Computer-aided Lenke classification of scoliotic spines

Neila Mezghani, Philippe Phan, Hubert Labelle, Carl Eric Aubin and Jacques de Guise

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

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. 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.
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).

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.

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 thoracolumbar/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 thoracolumbar/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 thoracolumbar/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).

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 Lenke chart.

<table>
<thead>
<tr>
<th>Method</th>
<th>Classification accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinicians using Lenke chart</td>
<td>77.7%</td>
</tr>
<tr>
<td>Clinicians using the rule-based diagram</td>
<td>93.02%</td>
</tr>
<tr>
<td>Computer classifier</td>
<td>99.66%</td>
</tr>
</tbody>
</table>

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 percentage of times the clinicians/classifier identifies a patient $i$ as being of class Type $j$.

<table>
<thead>
<tr>
<th>Predicted class</th>
<th>Real class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>Type 1</td>
</tr>
<tr>
<td></td>
<td>Type 2</td>
</tr>
<tr>
<td></td>
<td>Type 3</td>
</tr>
<tr>
<td></td>
<td>Type 4</td>
</tr>
<tr>
<td></td>
<td>Type 5</td>
</tr>
<tr>
<td></td>
<td>Type 6</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Method</th>
<th>Classification time / radiograph</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinicians using Lenke chart</td>
<td>31.66 second</td>
</tr>
<tr>
<td>Clinicians using the rule based diagram</td>
<td>23.33 second</td>
</tr>
<tr>
<td>Computer classifier</td>
<td>1/100 second</td>
</tr>
</tbody>
</table>

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.

ACKNOWLEDGEMENTS

The authors would like to thank the Programme MENTOR of the Canadian Institutes of Health Research, the Natural Sciences and Engineering Research Council (NSERC), and the Canada Research Chair in 3D Imaging and Biomedical Engineering.

REFERENCES


