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Computer-aided Lenke classification of scoliotic spines

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Abstract—The identification and classification of the spine deformity play an important role when considering surgical planning for adolescent patients with idiopathic scoliosis. The subject of this article is the Lenke classification of scoliotic spines using Cobb angle measurements. The purpose is two-fold: (1) design a rule-based diagram to assist clinicians in the classification process and (2) investigate a computer classifier which improves the classification time and accuracy. The rule-based diagram efficiency was evaluated in a series of scoliotic classifications by 10 clinicians. The computer classifier was tested on a radiographic measurement database of 603 patients. Classification accuracy was 93% using the rule-based diagram and 99% for the computer classifier. Both the computer classifier and the rule based diagram can efficiently assist clinicians in their Lenke classification of spine scoliosis.

Keywords—Scoliosis, Lenke model, decision-rules, computer-aided classifier

I. Introduction

ADOLESCENT idiopathic scoliosis (AIS) is a complex three-dimensional (3D) deformation of the natural shape of the spinal column. AIS patients have pathological spinal curves in the coronal plane, alteration of the kyphosis or lordosis in the sagittal plan, and rotation of the vertebrae. The AIS is present in 2% to 4% percent of children between 10 and 16 years of age [9]. Identification of scoliotic deformity plays an important role when considering operative intervention. By identifying the patterns of the patient's spinal deformity, the segmental instrumentation could be applied on the suggested levels of the scoliotic spine for the deformity corrections [7]. There are currently two recognized scoliosis deformity models, the King model [4] and the Lenke model [6]. The King model, proposed in 1983, which measures scoliotic deformities on coronal radiographs, describes five thoracic curve types (class) and recommends specific vertebral levels to be included in a spinal arthrodesis. The main problems of this model are the relatively low intra- and inter-observer reliability [1], [5], its bi-dimensional nature, and confinement to thoracic curves [5]. The Lenke model, proposed in 1998, adds the three-dimensional information by considering the spine deformity in the sagittal plane [10]. It is described in a chart, the Lenke chart, specifying the criteria to separate the spine curve shapes into six different types [5] (Figure 1). However, the Lenke model is complex and it suffers, just like the King model, from intra- and inter-observer reliability that has been considered low to fair. In fact, the Lenke study [6] has shown that, based on pre-measured radiographs and within a group of seven clinicians from the Scoliosis Research Society, the classification accuracy using the Lenke chart was 74%.

Recent advances in computing and technology have facilitated the development of computer-aided diagnosis systems and concomitant application to support clinicians in their decision-making. Automatic classification of pathologies has become an important research area in computer-aided decision for several biomedical applications. For scoliosis classification two approaches have been explored. The first used a geometric representation of the spines for classification [2], [8]. This approach is not based on measurements of a single parameter category, as with the Lenke model. Instead, it considers multiple features to describe the three-dimensional deformation which is quite a challenging task. The second approach is based on radiographic measurements. Strokes et al. [11], [12] have developed a computer algorithm for the classification of spinal curves according the King model. The development of that classification method has allowed the identification of curve types, but it is within the King model.

Our study deals with the Lenke classification of scoliotic spines using Cobb angle measurements. Based on objective criteria, the Lenke description of the spine curves is more accurate than the King model. Using this description, we investigated two classification schemes. One is a rule-based diagram to assist clinicians in the classification process. The other is a computer-based classifier to improve the classification accuracy and time. Both schemes are based on the Lenke chart criteria (Figure 1).

II. Materials and methods

A. Classification protocol

The criteria in the Lenke chart, shown in Figure 2, are used currently by clinicians to determine the spine curve type. The six curve types in coronal and sagittal radiographs have specific characteristics, which differentiate structural and nonstructural curves in the proximal thoracic, main thoracic, and thoracolumbar/lumbar regions. Based on these descriptions, we investigated two classification schemes.

In one scheme, the rule-based tree diagram is used by clinicians in the classification process. Ten clinicians (7 orthopaedic residents, 1 research nurse, and 2 orthopaedic surgeons) were asked to classify 72 scoliotic curves using their angle measurements. Thirty-six cases were to be classified from radiographic measurements using the Lenke chart only, and the remaining 36 using the rule-based diagram described in Section II-B. To avoid a training effect, we asked some clinicians to begin classification using the Lenke chart and then to perform classification using the decision-tree diagram. The other clinicians were asked to begin with the classification using the decision-tree diagram and then to perform classification using the Lenke chart.

CURVE TYPE				
Type	Proximal Thoracic	Main Thoracic	Thoracolumbar/Lumbar	Description
1	Non-Structural	Structural (Major)*	Non-Structural	Main Thoracic (MT)
2	Structural	Structural (Major)*	Non-Structural	Double Thoracic (DT)
3	Non-Structural	Structural (Major)*	Structural	Double Major (DM)
4	Structural	Structural (Major)*	Structural (Major)*	Triple Major (TM)§
5	Non-Structural	Non-Structural	Structural (Major)*	Thoracolumbar/Lumbar (TL/L)
6	Non-Structural	Structural	Structural (Major)*	Thoracolumbar/Lumbar-Main Thoracic (TL/L-MT)

STRUCTURAL CRITERIA
(Minor Curves)

Proximal Thoracic - Side Bending Cobb ≥ 25°
- T2-T5 Kyphosis ≥ +20°

Main Thoracic - Side Bending Cobb ≥ 25°
- T10-L2 Kyphosis ≥ +20°

Thoracolumbar/Lumbar - Side Bending Cobb ≥ 25°
- T10-L2 Kyphosis ≥ +20°

*Major = Largest Cobb measurement, always structural
Minor = All other curves with structural criteria applied
§Type 4 - MT or TL/L can be major curve

LOCATION OF APEX
(SRS Definition)

CURVE	APEX
Thoracic	T2-T11/12 Disc
Thoracolumbar	T12-L1
Thoracolumbar/Lumbar	L1/2 Disc-L4

Fig. 1. The chart describing the criteria of the Lenke curve classification

In the second scheme, the classification is completely automatic, i.e., a computer classification. It used a larger database, 603 scoliotic patients (including the 72 scoliotic patients classified by clinicians).

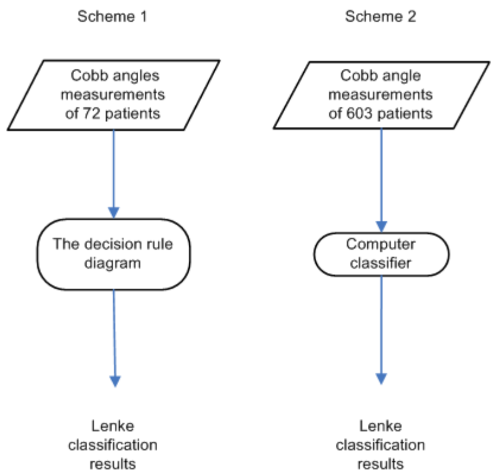

Fig. 2. Classification protocol

B. Decision rule diagram

Decision rules are powerful and popular tools for pattern classification and analysis. A decision-rule diagram translates a classification reasoning as a tree structure. Each node of the tree is either a leaf node, i.e., corresponding to a classification decision, or an intermediate decision node. The leaf node indicates a class of instances while the decision node specifies some test to be carried out on a single attribute-value, with one branch and sub-tree for each possible outcome of the test [3]. We translated the Lenke chart into the decision-rule tree of Figure 3. The input to this tree, its root node, is the set of Cobb angle measurements. The output is indicated by one of the leaf nodes and is the Lenke spine type.

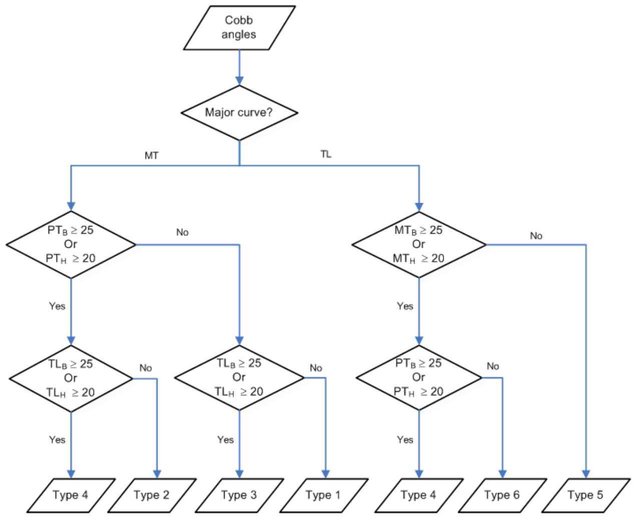

Fig. 3. The decision-rule diagram

The following angles are used to classify a given scoliotic spine shape based on the Lenke description [5]:

- TL and MT, which are the main thoracic and the thoracolumber/lumbar curves, respectively, on the coronal plane.
- PT_B, MT_B, and TL_B which designate, respectively, the proximal thoracic, the main thoracic, and the thoracolumber/lumbar curves on side-bending radiographs on the coronal plane.
- PT_H, MT_H, and TL_H which, respectively, are the proximal thoracic, the main thoracic, and the thoracolumber/lumbar kyphosis curves in the sagittal plane.

Note that for the PT_H, MT_H, and TL_H curves, the angle sign is important because it differentiates between lordosis and kyphosis.

C. *Evaluation of the classifiers' performance*

The classification methods are evaluated in terms of classification accuracies. It is the percentage of patient conditions that are classified correctly. The classification accuracy yields a representative global classification performance. To analyze the classification accuracy per Lenke class (Type 1 to Type 6), the confusion matrix is computed. The confusion matrix is a matrix of the predicted versus the real classes of the input data. For a given test sample, the entry (i, j) of the confusion matrix is the percentage of times the classifier identifies an input i as a pattern of class j. Each column of the matrix corresponds to the classifier output, and each row to the input. The classification accuracy for $i = j$ indicates the classification accuracy per class.

III. Experiments and Results

A set of classification experiments were carried out to test the performance of the classification methods (Figure 4).

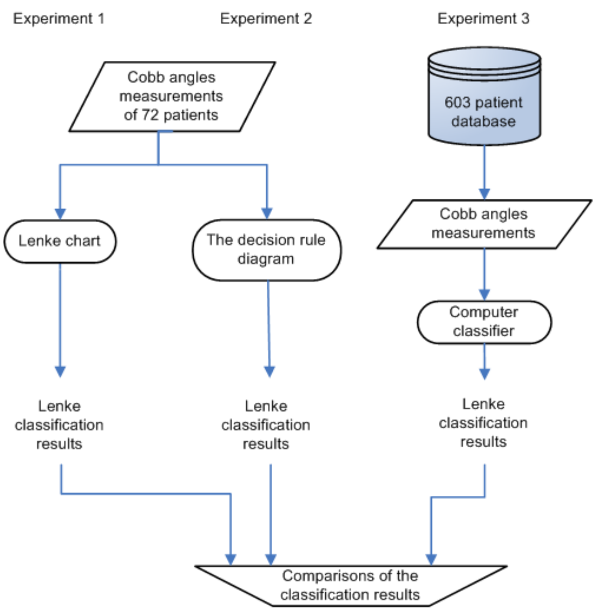

Fig. 4. Classification experiments

To test the performance of these schemes, which use the decision-rule diagram (Experiment 2 in Figure 4) and the computer-aided classifier (Experiment 3 in Figure 4), we conducted experiments, and compared the results to those by clinicians (Experiment 1 in Figure 4) who used directly the Lenke chart of Figure 4.

Table I summarizes the classification accuracies. The automatic computer-aided system achieved 99.66% of accuracy on the 603-patient database, compared to 93.02% of accuracy on a the 72-patient database by the clinicians using the decision-rule diagram and 77.7% on the 72-patient database by clinicians using the Lenke chart.

TABLE I
Error rates (in %)

Method	Classification accuracy
Clinicians using Lenke chart	77.7%
Clinicians using the rule-based diagram	93.02%
Computer classifier	99.66%

The confusion matrix of Table II, Table III, and Table IV shows the details of correct/incorrect classification. The confusion matrix elements corresponds to the mean pourcentage of times the cliniciens/classifier identifies a patient Type i as being of class Type j.

TABLE II
Confusion matrix achieved by the clinicians using the Lenke chart diagram (in %)

	Predicted class					
Real class	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
Type 1	76.8	9.0	12.3	0	1.6	0
Type 2	8.7	77.5	5.0	7.5	1.2	0
Type 3	5.2	3.9	84.2	6.5	0	0
Type 4	2.0	14.2	2.0	79.5	0	2.0
Type 5	11.7	0	0	2.9	82.3	2.9
Type 6	11.1	0	13.8	0	13.8	61.1

TABLE III
Confusion matrix achieved by the clinicians using the decision-tree diagram (in %)

	Predicted class					
Real class	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
Type 1	96.2	2.8	0	0	0.9	0
Type 2	3.1	92.7	0	4.1	0	0
Type 3	4.6	0	94.4	0.9	0	0
Type 4	0	8.1	1.3	90.5	0	0
Type 5	0	0	0	4.3	95.6	0
Type 6	0	0	4.5	0	18.1	77.2

TABLE IV
Confusion matrix using the computer-aided classifier (in %)

	Predicted class					
Real class	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6
Type 1	99.6	0.3	0	0	0	0
Type 2	0	100	0	0	0	0
Type 3	0	0	100	0	0	0
Type 4	0	0	0	100	0	0
Type 5	0	0	0	0	100	0
Type 6	0	0	0	3.1	0	96.9

In addition, we measured the classification times. The execution time for the computer-aided method was on an Intel Pentium 4 computer with a CPU of 3 GHz, using a visual C++ implementation. Table V shows that the classification time is very short when using the computer classifier, which maybe of value in clinical application.

TABLE V
CLASSIFICATION TIME

Method	Classification time / radiograph
Clinicians using Lenke chart	31.66 second
Clinicians using the rule based diagram	23.33 second
Computer classifier	1/100 second

IV. DISCUSSIONS AND CONCLUSION

In this study, we implemented and investigated two classification schemes: a decision-rule diagram and an automatic computer classifier. We conducted experiments to compare them to classification by clinicians who use directly the Lenke chart directly.

The classification accuracy achieved by clinicians using the Lenke chart is about 77%. This rate is comparable to other Lenke classification results in similar experiments [6].

Comparing the results listed at Table II and Table III, we note that the general tendency of the accuracy per class is to increase when we use the decision tree. For instance, using the Lenke chart the classification accuracy is 76.8% (Table II. line 3) where it is 96.2% (Table III. line 3) using the decision-tree diagram. Hence, the use of the decision-tree diagram has improved the clinicians' classification. In fact, when classifying a scoliotic spine into one of the curve types, multiple parameters (PT, MT, and TL angles standing and bending in the coronal plane and standing in the sagittal plane) have to be considered, which can be confusing when using only the chart description of curve-type classification from the original article. A simplified representation of the classification reasoning, as with the decision tree, is not subject to this confusion and therefore, improves accuracy.

The computer method had a 99.66% accuracy on the 603-patient database. The 0.34% of classification errors are due to some rare cases with a PT angle greater than the MT and TL angles. In the original description of the Lenke classification, only the main thoracic and the thoracolumbar curves can be described as major. Therefore, the use of a computer classifier on a large database has permitted us to account even for ambiguous cases.

The methods in this study can be investigated for other orthopedic conditions, particularly those for which classification criteria are available, based on radiographic features, for instance.

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