The Spine Journal 13 (2013) 1527–1533

THE SPINE JOURNAL

Technical Report

Artificial neural networks assessing adolescent idiopathic scoliosis: comparison with Lenke classification

Philippe Phan, MD[a,b,*], Neila Mezghani, PhD[c], Eugene K. Wai, MD[b], Jacques de Guise, PhD[c], Hubert Labelle, MD[a]

[a]*Research Center, Sainte-Justine University Hospital Center, 3175 Chemin de la Côte-Sainte-Catherine, Montreal, Quebec, Canada H3T 1C5*

[b]*Division of Orthopaedic Surgery, Department of Surgery, The Ottawa Hospital, University of Ottawa, Civic Campus, 1053 Carling Ave., Ottawa, Ontario, Canada K2A 3C8*

[c]*Imaging and Orthopaedics Research Laboratory (LIO), École de technologie supérieure, The CHUM Research Centre - Hôpital Notre-Dame, Pavillon J.A. de Sève, 1560, rue Sherbrooke Est, Y-1615 Montréal, Québec, Canada H2L 4M1*

Received 8 November 2012; revised 7 July 2013; accepted 14 July 2013

Abstract

BACKGROUND CONTEXT: Variability in classifying and selecting levels of fusion in adolescent idiopathic scoliosis (AIS) has been repeatedly documented. Several computer algorithms have been used to classify AIS based on the geometrical features, but none have attempted to analyze its treatment patterns.

PURPOSE: To use self-organizing maps (SOM), a kind of artificial neural networks, to reliably classify AIS cases from a large database. To analyze surgeon's treatment pattern in selecting curve regions to fuse in AIS using Lenke classification and SOM.

STUDY DESIGN: This is a technical concept article on the possibility and benefits of using neural networks to classify AIS and a retrospective analysis of AIS curve regions selected for fusion.

PATIENT SAMPLE: A total of 1,776 patients surgically treated for AIS were prospectively enrolled in a multicentric database. Cobb angles were measured on AIS patient spine radiographies, and patients were classified according to Lenke classification.

OUTCOME MEASURES: For each patient in the database, surgical approach and levels of fusion selected by the treating surgeon were recorded.

METHODS: A Kohonen SOM was generated using 1,776 surgically treated AIS cases. The quality of the SOM was tested using topological error. Percentages of prediction of fusion based on Lenke classification for each patient in the database and for each node in the SOM were calculated. Lenke curve types, treatment pattern, and kappa statistics for agreement between fusion realized and fusion recommended by Lenke classification were plotted on each node of the map.

RESULTS: The topographic error for the SOM generated was 0.02, which demonstrates high accuracy. The SOM differentiates clear clusters of curve type nodes on the map. The SOM also shows epicenters for main thoracic, double thoracic, and thoracolumbar/lumbar curve types and transition zones between clusters. When cases are taken individually, Lenke classification predicted curve regions fused by the surgeon in 46% of cases. When those cases are reorganized by the SOM into

FDA device/drug status: Not applicable.

Author disclosures: ***PP:*** Nothing to disclose. ***NM:*** Nothing to disclose. ***EKW:*** Nothing to disclose. ***JdG:*** Grant: CRC (H, Paid directly to institution/employer); Royalties: EOS /EMOVI (None); Stock Ownership: EMOVI (1.17%); Research Support: RTIS (H, Paid directly to institution/employer); Grants: CRSNG (F, Paid directly to institution/employer), RITS (H, Paid directly to institution/employer), CRC (H, Paid directly to institution/employer). ***HL:*** Support for travel to meetings for the study or other purposes: Medtronic Sofamor Danek (B); Stock Ownership: Spinologics, Inc. (30%); Speaking/Teaching Arrangements: DePuy, Medtronic (B); Trips/Travel: DePuy, Medtronic (B); Fellowship Support: DePuy (D, Paid directly to institution/employer).

The disclosure key can be found on the Table of Contents and at www.TheSpineJournalOnline.com.

This work was supported by the Fonds de la Recherche en Santé du Québec and MENTOR, a strategic training program of the Canadian Institutes of Health Research. Database access was permitted by the Spinal Deformity Study Group. Federal funds were received in support of this work. No benefits in any form have been or will be received from a commercial party related directly or indirectly to the subject of the manuscript. The authors would like to thank Mrs Polina Osler for her help in editing the illustrations.

* Corresponding author. Division of Orthopaedic Surgery, Department of Surgery, The Ottawa Hospital, University of Ottawa, Civic Campus, 1053 Carling Ave., Ottawa, Ontario, Canada K2A 3C8. Tel.: (613) 761-5168; fax: (613) 761-4661.

E-mail address: philippe.phan@gmail.com (P. Phan)

1529-9430/$ - see front matter
http://dx.doi.org/10.1016/j.spinee.2013.07.449

nodes, Lenke classification predicted the curve regions to fuse in 82% of the nodes. Agreement with Lenke classification principles was high in epicenters for curve types 1, 2, and 5, moderate in cluster for curve types 3, 4, and 6, and low in transition zones between curve types.

CONCLUSIONS: An AIS SOM with high accuracy was successfully generated. Lenke classification principles are followed in 46% of the cases but in 82% of the nodes on the SOM. The SOM highlights the tendency of surgeons to follow Lenke classification principles for similar curves on the SOM. Self-organizing map classification of AIS could be valuable to surgeons because it bypasses the limitations imposed by rigid classification such as cutoff values on Cobb angle to define curve types. It can extract similar cases from large databases to analyze and guide treatment.

Keywords: Adolescent idiopathic scoliosis; Surgical treatment; Lenke classification; Neural networks; Kohonen self-organizing maps

Introduction

Adolescent idiopathic scoliosis (AIS) is a complex three-dimensional deformity of the spine. Lenke classification for AIS [1] classifies it based on the six curve types according to the degree of deformity and the flexibility of each curve region (proximal thoracic, main thoracic, thoracolumbar/lumbar); this is done using cutoff criteria on Cobb angles measured on anteroposterior and sagittal X-rays. Curve regions included in the fusion are recommended based on the curve types. There is a know variability in the classification [2], surgical planning, and goals in the treatment of AIS [3] that could be accentuated by Cobb angle measurement variability evaluated to be up to 10° in scoliosis cases [4]. Several computer algorithms [5] have been used to classify AIS based on geometrical features. Those novel classifications have shown AIS subtypes and allowed a better assessment of AIS severity, but none of them have attempted to analyze AIS treatment patterns.

Our working hypothesis is that self-organizing maps (SOM), a kind of neural network and artificial intelligence algorithm, can reliably classify AIS and highlight treatment patterns. Our first objective is to use SOM to reliably classify AIS cases from a large database. Our second objective is to analyze surgeon's treatment pattern in selecting curve regions to fuse in AIS using Lenke classification and the SOM.

Methods

Data set

A complete data set of 1,776 AIS cases from 30 hospitals worldwide treated surgically by 63 surgeons between 2002 and 2008 was extracted from the Spinal Deformity Study Group database of AIS cases. A validated software by a third-party company (DrPro; PhDx, Albuquerque, NM, USA) was used to measure the eight basic Cobb angles used in the Lenke classification to define curve types from digitalized preoperative X-rays. For each AIS patient, levels of fusion were also retrieved, and the patients were classified according to Lenke classification by a systematic algorithm [6].

Classification and treatment association using SOM Kohonen maps

SOM Kohonen maps implement an algorithm of the clustering paradigm where large data patterns are mapped onto a small set of representative categories using a training process. Details on the algorithm used for this classification can be found in a former publication [7]. To evaluate the quality of a trained Kohonen network, the topological error is measured and represents the proportion of all nodes for which first and second-most similar nodes are not adjacent in the Kohonen map.

Matlab software (Mathworks, Inc., Natick, MA, USA) with Neural Network Toolbox was used to create an SOM based on the basic eight Cobb angles of each patient in the data set. Each node contains a weight vector of the eight basic Cobb angles, which were set by competitive training to optimize classification of each case from the database into a corresponding node. Neighboring nodes on the SOM have therefore characteristics differing only slightly for each of the eight Cobb angles. Lenke curve type was not used as an input to generate the SOM. The levels of fusion are divided into five categories based on the curve regions fused [8,9] (Table 1).

Statistical analysis

Descriptive statistics were used to calculate the ability of Lenke classification and the SOM to predict curve regions of the spine to be fused. Kappa statistical analysis at each node for agreement between fusion realized and fusion recommended by the Lenke classification for all cases in that

Table 1
Criteria for the determination of spine curve fusion

Regional curves	Vertebra selected for determination of curve fusion
PT	UIV higher or equal to T3
MT	UIV higher than T9 and LIV higher or equal to L2
TL/L	UIV lower or equal to T10 and/or LIV lower or equal to L3

PT, proximal thoracic; MT, main thoracic; TL/L, thoracolumbar; UIV, upper instrumented vertebra; LIV, lower instrumented vertebra.

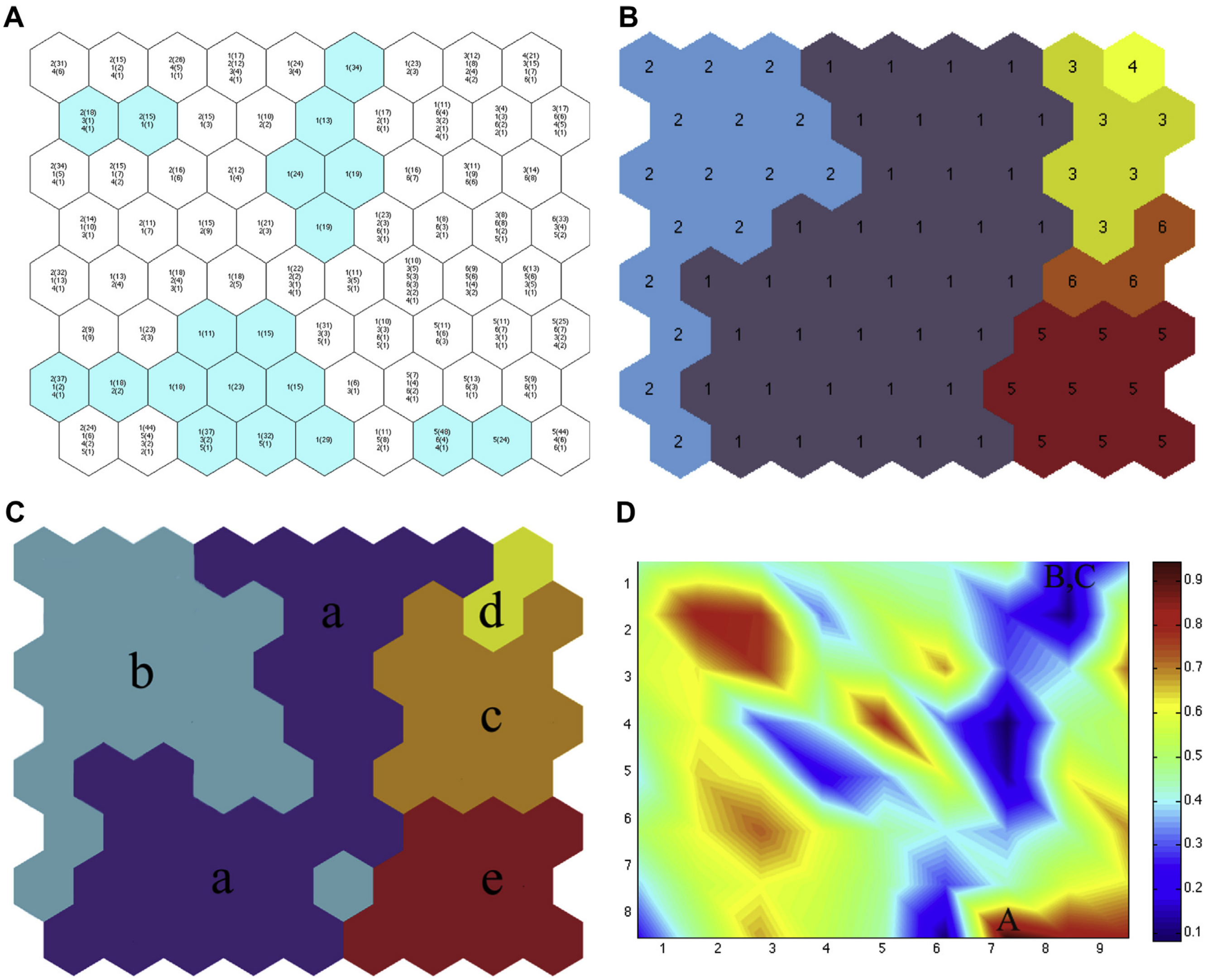

Fig. 1. (A) Self-organizing maps with adolescent idiopathic scoliosis (AIS) Lenke curve type frequencies in each of the nodes (epicenters with >90% of same curve types in blue). Each node contains the curve type followed by the number of subjects from the database assigned to this node with this curve type in parenthesis. (B) Self-organizing maps with each node tagged with the major AIS Lenke curve type. (C) Self-organizing maps with each node tagged with the major fusion pattern. (D) Matrix using edge gradient with kappa value for agreement between surgical treatment and recommendation by Lenke classification in each node. A kappa value scale is displayed on the right.

node is displayed in an agreement map of the SOM with edge gradient.

Results

Kohonen maps

A very accurate SOM was obtained; its topological error is 0.02. This demonstrates proper ordering of the nodes on the map, adequate neighboring, and very good accuracy of the classification [7]. Curve pattern clusters are visible on the SOM when each node is tagged with the major curve type in that node (Fig. 1, A and B).

Most nodes comprised mixed curve types, but 20 nodes comprised at least 90% of the same curve types (1, 2, and 5) and will be called epicenters. Using the major fusion pattern to tag each node, a harmonious distribution of curve fusion pattern is also obtained (Fig. 1, C) despite complete heterogeneity of treatment pattern in each node.

Table 2
Recommendation for fusion levels according to the Lenke classification principles

Lenke curve types	Fusion patterns	Structural curves to include in fusion
1 (MT)	a	MT
2 (double thoracic)	b	PT+MT
3 (double major)	c	MT+TL/L
4 (triple major)	d	PT+MT+TL/L
5 (TL/L)	e	TL/L
6 (TL/L-MT)	c	MT+TL/L

MT, main thoracic; PT, proximal thoracic; TL/L, thoracolumbar/lumbar.

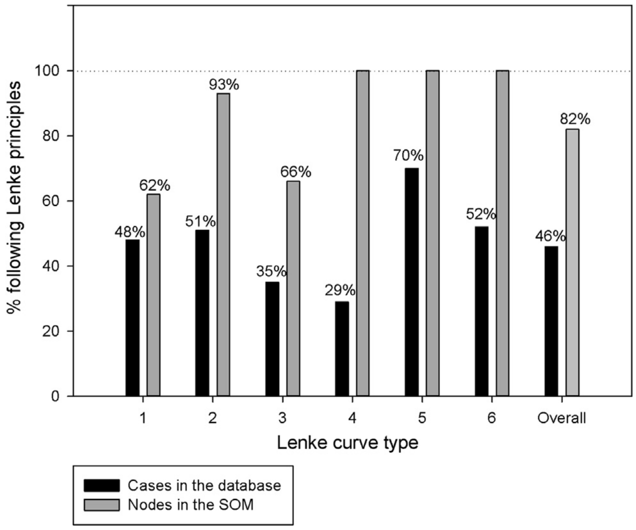

Fig. 2. Comparison of proportion of cases in the database and nodes in the self-organizing maps (SOM) following Lenke classification principles of curve fusion for adolescent idiopathic scoliosis.

Statistical analysis

Only 46% of cases followed Lenke classification principles for fusion (Table 2). When those same patients are plotted on the SOM, 82% of the nodes followed Lenke classification for fusion (Fig. 2).

The agreement map (Fig. 1, D) demonstrated almost perfect agreement (kappa >0.8) in the epicenters of curve types 1, 2 and 5; those clusters have high agreement between levels of fusion recommended by the Lenke classification and fusion performed on those patients. Between those epicenters, transition zones with low agreement (kappa between 0 and 0.2) are seen. For multiple region curve types (3, 6, and 4), nodes with fair to moderate agreement (kappa between 0.21 and 0.6) are observed.

Discussion

The complexity of AIS has led to the development of several clinical and computer-generated classifications to guide its evaluation and treatment. The Lenke classification for AIS is commonly used nowadays, but its reliability has been challenged [1,2]. A source of error can be the variability in Cobb angle measurement. Self-organizing maps can compensate for measurement variability by placing nodes with similar characteristics closer on the map. This study aimed at developing an SOM that could improve classification accuracy and study treatment variability.

A highly accurate AIS SOM was successfully developed. Because a computer does the classification, the SOM will consistently classify a patient to a node with perfect reproducibility. The reliability of this classification is

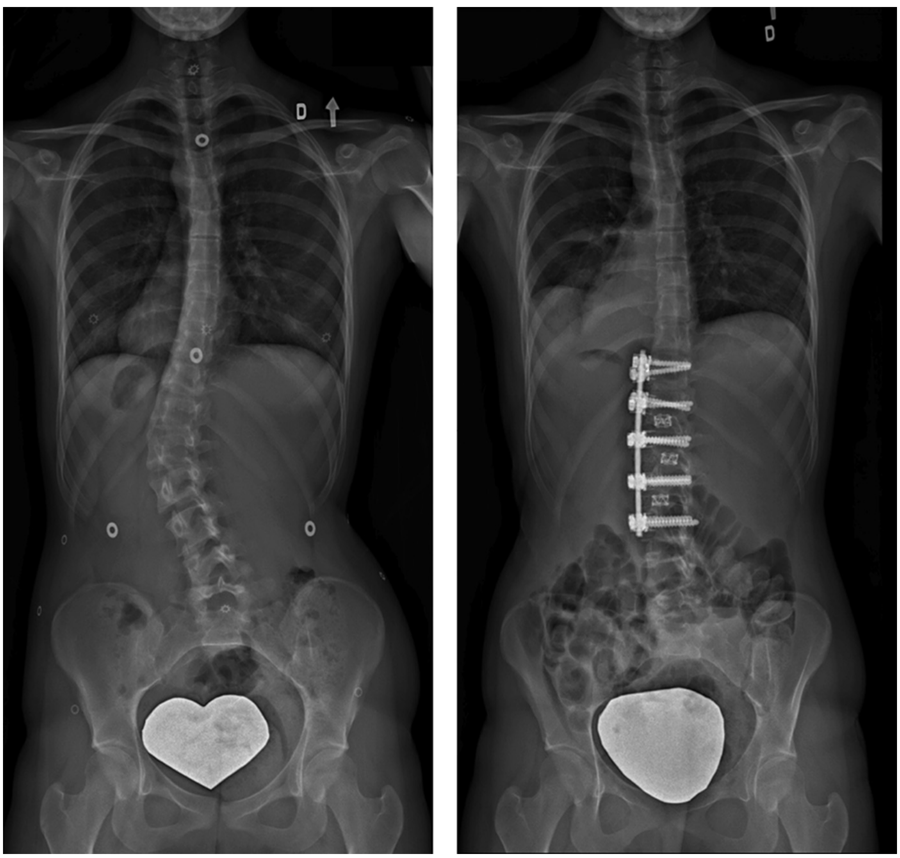

Fig. 3. Case A: 19 year-old woman with Lenke curve type 5 was treated with an anterior fusion of the thoracolumbar curve from T11 to L3.

only dependent on the Cobb angle measurements. Two neighboring nodes in the map are likely to contain the most similar patients in the database compared with nonadjacent nodes; therefore, the SOM can compensate for Cobb angle measurement variability. In the original article by Lenke et al. [1], high reliability in classification was found for curve types 1, 2, and 5 (kappa value >0.7) for which the SOM also defined epicenters. This suggests that those curve types have features that are well distinguished by humans and by the neural network alike.

In this study, we realized that surgeons tend to follow Lenke classification principles when treating similar curves on the SOM, but the exact curve type does not always dictate the fusion type. From the database, surgeons followed Lenke classification principles of fusion in 46% of cases but 82% of the nodes followed those principles in the SOM. This is in contrast with Lenke et al. [10] who describe 90% cases following those principles. Discrepancy for those results is suspected to arise from the methodology in the determination of region fused and the worldwide multicentric nature of the Spinal Deformity Study Group database, while Lenke et al. [10] studied five American centers, which might have more consistent approach to AIS treatment. Lenke principles are followed almost perfectly in epicenters for curve types 1, 2, and 5, regions with high kappa values on the agreement maps. Kappa values were lower for multiple curve types (Lenke 3, 6, and 4) and lowest in transition zones. Although intuitive, to our knowledge, this is the first description of such correlations between Lenke curve type and surgical treatment.

A possible limitation of this study is the determination of regions fused based on the vertebral levels included in the fusion. Nonetheless, this method has been accepted in several former peer-reviewed articles [8,9] from which we extracted the criteria used to determine which curves were fused. To optimize geometric regrouping, other parameters such as maximum plane of deformity, apical vertebral translation, or Lenke modifiers could have been used as additional inputs. Nonetheless, this study focused on the correlation of Lenke curve types and fusion patterns, and we decided to limit the input parameters to Cobb angles.

With the increase of large clinical databases, SOM could be used as search motors to extract similar patients and compare surgical strategies. Practically, given a new AIS patient, the surgeon can input her eight Cobb angles into the SOM, which returns its localization on the map and similar patients from the same and neighboring nodes. If the new patient is classified to an epicenter, surgical strategy has little variability and treatment suggested by Lenke principle can be applied with confidence. If the patient is classified to a node with low kappa, different surgical strategies applied to similar cases can be compared to extract the optimal treatment.

Fig. 4. Case B: 12-year-old female with Lenke curve type 1. On bending X-rays, proximal thoracic and thoracolumbar/lumbar curves correct just below 25°, making them nonstructural. Patient B was treated with a fusion of all three curve segments from T3 to L3.

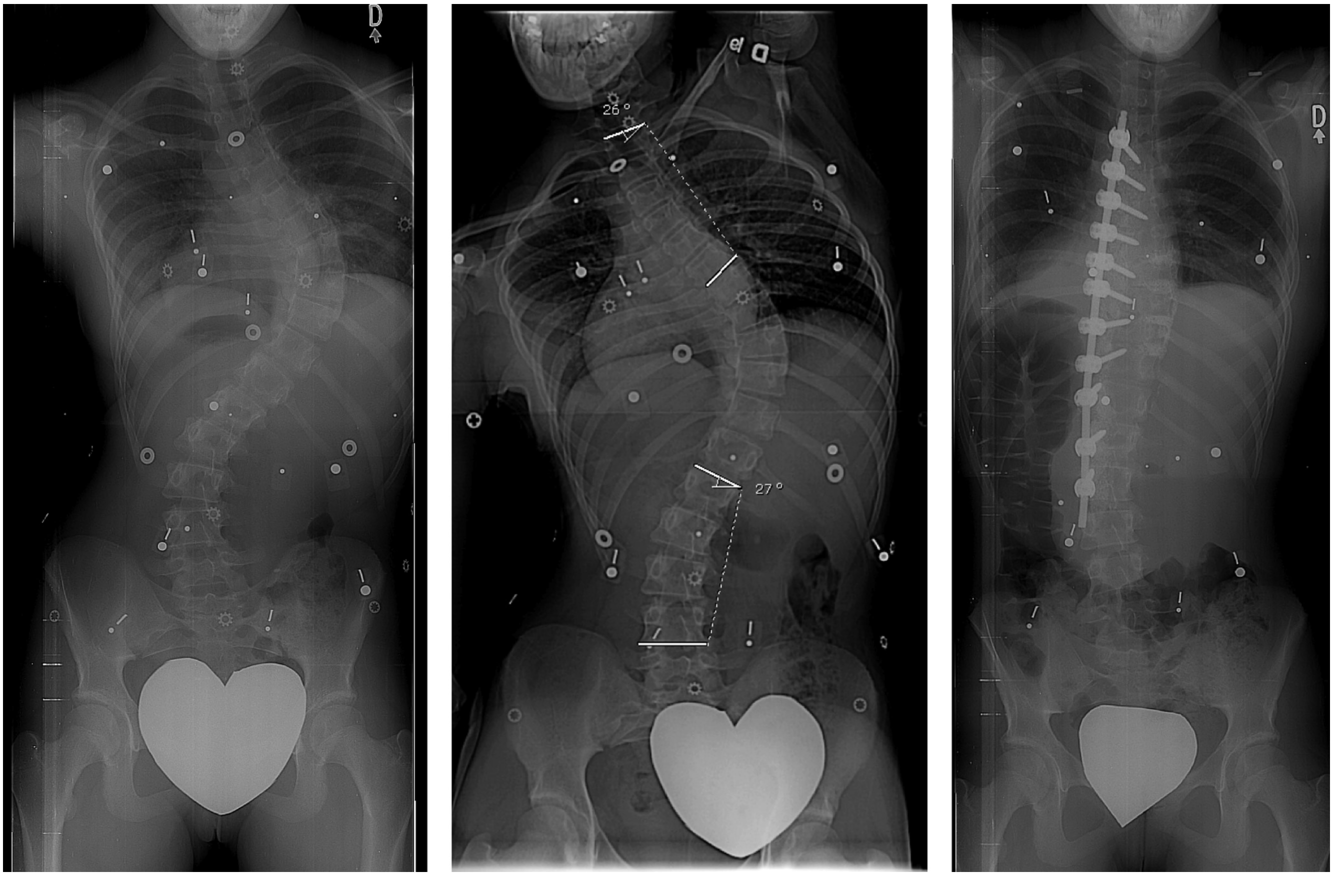

Fig. 5. Case C: 14-year-old female with Lenke curve type 4. On bending X-rays, Cobb angles of proximal thoracic and thoracolumbar/lumbar corrected to just above 25°; those curves are therefore considered structural. Patient C was treated with fusion of the main thoracic curve from T4 to L2.

Illustration of the cases

Patient A (Fig. 3) has a typical thoracolumbar curve, Lenke curve type 5, and was treated with a selective fusion by an anterior approach. She is at the epicenter of the curve type 5 on the SOM (Fig. 1, B) in a node with high kappa value on the agreement map (Fig. 1, D) confirming that her treatment is not controversial. Patient B (Fig. 4) has a Lenke curve type 1 (Fig. 1, B and D) but was treated with a fusion of all three curve segments. From this same node, patient C (Fig. 5) has Lenke curve type 4 (Fig. 1, B and D) and was treated with fusion of the main thoracic curve only. Both these patients are on a borderline node with high treatment variability and comprised Lenke 1, 2, 3, and 4 curve types (Fig. 1, A) for which all fusion patterns were applied. Patients B and C have Cobb angles on bending X-ray that are very close to the 25° cutoff that determines whether a curve is structural. The SOM is able to gather cases that are similar based on input parameters without cutoff values.

Conclusions

An AIS SOM with high accuracy was successfully generated and can compensate for variability in Cobb angle measurements. Cases with similar curve types were automatically grouped into clusters, and epicenters were defined. Lenke classification principles are followed in 46% of the cases but in 82% of the nodes on the SOM. Cases within epicenters were treated with high agreement with those principles. Using an unsupervised algorithm, the SOM highlights the tendency of surgeons to follow Lenke classification principle for similar curves on the SOM. Self-organizing map classification of AIS could be valuable to surgeons because it bypasses the limitations imposed by rigid classification such as cutoff values on Cobb angle to define curve types. It can extract similar cases from large databases to analyze and guide treatment.

References

[1] Lenke LG, Betz RR, Harms J, et al. Adolescent idiopathic scoliosis: a new classification to determine extent of spinal arthrodesis. J Bone Joint Surg Am 2001;83-A:1169–81.

[2] Richards B, Sucato D, Konigsberg D, Ouellet J. Comparison of reliability between the Lenke and King classification systems for adolescent idiopathic scoliosis using radiographs that were not premeasured. Spine 2003;28:1148–56; discussion 1156–7.

[3] Robitaille M, Aubin CE, Labelle H. Intra and interobserver variability of preoperative planning for surgical instrumentation in adolescent idiopathic scoliosis. Eur Spine J 2007;16:1604–14.

[4] Carman DL, Browne RH, Birch JG. Measurement of scoliosis and kyphosis radiographs. Intraobserver and interobserver variation. J Bone Joint Surg Am 1990;72:328–33.

[5] Phan P, Mezghani N, Aubin C-E, et al. Computer algorithms and applications used to assist the evaluation and treatment of adolescent idiopathic scoliosis: a review of published articles 2000-2009. Eur Spine J 2011;20:1058–68.

[6] Phan P, Mezghani N, Nault ML, et al. A decision tree can increase accuracy when assessing curve types according to Lenke classification of adolescent idiopathic scoliosis. Spine 2010;35: 1054–9.

[7] Mezghani N, Phan P, Mitiche A, et al, eds. A computer-aided method for scoliosis fusion level selection by a topologically ordered self-organizing Kohonen network. 20th International Conference on Pattern Recognition:August 23-26, 2010:4012–5.

[8] Lenke L. The Lenke classification system of operative adolescent idiopathic scoliosis. Neurosurg Clin N Am 2007;18:199–206.

[9] Lenke L, Betz R, Haher T, et al. Multisurgeon assessment of surgical decision-making in adolescent idiopathic scoliosis: curve classification, operative approach, and fusion levels. Spine 2001;26:2347–53.

[10] Lenke L, Betz R, Clements D, et al. Curve prevalence of a new classification of operative adolescent idiopathic scoliosis: does classification correlate with treatment? Spine 2002;27:604–11.