Analysis of factors that affect shoulder balance after correction surgery in scoliosis: a global analysis of all the curvature types

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Abstract

Purpose To identify factors that can affect postoperative shoulder balance in AIS.

Method 89 adolescent idiopathic scoliosis patients with six types of curvatures who underwent surgery were included in this study. Whole spine antero-posterior and lateral radiographs were obtained pre- and postoperatively. In radiograms, shape and changes in curvatures were analyzed. In addition, four shoulder parameters and coronal balance were analyzed in an effort to identify factors significantly related to postoperative shoulder balance.

Result In general, all the four shoulder parameters (CHD, CA, CRID, RSH) were slightly increased at final follow up (t test, $P < 0.05$), although there was a decrease in Lenke type II and IV curvatures. However, pre- and postoperative shoulder parameters were not significantly different between each curvature types (ANOVA, $P > 0.05$). Moreover, no significant differences of pre- and postoperative shoulder level between different level of proximal fusion groups (ANOVA, $P > 0.05$) existed. In the analysis

of coronal curvature changes, no difference was observed in every individual coronal curvatures between improved shoulder balance and aggravated groups ($P > 0.05$). However, the middle to distal curve change ratio was significantly lower in patients with aggravated shoulder balance ($P < 0.05$). In addition, patients with smaller preoperative shoulder imbalance showed the higher chance of aggravation after surgery with similar postoperative changes ($P < 0.05$).

Conclusions Significant relations were found between correction rate of middle, and distal curvature, and postoperative shoulder balance. In addition, preoperative shoulder level difference can be a determinant of postoperative shoulder balance.

Keywords Adolescent idiopathic scoliosis · Shoulder balance · Correction surgery

Introduction

In surgical treatment of scoliosis, surgeons have focused on the amount of coronal curvature correction, which can determine the surgical outcome. However, many factors contribute to adolescent idiopathic scoliosis (AIS) patient's satisfaction after surgery, such as, surgical scars, improved back shape, reduced coronal curvature, and reduced back pain. In addition, cosmesis of the back and shoulders with a coronally balance spine are critically important for AIS patients, and the achievement of shoulder balance is one of the most important measures of successful scoliosis surgery [1–9]. Traditionally, the left shoulder is often elevated in AIS patients with a double thoracic curve. Hence, the achievement of shoulder balance in such AIS patients is an important component of surgical decision making and of

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evaluations of clinical outcome [5, 10, 11]. In addition, fusion of double structural curvatures in such types with Lenke's criteria, appears to minimize postoperative shoulder imbalance [12–15]. However, several types of scoliosis without significant proximal thoracic curvature, and we have experienced postoperative shoulder imbalance for other curvature types exist. Moreover, shoulder imbalance can remain in the double thoracic type after instrumentation for either structural curvature. In addition, different levels of postoperative shoulder balance in patients with identical curve classifications and the same fusion level suggest that fusion level and curvature type are not the only factors that determine shoulder balance. It appears that other factors, which affect postoperative shoulder level after corrective surgery exist. Accordingly, the aim of this study was to identify factors that affect final postoperative shoulder level in all types of curvatures.

Materials and methods

Patient and radiological assessment

A total of 89 AIS patients who had been operated between 2005 and 2010 were included in the present study. The study group comprised 23 males and 66 females with an average age of 15.5 years (range 10.7–18.0 years). Exclusion criteria were revision surgery or scoliosis with other disease, such as, congenital, and cerebral palsy. In addition, we excluded the patients with less than 2 years of follow up. There were 19, 26, 11, 14, 7, and 12 Lenke type 1, 2, 3, 4, 5, and 6 patients, respectively. Whole spine standing antero-posterior (AP) and lateral radiographs were taken pre- and postoperatively (at final follow up; mean 27.5 months). The whole spine AP radiographs were taken at a standard tube-film distance of 180 cm, with the central ray targeting at the T6–T7 area. The subjects held onto a vertical pole with their hands at elbow level to keep the upper extremities from projecting over the spine. The typical radiographic exposure factors were 25 mAs and 100 kVp. To identify factors related to postoperative shoulder balance, several parameters were measured in radiograms, pre- and postoperatively.

Surgical procedure

A senior surgeon (SWS) performed the surgery, with only posterior pedicle screw fixation. To correct the curve, derotation maneuver was performed after fixation of the screws. Pre-contoured long rods were applied on pedicle screws, and forceful derotation was performed. In addition, if any residual curvature existed, in situ bending of

the rod was performed to obtain maximal corrections. Moreover, posterior fusion was performed with auto- and allogenic cancellous bone after decortication of the lamina. Overall, all the structural curvatures were instrumented with a pedicle screw according to Lenke's criteria in different types of curvatures [12, 13]. Particularly, in cases of structural proximal thoracic curvature (more than 25° of side bending Cobb angle), the fusion from T1 or T2 including proximal end of the curvature in the fusion segment was performed. In addition, in cases of prominent shoulder imbalance (<10 mm) with non-structural proximal thoracic curvature, the fusion from T2 or T3 was performed to correct the shoulder imbalance. In addition, in other types of scoliosis without significant proximal thoracic curvature, the fusion from below the T4 was performed to minimize the fusion segment.

Coronal curvature measures

All the curvatures were analyzed pre- and postoperatively. After selecting the main structural curvature, consecutive curvatures were identified by each portion, and included compensatory or non-structural curvatures (proximal, middle, distal). For all the curvatures, pre- and postoperative Cobb angles, postoperative changes of each curve and curve change ratios vs initial values were calculated.

Shoulder and truncal balance measures

The four parameters, which were previously studied, and coronal balance were analyzed.

Coracoid height difference (CHD, mm): Height difference between the horizontal lines passing through the upper margin of each coracoid process (Fig. 1a) [6, 16].

Clavicular angle (CA, °): angle between the line connecting the highest points of the clavicle in the horizontal plane (Fig. 1b) [6, 17].

Clavicle–rib intersection difference (CRID, mm): height difference between the horizontal lines passing thorough the point where the superior border of the clavicle intersects with the outer edge of the second rib on each side (Fig. 1c) [6, 16].

Radiographic shoulder height (RSH, mm): The difference in soft tissue shadow directly superior to the acromioclavicular joint on standing anteroposterior radiographs (Fig. 1d) [6, 17].

Coronal balance (CB, mm): The horizontal distance between the center of the S1 vertebra and vertical line drawn from the center of C7.

Pre- and postoperative values were calculated for the above-mentioned five parameters. In addition, we

Fig. 1 **a** Coracoid height difference (CHD, mm): Height difference between the *horizontal lines* passing through the upper margin of each coracoid process. **b** Clavicular angle (CA, °): Angle between the line connecting the highest points of the clavicle in the horizontal plane. **c** Clavicle–rib intersection difference (CRID, mm): Height difference

between the *horizontal lines* passing through the point where the superior border of the clavicle intersects with the outer edge of the second rib on each side **d** Radiographic shoulder height (RSH, mm): The difference in soft tissue shadow directly superior to the acromioclavicular joint

calculated postoperative changes in these parameters, and ratios of postoperative changes vs initial levels. The negative values represent the right shoulder elevation, whereas positive values represent the left elevation. Absolute values were used to examine any deviation from normal value regardless of the direction of shoulder or truncal imbalance.

Statistical analysis

Two orthopedic surgeons carried out measurements twice independently at least 1 week apart to decrease intra-observer (ICCs > 0.93, 95 % CI = 0.87–0.95) and inter-observer errors (ICCs > 0.90, 95 % CI = 0.84–0.91). Statistical analysis was performed to determine the presence of significant differences between groups and the nature of correlations between the above-mentioned parameters. All the analyses were performed using the SPSS version 13 (SPSS, Chicago, IL) and MedCalc version 11.5.1 (MedCalc Software, Belgium).

Results

Changes in coronal curvature

For the 89 study subjects, mean preoperative and postoperative Cobb angles, correction angle and rate of each curvature were proximal 32.4, 15.0, 17.8° (54.9 %), middle 58.4, 18.7, 40.0° (68.5 %), and distal 36.7, 10.5, 26.4° (71.9 %), respectively. Furthermore, there was a significant change in the values after surgery (*t* test, $P < 0.0001$).

Changes in general postoperative shoulder balance

Table 1 shows the pre- and postoperative values of parameters covering all the curvature types. Preoperatively, the four shoulder parameters were similar for the different curvature types (ANOVA, $P > 0.05$), except for type VI in CHD (ANOVA; Tukey post hoc test, $P = 0.028$). Besides, no significant differences between different curvature types

Table 1 Mean pre- and post operative values, and changes in shoulder balance in different curvature types

Lenke type								
	I	II	III	IV	V	VI	P	Total
Shoulder balance (4 parameters)								
CHD (mm)								
Pre-OP	5.6 ± 5.2	10.3 ± 9.9	7.3 ± 6.5	8.1 ± 8.8	7.8 ± 4.2	21.2 ± 24.8	*0.028	9.6 ± 11.6
Post-OP	13.6 ± 9.7	8.5 ± 8.4	9.6 ± 5.7	16.8 ± 10.6	9.6 ± 11.9	12.0 ± 5.9	0.199	12.7 ± 9.0
Change	16.2 ± 12.0	15.0 ± 13.7	9.3 ± 6.1	14.9 ± 15.6	12.0 ± 8.8	18.4 ± 16.2	0.787	14.9 ± 13.0
P	*0.006	*0.037	0.853	*0.001	0.823	0.272		*0.043
CA (°)								
Pre-OP	1.8 ± 1.4	2.6 ± 2.4	1.8 ± 1.7	2.9 ± 3.3	1.7 ± 1.0	4.1 ± 6.3	0.131	2.6 ± 3.0
Post-OP	3.3 ± 2.2	2.4 ± 2.0	4.0 ± 7.0	4.2 ± 2.3	3.5 ± 3.4	3.2 ± 1.2	0.946	3.5 ± 2.9
Change	4.1 ± 2.9	3.7 ± 3.5	4.8 ± 6.2	4.4 ± 4.0	3.2 ± 3.6	4.3 ± 4.1	0.970	4.1 ± 3.7
P	*0.015	0.222	0.424	0.216	0.448	0.356		*0.041
CRID (mm)								
Pre-OP	4.4 ± 4.0	8.2 ± 8.7	6.8 ± 9.1	5.1 ± 6.7	3.3 ± 3.7	15.2 ± 17.8	0.063	7.1 ± 9.3
Post-OP	8.8 ± 7.1	8.0 ± 6.3	9.2 ± 4.8	13.2 ± 6.7	10.1 ± 8.6	9.7 ± 5.3	0.476	10.5 ± 6.5
Change	11.9 ± 6.7	12.7 ± 11.1	11.9 ± 11.4	14.3 ± 8.6	6.8 ± 6.6	11.8 ± 12.9	0.861	12.3 ± 9.7
P	0.051	0.193	0.544	*0.008	0.133	0.367		*0.009
RSH (mm)								
Pre-OP	7.7 ± 6.8	10.9 ± 10.8	8.3 ± 6.9	8.6 ± 9.9	11.7 ± 9.4	16.9 ± 17.5	0.175	10.6 ± 12.7
Post-OP	15.6 ± 11.0	9.7 ± 8.7	11.5 ± 8.4	18.6 ± 11.8	16.5 ± 13.6	15.8 ± 5.5	0.613	15.1 ± 9.8
Change	19.9 ± 15.2	15.5 ± 16.8	15.1 ± 6.5	18.4 ± 15.4	14.6 ± 9.8	18.9 ± 17.9	0.922	17.4 ± 15.4
P	*0.007	*0.039	0.558	*0.011	0.616	0.576		*0.007
Coronal balance								
CB (mm)								
Pre-OP	50.4 ± 16.5	63.7 ± 23.5	59.0 ± 21.1	68.6 ± 20.3	53.3 ± 9.7	50.1 ± 7.9	0.060	58.9 ± 20.2
Post-OP	19.8 ± 8.5	21.8 ± 13.3	23.8 ± 11.8	32.2 ± 20.3	24.0 ± 13.4	18.4 ± 7.3	0.107	23.0 ± 13.5
Change	30.9 ± 17.6	43.1 ± 22.2	36.9 ± 22.9	36.8 ± 22.9	29.3 ± 16.9	31.7 ± 6.1	0.352	36.7 ± 20.1
P	*0.0001	*0.0001	*0.006	*0.0001	*0.041	*0.0001		*0.0001
N	19	26	11	14	7	12		89

To determine the differences in parameters between curvature types, ANOVA was used

To determine the differences in parameters between pre- and postoperative values, *t* test was used

CHD coracoid height difference, CA clavicular angle, CRID clavicle–rib interface difference, RSH radiologic shoulder height, CB coronal C7 plumb line, Pre-OP preoperative value, Post-OP postoperative value, Change postoperative changes

* Indicates statistical significance ($P < 0.05$)

were observed in terms of postoperative values and changes in these parameters (ANOVA, $P > 0.05$). However, 89 patients showed aggravated shoulder level differences at final follow up (*t* test, $P < 0.05$). According to curvature types, there was an increase in four shoulder parameters after surgery in Lenke type I, III, IV and V scoliosis, especially in type I and IV curvature with statistical significance (*t* test, $P < 0.05$). However, there was a decrease in the values in type II and VI, especially on type II with statistical significance (*t* test, $P < 0.05$). In addition, there was a significant improvement in the coronal balance in all curvature types (*t* test, $P < 0.05$), and was similar pre- and postoperatively between all the curvature types (ANOVA, $P > 0.05$).

Postoperative shoulder balance according to different proximal fusion level

Table 2 shows the pre- and postoperative values of parameters according to different proximal fusion levels in all the types of curvatures. We determined the fusion level up to T1 or T2, T3 and below T4 according to our experiences and the literature [5, 11, 14, 17]. In general, there was an increase in all the shoulder parameters after surgery in all the groups, although CA was slightly decreased in T1 or T2 fusion group without statistical significance (*t* test, $P > 0.05$). In addition, no significant differences in pre-operative shoulder level between different proximal fusion groups, and all the three groups showed the similar final

Table 2 Postoperative shoulder balance according to different proximal fusion level

	T1 or T2	T3	T4 below	<i>P</i>	Total
Shoulder balance (4 parameters)					
CHD (mm)					
Pre-OP	11.9 ± 11.3	10.2 ± 9.9	8.5 ± 15.1	0.645	9.6 ± 11.6
Post-OP	15.2 ± 10.4	10.7 ± 7.4	11.5 ± 7.9	0.113	12.7 ± 9.0
Change	16.2 ± 15.0	13.9 ± 11.8	14.4 ± 11.5	0.777	14.9 ± 13.0
<i>P</i>	0.144	0.279	*0.037		*0.043
CA (°)					
Pre-OP	2.9 ± 2.9	2.2 ± 2.5	2.9 ± 4.0	0.576	2.6 ± 3.0
Post-OP	2.7 ± 3.2	3.6 ± 3.8	3.1 ± 2.0	0.773	3.5 ± 2.9
Change	3.7 ± 3.7	4.4 ± 4.1	4.2 ± 3.2	0.765	4.1 ± 3.7
<i>P</i>	0.160	*0.045	0.814		*0.041
CRID (mm)					
Pre-OP	7.9 ± 9.3	7.2 ± 9.5	7.4 ± 9.4	0.989	7.1 ± 9.3
Post-OP	11.6 ± 97.0	10.4 ± 5.6	8.7 ± 6.7	0.306	10.5 ± 6.5
Change	12.2 ± 9.8	13.5 ± 10.9	10.6 ± 7.3	0.614	12.3 ± 9.7
<i>P</i>	*0.028	0.119	0.650		*0.009
RSH (mm)					
Pre-OP	12.7 ± 11.3	10.4 ± 10.3	8.6 ± 14.1	0.394	10.6 ± 12.7
Post-OP	16.5 ± 11.0	13.8 ± 8.8	14.9 ± 9.0	0.558	15.1 ± 9.8
Change	17.7 ± 17.2	17.6 ± 14.7	16.3 ± 11.5	0.942	17.4 ± 15.4
<i>P</i>	0.174	*0.031	0.283		*0.007
Coronal balance					
CB (mm)					
Pre-OP	57.9 ± 20.5	64.6 ± 21.9	51.1 ± 13.9	0.072	58.9 ± 20.2
Post-OP	25.8 ± 16.2	21.8 ± 12.2	19.9 ± 9.4	0.269	23.0 ± 13.5
Change	33.2 ± 21.6	43.3 ± 19.98	31.5 ± 14.8	0.061	36.7 ± 20.1
<i>P</i>	*0.0001	*0.0001	*0.0001		*0.0001

To determine the differences in parameters between different fusion levels, ANOVA was used

CHD coracoid height difference, *CA* clavicular angle, *CRID* clavicle–rib interface difference, *RSH* radiologic shoulder height, *CB* coronal C7 plumb line, *Pre-OP* preoperative value, *Post-OP* postoperative value, *Change* postoperative changes

* Indicates statistical significance ($P < 0.05$)

shoulder level with similar changes (ANOVA, $P > 0.05$) existed.

Analysis of possible factors to determine postoperative shoulder balance

Pre- and postoperative magnitude of coronal curvature (proximal, middle, and distal)

When the parameters in both the final shoulder balance aggravated and improved groups were analyzed, no significant difference between pre- and postoperative values and changes in proximal, and middle curvatures was observed between these two groups (t test, $P > 0.05$) (Table 3). However, changes in distal curvature was higher in CA and CRID aggravated group with statistical significance (t test; $P = 0.043$, $P = 0.048$, respectively). In

addition, it was consistently higher in CHD and RSH aggravated group without any statistical significance (t test; $P = 0.105$, $P = 0.266$, respectively).

Change ratio between coronal curvature [Change ratio = 1st curve changes (°)/2nd curve changes (°)]

When postoperative change ratio between each coronal curvature (proximal, middle, distal) was analyzed, it was observed that middle to distal curve change ratio (middle curve change/distal curve change) was significantly lower in aggravated group (CHD, CA, CRID; t test, $P < 0.05$) (Table 4). In addition, it was consistently lower in RSH aggravated group without any statistical significance (t test, $P = 0.469$). Besides, no significant difference in parameters between other comparisons (proximal vs. middle, proximal vs. distal; t test, $P > 0.05$) existed.

Table 3 Analysis of pre- and postoperative coronal curvature changes (proximal, middle, and distal) in the aggravated and improved shoulder balance groups

Shoulder balance (4 parameters)											Body balance				
CHD			CA			CRID			RSH			CB			
Agg (<i>n</i> = 56)	Imp (<i>n</i> = 33)	<i>P</i>	Agg (<i>n</i> = 56)	Imp (<i>n</i> = 33)	<i>P</i>	Agg (<i>n</i> = 60)	Imp (<i>n</i> = 29)	<i>P</i>	Agg (<i>n</i> = 58)	Imp (<i>n</i> = 31)	<i>P</i>	Agg (<i>n</i> = 8)	Imp (<i>n</i> = 81)	<i>P</i>	
Magnitude of proximal curve (°)															
Pre-OP	33.0 ± 12.9	31.3 ± 12.5	0.564	32.7 ± 12.6	31.9 ± 13.0	0.803	32.6 ± 12.2	31.9 ± 13.8	0.798	33.6 ± 12.8	30.2 ± 12.5	0.251	33.1 ± 22.0	32.4 ± 12.3	0.951
Post-OP	14.4 ± 9.1	16.1 ± 6.5	0.365	14.5 ± 9.0	15.9 ± 6.7	0.452	14.5 ± 9.0	16.0 ± 6.4	0.391	14.6 ± 8.9	15.7 ± 6.9	0.596	14.1 ± 12.2	15.0 ± 8.1	0.817
Change	18.8 ± 12.1	16.0 ± 9.5	0.273	18.4 ± 11.9	16.8 ± 10.2	0.540	18.3 ± 11.3	16.7 ± 11.3	0.556	19.1 ± 12.5	15.3 ± 8.2	0.147	24.6 ± 18.1	17.4 ± 10.9	0.214
Magnitude of middle curve (°)															
Pre-OP	59.3 ± 18.9	56.9 ± 15.1	0.546	58.2 ± 18.3	58.6 ± 16.4	0.925	58.3 ± 18.2	58.6 ± 16.3	0.935	58.3 ± 18.7	58.5 ± 15.3	0.963	60.9 ± 24.5	58.3 ± 17.3	0.770
Post-OP	19.6 ± 10.3	17.1 ± 9.8	0.283	19.2 ± 9.9	17.8 ± 10.6	0.562	19.4 ± 10.1	17.2 ± 10.3	0.357	19.0 ± 9.8	18.0 ± 10.8	0.681	18.1 ± 12.8	18.7 ± 10.1	0.915
Change	39.7 ± 14.4	39.8 ± 13.0	0.983	39.1 ± 13.7	40.8 ± 14.1	0.586	38.9 ± 13.5	41.4 ± 14.6	0.436	39.3 ± 14.5	40.5 ± 12.7	0.718	42.8 ± 18.2	39.6 ± 13.7	0.653
Magnitude of distal curve (°)															
Pre-OP	38.9 ± 15.6	33.0 ± 18.4	0.119	38.2 ± 15.6	34.2 ± 18.7	0.295	38.5 ± 16.1	32.9 ± 18.0	0.156	37.8 ± 16.3	34.7 ± 17.9	0.434	40.6 ± 14.0	36.5 ± 17.0	0.636
Post-OP	10.9 ± 7.7	9.7 ± 10.2	0.541	10.1 ± 7.3	11.1 ± 10.7	0.603	10.4 ± 7.8	10.5 ± 10.5	0.956	10.4 ± 7.2	10.5 ± 11.1	0.990	22.4 ± 18.4	9.9 ± 7.7	0.267
Change	28.1 ± 11.7	23.5 ± 13.8	0.105	28.2 ± 11.9	23.3 ± 13.4	*0.043	28.2 ± 12.3	22.6 ± 12.8	*0.048	27.5 ± 12.4	24.3 ± 13.0	0.266	18.3 ± 7.5	26.8 ± 12.8	0.102

To determine the differences between the groups, *t* test was used

CHD coracoid height difference, CA clavicular angle, CRID clavicle–rib interface difference, RSH radiologic shoulder height, Agg postoperative aggravated group, Imp postoperative improved group, CB coronal C7 plumb line, Change postoperative changes, Pre-OP preoperative value, Post-OP postoperative value

* Indicates statistical significance (*P* < 0.05)

Table 4 Analysis of differences in coronal curvature change (proximal, middle, and distal) in the aggravated and improved shoulder balance groups

	Shoulder balance (four parameters)				Body balance			
	CA		CRID		RSH		CB	
	Agg (n = 56)	Imp (n = 33)	P	Agg (n = 56)	Imp (n = 33)	P	Agg (n = 58)	Imp (n = 31)
Proximal vs middle curve								
Change ratio	0.55 ± 0.68	0.47 ± 0.40	0.543	0.55 ± 0.68	0.47 ± 0.39	0.574	0.56 ± 0.67	0.43 ± 0.38
Proximal vs distal curve								
Change ratio	1.19 ± 3.19	1.58 ± 2.85	0.578	1.18 ± 3.19	1.59 ± 2.85	0.552	1.17 ± 3.08	1.67 ± 3.04
Middle vs distal curve								
Change ratio	1.68 ± 0.96	2.33 ± 1.64	*0.049	1.65 ± 0.94	2.37 ± 1.64	*0.031	1.64 ± 0.91	2.49 ± 1.72

To determine the differences between groups, *t* test was used

CHD coracoid height difference, *CA* clavicular angle, *CRID* clavicle–rib interface difference, *RSH* radiologic shoulder height, *Agg* postoperative aggravated group, *Imp* postoperative improved group, *CB* coronal C7 plumb line, *Change ratio* 1st curve changes (°)/2nd curve changes (°)

* Indicates statistical significance ($P < 0.05$)

Table 5 Comparisons of pre- and postoperative values of shoulder parameters in the aggravated and improved groups

	Shoulder balance (four parameters)				Body balance			
	CA (°)		CRID (mm)		RSH (mm)		CB (mm)	
	Agg (n = 56)	Imp (n = 33)	P	Agg (n = 56)	Imp (n = 33)	P	Agg (n = 58)	Imp (n = 31)
Pre-OP	4.6 ± 4.5	18.0 ± 14.8	*0.0001	1.4 ± 1.1	4.7 ± 3.9	*0.0001	3.6 ± 3.4	14.5 ± 12.8
Post-OP	16.0 ± 8.5	7.3 ± 7.2	*0.0001	4.4 ± 3.1	2.1 ± 1.6	*0.0001	13.0 ± 5.7	5.4 ± 4.7
Change	14.2 ± 10.2	16.2 ± 16.9	0.541	3.9 ± 3.2	4.3 ± 4.5	0.661	11.7 ± 6.8	13.6 ± 14.0

To determine the differences between the groups, *t* test was used

CHD coracoid height difference, *CA* clavicular angle, *CRID* clavicle–rib interface difference, *RSH* radiologic shoulder height, *Agg* postoperative aggravated group, *Imp* postoperative improved group, *CB* coronal C7 plumb line, *Pre-OP* preoperative value, *Post-OP* postoperative value, *Change* postoperative changes

* Indicates statistical significance ($P < 0.05$)

Initial shoulder level differences (CHD, CA, CRID, and RSH)

When the preoperative value of each shoulder parameters was analyzed, significant differences existed between aggravated and improved groups. In the aggravated group, all the shoulder parameters (CHD, CA, CRID, and RSH) were lower preoperatively (t test, $P < 0.0001$), with similar postoperative changes (t test, $P > 0.05$) (Table 5).

ROC (receiver operating characteristic) curve analysis of related factors

To determine the most effective factor to postoperative aggravation of shoulder balance, we performed the ROC curve analysis. ROC curves were developed by calculating the sensitivity and 1-specificity values for the prediction of the rate of final shoulder level aggravation for the any possible factors. We analyzed ROC curve of the two coronal curvature factors (middle to distal curve change ratio, and magnitude of distal curve change) and four shoulder balance factors (preoperative CHD, CA, CRID, and RSH value), which exhibited significant differences in shoulder balance aggravated group. In terms of coronal curvature factors, middle to distal curvature change ratio showed the cut-off point at <1.83 with statistical significance ($P < 0.05$) (Fig. 2a). Besides, distal curvature change showed the cut-off point at 27.54 with statistical significance ($P < 0.05$) (Fig. 2b). In terms of four shoulder balance factors, pre CHD, CA, CRID, and RSH exhibited the cut-off point at <5.72 mm, $<2.7^\circ$, <4.47 mm, and <9.2 mm with statistical significance ($P < 0.0001$), respectively (Fig. 3a–d). Figure 4 shows the representative cases.

Discussion

The treatment of idiopathic scoliosis has improved considerably over the past several years due to advancements in spinal instrumentation and surgical procedures. In addition, standard treatment recommendations have been proposed for the different curve patterns [14, 18–21]. Moreover, the classification system devised by Lenke et al. [13] decades ago has been rendered as reliable and reproducible. This new classification provides a practical and treatment-based system that could pave the way for the introduction of standard surgical recommendations for idiopathic scoliosis. Recently, surgeons started to fuse the whole structural curve, and this appears to produce better results after AIS surgery [12–14]. For proximal thoracic curvatures, fusion of main and proximal thoracic curves that fulfill Lenke's criteria for double fusion provides good

shoulder balance results [5, 13–15]. Besides, Li et al. [5] reported that in 25 patients, 21 (84 %) achieved normal shoulder balance, and 4 (16 %) only minimal imbalance after double fusion of proximal curvature. However, various types of scoliosis with or without proximal thoracic structural curvature exist. Moreover, even if the surgeon achieves the successful correction of the proximal thoracic curvature, shoulder imbalance can remain regardless of the amount of coronal curvature correction, which can significantly worsen the outcome of the surgery [1–4, 6, 16, 17, 22]. Previously, Trobisch et al. reported the iatrogenic trunk imbalance after correction surgery, and they emphasized the importance of distal lumbar curvature correction. Undercorrection of the lumbar curve was identified as potential risk factor, whereas thoracic correction, coronal balance, angulation and translation of the lowest instrumented vertebra did not seem to influence postoperative trunk shift [23]. Therefore, prediction and analysis of the final shoulder level in all types of scoliosis can be an important factor, which can determine the surgical outcome. However, no systemic analysis of factors has been shown to predict postoperative shoulder balance, and analyses have focused on extent of fusion level in specific types of scoliosis, such as, in Lenke II and King V. Scoliosis is a whole spine deformity, with many different types of curvatures, and gross truncal balance and shoulder balance might be closely related to changes in whole curvature (e.g., middle, distal) as well as in the proximal thorax. Therefore, in this study, we hypothesized that other factors that determine final shoulder level in AIS regardless of the curvature type or fusion level exist.

Analysis of shoulder balance in different curvature types

In the present study, final shoulder level was slightly aggravated in 89 patients. However, no significant differences were found between different curvature types in terms of the changes in shoulder level or their preoperative values including, double thoracic curvature type. Although we observed significant improvements in shoulder level in Lenke II and VI curvatures, the results were contradictory to the previous reports, which have stated improvements in shoulder balance, with fusion of all the structural curvatures [5, 12, 14, 15]. Recently, many surgeons have focused on the proximal thoracic curvature corrections in specific types of scoliosis (e.g. Lenke II) with proven good results; although, many other types of scoliosis that should be treated exist. In this study, we found that significant shoulder imbalance could be found in another types of scoliosis, which have previously been neglected. Moreover, in the treatment of various types of scoliosis, final postoperative shoulder level can be aggravated regardless

Fig. 2 Receiver operating characteristic (ROC) curve analysis graph that predicts an aggravated shoulder balance after surgery with **a** middle to distal change ratio, and with **b** distal curvature changes [area under the ROC curve (AUC), 95 % CI (confidence interval), *P* value]

Fig. 3 Receiver operating characteristic (ROC) curve analysis graph that predicts an aggravated shoulder balance after surgery with preoperative shoulder level in CHD, CA, CRID and RSH (**a–d**) [area under the ROC curve (AUC), 95 % CI (confidence interval), *P* value]

of the significant proximal curvature corrections, although these amounted to only millimeters range in our study. Thus, it appears that middle or distal curvature correction can affect the final shoulder balance in various types of

scoliosis. Furthermore, we should reconsider the availability of proximal curvature correction in another type of scoliosis, which had been previously accepted as a gold standard for the postoperative improvement of shoulder

Fig. 4 **a** A 16.2-year-old male patient who showed the 31, 74 and 59° of proximal, middle and distal curvature with Lenke type 3/B/N curvature, respectively. Preoperatively, the patient showed shoulder level differences with -2.5 mm, -1.3° , -0.8 mm and -1.0 mm of CHD, CA, CRID and RSH, respectively. Patient also showed improved coronal curvature with 19, 35 and 18°, postoperatively. However, shoulder balance was aggravated postoperatively with 10.8 mm, 3.0° , 14.0 mm and 16.0 mm of 4 parameters. In our analysis of factors, the patient exhibited (1) smaller preoperative shoulder level difference and (2) smaller middle to distal change ratio (0.94), combination of (1) and (2) signifies an aggravation in shoulder

level difference. **b** A 16.4-year-old female patient who showed the 52, 78 and 29° of proximal, middle and distal curvature with Lenke type 2/A/N curvature. Preoperatively, the patient showed shoulder level differences with -23.6 mm, -6.0° , -20.5 mm and -30.9 mm of CHD, CA, CRID and RSH, respectively. Patient showed improved coronal curvature with 27, 23 and 3°, postoperatively. In addition, shoulder balance was improved postoperatively with 4.8 mm, 1.4° , 0.4 mm and 8.4 mm of 4 parameters. In our analysis of factors, the patient exhibited (1) larger preoperative shoulder level difference and (2) larger middle to distal change ratio (2.08), combination of (1) and (2) signifies an improvement in shoulder level difference

level in scoliosis with structural proximal thoracic curvature [5, 12, 14, 15]. We should also consider other factors, which are capable of affecting balance, so that it would be feasible to produce more balanced shoulders in any type of curvatures. The findings regarding postoperative shoulder balance are different from the literature, and might contribute to a change in the current concept of predicting postoperative shoulder level in AIS patients.

Analysis of shoulder balance in different proximal fusion level

Kuklo et al. [17] carried out a comparative analysis on 112 patients (proximal curvature $>20^\circ$) in terms of the shoulder balance. They divided the group into four groups according to proximal fusion level (T2, T3, T4 or T5, T4 below). Subsequently, they reported improvement in the postoperative shoulder level in all the groups. In addition, no significant differences in postoperative shoulder level between the groups exist. Li et al. [5] analyzed

postoperative shoulder balance in 25 Lenke type II curvatures. In their study, fusion was performed from T1 or T2 to the distal neutral vertebra of the thoracic curve. A significant improvement in shoulder balance was also demonstrated in their clinical series. However, the aforementioned studies have focused on scoliosis with structural proximal thoracic curvature as Lenke type II. Moreover, the result can be different in other types of scoliosis. In the present study, we analyzed the six types of scoliosis curvature with different proximal fusion level on final follow up radiogram. We performed fusion from T1 or T2 including proximal end of the curvature in the fusion segment with structural proximal thoracic curvature (more than 25° of side bending Cobb angle). In addition, we performed fusion from T2 or T3 to correct the shoulder imbalance in cases of prominent shoulder imbalance (<10 mm) with non-structural proximal thoracic curvature. However, final postoperative shoulder balance was slightly aggravated in 89 patients with various types of scoliosis. In addition, no differences in final shoulder level between

different proximal curvature fusion groups exist. Although appropriate proximal fusion may be a determinant of postoperative shoulder balance, and several literatures exist, which show good results, we experienced an unbalanced shoulder level after surgery despite the sufficient proximal fusion in several types of scoliosis. Therefore, another important factor that determines the final shoulder level in any type of scoliosis regardless of whether final proximal fusion level is needed.

Analysis of possible factors that might be related to final shoulder level

Middle and distal curvature correction

In this study, patients with larger middle curvature correction than distal or small distal curvature correction showed improvement in shoulder balance. It appears that correction rate differences between middle and distal curvatures can affect final shoulder level in several types of scoliosis, and can cause either improvement or aggravation in shoulder balance. We suppose that, in majority of scoliosis types, major or large structural curvature is located in middle thoracic region rather than in proximal region. Although proximal curvature correction may have a role in determining the shoulder balance, larger structural middle curvature correction may strongly affect the shoulder balance with the correction of rib cage and vertebral column construct in the thoracic area. However, distal curve is usually located in the lumbar area with flexible form, and might have important role in maintaining a balanced body and shoulder level with compensation. Therefore, excessive correction of distal curve with fusion can lead to collapse of the body balance with different shoulder level. Furthermore, it is supported by our results that show smaller distal curvature correction in shoulder level improved group. Therefore, if the distal curvature is not structural, we suggest shorter distal curvature fixation to preserve the compensatory role of the distal curvature.

Preoperative shoulder level

In this study, the aggravated group showed minimal initial shoulder imbalance than improved group with similar changes. Scoliotic curvature is composed of two or three structured or compensatory curvatures, which all influence the general body shape. It appears that, close relationship exists between curvatures, and this relation may produce the more balanced body shape as well as shoulder level. Apparently, in AIS patients with minimal shoulder imbalance, these coronal curvatures are in a balanced state with compensation, and correction surgery can collapse this state. Thus, seemingly excessive corrections increase the

risk of aggravated shoulder balance in less severely affected patients. It is also apparent that to produce more balanced shoulders, appropriate correction with respect to initial shoulder level is important.

Possible shoulder balance determinants

When we analyzed the ROC curve of related factors in final shoulder level aggravated group, the curve change ratio between middle and distal (middle curve change/distal curve change) showed the cut-off point at <1.83 in all the aggravated group. Moreover, although distal curve change showed the cut-off point at 27.54° , it was only available in CRID aggravated group. In terms of four shoulder balance factors, pre CHD, pre CA, pre CRID, and pre RSH showed the cut-off point at <5.7 mm, $<2.7^\circ$, <4.5 mm, and <9.2 mm in all the aggravated group. We can assume that approximately less than twice the amount of middle curvature correction than distal leads to more aggravated shoulder balance (with significant distal curve change). In addition, patients with smaller shoulder level differences which are less than the cut-off values are more susceptible to aggravation of shoulder balance after surgery. However, AUC (area under the ROC curve) of the pre CHD, CA, CRID and RSH ($0.783>$) were higher than that of middle to distal curve change ratio ($0.669>$) with higher statistical significance ($P < 0.0001$ vs. $P = 0.012$). It appears that preoperative shoulder level more strongly influences the final outcome than coronal curvature change ratio.

Recommendations for the surgery

In this study, we found that final shoulder level could be aggravated regardless of the curvature types or fusion level. In addition, it was observed that middle or distal curvature correction could be a factor that affects the postoperative shoulder balance in several types of scoliosis. However, surgeons should be reminded that it should be considered after sufficient fusion of structural proximal thoracic curvature, which have been accepted as gold standard. In addition, if residual shoulder imbalance after fixation of the proximal thoracic curvature exists, surgeons should focus on the correction of middle curvature as well as on minimizing the distal curvature fusion level. We think that correction of gross body balance with significant correction of middle curvature can improve the shoulder level in majority of the scoliosis types. In addition, initial shoulder level should be considered before surgery, which can affect the postoperative shoulder balance. Surgeons should be careful while performing correction surgery of scoliosis with minimal initial shoulder imbalance, which can lead to unfavorable results regardless of the fusion level or type of scoliosis.

Limitations of the present study

The present study is associated with several limitations. The number of subjects was small in some types of scoliosis (e.g., Lenke type V), and subjects were retrospectively gathered that might have a selective bias. In addition, our analysis results might not be available always to predict or prevent the postoperative shoulder level difference in clinical field, and it is hard to control the correction rate of each coronal curvature with current operative techniques. Particularly, although we performed the sufficient proximal fusion in significant upper thoracic curvatures, we could not confirm the standard level of fusion, which can minimize the postoperative shoulder imbalance. In addition, in some cases, we may miss the appropriate fusion level to the good postoperative shoulder balance. In addition, we did not use the direct vertebral rotation method (DVR) in the surgery, which may improve shoulder balance. However, we analyzed the shoulder balance with six types of scoliosis with a unique method in final follow up radiograms. Moreover, the present study identifies the factors related to postoperative shoulder balance, which have previously not been investigated. Finding the other factors besides the proximal fusion level, whether it is evident, may improve the clinical outcomes. Therefore, it is anticipated that the present findings provide useful information to surgeons, and will encourage further studies on the subject of analyzing postoperative shoulder level.

In conclusion, we found that several parameters affect final shoulder level after AIS surgery, regardless of the scoliosis type or proximal curvature changes. In particular, we found a significant relationship between correction rate difference of coronal curvatures (middle, distal) and final shoulder level. Moreover, preoperative shoulder level was the determinant of final shoulder level. Our findings caution that controlled correction of structural and compensating the curvatures considering initial shoulder level probably influence shoulder balance after scoliosis surgery, and we urge that further studies should be conducted on this topic.

Conflict of interest None.

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