The Spine Journal 19 (2019) 1518−1528

THE SPINE JOURNAL

Clinical Study

Modified PUMC classification for adolescent idiopathic scoliosis

Qianyu Zhuang, MD, Guixing Qiu, MD*, Qiyi Li, MD, Jianguo Zhang, MD, Jianxiong Shen, MD, Yipeng Wang, MD, Hong Zhao, MD, Yu Zhao, MD, Shugang Li, MD, Bin Yu, MD, Xiao Chang, MD, Shengru Wang, MD, Siyi Cai, MD, Xi Zhou, MD, Jinqian Liang, MD

Department of Orthopaedics, Peking Union Medical College Hospital, No.1 Shuaifuyuan, Wangfujing, Beijing 100730, China
Received 27 September 2018; revised 23 March 2019; accepted 25 March 2019

Abstract

BACKGROUND: The original Peking Union Medical College (PUMC) classification of adolescent idiopathic scoliosis (AIS) is one system to combine each type with corresponding surgical fusion guidance, presenting comparable interobserver reliability, and reproducibility with Lenke classification. However, during its application in previous over 10 years, we found 2 main problems of this classification, which required modification.

PURPOSE: (1) To evaluate the interobserver and intraobserver reliability, (2) to assess the effects of the added fusion criteria of proximal thoracic (PT) curve on improving postoperative shoulder balance of the modified PUMC classification of AIS.

STUDY DESIGN/SETTING: Retrospective analysis of our AIS cohort and prospective validation of its effectiveness.

PATIENT SAMPLE: Fifty sets of preoperative radiographs of AIS patients were randomly chosen from our AIS database. Furthermore, 46 consecutive AIS cases with PT curve were enrolled who underwent surgeries in our center from July 2007 to July 2013, with at least 2-year follow-up.

OUTCOME MEASURES: The classification results of 50 sets of preoperative radiographs by 5 surgeons. The shoulder balance was evaluated using radiographic shoulder height.

METHODS: Five surgeons independently evaluated and classified presurgical radiographs of 50 AIS patients based on the modified PUMC classification. Inter- and intraobserver reliabilities were calculated. Furthermore, the post-op shoulder balance was investigated in 46 consecutive cases of AIS with PT curve who were treated strictly based on the modified PUMC classification.

RESULTS: The Kappa coefficients of inter- and intraobserver reliability of the overall modified PUMC classification are 0.889 and 0.865, respectively. The Kappa coefficients of inter- and intraobserver reliability for the type II are 0.791 and 0.746, respectively. In addition, the shoulder balance rate of the 46 AIS patients with PT curve at the final follow-up was 95.7%.

CONCLUSIONS: Modified PUMC classification presents incremental improvement compared to our original published version, with high interobserver and intraobserver reliability and better performance of postoperative shoulder balance. Furthermore, the modified PUMC classification provides corresponding surgical fusion guidance for each subtype. Multicenter prospective studies with larger samples are still needed to further improve this system.

Keywords: Idiopathic scoliosis; Classification; Selective fusion; Modified; PUMC; Lenke

FDA device/drug status: Not applicable.

Author disclosures: ***QZ:*** Nothing to disclose. ***GQ:*** Nothing to disclose. ***QL:*** Nothing to disclose. ***JZ:*** Nothing to disclose. ***JS:*** Nothing to disclose. ***YW:*** Nothing to disclose. ***HZ:*** Nothing to disclose. ***YZ:*** Nothing to disclose. ***SL:*** Nothing to disclose. ***BY:*** Nothing to disclose. ***XC:*** Nothing to disclose. ***SW:*** Nothing to disclose. ***SC:*** Nothing to disclose. ***XZ:*** Nothing to disclose. ***JL:*** Nothing to disclose.

* Corresponding author. Department of Orthopaedics, Peking Union Medical College Hospital, Chinese Academy of Medical Sciences and Peking Union Medical College (CAMS & PUMC), 1 Shuaifuyuan, Wangfujing, Dongcheng district, Beijing 100730, China. Tel. 86-10-69152809; fax: 86-10-69152809.

E-mail address: qgxpumch@126.com (G. Qiu).

https://doi.org/10.1016/j.spinee.2019.03.008
1529-9430/

Introduction

Adolescent idiopathic scoliosis (AIS) is a complicated three-dimensional spinal deformity [1]. One of the most challenging problems is how to select fusion levels. Therefore, a rational and practical classification of AIS plays a significant role in the determination of surgical approach and fusion range [2,3].

The senior author of this study developed the PUMC (Peking Union Medical College) classification [4] in 2005 based on 427 cases of surgically treated idiopathic scoliosis in our center. The characteristic of this system is that with each classification type, the appropriate fusion strategy is provided while maintaining as many mobile segments as possible. A subsequent study [5] in 2008 compared the reliability of PUMC classification and Lenke classification systems, revealing that the PUMC classification's inter- and intraobserver percentage of agreement averaged 91.0% (Kappa coefficient 0.896) and 90.2% (Kappa coefficient 0.892), respectively.

However, during its application over 10 years, we found 2 main problems with this classification. First, some surgeons complained that subtype IIC was confusing and difficult to remember, which bring difficulties to its accurate application and surgical strategy-making. Second, the fusion criteria of proximal thoracic (PT) curve, which is significant for preoperative planning and postoperative shoulder balance, were not included in the original PUMC classification.

Therefore, in order to address these two major problems, we modified the original PUMC classification based on the retrospective analysis of our AIS cohort and then conducted a prospective validation of its effectiveness. The aims of this study were (1) to evaluate the interobserver and intraobserver reliability; (2) to assess the effects of the PT criteria added in the modified PUMC classification on improving postoperative shoulder balance.

Materials and methods

Introduction of the modified PUMC classification

We used the Scoliosis Research Society definition of a curvature (ie, the spine deviates from the midline with a Cobb angle more than 10°, and the furthest horizontal vertebra or disc from the midline on the standing anteroposterior view is defined as the apex). Thus, curves were counted and classified into single, double, and triple curves according to the apex number. Considering that the interobserver's variability ranges from 4.9° to 11.8° [6,7], we define a larger curve and a minor curve as a 10° difference, and 2 equivalent curves if the difference is less than 10° to avoid a dispute.

For each case, the following data were measured and recorded:

1) The Cobb angle of each curve.
2) Flexibility of the curvature: Flexibility (%)=(Cobb angle on standing−Cobb angle on convex bending)/Cobb angle on standing×100%.
3) Rotation of the apical vertebra: rotation of vertebral body was recorded from 0 to 4 using the Nash−Moe method [8].

Modified PUMC classification continues to classify scoliosis into three major types based on the numbers of curve apexes. The 3 major types are further divided into 15 subtypes (Table 1). The details of the modified classification are explained as follows:

Type I

Single curve with 1 apex.

IA: Thoracic curve, apex between T2 and T11−T12 disc.

IB: Thoracolumbar curve, apex at T12, T12−L1 disc, and L1.

IC: Lumbar curve, apex between L1−L2 and L4−L5 intervertebral disc.

Surgical strategy: single curve fusion.

Type II

Double curves with 2 apexes.

1) IIA

Double thoracic curve (major thoracic curve+PT curve), which is divided into IIA1 and IIA2.

IIA1 must meet all these three criteria, otherwise IIA2.

1. PT on AP film<30°.
2. PT on convex bending film<20°.
3. Right shoulder elevated.

Surgical strategy: IIA1: MT curve selective fusion; IIA2: both curves fusion.

2) IIB

Thoracic (T) curve>thoracolumbar/lumbar(TL/L) curve.

IIB1 must meet all the following four criteria, otherwise IIB2.

1. Thoracolumbar/lumbar kyphosis<10°.
2. Thoracolumbar/lumbar coronal Cobb angle≤45°.
3. Thoracolumbar/lumbar apical vertebra rotation<2 (Nash−Moe method).
4. Thoracolumbar/lumbar flexibility≥70%.

Surgical strategy: IIB1: thoracic curve selective fusion. IIB2: both curves fusion.

3) IIC

Thoracic curve<thoracolumbar/lumbar curve.

1. IIC1: Thoracic curve on convex bending film≤25°
2. IIC2: Thoracic curve on convex bending film>25°

Table 1
Modified PUMC classification

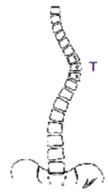
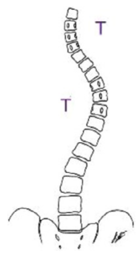
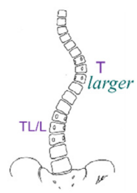
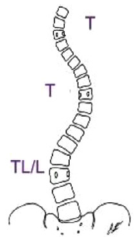
Major type	Apex numbers	Subtype	Characteristics	Schematic drawing	Selection fusion strategy
I Single curve	1	IA	Thoracic curve, apex between T2 and T11−T12 disc		Single curve
		IB	Thoracolumbar curve, apex at T12, T12−L1 disc, and L1		
		IC	Lumbar curve, apex between L1−L2 and L4−L5 disc		
II Double curves	2	IIA	Double thoracic curves IIA1: Not meet all of the three criteria: 1) Left shoulder elevated or as high as right shoulder 2) Cobb angle of PT curve <30° 3) Cobb angle of PT curve on convex bending radiograph <20° IIA2: Meet one of the aforementioned criteria		IIA1: Major thoracic curve IIA2: Double curves
		IIB	Thoracic curve plus thoracolumbar/lumbar curve, the former is at least 10° higher than the latter. IIB1: Fulfill all four criteria: 1) Without lumbar/thoracolumbar kyphosis (<10°) 2) Cobb angle of lumbar/thoracolumbar <45° 3) Apical rotation of lumbar/thoracolumbar curve <II° 4) Flexibility of lumbar/thoracolumbar curve >70% IIB2: Not meet any of the aforementioned criteria		IIB1: Thoracic curve IIB2: Double curves
		IIC	Thoracic curve plus lumbar/thoracolumbar curve, the former is at least 10° smaller than the latter. IIC1: Cobb angle of the thoracic curve on convex bending radiograph <25° IIC2: Cobb angle of the thoracic curve on convex bending radiograph >25°		IIC1: Lumbar/thoracolumbar curve IIC2: Double curves
		IID	Thoracic curve plus lumbar/thoracolumbar curve, the curve magnitude difference <10°. IID1: Flexibility of thoracic curve <lumbar/thoracolumbar curve IID2: Flexibility of thoracic curve >lumbar/thoracolumbar curve		IID1: Refers to IIB IID2: Refers to IIC

Table 1 (***Continued***)

Major type	Apex numbers	Subtype	Characteristics	Schematic drawing	Selection fusion strategy
III Triple curves	3	IIIA	Lumbar curve meets IIB1 criteria IIIA1: PT curve and shoulder balance meet IIA1 criteria IIIA2: PT curve and shoulder balance meet IIA2 criteria		Lumbar/thoracolumbar curve not be fused PT curve refers to IIA
		IIIB	Lumbar curve meets IIB1 criteria IIIB1: PT curve and shoulder balance meet IIA1 criteria IIIB2: PT curve and shoulder balance meet IIA2 criteria		Lumbar/thoracolumbar curve be fused PT curve refers to IIA

Surgical strategy: IIC1: thoracolumbar/lumbar curve selective fusion. IIC2: both curves fusion.

4) IID

Thoracic curve≈thoracolumbar/lumbar curve (Cobb angle difference less than 10°).

1. IID1: Thoracic curve's flexibility<thoracolumbar/lumbar curve's flexibility, which can be viewed as thoracic curve>thoracolumbar/lumbar curve
2. IID2: Thoracic curve's flexibility>thoracolumbar/lumbar curve's flexibility, which can be viewed as thoracic curve<thoracolumbar/lumbar curve

Surgical strategy: IID1: refer to IIB; IID2: refer to IIC.

Type III

Triple curves with 3 apexes.

1) IIIA: Lumbar curve meet IIB1 criteria;
   1. IIIA1: PT curve and shoulder balance meet IIA1 criteria
   2. IIIA2: PT curve and shoulder balance meet IIA2 criteria
2) IIIB: Lumbar curve meets IIB2 criteria.
   1. IIIB1: PT curve and shoulder balance meet IIA1 criteria
   2. IIIB2: PT curve and shoulder balance meet IIA2 criteria

Surgical strategy: IIIA: MT need fusion, while L curve need not fusion, PT fusion criteria refer to IIA. IIIB: MT and L curve need fusion, PT fusion criteria refer to IIA.

Investigation of the interobserver and intraobserver reliability of the modified PUMC classification

The senior author randomly chose 50 sets of good-quality preoperative radiographs from the AIS database in our center who underwent surgery from July 2007 to July 2013. The standing posterior−anterior, sagittal, and supine side-bending radiographs of these patients were randomly numbered with the patients' information blinded. Each digital radiograph was then printed for 10 copies on A4 paper. Three practicing spine attending surgeons, two spine residents were chosen to classify the radiographs independently according to the modified PUMC classification, who had obtained system training of PUMC classification and had been used the classification for at least 1 year.

All the radiographs were not premeasured, and all five surgeons were given sufficient time to measure the angles and classify the radiographs. Surgeons worked individually in different places and were not allowed to discuss about the radiographs throughout the classification process. The data were then collected to evaluate the interobserver reliability. Three weeks later, all the radiographs were randomly numbered and printed again. Each observer repeated the classification to evaluate the intraobserver reliability.

The data from the classification were then tested for reliability and the Kappa coefficient was calculated. According to Svanholm et al [9], when Kappa coefficients are greater than 0.75, the results can be considered as good-to-excellent, Kappa coefficients between 0.50 and 0.75 are fair, and values less than 0.50 are not reliable. Kappa statistics and data comparison were computed by using STATA 12.0 (StataCorp LP, Texas).

The influence of the PT fusion criteria in the modified PUMC classification on the postoperative shoulder balance

Forty-six consecutive cases of AIS with PT curve were enrolled who underwent surgeries in our center from July 2007 to July 2013, with at least 2-year follow-up. For all these cases, the surgical plan was designed strictly based on the modified PUMC classification, and then fulfilled accordingly during the surgery. The shoulder balance at the last follow-up was evaluated using radiographic shoulder height. Radiographic shoulder height is defined as the linear distance measured in millimeters between the superior horizontal reference line, which passes through the intersection of the soft tissue shadow of the shoulder and a line drawn vertically up from the acromial clavicular joint of the cephalad shoulder, and the inferior horizontal reference line constructed in a similar fashion over the caudal acromial clavicular joint. The linear distance is positive if the left shoulder is up and negative if the right shoulder is up.

"Shoulder balance" was defined as the discrepancy of the post-op shoulder levels≤10 mm, "mild imbalance" as being between 10 mm and 20 mm, "moderate imbalance" as being between 20 mm and 30 mm, and "severe imbalance" as being more than 30 mm [10].

Results

Interobserver and intraobserver reliability of the modified PUMC classification

The Kappa coefficients of inter- and intraobserver reliability of the modified PUMC classification are 0.889 and 0.865, respectively. All 5 surgeons made the consistent classification for 14 type I cases and 6 type III cases. In addition, the Kappa coefficients of inter- and intraobserver reliability for the 30 type II cases are 0.791 and 0.746, respectively (Tables 2 and 3). The Kappa coefficient of the subtype IIA2 is highest (0.9417) in type II cases, while that of the IIA1 (0.2399) and IIC2 (0.1497) are relatively lowest. A total of 14 cases out of the 50 (28%) had disagreement in the classification (cases 1, 5, 6, 8, 9, 15, 24, 35, 37, 38, 43, 44, 49, 50; Table 4).

Postoperative shoulder balance using the PT fusion criteria

The follow-up results (≥2 years) of the 46 cases show that there are a total of 44 cases being "balance", 1 "mild imbalance", and 1 "moderate imbalance." The total balance rate is as high as 95.7% (Table 5). There are only two cases of shoulder imbalance. One case (Fig. 1) showed level shoulders prior to the surgery, but presented "mild imbalance" with the left shoulder being 15 mm higher immediately post the surgery, and 18 mm higher at the 2.6-year follow-up. Another case (Fig. 2) presented the left shoulder elevation (22 mm higher).

Table 2
The analysis of the interobserver reliability of type II of modified PUMC classification

Subtype	Kappa coefficient	Z Value	*P* Value
ⅡA1	0.2399	4.15	.0000
ⅡA2	0.9417	16.31	.0000
ⅡB1	0.7052	12.21	.0000
ⅡB2	1.0000	17.32	.0000
ⅡC1	0.8137	14.09	.0000
ⅡC2	0.1497	2.59	.0048
ⅡD1	0.7089	12.28	.0000
ⅡD2	0.9019	15.62	.0000
Total	0.7906	27.25	.0000

Table 3
The analysis of the intraobserver reproducibility of type II of modified PUMC classification

Observer	Percentage of the same Repeated classification	Kappa coefficient	Z Value	*P* Value
A	86.67%	0.8307	9.19	.0000
B	73.33%	0.6726	8.19	.0000
C	76.67%	0.7042	7.87	.0000
D	76.67%	0.6961	7.40	.0000
E	86.67%	0.8283	9.06	.0000
Mean	80.00%	0.7464		

In these 46 patients, a total of 39 patients required PT fusion according to our classification system and therefore underwent PT fusion. The PT characteristics and pre-op shoulder balance status of the 39 patients are described in Table 6, the possible treatment strategy using Lenke and Suk criteria are also presented as comparison with PUMC system. All 39 patients need PT fusion according to Suk criteria, and 26 patients need PT fusion according to Lenke criteria.

Discussion

Although most researchers agree that PT curve plays an important role in shoulder balance and cosmetic appearance, conflicts still exist regarding the PT fusion criteria. In the Lenke classification, PT should be fused if PT on the convex bending film≥25° or the sagittal cobb angle of T2−T5≥20° [11,12]. Suk et al suggested that the PT should be fused if its coronal Cobb angle>25°, or the left shoulder is higher than or equal to the right shoulder [13]. Bridwell et al stated that the PT should be fused if its coronal Cobb angle>40°, and its Cobb angle on the convex bending film>25° [14].

Based on our retrospective study results and clinical observation, we propose the PT fusion criteria in the modified PUMC classification: (1) the left shoulder is elevated or as high as the right shoulder; (2) PT curve on AP film≥30°; (3) PT curve on the convex bending film≥20° (Table 1). Based on the fusion criteria of the PT, IIA is divided into IIA1 and IIA2. PT can be spared in IIA1, while must be fused in IIA2.

In the present study, we prospectively investigated the effectiveness of our PT fusion criteria. Our results show relatively excellent shoulder balance (44/46 cases) at the 2-year follow-up. There are only two cases of shoulder imbalance. One case (Fig. 1) showed level shoulders prior to the surgery, but presented "mild imbalance" with the left shoulder being 15 mm higher immediately post the surgery, and 18 mm higher at the 2.6-year follow-up. The possible reason might be due to relatively insufficient numbers of

Table 4
Modified PUMC classification results

Pt ID	A1	A2	B1	B2	C1	C2	D1	D2	E1	E2
1	ⅡD1	ⅡD1	ⅡC2	ⅡD1	ⅡD1	ⅡD1	ⅡC2	ⅡC2	ⅡD1	ⅡD1
2	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1
3	ⅢA1	ⅢA1	ⅢA1	ⅢA1	ⅢA1	ⅢA1	ⅢA1	ⅢA1	ⅢA1	ⅢA1
4	ⅡB2	ⅡB2	ⅡB2	ⅡB2	ⅡB2	ⅡB2	ⅡB2	ⅡB2	ⅡB2	ⅡB2
5	ⅡC1	ⅡC1	ⅡC1	ⅡD1	ⅡD1	ⅡC1	ⅡD1	ⅡC1	ⅡC1	ⅡC1
6	ⅡD2	ⅡD2	ⅡD2	ⅡD2	ⅡD2	ⅡD2	ⅡD2	ⅡC2	ⅡD2	ⅡC1
7	ⅠC	ⅠC	ⅠC	ⅠC	ⅠC	ⅠC	ⅠC	ⅠC	ⅠC	ⅠC
8	ⅡD1	ⅡB1	ⅡD1	ⅡB1	ⅡB1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1
9	ⅡD1	ⅡD2	ⅡD2	ⅡD2	ⅡC1	ⅡD1	ⅡD1	ⅡC1	ⅡD1	ⅡD1
10	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA
11	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1
12	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2
13	ⅢA1	ⅢA1	ⅢA1	ⅢA1	ⅢA1	ⅢA1	ⅢA1	ⅢA1	ⅢA1	ⅢA1
14	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB
15	ⅡD1	ⅡB2	ⅡD1	ⅡB2	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1
16	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA
17	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2
18	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1
19	ⅠC	ⅠC	ⅠC	ⅠC	ⅠC	ⅠC	ⅠC	ⅠC	ⅠC	ⅠC
20	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB
21	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2
22	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA
23	ⅡB1	ⅡB1	ⅡB1	ⅡB1	ⅡB1	ⅡB1	ⅡB1	ⅡB1	ⅡB1	ⅡB1
24	ⅡD1	ⅡB1	ⅡD1	ⅡB1	ⅡB1	ⅡD1	ⅡB1	ⅡD1	ⅡB1	ⅡB1
25	ⅢB2	ⅢB2	ⅢB2	ⅢB2	ⅢB2	ⅢB2	ⅢB2	ⅢB2	ⅢB2	ⅢB2
26	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1
27	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB
28	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2
29	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1
30	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB
31	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1
32	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1	ⅡC1
33	ⅢB2	ⅢB2	ⅢB2	ⅢB2	ⅢB2	ⅢB2	ⅢB2	ⅢB2	ⅢB2	ⅢB2
34	ⅠC	ⅠC	ⅠC	ⅠC	ⅠC	ⅠC	ⅠC	ⅠC	ⅠC	ⅠC
35	ⅡC1	ⅡC1	ⅡC1	ⅡD1	ⅡC1	ⅡC1	ⅡC1	ⅡD1	ⅡC1	ⅡC1
36	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB
37	ⅡC1	ⅡC1	ⅡC2	ⅡC2	ⅡC1	ⅡC2	ⅡC1	ⅡC1	ⅡC1	ⅡC2
38	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡC1	ⅡD1	ⅡD1
39	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA
40	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2
41	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA2
42	ⅢB1	ⅢB1	ⅢB1	ⅢB1	ⅢB1	ⅢB1	ⅢB1	ⅢB1	ⅢB1	ⅢB1
43	ⅡD1	ⅡD1	ⅡD1	ⅡC1	ⅡC1	ⅡD2	ⅡD1	ⅡC1	ⅡC1	ⅡD1
44	ⅡD2	ⅡD2	ⅡD2	ⅡD2	ⅡD2	ⅡC2	ⅡD2	ⅡD2	ⅡD2	ⅡD2
45	ⅢA2	ⅢA2	ⅢA2	ⅢA2	ⅢA2	ⅢA2	ⅢA2	ⅢA2	ⅢA2	ⅢA2
46	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB	ⅠB
47	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1	ⅡD1
48	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA	ⅠA
49	ⅡA2	ⅡA2	ⅡA1	ⅡA1	ⅡA2	ⅡA2	ⅡA2	ⅡA2	ⅡA1	ⅡA1
50	ⅡB1	ⅡB1	ⅡB1	ⅡD1	ⅡB1	ⅡB1	ⅡD1	ⅡD1	ⅡB1	ⅡD1

Each observer (A, B, C, D, and E) recorded results from two separate occasions (1=first evaluation, 2=second evaluation).

screws on the PT area, with only T2 and T6 as the anchor points on the concave side. On the other hand, the relative "over-correction" of the MT curve resulted in the small residual MT and large residual PT curves, which together led to the elevated left shoulder. Another case (Fig. 2) presented the left shoulder elevation (22 mm higher), which may be due to the inappropriate selection of upper instrumental vertebra. We speculate that the shoulder balance might be improved if we choose T1 as the upper instrumental vertebra instead of T2.

Based on the modified PUMC classification, our strategy to achieve shoulder balance in AIS cases are as follows:

1) Identification of PT: we use the Scoliosis Research Society definition of a curvature to identify the presence of PT. If in the PT area, the spine deviates from the

Table 5
Postoperative shoulder balance using PT fusion criteria in modified PUMC classification

Subtype	Total no.	Pre-op left shoulder higher	Pre-op right shoulder higher	Pre-op level shoulders	Post-op balance	Post-op mild imbalance	Post-op moderate imbalance	Post-op severe imbalance	Post-op balance rate (%)
IIA1	3	0	3	0	3	0	0	0	100
IIA2	19	8	3	8	17	1	1	0	89.5
IIIA1	3	0	3	0	3	0	0	0	100
IIIA2	14	3	3	8	14	0	0	0	100
IIIB1	1	0	1	0	1	0	0	0	100
IIIB2	6	2	3	1	6	0	0	0	100
Total	46	13	16	17	44	1	1	0	95.7

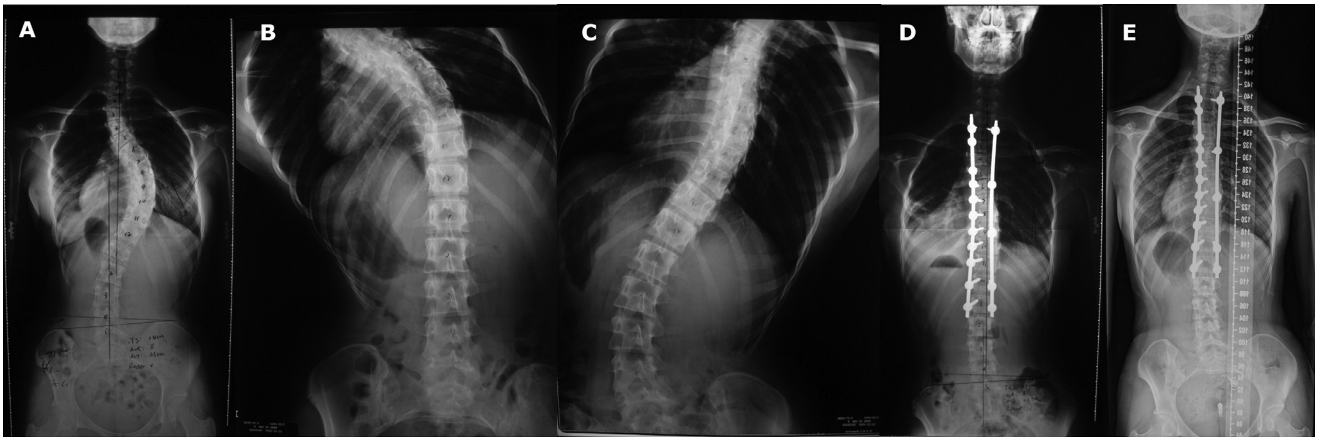


Fig. 1. A 16-year-old AIS girl (PUMC IIA2) with level shoulders prior to the surgery (A), but presented “mild imbalance” with the left shoulder being 15 mm higher immediately post the surgery (D), and 18 mm higher at the 2.6-year follow-up (E). Left and right bending film were also presented as (B) and (C). The possible reason for the shoulder imbalance after surgery might be due to relatively small numbers of screws on PT area with only T2 and T6 as the anchor points on the concave side. Therefore, the distraction force is not enough to correct the PT, which being from preoperatively 35° to 21°. On the other hand, the MT gained relatively “over-correction,” which being from preoperatively 58° to 7°. As a result, the “small left MT” and the “large right PT” together led to the elevated left shoulder.

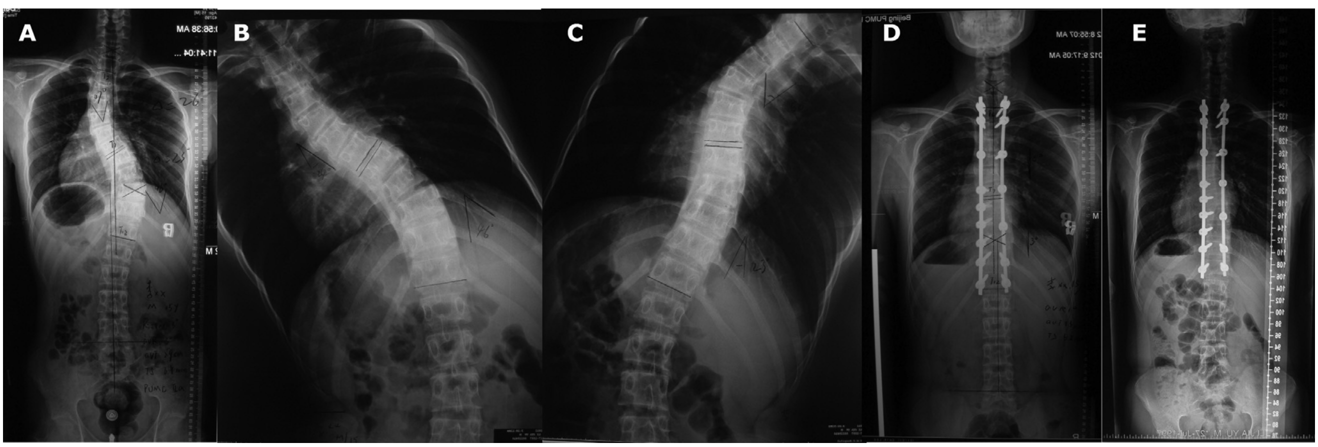


Fig. 2. A 14-year-old AIS boy (PUMC IIA2) with double thoracic curves showed the elevated left shoulder (20 mm higher) prior to surgery (A). Left and right bending film were also presented as (B) and(C). Although the shoulder balance was achieved immediately post the surgery (D), the 2.4-year follow-up results revealed that the left shoulder was 22 mm higher than the right one (E). The possible reason may be that T2 vertebra, which was most proximal to the fusion area, developed tilt with left elevated at the final follow-up, with the angle between T2 upper endplate and the horizontal line being 10° (being 0° post-op immediately), which led to the elevated left shoulder. Therefore, we speculate that shoulder balance might be improved if we extend the proximal fusion level from T2 to T1.

Table 6
Characteristics of 39 patients in our cohort who required PT fusion according to modified PUMC classification

Case no.	PT on AP Film (°)	PT on bending film (°)	T2−T5 sagittal Cobb angle (°)	Right shoulder elevated	PT fusion based on Suk's criteria*	PT fusion based on Lenke classification†	PT fusion based on PUMC classification	PUMC classification	Fusion levels	RSH immediately post-op	RSH at the final follow-up	Shoulder imbalance grade
1	32	21	3	Yes	Yes	No	Yes	IIIA2	T2−12	0	0	Balance
2	32	2	15	No	Yes	No	Yes	IIA2	T2−L2	10	0	Balance
3	42	32	15	No	Yes	Yes	Yes	IIA2	T2−L3	4	4	Balance
4	38	25	20	No	Yes	Yes	Yes	IIA2	T2−L2	16	−4	Balance
5	32	6	15	No	Yes	No	Yes	IIA2	T2−L1	4	8	Balance
6	45	25	20	No	Yes	Yes	Yes	IIIA2	T2−L1	8	4	Balance
7	45	40	16	Yes	Yes	Yes	Yes	IIA2	T2−L1	10	4	Balance
8	48	36	10	Yes	Yes	Yes	Yes	IIIB2	T2−L2	4	10	Balance
9	44	33	2	No	Yes	Yes	Yes	IIIA2	T2−L1	18	3	Balance
10	38	21	10	No	Yes	No	Yes	IIA2	T2−L3	22	0	Balance
11	38	28	14	No	Yes	Yes	Yes	IIIA2	T2−L1	12	8	Balance
12	40	25	15	No	Yes	Yes	Yes	IIIA2	T2−T12	10	−4	Balance
13	50	38	10	No	Yes	Yes	Yes	IIIB2	T2−L4	4	10	Balance
14	33	21	12	No	Yes	No	Yes	IIA2	T2−L3	8	5	Balance
15	37	24	24	No	Yes	Yes	Yes	IIA2	T2−L2	0	7	Balance
16	52	35	10	Yes	Yes	Yes	Yes	IIA2	T2−L2	0	0	Balance
17	36	20	10	No	Yes	No	Yes	IIA2	T2−L2	28	0	Balance
18	30	28	15	Yes	Yes	Yes	Yes	IIIA2	T2−12	8	10	Balance
19	36	30	16	No	Yes	Yes	Yes	IIIA2	T2−12	25	0	Balance
20	30	25	10	No	Yes	Yes	Yes	IIIA2	T2−L2	10	8	Balance
21	35	25	10	Yes	Yes	Yes	Yes	IIIB2	T2−12	0	0	Balance
22	58	53	22	No	Yes	Yes	Yes	IIA2	T2−12	−10	−8	Balance
23	38	14	13	No	Yes	No	Yes	IIIB2	T3−12	−2	3	Balance
24	32	22	22	No	Yes	Yes	Yes	IIA2	T2−11	4	5	Balance
25	38	12	14	No	Yes	No	Yes	IIIA2	T2−T12	−2	0	Balance
26	40	22	18	No	Yes	No	Yes	IIA2	T1−L1	5	0	Balance
27	40	32	30	No	Yes	Yes	Yes	IIIA2	T2−T11	−4	−4	Balance
28	40	30	13	No	Yes	Yes	Yes	IIIA2	T2−T12	5	5	Balance
29	47	24	16	No	Yes	No	Yes	IIA2	T2−T12	0	22	Moderate imbalance
30	30	20	6	Yes	Yes	No	Yes	IIA2	T2−T12	10	10	Balance
31	35	25	36	No	Yes	Yes	Yes	IIA2	T2−L1	15	18	Mild imbalance
32	30	25	16	No	Yes	Yes	Yes	IIA2	T2−L1	20	0	Balance
33	31	25	11	No	Yes	Yes	Yes	IIIA2	T2−T11	4	5	Balance
34	32	26	8	No	Yes	Yes	Yes	IIIA2	T2−T12	6	9	Balance
35	36	15	6	No	Yes	No	Yes	IIIB2	T2−L3	36	10	Balance
36	70	58	26	No	Yes	Yes	Yes	IIA2	T1−T9	4	8	Balance
37	45	35	20	Yes	Yes	Yes	Yes	IIIA2	T2−T12	0	0	Balance
38	40	25	7	Yes	Yes	Yes	Yes	IIIB2	T2−L4	0	9	Balance
39	30	5	5	Yes	Yes	No	Yes	IIA2	T2−L2	25	4	Balance

* Suk's criteria for PT fusion include coronal Cobb angle of PT>25°, or the left shoulder is higher than or equal to the right shoulder.
† Lenke's criteria for PT fusion include PT on the convex bending film≥25°, or the sagittal Cobb angle of T2−T5≥20°.

midline with a Cobb angle more than 10°, the presence of PT will be determined.

2) Determination of PT fusion: we use the PT fusion criteria in the modified PUMC classification for the decision-making: ① the left shoulder is elevated or as high as the right shoulder; ② PT curve on AP film≥30°; ③ PT curve on the convex bending film≥20°.If any one of these three criteria are met, the PT curve should be fused.
3) Intraoperative correction: our aim is to achieve the balance of corrected PT and MT during surgery. First, we try our best to correct the PT curve using the compression maneuver on the convex side and distraction maneuver on the concave side, since usually PT curve is more inflexible than MT curve. Second, we will pay much attention to avoid over-correction of MT curve. Third, we use intraoperative fluoroscopy to evaluate the balance of two corrected curves and shoulder balance. Last, we will make the final adjustment of the shoulder balance based on the intraoperative fluoroscopic results. For example, if the left shoulder is still a little bit higher than the right one, we will further perform “level by level” compression of the PT on the left side and the distraction on the right side.

The original type II includes eight subtypes. Type IIA contains no subtypes, IIB and IID 2 subtypes, respectively. IIC is defined as the thoracic curve being nearly equal to lumbar/thoracolumbar curve, which is further divided into three subtypes (IIC1, IIC2, and IIC3) according to the flexibility of curves.

In clinical application, some users complain that the original type II is hard to understand and remember, and often leads to confusion. Our analysis concludes two possible reasons: First, in the original version, the surgical strategy of IIC can refer to that of IIB and IID after the comparison of the flexibility of the two curves. However, the IIC was designed in the middle of IIB and IID, which is difficult for the users to understand. Second, the original IIC was divided into three subtypes based on not only the flexibility of both curves but also the MT curve performance on the bending film, therefore being too complicated to use.

Based on above analysis, we made modification for type II. The modified type II includes eight subtypes with IIA, IIB, IIC, and IID, each of which includes two subtypes, respectively. IIA is defined as double thoracic curves. IIB is defined as double curves with thoracic curve being larger than TL/L curve. The thoracic curve should be fused as the larger one, and whether the TL/L curve should be fused lies on four fusion criteria, which consider not only the Cobb angle on the coronal plane, but the presence of thoracolumbar kyphosis and the apical vertebra rotation of TL/L curve. IIC is defined as double curves with thoracic curve being smaller than TL/L curve. The TL/L curve should be fused as the larger one, and whether the thoracic curve should be fused according to its fusion criteria. IID is defined as double curves with thoracic curve and TL/L curve being nearly equal. Based on the flexibility of the two curves, IID can be further divided into IID1 and IID2, and the selective fusion criteria refer to IIB and IIC, respectively. In summary, the modified PUMC classification simplifies type II by deletion of confusing original subtype IIC and addition of subtype IID which can be treated referring to the criteria of IIB and IIC.

Our previous study [5] reported that the Kappa coefficients of inter- and intraobserver reliability were 0.675 and 0.690, respectively, for overall Lenke classification, which was similar to 0.50 and 0.60 as reported by Richards et al [15]. The present study shows that the Kappa coefficients of both inter- and intraobserver reliability of modified PUMC classification are more than 0.75, which are rated as good-to-excellent. The Kappa coefficients of type I and type III were as high as 1, which means completely consistent. Even for type II which is relatively complicated, the Kappa coefficients of inter- and intraobserver reliability reaches 0.791 (good-to-excellent) and 0.746 (fair), respectively. The possible reason for such high interobserver and intraobserver reliability may be due to the deletion of the original subtype IIC1, IIC2, and IIC3 which is confusing for observers in the modified classification.

It should be noted that the Kappa coefficients of IIA1 and IIC2 in our results are very low. As for the low consistency rate of IIA1, the possible explanations may be that it is technically more difficult for the observers to reach the consensus as IIA1, rather than IIA2. For example, for a case with both MT and PT, it can be classified as IIA1 only if all the three criteria are met at the same time, while can be classified as IIA2 if just one of the three criteria is met. That means the five observers are required to reach the agreement on all the 3 three criteria to classify a double thoracic curve case as IIA1, which is relatively technically difficult.

To explain the low Kappa coefficient of IIC2, we reviewed all the raw data (Table 4) and found that IIC2 needs be differentiated from IIC1, IID1, and IID2, while IIC1 just needs to be differentiated from IIC2. For example, for a case with a significantly smaller T curve and a larger L curve, it is relatively easy for the participants to reach the consensus as IIC1. However, for a case with a T curve and a L curve with similar Cobb angles, it is relatively confusing for the participants to decide whether it should be classified as IIC2 or IID (including IID1 and IID2), especially considering the measure error.

In summary, Kappa coefficients of both inter- and intraobserver reliability of modified PUMC classification are satisfying, but relatively low reliability of subtype IIA1 and IIC2 should be noted.

Previous studies had reported criteria/variables for determining selective thoracic fusion, including apical vertebral translation (AVT) and apical vertebral rotation (AVR) ratios (Thoracic:T/L>1.2) and coronal cobb ratio (Thoracic:T/L>1.2), of which AVT ratio has been found to be most important. And for selective lumbar fusion, ratios of AVT, AVR, and coronal Cobb (T/L:Thoracic>1.25) were considered as the most important variables. These principles emphasized the value of the ratio of AVT, AVR, and coronal Cobb. In our classification, we also considered Cobb angle and rotation status of curves on A−P film as the important parameters. Considering that the Cobb angle is also in proportion to AVT, we feel that our classification also covers these three important factors (AVT, AVR, and coronal Cobb) for the decision-making. In addition, we added the flexibility on the bending film and the kyphosis status on the sagittal plane into our system, with the hope that we can make our decision on the consideration of three-dimensional characteristics. Further prospective studies are needed to compare our criteria and previous "1.2 ratio principle" and the "1.25 ratio principle" in the future.

Determination of LIV for selective fusion is also very important. As for the LIV for selective thoracic fusion, we usually use the last substantially touched vertebra as the LIV in our center. We will consider the stable vertebra as the LIV only when (1) the patient is significantly skeletal immature (eg, Risser sign is less than 1 and the patient is before menarche) or (2) the Cobb angle of the thoracic curve and the lumbar curve is nearly equal (the difference between them is less than 10°). As for the LIV for selective lumbar fusion, our LIV selection criteria for Lenke V curves (selective lumbar fusion cases of possibly PUMC IB, IC, or IIC1 or IID2) were as follows: (1) the most cephalad vertebrae touched by central sacrum vertical line; (2) Nash−Moe rotation being equal or less than grade I on the standing AP radiograph; (3) two-thirds of the vertebral body being within the Harrington stable zone on the concave bending film; (4) not at the apex of kyphosis. We will further discuss about these above criteria in detail in our next papers.

For years, the King−Moe classification was the earliest described and widely used system for guiding treatment in AIS [16]. However, it was found to have shortcomings as follows: first, it classifies curves based only on the coronal plane, while not considering the sagittal and axial plane [17]. Second, its low inter- and intraobserver reliability has been reported by many authors [18,19]. Third, it describes only variants of the thoracic curve, leaving some other curve types such as thoracolumbar or lumbar curves unable to be classified [20]. Last, the selective fusion criterion is absent for type II, thereby often causing postoperative lumbar curve decompensation [21].

The Lenke classification [12] addresses these shortcomings and is now considered most widely used for classifying AIS and guiding treatment. However, several problems still exist: first, it includes 3 components and 42 theoretical types, thus being relatively complicated for its users to remember and use. Second, the definition of structural curve does not adjust accordingly for PT curve, MT curve, and TL/L curve, which present different flexibility and mobile characteristics [22,23]. Third, Lenke classification failed to consider the axial plane (a reflection of vertebral body rotation), which has been reported have important influence on the successful rate of selective fusion [24−26]. Last, many studies demonstrated that the definition of ">25°on the bending film" is not enough to help surgeons to determine whether or not to perform selective fusion for Lenke 1B and 1C cases [27,28]. Furthermore, different centers still have conflicts in terms of the application of Lenke classification in Lenke 1B and 1C cases [28−30].

Modified PUMC classification presented in this study is different from King−Moe and Lenke classifications. First, it classifies major types based on the numbers of apexes rather than the location of the curves, 1 apex for type I, 2 apexes for type II, and 3 apexes for type III. It was then further divided into 15 subtypes, being much less complicated than Lenke classification. Second, both our previous study [5] and the present one show that the inter- and intraobserver reliability of the modified PUMC classification is better than that of Lenke classification. Third, modified PUMC classification presents clear criteria for the selective fusion of PT, MT, TL/L, and corresponding surgical fusion guidance for each subtype. Fourth, modified PUMC classification considers not only the coronal and sagittal plane parameters but also the axial plane parameters such as the apical vertebra rotation. Last, as our previous study demonstrated [5], the errors of Cobb angle measurement (<10°), although may lead to discrepancy of IIB and IIC or IID, do not influence surgical fusion range selection.

However, the modified PUMC classification also have several possible limitations: first, in our system, when dealing with triple curves, we always regard the middle MT curve as the primary curve with the PT and L curve being the secondary curve. So we assumed that the MT should be fused in triple curves and discuss the selective fusion criteria for the other two curves in our classification. However, if there is a case with triple curves including a relatively smaller and flexible MT, a larger and rigid L curve and a large but flexible PT, and the left shoulder is higher, all 3 curve fusion will be suggested according to our classification, although only the T−L/L curve would be considered as the structural curve in the Lenke classification and the elevated left shoulder would likely correct with the correction of the T−L/L curve without having to address the PT and main thoracic curves. Although we reviewed our AIS database and have not found the case like this, we feel that it is one possible limitation in our classification. If we are facing this scenario, we will take it as the exception condition which is not included in our classification, and adopt the strategy with only the T−L/L curve being fused. Second, although the Kappa coefficients of both inter- and intraobserver reliability of modified PUMC classification are satisfying, the relatively low reliability of subtype IIA1 and IIC2 should be noted and required further research. In addition, there might be some internal bias since all the observers were experienced in using this system were tested. Third, although we add one criterion for determining selective thoracic fusion using the Nash−Moe criteria, it does not necessarily make our classification system truly have three-dimensional characteristics. Further studies on the real 3D classifications of AIS are still needed in the future. Last, the gray zone due to measured error and "rule breakers" also exist in our classification.

Conclusion

In summary, the modified PUMC classification is an incremental improvement compared to our original published version, with high interobserver and intraobserver reliability and better performance of postoperative shoulder balance. Furthermore, the modified PUMC classification presents corresponding surgical fusion guidance for each subtype. Compared with the original version, the modified one is more simple and more practical. However, there is still limitation for this modified version, and certainly we still need conduct more multicenter prospective studies with larger samples to further improve our classification.

References

[1] de Kleuver M, Lewis SJ, Germscheid NM, Kamper SJ, Alanay A, Berven SH, et al. Optimal surgical care for adolescent idiopathic scoliosis: an international consensus. Eur Spine J 2014;23:2603–18.

[2] Kadoury S, Labelle H. Classification of three-dimensional thoracic deformities in adolescent idiopathic scoliosis from a multivariate analysis. Eur Spine J 2012;21:40–9.

[3] Erken HY, Burc H, Saka G, Aydogan M. Disagreements in surgical planning still exist between spinal surgeons in adolescent idiopathic scoliosis: a multisurgeon assessment. Eur Spine J 2014;23:1258–62.

[4] Qiu G, Zhang J, Wang Y, Xu H, Zhang J, Weng X, et al. A new operative classification of idiopathic scoliosis: a peking union medical college method. Spine 2005;30:1419–26.

[5] Qiu G, Li Q, Wang Y, Yu B, Qian J, Yu K, et al. Comparison of reliability between the PUMC and Lenke classification systems for classifying adolescent idiopathic scoliosis. Spine 2008;33:E836–42.

[6] Loder RT, Urquhart A, Steen H, Graziano G, Hensinger RN, Schlesinger A, et al. Variability in cobb angle measurements in children with congenital scoliosis. J Bone Joint Surg 1995;77:768–70.

[7] Morrissy RT, Goldsmith GS, Hall EC, Kehl D, Cowie GH. Measurement of the Cobb angle on radiographs of patients who have scoliosis. Evaluation of intrinsic error. J Bone Joint Surg 1990;72:320–7.

[8] Nash Jr. CL, Moe JH. A study of vertebral rotation. J Bone Joint Surg 1969;51:223–9.

[9] Svanholm H, Starklint H, Gundersen HJ, Fabricius J, Barlebo H, Olsen S. Reproducibility of histomorphologic diagnoses with special reference to the kappa statistic. APMIS 1989;97:689–98.

[10] Kuklo TR, Lenke LG, Graham EJ, Won DS, Sweet FA, Blanke KM, 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.

[11] Lenke LG, Edwards 2nd CC, Bridwell KH. The Lenke classification of adolescent idiopathic scoliosis: how it organizes curve patterns as a template to perform selective fusions of the spine. Spine 2003;28: S199–207.

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

[13] Suk SI, Kim WJ, Lee CS, Lee SM, Kim JH, Chung ER, 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.

[14] Bridwell KH. Selection of instrumentation and fusion levels for scoliosis: where to start and where to stop. Invited submission from the joint section meeting on disorders of the spine and peripheral nerves, March 2004. J Neurosurg Spine 2004;1:1–8.

[15] Richards BS, Sucato DJ, Konigsberg DE, Ouellet JA. 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 1156-1147.

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

[17] Hoashi JS, Cahill PJ, Bennett JT, Samdani AF. Adolescent scoliosis classification and treatment. Neurosurg Clin N Am 2013;24:173–83.

[18] Behensky H, Giesinger K, Ogon M, Krismer M, Hannes B, Karlmeinrad G, et al. Multisurgeon assessment of coronal pattern classification systems for adolescent idiopathic scoliosis: reliability and error analysis. Spine 2002;27:762–7.

[19] Cummings RJ, Loveless EA, Campbell J, Samelson S, Mazur JM. Interobserver reliability and intraobserver reproducibility of the system of King et al. For the classification of adolescent idiopathic scoliosis. J Bone Joint Surg 1998;80:1107–11.

[20] Ovadia D. Classification of adolescent idiopathic scoliosis (AIS). J Child Orthop 2013;7:25–8.

[21] Roye Jr. DP, Farcy JP, Rickert JB, Godfried D. Results of spinal instrumentation of adolescent idiopathic scoliosis by king type. Spine 1992;17:S270–3.

[22] Chang KW, Chen YY, Wu CM, Leng X, Chen TC. Could structural and noncompensatory Lenke 3 and 4c lumbar curves be nonstructural and compensatory? Lenke 1, 2, 3, and 4 curve types were similar and could be considered collectively as a single indication for selective thoracic fusion. Spine 2014;39:1850–9.

[23] Zhang Y, Lin G, Wang S, Zhang J, Shen J, Wang Y, et al. Higher flexibility and better immediate spontaneous correction may not gain better results for non-structural thoracic curve in Lenke 5c AIS patients-risk factors for its correction loss. Spine 2016;41:1731–9.

[24] Na KH, Harms J, Ha KY, Choi NY. Axial plane lumbar responses after anterior selective thoracic fusion for main thoracic adolescent idiopathic scoliosis. Asian Spine J 2008;2:81–9.

[25] Ritzman TF, Upasani VV, Bastrom TP, Betz RR, Lonner BS, Newton PO. Comparison of compensatory curve spontaneous derotation after selective thoracic or lumbar fusions in adolescent idiopathic scoliosis. Spine 2008;33:2643–7.

[26] Atmaca H, Inanmaz ME, Bal E, Caliskan I, Kose KC. Axial plane analysis of Lenke 1a adolescent idiopathic scoliosis as an aid to identify curve characteristics. Spine J 2014;14:2425–33.

[27] Newton PO, Faro FD, Lenke LG, Betz RR, Clements DH, Lowe TG, et al. Factors involved in the decision to perform a selective versus nonselective fusion of Lenke 1b and 1c (King-Moe ii) curves in adolescent idiopathic scoliosis. Spine 2003;28:S217–23.

[28] Crawford 3rd CH, Lenke LG, Sucato DJ, Richards 3rd BS, Emans JB, Vitale MG, et al. Selective thoracic fusion in Lenke 1c curves: prevalence and criteria. Spine 2013;38:1380–5.

[29] Betz RR. Should all AIS 1c curves be fused selectively? Spine 2016;41(Suppl 7):S16–7.

[30] Boniello AJ, Hasan S, Yang S, Jalai CM, Worley N, Passias PG. Selective versus nonselective thoracic fusion in Lenke 1c curves: a meta-analysis of baseline characteristics and postoperative outcomes. J Neurosurg Spine 2015;23:721–30.