Discrepancy between radiographic shoulder balance and cosmetic shoulder balance in adolescent idiopathic scoliosis patients with double thoracic curve

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Abstract Shoulder balance is one of the key components to the body deformity in adolescent idiopathic scoliosis (AIS) patients with double thoracic curve and shoulder cosmesis plays an important role in patients' satisfaction of surgical outcomes. Up to now, only radiographic parameters were used to evaluate the shoulder balance in literatures; no corresponding cosmetic parameters have been developed to evaluate the cosmetic shoulder balance. Meanwhile, we often confronted that perfect radiographic shoulder balance was achieved, but the patients complained about the residual cosmetic deformity. This phenomenon implied that discrepancy may exist between radiographic shoulder balance and cosmetic shoulder balance. The present study was carried out to investigate the correlation between radiographic and clinical cosmetic shoulder balance in AIS patients with double thoracic curve. Thirty-four AIS patients were recruited for this study. All the patients had a double thoracic curve. Six cosmetic parameters—inner shoulder height (SHi), outer shoulder height (SHo), shoulder area index 1 (SAI1), shoulder area index 2 (SAI2), shoulder angle (α_1) and axilla angle (α_2) were developed and measured on the standing photographs. Also, seven radiographic parameters—T1 tilting (T1), first

rib angle (FRA), clavicle angle (CA), coracoid process height (CPH), clavicle-rib cage intersection (CRCI), first rib-clavicle height (FRCH), trapezius length (TL) were measured on the standing posterior–anterior radiographs. Correlation analysis was made between cosmetic parameters and radiographic parameters. SHi was found to be significantly correlated with T1, FRA, CA, CPH, CRCI ($P < 0.05$), among which FRA had the highest correlation coefficient. SHo was found to be significantly correlated with T1, FRA, CA, CPH, CRCI, FRCH ($P < 0.05$), among which CRCI had the highest correlation coefficient. However, none of the correlation coefficient was greater than 0.8. The correlation coefficients between radiographic parameters and SAI1, SAI2, α_1 , α_2 were also below 0.8 that were similar with SH. The results indicated that radiographic parameters could only partially reflect the shoulder cosmetic appearances. However, none of the existing parameters can accurately reflect the shoulder cosmetic appearance. As cosmesis is critical important to patients' satisfaction, spine surgeons should pay more attention to the cosmetic shoulder balance rather than radiographic shoulder balance.

Keywords Adolescent idiopathic scoliosis · Double thoracic curve · Radiographic · Cosmesis

Introduction

There are many factors contributing to adolescent idiopathic scoliosis (AIS) patient satisfaction after surgery, such as surgical scars, improved back shape, reduced radiological Cobb angle, and back pain [11]. However, cosmesis of the back and shoulders are critically important to the AIS patients and also a big concern of the patients

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family [1, 2, 10, 12, 24]. There were several reports of psychological distress in adolescent females due to clinical deformity [4, 7, 9]. Individuals with idiopathic scoliosis may have several pronounced clinical deformities, among which uneven shoulders are often quite prominent. Raso et al. [19] showed that shoulder angle defined as the angle between the horizontal line and the line through two inflection points of the shoulders is one of three features which predicted 75% of the overall impression of body deformity. The left shoulders are often elevated by the proximal thoracic curves in AIS patients with double thoracic curve. Hence, the evaluation of shoulder balance in AIS patients with double thoracic curve is very important for decision making of the spine surgeons and for the evaluation of clinical outcome.

Since the Cotrel-Dubousset instrumentation (CDI) has become a well-accepted technique for the correction of spine deformity, shoulder balance has gained more attention by the spine surgeons. In the literatures, many radiographic parameters have been developed to evaluate the shoulder balance, such as T1 tilting, unlevelled first ribs, clavicle angle, and, etc. [3, 8, 14]. Radiologically, spinal fusion with instrumentation has achieved great success in deformity correction [5, 18, 20]. However, surgeons' technical success does not necessarily translate into patient satisfaction with the surgical outcome [6, 22]. It is not unusual that surgical patients find themselves confronted with residual cosmetic deformity despite dramatic improvements in the radiological deformity of their spine [13, 15, 17, 23, 25].

Actually, in the literatures, shoulder balance was commonly referred to as radiographic shoulder balance, without consideration on cosmetic shoulder balance, and radiographic balanced shoulder was always regarded as leveled shoulder height. However, whether the radiographic balanced shoulder could fully reflect the cosmetic balanced shoulder has not been fully investigated. Furthermore, the cosmetic shoulder balance may not only include leveled shoulder height, but also cover some other aspects, such as the areal balance and symmetry between left and right shoulders, and, etc. Hence, the purpose of this study was to develop several cosmetic parameters of the shoulders and to investigate the correlation between the shoulder cosmesis and the radiographic measurements.

Subjects and methods

Subjects

Thirty-four AIS girls were recruited into this study. All the patients had double thoracic curve with right main thoracic curve and a left proximal thoracic curve that could lead to

the shoulder imbalance. Patients with non-idiopathic scoliosis, leg-length discrepancy, pelvis tilt or hip flexion deformity were excluded from the study. The average age was 14.3 years (range 11–17), the average Risser signs was 2.8 (range 1–5). The average main thoracic curve was 53.0° (range 40°–89°), and the average proximal thoracic curve was 44.3° (range 34°–65°) (Table 1). The apexes of the main thoracic curves ranged from T8 to T9. The apexes of the proximal thoracic curves were T3, and occasionally located at the vertebral disc of T3–4. Informed consents were obtained from the patients and their parents.

Radiographic measurements

All the patients had a standing posterior–anterior (PA) radiograph in a relaxed standing position. In addition to the Cobb angle and Risser sign, seven radiographic shoulder balance parameters as adopted by Bago et al. [3] and Kuklo et al. [14] were measured on each radiograph (Fig. 1). CPH, CRCI, FRCH, TL (see below) were measured by using the scale on the radiograph.

- (1) T1 tilt (T1): Is the angle between the horizontal line and the line through the upper endplate of T1. Positive T1 tilt was defined as the angulation of the upper endplate of T1 to the horizontal line with the left proximal vertebral body up and right lower vertebral body down (Fig. 1a).

Table 1 Summary of shoulder radiographic and cosmetic measurements

	Measurements	Means $\pm$ SD	Range
Radiographic	Cobb_PT (°)	44.3 $\pm$ 8.17	34–65
	Cobb_T (°)	53.0 $\pm$ 13.5	40–89
	T1 (°)	11.3 $\pm$ 4.53	0–21
	FRA (°)	7.85 $\pm$ 3.77	0–16
	CA (°)	−0.29 $\pm$ 2.93	−4.5 to 6.3
	CPH (cm)	0.02 $\pm$ 1.3	−2.8 to 2.6
	CRCI (cm)	0.10 $\pm$ 0.87	−1.5 to 2.2
	FRCH (cm)	0.85 $\pm$ 0.60	−0.4 to 2.4
	TL (cm)	−0.21 $\pm$ 0.95	−2.6 to 1.5
Cosmetic	SHi (cm)	1.10 $\pm$ 0.60	0–2.5
	SHo (cm)	0.97 $\pm$ 0.89	−0.5 to 3.5
	SAI1	1.09 $\pm$ 0.08	0.95–1.33
	SAI2	1.17 $\pm$ 0.14	0.94–1.54
	α 1 (°)	1.42 $\pm$ 1.81	−1.5 to 5.5
	α 2 (°)	−0.86 $\pm$ 2.38	−6.5 to 4.4

Cobb_PT the proximal thoracic curve, *Cobb_T* the main thoracic curve, *T1* T1 tilt, *FRA* first rib angle, *CA* clavicle angle, *CPH* coracoid process height, *CRCI* clavicle-rib cage intersection, *FRCH* first rib-clavicle height, *TL* trapezius length, *SHi* inner shoulder height, *SHo* outer shoulder height, *SAI1* shoulder area index 1, *SAI2* shoulder area index 2, α 1 shoulder angle, α 2 axilla angle

Fig. 1 Schematic drawings of radiographic parameters and shoulder cosmetic measurements: **a** *T1* T1 tilt, **b** *FRA* first rib angle, **c** *CA* clavicle angle, **d** *CPH* coracoid process height, **e** *CRCI* clavicle-rib cage intersection, **f** *FRCH* first rib-clavicle height, **g** *TL* trapezius length, **h** *SH* shoulder height, **i** *SAI1* shoulder area index 1, **j** *SAI2* shoulder area index 2, **k** $\alpha 1$ shoulder angle, **l** $\alpha 2$ axilla angle

- (2) First rib angle (FRA): The tilt of a tangential line that connects both the superior borders of first ribs. Positive FRA indicates an inclination to the right of this reference line (Fig. 1b).
- (3) Clavicle angle (CA): Is the angle between the horizontal line and the tangential line connecting the highest two points of each clavicle. Positive CA was defined as the left clavicle up and the right clavicle down (Fig. 1c).
- (4) Coracoid process height (CPH): A horizontal line was traced in the superior edge of each coracoid process. The height difference between the right and left lines was recorded. Positive CPH was defined as the higher side was the left (Fig. 1d).
- (5) Clavicle-rib cage intersection (CRCI): The clavicle intersects the outer face of the rib cage to a variable height. A horizontal line was traced through this point; the difference between the left and right lines was defined as CRCI, with a positive value adopted when the higher side was left (Fig. 1e).
- (6) First rib–clavicle height (FRCH): FRCH was defined as the difference between the vertical distances of first rib apex to superior clavicle between left and right side. The positive value was adopted when the vertical distance is larger in the left side (Fig. 1f).
- (7) Trapezius length (TL): TL was defined as the difference of the horizontal distance of the T2 pedicle to second rib–clavicle intersection between left and right side. The positive value was adopted when the horizontal distance is larger in the left side (Fig. 1g).

Cosmetic measurements

The patients were photographed from the back in neutral standing position on level ground wearing an underpants and with their shoes removed. To preserve the privacies of the patients, we didn't study the cosmesis with the picture taken from the front. One tape measure was put on the back and was used as a scale for the measurement of shoulder height. The photographs were transferred to the computer. By using the *image-Pro Plus 6.0* image analysis software, six cosmetic parameters were measured on each photograph.

- (1) Shoulder height (SH): The horizontal line through the higher axilla intersects the arms at P (left) and Q (right), the plumb line through midpoint of the neck on each PA photo intersects this horizontal line at O, and the trisection lines of OP, OQ intersect the shoulders at A, B (left), and A', B' (right). The difference between the heights of A and A' is defined as the inner shoulder height (SHi), and that between B and B' is defined as the outer shoulder height (SHo).

Positive SH is defined as the left shoulder up and the right shoulder down. The position of SHo is to some extent similar with the shoulder height of Kuklo's study [14] (Fig. 1h).

- (2) Shoulder area index 1 (SAI1): The area surrounded by m , l_1 , the superior margin of the shoulders and the outer margin of the upper arms was divided by the plumb line through midpoint of the neck into area $a1$ and area $a2$, the ratio $a1/a2$ was defined as SAI1. (m is the line connecting the two inflection points (right and left) between the shoulder and neck, l_1 is the horizontal line through the higher axilla) (Fig. 1i).
- (3) Shoulder area index 2 (SAI2): The area surrounded by m , l_2 , the superior margin of the shoulders was divided by the plumb line through midpoint of the neck into area $b1$ and area $b2$, the ratio $b1/b2$ was defined as SAI2. (m is the line connecting the two inflection points (right and left) between the shoulder and neck, l_2 is the horizontal line through the lower inflection point between the shoulder and the upper arm) (Fig. 1j).
- (4) Shoulder angle ($\alpha1$): The angle between the horizontal line and the line through two inflection points of the shoulders and upper arms was defined as $\alpha1$. Positive $\alpha1$ indicates the left shoulder up and the right shoulder down (Fig. 1k).
- (5) Axilla angle ($\alpha2$): The angle between the horizontal line and the line through both axillae was defined as $\alpha2$. Positive $\alpha2$ indicates the left axilla up and the right axilla down (Fig. 1l).

Statistical analysis

All parameters were measured twice; measurement agreement between the first time and second time was estimated by a correlation analysis. The statistical analysis was performed by SPSS 13.0 for Windows. Correlation analysis was made between the cosmetic parameters and the radiographic parameters. Statistical significance was set at $P < 0.05$.

Results

The magnitude of shoulder radiographic and cosmetic parameters was listed in detail under Table 1. All patients had a neutral or positive T1 tilting (T1, range 0–21°) and first rib angle (FRA, range 0–16°) in this study, but the CA ranged from –4.5° to 6.3°. The magnitude of CPH, CRCI, FRCH, TL were either negative or positive (Table 1). For the cosmetic parameters, SHi ranged from 0 to 2.5 cm, while SHo ranged from –0.5 cm to 3.5 cm. The average shoulder area index 2 (SAI2) was 1.17; while the average

shoulder area index 1 (SAI1) was 1.09. Thus, SAI2 was more sensitive to the disproportion of left and right shoulders than SAI1. The shoulder angle ($\alpha 1$) ranged from -1.5° to 5.5° , while axilla angle ($\alpha 2$) ranged from -6.5° to 4.4° .

The correlation coefficients between SHi and radiographic parameters ranged from -0.12 to 0.61 , and SHi was found to be significantly correlated with T1 tilting, first rib angle, clavicle angle, coracoid process height and clavicle-rib cage intersection (T1, FRA, CA, CPH and CRCI) ($P < 0.05$), among which FRA had the highest correlation coefficient. The correlation coefficients between SHo and radiographic parameters ranged from -0.22 to 0.74 , and SHo was significantly correlated with T1 tilting, FRA, CA, CPH, CRCI and FRCH ($P < 0.05$), among which CRCI had the highest correlation coefficient (Table 2). There were also several radiographic parameters correlated significantly with SAI1, SAI2, $\alpha 1$ and $\alpha 2$. The most significantly radiographic parameters correlated with SAI1, SAI2, $\alpha 1$, $\alpha 2$ were FRA, CA, CA, and CRCI, respectively. Although significant correlation were found between radiographic parameters and cosmetic measurements, none of the correlation coefficient was greater than 0.8.

The correlation coefficients between the first measurement and second measurement for T1, FRA, CA, CPH, CRCI, FRCH, TL, SHi, SHo, SA21, SAI2, $\alpha 1$, $\alpha 2$ were 0.96, 0.98, 0.99, 0.98, 0.99, 0.97, 0.98, 0.96, 0.99, 0.87, 0.85, 0.89, 0.95, respectively.

Discussion

One of the great concerns of the AIS patients is the cosmetic improvement after surgery. The cosmesis of the back and shoulders is of great importance to the adolescents with idiopathic scoliosis and their family [1, 2, 10, 19, 21]. Raso et al. [19] showed that the shoulder balance plays an important role in the cosmesis of AIS patients. The left shoulders were often elevated in AIS patients with double thoracic curves with positive T1 tilting. Hence, it is very important for the spine surgeons to evaluate the shoulder balance in AIS patients with double thoracic curves. Actually, the shoulder balance is an important indication to decide whether or not to instrument to the proximal thoracic curve [16, 23]. However, up to now, only radiographic parameters have been used to evaluate the shoulder balance in the literatures without any measurable cosmetic parameters. In the present study, several cosmetic parameters were developed to evaluate the cosmetic shoulder balance. The results indicated that the radiographic shoulder balance could not fully reflect the cosmetic shoulder balance; discrepancy did exist between radiographic shoulder balance and cosmetic shoulder balance. As none of the radiographic parameters correlated excellently with the cosmetic parameters, it is suggested that the cosmetic parameters serve as a supplement to the radiographic parameters in the evaluation of shoulder balance.

Table 2 Correlations between shoulder cosmesis and the radiographic measurements

	Cobb_PT	Cobb_T	T1	FRA	CA	CPH	CRCI	FRCH	TL
SHi									
Correlation	0.16	-0.12	0.54	0.61	0.38	0.40	0.47	0.03	0.20
P value	0.37	0.051	<0.01*	<0.01*	0.03*	0.02*	<0.01*	0.87	0.26
SHo									
Correlation	0.004	-0.22	0.51	0.53	0.73	0.67	0.74	-0.45	0.21
P value	0.98	0.22	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*	0.22
SAI1									
Correlation	0.03	-0.17	0.48	0.65	0.60	0.48	0.59	-0.34	0.21
P value	0.85	0.34	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*	0.05	0.24
SAI2									
Correlation	0.09	-0.11	0.47	0.59	0.64	0.58	0.64	-0.41	0.03
P value	0.61	0.52	<0.01*	<0.01*	<0.01*	<0.01*	<0.01*	0.02*	0.85
$\alpha 1$									
Correlation	-0.03	-0.20	0.32	0.45	0.61	0.58	0.60	-0.38	0.10
P value	0.86	0.26	0.07	<0.01*	<0.01*	<0.01*	<0.01*	0.03*	0.56
$\alpha 2$									
Correlation	-0.31	-0.43	0.22	0.37	0.51	0.48	0.53	-0.30	0.06
P value	0.07	0.01*	0.20	0.03*	<0.01*	<0.01*	<0.01*	0.08	0.76

Abbreviations as showed in Table 1

* $P < 0.05$

Radiographic parameters of the shoulder and cosmetic shoulder height

Many radiographic parameters have been used to evaluate the shoulder balance in the literatures, and the radiographic balanced shoulder was usually regarded as cosmetic leveled shoulder height. Bago et al. [3] tried to investigate the relationship between the shoulder height and the radiographic parameters. He reported on four radiographic measurements to estimate shoulder height in scoliosis. Correlation coefficients between each measurement and shoulder level were 0.54 for T1 tilting ($P = 0.001$), 0.63 for first rib inclination ($P < 0.001$), 0.96 for coracoid process ($P = 0.0001$), and 0.93 for clavicle-rib cage intersection ($P = 0.0001$). The interobserver error of clavicle-rib cage intersection is significantly lower than the coracoid process; hence the author suggested that the point at which the clavicle and rib cage intersect is the most reliable landmark to estimate the shoulder height on the radiographs of scoliotic spines. In their study [3], a horizontal line was traced at the upper margin of each acromioclavicular joint. The difference in millimeters between the right and left lines was considered to be the shoulder level by the authors. It is obviously that the soft tissues superior to the acromioclavicular joints also contribute to the cosmetic shoulder height because of asymmetry of the soft tissues between left and right often occurs. Therefore, in the study, they actually correlated radiographic shoulder height to several other radiographic parameters. In another study [14], the shoulder height was defined as the graded height difference of soft tissue shadows directly superior to the acromioclavicular joints. However, the author only correlated the preoperative radiographic parameters to the postoperative shoulder balance without assessing the relationship between preoperative radiographic parameters and preoperative shoulder balance.

We correlated the preoperative radiographic parameters to the cosmetic shoulder height preoperatively in the present study. The cosmetic shoulder heights were measured directly on the photographs. The results showed that the correlation coefficients between T1 tilting, first rib angle (T1, FRA) and shoulder height were similar with Bago's [3] study (Table 1), which indicated that T1, FRA were moderately correlated with the shoulder level. The correlation coefficients between CPH, CRCI and shoulder level were not as significant as Bago's study; it was 0.40 for CPH, 0.47 for CRCI with SHi, and 0.67 for CPH, 0.74 for CRCI with SHo. The difference between the results of our study and Bago's study may be due to the fact that Bago's study ignored the soft tissue directly superior to the acromioclavicular joints, while we measured the cosmetic shoulder levels. CA, FRCH, TL were used by Kuklo [14] to

evaluate the shoulder height. Our results showed that only CA was moderately correlated with the shoulder level. Hence, our study showed that all the correlation coefficients between the cosmetic shoulder height and radiographic parameters were not greater than 0.8. It indicated that radiographic balanced shoulders may not exactly reflect the cosmetic balanced shoulders. Thus, the evaluation of shoulder height in the photographs is also very important.

Two types of cosmetic findings may exist in terms of left shoulder level in AIS patients with positive T1 tilting. One has elevated left inner shoulder and elevated left outer shoulder; the other has elevated left inner shoulder and descended left outer shoulder. Hence, in the present study, two parameters, i.e., SHi and SHo were used to comprehensively reflect the cosmetic shoulder height. The location of SHo was to some extent similar with the traditional shoulder height of Bago [3] and Kuklo's [14] study, while SHi was a parameter first used by us to evaluate the cosmetic shoulder height.

Radiographic parameters of the shoulder and other cosmetic appearances

Shoulder cosmesis may not only include the shoulder height, but also include the shoulder angle, axilla angle and the areal balance between the left and right shoulders. Hence, besides the SH, several other cosmetic parameters were developed to evaluate the cosmetic shoulder balance in the present study. The $\alpha 1$, SAI1, SAI2 serve as supplements to SH. Shoulder angle emphasizes the imbalance of the inflection points of left and right shoulders, while SAI1 and SAI2 emphasizes the general areal imbalance between left and right shoulders. As the results showed, SAI2 is more sensitive to the disproportion of left and right shoulders than SAI1. Axilla angle reflects the imbalance between the left and right axillae. The results showed that none of the radiographic parameters could exactly reflect these cosmetic parameters, which were similar to SH. Hence, it might not be of convincing evidence to use radiographic parameters to predict the shoulder cosmesis. As shoulder cosmesis is critically important to the adolescent with idiopathic scoliosis, while none of radiographic parameters can exactly reflect the shoulder cosmesis, thus the evaluation of the shoulder cosmetic appearance could be of great importance to the spine surgeons.

One pitfall of the measurement of these cosmetic parameters was the locating of inflection point either between the shoulder and neck or between the shoulder and the upper arm. It could be reflected by the correlation coefficient between the first measurement and second measurement. Hence, more objective cosmetic parameters

need to be developed to reflect the cosmetic appearance of the shoulder in the future. Furthermore, the cosmetic parameters developed in the present study could only reflect the posterior cosmetic appearance. Cosmesis study from the front may be more important for the patient themselves when looking in the mirror. Hence, based on the premise that patients' privacies were preserved, cosmesis study from the front or even three dimensional studies need to be conducted in the future.

Conclusion

The radiographic evaluation of shoulder balance is important for the spine surgeons to make surgical decision in patients with double thoracic curve, but it cannot fully reflect the cosmetic shoulder balance. The shoulder balance should also include the cosmetic aspect. As the cosmesis of the back and shoulders is critically important to the patients' satisfaction, and none of the radiographic parameters correlated excellently with the cosmetic parameters, we suggest spine surgeons should pay more attention to the cosmetic shoulder balance rather than radiographic shoulder balance to make surgical decision.

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