Int J Clin Exp Med 2018;11(8):8495-8501
www.ijcem.com /ISSN:1940-5901/IJCEM0068413

Original Article

Correlation analysis of spontaneous lumbar curve correction with cross-sectional rotational deformity after fusion surgery for Lenke 1 adolescent idiopathic scoliosis (AIS)

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Received November 2, 2017; Accepted April 4, 2018; Epub August 15, 2018; Published August 30, 2018

Abstract: We aimed to investigate the relationship between rotational deformity and spontaneous correction of lumbar curve in cases of Lenke 1 adolescent idiopathic scoliosis (AIS), when position relation between the lowest instrumented vertebra and stable vertebra remains relatively unchanged. A total of 53 patients with Lenke 1 AIS, with right thoracic curve, were diagnosed in our hospital from March 2010 to March 2014. These were retrospectively reviewed. Before surgery, antero-posterior (AP) lateral and side-bending (SB) radiographs of full-length spines in the standing position were collected. More than 2 years of follow up was conducted for all patients. Coronal balance parameters presenting as center sacral vertical line (CSVL), thoracic and lumbar apical vertebral translation (AVT), Cobb angles of thoracic and lumbar curves, sagittal plane parameters, and other indexes of patients were recorded. Perdriolle method was used to measure total rotations of all vertebrae of thoracic and lumbar curves in full-length spine radiographs, in the standing position, and SB radiographs. Thoracic and lumbar curve corrections and other indexes relating to balance, at 2 years after surgery, were calculated. Lenke 1 AIS was divided into two types: Lenke 1-L type and Lenke 1-R type. Furthermore, Lenke 1-L and Lenke 1-R AIS were divided into subgroup A and subgroup B, respectively. Pearson's correlation analysis was performed for spontaneous lumbar curve correction and other parameters, at 2 years after surgery, in each group. In this research, it was found that among patients with Lenke 1-L AIS, lumbar curve correction (%) in subgroup B was significantly higher than in subgroup A. Among patients with Lenke 1-R AIS, lumbar vertebra derotation percentage in SB radiographs of subgroup B was obviously increased compared with that of subgroup A. In Lenke 1-L A and B subgroups, spontaneous lumbar curve correction at 2 years after surgery was negatively correlated with preoperative lumbar vertebra rotation (LVR) and positively related to the main thoracic curve correction. Among patients with Lenke 1-R AIS, it was only found in subgroup A that total LVR was associated with spontaneous correction. Additionally, spontaneous lumbar curve correction had a significant correlation with thoracic curve correction in subgroups A and B. Among patients with Lenke 1-L AIS, spontaneous lumbar curve correction was negatively correlated with rotational deformity degree of lumbar curve. However, as fused segments got close to and exceeded SV, negative correlation gradually weakened. Among patients with Lenke 1-R AIS, there was no definite correlation of rotational deformity of lumbar curve with spontaneous correction but spontaneous lumbar curve correction was more easily affected by thoracic curve correction.

Keywords: Adolescent idiopathic scoliosis, lumbar curve, thoracic curve, rotational deformity

Introduction

Adolescent idiopathic scoliosis (AIS) is the most common type of scoliosis among patients, accounting for 80%. Moreover, most deformities are located in the thoracic spine of patients. Although idiopathic scoliosis seldom causes obvious symptoms in adolescents, chest and back pain and other symptoms occur in adulthood because of decompensation of the three-dimensional structural balance of the spine, especially sagittal decompensation. This can seriously affect patient quality of life [1].

In 1983, King et al. [2] laid a foundation for scoliosis typing, first determining through typing when selective fusion was performed for patients with main thoracic curve. In 2001, Lenke

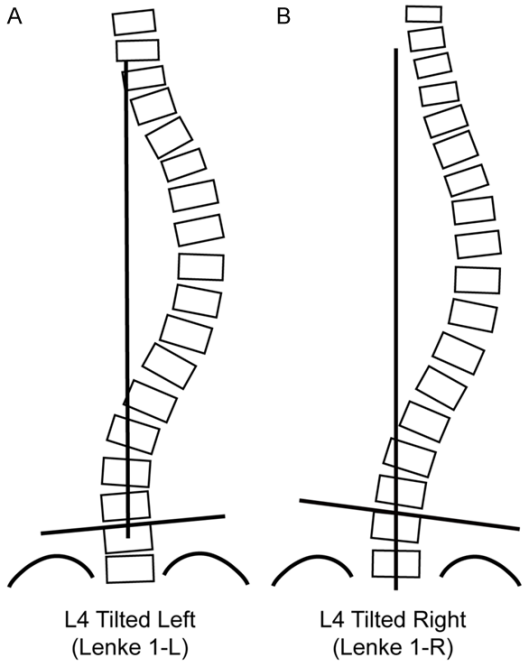

Figure 1. Lenke 1 scoliosis is divided into L type and R type according to inclination of the L4 vertebra. A. L4 tilted left (Lenke 1-L); B. L4 tilted right (Lenke 1-R).

et al. [3] proposed a new typing system. This system included sagittal plane parameters allowing surgeons to formulate fusion strategies, before surgery, that are more consistent with individual requirements and decreasing errors caused by incorrect identification of scoliosis type in the process of selective fusion. Lenke reviewed postoperative correction effects in patients receiving selective fusion and then proposed that selective fusion was safe when the ratio of the thoracic apical vertebral rotation to lumbar apical vertebral rotation was higher than 1.0 [4]. Other researchers have also put forward the concept of neutral vertebra, holding that spinal stability after fusion was correlated with degree of rotation and distortion of the fused lower intervertebral disc [5]. However, among AIS patients receiving selective fusion, the impact of rotational deformity and derotation effect of lumbar vertebra on spontaneous lumbar curve correction still remains unclear, when lumbar curve Cobb angles and lumbar apical vertebral translation (LAVT) are the same.

In order to discuss influence of selective fusion on the spine within the same typing system, Lenke 1 AIS patients were divided into Lenke 1-L type and Lenke l-R type, according to methods put forward by Miyanji et al. [6]. The relationship between degree of axial rotational deformity of the lumbar curve and its spontaneous correction was studied in the two types, as the relationship between the lowest instrumented vertebra (LIV) and stable vertebra (SV) was fixed.

Patients and methods

General information

In this retrospective analysis, 53 patients with Lenke 1 adolescent idiopathic scoliosis, with right thoracic curve, were diagnosed in our hospital from March 2010 to March 2014. This study was approved by the Ethics Committee of Hai'an Hospital Affiliated to Nantong University. Signed written informed consent was obtained from all participants. Before surgery, conventional antero-posterior (AP) lateral and side-bending (SB) radiographs of full-length spines, in standing position, were collected. All patients with abnormalities of the nervous system (such as diastematomyelia and Chaffs deformity) in spinal magnetic resonance imaging (MRI) were excluded. All patients underwent posterior-only pedicle screw fixation, of which, 8 patients had the operated segment ended at T11, 25 patients at T12, and 20 patients at L1. The duration of follow up was more than 2 years (27-132 months, with an average of 39.5 months) and average age of patients at the time of the surgery was 15.2 years old. Coronal balance parameters, presenting as distance from C7 vertebra to center sacral vertical line (CSVL), thoracic and lumbar apical vertebral translation (AVT), thoracic Cobb angle, lumbar Cobb angle, sagittal plane parameters, and other indexes of the patients, were recorded. Thoracic and lumbar curve corrections and other indexes relating to balance were measured at 3 months and 2 years after surgery, respectively.

Grouping

According to methods described by Miyanji et al. [6], among Lenke 1 AIS patients, if the L4 vertebra tilted to the left, the curve would be defined as left lateral bending and was presented as Lenke l-L. If the L4 vertebra tilted to the right, the curve would be defined as Lenke l-R (**Figure 1**). When L4 vertebra was in the neutral position without tilt, tilt direction was assessed

Table 1. Imaging results of Lenke 1-L group

Parameters	Group L-A (n=11)		Group L-B (n=22)		P
	Mean	SD	Mean	SD	
Preop thoracic	48	8	53	6	NS
Post 2 year thoracic	16	10	19	10	NS
Thoracic curve correction (%)	65	13	61	10	NS
Preop lumbar	25	8	30	7	NS
Lumbar curve correction (%)	23	12	34	13	0.003
Total LVR AP	11	23	16	28	NS
Total LVR SB	9	21	14	26	NS
Total LVR derotation (%)	20	6	15	12	NS
Preop CSVL	-0.7	0.8	-0.6	0.7	NS
Post CSVL	-1.1	1.5	-0.5	0.8	NS
Preop lumbar AVT	1.3	0.5	1.7	1.2	NS
Post lumbar AVT	0.6	0.3	0.7	0.3	NS
Preop sagittal T5-12	20	8	22	16	NS
Post sagittal T5-12	19	5	17	9	NS
Preop sagittal L1-5	38	9	40	10	NS
Post sagittal L1-5	39	7	35	7	NS

Abbreviation: LVR: Lumbar vertebral rotation. AP: anteroposterior. SB: Sagittal balance. CSVL: Center sacral vertical line. AVT: Apical vertebrate tilt.

based on the the proximal vertebra. Patients with Lenke 1A-R AIS were identical to those with King/Moe IV AIS. There were 33 patients with Lenke 1A-LAIS and 20 with Lenke 1A-RAIS. In the two groups, patients were further divided into subgroup A and subgroup B, respectively, in accordance with the relationship between LIV and SV. In subgroup A of Lenke 1-L, LIV=SV-l; in subgroup B: LIV=SV/SV+1. In subgroup A of Lenke 1-R, LIV=SV-2; in subgroup B: LIV=SV/SV-1.

Rotation measurement

Among all patients with Lenke l-L and Lenke l-R AIS, the Perdriolle method was used, before surgery, to measure total rotations of all vertebrae of thoracic and lumbar curves in full-length spine radiographs, in the standing position, and SB radiographs. Postoperative radiographs, in the standing position [7], were used as well. Meanwhile, total axial lumbar vertebrae derotation in side-bending radiographs were measured and presented as 100 - [100 × SB]/AP.

Statistical analysis

Parameters in subgroup A and subgroup B of patients with Lenke l-L and Lenke l-R AIS were recorded and analyzed, respectively. Independent-samples t-test was used for comparison between subgroup A and subgroup B. Pearson's correlation analysis was performed for spontaneous lumbar curve correction and other parameters, at 2 years after surgery. All data were analyzed using Statistical Product and Service Solutions (SPSS) 22.0. P<0.05 suggested a statistically significant difference.

Results

Lenke 1-L group

Among patients with Lenke l-LAIS, 11 (33.33%) had LIV=SV-1 (L-A group) and 22 (66.67%) had LIV=SV/SV+1 (L-B group). It was shown that lumbar curve correction (%) in subgroup B was significantly higher than in subgroup A and the difference was statistically significant (P=0.003). However, there were no statistically significant differences in preoperative Cobb angles and correction of thoracic and lumbar curves, total lumbar vertebra rotations (LVRs), CSVLs before and after surgery, AVTs, and sagittal balance parameters between the two groups (**Table 1**).

Lenke 1-R group

Among patients with Lenke l-R AIS, 13 (65%) had LIV=SV-2 (R-A group) and 7 (35%) had LIV=SV/SV-1 (R-B group). It was indicated that lumbar vertebra derotation percentage in SB radiograph of subgroup B was obviously increased compared with subgroup A and the difference was statistically significant (P=0.028). However, there were no statistically significant differences in preoperative Cobb angles and correction of thoracic and lumbar curves, total LVRs, CSVLs before and after the surgery, AVTs, and sagittal balance parameters between the two groups (**Table 2**).

Correlation analysis

In order to determine the relationship between rotational deformity of lumbar curve and spontaneous lumbar curve correction, correlation analyses were performed on the ratio of lumbar

Table 2. Imaging results of Lenke 1-R group

Parameters	Group R-A (n=13)		Group R-B (n=7)		P
	Mean	SD	Mean	SD	
Preop thoracic	48	6	50	9	NS
Post 2 year thoracic	18	7	20	6	NS
Thoracic curve correction (%)	60	10	56	7	NS
Preop lumbar	22	9	28	7	NS
Lumbar curve correction (%)	38	11	50	6	NS
Total LVR AP	21	17	13	30	NS
Total LVR SB	21	15	9	27	NS
Total LVR derotation (%)	17	8	33	7	0.028
Preop CSVL	-1.2	0.5	-0.8	0.7	NS
Post CSVL	-0.7	1.3	-0.4	1.3	NS
Preop sagittal T5-12	18	6	21	10	NS
Post sagittal T5-12	16	7	19	7	NS
Preop sagittal L1-5	38	10	39	13	NS
Post sagittal L1-5	39	10	40	12	NS

Abbreviation: LVR: Lumbar vertebral rotation. AP: anteroposterior. SB: Sagittal balance. CSVL: Center sacral vertical line. AVT: Apical vertebrate tilt.

Table 3. Relationship between spontaneous correction rate of lumbar curvature and imaging parameters in Lenke 1-L group after 2-year follow up

Parameters	Group L-A	Group L-B
Preop thoracic	NS	NS
Post thoracic	NS	NS
Thoracic curve correction (%)	r=0.381 (P=0.002)	r=0.603 (P<0.001)
Preop lumbar	NS	NS
Total LVR AP	r=-0.571 (P<0.001)	r=-0.318 (P=0.012)
Total LVR SB	r=-0.409 (P<0.001)	NS
Total LVR derotation (%)	NS	NS
Preop CSVL	NS	NS
Post CSVL	NS	NS
Preop lumbar AVT	NS	NS
Post lumbar AVT	NS	NS
Preop sagittal T5-12	NS	NS
Post sagittal T5-12	NS	NS
Preop sagittal L1-5	NS	NS
Post sagittal L1-5	NS	NS

Abbreviation: LVR: Lumbar vertebral rotation. AP: Anteroposterior. SB: sagittal balance. CSVL: Center sacral vertical line. AVT: Apical vertebrate tilt.

curve correction, in the follow-up 2 years after surgery, to preoperative Cobb angle, total LVR AP, total LVR SB, total LVR derotation in SB radiographs, and other indexes.

Among patients with Lenke I-L AIS, after grouping in accordance with relationship between fused segments and SV, it was discovered that 3 patients had trunk decompensation. Two years after surgery, in subgroup A (of which the fused segments were located above SV), while total LVR (including total LVR AP + total LVR SB) had significant correlation with spontaneous lumbar curve correction (r=-0.571, P<0.001; r=-0.409, P<0.001). Although total LVR AP was significantly correlated with spontaneous lumbar curve correction in subgroup B (of which the fused segments were located at or below the SV), the correction degree was decreased compared with that in subgroup A (r=-0.318, P=0.012). This indicates that such correlativity was weakened gradually as fused segments moved downward along the SV. In subgroup B of Lenke I-L AIS, correlation of spontaneous lumbar curve correction with thoracic curve correction (%) was more remarkable than that in subgroup A (r=0.603, P<0.001 VS. r=0.381, P=0.002) (**Table 3**).

Among patients with Lenke I-R AIS, the relationship between total LVR (including total LVR AP + total LVR SB) and spontaneous lumbar curve correction was discovered only in subgroup A, where the fusion was located 2 segments above the SV (r=0.433, P<0.001; r=0.298, P=0.021). In subgroup B of Lenke I-R AIS, correlation of spontaneous lumbar curve correction with thoracic curve correction (%) was more remarkable than in subgroup A (r=0.609, P<0.001 VS. r=0.469, P<0.001) (**Table 4**).

Discussion

Idiopathic scoliosis is a complex three-dimensional deformity where spinal deformity occurs

Table 4. Relationship between compensatory lumbar Cobb Angle correction and imaging parameters in Lenke 1-R group

Parameters	Group R-A	Group R-B
Preop thoracic	NS	NS
Post thoracic	r=0.412 (P<0.001)	NS
Thoracic curve correction (%)	r=0.469 (P<0.001)	r=0.609 (P<0.001)
Preop lumbar	NS	NS
Total LVR AP	r=-0.433 (P<0.001)	NS
Total LVR SB	r=-0.298 (P=0.021)	NS
Total LVR derotation (%)	NS	NS
Preop CSVL	NS	NS
Post CSVL	NS	NS
Preop sagittal T5-12	NS	NS
Post sagittal T5-12	NS	NS
Preop sagittal L1-5	NS	NS
Post sagittal L1-5	NS	NS

Abbreviation: LVR: Lumbar vertebral rotation. AP: anteroposterior. SB: sagittal balance. CSVL: Center sacral vertical line.

in a three-dimensional plane. With constant aggravation of the deformity, wedge-shaped changes are generated in the vertebrae. Many scholars believe that along with development of primary segments of the lateral curve, lateral curve also occurs in compensatory segments of the spine, developing along with the advance of the thoracic curve. It is believed that such lateral curves may be an approach that the spine attempts in order to restore balance. Therefore, if selective fusion is conducted for the thoracic spine when correcting scoliosis, spontaneous correction will occur in the lumbar spine [8, 9].

In the history of surgical treatment of the spine, fused segments during surgery were first determined to be in accordance with correction in preoperative antero-posterior and lateral radiographs. Although it was emphasized at that time that fusion strategies were formulated according to differences in every vertebra [10], postoperative trunk decompensation still cannot be avoided. In 1983, King and Moe introduced a kind of typing system specific to AIS, based on imaging. For the first time, this system helped spine surgeons formulate fusion strategies [2]. They proposed that it was not necessary to fuse to the lower vertebra of the compensatory lumbar curve in scoliosis surgery. As for King II scoliosis, it is suitable to merely fuse to the SV of the thoracic curve. The King typing system and its fusion strategies were a milestone for scoliosis correction. Utilizing fusion strategies based on King typing, a good coronal balance has been obtained among scoliosis patients receiving correction through the Harrington spinal instrumentation system. However, since the 1980s, the spinal instrumentation system has been ungraded. Spinal correction capability has been enhanced constantly as coronal and sagittal decompensation gradually occurs in patients guided by the King typing system. People have become aware that applying King typing to guide fusion with hybrid instrumentation of screws and hooks may lead to coronal decompensation of the spine [11-13]. For this reason, Lenke et al. [3] reviewed cases of the disease and concluded a new kind of AIS typing system. In the Lenke typing system, physicians can determine different Lenke types mainly according to morphology and main curve location in coronal and sagittal planes of the scoliosis, as well as lumbar apical vertebra and thoracic kyphosis correction typing. Patients with Lenke I AIS are the most common. They are utilized to study and analyze selective fusion strategies. Lenke defined Lenke 1A scoliosis as the combination of main thoracic curve with compensatory lumbar curve, of which the pedicle of the apical vertebra does not exceed the opposite side of the CSVL. This includes King III type (type C thoracic curve, of which the compensatory lumbar curve does not exceed the CSVL) and King IV type (long thoracic curve complicated with the L4 vertebral inclination, entering into the scoliosis), in original King typing system. The Lenke typing system not only considers coronal deformity but also includes the measurement of sagittal plane parameters. Lenke typing system has a better intra-observer and inter-observer reliability than the King typing system, but there are still a lot of factors that cannot explain the postoperative imbalance in patients for selection of fused segments [14, 15]. As a result, many scholars still currently use the King typing system to investigate selective fusion on idiopathic scoliosis [16]. In order to integrate the two typing systems into one and make the prep-

aration of selective fusion strategies more precise, Lenke 1 scoliosis was divided into L type and R type, in accordance with methods described by Miyanji et al. [6]. L type consisted of King II and III type scoliosis and R type included a part of King IV and V type scoliosis.

Rotational deformity of the spine is also an important factor influencing balance during selective fusion. Lenke et al. [17] put forward that selective fusion is safe if the ratio of lumbar apical vertebral rotation to thoracic capital vertebral rotation is lower than 1.0. Meanwhile, some scholars [18] found in Lenke 3C selective fusion that, compared with other indexes, correction of lumbar apical vertebral rotation in SB radiographs can better predict occurrence of postoperative decompensation.

In this research, we found, among patients with Lenke 1-L AIS, that spontaneous lumbar curve correction was negatively correlated with rotational deformity degree of lumbar curve, indicating that axial rotational deformity of the spine affects restoration of coronal balance. Moreover, the more severed axial rotational deformity was, the more difficult spontaneous correction would be. However, as fused segments exceeded the SV, such a negative correlation was gradually weakened. As early as the days of Harrington, it was found that a vast majority of spinal derotation correction occurs outside fused segments [19]. Although current pedicle screw techniques can have a powerful control on the spine in a three-dimensional plane, the effect of correction with convertible rods on spinal derotation remains fairly limited. Therefore, Suk et al. [20] proposed that rotating neutral vertebrae is a vital factor in selection of distally fused segments to decrease impact of the rotational deformity of the spine on balance restoration. However, when the direct vertebral derotation technique is used to correct thoracic curve, it can be directly ended at the rotated neutral vertebrae [21]. In this research, we found that thoracic vertebrae play a role in direct derotation and axial rotation of the lumbar curve at the same time, thus lowering the degree of rotational deformity of the lumbar curve and then alleviating impact of rotational deformity on spontaneous correction. However, among patients with Lenke 1A-R AIS, relationship between rotational deformity of lumbar curve and spontaneous correction was not detected but spontaneous lumbar curve correction was more affected by thoracic curve correction. Therefore, this group of AIS patients may need different fusion strategies.

Conclusion

Dividing Lenke 1 scoliosis into L type and R type can replace the King typing system more precisely in formulating functions of fused segments in the thoracic curve. In Lenke 1-L AIS, the lower vertebra shall be selected at or below SV when there is a serious rotational deformity. However, in Lenke 1-R AIS, rotational deformity of the lumbar curve has no significant correlation with spontaneous correction and spontaneous lumbar curve correction is more affected by thoracic curve correction. As a result, more attention should be paid to thoracic curve correction and overall balance during fusion.

Disclosure of conflict of interest

None.

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