35th Annual International Conference of the IEEE EMBS
Osaka, Japan, 3 - 7 July, 2013

Computerized Lenke Classification of Scoliotic Spine

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Abstract— **A computer-aided approach was proposed to reduce the variability in the Lenke classification. At the first step, endplate inclination of each vertebra on both the coronal and sagittal radiographs was measured by a computerized system. The Cobb angles of the proximal thoracic, the main thoracic, and the thoracolumbar/lumbar curves were then automatically calculated in the standing and side-bending coronal planes and the standing sagittal plane. A computerized algorithm automatically classified the spinal type. The classification results of 37 scoliotic patients by five observers showed that with the computer aid, the average interobserver and intraobserver kappa values were improved from 0.77 to 0.88 and from 0.68 to 0.83, respectively. This computerized tool can assist in the Lenke classification of scoliosis.**

I. INTRODUCTION

Scoliosis is a complex three-dimensional (3D) deformity of the spine [1]. Classification of spinal curve pattern plays an important role in the preoperative surgical planning for the selection of fusion levels. King classification [2] and Lenke classification [3] are two widely used classification methods. King classification defines five types of thoracic curves based on measurements in the coronal plane. Compared with the King classification, the Lenke classification presents a more global scheme that also considers the thoracolumbar/lumbar curves based on measurements in both coronal and sagittal planes. Since both classification methods rely on subjective identification and measurement of the radiographic features, reliability is an issue of concern. Ogon *et al.* [4] claimed that the Lenke classification had overall better reliability than the King classification while Richards *et al*. [5] reported only fair reliability of the Lenke system.

Recently, some studies developed computer-aided methods to measure scoliosis curves or to extract the features of spinal deformity on radiographs. Stokes *et al.* [6] developed a computer program to calculate Cobb angles based on analysis of coordinates of vertebral landmarks on each radiograph and then to identify the King types using a rule-based algorithm. Their approach required manual identification of numerous landmarks (70 landmarks per radiograph). The inherent inaccuracy in landmark identification might result in measurement errors. Lin [7] implemented an artificial neural network to automatically identify the King types based on features extracted from a simplified 3D spine model by the total curvature analysis, which was different from the traditional way of measuring scoliotic curves (Cobb or Ferguson angle). Lin *et al.* [8] also presented a preliminary study for computer-aided Lenke classification where reliability was not reported. Mezghani *et al.* [9] proposed a rule-based program for the Lenke classification based on the Cobb measurements. The variability in the Cobb measurement might introduce variability in classification. In our previous study [10], a semi-automatic approach was developed to improve the reliability in the measurement of Cobb angle. In this study, we propose a computerized Lenke classification approach using the computer-aided Cobb measurement to reduce the variability in the Lenke classification.

II. MATERIALS AND METHODS

Radiographs taken from 37 patients with scoliosis were used (29 female and 8 male, age 13.5 ± 3.1 years, Cobb angle 52° ± 17°), which met the inclusion criteria: (1) diagnosis of idiopathic scoliosis, (2) ages between 9–18 years, (3) no prior spine surgery, and (4) Cobb angle less than 90 degree. The exclusion criteria were patients who had other musculoskeletal or neurological disorders. According to the Lenke classification [3], there were 14, 2, 5, 1, 7, and 8 cases classified as Type 1, 2, 3, 4, 5, and 6, respectively. Ethics approval of this study was granted from the local ethics board.

In our previous study [10], a system based on the fuzzy Hough transform (FHT) was developed to automatically measure the Cobb angle of a spinal curve. In this study we used this approach to identify the inclination of each vertebral endplate for automatic Lenke classification. This technique is described in the following subsection.

A. Measurement of Vertebral Endplate Inclination

Each radiograph that contained vertebrae from T1 to L5 was normalized to a standard height of 1000 pixels. The user assigned the names of the most upper and lower thoracic vertebrae on the radiograph. From the most upper thoracic vertebra, the user successively selected vertebrae by clicking the mouse at the vertebrae. Once the user clicked at a vertebra, a rectangle of 100 × 80 pixels was created as the initial region of interest (ROI). The user could adjust the ROI to fit the vertebra by magnification or minification, clockwise or anticlockwise rotation, and up, down, left, or right movement of the ROI. As an example, Fig. 1 shows the selected ROIs on a coronal radiograph. For each ROI, the Canny edge detector was performed to obtain the required edge image for the FHT. To delete noises and artifacts, an inner rectangle and an outer rectangle according to the ROI rectangle were automatically defined in the algorithm. The distance between the inner

* This work was supported by the Natural Science Foundation of China (No. 61002049) and the Key Project of Chinese Ministry of Education (No. 211173).

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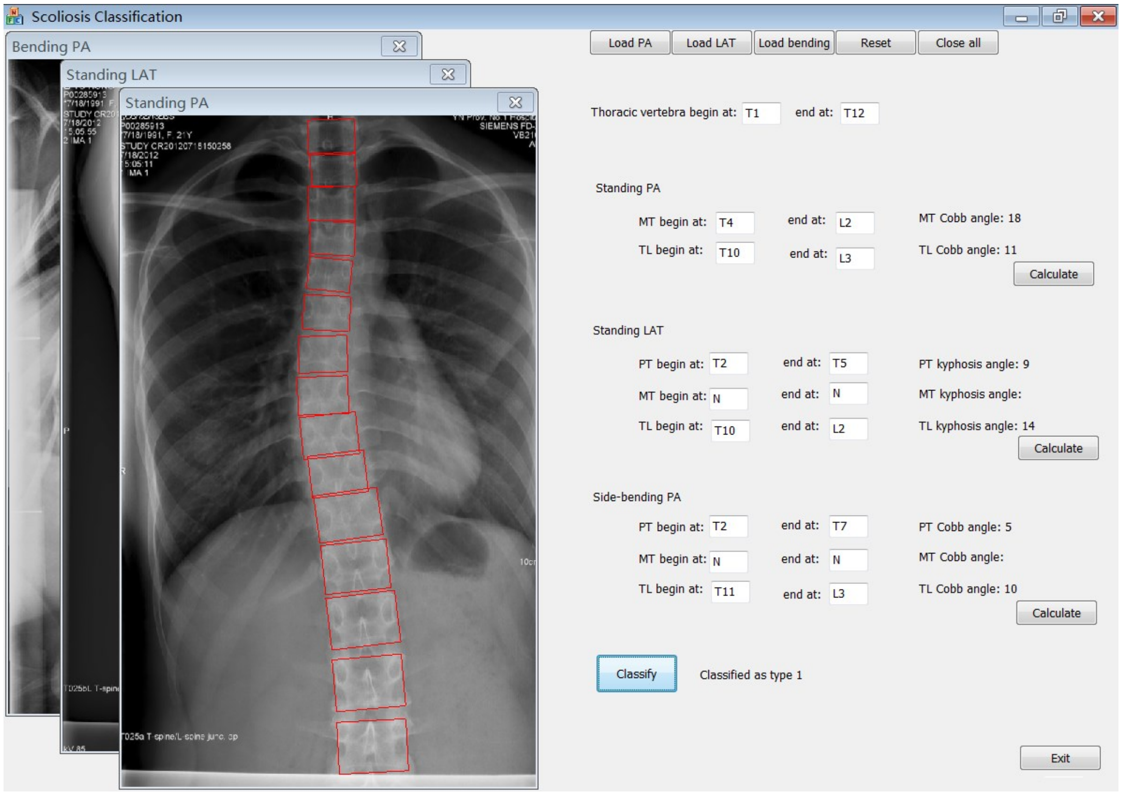

Figure 1. Interface of the computerized Lenke classification.

rectangle and the ROI was 1/6 of the width of the ROI, and the distance between the outer rectangle and the ROI was 1/8 of the width of the ROI. The noises and artifacts inside the inner rectangle and outside the outer rectangle were then deleted. As an example, Fig. 2 shows an ROI (Fig. 2(a)), the edge image of the ROI (Fig. 2(b)), and the edge image with noises deleted (Fig. 2(c)). The FHT with the vertebral shape constraints was performed to detect the lines that best fit the two endplates of a vertebra. The shape constraints were (1) the distance between two endplates of a vertebra was in the range of 30 to 60 pixels, and the distance between two vertical edges was in the range of 40 to 80 pixels; (2) the angle difference between two endplates or two vertical edges of a vertebra was less than 10 degree; (3) the average angle of two endplates was titled less than 45 degree, and the average angle of the vertical edges was between 45 and 90 degrees; (4) the endplates and the vertical edges were close to perpendicular to each other. More details of this technique were described by Zhang *et al*. [10]. As shown in Fig. 2(d), two end lines fitted to the vertebral endplates were detected. Each endplate inclination was recorded automatically.

(a) (b) (c) (d)

Figure 2. Detection of endplate inclination. (a) ROI. (b) Edge image of the ROI. (c) Edge image with noises deleted. (d) Detected endplates.

B. Calculation of Curve Angles

To classify the scoliotic spine, the Cobb angles were measured in the coronal and sagittal planes for the following curves: (1) the main thoracic (MT) and the thoracolumbar/lumbar (TL) curves on the standing coronal radiograph; (2) the proximal thoracic (PT_B), the main thoracic (MT_B), and the thoracolumbar/lumbar (TL_B) curves on the side-bending coronal radiograph; (3) the proximal thoracic (PT_S), the main thoracic (MT_S), and the thoracolumbar/lumbar (TL_S) kyphosis curves on the sagittal radiograph.

For each curve, users input the names of the most upper and lower vertebrae of the curve. The computer automatically calculated the Cobb angle of this curve from the inclinations of the superior/inferior endplates of the vertebrae measured on this curve. As shown in Fig. 1, the Cobb angles of the curves assigned by the user are displayed.

C. Computer-Aided Lenke Classification

In the Lenke system, there are four types of curve pattern locations along the spinal column: the proximal thoracic, the main thoracic, the thoracolumbar, and the lumbar. The Lenke classification defines six curve types. The deformity is classified as Type 1 (main thoracic) if there are a structural major curve in the main thoracic region and minor non-structural curves elsewhere; Type 2 (double thoracic) if there are a major structural curve in the main thoracic region, a minor but structural curve in the proximal thoracic region, and minor non-structural curves elsewhere; Type 3 (double major) if there are a major curve in the main thoracic region, a minor structural curve in the thoracolumbar/lumbar region, and minor nonstructural curves elsewhere; Type 4 (triple major) if there are a major curve in the main thoracic region (or the thoracolumbar/lumbar region), and minor structural curve in both proximal thoracic and thoracolumbar/lumbar (or main thoracic) regions; Type 5 (thoracolumbar/lumbar) if there are a major curve in the thoracolumbar/lumbar region, and minor non-structural curves elsewhere; and Type 6 (thoracolumbar/lumbar-main thoracic) if there are a major curve in the thoracolumbar/lumbar region, a minor structural curve in the main thoracic region and minor nonstructural curve in the proximal thoracic region. The Type 6 and Type 3 curves differ only by which region is major and structural. If the Cobb angle of the main thoracic curve is equal to that of the thoracolumbar/lumbar curve then the main thoracic curve is considered major and therefore is a Type 3 curve.

A curve segment with the largest Cobb angle as measured on the coronal radiograph (also known as the major curve) is always considered structural. The criteria for a minor curve to be classified as structural are (1) the sagittal plane angle of at least 20 degree or (2) the side-bending coronal Cobb angle of at least 25 degree.

Based on the computer-aided Cobb measurement, the Lenke types were automatically classified by using the computerized classification algorithm, as presented in Fig 3, which used the following logic:

If there was a major curve in the main thoracic region, then the scoliosis was Type 1 if both proximal thoracic and thoracolumbar/lumbar curves were nonstructural, Type 2 if the thoracolumbar/lumbar curve was nonstructural and the proximal thoracic curve was structural, and Type 3 if the thoracolumbar/lumbar curve was structural and the proximal thoracic curve was nonstructural. Otherwise (i.e., the major curve in the thoracolumbar/lumbar region), the scoliosis was Type 5 if the main thoracic curve was nonstructural, and Type 6 if the main thoracic curve was structural and the proximal thoracic curve was nonstructural. If the proximal thoracic, the main thoracic, and the thoracolumbar/lumbar curves were structural, the scoliosis was classified as Type 4.

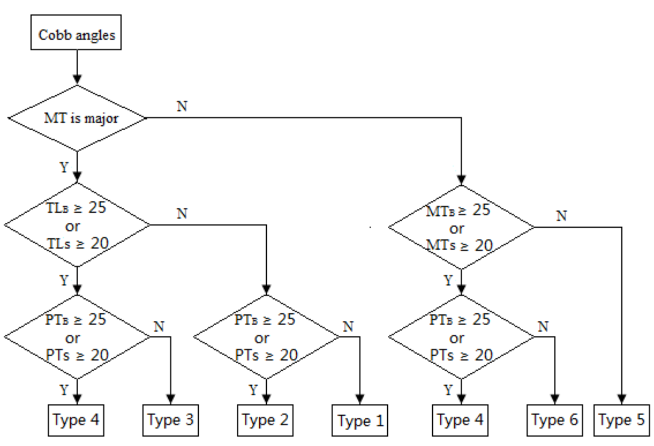

Figure 3. Flowchart of the classification algorithm.

D. Evaluation

In this study, five observers participated in the experiments including a pediatric orthopedic surgeon with 10 years of experience in scoliosis clinic, an orthopedic resident, a musculoskeletal radiologist, a medical student without experience in orthopedic radiology, and the software developer without clinical experience. Each observer performed the tasks of assigning names of the upper and lower vertebrae on the curves to be analyzed and setting the ROI for each vertebra on radiographs three times over a period of three weeks. Without the computer-aid, the surgeon and the resident also respectively classified the Lenke types three times using only the chart description of curve-type classification in the traditional Lenke method based on the traditional Cobb measurement.

The kappa statistic [11] was used to assess the variability in the Lenke classification under the conditions of with and without the computer-aid. Under each of the two conditions, the kappa statistic was calculated for paired sets of classifications by each observer (intraobserver repeatability) or between observers (interobserver reliability), using all combinations of paired observations. The resulting values were averaged over combinations of pairs (intraobserver or interobserver) to provide an overall measure of variability.

III. Results

The Intraobserver repeatability is shown in Table I. With the computer aid, the kappa value was in the range from 0.82 to 0.92 for the five observers, which was in the excellent range (>0.80). By using the computerized method, the kappa value was improved from 0.81 to 0.91 and from 0.73 to 0.86 for the surgeon and the resident, respectively. The average kappa value and the average classification consistency were improved to 0.88 and 90%, respectively.

The Interobserver reliability is shown in Table II. By using the proposed method, the average interobserver kappa value was improved from 0.68 to 0.83 and the average interobserver consistency was improved from 72% to 85%. With the traditional method, the two observers in all three trials consistently classified 20 patients while with the computerized method, all five observers consistently classified 25 patients. With the traditional method, the overall interobserver kappa values increased from 0.65 to 0.69 over the three series of measurement while with the computerized method, the kappa values increased from 0.78 to 0.87.

TABLE I. INTRAOBSERVER REPEATABILITY

Observer	Consistency (%)	Kappa Value
1	95	0.91
2	89	0.86
3	89	0.87
4	84	0.82
5	95	0.92
Average of with aid	90	0.88
1 without aid	84	0.81
2 without aid	78	0.73
Average of without aid	81	0.77

TABLE II. INTEROBSERVER RELIABILITY

Trial	Consistency (%)		Kappa Value	
	With aid	*Without aid*	*With aid*	*Without aid*
1	81	70	0.78	0.65
2	86	73	0.83	0.69
3	89	73	0.87	0.69
Average	85	72	0.83	0.68

IV. DISCUSSION

Reliability of the spinal deformity classification has been an important topic in the orthopedic community. Many studies reported the reliability of the King classification and Lenke classification. Some studies obtained only poor to fair reliability [4, 5]. This paper proposed a computer-aided method to reduce the variability in the Lenke classification. The experimental results of this study indicated that the task of measuring scoliosis curves on radiographs and subsequently classifying the curve type was more reliable with the aid of a computerized tool. The improvement of reliability was due to two factors. First, the reliability of curve measurement was improved by the computer-aided Cobb measurement method whose accuracy and reliability had been demonstrated in our previous study [10]. Second, the judgment errors were reduced by the computerized classification algorithm. Since multiple parameters should be considered in the Lenke classification (i.e., the angles of the proximal thoracic, the main thoracic, and the thoracolumbar/lumbar curves on the standing and side-bending coronal radiographs and on the sagittal radiograph), using only the chart description of curve-type classification in the traditional Lenke method would be confusing and subjective. A computerized system that was more objective and was immune to this confusion could therefore improve reliability. Although the proposed method still required user judgment to measure the Cobb angle (i.e. to determine the curves to be measured and to fit the ROIs to vertebrae), very few user interaction and skills were required. Using this computerized tool, even an observer with less clinical experience could achieve excellent reliability (e.g., kappa value of 0.82 by the student, and 0.92 by the software developer). The comparison of the three trials suggested that reliability could be improved when the observer's experience of using this computerized tool improved.

This technique might be extended to assist other classification systems. Our future work would focus on computer-aided selection of fusion levels for the scoliosis correction.

V. CONCLUSION

The proposed computerized tool can assist in the Lenke classification. It reduced the technical errors in the Cobb angle measurement and the human judgmental errors in the Lenke classification. The computer-aided method had reliability superior to that achieved without the computer aid. It can be used equally well by individuals with less clinical experience.

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