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Original Article

Evaluation of balance in young adults with idiopathic scoliosis

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ABSTRACT

Objectives: This study aims to evaluate the relation of scoliosis with coronal and sagittal balance parameters and the effect of postural balancing in young adults with idiopathic scoliosis.

Patients and methods: Between April 2017 and June 2017, a total of 24 patients (7 males, 24 females; mean age 20.3±2 years; range 17 to 24) who were diagnosed with scoliosis and 65 age- and sex-matched healthy controls (20 males, 45 females; mean age 20.3±1.6 years; range 19 to 25) were included in the study. The Cobb angle, sagittal balance, coronal balance, and truncal shift were measured with radiographs in the patient group. The Biodex Balance System (BBS) was used to assess the general stability index, anterior-posterior and medial-lateral stability index, and fall risk.

Results: All balance parameters were significantly worse in the patient group than in the control group ($p<0.05$). The static balance was mostly associated with sagittal balance, followed by coronal balance. In the patients with left scoliosis, sagittal balance was 93% negative and 67% of the patients gave their weight to the back. Coronal balance was negative in 60% of the patients and 93.3% of the patients were weighted to the right side. In 89% of the patients with right scoliosis, sagittal balance was negative and 89% of the patients gave their weight to the back. Coronal balance was 44% neutral and 78% of the patients gave their weight to the right side.

Conclusion: In patients with scoliosis, the static balance is worse than healthy individuals. Static balance is mostly related to sagittal balance and also to coronal balance. While the coronal balance tends to be in the direction of the curve, both right and left scoliosis give more weight to the right.

Keywords: Balance, coronal, mature, sagittal, scoliosis.

Postural balance is one of the most important factors determining the ability of a person to make and maintain his/her movements. Adequate postural balancing is an important proof of proper neuromuscular control and communication between the central nervous system and muscles.[1] Balance is related to the integration of data related to visual, somatosensorial, and vestibular systems.[1,2] According to the International Scientific Society on Scoliosis Orthopaedic and Rehabilitation Treatment (SOSORT) definition, scoliosis is a general term comprising a heterogeneous group of conditions consisting in changes in the shape and position of the spine, thorax, and trunk. From this point of view, scoliosis is a clinical condition which affects the entire body by disrupting the sagittal, coronal, and axial balance of the spine.[3] Many authors have suggested that scoliosis develops due to central nervous system dysfunction and that impaired balance function may be associated with it.[4-9] According to some authors, the imbalance of load distribution in the vertebral body is also responsible for the progression of the disease.[10,11] In the same age, static balance was found to be worse in adolescent idiopathic scoliosis (AIS) in relation to the degree of scoliosis.[2,4,12] In these patients, body sway increased, particularly in case of somatosensory and visual disorders.[12-15]

The balance evaluation in scoliosis trials is mostly done with deformations in coronal planes.[3-5,16,17] However, in the sagittal planar evaluation, spinal sagittal alignment is closely related to postural instability and fall.[5,16] On the other hand, since AIS

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patients are still in the growth period, the balance dynamics may differ from adults.

In the present study, we aimed to evaluate the relation of scoliosis with coronal and sagittal parameters and to evaluate the effect of postural balancing in young adults with idiopathic scoliosis.

PATIENTS AND METHODS

This single-center, cross-sectional study was carried out at Pamukkale University, Faculty of Medicine, Department of Physical Therapy and Rehabilitation between April 2017 and June 2017. Patients with more than 10-degree scoliosis in the 18 to 25 age range were included in the study. The scoliotic and healthy individuals were matched in terms of age and sex. *Exclusion criteria for both groups were as follows:* having vision and balance-related disorders, using medication which could affect the central nervous system and balance, muscle weakness or pain which could affect the standing posture, having musculoskeletal system abnormalities and mental retardation. Accordingly, a total of 24 patients (7 males, 24 females; mean age 20.3±2 years; range 17 to 24) who were diagnosed with scoliosis and 65 age- and sex-matched healthy controls (20 males, 45 females; mean age 20.3±1.6 years; range 19 to 25) were included in the study. Data including age, sex, height (cm), weight (kg), body mass index (BMI) (kg/m^2), and occupation were recorded. Graphical measurements were made only from the current graphs of the study group. A written informed consent was obtained from each participant. The study protocol was approved by the institutional Ethics Committee (No. 2017/6, Date: 18.04.2017). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Radiographic measurements

Radiological evaluations were performed by an experienced physiatrist. The Cobb angle, sagittal balance, coronal balance, and truncal shift were evaluated.

Cobb angle: According to the Scoliosis Research Society (SRS) definition, the Cobb method of quantifying curve severity measures both curvature and the degree of tilt of the end vertebrae.[18,19] The uppermost vertebra of the curve on the posteroanterior radiographies were found and a line was drawn parallel to the upper end plate of the upper end vertebrae, then a line was drawn parallel to the lower end plate of the lower end vertebra. The angle at the intersection of the

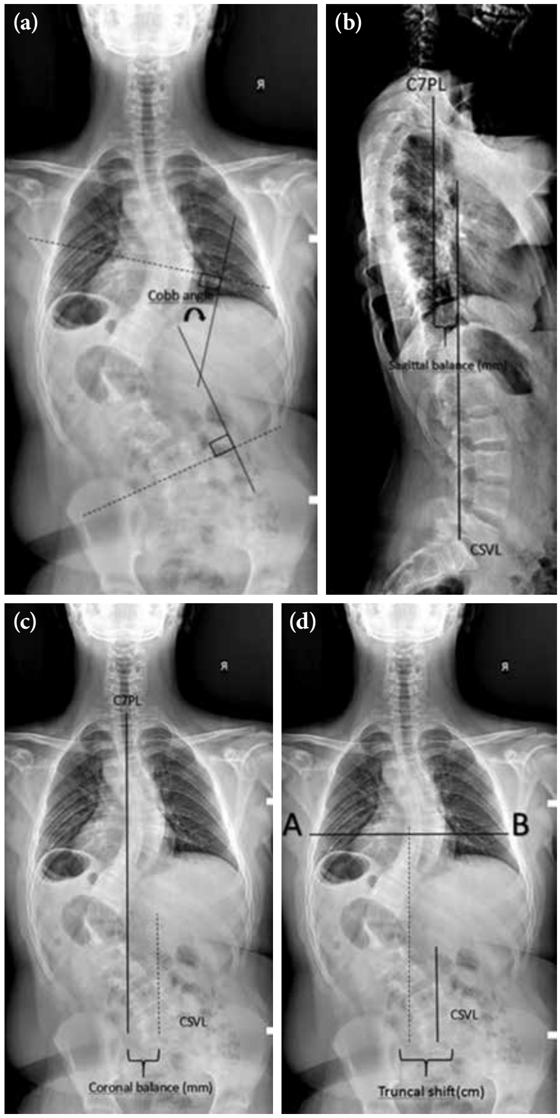

Figure 1. Radiographic measurements. **(a)** Measurement of Cobb angle. First, the apex vertebra (the most prominent vertebrae) was determined. According to apex vertebrae, upper and lower end vertebras where the end points of the vertebral tilting were obtained. Perpendicular lines were, then, drawn along the endplates, and the angle between the lines where they intersect, measured. **(b)** Measurement of sagittal balance. On the lateral radiograph, the first C7PL was drawn. The distance between C7PL and CSVL, the line was started the posterosuperior corner of S1 vertebral body, was measured. **(c)** Measurement of coronal balance on the posteroanterior radiograph. The first C7PL was drawn. The distance between C7PL and CSVL, the line starting from the center of S1 vertebral body, was measured. **(d)** Measurement of truncal shift. A horizontal line was drawn through the apex of the thoracic curve. The line was drawn down perpendicularly at the mid-point of this line named VTRL **(a, b)** (dashed). Finally, the CSVL was drawn with the line from the S1 midpoint (bold). Trunk shift was determined as distance between VTRL and CSVL.

C7PL: C7 plumbline; CSVL: Center sacral vertical line; VTRL: Vertical trunk reference line.

lines perpendicular to these lines was recorded as the Cobb angle (degrees) (Figure 1).[18-21]

Sagittal balance: In the lateral radiographs, a vertical line (plumb line) was drawn starting from the middle point of the C7 vertebrae and intersecting the S1 upper end plate. The distance of this line to the S1 superoposterior point was measured. Positive sagittal balance was present, when C7 was anterior to S1 and was negative, when posterior to S1. If C7 was directly over S1, the spine was considered in neutral balance. The balance values were determined by placing the + and - marks and the deviation distance was recorded in mm (Figure 1).[19]

Coronal balance: In the posteroanterior standing graphs, a vertical line (C7 plumb line) was drawn starting from the middle point of the C7 vertebra. The distance from this line to the sacrum midline was measured. If the vertical line passed through this point, it was considered neutral, positive if passing through on the right, and negative if passing on the left. The balance values were determined by placing the + and - marks and the deviation distance was recorded in mm (Figure 1).[18]

Trunk shift: Posteroanterior radiography was used to show the apex of the thoracic curve. The left end of the trunk and the right end of the trunk were joined together by a mark. A vertical trunk reference line was drawn from the center of this line. The trunk shift was found by measuring the distance of the vertical trunk reference line to the C7 plumb line. If the distance was more than 2 cm, it was defined as trunk shift (Figure 1).[17]

Balance evaluation was performed using the Biodex Balance System (BBS) (Biodex Inc., Shirley, NY, USA) with the postural stability test (PST). The BBS allows the evaluation of neuromuscular control to be maintained in the closed chain. It also allows multiplanar testing by quantifying the ability to maintain single or double-sided postural stability on static or non-static surfaces.[22-25] The PST can be used to assess the general stability index (GSI), anterior-posterior stability index (APSI), medial-lateral stability index (MLSI), and fall risk (FRT). The GSI expresses general balance ability, MLSI right-left balance ability, and APSI front-rear balance ability. The high values obtained from these tests indicate the balance deterioration and increased risk of falling. Participants were tested with the bare feet on the BBS platform, their arms on the sides and their legs shoulder width wide so that they could provide the balance most comfortably in the upright posture position. The patient's foot coordinates were recorded. Records were accepted as permanent foot coordinates throughout all measurements. Evaluations were made at the same time of the day (11.00 AM-01.00 PM). Each patient was given information about the tests and the rules they were supposed to obey. During the test period, the patients were evaluated in three periods. Each period lasted 20 sec and was interrupted for 10 sec between each period. The results of the three tests were automatically calculated by the operating system of the

Table 1. Demographic and clinical characteristics of patient and control groups

	Scoliosis group (n=24)					Control group (n=65)					
	n	Mean±SD	Median	Min-Max	IQR	n	Mean±SD	Median	Min-Max	IQR	*p*
Age (year)		20.3±2	20	17-24	50-3		20.3±1.6	20	19-25	0-1	0.70
Height (cm)		168±9.2	167	155-193	5-8		168±7.8		153-187	167-11	0.76
Weight (kg)		60.9±14.7		42-100	56-18		64.3±12.4		46-110	62-13	0.09
BMI (kg/m^2)		21.1±3.7		15.4-32.3	20.4-4.11		22.6±3.5		17.1-35.5	22.3-3.6	0.03*†
Sex											0.884‡
Female	17					45					
Male	7					20					
Balance parameters APSI		0.29±0.12		0.1-0.5	0.3-0.2		0.21±0.07		0.1-0.4	0.2-0	0.001*†
MLSI		0.25±0.11		0-0.5	0.2-0.1		0.17±0.08		0-0.4	0.2-0.1	0.0001*†
GSI		0.4±0.2		0.1-0.7	0.4-0.2		0.3±0.09		0.1-0.5	0.3-0.2	0.02*†
FRT		1.5±0.36		0.9-2.4	1.4-0.4		1.16±0.17		0.7-1.5	1.2-0.2	0.0001*†

SD: Standard deviation; Min: Minimum; Max: Maximum; IQR: Interquartile range; BMI: Body mass index; APSI: Anterior-posterior stability index; MLSI: Medial-lateral stability index; GSI: General stability index; FRT: Fall risk test; * Mann-Whitney U test; † p<0.05 statistically significant; ‡ Chi-square test.

device and the average score was recorded. During the measurement of posturography, the value of the left/right weight bearing and the forward/backward weight bearing were calculated based on the zone in which the load was given the longest time as the percent time. Neither patients nor participants were familiar the balance device, and all participants used the BBS device for the first time.

Statistical analysis

The power analysis was made by sample size calculator (at www.dssresearch.com) and power of the study was designed to be 80% (beta= 20 and alpha= 0.05, effect size=0.69). Accordingly, the number of patients included in both groups was at least 21.[26,27] According to the means and standard deviation (SD), the effect size was calculated as 0.69.

Statistical analysis was performed using the PASW version 17.0 software (SPSS Inc., Chicago, IL, USA). Descriptive data were expressed in mean ± SD and median (min-max) values and number and frequency. The chi-square test was used to compare categorical data between the groups. The Mann-Whitney U test was used for the comparison of data between the groups. The Spearman correlation analysis was performed to investigate the relationship between dynamic posturography data and radiographic data. The correlation coefficients were interpreted as follows: r= 0 No linear relationship; <0.2= A very weak linear relationship, 0.2-0.4= A weak linear relationship, 0.4-0.6= A moderate linear relationship; 0.6-0.8= A strong linear relationship; and 0.8> Perfect linear relationship. A *p* value of <0.05 was considered statistically significant.

RESULTS

There was no significant difference in the age and sex between the patient and control groups. However, the control group had significantly higher BMI values. In addition, all balance parameters (GSI, APS, MLSI, FRT) were worse in the scoliosis group than in the control group (Table 1).

The evaluations of the patients in the scoliosis group according to the Cobb angle are shown in Table 2. The measurements of the Cobb angles, sagittal balance, coronal balance, and truncal shift values which were obtained from the radiographs of the scoliosis group were as follows: Thoracic Cobb angle 17.1±9.5 degree (range, 10 to 40), thoracic lumbar Cobb angle 14.1±3.6 degree (10 to 21), lumbar Cobb angle 18.9±8 degree (11 to 32), sagittal balance, 5.05±3.02 cm (0.5 to 12), coronal balance 1.27±1.24 cm (0 to 4), and truncal shift 0.71±1.16 cm (0 to 4).

Correlation of the radiological parameters (Cobb angle, sagittal balance, coronal balance, truncal shift) and balance data (GSI, APSI, MLSI, FRT) of the scoliosis group are presented in Table 3. Accordingly, the patients were most affected by sagittal balance than coronal balance. Sagittal balance showed a statistically significantly positive and moderate correlation with all PST data (sagittal balance and APSI p=0.001, r=0.657; sagittal balance and MLSI p=0.021, r=0.470; sagittal balance and FRT p=0.002, r=0.598), except for the GSI (p=0.056, r=0.420). Coronal balance was found to have

Table 2. Cobb angle measurement of scoliosis group (major curves are written in first place)

Patient 1	Right thoracal Left lumbar	25° 23°
Patient 2	Left thoracolumbar	10°
Patient 3	Right thoracal	12°
Patient 4	Right thoracal Left lumbar	15° 11°
Patient 5	Right thoracal	12°
Patient 6	Right thoracolumbar	15°
Patient 7	Right thoracal Left lumbar	12° 12°
Patient 8	Left thoracal	11°
Patient 9	Left thoracal Right lumbar	30° 26°
Patient 10	Left thoracolumbar	10°
Patient 11	Left thoracal Right lumbar	40° 20°
Patient 12	Left thoracolumbar	17°
Patient 13	Right thoracal	10°
Patient 14	Left lumbar Right thoracal	27° 11°
Patient 15	Right thoracal Left lumbar	10° 11°
Patient 16	Right lumbar Left thoracal	32° 30°
Patient 17	Right thoracal Lumbar	10° 15°
Patient 18	Right thoracolumbar	21°
Patient 19	Left thoracolumbar	15°
Patient 20	Left thoracal	16°
Patient 21	Left thoracal	14°
Patient 22	Left thoracolumbar	14°
Patient 23	Left thoracolumbar	13°
Patient 24	Left thoracal	10°

Table 3. Correlation of radiological parameters and balance data of scoliosis group

	GSI		APSI		MLSI		FRT	
	p	r	*p*	r	*p*	r	*p*	r
Thoracal Cobb degree	0.357	-0.256	0.913	-0.031	0.145	-0.395	0.474	0.200
Thoracolumbar Cobb degree	0.878	0.060	0.876	0.106	0.835	0.082	0.306	0.385
Lumbar Cobb degree	0.420	-0.333	0.454	-0.310	0.381	-0.360	0.149	-1.560
Sagittal balance (mm)	0.056	0.420	**0.001***	**0.657**	**0.021***	**0.470**	**0.002***	**0.598**
Coronal balance (mm)	0.293	-0.222	0.945	-0.015	0.07	-0.376	**0.05***	**-0.134**
Truncal shift	0.922	-0.021	0.576	0.120	0.298	-0.222	0.708	0.081
Age (year)	0.378	-0.095	-0.584	-0.059	0.354	-0.099	0.651	0.049
Body mass index (kg/m^2)	0.871	-0.017	0.320	0.107	0.964	-0.05	0.619	-0.054

GSI: General stability index; APSI: Anterior-posterior stability index; MLSI: Medial-lateral stability index; FRT: Fall risk test. Statistical analysis: Spearman correlation analysis, p<0.05 statistically significant.

a very weak and negative correlation with the fall risk (p=0.05, r=-0.134).

According to the convex directions, the patients with right and left scoliosis were divided into two groups. The load on the right or left side of the patient was compared to the coronal balance and also the load the patient gave to the front or back was compared to the sagittal balance (Tables 4 and 5). Coronal balance in the patients with left scoliosis was negative in nine patients (60%), positive in two patients (13.3%), and neutral in four patients (26.6%). Fourteen patients (93.3%) gave more weight to the right side and one patient (6.7%) to the left side. Coronal balance was more negative according to the direction of the curve, and patients gave more weight to the right side. Sagittal balance was negative in 14 patients (93.3%) and positive in one patient (6.7%). Five patients (33.3%) had anterior weight and 10 patients (66.6%) had more back weight in terms of the forward/backward weight bearing.

Table 4. Coronal/sagittal balance, right/left, front/back ratio of weight bearing in patients with left scoliosis

	Left scoliosis patients		Coronal balance	Right/left weight bearing	Sagittal balance	Front/back weight bearing
Patient 2	Left toracolumbar	10°	-1.0	86/14	-3.0	20/80
Patient 8	Left thoracal	11°	0	86/14	-12	29/71
Patient 9	Left thoracal Right lumbar	30° 26°	0	91/9	-5	11/89
Patient 10	Left thoracolumbar	10°	-1	98/2	-2	30/70
Patient 11	Left thoracal Right lumbar	40° 20°	1.5	62/38	-9	33/67
Patient 12	Left thoracolumbar	17°	1	19/81	-7	58/42
Patient 14	Left lumbar Right thoracal	27° 11°	-3	89/11	2	45/55
Patient 15	Left lumbar Right thoracal	11° 10°	0	75/25	-7	40/60
Patient 17	Left lumbar Right thoracal	15° 10°	-2	54/46	-4	33/67
Patient 19	Left thoracolumbar	15°	-2	87/13	-2	60/40
Patient 20	Left thoracal	16°	-4	74/26	-3.5	54/46
Patient 21	Left thoracal	14°	-4	59/41	-10	41/59
Patient 22	Left thoracolumbar	14°	0	69/31	-1	44/56
Patient 23	Left thoracolumbar	13°	-1.5	56/44	-6.5	61/39
Patient 24	Left thoracal	10°	-1	99/1	-5	54/46

Table 5. Coronal/sagittal balance, right/left, front/back ratio of weight bearing in patients with right scoliosis

	Right scoliosis patients		Coronal balance	Right/left weight bearing	Sagittal balance	Front/back weight bearing
Patient 1	Right thoracal Left lumbar	25° 23°	0.5	79/21	-0.5	58/42
Patient 3	Right thoracal	12°	1.5	70/30	-3	40/60
Patient 4	Right thoracal Left lumbar	15° 11°	0	43/57	-6	48/52
Patient 5	Right thoracal	12°	2.5	83/17	1.5	36/64
Patient 6	Right thoracolumbar	15°	0	83/17	-6	32/68
Patient 7	Right thoracal Left lumbar	12° 12°	-2	73/27	-7	3/97
Patient 13	Right thoracal	10°	0	28/72	-9	24/76
Patient 16	Right lumbar Left thoracal	32° 30°	2	80/20	-4	30/70
Patient 18	Right thoracolumbar	21°	0	54/46	-5	26/74

In the patients with right scoliosis, coronal balance was negative in 11 patients (11.1%), positive in four patients (44.4%), and neutral in four patients (44.4%). Seven patients (77.7%) gave right side and two patients (22.3%) left side weight while weight bearing. The coronal balance was again more positive/neutral, and the patients gave more weight to the right side. Sagittal balance was negative in eight patients (88.8%) and positive in one patient (11.2%). One patient (11.2%) gave anterior weight and eight patients (88.8%) had more back weight in terms of anterior/posterior weight bearing. Sagittal balancing and weighting were similar.

DISCUSSION

According to the results of this study, static balance was worse in young adults with idiopathic scoliosis than healthy controls. Static balance was most commonly associated with sagittal balance, followed by coronal balance. No correlation was found between the Cobb angle and balance parameters. Coronal balance tended to be in the direction of the curve, while right or left weighting was more on the right side in both right and left scoliosis. Sagittal balance tended to be negative in both right and left scoliosis, and weight bearing was similarly more backward in both groups.

The changes in balance and sagittal-coronal plane in AIS have been shown in many studies. According to the controls, when postural sway was evaluated in children with AIS, both lateral and medial increase and an enlarged center of pressure, increased body sway, poor static balance were detected.[13,28,29] The static balance becomes worse in patients with visual impairment or proprioceptive disturbance, compared to normal controls.[13-15] The impaired balance function is also related to the severity of the scoliotic curvature.[8] In a study, adolescents with more than 15° scoliosis showed a decrease in postural control preciseness and greater sway in the mediolateral axis.[30] In studies investigating gait characteristics in patients with AIS, the direction of the curve, severity, and vertebral rotation were not correlated with walking asymmetry and right/left asymmetry.[4,31,32] According to the direction of the convexity, the gait parameters (right convexity in patients with right lower extremity walking patterns) were found in patients with abnormal somatosensory evoked potentials, which was emphasized in the etiology.[2] Another etiological and progression-related factor in AIS was sagittal and coronal balances. Different coronal deformities produce different sagittal profiles, but coronal curve patterns are formed by changes in the sagittal profile.[33-35] According to sagittal evaluations in AIS studies, posterior inclinations were reported to be higher in both thoracic and lumbar scoliosis.[24,34]

Adult and adolescent scoliosis are some different features fundamentally from each other. In the adulthood, it is assumed that the curvatures above 30 degrees are progressive, and it is considered a stable course for lower grades. However, there is still a lack of data regarding the course of adult scoliosis. One of the major parameters for both progression and pain in adult scoliosis is the sagittal balance.[3] Also, it is well-known that the patterns of motion of adults and adolescents are different. In adults, the positions and movements of body segments are provided by static and dynamic proprioceptive systems.[36,37] In healthy adolescents, the motion sensation is more distorted compared to adults, resulting in movement patterns, leading to excessive movement of the end position.[36] These changes manifest themselves in the trunk, particularly.[37]

In a study of similar evaluations in young adults with idiopathic scoliosis, patients with a mean age of 24 were divided into four groups (Cobb angle ≤20°, 21-20°, 41-60°, ≥61°) according to the severity of the Cobb angle. In the group with Cobb angle below 20, sagittal balance was significantly different than the other groups and it was in positive values (mean distance 3.2±29.96 mm). The sagittal balance was in negative value in patients with the Cobb angle was above 20 degrees. Coronal curvature is also associated with sagittal balance.[38] In our study, the Cobb angles were below 20°. However, the sagittal balance values were negative. Sagittal balance was 93% negative in the patients with left scoliosis and 66% of the patients gave their weight to the back. In our patient group with young adults with idiopathic scoliosis, both elderly and adolescent scoliosis patients were similarly associated with static balance as well as coronal balance, which is most associated with sagittal balance.[33,35]

In our study, the homogeneous group of patients could not be used in terms of scoliosis location and direction and the low number of patients was considered a limitation. It is also considered a limitation, due to the fact that the level of physical activity was unable to be assessed, although it is an important variable affecting the balance.[39]

Scoliosis has also a potential to cause balance disorder and, in particular, sagittal balance has a close relationship with falls. The knowledge of how the disorders continue to transition to adulthood is an important clinical condition.[35]

In conclusion, sagittal balance, which is closely related to the etiology and progression of AIS, is closely related to balance in young adults with idiopathic scoliosis. To regulate exercise and daily living activities, it is important to address into scoliosis and it is necessary to evaluate the contribution of exercises to long-term balance, fall, and curvature progression.

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REFERENCES

1. Kwon YH, Choi YW, Nam SH, Lee MH. The influence of time of day on static and dynamic postural control in normal adults. J Phys Ther Sci 2014;26:409-12.
2. Lao ML, Chow DH, Guo X, Cheng JC, Holmes AD. Impaired dynamic balance control in adolescents with idiopathic scoliosis and abnormal somatosensory evoked potentials. J Pediatr Orthop 2008;28:846-9.
3. Negrini S, Donzelli S, Aulisa AG, Czaprowski D, Schreiber S, de Mauroy JC, et al. 2016 SOSORT guidelines: orthopaedic and rehabilitation treatment of idiopathic scoliosis during growth. Scoliosis Spinal Disord 2018;13:3.
4. Barrack RL, Whitecloud TS 3rd, Burke SW, Cook SD, Harding AF. Proprioception in idiopathic scoliosis. Spine (Phila Pa 1976) 1984;9:681-5.
5. Driscoll DM, Newton RA, Lamb RL, Nogi J. A study of postural equilibrium in idiopathic scoliosis. J Pediatr Orthop 1984;4:677-81.
6. Geissele AE, Kransdorf MJ, Geyer CA, Jelinek JS, Van Dam BE. Magnetic resonance imaging of the brain stem in adolescent idiopathic scoliosis. Spine (Phila Pa 1976) 1991;16:761-3.
7. Wyatt MP, Barrack RL, Mubarak SJ, Whitecloud TS, Burke SW. Vibratory response in idiopathic scoliosis. J Bone Joint Surg [Br] 1986;68:714-8.
8. Yamada T, Machida M, Kimura J. Far-field somatosensory evoked potentials after stimulation of the tibial nerve. Neurology 1982;32:1151-8.
9. Ford DM, Bagnall KM, McFadden KD, Greenhill BJ, Raso VJ. Paraspinal muscle imbalance in adolescent idiopathic scoliosis. Spine (Phila Pa 1976) 1984;9:373-6.
10. Zetterberg C, Björk R, Ortengren R, Andersson GB. Electromyography of the paravertebral muscles in idiopathic scoliosis. Measurements of amplitude and spectral changes under load. Acta Orthop Scand 1984;55:304-9.
11. Bernier JN, Perrin DH. Effect of coordination training on proprioception of the functionally unstable ankle. J Orthop Sports Phys Ther 1998;27:264-75.
12. Gauchard GC, Lascombes P, Kuhnast M, Perrin PP. Influence of different types of progressive idiopathic scoliosis on static and dynamic postural control. Spine (Phila Pa 1976) 2001;26:1052-8.
13. Chen PQ, Wang JL, Tsuang YH, Liao TL, Huang PI, Hang YS. The postural stability control and gait pattern of idiopathic scoliosis adolescents. Clin Biomech (Bristol, Avon) 1998;13:S52-S58.
14. Herman R, Mixon J, Fisher A, Maulucci R, Stuyck J. Idiopathic scoliosis and the central nervous system: a motor control problem. The Harrington lecture, 1983. Scoliosis Research Society. Spine (Phila Pa 1976) 1985;10:1-14.
15. Byl NN, Gray JM. Complex balance reactions in different sensory conditions: adolescents with and without idiopathic scoliosis. J Orthop Res 1993;11:215-27.
16. Blanke KM, Kuklo TR, Lenke LG, O'Brien MF, Polly DW, Richards BS, et al. Adolescent idiopathic scoliosis. In: O'Brien MF, Kuklo TR, Blanke KM, Lenke LG, editors. USA: Medtronic Sofamor Danek; 2008. p. 49-70.
17. Trobisch PD, Samdani AF, Pahys JM, Cahill PJ. Postoperative trunk shift in Lenke 1 and 2 curves: how common is it? and analysis of risk factors. Eur Spine J 2011;20:1137-40.

18. Karami M, Maleki A, Mazda K. Assessment of coronal radiographic parameters of the spine in the treatment of adolescent idiopathic scoliosis. Arch Bone Jt Surg 2016;4:76-380.
19. Kebaish KM. Spinal sagittal plane deformities: etiology, evaluation, and management. Seminars in Spine Surgery 2009;21:41-8.
20. Available at: https://www.srs.org/professionals/online-education-and-resources/glossary/three-dimensional-terminology-of-spinal-deformity
21. Available at: http://www.oref.org/docs/default-source/default-document-library/sdsg-radiographic-measuremnt-manual.pdf?sfvrsn=2
22. Cachupe WJC, Shifflett B, Kahanov L, Wughalter EH. Reliability of biodex balance system measures. Meas Phys Educ Exerc Sci 2001;5:97-108.
23. Visser JE, Carpenter MG, van der Kooij H, Bloem BR. The clinical utility of posturography. Clin Neurophysiol 2008;119:2424-36.
24. Arnold BL, Schmitz RJ. Examination of balance measures produced by the biodex stability system. J Athl Train 1998;33:323-7.
25. Baldwin SL, VanArnam TW, Ploutz-Snyder LL. Reliability of dynamic bilateral postural stability on the Biodex Stability System in older adults. Med Sci Sport Exerc 2004;36:524-38.
26. Available at: https://www.dssresearch.com/knowledgecenter/toolkitcalculators/samplesizecalculators.aspx.
27. Kuo FC, Hong CZ, Lai CL, Tan SH. Postural control strategies related to anticipatory perturbation and quick perturbation in adolescent idiopathic scoliosis. Spine (Phila Pa 1976) 2011;36:810-6.
28. Nault ML, Allard P, Hinse S, Le Blanc R, Caron O, Labelle H, et al. Relations between standing stability and body posture parameters in adolescent idiopathic scoliosis. Spine (Phila Pa 1976) 2002;27:1911-7.
29. Samuelsson L, Norén L. Trunk rotation in scoliosis. The influence of curve type and direction in 150 children. Acta Orthop Scand 1997;68:273-6.
30. Haumont T, Gauchard GC, Lascombes P, Perrin PP. Postural instability in early-stage idiopathic scoliosis in adolescent girls. Spine (Phila Pa 1976) 2011;36:847-54.
31. Chow DH, Kwok ML, Au-Yang AC, Holmes AD, Cheng JC, Yao FY, et al. The effect of load carriage on the gait of girls with adolescent idiopathic scoliosis and normal controls. Med Eng Phys 2006;28:430-7.
32. Schizas CG, Kramers-de Quervain IA, Stüssi E, Grob D. Gait asymmetries in patients with idiopathic scoliosis using vertical forces measurement only. Eur Spine J 1998;7:95-8.
33. Schlösser TP, Shah SA, Reichard SJ, Rogers K, Vincken KL, Castelein RM. Differences in early sagittal plane alignment between thoracic and lumbar adolescent idiopathic scoliosis. Spine J 2014;14:282-90.
34. Schlösser TPC, Vincken KL, Rogers K, Castelein RM, Shah SA. Natural sagittal spinopelvic alignment in boys and girls before, at and after the adolescent growth spurt. Eur Spine J 2015;24:1158-67.
35. Kim J, Hwang JY, Oh JK, Park MS, Kim SW, Chang H, et al. The association between whole body sagittal balance and risk of falls among elderly patients seeking treatment for back pain. Bone Joint Res 2017;6:337-44.
36. Assaiante C, Barlaam F, Cignetti F, Vaugoyeau M. Body schema building during childhood and adolescence: a neurosensory approach. Neurophysiol Clin 2014;44:3-12.
37. Cignetti JF, Caudron S, Vaugoyeau M. Assaiante C. Body schema disturbance in adolescence: from proprioseptive integration to the perception of human movement. J Mot Learn Dev 2013;1:49-58.
38. Hong JY, Kim KW, Suh SW, Park SY, Yang JH. Effect of coronal scoliotic curvature on sagittal spinal shape: analysis of parameters in mature adolescent scoliosis patients. Clin Spine Surg 2017;30:418-22.
39. Akkaya N, Doğanlar N, Çelik E, Aysşe SE, Akkaya S, Güngör HR, et al. Test-retest reliability of tetrax® static posturography system in young adults with low physical activity level. Int J Sports Phys Ther 2015;10:893-900.