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

Comparison of Geometric Torsion in Scoliosis under Lenke Classification*

Junhua Zhang, Liang Lv

Abstract— **The objective of this study is to investigate whether three dimensional (3D) variability exists within the Lenke classification, and to evaluate the correlations between the 3D features and the Cobb angle used in the Lenke classification. Forty-nine scoliotic patients with Lenke Type 1 curve were selected for analysis. For each patient, the 3D spine model was reconstructed from biplanar radiographs, and the geometric torsion was then calculated from the reconstructed spine model. An analysis of variance (ANOVA) was performed regarding the average torsion, the maximum torsion, and the Cobb angle, with the patients subdivided according to the torsion pattern. Results showed that a statistically significant difference was observed for the torsion parameters (i.e., the average torsion and the maximum torsion) between subgroups within the Lenke Type 1 curves while no statistically significant difference was found regarding the Cobb angle. The strengths of correlations between the torsion parameters and Cobb angle were stronger in the subgroup with torsion pattern of Type A. These results add the evidence that 3D geometric torsion reveals structural differences that are not apparent in the Cobb measurement.**

I. INTRODUCTION

Scoliosis is a three-dimensional (3D) deformation of the spine characterized by both lateral spinal curvature and vertebral rotation [1]. It affects about 2–4% of the adolescent population [2]. Scoliotic deformity classification is important for proper planning of the conservative or surgical treatments. Currently, two main classification systems, the King classification [3] and the Lenke classification [4], are aimed at guiding surgical treatment by selection of the appropriate fusion and instrumentation levels. The King classification is based on measurement on the coronal radiograph, which is inadequate for describing 3D spinal deformities. Carpineta *et al.* [5] demonstrated that the 3D variability existed within each type of the King classification. The Lenke classification that uses measurements in both coronal and sagittal planes describes the scoliotic curves in a more global sense. However, it is still based on the measurements of the two-dimensional (2D) projection of the spine on radiographs, which represents a simplification of the 3D spinal deformity involved in scoliosis. Sangole *et al.* [6] and Kadoury *et al.* [7] demonstrated the presence of subgroups relevant to surgical planning, within Lenke Type 1 curves.

Poncet *et al.* [8] proposed a classification system that defined three patterns of scoliotic curves based on the spinal geometric torsion. Duong *et al.* [9] used a wavelet transform of the vertebrae centroids and a fuzzy clustering algorithm to group 3D spine shapes. Both methods were technically elegant and illustrated that 3D classifications were important. However, those methods are not considered to be very intuitive by physicians.

Sangole *et al.* [6] calculated four indices of the thoracic segment within Lenke Type 1 curves and proposed a new means to report 3D spinal deformities bases on planes of maximal curvature. Kadoury *et al.* [7] analyzed five features of Lenke Type 1 curves by a non-linear manifold imbedding algorithm. They demonstrated the existence of an additional hyper-kyphotic subgroup in Lenke Type 1 curves and concluded that the complex space of spine variability could be modeled by a low-dimensional manifold. In both methods, the indices used were extracted from a 2D plane. Different spinal shapes can produce the same 2D view in a particular projection. Because of the 3D nature of scoliosis, the 3D index of scoliotic deformity is clinically important. The purpose of this study is to investigate whether 3D variability exists within the Lenke classification and to evaluate the correlations between the 3D features and the Cobb angle used in the Lenke classification. The geometric torsion is a true 3D measurement [1, 8]. In this study, we calculated the geometric torsion for the curves of Lenke type 1, and investigated the meaning of adding this 3D index in the context of the Lenke classification.

II. MATERIALS AND METHODS

A. Three-Dimensional Data

Forty-nine idiopathic scoliotic patients (43 boys and six girls) with Lenke type 1 curve were selected in this study. The average age at the time of the visit was 14 ± 3 years. Patients with a previous spinal surgery were excluded. The mean thoracic Cobb angle was 35 ± 14° (range, 15–59°). For each patient one posteroanterior (PA) and one later (LAT) radiograph were obtained. Ethics approval of this study was granted from the local ethics board.

For each subject, a 3D reconstruction of the spine from biplanar radiographs was performed using the self-calibration algorithm [10] that computed the geometrical parameters of the radiographic setup. For this purpose, six anatomic landmarks per vertebra were identified and matched on biplanar images by an expert who had been involved in a scoliosis clinic for 12 years. These landmarks were the centers of the superior and inferior endplates and the superior and inferior extremities of pedicles on each vertebra. The first step of the self-calibration method was to reconstruct the six

---

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

J. Zhang is with the Electrical Engineering Department, Yunnan University, Kunming, CO 650091 China, (phone: 86-871-65031301; fax: 86-871-65031301; e-mail: jhzhang_2006@yahoo.com.cn).

L. Lv is with the Radiology Department, the First People's Hospital of Yunnan Province, Kunming, CO 650032 China (e-mail: llyn99@163.com).

978-1-4577-0216-7/13/$26.00 ©2013 IEEE

landmarks per vertebra using the initial approximation of the geometrical parameters. The 3D landmarks were then retro-projected onto biplanar images using the projection matrices calculated from the geometrical parameters. The geometrical parameters were then updated based on the Levenberg-Marquardt algorithm [11] that minimized the mean squared distance between the projections of the landmarks of unknown 3D coordinates and those identified by the expert on the biplanar images. The set of parameters were therefore regenerated and were used for the reconstruction and projection again. This procedure is repeated until the system reaches a steady state, where the landmark retro-projection error falls to a minimum. The optimized geometrical parameters of the radiographic system were used to obtain the final 3D coordinate for a pair of matched landmarks. As an example, Fig. 1 shows the PA and LAT radiographs of a scoliotic spine and the reconstructed 3D spine model.

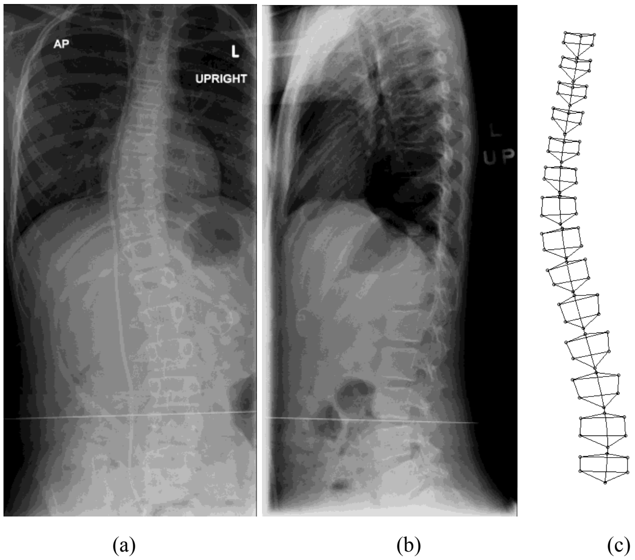
B. *Geometric Torsion Calculation*

Based on the reconstructed 3D landmarks, the 3D vertebral centroid was computed as the mean of the four bases of pedicles. For each individual shape of the 49 reconstructed spines, a mathematical parametric description was obtained by fitting a 3D curve through vertebral centroids using a least square Fourier series method. In the discrete space, this 3D curve of central axis was represented by a series of points. These points formed a series of connected vectors, as shown in Fig. 2. Given these 3D points, the discrete form of geometric torsion T was calculated according to the definition proposed in [12]:

$$T_{123} = \frac{1}{K_{12} \cdot K_{23}} \frac{\sin \gamma_{123}}{S_{123}} \tag{1}$$

where K was the discrete form of curvature:

$$K_{12} = \frac{\sin \alpha_{12}}{S_{12}}, \quad K_{23} = \frac{\sin \alpha_{23}}{S_{23}} \tag{2}$$



(a) (b) (c)

Figure 1. 3D reconstruction of the spine. (a) PA radiograph. (b) LAT radiograph. (c) Reconstructed spine model.

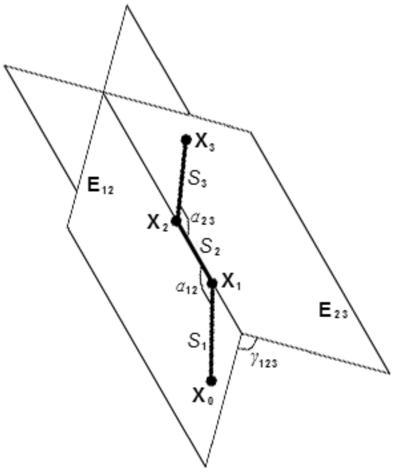


Figure 2. Geometrical representation of curvature and torsion.

As illustrated in Fig. 2, S_{12} is the average length of segments S_1 and S_2, and S_{123} is the average length of segments S_1, S_2, and S_3. The α_{12} denotes the angle of deformity between two vectors $\mathbf{e}_1$ and $\mathbf{e}_2$, where $\mathbf{e}_1 = (\mathbf{x}_1 - \mathbf{x}_0) / S_1$, and $\mathbf{e}_2 = (\mathbf{x}_2 - \mathbf{x}_1) / S_2$. The γ_{123} denotes the torsion angle between the two planes determined by the vectors:

$$\mathbf{E}_{12} = \mathbf{e}_1 \times \mathbf{e}_2 , \ \mathbf{E}_{23} = \mathbf{e}_2 \times \mathbf{e}_3. \tag{3}$$

C. *Torsion Curve Patterns*

According to the study by Poncet *et al.* [8], there are three patterns of torsion named Type A, B, and C. In Type A curves, the maximum torsion is located in the upper-end vertebrae region, and the minimum torsion occurs in the opposite end vertebrae region. In Types B and C curves, the maximum torsion is located in both the upper-end and lower-end vertebrae regions, and the minimum torsion occurs in the apical vertebrae region. In Types A and C curves, the torsion value is unidirectional, whereas Type B curves are subjected to torsion in opposite directions. That is, in Type B, the segments above and below the apex present a torsion behavior of opposite direction.

Of the 49 main thoracic curves of Lenke Type 1, 26 manifested a torsion pattern of Type A, 15 of Type B, and 8 of Type C. The average torsion value of a spine curve was calculated. To investigate if any differences existed within Lenke Type 1 regarding the average torsion, the maximum torsion, and the Cobb angle, an analysis of variance (ANOVA) was performed with the patients subdivided according to the torsion pattern. Moreover, two sets of correlation coefficients were calculated for each subgroup. The first set of correlations was between the average torsion and the Cobb angle. The second set of correlations was between the maximum torsion and the Cobb angle.

III. RESULTS

The mean values of the average torsion, the maximum torsion, and the Cobb angle for each subgroup are presented in Table I. A statistically significant difference was observed between Types A and B curves regarding the average torsion ($P = 0.03$) and the maximum torsion ($P = 0.03$), and between

Types A and C curves regarding the average torsion ($P = 0.03$) and the maximum torsion ($P = 0.02$). There was no statistically significant difference between Types B and C curves regarding both torsion parameters ($P > 0.05$). Regarding the Cobb angle, we failed to find statistically significant difference among three subgroups ($P > 0.05$).

The correlation strengths are compared in Table II. It is shown that the strengths of correlations between the Cobb angle and the torsion parameters (i.e., the average torsion and the maximum torsion) are stronger in Type A curves than in Types B and C curves.

TABLE I. PARAMETERS COMPARISON WITHIN LENKE TYPE 1 CURVES

Mean Value	Type A	Type B	Type C
Average torsion (mm^{-1})	0.027	0.039	0.040
Maximum torsion (mm^{-1})	0.045	0.063	0.066
Cobb angle (°)	30.68	31.16	30.95

TABLE II. CORRELATION COMPARISON WITHIN LENKE TYPE 1 CURVES

Correlation Coefficient	Type A	Type B	Type C
Average torsion vs Cobb angle	0.24	0.19	0.11
Maximum torsion vs Cobb angle	0.22	0.16	0.14

IV. DISCUSSION

The scoliotic spine has a deformity in three dimensions with components not only in the coronal plane but also in the sagittal and transverse planes. Yet, its assessment and classification are usually based on 2D radiographic measurement. The Lenke classification has the advantages over the King classification of considering the curve patterns in the sagittal plane. However, it still relies on the Cobb angle measured on 2D x-ray images that cannot fully characterize the 3D scoliotic deformity. Therefore, the Lenke classification does not consider all three dimensions of the deformity. As shown in the results section, for the Cobb angle, there was no statistically significant difference among the three subgroups, whereas for the two torsion parameters (i.e., the average torsion and the maximum torsion), there were statistically significant differences between subgroups subdivided according to the torsion pattern within the Lenke Type 1 curves. These results indicate that the Lenke classification used alone cannot fully distinguish between the 3D spinal deformities of various geometric torsion patterns. Therefore, addition of subcategories based on 3D features in the Lenke classification is necessary for adequate 3D evaluation of scoliotic deformities.

The geometric torsion as a feature of 3D curves has been recognized as a valid 3D measurement by the Scoliosis Research Society [1]. Poncet *et al.* [8] proposed a classification method based on the spinal geometric torsion. Any attempt at 3D classification of spinal deformities must be based on clinical relevance. Currently, the Cobb angle method is the gold standard to assess the severity of scoliosis [1]. In this study, the correlation coefficients were calculated and compared on both the Cobb angle relative to the average torsion and to the maximum torsion. Results showed that the Cobb angle was more correlated to the torsion parameters in the subgroup with torsion pattern of Type A than in those with Types B or C. This study suggests that a 3D classification of the scoliotic curve patterns can be clinically relevant by defining subpatterns of the Lenke classes.

There were some limitations of our study. First, we were limited in the small number of patients and a possible selection bias. There were only eight cases of Type C. A small variance might have been lost. This study only involved patients with Lenke Type 1 curves. Further investigation of the extent of variations with other types of scoliotic curves is necessary to fully evaluate the importance of geometric torsion in the context of the Lenke classification. Second, this method depended on the person scoring the input images. Some comparison between scorers should be performed. Furthermore, some comparison between the scoring using this method and some reference methods like CT or MRI that would reliably show the actual 3D curvature should be performed. Finding the best way to estimate Lenke classification should also be included in future research.

V. CONCLUSION

We compared the 3D geometric torsion features among the subgroups within Lenke Type 1 curves and observed statistically significant torsion variance. This study adds the evidence that 3D geometric torsion reveals structural differences that are not apparent in the Cobb measurement.

REFERENCES

[1] I. A. F. Stokes, "Three-dimensional terminology of spinal deformity. A report presented to the Scoliosis Research Society by the Scoliosis Research Society Working Group on 3-D terminology of spinal deformity," *Spine*, vol. 19, pp. 236–248, Jan. 1994.

[2] B. P. Yawn, R. A. Yawn, D. Hodge, M. Kurland, W. J. Shaughnessy, D. Ilstrup, and S. J. Jacobsen, "A population-based study of school scoliosis screening," *JAMA*, vol. 282, pp. 1427-1432, Oct. 1999.

[3] H. A. King, J. H. Moe, D. S. Bradford, and R. B. Winter, "The selection of fusion levels in thoracic idiopathic scoliosis," *J. Bone Joint Surg. Am.*, vol. 65, pp. 1302–1313, Dec. 1983.

[4] L. G. Lenke, R. R. Betz, J. Harms, K. H. Bridwell, D. H. Clements, T. G. Lowe, and K. Blanke, "Adolescent idiopathic scoliosis: a new classification to determine extent of spinal arthrodesis," *J. Bone Joint Surg Am.*, vol. 83, pp. 1169–1181, Aug. 2001.

[5] L. Carpineta and H. Labelle, "Evidence of three-dimensional variability in scoliotic curves," *Clin. Orthop. Relat. Res.*, vol. 412, pp. 139–148, Jul. 2003.

[6] A. P. Sangole, C. E. Aubin, H. Labelle, I. A. F. Stokes, L. G. Lenke, R. Jackson, and P. Newton, "Three-dimensional classification of thoracic scoliotic curves," *Spine*, vol. 34, pp. 91–99, Jan. 2009.

[7] S. Kadoury and H. Labelle, "Classification of three-dimensional thoracic deformities in adolescent idiopathic scoliosis from a multivariate analysis," *Eur. Spine J.*, vol. 21, pp. 40–49, Jan. 2012.

[8] P. Poncet, J. Dansereau, and H. Labelle, "Geometric torsion in idiopathic scoliosis: three-dimensional analysis and proposal for a new classification," *Spine*, vol. 26, pp. 2235–2243, Oct. 2001.

[9] L. Duong, F. Cheriet, and H. Labelle, "Three-dimensional classification of spinal deformities using fuzzy clustering," *Spine*, vol. 31, pp. 923–923, Apr. 2006.

[10] S. Kadoury, F. Cheriet, J. Dansereau, and H. Labelle, "Three-dimensional reconstruction of the scoliotic spine and pelvis from uncalibrated biplanar x-ray images," *J. Spinal Disord. Tech.*, vol. 20, pp. 160–167, Apr. 2007.

[11] D. W. Marquardt, “An algorithm for least-squares estimation of nonlinear parameters,” *J. Soc. Indust. Appl. Math*. vol. 11, pp. 431–441, Jun. 1963, July 1993.

[12] H. Lin, “Identification of spinal deformity classification with total curvature analysis and artificial neural network,” *IEEE Tran. Biomed. Eng.*, vol. 55, pp. 376–382, Jan. 2008.