Original Article

Morphology and deformity of the shoulder and pelvis in the entire spine radiographs of adolescent idiopathic scoliosis

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Background: To investigate the deformity and asymmetry of the shoulder and pelvis in adolescent idiopathic scoliosis (AIS) patients.

Methods: This retrospective cross-sectional study enrolled 223 AIS patients with a right thoracic curve or left thoracolumbar/lumbar curve who underwent spine radiographs at the Third Hospital of Hebei Medical University between November 2020 and December 2021. The following parameters were measured: Cobb angle, clavicular angle, glenoid obliquity angle, acromioclavicular joint deviation, femoral neck-shaft projection angle, iliac obliquity angle, acetabular obliquity angle, coronal trunk deviation distance, and spinal deformity deviation distance. The Mann–Whitney U test, Kruskal–Wallis H test were used for inter-group comparisons, and Wilcoxon signed-rank test were used for intra-group left and right sides comparisons.

Results: Shoulder and pelvic imbalances were found in 134 and 120 patients, respectively, and there were 87, 109, and 27 cases of mild, moderate, and severe scoliosis, respectively. Compared with mild scoliosis patients, the difference in the acromioclavicular joint offset on bilateral sides was significantly increased in moderate and severe scoliosis [11.04, 95% confidence interval (CI): 0.09–0.14 for mild, 0.13–0.17 for moderate, and 0.15–0.27 for severe scoliosis, P=0.004], and the difference in the femoral neck-shaft projection angle on bilateral sides was significantly enhanced with scoliosis aggravation (14.14, 95% CI: 2.34–3.41 for mild, 3.00–3.94 for moderate, and 3.57–6.43 for severe scoliosis, P=0.001). The acromioclavicular joint offset was significantly larger on the left than that on the right in patients with a thoracic curve or double curves (thoracic curve −2.75, 95% CI: 0.57–0.69 for the left and 0.50–0.63 for the right, P=0.006; double curve −3.27, 95% CI: 0.60–0.77 for the left and 0.48–0.65 for the right, P=0.001). The femoral neck-shaft projection angle was significantly larger on the left than right in patients with a thoracic curve (−4.46, 95% CI: 133.78–136.20 for the left and 131.62–134.01 for the right, P<0.001), but larger on the right than left in patients with thoracolumbar/lumbar curve (thoracolumbar −2.98, 95% CI: 133.75–136.70 for the left and 135.13–137.82 for the right, P=0.003; lumbar −3.24, 131.97–134.56 for the left and 133.76–136.26 for the right, P=0.001).

Conclusions: In AIS patients, shoulder imbalance has a greater impact on coronal balance and spinal scoliosis above the lumbar segment, whereas pelvic imbalance has a greater impact on sagittal balance and spinal scoliosis below the thoracic segment.

Keywords: Adolescent idiopathic scoliosis (AIS); shoulder balance; pelvis balance; entire spine radiographs

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Introduction

Adolescent idiopathic scoliosis (AIS) is the most common spinal deformity affecting the growth and development of adolescents, resulting in deformation of the 3-dimensional (3D) shape of the spine (1-4). AIS affects not only the development of the spine, but also bone development in other parts of the body, organ function, and mental health to varying degrees, resulting in high and low shoulders, flat back, razor back, thoracic deformity, pelvic tilt, long and short legs, and in serious cases, abnormal cardiopulmonary function, which significantly damage the physical and mental health of teenagers (5-7). The spine is located in the middle of the human trunk and is the primary structure maintaining trunk balance. Under normal circumstances, the motion system of the human body is symmetrical, with the spine acting as the central axis, and the muscles, bones, and nerves on both sides being symmetrically distributed. However, when the spine is subjected to long-term and repeated asymmetrical forces, its stability will be affected, thereby affecting the normal arrangement of the symmetrical structure of the human body (8). Therefore, a "symmetrical structure and asymmetrical force" theory was hypothesized in patients with scoliosis, which may provide a theoretical basis for the treatment of AIS (8).

The shoulder joint connects the upper limb bones on both sides through the upper limb belt bone, joint capsule, muscle, and ligament, protecting and limiting the excessive movement of the joint. Under the synergistic and antagonistic effects of these muscles and ligaments, a mechanical balance is achieved to maintain the stability of the shoulder structure. When scoliosis occurs, the spine loses its normal balance. To maintain this balance, other parts of the body will undergo compensatory changes. In the shoulder, this is often manifested as unequal height on both sides, accompanied by changes in the position of bones on both sides of the upper limbs and changes in the tension of muscles and ligaments, which will affect the correspondence of various components of the shoulder joint (9,10).

As a central and important force-bearing part of the human body, the pelvis is located between the spine and lower limbs and maintains the balance of the human body. The cervical, thoracic, and lumbar segments are the 3 segments of vertebral rotation, and the pelvis has been proposed as the fourth rotational plane of scoliosis. For AIS patients, when 1 segment is unstable, the other segments will compensate to restore the balance of the whole spine. 3D changes in the pelvis, such as inclination and pelvic rotation, affect the balance of the entire body (11,12). By analyzing the imaging data and relevant laws and characteristics of shoulder and pelvic morphological imbalance in AIS patients, this study aimed to investigate the internal correlation between scoliosis and body asymmetry to provide new ideas for the prevention and treatment of adolescent scoliosis in the future. We present the following article in accordance with the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) reporting checklist (available at https://qims.amegroups.com/article/view/10.21037/qims-22-656/rc).

Methods

Participants

This retrospective, single-center, cross-sectional study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and was approved by the Ethics Committee of the Third Hospital of Hebei Medical University. The legal guardians of the AIS patients provided written informed consent to participate in this study. A total of 223 AIS patients with a right thoracic curve or left thoracolumbar/lumbar curve who underwent anteroposterior and lateral radiographs of the entire spine at the third Hospital of Hebei Medical University between November 2020 and December 2021 were enrolled (*Figure 1*). The inclusion criteria were as follows: (I) patients with AIS who underwent anteroposterior and lateral

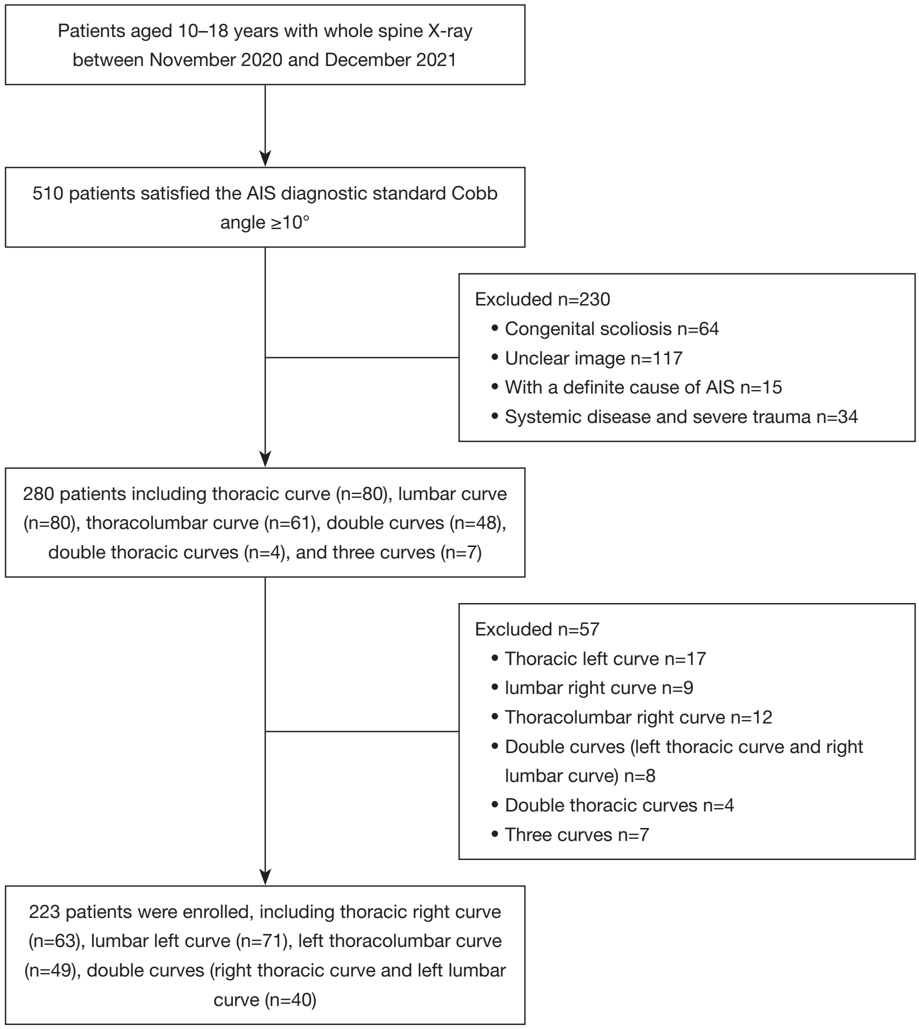

Figure 1 Flowchart showing the AIS patient enrollment process. AIS, adolescent idiopathic scoliosis.

radiographs of the entire spine; (II) Cobb angle >10°; (III) aged 10–18 years; (IV) no surgical or bracing treatment; and (V) the direction of scoliosis on the right side in the thoracic segment (right thoracic curvature) and left side in the thoracolumbar/lumbar segment (left thoracolumbar or lumbar curvature), which accounted for the majority of scoliosis cases (13). The exclusion criteria were as follows: (I) patients with congenital scoliosis, including hemivertebra, butterfly vertebra, and poor vertebral segmentation; (II) scoliosis with definite etiology, including secondary neurofibromatosis, Marfan syndrome, and syringomyelia; (III) history of pelvic, hip, and lower limb diseases or abnormal function and structure; (IV) spinal tumors, history of trauma and infection, metabolic bone diseases, and congenital diseases; and (V) unclear images which may affect the measurement of relevant parameters. Patients with a left thoracic curvature and right lumbar curvature were also excluded for the following reasons. In patients with the left thoracic curvature, most of the lateral curvature was smaller, within 20°, and the main curvature was closer to the cervical spine. In patients with right lumbar scoliosis, most cases had wedge-shaped vertebral bodies in the lumbar spine, and according to the degree of vertebral body deformation in these patients, it occurred either before or after birth and belonged to the category of infantile or congenital scoliosis.

Imaging examination and measurement

Full spine anteroposterior and lateral X-ray radiographs were obtained by a Siemens Ysio max Digital Medical X-ray

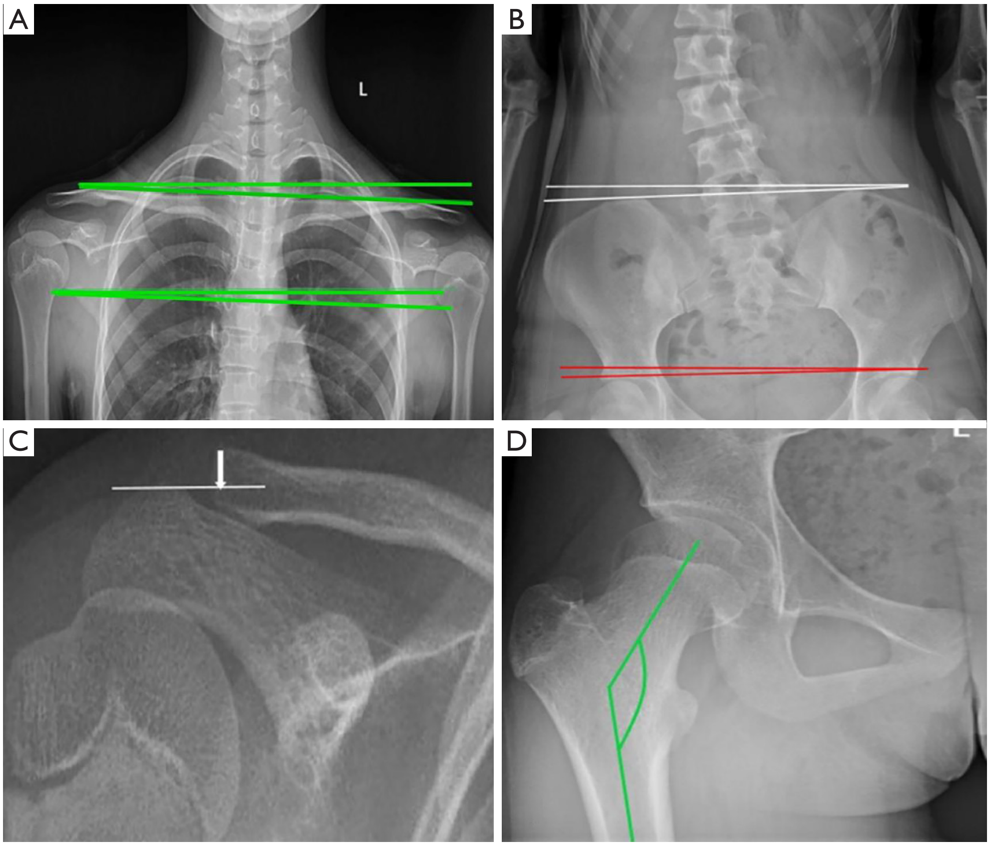

Figure 2 Measurement of the CA, glenoid inclination, IO, acetabular inclination angle, acromioclavicular joint offset, and projection angle of the femoral neck shaft. (A) The two lines above indicate the CA, which is the included angle between the line connecting the highest points of the clavicles on both sides and the reference line of the horizontal line. The lines below represent the glenoid inclination angle, which is the included angle of the tangent line of the glenoid lower edge of both glenohumeral joints. (B) The white lines above represent the IO: the included angle between the line connecting the highest points of the bilateral iliac crest and the horizontal reference line. The red lines below represent the acetabular inclination angle: the included angle of the tangent line of the uppermost edge of both acetabula. (C) The white arrow indicates the acromioclavicular joint offset: the vertical distance from the upper tip of the acromion to the upper outer edge of the clavicle. (D) The projection angle of the femoral neck shaft is shown: the angle between the long axis of the femoral neck and the extension line of the long axis of the femoral shaft. CA, clavicle angle; IO, iliac obliquity.

photography system (Siemens, Erlangen, Germany) using a special filter grid for full-length spinal photography and a film distance of 300 mm.

Anteroposterior position: anatomical position, eyes straight ahead, hands naturally drooping, palms facing forward, both hips and knees naturally extended, and feet placed together.

Lateral position: standing naturally with hands on the support in front.

Photographs were taken by 2 technicians with over 5 years of relevant working experience. All indexes were measured by 2 clinicians with 3 years of relevant working experience and were performed on the picture archiving and communication systems (PACS; Donghua iMedical PACS 2020; Beijing, China), including the Cobb angle, clavicular angle (CA) (6), glenoid obliquity angle, acromioclavicular joint deviation or offset (14), femoral neck-shaft projection angle, iliac obliquity angle (IO) (15), acetabular obliquity angle, coronal width ratio of the left and right pelvis (L/R) (16), coronal trunk deviation distance, and spinal deformity deviation distance on the sagittal plane (17,18) (*Figures 2,3*). There was no missing data.

AIS was defined as a Cobb angle >10°. A CA ≥2° was defined as shoulder imbalance, and the left side being higher was considered positive (5). An IO ≥2° was defined

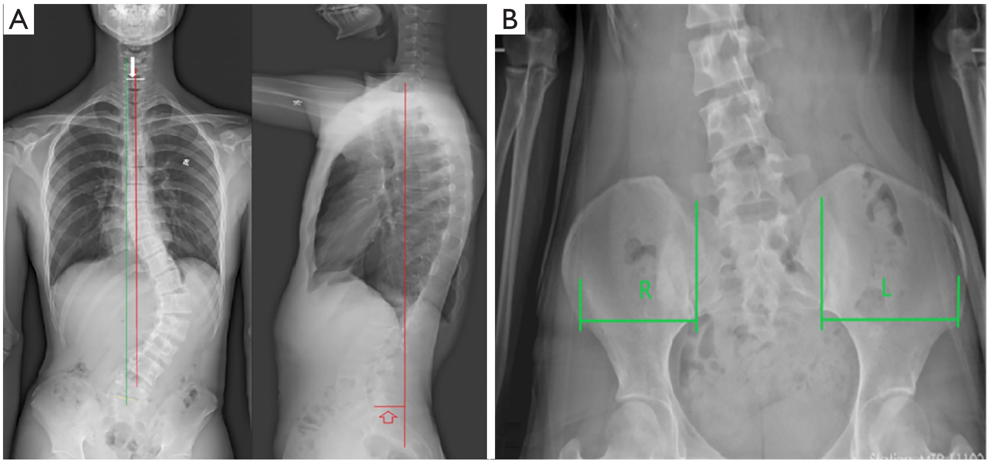

Figure 3 Measurement of the spinal coronal torso offset distance, sagittal plane offset distance, and the coronal width ratio of the left and right pelvis (L/R). (A) The white arrow on the left indicates the coronal torso offset distance: the horizontal distance of the C7 plumb line to the sacral midline. The red arrow on the right figure represents the offset distance of the sagittal plane of the spine: the horizontal distance between the vertical line passing through the center of the C7 vertebral body and the upper rear corner of the S1 vertebral body. (B) The coronal width ratio of the left and right pelvis is shown: the horizontal distance between the lower edge of the medial sacroiliac joint and the lateral anterior superior iliac spine.

as pelvic imbalance, and the left side being higher was recorded as positive (15). A coronal width ratio of the left and right halves of the pelvis (L/R) <1 represented a right rotation of the pelvis, and an L/R ratio <1 reflected a left rotation of the pelvis (16). All data were evaluated by researchers without the use of automatic software programs.

Statistical analysis

The software SPSS 26.0 (IBM Corp., Armonk, NY, USA) was used for data analysis . To achieve an α error probability of 0.05, a power (1-β error probability) of 95%, and 2 tails, a total of 42 patients were needed. Enumeration data were expressed as the median (interquartile range). The Mann–Whitney U test was used to compare the imaging parameters of the shoulder and pelvic balance and/or imbalance groups. The Kruskal–Wallis H test was used to compare the imaging parameters of patients with different severities and types of AIS. The Wilcoxon signed-rank test was used to for intra-group comparison of the left and right sides. Statistical significance was set at $P<0.05$.

Results

Participants

A total of 223 patients aged 10–18 (mean 13.66±2.06) years were enrolled, including 68 (30.49%) males and 155 (69.51%) females. The Cobb angle ranged from 10.10° to 59.90°. There was mild scoliosis (10°< Cobb angle ≤20°) in 87 (39.00%) patients, moderate scoliosis (20°< Cobb angle ≤45°) in 109 (48.90%) patients, and severe scoliosis (Cobb angle >45°) in 27 (12.10%) patients. As for the types of scoliosis, 63 (28.25%) patients had a thoracic curve, 71 (31.84%) had a lumbar curve, 49 (21.97%) had a thoracolumbar curve, and 40 (17.94%) had double curves (*Table 1*).

The methods of scoliosis determination were also collected. Among the 223 AIS patients, 102 (45.7%) were noticed by their families or friends, 94 (42.2%) were found in physical or imaging examinations, and 27 (12.1%) were observed by the patients themselves. Although most AIS patients had no subjective feelings, 15 patients had sought medical help because of shoulder or back pain.

Shoulder morphology

Among the 223 included patients, 134 had shoulder imbalance (CA ≥2°), with a shoulder imbalance rate of 60.09%, and the shoulder imbalance rate of lumbar curve was the lowest (53.50%) (*Table 1*). The glenoid obliquity angle and the difference between the clavicular and glenoid obliquity angles were all significantly larger in the shoulder

Table 1 Patients with shoulder and pelvic imbalance in different types of scoliosis

Variables	Thoracic curve (n=63)	Lumbar curve (n=71)	Thoracolumbar curve (n=49)	Double curves (n=40)	Total (n=223)
Shoulder imbalance	39 (61.90%)	38 (53.50%)	33 (67.30%)	24 (60.00%)	134 (60.09%)
Pelvic imbalance	26 (41.20%)	43 (60.50%)	29 (59.10%)	22 (55.00%)	120 (53.81%)

Table 2 Characteristics of patients with balance and imbalance in shoulder

Variables	Shoulder balance (n=89), median (IQR), 95% CI	Shoulder imbalance (n=134), median (IQR), 95% CI	U	P value
CA	1.30 (0.70), 1.25–1.41	2.80 (1.20), 2.88–3.21	–	–
Glenoid obliquity angle	0.70 (1.10), 0.74–1.03	2.10 (1.70), 2.01–2.47	2,274.0	<0.001**
Clavicular-glenoid inclination angle difference	0.60 (0.70), 0.59–0.81	0.80 (1.00), 0.87–1.54	4,835.5	0.02**
Coronal trunk deviation distance	1.00 (0.89), 0.88–1.19	1.63 (1.40), 1.69–2.00	2,878.5	<0.001**
Spinal sagittal deviation distance	−1.65 (4.27), −1.77 to −0.61	−1.73 (4.10), −2.07 to −1.01	5,480.0	0.31

**, P<0.01. CA, clavicle angle; IQR, interquartile range: CI, confidence interval.

Table 3 Analysis of the left and right acromioclavicular joint offset and neck-shaft projection angle of different scoliosis types

Group	Acromioclavicular joint deviation (mm), median (IQR), 95% CI				Neck-shaft projection angle (°), median (IQR), 95% CI			
	Left	Right	Z	P value	Left	Right	Z	P value
Thoracic curve (n=63)	0.60 (0.28), 0.57–0.69	0.53 (0.30), 0.50–0.63	−2.75	0.006**	134.00 (6.20), 133.78–136.20	132.50 (6.60), 131.62–134.01	−4.46	0.000**
Lumbar curve (n=71)	0.67 (0.37), 0.66–0.78	0.63 (0.36), 0.62–0.76	−1.88	0.06	133.40 (7.50), 131.97–134.56	134.30 (6.50), 133.76–136.26	−3.24	0.001**
Thoracolumbar curve (n=49)	0.67 (0.29), 0.63–0.78	0.67 (0.36), 0.60–0.74	−1.68	0.09	134.80 (5.35), 133.75–136.70	136.60 (4.15), 135.13–137.82	−2.98	0.003**
Double curves (n=40)	0.69 (0.42), 0.60–0.77	0.58 (0.42), 0.48–0.65	−3.27	0.001**	132.80 (9.10), 130.62–134.02	132.40 (6.90), 131.54–134.65	−1.36	0.13

**, P<0.01. IQR, interquartile range: CI, confidence interval.

imbalance group than those in the shoulder balance group [2,274.0, 95% confidence interval (CI): 0.74–1.03 for shoulder balance and 2.01–2.47 for shoulder imbalance, P<0.001; 4,835.5, 95% CI: 0.59–0.81 for shoulder balance and 0.87–1.54 for shoulder imbalance, P=0.02, respectively] (*Table 2*).

The acromioclavicular joint deviation was significantly greater on the left than on the right in patients with a thoracic curve and double curves (thoracic curve −2.75, 95% CI: 0.57–0.69 for the left and 0.50–0.63 for the right, P=0.006; double curves −3.27, 95% CI: 0.60–0.77 for the left and 0.48–0.65 for the right, P=0.001), but no significant difference existed between the left and right sides in patients with a lumbar or thoracolumbar curve (lumbar curve −1.88, 95% CI: 0.66–0.78 for the left and 0.62–0.76 for the right, P=0.06; thoracolumbar curve −1.68, 95% CI: 0.63–0.78 for the left and 0.60–0.74 for the right, P=0.09) (*Table 3*).

The distribution of difference between the left and right sides of acromioclavicular joint deviation in different degrees of scoliosis was significantly different (H=11.043, P=0.004). A significant difference was found between the mild and moderate scoliosis groups (−22.2, 95% CI: 0.09–0.14 for mild scoliosis and 0.13–0.17 for moderate scoliosis, P=0.017) and the mild and severe scoliosis groups (−42.8, 95% CI: 0.15–0.27 for severe scoliosis, P=0.003) (*Table 4*). However, no significant difference existed between

Table 4 Difference in the acromioclavicular joint deviation and neck-shaft projection angle in various curve degrees

Variables	Mild scoliosis (n=87), median (IQR), 95% CI	Moderate scoliosis (n=109), median (IQR), 95% CI	Severe scoliosis (n=27), median (IQR), 95% CI	H	P value
Left-right deviation difference of AC	0.08 (0.13), 0.09–0.14	0.13 (0.13), 0.13–0.17	0.20 (0.23), 0.15–0.27	11.04	0.004**
Left-right difference of NSPA	2.10 (2.10), 2.34–3.41	3.10 (3.00), 3.00–3.94	4.10 (3.40), 3.57–6.43	14.14	0.001**

**, P<0.01; AC, acromioclavicular joint (mm); NSPA, neck-shaft projection angle (°). IQR, interquartile range: CI, confidence interval.

Table 5 Characteristics of patients with balance and imbalance in pelvis

Variables	Pelvic balance (n=103), median (IQR), 95% CI	Pelvic imbalance (n=120), median (IQR), 95% CI	U	P value
Coronal IO	1.20 (0.70), 1.20–1.35	2.90 (1.30), 3.01–3.40	–	–
Acetabular obliquity angle	1.00 (1.00), 0.95–1.25	1.30 (1.40), 1.31–1.71	4988.5	<0.001**
Pelvic-acetabular tilt angle difference	0.80 (0.90), 0.70–0.95	2.10 (2.30), 1.99–2.56	2502.0	<0.001**
Coronal trunk deviation distance	1.36 (1.41), 1.26–1.65	1.40 (1.03), 1.44–1.75	5571.5	0.21
Spinal sagittal deviation distance	−1.29 (4.06), −1.68 to −0.59	−1.88 (4.08), −2.19 to −1.12	5476.0	0.14

**, P<0.01. IO, iliac obliquity; IQR, interquartile range: CI, confidence interval.

the moderate and severe scoliosis groups (−20.6, 95% CI: 0.13–0.17 for moderate and 0.15–0.27 for severe scoliosis, P=0.137).

Pelvic morphology

Among the 223 AIS patients, 120 experienced pelvic imbalance (IO ≥2°), with a pelvic imbalance rate of 53.81%, and the pelvic imbalance rate in the thoracic curve group was the lowest (41.20%) (*Table 1*). The acetabular obliquity angle and difference in the pelvic-acetabular inclination angle in the pelvic imbalance group were significantly higher than those in the pelvic balance group (4,988.5, 95% CI: 0.95–1.25 pelvic balance and 1.31–1.71 for pelvic imbalance, P<0.001; 2,502.0, 95% CI: 0.70–0.95 for pelvic balance and 1.99–2.56 for pelvic imbalance, P<0.001) (*Table 5*).

The femoral neck-shaft projection angle was significantly greater on the left than on the right in patients with a thoracic curve (−4.46, 95% CI: 133.78–136.20 for the left and 131.62–134.01 for the right, P<0.001), but was significantly greater on the right than on the left in patients with a lumbar and thoracolumbar curve (lumbar curve −3.24, 95% CI: 131.97–134.56 for the left and 133.76–136.26 for the right, P=0.001; thoracolumbar curve −2.98, 95% CI: 133.75–136.70 for the left and 135.13–137.82 for the right, P=0.003) (*Table 3*). The distribution of the difference in femoral neck-shaft projection angle was significantly (H=14.14, P=0.001) different on the left and right sides in patients with different degrees of scoliosis (*Table 4*). A significant difference also existed in the femoral neck-shaft projection angle on the right and left sides between the mild and moderate (−21.6, 95% CI: 2.34–3.41 for mild and 3.00–3.94 for moderate scoliosis, P=0.020) or severe (−51.1, 95% CI: 2.34–3.41 for mild and 3.57–6.43 for severe scoliosis, P=0.001) scoliosis groups and between the moderate and severe scoliosis groups (−29.5, 95% CI: 3.00–3.94 for the moderate and 3.57–6.43 for severe scoliosis, P=0.033).

Direction of the shoulder and pelvis

Among patients with shoulder imbalance (CA ≥2°), 88 (65.67%) patients had a higher right shoulder whereas 46 (34.33%) had a higher left shoulder (*Table 6*). Among patients with pelvic imbalance (IO ≥2°), 87 (72.50%) patients were higher on the right pelvis while 33 (27.50%) were higher on the left pelvis. Furthermore, the pelvis was dextral in 79 (65.83%) patients but sinistral in 41 (34.17%).

Imbalance occurred in both the pelvis and shoulder in 71 (31.84% or 71/223) patients (*Table 7*), including higher shoulder and pelvis on the right in 29 cases (40.84%), left shoulder higher and right pelvis higher in 20 cases (28.17%), right shoulder higher and left pelvis higher in 13 cases (18.31%), and higher shoulder and pelvis on the left in 9

Table 6 Direction distribution of overall shoulder and pelvic imbalance

	Shoulder imbalance (n=134)		Pelvic imbalance (n=120)			
	Right higher	Left higher	Right higher	Left higher	Dextral (L/R<1)	Left rotation (L/R>1)
Total	88 (65.67%)	46 (34.33%)	87 (72.50%)	33 (27.50%)	79 (65.83%)	41 (34.17%)

L/R is the ratio of the width of the left iliac crest to the width of the right iliac crest (L/R <1 signifies dextral rotation of the pelvis, L/R>1 denotes left-handed rotation of the pelvis).

Table 7 Consistency of the imbalance direction of the shoulder and pelvis (n=71)

Shoulder	Higher on the right pelvis (n=49)	Higher on the left pelvis (n=22)
Higher on the right	29 (40.84%)	13 (18.31%)
Higher on the left	20 (28.17%)	9 (12.68%)

Table 8 Pelvic tilt and rotation of different scoliosis types

	Thoracic curve (n=63)	Thoracolumbar curve (n=49)	Lumbar curve (n=71)	Double curves (n=40)
L/R<1 group (pelvic right rotation)				
High on the right pelvis	24 (38.10%)	14 (28.57%)	35 (49.30%)	28 (70%)
High on the left pelvis	26 (41.27%)	6 (12.24%)	11 (15.49%)	9 (22.5%)
L/R>1 group (pelvic left rotation)				
High on the right pelvis	8 (12.70%)	21 (42.86%)	21 (29.58%)	1 (2.5%)
High on the left pelvis	5 (7.94%)	8 (16.33%)	4 (5.63%)	2 (5%)

L/R is the ratio of the width of the left iliac crest to the width of the right iliac crest.

cases (12.68%).

Among the 63 patients with a thoracic curve (*Table 8*), the pelvis was dextral in 50 (79.37%), including 24 (38.10%) patients with a higher pelvis on the right. Among the 49 patients with a thoracolumbar curve, 20 (40.82%) patients had pelvic dextrorotation, including 14 (28.57%) cases with a higher pelvis on the right. Among the 71 patients with a lumbar curve, 46 (64.79%) patients had pelvic dextrorotation, including 35 (49.30%) cases with a higher pelvis on the right side. Among the 40 patients with the double curves, 37 (92.5%) patients had pelvic dextrorotation, including 28 (70%) patients with a higher pelvis on the right.

The coronal trunk offset distance in the shoulder imbalance group was greater than that in the balance group, and the difference was statistically significant (2878.5, 95% CI: 0.88–1.19 for shoulder balance and 1.69–2.00 for shoulder imbalance, P<0.001), and the spinal sagittal offset distance was not statistically significant between the 2 groups (5480.0, 95% CI: −1.77–−0.61 for shoulder balance and −2.07–−1.01 for shoulder imbalance, P=0.31). Moreover, there was no significant difference in the coronal trunk deviation and sagittal spine deviation distances between the pelvic balance and imbalance groups (coronal trunk deviation distance 5,571.5, 95% CI: 1.26–1.65 for pelvic balance and 1.44–1.75 for pelvic imbalance, P=0.21; sagittal spine deviation distance 5,476.0, 95% CI: −1.68 to −0.59 for pelvic balance and −2.19 to −1.12 for pelvic imbalance, P=0.14).

Discussion

Major findings

In this study investigating the deformity and asymmetrical changes of the shoulder and pelvis on imaging of patients with AIS, it was found that shoulder imbalance has a significantly greater impact on the coronal balance and spinal scoliosis above the lumbar segment, and pelvic imbalance has a greater impact on the sagittal balance and spinal scoliosis below the thoracic segment. With the aggravation of scoliosis, the asymmetry of the shoulder and pelvis increases and is affected by different scoliosis types. Most AIS patients with a right thoracic curve or a left thoracolumbar/lumbar curve have a deformity on the right shoulder and pelvis.

Shoulder imbalance

Shoulder imbalance is present when the clavicular angle of the coronal plane exceeds 2° (19). In this study, 134 of 223 (60.09%) AIS patients had shoulder imbalance, with the lowest rate in patients with a lumbar curve (53.50%), suggesting that lumbar spine deformity has little impact on shoulder balance. The deformity above the lumbar segment has a relatively considerable impact on shoulder balance. These results are in good agreement with previous findings (20).

Compared with patients with shoulder balance, the glenoid obliquity angle and clavicular glenoid obliquity angle in patients with shoulder imbalance are significantly larger, indicating that with the inclination of the clavicles on both sides, the scapula also tilts in the same direction but not at the same degree. This may be related to shoulder rotation, small joint correspondence difference, force imbalance, and scoliosis (especially thoracic spinal deformity). The rotation of the scapula is mainly controlled by the muscles around it. The activity of the anterior serratus muscle is weakened whereas the activity of the superior trapezius muscle is enhanced, resulting in decreased upward rotation and backward inclination but increased upward lifting of the scapula (21). In clinical work, some patients with scoliosis have been found to have a pterygoid scapula. Under normal circumstances, the scapula is kept close to the chest wall by the synergistic and antagonistic effects of the serratus anterior muscle, trapezius muscle, rhomboid muscle, and pectoralis minor muscle. When these muscles are mechanically imbalanced, the inner and lower edges of the scapula are tilted due to insufficient traction force, thus forming a pterygoid scapula.

Symmetrical structure of the shoulder

The acromioclavicular joint is composed of the acromion end of the clavicle and the acromion of the scapula, which are greatly affected by the position changes of the clavicle, scapula, and surrounding muscles (21). Therefore, to evaluate the morphology of the left and right acromioclavicular joints by acromioclavicular joint offset, this study took the symmetry of bilateral acromioclavicular joints as the representative to explore the influence of spinal deformity on shoulder symmetry structure in AIS patients (14). In patients with different types of scoliosis, the left (concave side) acromioclavicular joint offset of patients with a thoracic curve was greater than that on the right (convex side) (–2.75, 95% CI: 0.57–0.69 *vs.* 0.50–0.63, P=0.006). There was no significant difference between the left and right acromioclavicular joint offset in patients with lumbar/thoracolumbar curves. This indicates that the asymmetry of the acromioclavicular joint is greatly affected by the scoliosis of the thoracic segment, which may be due to varying mechanisms of action in different scoliosis types, and the balance state of the shoulder is greatly affected by spinal deformity above the lumbar segment. In addition, our study also found that with the increase of the scoliotic degree, the difference of acromioclavicular joint offset between the 2 sides gradually increased, suggesting that the shoulder imbalance may increase with the progression of scoliosis. The asymmetry and rotation of the shoulders in AIS patients may be caused by abnormal biomechanics.

In our study, all AIS patients showed different degrees of unequal shoulder heights on both sides. The long-term presence of this asymmetrical posture will lead to an asymmetrical mechanical structure of the shoulder muscles, ligaments, and fascia on both sides, resulting in the tension of the deltoid muscle and levator scapulae muscle groups on the higher side, as well as the surrounding ligaments and fascia. Moreover, when pulled to varying degrees, proprioceptive receptors like muscle spindle and tendon organs in muscle ligaments will transmit human spatial position signals to the center and cause long-term asymmetrical posture and force imbalance, thereby hindering the function of the muscle spindle system and affecting the posture balance of patients (22). Long-term abnormal sitting, writing, and bag-carrying posture will also produce the same effect, and the shoulders on both sides of the spine will be compensated in response to asymmetry stress changes in all directions, which will affect the originally symmetrical shoulders and sequential spine to promote the formation and progression of high and low shoulders and scoliosis (23).

Pelvic imbalance

The whole spine orthopedic film shows the inclination of the pelvis position and left-right asymmetry, such as the unequal width of the iliac bones on both sides, the unequal femoral neck-shaft projection angle, and the obturator morphological asymmetry. Therefore, the inclination angle of the iliac bone and acetabulum was selected to evaluate the pelvic imbalance in this study.

Coronal pelvic imbalance is present when the iliac inclination angle exceeds 2° (15). In our study, 120 (53.81%) of 223 patients with AIS showed coronal pelvic imbalance, with the lowest rate (41.20%) in patients with a thoracic curve. Thus, thoracic spinal deformity has little impact on pelvic balance, whereas deformities below the thoracic spine have a relatively larger impact on pelvic balance. Compared to patients with pelvic balance, the difference in the acetabular inclination angle and pelvic acetabular inclination angle in patients with pelvic imbalance was significantly larger. Under normal circumstances, when the pelvis only tilts on the coronal and sagittal planes, the iliac bone tilt angle should change synchronously with the acetabular tilt angle. However, the difference between the pelvic acetabular tilt angle in the imbalance group was significantly larger, which illustrates that the pelvis also rotates to varying degrees while tilting.

Generally, the ratio of the distance between the left and right anterior superior iliac spine and the lower edge of the sacroiliac joint (L/R ratio) is used to represent the rotation degree of the horizontal plane of the pelvis. An L/R <1 signifies right rotation whereas an L/R >1 represents left rotation of the pelvis (16). The pelvis is in a neutral state when L/R =1. In our study, the proportion of left-right pelvic imbalance in 63 patients with a thoracic curve was similar but there were more patients with right-rotational pelvis (L/R <1) (50/63), which is consistent with the literature (13). The pelvis is one rotation plane of scoliosis, and the inclination and rotation of the pelvis are the continuation or compensation of the scoliotic curve. The thoracic vertebra bends to the right, and the muscles and ligaments attached to the spinal appendages are pulled towards the midline to rotate the vertebral body and appendages clockwise. With the thoracic vertebrae bending to the right, the lumbar vertebrae curve to the left in compensation, and the lumbar vertebral body and appendages rotate counterclockwise. However, there are 2 modes of compensation in the pelvis. The first is the continuation of the compensatory left bending and counterclockwise rotation from the lumbar vertebra to the pelvis; that is, the left rotation of the pelvis (L/R >1). The second mode is the slight clockwise rotation or right rotation of the pelvis (L/R <1) to compensate for the lumbar left bending (24). In our study, the pelvis in most patients with thoracic lordosis rotated to the right side, which is due to the second mode of compensation of the pelvis.

Among the 120 patients with lumbar/thoracolumbar curves, there was little difference in the proportion of patients with left and right pelvic rotation, whereas more patients were higher on the right side of the pelvis (91/120). This may indicate that different types of scoliosis have different effects on the pelvis, with the thoracic curve mainly affecting the rotation of the pelvis and the lumbar curve mainly affecting the left and right tilt of the pelvis.

When the pelvis tilts to one side, the psoas quadratus muscle, erector spinalis muscle, and paravertebral thoracolumbar fascia on the higher side contract, applying horizontal thrust to the spine on the opposite side, while deep muscles such as the multifidus muscle on the lower side of the pelvis passively lengthen and become tenser, resulting in horizontal tension to the spine on the same side. These forces are imbalanced on both sides of the spine and will aggravate scoliosis. When the pelvis rotates to one side, the ipsilateral external oblique muscle, vertical spinal muscle group (multifidus muscle), gluteus maximus, contralateral internal oblique muscle, and iliopsoas muscle cooperate to contract (25). The left-right interaction of these muscles changes the original mechanical balance of the pelvis and aggravates the pelvic rotation, resulting in a deviation of the gravity center of the body as well as rotation and curving of the spine to aggravate the deformity of the spine (25,26). Conversely, scoliosis and rotation deformity of the spine will also affect the pelvis. The obstacle of spinal proprioceptive function will lead to a decline in the ability to perceive the position of trunk movement and achieve spinal function stability, resulting in abnormal spinal posture (26). Therefore, promptly correcting the abnormal stress of spinal pelvic asymmetry in AIS patients is of great significance to delay and improve the disease progression and posture of AIS patients.

Pelvic symmetry

The lower limbs connect to the pelvis via the hip joint. When the pelvis rotates and tilts, the corresponding relationship between the hip joint and the position of the lower limbs will also change accordingly. In our study, the right (convex side) femoral neck-shaft projection angle of patients with a thoracic curve was smaller, and the left (convex side) neck-shaft projection angle of patients with a lumbar/thoracic curve was smaller, suggesting that the femoral neck-shaft projection angle was larger on the concave side than that on the convex side, which is consistent with the conclusion reached by other researchers (27). The bilateral difference in the femoral neck-shaft projection angle may be related to the change in pelvic position, such as inclination and rotation.

In patients with a thoracic curve, the femoral neck-shaft projection angle on the left (concave side) is greater than that on the right (convex side), which could be related to the compensation of thoracic scoliosis (right thoracic curve). Compensatory rotation of the pelvis, hip joint, and femur also occurs. When the pelvis is dominated by right rotation, the right femur is compensated by internal rotation, and the right femoral neck-shaft projection angle is greater than that on the left (28).

In patients with a lumbar/thoracolumbar curve, the femoral neck-shaft projection angle on the left (convex side) is smaller, which may be related to the inclination of the pelvis in patients with a lumbar curve/thoracolumbar curve. According to Volkman's law, cartilage ossification is affected by force and becomes slower on the side with larger compressive stress (29). When the pelvis tilts, the proximal femur compressive stress of the lower side is larger, thereby inhibiting the ossification of cartilage and reducing the development of the femoral neck-shaft projection angle smaller relative to that on the opposite side. In our study, the pelvis of patients with a lumbar/thoracolumbar curve was mostly high on the right (inclined on the left), which may lead to limited cartilage ossification in the proximal femur and a smaller femoral neck-shaft projection angle on the left than that on the right.

In this study, the pelvis of patients with a thoracic curve was mostly right rotated, and the right (convex side) femoral neck-shaft projection angle was smaller. The pelvis of patients with a lumbar/thoracolumbar curve was mostly higher on the right, and the left (convex side) femoral neck-shaft projection angle was smaller. Thus, the shape and position of the pelvis and the femoral neck-shaft projection angle are affected by scoliosis. With the aggravation of scoliosis, the difference in the femoral neck-shaft projection angle on both sides increases, indicating that pelvic asymmetry is related to the progression of scoliosis.

Balance of both shoulders and the pelvis

In this study, the coronal trunk deviation distance and spinal sagittal deviation distance were used to represent the overall balance of the trunk coronal and sagittal planes, and the imbalance direction of the shoulder and pelvis and their relationship with trunk balance were analyzed.

Patients with a higher right shoulder accounted for 65.67%, and those with a higher right pelvis and greater right rotation accounted for 72.50% and 65.83%, respectively. There was total of 71 cases of concurrent shoulder and pelvis imbalance, and more patients had a higher shoulder and pelvis on the right side (40.84%, 29 cases). This indicates that patients with a right thoracic curvature and left thoracolumbar/lumbar curvature often have right pelvic rotation and a higher shoulder and pelvis on the right, suggesting a left inclination of the shoulder and pelvis. In addition to the factor of right-handedness, this may also be related to the poor writing and sitting posture of the patient.

In our study, a significant difference was revealed in the coronal trunk deviation distance between the shoulder balance and imbalance groups, with the trunk offset being greater in the imbalance group. However, there was no significant difference between the pelvic balance and imbalance groups. Furthermore, there was also no significant difference in the sagittal deviation distance between the shoulder and pelvic balance and imbalance groups, but the median sagittal deviation distance of patients with pelvic imbalance was smaller than that in those with pelvic balance. This may indicate that compared with patients in the pelvic balance group, those in the imbalance group had a greater tendency to trunk retroversion, suggesting a notable relationship between shoulder balance and trunk coronal balance and a certain correlation between pelvic balance and trunk sagittal balance.

Our study also found that shoulder imbalance was more closely related to the spine above the lumbar segment, whereas pelvic imbalance was more closely related to the spine below the thoracic segment. The balance of the shoulder and pelvis and scoliosis affect each other. The imbalance of the shoulder and pelvis affects the posture of patients and subsequently the shape of the spine. When scoliosis occurs, the shoulder and pelvis, as the connecting structure of the spine and limbs, will also be affected in terms of their shape (tilt, rotation, etc.) as well as the corresponding relationships between various joints. Therefore, in AIS patients, the causes of shoulder and pelvis imbalance may originate from both the primary shoulder and pelvis or from scoliosis.

Limitations

Some limitations existed in this study, including its retrospective and single-center design, the lack of a control group of normal patients, the fact that only Chinese patients were enrolled, and the small patient cohort, which may affect the explanation and generalizability of the results. Future studies will have to be performed internationally involving different medical centers and patients of different races in a prospective controlled manner to resolve these issues and achieve better outcomes.

Conclusions

Shoulder imbalance has a significantly greater impact on the coronal balance and spinal scoliosis above the lumbar segment, and pelvic imbalance has a greater impact on the sagittal balance and spinal scoliosis below the thoracic segment. With the aggravation of scoliosis, the asymmetry of the shoulder and pelvis increases and is affected by different scoliosis types. Most AIS patients have right shoulder and pelvis deformities. These findings may be beneficial to the development of treatment plans for AIS patients.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This retrospective single-center study was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and approved by the Ethics Committee of the Third Hospital of Hebei Medical University. The legal guardians of the AIS patients signed the informed consent to participate.

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