RESEARCH ARTICLE

Assessment of Neck Imbalance in Adolescent Idiopathic Scoliosis Patients: A Cross-Section Study Based on Body Image of 115 Patients with Main or Double Thoracic Curve

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Objective: Neck imbalance negatively affects body aesthetics of adolescent idiopathic scoliosis (AIS) patients. The evaluation of neck imbalance is currently limited to radiographic parameters, but lacks visual indicators. Therefore, the purpose of this study was to establish indexes of neck imbalance based on body image and to investigate whether these indexes can truly reflect neck imbalance in AIS patients.

Methods: We performed a cross-sectional study at a single institution between June 2017 and September 2020 and there were 115 subjects involved in this research. All patients were diagnosed with adolescent idiopathic scoliosis, Lenke type I/II. Radiographic parameters measured included cervical axis tilt (CAT), T1 tilt, first rib angle (FRA), clavicle angle (CA), radiographic shoulder height (RSH), proximal thoracic curve (PTC), apical vertebra translation of proximal thoracic (AVT of PT), main thoracic curve (MTC), apical vertebra translation of main thoracic (AVT of MT) and coronal balance (CB/C7PL-CSVL). Neck imbalance indexes were obtained and measured following a standardized manner. Intra-class correlation coefficient (ICC) analysis was performed for neck imbalance indexes to determine their intra-observer and inter-observer reliability, and correlation tests were performed for neck imbalance indexes with the radiographic parameters mentioned above.

Results: Strong intraobserver and interobserver reliability were observed in neck imbalance index (NII) 1 (0.91 and 0.88), neck imbalance index 2 (0.85 and 0.81) and NII 3 (0.82 and 0.80), $P < 0.05$. Significant correlation was found in cervical axis tilt ($R = 0.81$ for NII 1, $R = 0.77$ for NII 2 and $R = 0.78$ for NII 3), T1 tilt ($R = 0.43$ for NII 1, $R = 0.52$ for NII 2 and $R = 0.48$ for NII 3), first rib angle ($R = 0.41$ for NII 1, $R = 0.48$ for NII 2 and $R = 0.43$ for NII 3), proximal thoracic curve ($R = 0.36$ for NII 2) and apical vertebra translation of proximal thoracic ($R = -0.37$ for NII 2 and $R = -0.35$ for NII 3) with neck imbalance indexes. Neck imbalance index 1 showed the highest correlation with cervical axis tilt ($R = 0.81$, $P < 0.01$).

Conclusions: Neck imbalance indexes established in our study were in good correlation with cervical axis tilt (CAT), At the meantime, they showed significant correlations with T1 tilt and first rib angle (FRA). Our study provides a practical method for measurement of neck imbalance regarding realistic perspective and makes up for the lack of photographic indexes about neck imbalance.

Key words: Adolescent idiopathic scoliosis; Neck imbalance; Radiographic image; Thoracic curve

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Introduction

Adolescent idiopathic scoliosis (AIS) is a three-dimensional deformity of the spine, often involving lateral deviation of the vertebrae, loss of anterior and posterior curvature, and rotation of the vertebrae.[1] AIS usually causes negative impacts on patients' body appearance, resulting in low evaluation of patients themselves, and even psychological distresses in some female adolescents.[2–5] In most cases, Spinal surgeons are committed to the major curve correction on X-ray plain films to improve spinal deformities. However, people intuitively assess body image from observation, rather than from measurements of X-ray imaging metrics. At the same time, studies have reported that spinal orthopedic surgery sometimes successfully improves scoliosis on plain radiographs, without a corresponding increase in patients' satisfaction with treatment.[6,7] Therefore, there should be visual indicators to help physicians better evaluate body deformity in AIS patients.

Shoulder imbalance greatly affects the aesthetics performance of AIS patients' back,[8] and several parameters based on X-ray film have been proposed to assess shoulder imbalance of scoliosis patient.[9–12] In order to assess malformation, Qiu *et al*[13] defined a set of photo-based parameters to evaluate the cosmetic performance of shoulder and back in AIS patients. Similarly, Akel *et al*[14] built a new clinical picture-index to reflect the actual shoulder balance level in the asymptomatic adolescent population.

Neck imbalance harms AIS patient body cosmesis, and degrades treatment satisfaction of patients and their families.[15–17] Neck imbalance may be related to several reasons, Campbell *et al*[18] found that patients with severe congenital thoracic scoliosis could have prominent neck imbalance. Kwan *et al*[19] found that T1 tilt was significantly correlated with the clinical neck imbalance in their retrospective study. Meanwhile, cervical axis tile (CAT) is widely used as a radiographic index in the evaluation of neck imbalance. Few researches have focused on neck imbalance in realistic view, and the actual appearance of deformation may be equivalently significant in evaluation and surgical treatment. Therefore, the purpose of our study is: (i) to establish a couple of neck imbalance indexes based on photograph; and (ii) to analyze the reliability of these indexes with existing radiographic parameters such as CAT and T1 tilt.

Method

Subjects

This is a cross-section study based on June 2017 to September 2020 patients' data from a single institution. The study was lined with the Declaration of Helsinki, approved by the Second Affiliated Hospital of Wenzhou Medical University Ethics Committee (ethic code: LCKY2020-164) and written informed consent was obtained from each patient.

Inclusion and Exclusion Criteria

Each patient involved had both full posteroanterior spine X-ray film and photographs of upright standing posture taken behind them. The inclusion and exclusion criteria for this study were listed as follows, Incision criteria: (i) the clinical diagnosis was adolescent idiopathic scoliosis; and (ii) Lenke type was I or II. Exclusion criteria: (i) patients who have undergone scoliosis correction surgery; (ii) patients who have deformity or pathology of cervical spine; and (iii) patients missing full-length posteroanterior film of spine or body photograph shot from behind.

The following data were collected and recorded for each participant: gender, age, Lenke type (main thoracic scoliosis or double thoracic scoliosis), neck imbalance indexes and radiological parameters referring to neck imbalance.

Acquisition of Radiographic Parameters

The posteroanterior full-length standing radiographs of the spine were captured as follows: tell patient to be relaxed; posteroanterior views of the whole spine including the lower cervical vertebrae, both shoulders, and both hips; take off shoes to avoid spine deviation caused by excessive shoe wear; keep hands naturally hanging on both sides of body and stand upright. The radiographic parameters obtained included: cervical axis tilt (CAT):[19] angle between the cervical axis (the line connecting center of odontoid process and center of C7 vertebra) and the vertical axis. T1 tilt:[11] the angle between the upper end-plate of T1 vertebra and the horizontal line. First rib angle (FRA):[11] the angle between the tangent line of superior margin of first rib and the horizontal line. Clavicle angle (CA):[8] the angle between the line connecting the highest point of the left and right clavicle and the horizontal line. Radiographic shoulder height (RSH):[12] vertical distance between superior horizontal reference line (SHRL) and inferior horizontal reference line (IHRL), where SHRL is a horizontal line that passes through the intersection of the soft tissue shadow of the shoulder and the perpendicular line of the acromioclavicular joint on the higher side, IHRL is a horizontal line that passes through the intersection of the soft tissue shadow of the shoulder and the perpendicular line of the acromioclavicular joint on the lower side. Parameters mentioned above are shown in Fig. Fig. 1A, B. Radiographic parameters related to thoracic curve: proximal thoracic curve (PTC), apical vertebra translation of proximal thoracic (AVT of PT), main thoracic curve (MTC), apical vertebra translation of main thoracic (AVT of MT) and coronal balance (CB/C7PL-CSVL) were also taken into analysis in our study.

Acquisition of Neck Imbalance Indexes

The photographs were taken within 1 day of the patients' full-length spine radiography. For the protection of patients' privacy, we obtained the photographs from behind the patients. Patients stood upright on the level floor with their shoes removed, completely exposed neck and shoulder, kept the body and face parallel to the wall and both upper limbs drooping naturally on both sides of body. The photographs were taken by the same physician 1.5 to 2 meters away from the patient. The main manifestation of neck imbalance is the

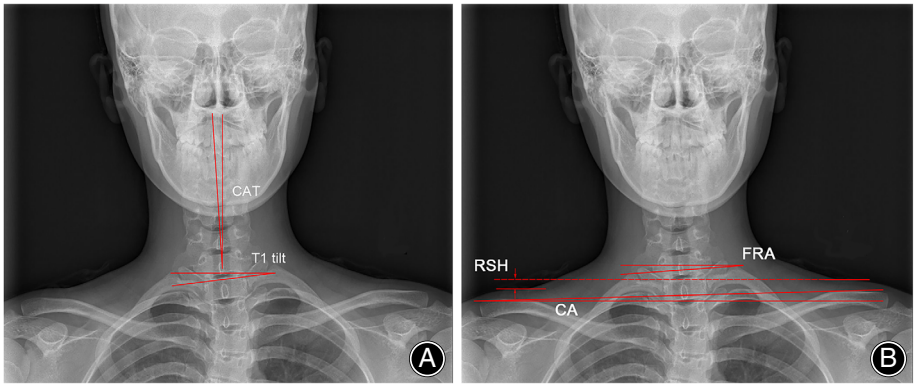

Fig. 1 Radiographic parameters used to evaluate shoulder and neck imbalance. (A) CAT: angle between the cervical axis (line connecting center of odontoid process and center of C7 vertebra) and the vertical axis. T1 tilt: angle between the upper end-plate of T1 vertebra and the horizontal line. (B) FRA: angle between the tangent line of superior margin of first rib and the horizontal line. CA: angle between the line connecting the highest point of the left and right clavicle and the horizontal line. RSH: Vertical distance between superior horizontal reference line (SHRL) and inferior horizontal reference line (IHRL)

tilt of the cervical axis on coronal plane, we developed a set of parameters to get a full measurement of that, neck imbalance index 1 (NII 1) is a measurement of neck tilt on axis. Neck imbalance index 2 (NII 2) reflects neck tilt regarding the horizontal direction. Neck imbalance index 3 (NII 3) reflects neck tilt by the area ratio. After the photographs were uploaded to the computer, the measurement was completed by Image-pro plus software version 6.0 (Media Cybernetics Inc., Rockville, MD, USA).

Neck imbalance index 1 (NII 1)

Draw line l_1 connecting the junction point of earlobe and cheek on both sides, make l_1's perpendicular bisector m, the angle between m and the vertical line is defined as neck imbalance index 1 (Figure 2A).

Neck imbalance index 2 (NII 2)

Draw line l_2 connecting the inflection point of neck and cheek on both sides, the angle between l_2 and the horizontal line is defined as neck imbalance index 2 (Figure 2B).

Neck imbalance index 3 (NII 3)

Draw line l_1 connecting the earlobe and cheek junction point on both sides, pass through the higher inflection point of neck and shoulder draw the horizontal line l_3, pass the midpoint of l_1 draw the vertical line v, v divided the area surrounded by l_1, l_3 and the lateral margin of neck into A_1 and A_2, the ratio of A_1 area to A_2 area was defined as neck imbalance index 3 (Figure 2C).

Statistical Analysis

For the statistical description, values were taken for all radiographic and photographic parameters and positive or negative represents the direction of imbalance. Intra-class correlation coefficient (ICC) method was used to verify interobserver and intraobserver reliability of each neck imbalance index. Pearson correlation analysis was used to analyze the correlation between neck imbalance indexes and radiographic parameters. All the statistical analyses were performed by SPSS software version 21.0 (IBM, Armonk, NY, USA). $P < 0.05$ was considered to have statistical significance.

Results

General Results

There were 115 subjects involved in our study. The mean age was 14.2 ± 3.1 years old. Seventy-four patients (64%) were females and 41 (36%) were males. Eighty-two patients (72%) had main thoracic curves and 33 (28%) had double thoracic curves.

Assessment Outcomes

With the neck imbalance indexes, the mean value of NII 1 was 3.74 ± 3.69°, while the mean values of NII 2 and NII 3 were 3.79 ± 3.69° and 1.05 ± 0.05 respectively.

With radiographic parameters, the mean values of each parameter were CAT: 4.65 ± 3.37°, T1 Tilt: 5.83 ± 4.71°, FRA: 3.74 ± 4.87°, CA: 0.00 ± 1.96°, RSH: −2.33 ± 11.87 mm, PT Cobb: 27.37 ± 12.25°, AVT of PT: −5.95 ± 5.21°, MT cobb: 40.85 ± 12.16°, AVT of MT: 32.14 ± 13.98 mm, CB: 0.65 ± 12.48 mm. The magnitude of neck imbalance indexes and radiographic parameters were shown in Table 1.

ICC Results

In the term of intraobserver reliability analysis, neck imbalance indexes were measured by one physician through *Image-pro plus* software. Four weeks later, the same physician repeated the measurement using the same method. The ICC analysis results for each index were: 0.91 for NII 1, 0.85 for NII 2 and 0.82 for NII 3, $P < 0.05$. in terms of interobserver reliability analysis, the same measurement method was taken by another physician. The ICC analysis results were 0.88 for

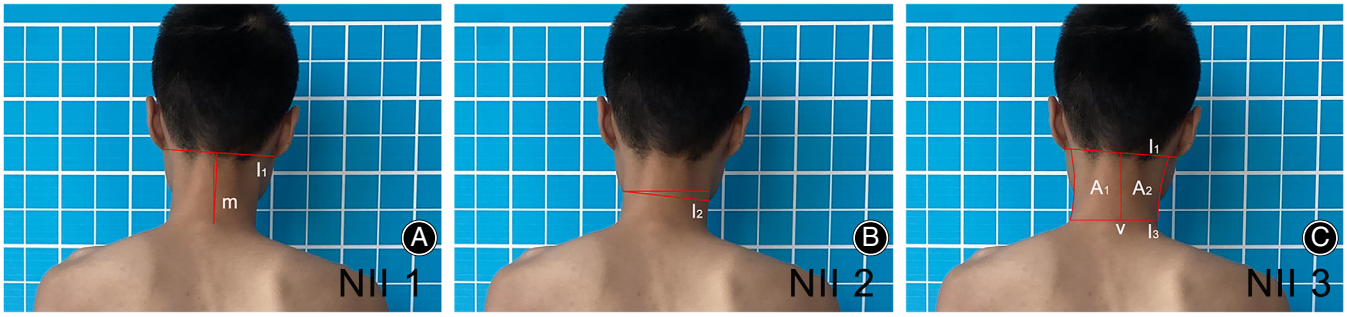

Fig. 2 Photographic indexes used to evaluate neck imbalance. Neck imbalance index 1(NII 1): draw line l_1 connecting earlobe and cheek junction point on both sides, make the perpendicular bisector m of l_1, the angle between m and vertical line is defined as NII 1 (A). Neck imbalance index 2 (NII 2): draw line l_2 connecting the inflection point of neck and cheek on both sides, the angle between l_2 and horizontal line is defined as NII 2 (B). Neck imbalance index 3 (NII 3): draw line l_1 connecting earlobe and cheek junction point on both sides, pass the higher inflection point of neck and shoulder draw the horizontal line l_3, pass the midpoint of l_1 draw the vertical line v, v divided the area surrounded by l_1, l_3 and the lateral margin of neck into A_1 and A_2, the ratio of A_1 area to A_2 area was defined as neck imbalance index 3 (C)

TABLE 1 Magnitude of radiological and photographic parameters

Measurements	N	Minimum	Maximum	Mean	SD
CAT (°)	115	−4.50	12.20	4.65	3.37
T1 Tilt (°)	115	−7.20	14.00	5.83	4.71
FRA (°)	115	−5.80	14.00	3.74	4.87
CA (°)	115	−5.00	4.00	0.00	1.96
RSH (mm)	115	−28.1	15.6	−2.33	11.87
PT Cobb (°)	115	0.00	54.70	27.37	12.25
AVT of PT (mm)	115	−20.35	1.80	−5.95	5.21
MT Cobb (°)	115	24.60	68.70	40.85	12.16
AVT of MT (mm)	115	5.70	64.90	32.14	13.98
CB (mm)	115	−19.70	28.20	0.65	12.48
NII 1 (°)	115	−4.20	11.70	3.74	3.69
NII 2 (°)	115	−5.30	9.3	3.79	3.69
NII 3	115	0.95	1.14	1.05	0.05

Abbreviations: AVT of MT, apical vertebra translation of main thoracic; AVT of PT, apical vertebra translation of proximal thoracic; CA, clavicle angle; CAT, cervical axis tilt; CB, coronal balance; FRA, first rib angle; MT, main thoracic; NII 1, neck imbalance index 1; NII 2, neck imbalance index 2; NII 3, neck imbalance index 3; PT, proximal thoracic; RSH, radiographic shoulder height.

NII 1, 0.81 for NII 2 and 0.80 for NII 3, $P < 0.05$. Details of ICC results were shown in Tables 2 and 3.

Correlation Analysis Outcomes

The correlation analysis between radiographic parameters and neck imbalance indexes was performed using the Pearson correlation test. The results showed that there were significant correlations between all three neck imbalance indexes and CAT ($R = 0.81$ for NII 1, $R = 0.77$ for NII 2 and $R = 0.78$ for NII 3), T1 tilt ($R = 0.43$ for NII 1, $R = 0.52$ for NII 2 and $R = 0.48$ for NII 3) and FRA ($R = 0.41$ for NII 1, $R = 0.48$ for NII 2 and $R = 0.43$ for NII 3), ($P < 0.05$), there were significant correlation between NII 2 and PT Cobb ($R = 0.36$, $P < 0.05$) and AVT of PT ($R = -0.37$, $P < 0.05$), and significant correlation between NII 3 and AVT of PT ($R = -0.35$, $P < 0.05$). CA, RSH, MT Cobb, AVT of MT and CB did not show significant results with neck imbalance indexes. The details of correlation analysis were shown in Table 4.

Discussion

Summary of the Major Results of the Study

We have built several photo-based neck imbalance parameters and ICC analysis showed that neck imbalance parameters have strong intra-observer and inter-observer reliability. Afterwards, the correlation was tested between radiographic parameters and neck imbalance indexes, and the results showed that all three indexes are suitable for the measurement of neck imbalance in AIS patients, in that they showed excellent consistencies with CAT. Meanwhile, our indexes showed normal consistencies with T1 tilt and FRA.

The Need for Photographic Indicators in AIS Patients

Many studies have expounded on the adverse effect of body deformities and demonstrated how we should evaluate it on X-ray image in AIS patients.[9,13,14,20] X-ray radiation is cheap, convenient, and has outstanding advantages in bone imaging, therefore, it has been used to assess the degree of scoliosis and shoulder balance. However, excessive radiological exposure causes negative effects on patients' health. Photographic assessment of AIS patients is superior to X-ray in terms of cost and convenience, but it has not been widely incorporated into clinical practice. In addition to the fact that radiography is irreplaceable, photographic parameters sometimes do not present a good correlation with radiographic parameters. But in any case, photographic parameters have its value in the assessment of body deformities. Neck imbalance is a body morphological abnormality in AIS patients and sometimes it presents so prominently in postoperative individuals.[15,16] However, there lacks an appearance-based and quantitative evaluation for AIS patient's neck imbalance.

TABLE 2 Intraobserver reliability of photographic measurement methods

Photographic methods	ICC	95% confidence interval		*P*
		Lower	Upper	
NII 1(°)	0.91	0.87	0.95	<0.01
NII 2(°)	0.85	0.80	0.89	<0.01
NII 3	0.82	0.77	0.86	<0.05

Abbreviations: NII 1, neck imbalance index 1; NII 2, neck imbalance index 2; NII 3, neck imbalance index 3.

TABLE 3 Interobserver reliability of photographic measurement methods

Photographic methods	ICC	95% confidence interval		*P*
		Lower	Upper	
NII 1(°)	0.88	0.83	0.92	<0.01
NII 2(°)	0.81	0.75	0.88	<0.01
NII 3	0.80	0.74	0.84	<0.05

Abbreviations: NII 1, neck imbalance index 1; NII 2, neck imbalance index 2; NII 3, neck imbalance index 3

The Current Ways of Neck Imbalance Measuring

CAT was firstly proposed to measure neck imbalance in those with thoracic curve disorder[18] and is widely used in evaluation of neck imbalance in AIS patients.[15,16,21–23] It is defined as the angle of the vertical axis and the line connecting the center of the odontoid process and the center of the C7 vertebral body, thus reflecting the degree of cervical imbalance. In terms of the reproducibility of measurement, CAT was found to have strong intra-observer (0.96) and inter-observer (0.86) reliability in Kwan *et al.*'s[19] research. Meanwhile, in their study, CAT as well as T1 tilt showed statistical differences among neck tilt grading (the grading was defined as: no neck tilt was observed as Grade 0, neck tilt was observed and the patient could self-correct as Grade I, neck tilt was observed and the patient could not self-correct as Grade II, neck tilt was observed, and the height difference of trapezius muscle was greater than 1 cm as grade III). However, this clinical neck tilt grading method has some defects. First, it seems a little subjective to determine whether there is a neck tilt through naked-eye observation. Besides, this grading method paid much attention to the evaluation of medial shoulder imbalance but not enough to the neck tilt itself. Lastly, it lacks a sequential and quantitative indicator for neck tilt. Elaborative measurement method has better application value for clinical work, our method compensated the scarceness of quantitative measurement in neck imbalance evaluation and the data showed good consistency with CAT.

TABLE 4 Correlation analysis of radiological and photographic parameters

	CAT	T1 Tilt	FRA	CA	RSH	PT Cobb	AVT of PT	MT Cobb	AVT of MT	CB
NII 1										
Correlation	0.81**	0.43*	0.41*	0.02	0.00	0.32	−0.23	0.08	0.19	0.04
p value	<0.01	0.01	0.01	0.92	0.91	0.06	0.18	0.66	0.28	0.84
NII 2										
Correlation	0.77**	0.52**	0.48*	0.19	0.22	0.36*	−0.37*	−0.02	−1.00	0.03
p value	<0.01	<0.01	<0.01	0.28	0.21	0.03	0.03	0.91	0.59	0.87
NII 3										
Correlation	0.78**	0.48**	0.43*	0.12	0.04	0.27	−0.35*	0.02	0.07	−0.04
p value	<0.01	<0.01	0.01	0.47	0.79	0.11	0.03	0.93	0.67	0.83

Abbreviations: AVT of MT, apical vertebra translation of main thoracic; AVT of PT, apical vertebra translation of proximal thoracic; CA, clavicle angle; CAT, cervical axis tilt; CB, coronal balance; FRA, first rib angle; MT, main thoracic; NII 1, neck imbalance index 1; NII 2, neck imbalance index 2; NII 3, neck imbalance index 3; PT, proximal thoracic; RSH, radiographic shoulder height.; * Means there was a significant correlation at 0.05 level (bilateral).; ** Means there was a significant correlation at 0.01 level (bilateral).

Patients with severe thoracic scoliosis were more likely to present neck imbalance, this could be due to cervical spine's "bending" capacity for spinal coronal imbalance is insufficient. In that way, for compensation of the rigid proximal thoracic curve, just like the considerable incline of the sacrum can be balanced by aggravation or alleviation of upper lumbar curve lordosis, cervical tilt is the consequence. Although the correlation is weak, our data showed that there were significant correlations between PT and NII 2, as well as AVT of PT and NII 2 and NII 3.

T1 tilt is defined as the angle between the horizontal line and the parallel line of end-plate of T1 vertebra,[9] used to evaluate shoulder balance, especially medial shoulder balance. It is accepted that the T1 vertebra, as the "ground" of cervical spine, whose inclination will cause neck imbalance accompanied by medial shoulder imbalance.[15–17] According to Chan *et al.*'s research,[21] a higher degree of upper instrumented vertebrae (UIV) tilt angle, would aggravate postoperative CAT and T1 tilt among Lenke type 1/2 AIS patients. Similarly, Kwan *et al.*[23] found patients with + ve postoperative UIV tilt angle had more possibility of developing + ve medial shoulder imbalance (T1 tilt $\geq +4$ °) as well as + ve neck imbalance (cervical axis tilt $\geq +4$ °).[23] We took T1 tilt and FRA into analysis in our research, the results showed that neck imbalance indexes were moderately correlated with T1 tilt, as well as FRA. FRA is an equivalent indicator of T1 tilt. The first rib connected to T1 vertebra, showed a similar correlation as T1 tilt with neck imbalance index. Also, other shoulder imbalance parameters, such as CA and RSH, are normally used to assess lateral shoulder imbalance, did not present a significant correlation with the neck imbalance indexes. The reason may be that lateral shoulder imbalance and neck imbalance are distinct phenomenon.[15,16,19]

Limitations and Strengths

We acknowledge there are several limitations in our study. First, our study lacked the patients' self-assessment for assessing the reliability of our neck imbalance indexes. Also, our research is based on the preoperative subjects and more work should be done to determine whether surgical treatment will affect such correlations. Lastly, although we have standardized patients' posture while shooting, the posture still possibly changed between the radiographic and photographic operation.

Conclusion

Spinal surgeon needs a reliable and conventional index to assess visual neck imbalance in AIS patients. Our neck imbalance indexes have shown good correlations with established X-ray parameters, especially neck imbalance index 1, which showed excellent consistency with cervical axis tilt; they could be applicable for evaluating AIS patients' neck imbalance.

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Author Contributions

Xiangyang Wang contributed to the study conceptualization and project administration; Huawei Zhang analyzed the data and wrote the original and revised manuscript; Ben Wang contributed to the study methodology and result validation; Aimin Wu and Zaher Ali Mohamed Meftah contributed to the reviewing; Chongan Huang and Xiangxiang Pan provided the resources; Boda Chen contributed to data Curation; Libin Ni visualized all tables; Yifeng Shi visualized all figures; All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that they have no competing interests.

References

1. Choudhry MN, Ahmad Z, Verma R. Adolescent idiopathic scoliosis. Open Orthop J. 2016;10:143–54.
2. Bengtsson G, Fallstrom K, Jansson B, et al. A psychological and psychiatric investigation of the adjustment of female scoliosis patients. Acta Psychiatr Scand. 1974;50:50–9.
3. Cochran T, Irstam L, Nachemson A. Long-term anatomic and functional changes in patients with adolescent idiopathic scoliosis treated by Harrington rod fusion. Spine. 1983;8:576–84.
4. Iwahara T, Imai M, Atsuta Y. Quantification of cosmesis for patients affected by adolescent idiopathic scoliosis. Eur Spine J. 1998;7:12–5.
5. Asher MA, Lai SM, Glattes RC, Burton DC, Alanay A, Bago J. Refinement of the SRS-22 health-related quality of life questionnaire function domain. Spine. 2006;31:593–7.
6. Tones M, Moss N, Polly DW Jr. A review of quality of life and psychosocial issues in scoliosis. Spine. 2006;31:3027–38.
7. Bao H, Yan P, Lonner B, et al. Validation of the simplified Chinese version of the body image disturbance questionnaire-scoliosis. Spine. 2015;40:E1155–60.
8. Raso VJ, Lou E, Hill DL, Mahood JK, Moreau MJ, Durdle NG. Trunk distortion in adolescent idiopathic scoliosis. J Pediatr Orthop. 1998;18:222–6.
9. Bago J, Carrera L, March B, et al. Four radiological measures to estimate shoulder balance in scoliosis. J Pediatr Orthop B. 1996;5:31–4.
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. Ono T, Bastrom TP, Newton PO. Defining 2 components of shoulder imbalance: clavicle tilt and trapezial prominence. Spine. 2012;37:E1511–6.
12. Kuklo TR, Lenke LG, Won DS, Graham EJ, Sweet FA, Betz RR, et al. Spontaneous proximal thoracic curve correction after isolated fusion of the main thoracic curve in adolescent idiopathic scoliosis. Spine. 2001;26:1966–75.
13. Qiu XS, Ma WW, Li WG, et al. Discrepancy between radiographic shoulder balance and cosmetic shoulder balance in adolescent idiopathic scoliosis patients with double thoracic curve. Eur Spine J. 2009;18:45–51.
14. Akel I, Pekmezci M, Hayran M, et al. Evaluation of shoulder balance in the normal adolescent population and its correlation with radiological parameters. Eur Spine J. 2008;17:348–54.
15. Yang Y, Yang M, Yang Z, et al. Postoperative neck tilt in Lenke 1 and 2 AIS patients after correction surgery: a novel predictive index. BMC Musculoskelet Disord. 2019;20:405.
16. Jiang J, Qian BP, Qiu Y, Wang B, Yu Y, Zhu ZZ. Full fusion of proximal thoracic curve helps to prevent postoperative cervical tilt in Lenke type 2 adolescent idiopathic scoliosis patients with right-elevated shoulder. BMC Musculoskelet Disord. 2017;18:362.

17. Chen Z, Qiu Y, Zhu Z, Li S, Chen X, Xu L, et al. Posterior-only hemivertebra resection for congenital cervicothoracic scoliosis: correcting neck tilt and balancing the shoulders. Spine. 2018;43:394–401.
18. Campbell RM Jr, Adcox BM, Smith MD, et al. The effect of mid-thoracic VEPTR opening wedge thoracostomy on cervical tilt associated with congenital thoracic scoliosis in patients with thoracic insufficiency syndrome. Spine. 2007;32:2171–7.
19. Kwan MK, Wong KA, Lee CK, Chan CYW. Is neck tilt and shoulder imbalance the same phenomenon? A prospective analysis of 89 adolescent idiopathic scoliosis patients (Lenke type 1 and 2). Eur Spine J. 2016;25:401–8.
20. Menon KV, Tahasildar NS. What constitutes shoulder imbalance in adolescent idiopathic scoliosis? Aesthetic threshold for surgical correction. World Neurosurg. 2020;138:e827–38.
21. Chan CYW, Chiu CK, Ler XY, et al. Upper instrumented vertebrae (UIV) tilt angle is an important postoperative radiological parameter that correlates with postoperative neck and medial shoulder imbalance. Spine. 2018;43: E1143–51.
22. Chiu CK, Chan CYW, Tan PH, Goh SH, Ng SJ, Chian XH, et al. Conformity and changes in the radiological neck and shoulder balance parameters throughout 3-year follow-up period: do they remain the same? Spine. 2020;45: E319–28.
23. Kwan MK, Lee SY, Ch'ng PY, et al. A positive (+ve) postoperative upper instrumented vertebra tilt angle (>/=0 degrees) significantly increases the risk of medial shoulder and neck imbalance in lenke 1 and 2 adolescent idiopathic scoliosis patients. Spine. 2020;45:E694–703.