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Comparison of gait and sagittal plane arm swing between individuals with adolescent idiopathic scoliosis and healthy individuals

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Arm swing and energy consumption play an important role in the realization of an effective gait. However, research on arm swing and energy consumption during gait in individuals with adolescent idiopathic scoliosis (AIS) is limited. The aim of this study was to investigate the spatiotemporal characteristics of gait, arm swing angles in the sagittal plane, energy consumption in individuals with AIS, to compare them with their healthy peers in this regard. 26 diagnosed with AIS and 21 healthy were included in this study. Evaluation measures were based on the Cobb angle, axial trunk rotation, trunk symmetry, sagittal curve measurements, spatiotemporal characteristics of gait with the GAITRite electronic walkway, sagittal plane arm swing with two video-camera recordings, and energy consumption. There were a decrease in right-sided sagittal arm swing, an increase in energy consumption, in left-side step time and right-side double support time in the scoliosis group compared to the control group. The other spatiotemporal characteristics of the gait were similar in both groups. The evaluation of arm swing, energy consumption, and gait of individuals with AIS may contribute to the development of rehabilitation programs by better identifying the deficiencies of individuals with AIS.

Keywords: Scoliosis, gait, arm swing, energy consumption, adolescent.

INTRODUCTION

Adolescent idiopathic scoliosis (AIS) is the most common structural three-dimensional spinal deformity with a frequency of 1% to 4%. This spinal deformity is defined as a three-dimensional structural deformity of the spine characterized by more than 10° of lateral curvatures accompanying axial rotation and deviated physiological curves in the sagittal plane. Although the etiology of AIS is not fully known, genetic predisposition, connective tissue abnormalities, imbalance between skeletal development and muscle maturation, and postural balance-stability defect during growth are considered as the main causes[1].

Gait is one of the activities that individuals with idiopathic scoliosis do most in daily life just like every individual. An effective gait requires an integrated operation of the physiological systems, the central and peripheral nervous systems, the moving and supporting musculoskeletal system, and the cardiopulmonary system. Depending on the three-dimensional trunk asymmetry occurring in the AIS, changes are seen in the center of body mass. In order to maintain the balance during gait, some changes may occur in walking patterns. It is stated that spinal mobility, trunk balance, and changing movement patterns are affected at each step in AIS[2]. In previous studies, it has been observed that velocity, cadence, stride length, range of motion in the pelvis, hip, and knee, symmetry of ground reaction force during stance and swing phases, and energy consumption are affected in individuals with AIS[3-7]. According to a review article on walking and energy consumption in AIS, in most of the 33 studies, there were no significant differences in velocity, cadence, and step width between individuals with scoliosis and healthy participants, while individuals with scoliosis showed a decrease in hip and pelvic movements compared to healthy individuals, an increase in energy consumption while walking, and step patterns and the ground reaction force were asymmetric. Studies comparing the effects of gait on the spatiotemporal and kinematic parameters of individuals with AIS and healthy individuals are needed[2].

During gait, the arms swing more than the legs. These swings also reduce energy consumption by reducing the angular momentum around the vertical axis of the body[8,9]. At the same time, arm swing also affects gait parameters. In a study investigating the effect of excessive arm swing on velocity and cadence in healthy individuals, it was reported that an increased arm swing pattern causes an increase in velocity and cadence, and an upper extremity swing pattern can create compensations in lower extremity and gai[10]. To our knowledge, there are a few studies investigating arm swing in individuals with AIS. According to these studies, a decrease in arm swing in the frontal and transverse plane, an increase in arm swing in the sagittal plane, and asymmetry in arm swing in the sagittal plane were observed in individuals with AIS[5,11,12]. However, there are not enough studies in the literature clearly interpreting the relationship between arm swing and gait in individuals with AIS.

Most of the previous studies focused on gait, energy consumption during gait, and range of motion in individuals with AIS[2]. However, the spatiotemporal characteristics of gait, changes in sagittal plane arm swing angles, and the effect of this on energy consumption of individuals with AIS have not been investigated adequately. The aim of this study was to examine the spatiotemporal characteristics of gait, arm swing angles in the sagittal plane, and energy consumption in individuals with AIS and to compare them with their healthy peers.

We hypothesize that individuals with adolescent idiopathic scoliosis will differ in terms of gait parameters, sagittal plane arm swing and energy consumption according to healthy individuals.

MATERIALS AND METHODS

This study was approved by the university ethics committee (GO 20/1039). The consent of the participants as well as their families were obtained. 26 individuals with AIS presented to the University's Faculty of Physical Therapy and Rehabilitation clinic were examined and included in the scoliosis group. The control group consisted 21 healthy adolescents, who were matched with the scoliosis group in terms of age, height, weight, and body mass index.

The inclusion criteria for the scoliosis group were as follows: having scoliosis above 10 degrees, being between the ages of 10 and 18, having a single- or double-curve pattern, and not having any previous treatment related to scoliosis.

The inclusion criteria for the control group were as follows: willingness to participate in the study, having similar demographic characteristics with the scoliosis group, and not having any spinal deformity.

The exclusion criteria for the scoliosis and control groups were the presence of neurological, neuromuscular, systemic, rheumatological, or musculoskeletal diseases, joint diseases that may affect walking performance, trauma, previous spinal surgery, and active regular sports activities.

Demographic data and patient characteristics, including age, gender, height, body mass index and curve pattern, were collected. Curve patterns were identified and recorded according to the Lenke classification system. Curve magnitudes were assessed with the measurement of the Cobb angles using antero-posterior X-ray graphs. Axial trunk rotation (ATR) was measured with the scoliometer using Adam's test. Asymmetries of the trunk was measured with the Anterior and Posterior Trunk Symmetry Indexes (ATSI and POTSI). Thoracic kyphosis and lumbar lordosis angles were measured with the flexiruler. Measurement of Cobb angles and ATSI-POTSI values were performed by the Surgimap Version 2.3.2.1[13]. Spatiotemporal gait parameters were examined with the GAITRite electronic walkway. Two video camera recordings taken laterally during gait assessment with the GAITRite were analyzed using the Kinovea software and arm swing angles in the sagittal plane were determined. Energy consumption was evaluated based on a 100-meter walk using the Physiological Cost Index (PCI).

The Lenke classification system is identified according to curve type (1-6) with a sagittal thoracic modifier (-, N, +) and a lumbar spine modifier (A, B, C). Curve types are based on SRS-Schwab definition as follows: Type 1: main thoracic curve and there may also be proximal thoracic and thoracolumbar/lumbar nonstructural curves; Type 2: a double thoracic curve and there may also be a nonstructural thoracolumbar/lumbar curve; Type 3: a double major curve but the main thoracic curve is major; Type 4: a triple major curve with structural curves in the proximal thoracic, main thoracic, and thoracolumbar/lumbar regions; Type 5: thoracolumbar/lumbar is the single main curve and there may also be proximal thoracic and main thoracic nonstructural curves; Type 6: a major thoracolumbar/lumbar curve and structural thoracic curve, there may also be nonstructural proximal thoracic curve[14,15].

Cobb angle is known as the gold standard in the measurement of curve magnitude on antero-posterior X-ray graphs. According to this method, the angle between the lines drawn parallel to the upper edge of the upper-end vertebra participating in the curvature and the lower edge of the lower-end vertebra is defined as the Cobb angle[14].

Figure I. — a) Photogrammetric evaluation for the measurement of anterior trunk symmetry, b) Photogrammetric evaluation for the measurement of posterior trunk symmetry.

The measurement of ATR was performed with the scoliometer Adam's test. The patient's feet are 15 cm apart, knees are tense, shoulders are loosely bent forward, the scoliometer is placed on the curve apex and the measured rotation degrees are recorded[16].

ATSI and POTSI were used to measure trunk asymmetry with the photographic evaluation of posture. Markers were attached to the reference points determined by palpation on the front and back of the body and photographs were taken with a smartphone camera placed at a distance of 173 cm. These photographs were measured using the Surgimap Version 2.3.2.1 and 6 indexes were obtained and calculated separately for the front and back of the body (Figure 1)[17].

Thoracic kyphosis and lumbar lordosis angles was measured with flexiruler. This objective method requires determining the spinous process references (C7, T1, T12, L5, S1), placing the flexiruler on the spine, and calculating the resulting contour on paper. This method has high intra-rater reproducibility[18].

Spatiotemporal characteristics of gait were evaluated with the GAITRite electronic walkway system (CIR System INC. Clifton, NJ, USA). This walkway is a pressure-activated gait analysis system with 18,432 sensors and provides data at a frequency of 60-120 Hz. These spatio-temporal characteristics are as follows: right/left step time, right/left step length, right/left stride length, right/left base of support, right/left foot progression angle, right/left single support time, right/left double support time, velocity, and cadence. For gait analysis, all participants were asked to walk 3 times at a self-selected natural walking pace and the average of gait parameters of the 3 walks was recorded for analysis[19,20].

For the analysis of arm swing angles in the sagittal plane, video recordings were made by smartphone cameras placed on both sides of the GAITRite walkway 2 meters from the center[20]. These recordings were made simultaneously with gait analysis. Obtained video recordings were analyzed through the Kinovea Software[21]. From the recorded videos, maximum flexion and maximum extension angles of the shoulder joint were measured. The sum of the maximum flexion and extension angles was recorded as the total arm swing angle. Maximum flexion, maximum extension, and total arm swing angles were recorded for the right and left shoulder[20,22].

The energy consumption levels of the participants were determined with the PCI. They were asked to walk 100 meters at a self-selected speed with their natural walking. Their heart rates were measured and recorded according to radial pulses from the wrist before and after gait. As they started walking, the chronometer was started and the time to complete the distance of 100 meters was recorded. The PCI was calculated by dividing the difference between post-gait heart rate and resting heart rate by walking speed[9].

After verifying that the numerical variables do not conform to the normal distribution by visual (using histogram and probability graphs) and analytical methods (using Kolmogorov-Smirnov/ Shapiro-Wilk tests), Mann-Whitney U test was used to compare the differences between the groups. Data are presented as means (X) and standard deviation (SD:95% confidence intervals (CIs)). Any p value less than 0.05 was accepted statistically significant. All analyses were performed with SPSS for Windows, version 23.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

Of the 97 patients presented to the clinic, 26 individuals with AIS met the inclusion criteria. Seventy-one patients could not participate in the study. Exclusion reasons were as follows: rheumatological diseases, neurofibromatosis, congenital scoliosis, lumbosacral transitional vertebra, spondylosis, tibialis posterior insufficiency, a history of previous conservative treatment or surgical treatment and age. This study was

Table 1. — Demographic and scoliosis-specific clinical characteristics of the participants

	Scoliosis Group Mean (SD)	**Control Group** Mean (SD)	***p* value**
Age (year)	14.9 (2.6)	14.5 (3.2)	0.625
Height (cm)	163.6 (11.2)	156.7 (19.7)	0.173
Body Mass (kg)	51.9 (11.4)	50.7 (19.1)	0.881
Body Mass Index (kg/m²)	19.2 (2.9)	19.7 (3.6)	0.585
Gender n (%)			
Girl	19 (73)	13 (61)	n/a
Boy	7 (27)	8 (39)	n/a
Curve Magnitude (°)			
Thoracic Cobb's angle	25.3 (9.0)	n/a	n/a
Lumbar Cobb's angle	22 (9.5)	n/a	n/a
Axial Trunk Rotation (°)			
Thoracic	7.1 (3.5)	n/a	n/a
Lumbar	6.0 (3.0)	n/a	n/a
Curve Pattern (Lenke) n (%)			
Type 1	11 (42.1)	n/a	n/a
Type 3	3 (11.4)	n/a	n/a
Type 5	10 (38.4)	n/a	n/a
Type 6	2 (7.6)	n/a	n/a
Values are frequency or mean (standard deviation).			

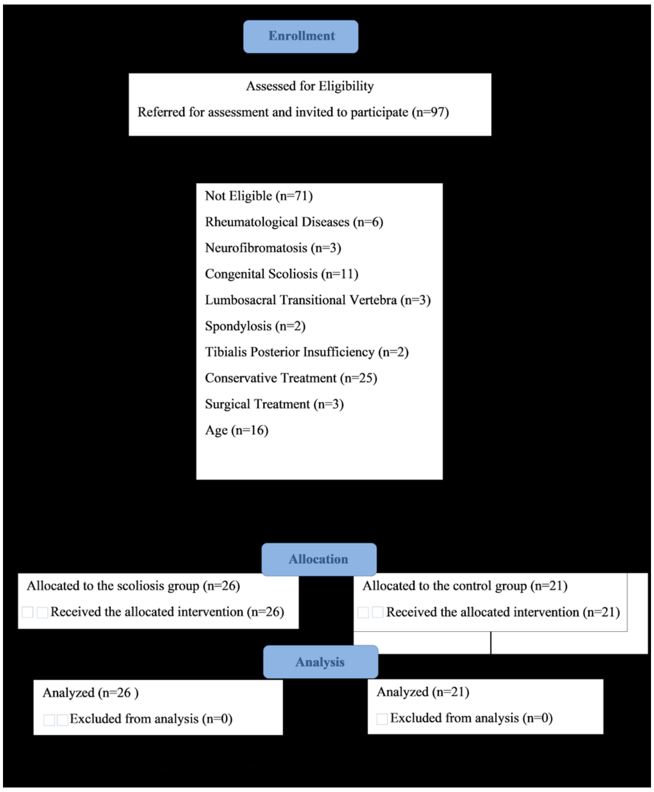

Figure 2. — Flow chart for participant enrollment.

completed with 26 participants in the scoliosis group and 21 participants in the control group (Figure 2).

The mean (±SD) ages of the scoliosis and control groups were 14.9±2.6 years and 14.50±3.2 years, respectively. Intergroup comparisons revealed no significant differences between the groups in terms of age ($p > 0.05$) (Table 1). There were 19 girls (% 73) and 7 boys (% 27) in the scoliosis group, and 13 girls (% 61) and 8 boys (% 39) in the control group. In scoliosis group, the mean (±SD) thoracic and lumbar Cobb angles were 25.3±9.0° and 22±9.5° respectively, and the mean (±SD) thoracic and lumbar axial trunk rotation angles were 7.1±3.5° and 6.0±3.0°, respectively. According to the Lenke classification, the highest number of individuals was Type 1, which was followed by Type 5, Type 3, and Type 6. Participants' demographic and scoliosis-specific clinical characteristics are shown in Table 1.

The descriptive statistics of the trunk symmetry and sagittal measurements of the scoliosis and control groups are given in Table 2. There was no statistical difference between the scoliosis group and the control group in terms of thoracic kyphosis and lumbar lordosis angle values ($p>0.05$).

When we examined the gait characteristics, it was found that left side step time and right double support time values were greater in the scoliosis group than in the control group ($p=0.045$ and $p=0.038$, respectively). There was no difference between the groups in terms of other spatiotemporal characteristics of gait ($p>0.05$) (Table 3).

When the groups were compared in terms of the sagittal plane arm swing during gait, it was found that

Table 2. — Information about trunk asymmetry and sagittal measurements

	Scoliosis Group Mean (SD)	**Control Group** Mean (SD)	***p* value**
Trunk Symmetry			
ATSI	23.6 (10.6)	n/a	n/a
POTSI	21.8 (8.7)	n/a	n/a
Sagittal Measurements			
Thoracic Kyphosis (°)	31.7 (9.4)	36 (9.6)	0.241
Lumbar Lordosis (°)	41.6 (14.2)	42 (13.1)	0.864

ATSI: Anterior Trunk Symmetry Index; POTSI: Posterior Trunk Symmetry Index.Values are frequency or mean (standard deviation).

Table 3. Comparison of spatiotemporal characteristics of gait, arm swing angles and energy consumption between groups

	Scoliosis Group			**Control Group**			***p* value**
Outcome	Min	Max	Mean (SD)	Min	Max	Mean (SD)	
Gait Characteristics							
Step Time-R (sec)	0.54	0.91	0.63 (0.90)	0.42	0.74	0.58 (0.07)	0.095
Step Time-L (sec)	0.52	0.90	0.63 (0.07)	0.42	0.78	0.58 (0.08)	**0.045***
Step Length-R (cm)	48.86	75.67	59.24 (6.30)	38.49	73.51	56.90 (7.99)	0.358
Step Length-L (cm)	47.68	73.60	58.66 (6.68)	43.93	70.84	56.67 (6.84)	0.521
Stride Length-R (cm)	99.15	150.93	118.58 (12.98)	82.99	114.48	114.10 (12.98)	0.535
Stride Length-L (cm)	98.30	147.97	118.73 (12.57)	82.20	145.72	114.47 (14.87)	0.429
Single Support Time-R (sec)	0.38	0.52	0.43 (0.03)	0.33	0.54	0.42 (0.05)	0.079
Single Support Time-L (sec)	0.39	0.52	0.44 (0.03)	0.33	0.54	0.41 (0.05)	0.054
Double Support Time-R (sec)	0.19	0.67	0.31 (0.09)	0.16	0.43	0.27 (0.05)	**0.038***
Double Support Time-L (sec)	0.20	0.64	0.34 (0.10)	0.16	0.47	0.29 (0.07)	0.095
Base of Support-R (cm)	3.86	14.69	9.69 (2.57)	4.83	13.54	8.93 (2.30)	0.315
Base of Support-L (cm)	4.16	14.64	9.62 (2.57)	4.95	13.55	9.10 (2.19)	0.467
Foot Progression Angle-R (°)	-3.67	17.50	5.71 (6.25)	-7.133	23.07	3.50 (7.09)	0.223
Foot Progression Angle-L (°)	-9.50	12.77	2.12 (5.93)	-10.63	10.60	0.40 (6.25)	0.454
Cadence (step/min)	83.83	117.60	100.18 (7.86)	80.07	144.13	105.70 (14.40)	0.185
Velocity (cm/sec)	73.93	138.93	98.69 (15.47)	73.80	123.27	99.53 (14.74)	0.454
Sagittal Plane Arm Swing Angles							
Max Arm Flexion Angle (°)-R	2.67	22.33	9.47 (3.95)	6.67	21	13.80 (4.30)	**0.001***
Max Arm Flexion Angle (°)-L	6.33	17.67	10.89 (3.26)	2	17.67	11.92 (4.42)	0.23
Max Arm Extension Angle (°)-R	0	11.67	5.02 (2.92)	0	17.33	7.36 (4.39)	**0.049***
Max Arm Extension Angle (°)-L	0.67	19.67	7.92 (5.16)	1.33	17	10.09 (3.84)	0.128
Total Arm Swing Angle (°)-R	7.67	29	14.50 (5.32)	9	38.33	21.17 (7.06)	**0.001***
Total Arm Swing Angle (°)-L	8.33	36.33	18.82 (7.59)	3.33	34.33	22.01 (7.19)	0.106
Energy Consumption (in beats/m)							
Physiological Cost Index	0.03	0.51	0.17 (0.12)	0	0.24	0.09 (0.06)	**0.041***

R: Right; L: Left; Min:Minimum; Max:Maximum. *p < 0.05 differences between the groups in terms of mean (standard deviation).

there was a statistical decrease in the right arm maximum flexion, maximum extension, and total arm swing angles in the scoliosis group compared to the control group (p=0.001, p=0.049, and p=0.001, respectively). The arm swing angles of the left arm did not show a statistical difference between the groups (p>0.05). When the energy consumption of the groups was compared according to PCI, the energy consumption level of the scoliosis group was statistically greater than that of the control group (p=0.041) (Table 3).

DISCUSSION

The present study showed that right side arm swing decreased and energy consumption increased during gait in individuals with AIS.

In terms of spatiotemporal characteristics of gait, step time and double support time were different in the scoliosis group compared to the control group. Previous studies have shown that the pelvis-hip kinematics and ground reaction force symmetry during the stance and swing phases of individuals with AIS are affected[5-7]. The difference in our study may also be due to the differences in the step-taking patterns of the scoliosis group.

Our study showed that there was no difference between scoliosis and control groups in terms of cadence and velocity. In previous studies, individuals with scoliosis are generally similar to healthy individuals in terms of velocity and cadence[5,23,24]. However, there are also studies showing that velocity and cadence are decreased in individuals with scoliosis compared to healthy individuals[4,11]. Syczewska et al. stated that individuals with double curves exhibited gait pathologies in relation to the severity of the curve, and as the curve severity increased, velocity and cadence decreased compared to the control group[25].

We found that the right and left side step times in the scoliosis and control groups were close to each other, but the left side step time was longer in the scoliosis group. The reason for this difference may be due to the fact that individuals with scoliosis usually have a deviation in the center of gravity towards the convexity side, so they stand on the convex side of the lower extremity for a longer time in order to maintain balance while taking a step[11,26].

There was no difference between the groups in terms of step length and stride length in the present study. While there are studies reporting no difference in stride length between scoliosis and control groups, there are also studies showing a decrease in individuals with AIS regardless of the curve type[12,23-25]. It is stated that these contradictory results may be due to the difference in deformity severity[24]. In the present study, variability in terms of curve severity may not have been detected because its effects on gait function were mild.

The single support times of the groups were similar in the present study. In previous studies, the single support time of individuals with AIS was generally less than that of healthy individuals[23,24]. Yang et al. reported that individuals with AIS had a longer single support time on the right side than on the left side[24]. According to Bortone et al., the reason for the difference in the single support time between individuals with AIS and healthy individuals may be the reduced single support time on the concave side[11]. Wu et al. reported that as the curve intensity increases, the time of single support on the concave side decreases, and it becomes more difficult to maintain balance during walking[26].

Individuals with AIS are expected to increase the double support time as a strategy to maintain balance during walking. Wu et al. demonstrated that Lenke 1 individuals with AIS had a longer time of double support than healthy peers. At the same time, due to the changes in the sagittal and frontal planes, difficulties occur in the smooth realization of body weight transfer on both the convex and concave sides[26]. We found that the right side double support time was longer in the scoliosis group. The present results show that double support times increased to provide stability during walking due to deviations in the center of gravity in the scoliosis group.

The role of the base of support is important in maintaining postural stability during gait[26]. Gauchard et al. showed that the severity of the curve affects lateral instability and the postural stability of individuals with AIS[27]. Bortone et al. showed that the base of support of individuals with AIS increased compared to the control group[11]. The present study showed no difference between groups in terms of base of support. An unexpected finding, however, suggests that the scoliosis group may have activated other compensatory mechanisms while maintaining stability in the anterior plane.

If the foot progression angle is negative, the load on the lateral part of the foot increases, and if it is positive, the load on the medial part of the foot increases[28]. There are deviations in foot pressure centers of individuals with AIS compared to healthy individuals[27,28]. Previous studies have reported that there is an increase in pressure in the medial of the foot compared to the lateral and a decrease in gait stability, especially in individuals with moderate and severe AIS[4,29]. Foot pressure analysis was not performed in our study; however, the angle of foot progression provided insight into the areas of the foot under pressure. According to the present results, there was no difference in foot progression angle between groups. In fact, in individuals with AIS, especially in moderate and severe scoliosis, it is expected that the pressure in the medial foot will increase, and therefore, the angle of foot progression will increase. It can be thought that the scoliosis group participating in the study achieved stability during walking with different compensatory mechanisms without the need to increase the foot progression angle.

We observed a decrease in right arm swing in the scoliosis group. It is stated that the swing of the upper extremities causes a decrease in vertical body center of gravity transfer and ground reaction force momentum[30]. In this way, it is ensured that the body consumes less energy, and balance, postural control, and rotational stability of the body improve while walking[10,31]. A previous study reported that there was an asymmetrical arm and elbow swing angle in the sagittal plane during gait without any systematic pattern, and the magnitude of the asymmetry side and arm swing was not related to the severity of the curve[12]. Mahaudens et al. found that arm swing in the frontal plane decreased in individuals with AIS when compared to the control group[5]. On the other hand, Bortone et al. showed that individuals with AIS had an increased shoulder range of motion in the sagittal plane compared to the control group and a decreased shoulder range of motion in the transverse plane[11]. Our results suggest that due to the asymmetrical deformity of the AIS, the step time and double support time are asymmetrical, and these individuals exhibit asymmetrical patterns in arm swing angles to compensate for their three-dimensional sways during gait.

We found that the scoliosis group consumed more energy than the control group. According to the majority of studies in terms of energy consumption, individuals with AIS consume more energy during gait than their healthy peers, and this may be due to the increase in femoral muscle activation time[2]. Santos et al. reported that the decrease in muscle strength in individuals with AIS, thus increased heart rates and oxygen consumption rates, may explain the decrease in their performance in short distances[32]. However, Mahaudens et al. found that, in individuals with AIS, the decrease in the mechanical work done by the muscles reduces the vertical displacement of the body's center of gravity and decreases the energy consumption by decreasing the hip-pelvic movements[2,33]. In some studies, there is no difference in energy consumption between AIS and their healthy peers[34,35]. According to the literature, the different results found in terms of energy consumption are due to the differences in the severity of the deformity and the methods of evaluating energy consumption[2]. In line with the present results, it may be beneficial to add aerobic exercises to the rehabilitation programs of individuals to regulate the increased energy consumption in individuals with AIS.

In the present study, only the sagittal plane arm swing in relation with gait was examined. However, AIS is a deformity that affects the spine in all three dimensions. The fact that arm swing was not evaluated in the frontal and transverse planes in our study is one of the limitations of the study. Since there are individuals with double curves in the scoliosis group, we couldn't make a comparison of convex and concave sides with healthy peers. Although PCI is a valid, reliable and simple tool for measuring energy consumption, it has been shown to be moderate in its reproducibility and ability to detect small differences in oxygen cost (36). Therefore, energy consumption would be evaluated using technological devices in advanced studies. In order to better understand gait, arm swing, and energy consumption in individuals with AIS in future studies, it is necessary to categorize and compare individuals with AIS in larger sample groups according to curve type and severity.

CONCLUSION

Our study showed that sagittal plane arm swing decreased, energy consumption increased, and spatio-temporal characteristics of gait were affected in the scoliosis group during walking. We think that it would be beneficial to plan rehabilitation programs by considering gait, arm swing, and energy consumption in individuals with AIS. In individuals with AIS, more studies are needed on gait as well as the effects of arm swing on gait.

Conflict of interest: None.

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The study was approved by the Hacettepe University Research Ethics Board. The patients were informed about the study and measurement methods and thereby, signed informed consent forms were obtained.

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