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Commentary

Challenges in the classification of adolescent idiopathic scoliosis and the utility of artificial neural networks

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COMMENTARY ON: Phan P, Mezghani N, Wai EK, et al. Artificial neural networks assessing adolescent idiopathic scoliosis: comparison with Lenke classification. Spine J 2013;13:1527–33 (*in this issue*).

Pediatric spinal deformity surgeons continue to face numerous challenges in determining an ideal classification of adolescent idiopathic scoliosis (AIS), and consequently, clinical decision making remains complex and inconsistent when determining the extent of spinal arthrodesis. Despite these challenges, the primary goal in the surgical management of AIS remains unchanged: achieving solid fusion in a well-balanced spine. While surgeons seek to minimize the number of fusion levels, this balance, in which the head is centered over the pelvis, decreases the risk of postoperative deformity progression.

However, even with advances in spinal instrumentation and surgical techniques, insufficient understanding of curve morphology and subsequent improper selection of fusion levels may result in suboptimal outcomes. Without adequate planning and a thorough understanding of the complex three-dimensional characteristics of each patient's curve, the inappropriate exclusion of a structural curve or spinal segment within the arthrodesis may result in "adding-on," decompensation, shoulder imbalance, or junctional kyphosis [1–5].

The opposite error, of indiscriminate and excessive inclusion of fusion levels, may be equally detrimental, leading to unnecessary loss of motion segments and increased risk of adjacent segment pathology that is of particular concern in the lower lumbar spine [6–13]. The potentially dire consequences of inappropriate curve classification and fusion level selection are tremendously burdensome to the patient and their family, and complications requiring revision surgery significantly increase costs and resource utilization from the health care system for these otherwise healthy individuals. Therefore, determining an ideal classification that guides selection of optimal fusion levels remains an important area of debate and research.

The most recent and widely used classification for AIS was developed by Lenke et al. [14], although some continue to use the King et al. classification from 1983 [15]. Criticisms of the King classification included poor-to-fair validity, reliability, and reproducibility [16,17], morphological characterization of the deformity in only the coronal plane (one-dimension), incomplete description of all curve types (exclusion of thoracolumbar, lumbar, and double or triple major curves), and limited clinical applicability in

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determining the extent of arthrodesis with modern instrumentation [14]. Overall, the Lenke classification has improved the understanding and classification of AIS by using two-dimensional radiographic parameters (coronal and sagittal planes) and development of lumbar and sagittal modifiers, thus facilitating effective communication and a common language to describe curve morphology between surgeons [14]. The authors also provided guidelines, using expert opinion/consensus and available scientific evidence, for clinical decision making when determining the appropriate vertebral levels to be included in an arthrodesis.

However, with increasing utilization and experience with the Lenke classification, criticisms have inevitably emerged, but these were foreshadowed and mentioned as potential shortcomings during the initial report of the classification. First, ‘‘One criticism of this classification concerns the definition of structural minor curves. There has been no universally accepted and reproducible definition of a structural minor curve’’ [14]. Since this statement over a decade ago, there remains no standardized definition of a structural minor curve and continues to be a significant challenge in determining an ideal classification. The Lenke classification considers a minor curve to be structural if it remains larger than 25° on a supine side bending radiograph or if a curve region demonstrates hyperkyphosis with a focal sagittal Cobb measurement of 20° or more. However, there have been challenges in applying the 25° threshold because of the variability in technique (supine, push-prone, traction, etc), patient effort when performing a side bending film [18], and the inherent measurement error between different surgeons [19].

With forethought, Lenke et al. acknowledged, ‘‘Grading the curve as structural does not suggest that all structural minor curves, regardless of magnitude, are to be included in the arthrodesis…The clinical examination of the patient is also a critical component in the surgical decision-making process and may override radiographic information for certain curve patterns’’ [14]. This obviously leaves room for interpretation by each surgeon to determine if a curve is structural and whether it significantly contributes to the patient’s deformity and spinal balance. Therefore, deviations from the Lenke classification are expected, and although different studies report a range of up to 40% in treatment selection variation for certain Lenke curve types [20], the initial report of the Lenke classification found 31 of 315 (10%) [14,21,22] patients had structural regions that were not included in the arthrodesis or had nonstructural regions included in the arthrodesis. This inconsistency and variability in decision making may certainly be frustrating when determining the optimal treatment plan between surgeons and also confusing for the patient and family during counseling.

Another major criticism was, ‘‘An initial effort to include a grade for lumbar alignment in the axial plane as one of the structural criteria was found to be difficult to reproduce and thus was abandoned…In the absence of a reliable, simple, and universally accepted method of three-dimensional modeling of scoliotic deformities, two-dimensional radiographs (coronal and sagittal) remain the standard’’ [14]. Again, over a decade has passed since this statement and biplanar radiographs remain the standard for assessing and classifying AIS. Therefore, present and future efforts on improving the classification are undoubtedly focused on a three-dimensional analysis, including an assessment of rotational deformity [23–25].

In addition to the aforementioned challenges, the historical framework for developing a classification system is being examined. Previous classifications, including the Lenke classification, were developed based on expert opinion and literature review to select certain radiographic measurements or clinical factors that may be important in determining treatment and patient outcomes [21]. Although it may appear preferable in clinical decision making to use a single factor that is highly predictive, this approach rarely is adequate because there is usually no single definitive factor. As our understanding of AIS continues to grow, we have appreciated that numerous variables with complex interconnections must be weighed to determine a patient’s optimal treatment and outcome. Even in terms of the Lenke classification, an initial criticism was that the 42 different derived curve classifications would be excessively complicated for use in the clinical setting. However, a counterpoint would be that the Lenke classification remains oversimplified by failing to take into account numerous radiographic parameters and clinical factors that could potentially impact clinical decision making and outcomes. Based on these concerns, there has been some attention on a potential paradigm shift in the development of a classification for AIS through the application of advanced multifactorial computational data analysis and artificial neural networks (ANNs), with focus on individual patient prediction models and treatment plans rather than trying to identify generalized independent risk factors [26,27].

For many practicing spine surgeons, the concept and theory underlying ANNs may be unfamiliar; however, a complete review of ANNs is beyond the scope of this discussion. There are many types of ANNs but all attempt to mimic the higher-level activities and architecture of the human brain through a series of computer algorithms [26,27]. As in the human brain, there are neurons and synapses with various synaptic connection strengths (referred to as ‘‘weights’’) for each connected pair of neurons [27]. Data are presented to an ANN through a layer of simple computing nodes that operate as nonlinear summing devices, which are then richly interconnected by weighted connection lines and these weights are adjusted when additional data are presented to the network during a ‘‘training’’ process [26]. The first computational, trainable ANNs were developed in 1959 by Rosenblatt and have been an active field of research that have matured greatly over the past 50 years, with applications in the military, financial systems, and other medical specialties such as oncology and trauma prognosis/survival models [26]. In fact, comparison of computerized multivariate analysis with human expert opinions have been performed in some studies, and some published comparisons identify areas in which neural network diagnostic capabilities appear to exceed that of the experts [26,28,29].

We commend the authors of the study ''Artificial neural networks assessing adolescent idiopathic scoliosis: comparison with Lenke Classification'' [30] in an effort to improve our understanding of AIS by analyzing the ability of a Kohonen self-organizing map (SOM), a specific type of ANN, to reliably classify AIS based on radiographic measurements from a large database of surgically treated AIS patients. The authors also set out to determine the ability of a SOM to select the appropriate fusion pattern based on the Lenke classification. The authors concluded that the use of a Kohonen SOM successfully classified the various curves types reliably and may be a novel and viable method to classify AIS. In addition to present classifications based on the practical clinical experience and mastery of the published literature by human experts, we can, in addition, use ANNs and advanced multivariate computer analysis to analyze the numerous potentially relevant factors simultaneously and to better understand the trends in the data that occur over a population of AIS patients. Artificial neural networks may be ready for further serious development for the classification of AIS [31], but the use of Kohonen SOMs must undergo further validation and verification, and ultimately, a humanized front-end software module or interface must be developed to collect data and to deliver an understandable output to the practicing surgeon.

A practical consideration for implementation of an ANN in clinical practice for scoliosis patients includes the development of a standardized guideline for radiographic evaluation. The variability in radiographic technique and quality remains a significant limitation and a reliable, reproducible method to determine curve severity and flexibility that will be necessary to calibrate/train and then implement a valid ANN. Another challenge in the development and utilization of an ANN for clinical decision making is determining an optimal method for evaluating the skeletal age and remaining spinal growth, which are variable depending on the surgeon's training and preference. Furthermore, the various surgical techniques for curve correction/derotation, multiple options for surgical approach (anterior/posterior/combined), different biomaterials (ie, titanium, stainless steel, cobalt-chromium) and types of instrumentation (ie, wires, staples, hooks, screws), and continued advances in technology may make it considerably difficult for any future classification, even with the use of an ANN, to determine optimal fusion levels. Furthermore, the application of ANNs will require collaboration with computer scientists, engineers, mathematicians, and statisticians; however, the ability to provide a significant insight and additional knowledge with advanced multivariate computer modeling appears promising.

References

[1] Kim YJ, Bridwell KH, Lenke LG, et al. Proximal junctional kyphosis in adolescent idiopathic scoliosis following segmental posterior spinal instrumentation and fusion: minimum 5-year follow-up. Spine 2005;30:2045–50.

[2] Lowe TG, Lenke L, Betz R, et al. Distal junctional kyphosis of adolescent idiopathic thoracic curves following anterior or posterior instrumented fusion: incidence, risk factors, and prevention. Spine 2006;31:299–302.

[3] Cho RH, Yaszay B, Bartley CE, et al. Which Lenke 1A curves are at the greatest risk for adding-on… and why? Spine 2012;37:1384–90.

[4] Kuklo TR, Lenke LG, Graham EJ, et al. Correlation of radiographic, clinical, and patient assessment of shoulder balance following fusion versus nonfusion of the proximal thoracic curve in adolescent idiopathic scoliosis. Spine 2002;27:2013–20.

[5] Wang Y, Bunger CE, Zhang Y, et al. Distal adding-on in Lenke 1A scoliosis: how to more effectively determine the onset of distal adding-on. Spine 2013;38:490–5.

[6] Lenke LG, Bridwell KH, Baldus C, et al. Ability of Cotrel-Dubousset instrumentation to preserve distal lumbar motion segments in adolescent idiopathic scoliosis. J Spinal Disord 1993;6:339–50.

[7] Suk SI, Kim WJ, Lee CS, et al. Indications of proximal thoracic curve fusion in thoracic adolescent idiopathic scoliosis: recognition and treatment of double thoracic curve pattern in adolescent idiopathic scoliosis treated with segmental instrumentation. Spine 2000;25:2342–9.

[8] Suk SI, Lee SM, Chung ER, et al. Determination of distal fusion level with segmental pedicle screw fixation in single thoracic idiopathic scoliosis. Spine 2003;28:484–91.

[9] Sarlak AY, Atmaca H, Kim WJ, et al. Radiographic features of the Lenke 1A curves to help to determine the optimum distal fusion level selection. Spine 2011;36:1592–9.

[10] Marks M, Newton PO, Petcharaporn M, et al. Postoperative segmental motion of the unfused spine distal to the fusion in 100 patients with adolescent idiopathic scoliosis. Spine 2012;37:826–32.

[11] Lee MC, Ounpuu S, Solomito M, et al. Loss in spinal motion from inclusion of a single mid-lumbar level in posterior spinal fusion for adolescent idiopathic scoliosis. Spine 2013;38:E1405–10.

[12] Kuklo TR, Lenke LG, Won DS, et al. Spontaneous proximal thoracic curve correction after isolated fusion of the main thoracic curve in adolescent idiopathic scoliosis. Spine 2001;26:1966–75.

[13] Lenke LG, Betz RR, Bridwell KH, et al. Spontaneous lumbar curve coronal correction after selective anterior or posterior thoracic fusion in adolescent idiopathic scoliosis. Spine 1999;24:1663–71; discussion 1672.

[14] 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.

[15] King HA, Moe JH, Bradford DS, et al. The selection of fusion levels in thoracic idiopathic scoliosis. J Bone Joint Surg Am 1983;65:1302–13.

[16] Cummings RJ, Loveless EA, Campbell J, et al. Interobserver reliability and intraobserver reproducibility of the system of King et al. for the classification of adolescent idiopathic scoliosis. J Bone Joint Surg Am 1998;80:1107–11.

[17] Lenke LG, Betz RR, Bridwell KH, et al. Intraobserver and interobserver reliability of the classification of thoracic adolescent idiopathic scoliosis. J Bone Joint Surg Am 1998;80:1097–106.

[18] Hamzaoglu A, Talu U, Tezer M, et al. Assessment of curve flexibility in adolescent idiopathic scoliosis. Spine 2005;30:1637–42.

[19] Richards BS, Sucato DJ, Konigsberg DE, et al. 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.

[20] Ogon M, Giesinger K, Behensky H, et al. Interobserver and intraobserver reliability of Lenke's new scoliosis classification system. Spine 2002;27:858–62.

[21] Lenke LG, Betz RR, 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.

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

[23] Duong L, Mac-Thiong JM, Cheriet F, et al. Three-dimensional subclassification of Lenke type 1 scoliotic curves. J Spinal Disord Tech 2009;22:135–43.

[24] Duong L, Cheriet F, Labelle H. Three-dimensional classification of spinal deformities using fuzzy clustering. Spine 2006;31:923–30.

[25] Petit Y, Aubin CE, Labelle H. Three-dimensional imaging for the surgical treatment of idiopathic scoliosis in adolescents. Can J Surg 2002;45:453–8.

[26] Dayhoff JE, DeLeo JM. Artificial neural networks: opening the black box. Cancer 2001;91:1615–35.

[27] Rodvold DM, McLeod DG, Brandt JM, et al. Introduction to artificial neural networks for physicians: taking the lid off the black box. Prostate 2001;46:39–44.

[28] Burke HB, Goodman PH, Rosen DB, et al. Artificial neural networks improve the accuracy of cancer survival prediction. Cancer 1997;79:857–62.

[29] Snow PB, Smith DS, Catalona WJ. Artificial neural networks in the diagnosis and prognosis of prostate cancer: a pilot study. J Urol 1994;152:1923–6.

[30] Phan P, Mezghani N, Wai EK. Artificial neural networks assessing adolescent idiopathic scoliosis: comparison with Lenke classification. Spine J 2013;13:1527–33.

[31] Phan P, Mezghani N, Aubin CE, 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.