present in this study. The 3-dimensional measurement of vertebral landmarks was reported as having a standard deviation of 1.5 mm in the vertical direction, 0.9 mm in the horizontal (left-right) direction, and 3.8 mm in the horizontal (front-back) direction in a study of combined inter- and intraobserver variability.[5] Thus, the errors are greater in the anteroposterior direction in the stereoradiography method employed here. Delorme *et al*[9] reported that inter- and intraobserver variabilities were of approximately equal magnitude in measuring radiographs by a similar technique. The accuracy with which the spinal shape could be measured, together with changes resulting from postural variability were likely the main limitations of this study.

Patients with small scoliosis curvatures were included by selecting those with 2 curves each having a curvature greater than 9° by automatic Cobb angle measurement that uses the normals to the curved line passing through the centers of the vertebrae in the coronal plane. This threshold value corresponds to the 10° value conventionally used to indicate presence of a scoliosis because the automatic Cobb angle measurement is about 12% greater than the Cobb angle values obtained from relative inclinations of the endplates.[5] Similarly, the threshold values of 18° and 27° Cobb angles were selected for the evaluations of classification consistency to correspond to 20° and 30° by the conventional measurement.

Patients studied here represent a diverse group probably representative of those seen in a scoliosis clinic, and included a large range of Cobb angle magnitudes. In each instance, there were 2 (and only 2) scoliosis curves of significant magnitude, with curve apices in the range T4 to L3. In selecting the 245 cases that met these criteria, 8 cases with a single curve were excluded. In the selected cases, the 2 curves were designated as "upper" and "lower" to avoid using classifications based on the anatomic level of the curve apex. There were 35 instances of a "proximal thoracic" curve (apex at T4 or T5), and of these, 19 were left-convex, but in all cases they were paired with a curve to the opposite side, and having an apex at T11 or below. No curve had an apex at T10, and there were no double thoracic curves.

These findings from a clinic population having a large range of scoliosis magnitude may have implications for management and treatment of patients having either small or large curves. The classification draws attention to the importance of the rotation of the PMC, which represents the interaction between curvatures in the frontal and sagittal planes. This shape property may be helpful in planning surgery, but patient groupings based on it should not be the sole determinant of surgical planning.

Classification of scoliosis has traditionally been used primarily in surgical planning for patients having large curves. It is also possible that classification of curve types that includes measurements of the PMC could be used in assessing the likelihood of progression and indications for bracing for patients having small curves.

The finding that most of the other spinal shape measurements (Cobb angle, apex levels, and axial rotation of the apical vertebrae) did not show distinct groupings suggests that spinal deformity classifications based on those variables are not distinct, and that there is a continuous distribution of patients' spinal shape. Management decisions should be treated individually according to continuous variable measurements, not by arbitrarily determined groupings.

■ Key Points

- A Cluster analysis of the 3-dimensional shape of spines of clinic patients with scoliosis revealed 4 distinct groupings with differing permutations of positive and negative rotations of the plane of maximum curvature (PMC) of the 2 curve regions.
- The PMC rotation depends on the signs of the sagittal and coronal plane curvatures (kyphosis/lordosis and right/left scoliosis).
- For 56 patients observed longitudinally the classification groupings were only consistent in 25 patients. A slight curvature in the sagittal plane is liable to postural variations and effects of measurement errors that can change the assigned group.
- Other major spinal shape parameters (curve apex levels, Cobb angle, and apical vertebral rotation) had substantial overlap between the 4 groups identified, indicating that groupings based on PMC rotation alone should not be used in planning management of these patients.
- The study draws attention to the PMC of scoliosis curves.

Acknowledgments

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