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Original Article

Evaluation of Balance and Gait in Idiopathic Scoliosis

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ABSTRACT

Objective: Idiopathic scoliosis (IS) is a three-dimensional deformity of the spine, defined radiographically as a lateral deviation of more than 10 degrees in the coronal plane, characterized by sagittal and transverse plane changes. Balance and walking are the most common activities of daily living. In our study, we aimed to analyze the effect of the curvature on balance and walking in IS individuals, who have a reduced risk of progression and whose curvatures are generally stable, by analyzing quantitative data.

Methods: The study included 34 patients with IS and 34 healthy individuals. All participants were questioned about their socio-demographic and physical characteristics. Balance parameters were recorded using a multi-axis, motorized platform system called Huber 360 with built-in force sensors and handles. The participants' gait analysis was performed using a Zebris FDM type 3 (Zebris Medical GmbH, Germany) walking platform.

Results: When gait parameters were examined, step time and walking cycle duration were significantly higher in the IS group compared to the control group (p=0.007 and p=0.008, respectively). On the contrary, right-foot loading response and walking speed of the control group were significantly higher than the scoliosis group (p=0.006 and p=0.0003, respectively). Stability speed with eyes closed was significantly higher in the IS group compared to controls (14.55±3.5 mm/s and 12.6±4.6 mm/s, respectively, p=0.012). No significant differences were observed between the groups in terms of other balance and gait characteristics.

Conclusion: This study revealed that balance and gait were affected in patients with IS, and individuals with scoliosis had poor balance and walking skills compared to healthy individuals. Therefore, in scoliosis rehabilitation, balance and walking problems that may be caused by spinal curvatures should definitely be taken into consideration.

INTRODUCTION

Idiopathic scoliosis (IS) is a three-dimensional deformity of the spine, defined radiographically as a lateral deviation of more than 10 degrees in the coronal plane, characterized by sagittal and transverse plane changes. The underlying factors in the etiology of IS and the cause of the deformity are not fully known. Since more than one factor is seen to be effective in the pathogenesis of IS, a multifactorial pathogenesis is considered. The most commonly blamed factors include maturation disorders of the central and peripheral nervous system, connective tissue disorders in elastic and collagen fibers, muscle and bone diseases, platelet disorders, melatonin, calmodulin, growth hormone imbalances, and leptin deficiency.[1] Scoliosis is divided into structural and non-structural scoliosis. One of the most common etiological causes of structural scoliosis is IS, and 75-80% of all scoliosis cases are in this group.[2]

Scoliosis is a three-dimensional torsional deformity that occurs with the rotation of one or more vertebrae in the spine. Chest deformity and pelvic asymmetry are often seen together with spinal deformity.[3] This deformity, which is usually painless, is asymptomatic and easily overlooked. In advanced and untreated cases, there is a high risk of developing significant health problems such as acute/chronic back and waist pain, cardiopulmonary dysfunction, functional limitation, depression, and deterioration in quality of life due to cosmetic deformity. IS classification is classically made based on the age at which the deformity is first diagnosed. The classical classification of idiopathic scoliosis according to age is: 1. Infantile (0-3 years) 2. Juvenile (3-10 years) 3. Adolescent (10-18 years) 4. Adult (18 years and older) IS. 80-90% of IS occurs during adolescence.[4] It is frequently seen during childhood and adolescence, when the growth plates develop, between the ages of 6 and 24 months, 5 and 8 years, and 11 and 14 years. These periods are also the most obvious progression period in IS. After the completion of spinal growth in adolescence, the potential for progression of IS is much lower. In adulthood, it may progress as a result of spinal collapse and progressive osseous deformities.[5] After skeletal maturation, it may progress by one or two degrees per year, especially in cases with scoliosis exceeding 50°, and it is reported that curves with angles less than 35 degrees generally remain stable.[5] Knowing the risk of progression in IS is important for determining and continuing the treatment.

Postural balance is one of the most important factors that determine a person's ability to make and maintain movements. Adequate postural balance is an important proof of proper neuromuscular control and communication between the central nervous system and the muscles. Balance is related to the integration of data from the visual, somatosensory, and vestibular systems.[6] In scoliosis, poor posture causes imbalance in the spine, fatigue, and ultimately pain due to nociceptive stimuli. In order to correct the poor posture, the muscles are overstretched, and over time, spasm and pain occur in the muscles. As the apical region is approached on the convex side of the scoliotic curvature, spinal mobility decreases, the muscles on the convex side of the curvature are overstretched and strain the ligaments, and on the concave side, weakness and shortening occur in the muscles. As a result of scoliosis, the posture of the patients is deteriorated, the biomechanics of the spine are affected due to the poor posture, disuse atrophies develop, and this causes asymmetrical loads in the spine.

Carrying more body weight on one side also affects the load distribution of the lower extremity. This situation can cause postural control and body balance to deteriorate, and walking mechanics, including the kinematics of the lower extremity joints, can cause gait asymmetries and the development of a pathological gait. In addition, asymmetries in walking can affect the trunk-pelvis balance and cause the curve to progress.[7] Therefore, balance and walking training that affects the trunk-pelvis balance in the opposite direction according to the individual's curvature is of great importance in the exercise program planned for scoliosis treatment.

To our knowledge, there is no study that evaluates the effect of curvature on balance and walking, especially in adult IS, with quantitative analysis and data. The aim of this study is to examine the effect of curvature on balance and walking in adult IS individuals, in a period when the risk of progression has decreased, and the curvatures are generally stable.

MATERIALS AND METHODS

From February 2024 to May 2024, 34 IS patients and 34 healthy individuals were recruited for this study. In this observational case-control study, the patients were included if they were diagnosed with IS and healthy controls with a natural spine curve. Approval for this study was obtained from Bilkent City Hospital Ethics Committee (E2-24-6163), and the study was conducted in accordance with The Declaration of Helsinki.

The exclusion criteria of the study were determined as: other types of scoliosis, musculoskeletal system pathologies that may create asymmetry in the body and balance, primary pathologies of the ear, benign paroxysmal positional vertigo, Meniere's disease, previous head trauma, previous spinal surgery, presence of neurological disease, presence of metabolic disease, presence of rheumatological disease, and malignancies. All groups underwent demographic data collection and physical examination. Sociodemographic information (age, gender, height, weight, body mass index, employment status, education, smoking habitus, sports activity, family history of scoliosis, twin pair, foot size, hand dominance, pain assessment (rest and activity visual analog scale (VAS)), lower extremity length difference (shorter extremity side)) was recorded in IS and healthy individuals. All patients' measurements and evaluations in the study were performed and recorded by the same physician. The Cobb method is considered the gold standard for determining spinal curve severity in frontal plane radiography.[8] In this study, the Cobb angles of all individuals with scoliosis were measured and recorded in degrees.

Before the balance and gait analysis, all individuals in both groups were informed about how the tests would be performed. Balance parameters were recorded using a multi-axis, motorized platform system called Huber 360, which has built-in force sensors and handles. Participants' age, height, and weight information were recorded on the device before the test began. Participants were placed on the balance platform with their feet positioned according to the guidelines on the measurement plate while climbing onto the platform. During the measurement, participants were asked to stand as quietly as possible, without moving, and looking ahead, with their arms crossed in front of their chests, touching the opposite shoulder. Postural balance was evaluated in two different test conditions, lasting 30 seconds. Stability (eyes open (EO) and eyes closed (EC)) area, speed, single-leg (right and left separately) area, and walking step count data were recorded.

The participant was asked to step on the guidelines on the force platform and keep their arms together at the sides of the body. Before starting the test, the platform was calibrated according to the foot position by selecting "Reposition" on the application. With the test start command, the participant was asked to bend forward, backward, right, and left at the maximum level, each lasting 8 seconds, without lifting the sole and heel of the foot or taking a corrective step. In this way, the stability limits area of the person was tested and determined in four directions.

The Zebris FDM type 3 (Zebris Medical GmbH, Germany) walking platform was used to measure the spatio-temporal parameters of the participants during walking. The age, height, and weight information of the participants were recorded in the system. The participants were asked to take off their shoes and socks and walk barefoot at their own natural pace for 2 minutes from one end to the other.

In order to eliminate the acceleration and deceleration phases of walking during the turns, the participants started walking from a distance of 2.5 m on the 3+2 m platform and turned from a distance of 2.5 m. The participants walked from end to end on a total of a 10 m platform for 2 minutes, and the data were obtained from the 298 x 54.2 cm section containing the sensor and stored by computer and analyzed. The left and right forefoot, heel maximum load (% of body weight), walking cycle duration, cadence, and walking speed data of all patients were recorded using the Zebris Medical GmbH system.

Statistical Analysis

Statistical analyses of the study were performed using the IBM SPSS 26.0 package program (SPSS, Inc, Chicago, Illinois). In the comparison of demographic and clinical data, and balance and gait analysis data of the scoliosis and control groups, the chi-square test was used for categorical data, the independent sample t-test for normally distributed data, and the Mann-Whitney U test was used for non-normally distributed data. The Shapiro-Wilk test was used to determine whether the data were normally distributed. The goodness of fit of the model was evaluated by the Hosmer-Lemeshow test. All statistical analyses were evaluated at a 95% confidence interval, and statistical significance was assessed at $p<0.05$.

RESULTS

The baseline demographic and clinical characteristics of the study participants are shown in Table 1. The median age of the IS group (23 female and 11 male) was 22 (18-

Table 1. Baseline demographic and clinical characteristics of study participants

Parameters	IS Patients (n=34) n (%) or Median (Min-Maks)	Controls (n=34) n (%) or Median (Min-Maks)	p-value
Age (years)	22 (18-45)	23 (22-47)	0.047*[2]
Gender			
Male	11 (32.4)	11 (32.4)	1[3]
Female	23 (67.6)	23 (67.6)	
Body mass index (kg/m2)	21.5 (17.3-33.8)	22.65 (18.3-36.3)	0.115[2]
Underweight	3 (8.8)	1 (2.9)	0.473[3]
Normal weight	23 (67.6)	22 (64.7)	
Overweight/Obese	8 (23.5)	11 (32.4)	
Employment status			
Unemployed	3 (8.8)	4 (11.8)	0.212[3]
Worker	16 (47.1)	9 (26.5)	
Student	15 (44.1)	21 (61.8)	
Sports activity			
No	25 (73.5)	28 (82.4)	0.38[3]
Yes	9 (26.5)	6 (17.6)	
Smoking			
No	29 (85.3)	27 (79.4)	0.525[3]
Yes	5 (14.7)	7 (20.6)	
Hand dominance			
Left	5 (14.7)	5 (14,7)	1[3]
Right	29 (85.3)	29 (85.3)	
Shoe number	39.5 (35-45)	39 (36-45)	0.666[2]
Family history of scoliosis			
No	27 (79.4)	31 (91.2)	0.171[3]
Yes	7 (20.6)	3 (8.8)	
Low back pain			
No	26 (76.5)	27 (79.4)	0.77[3]
Yes	8 (23.5)	7 (20.6)	
VAS Rest	0 (0-30)	0 (0-30)	0.62[2]
VAS Activity	0 (0-50)	0 (0-40)	0.648[2]
Lower extremity length difference			
No	30 (88.2)	32 (94.1)	0.673[3]
Yes	4 (11.8)	2 (5.9)	

[2]: Mann Whitney U test; [3]: , Chi-square test; *: $p<0.05$

Table 2. Balance parameters of IS and control groups

Parameters	IS Patients (n=34)			Controls (n=34)			p-value
	Median	Min-Maks	Mean±SD	Medyan	Min-Maks	Mean±SD	
Stability area with eyes opened (mm^2)	275.15	38.29-1330.12	371.15±361,7	163.51	35.12-2962,75	338.27±521.6	0.315[2]
Stability speed with eyes opened (mm/s)	10.815	5.76-18.23	11.49±3.7	9.365	6.3-22.88	10.35±3.4	0.139[2]
Stability acquisition time with eyes opened (sec)	30	30-30	30±0	30	30-30	30±0	1[2]
Stability area with eyes closed (mm^2)	442.46	52.43-2009.06	529.95±440.4	263.085	44.37-1288.56	354.61±294	0.108[2]
Stability speed with eyes closed (mm/s)	14.66	7.23-19.62	14.55±3.5	10.76	7.61-27.92	12.6±4.6	0.012[*2]
Stability acquisition time with eyes closed (sec)	30	30-30	30±0	30	30-30	30±0	1[2]
Left leg area (mm^2)	759.71	268.95-7981.76	1016.46±1305.8	669.495	340.98-2919.27	996.43±686.1	0.589[2]
Left leg acquisition time (sec)	30	30-30	30±0	30	30-30	30±0	1[2]
Right leg area (mm^2)	592.43	285.68-9162.19	953.5±1524.2	635.295	295.47-2696.7	913.37±609.1	0.404[2]
Right leg acquisition time (sec)	30	30-30	30±0	30	30-30	30±0	1[2]
Walking step count	70	52-100	70.94±10.5	77	45-112	76.35±14.3	0.085[2]
Walking gain time (sec)	50	50-50	50±0	50	50-50	50±0	1[2]
Stability limits area (mm^2)	68847.335	29056.79-104652.33	69119.32±17746.3	70780.505	35121.56-124693.69	75369.36±23720	0.223[1]

[1]: Independent samples t test; [2]: Mann Whitney U test; [*]: $p<0.05$.

Table 3. Comparison of spatio-temporal parameters of the participants

Parameters	IS Patients (n=34)			Controls (n=34)			p-value
	Median	Min-Maks	Mean±SD	Median	Min-Maks	Mean±SD	
Forefoot loading-left foot (%)	104	90-112	103.26±4.3	105	99-113	105.35±3.7	0.07[2]
Heel loading-left foot (%)	77.5	70-86	77.59±4.1	79	68-88	78.65±4.9	0.337[1]
Forefoot loading-right foot (%)	105	92-115	104.56±4	107.5	97-121	107.41±5	0.006[**2]
Heel loading-right foot (%)	78	60-85	77.94±4.9	79	68-96	78.56±5.9	0.868[2]
Step time-left (sec)	0.62	0.49-0,76	0.63±0.1	0.59	0.49-0.69	0.59±0.1	0.007[**1]
Step time-right (sec)	0.625	0.47-0,74	0.62±0.1	0.585	0.49-0.69	0.59±0.1	0.005[**1]
Walking cycle duration (sec)	1.25	0.96-1,49	1.25±0.1	1.17	0.98-1.36	1.17±0.1	0,008[**1]
Cadence (steps/min)	98.5	81-117	98.82±9.8	103	88-122	103.21±8.8	0.057[1]
Walking speed (m/s)	3.2	2-4.4	3.25±0.4	3.6	2.9-5.5	3.71±0.5	0.0003[**2]

[1]: Independent samples t test; [2]: Mann Whitney U test; *: $p<0.05$; **: $p<0.01$

45) years, and the mean age of the control group (23 female and 11 male) was 23 (22-47) 9 years (p=0.047). All groups had a female predominance. However, there was no statistically significant difference between the IS group and the control group in terms of gender, body mass index, employment status, sports activity, smoking habitus, dominant hand, family history of scoliosis, back pain, foot number, VAS score, and lower extremity length difference findings (p>0.05).

Table 2 lists the results of the balance analysis of the study population. When the balance parameters of the participants were examined under EO and EC conditions, it was revealed that stability speed with EC was significantly higher in the IS group compared to controls (14.55±3.5 mm/s and 12.6±4.6 mm/s, respectively, p=0.012). On the other hand, no statistically significant differences were found between the scoliosis group and the control group in terms of other balance parameters.

Table 3 presents the comparisons of the right- and left-foot loading measurement values, cadence, walking speed, and step duration of the participants. In the forefoot loading measurements comparison, it was observed that the maximum right-foot loading value of the control group was significantly higher than the scoliosis group (107.41±5 vs. 104.56±4, p=0.006), whereas no significant difference was observed in the left foot. Similarly, a higher walking speed was recorded in the control group compared to the IS group (3.71±0.5 m/s and 3.25±0.4, respectively, p=0.0003). On the contrary, a higher step duration was found in the IS group compared to the control group in the right and left foot of the study subjects (0.62±0.1 sec and 0.59±0.1 sec, p=0.005 vs. 0.63±0.1 sec and 0.59±0.1 sec, respectively, p=0.007). Moreover, the evaluation of the walking cycle duration of the participants showed that the walking cycle duration was also significantly higher in patients with scoliosis compared to healthy subjects (1.25±0.1 sec and 1.17±0.1 sec, respectively, p=0.008). We also analyzed the cadence and observed that there were no significant differences for walking cadence (p>0.05).

DISCUSSION

To our knowledge, this study is the first to evaluate balance and walking parameters in adults with IS using current quantitative analysis. In the study, it was demonstrated that there were differences in the balance and walking analyses between the patients with IS and healthy controls. Balance and walking were affected in individuals with scoliosis, and patients with scoliosis had poorer balance and walking skills compared to healthy individuals.

The spine is extremely important in ensuring efficient human movement, primarily by providing the balance element that the body requires while it is moving. In this state, the spine function and the walking function are inseparable working mechanisms. Therefore, in recent years, walking and balance analysis studies have increasingly begun to be applied to spinal diseases. In our study, in the balance parameters obtained with the force platform, the stability speed with EC was significantly higher in the IS group compared to the control group, indicating that the balance of patients with IS is weaker than that of healthy individuals. In addition, although the stability area evaluated with EO and EC, and the stability speed evaluated with EO in the IS group were not statistically significant, they were numerically higher than those of healthy individuals, indicating that balance skills are also weaker in individuals with scoliosis.

Similarly, the fact that the IS group approached the stability limits less and that the stability limits area of the scoliosis group was numerically lower than that of healthy individuals, although not statistically significant, again shows the weak balance skills in individuals with scoliosis. Yamada et al.[9] found a positive correlation between scoliosis progression rate and balance disorder in individuals with AIS. Poor body segmental alignment as a result of IS has been associated with a lateral displacement of the body's center of mass, affecting the body's dynamic balance during walking. IS has also been shown to affect gait mechanics, including temporal distance parameters, ground reaction forces, and lower extremity joint kinematics.[10] Such kinematic changes are thought to be a compensatory mechanism to maintain whole-body balance during walking.[11]

Mahaudens et al.[12] reported that 6 months of corset use in the treatment of patients with idiopathic scoliosis reduced the curvature by 25% and that the patients' walking data improved with the correction of the curvature. In our study, in the gait analysis, it was observed that the cadence and walking speed decreased in the IS group and the walking cycle time was prolonged due to this decrease. Chen et al.[13] and Giakas et al.[14] also demonstrated the existence of a decrease in cadence and step length in their studies. In another study, Yang et al.[15] found no statistically significant difference in walking speed, step length, and cadence in scoliosis patients, contrary to expectations. Although the results differ, a meta-analysis study by Mahaudens et al.[16] reported that scoliosis shortens the duration of the stance phase in walking data, prolongs the double stance phase, and slows down walking speed. Considering that balance is also impaired in scoliosis cases, it has been suggested that changes in walking data should be evaluated from this perspective.

The present study has some limitations. One of the limitations of the study was that other external forces and kinematics, such as the loads at the cervico-thoracic and lumbosacral joints, were not assessed, which might have provided a better understanding of the role of balance and gait in IS. Another limitation of our study was the relatively small sample size. So, future large, prospective, and randomized clinical trials are required to confirm our results.

Conclusion

Adult IS is associated with poor balance and walking skills compared to healthy individuals. This demonstrates that patients with scoliosis should be evaluated in terms of static and dynamic balance and walking, and should be followed up regularly.

Ethics Committee Approval

The study was approved by the Bilkent City Hospital Ethics Committee (Date: 24.01.2024, Decision No: E2-24-6163).

Informed Consent

Retrospective study.

Peer-review

Externally peer-reviewed.

Authorship Contributions

Concept: T.O.C., E.Y.; Design: T.O.C., E.Y.; Supervision: T.O.Y., E.Y., S.S.K., H.B.S.; Fundings: T.O.Y., E.Y., S.S.K.,

H.B.S., N.O.K.G.; Materials: T.O.C., S.S.K., N.O.K.G.; Data: T.O:C., S.S.K., H.B.S.; Analysis: T.O.C., E.Y., H.B.S.; Literature search: T.O.Y., E.Y., S.S.K., H.B.S.; Writing: T.O.Y., E.Y., S.S.K., H.B.S.; Critical revision: T.O.Y., E.Y., S.S.K., H.B.S., N.O.K.G.

Conflict of Interest

None declared.

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İdiyopatik Skolyozda Denge ve Yürümenin Değerlendirilmesi

Amaç: İdiyopatik skolyoz (İS), koronal düzlemde 10 dereceden fazla lateral sapma olarak radyografik olarak tanımlanan, sagital ve transvers düzlem değişiklikleriyle kendini gösteren, omurganın üç boyutlu bir deformitesidir. Denge ve yürüme günlük yaşamın en yaygın aktiviteleridir. Çalışmamızda, ilerleme riski azalmış ve eğrilikleri genellikle stabil olan İS bireylerinde eğriliğin denge ve yürüyüş üzerindeki etkisini analiz etmeyi amaçladık.

Gereç ve Yöntem: Çalışmaya 34 İS hastası ve 34 sağlıklı birey alındı. Tüm katılımcılara sosyo-demografik ve fiziksel özellikleri soruldu. Denge parametreleri, yerleşik kuvvet sensörleri ve tutacakları olan Huber 360 adlı çok eksenli, motorlu bir platform sistemi kullanılarak kaydedildi. Katılımcıların yürüme analizi, Zebris FDM tip 3 (Zebris Medical GmbH, Almanya) yürüme platformu kullanılarak gerçekleştirildi.

Bulgular: Yürüme parametreleri incelendiğinde, adım atma süresi ve yürüme döngüsü süresi İS grubunda kontrol grubuna göre anlamlı olarak yüksekti (sırasıyla, p=0.007 ve p=0.008). Buna karşın, kontrol grubunun sağ ayak yükleme yanıtı ve yürüme hızı skolyoz grubuna göre anlamlı olarak yüksekti (sırasıyla, p=0.006 ve p=0.0003). Gözler kapalıyken stabilite hızı İS grubunda kontrol grubuna göre anlamlı olarak yüksekti (sırasıyla, 14.55±3.5 mm/s ve 12.6±4.6 mm/s, p=0.012). Diğer denge ve yürüyüş özellikleri açısından gruplar arasında anlamlı bir fark gözlenmedi.

Sonuç: Bu çalışma, İS hastalarında denge ve yürüyüşün etkilendiğini ve skolyozlu bireylerin sağlıklı bireylere göre zayıf denge ve yürüme becerilerine sahip olduğunu ortaya koymuştur. Bu nedenle skolyoz rehabilitasyonunda omurga eğriliklerinden kaynaklanabilecek denge ve yürüyüş sorunlarının mutlaka dikkate alınması gerekmektedir.

Anahtar Sözcükler: Denge; idiyopatik skolyoz; yürüyüş analizi.