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Effects of A Spinal Brace on The Functional Profile of The Feet in Adolescent Idiopathic Scoliosis

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ABSTRACT

Purpose: To assess the impact of a spinal brace on the functional profile of the feet in patients with adolescent idiopathic scoliosis (AIS).

Patients and Methods: The subjects were 21 female AIS patients with double curves (range: 20°–45°). Baropodometry and stabilometry analysis during standing and walking and were performed without bracing and after 7 days of bracing. Plantar force distribution, contact area, foot angle, mean and peak foot pressures, step length, step width, cadence, and gait speed, center of pressure path length and sway velocities and confidence ellipse area were recorded.

Results: Bracing did not affect baropodometry parameters during standing ($p>0.05$). However, left foot plantar contact area was greater, mean pressure and peak pressures on the left foot were lower with bracing compared to without bracing ($p<0.05$) during walking. Cadence decreased with bracing. There was no change in stabilometry results ($p>0.05$).

Conclusion: Spinal bracing created more symmetrical plantar pressure distribution between the feet during gait. However, bracing tends to alter temporal-spatial walking parameters and disrupt gait in patients with double curve scoliosis.

Key words: scoliosis, gait, postural balance, foot

ADOLESAN İDİYOPATİK SKOLYOZDA SPİNAL ORTEZİN AYAK FONKSİYONEL PROFİLİNE ETKİSİ

ÖZET

Amaç: Adolesan idiyopatik skolyozlu (AİS) bireylerde, spinal ortezin ayak fonksiyonel profiline etkisini incelemek.

Hastalar ve Yöntem: Çalışmaya çift eğrisi olan (20° ile 45° arasında) 21 AİS'li kız birey alındı. Ayakta duruş ve yürüyüş sırasında baropodometri ve stabilometri değerlendirmeleri, korse öncesi ve korselemeden yedi gün sonra, korse ile tekrarlandı. Plantar kuvvet dağılımı, temas alanı, ayak açısı, ortalama ve maksimum basınçlar, adım uzunluğu, adım genişliği, kadans, yürüyüş hızı, vücut basınç merkezi uzunluğu, salınım hızı ve güven alanı kaydedildi.

Bulgular: Korseleme ayakta duruş sırasında, baropometri sonuçlarını etkilemedi ($p>0,05$). Sağ ayak ile karşılaştırıldığında, yürüyüş sırasında, korseli durumda korsesize göre, sol ayak plantar temas alanı fazlayken, ortalama ve maksimum basınçları azdı ($p<0,05$). Kadans, korseleme ile azaldı. Stabilometri sonuçlarında ise değişiklik gözlenmedi ($p<0,05$).

Sonuç: Spinal ortezleme, yürüyüş sırasında plantar basınç dağılımında daha fazla simetri yarattı. Ancak bununla birlikte, ortezleme, çift eğri paternli skolyozlarda, yürüyüşün zaman-mesafe karakteristiklerini değiştirerek yürüyüşü bozma eğilimindedir.

Anahtar sözcükler: skolyoz, yürüyüş, postural denge, ayak

Idiopathic scoliosis is a complex three-dimensional deformity, defined as lateral deviation and axial rotation of the spine (1). The scoliotic deformity includes both translational and angular asymmetry of the vertebrae, rib cage, and back surface (2). Because of its three-dimensional characteristic, compared to segmental problems, the trunk distortion affects the whole body in scoliosis. The body asymmetries in idiopathic scoliosis are reported to involve the trunk, pelvis, and lower limbs (3).

For moderate curves (primary curve 20°–45° Cobb), bracing is the standard treatment method during skeletal growth to prevent progression of the deformity (4), to restore spinal misalignment, and to maintain spinal balance (5). A recent Cochrane review reported that rigid (polyethylene) bracing and full-time wear increases the success rate (1). There have been several types of braces for scoliosis of disparate design, material characteristics, and treatment protocols (6). However, they are all based on the three-point pressure system to push against the spine from the exterior to move the spinal column back into its correct location (1). Because of the restrictive nature of braces due to continuous pressure on the trunk during long duration use and mobility restriction, bracing may affect lower extremity biomechanics during functional activities, such as standing and walking (7).

Foot structure and biomechanics constitute an essential connection between the human body and the ground. Therefore, the foot plays a critical role in maintaining biomechanical function of the lower extremities, which includes provision of balance and stabilization during human locomotion (8). The foot provides structural support and is exposed to repetitive body-weight loads in relation to ground. Asymmetries in plantar pressure distributions have been reported to predispose the individual to disorders in functional activities (9). Computerized pedobarography platforms are commonly used in clinical and research settings for evaluating the interaction between foot biomechanics and postural stability parameters (10). The data obtained from a plantar pressure distribution assessment suggested its usefulness in the evaluation and management of foot and lower extremity disorders (9).

It was previously reported that long-term (6 months) spinal bracing generated changes in gait biomechanics in terms of increased pelvis and hip motion, decreased stance phase time and cadence, and increased step length (7). However, there are studies demonstrating decreased pelvis and hip mobility, immediately (11) and one-year after bracing (12). However, they found no changes in kinetics or kinematics of knee and ankle joints (12). A preliminary baropodometric survey found improvement in lower limb load asymmetry and improvement in postural stability during standing and gait with the Chêneau brace (13). Bracing studies focus mainly on pelvis and hip joint characteristics. The effects of a spinal brace on foot biomechanics in relation to the locomotor mechanism have not been studied sufficiently. We hypothesized that a spinal brace would alter plantar pressure distribution, temporo-spatial gait characteristics and postural balance. Therefore, the aim of this study was to assess the short-term effects of a spinal brace on the functional profile of the feet during standing and gait, and its possible relationship to postural balance in patients with adolescent idiopathic scoliosis (AIS).

Material and method

The Subjects

Twenty-one female patients with AIS, ages 10–16 years, who had a double curve pattern with thoracic (primary) and lumbar (secondary) curves in the coronal plane and a primary curve magnitude between 20° and 45° of Cobb angle participated in this study. For determining primary curves, the larger curve (by ≥4°) was assigned primary curve status (14). Patients were recruited from the orthotic and biomechanics department of the university. Patients were excluded if they did not consent to the study or wear a spinal brace, had a congenital curve, neuromuscular, rheumatologic, renal, cardiovascular, pulmonary or vestibular diseases, tumors, underwent surgical correction, or previously had conservative therapy.

The study was approved by the Ethical Committee of the university and informed consent was obtained from patients and parents.

Outcome measures

Age, sex, body weight, height, and body mass index (BMI) were recorded at baseline. Risser grade for skeletal maturity and Cobb angle of each curve for curve magnitude were measured on standard standing anteroposterior spine radiograph at baseline. For determining Risser grade, an index of maturity rated on a scale of 0–5 (where grade 0 indicates no ossification center at the level of iliac crest apophysis, and grade 5 indicates complete ossification and fusion of the iliac crest apophysis) (15). In addition to baseline measurement, Cobb angle of the primary curve was measured following brace fabrication to determine initial in-brace correction (with the brace on). Cobb angle measurements on standing full-spine anteroposterior radiographs are considered to be the gold standard for curve magnitude (16).

The baropodometric and stabilometric tests were performed under two conditions without bracing at baseline and with 7 days of bracing with brace on (17). The tests conducted by the second investigator, who had four-year experienced in baropodometric analysis. To obtain baropodometric and stabilometric data, a Modular Electronic Baropodometer (Diasu Company, Rome, Italy; 5 m long and 40 cm wide; 4024 sensors; frequency, 300 MHz) elaboration with Milletrix software was used (18). The measuring system comprised the platform placed on the floor, and connected to a computer running the manufacturer's software. The assessments were taken during static (standing) and dynamic (gait) conditions. No instructions were given to the subjects as to how to step onto the device; this allowed them to assume their habitual standing posture and walking characteristics. The measurements took place in a room with uniform brightness, and each patient stood on the platform for 10 s before the tests. All patients looked at a light source during the test with open eyes. The test-retest reliability of the baropodometric measurement was demonstrated to be moderate to good, ranging from 0.62 to 0.99 in the adolescent population (19).

Static baropodometry evaluates body weight distribution, loading surface, and foot angle during standing. The patients were requested to stand barefoot on the force plate platform with their arms resting down alongside the trunk and to maintain this position for 1 min while looking directly straightforward with their eyes open. The following data were collected for each foot: 1) forefoot plantar force percentage (%); 2) rear foot plantar force percentage (%); 3) plantar contact area (cm^2); 4) total plantar force; and 5) foot angle (°).

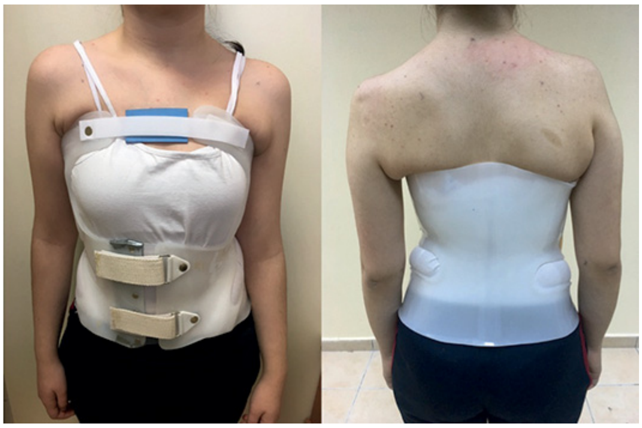
Dynamic baropodometry evaluates spatiotemporal gait parameters, body weight distribution, and ground reaction forces during the gait cycle. The patients were requested to walk barefoot continuously along a 5-m long platform, for 3 min, before arriving at a walking platform. The following parameters were evaluated by the baropodometric gait assessment: 1) plantar contact area (cm^2); 2) total plantar force; 3) foot angle: the angle between the direction of progression of the subject and a reference line on the sole of each foot (°); 4) mean pressure: mean pressures exerted on the ground (kg/cm^2); 5) peak pressure: maximum pressures exerted on the ground (kg/cm^2); 6) cadence: steps per min (steps/min); 7) step length: the distance the body moves forward during a ground contact period (cm); 8) step width: the lateral distance between the average center of pressure (COP) acting under each foot (cm); and 9) gait speed (cm/s).

Stabilometry quantifies the body COP sways as a predictor of postural stability. The three following parameters were assessed: 1) length of path: the linear length of the COP sway path in 52 s (mm), 2) confidence ellipse area: an area that includes 95% of samples of a statokinesigram that evaluates COP sways (mm^2); 3) COP sway velocities along anteroposterior and laterolateral directions. Stabilometric parameters were evaluated with eyes open or closed (18).

Furthermore, brace-wearing time per day was recorded for each person to determine brace compliance.

Intervention

All patients were treated with the same spinal brace (Figure 1). All spinal braces were fabricated by the same certified orthotist using a plaster cast was taken to capture the body shape of each patient. A rigid (polyethylene), symmetrical, patient-oriented, custom-made characteristic design thoraco-lumbo-sacral spinal brace was fabricated. The brace had a three-dimensional corrective pressure system while protecting lumbar lordosis and allowing thoracic expansion and free movement ability to the trunk and extremities to achieve a symmetrical posture and optimal curve correction. All patients were prescribed full-time (23 h daily) bracing.



Statistical analysis

Sample size was based on a pilot study with nine patients using a power of 0.80 and α=0.05. It was calculated that a minimum of 20 participants would be necessary considering the primary outcome of cadence. Statistical analyses were performed using SPSS 11 (SPSS, Chicago, IL). Data was tested for normality using the Kolmogorov-Smirnov test; however, the data did not show a normal frequency distribution. Wilcoxon rank-sum test was used to compare the baropodometric and stabilometric outcomes between with and without bracing. A value of $p<0.05$ was considered significant. All data are given as mean ± standard deviation.

Results

Sixty-seven patients with AIS were assessed for eligibility. Thirty were excluded from the study for not meeting the inclusion criteria, and sixteen patients refused to participate in the study. Feeling too tired for the assessments and lack of time were cited as reasons for not participating. Twenty-one patients agreed to participate in the study. All patients completed the one-week brace-wearing process, and attended the final assessments.

Demographic and clinical features of the patients are shown in Table 1. The patients consisted of 21 female adolescents with right thoracic-left lumbar double-curve pattern scoliosis. The average Cobb angle of the thoracic curve was 33.9° (range: 22°–45°) and lumbar curve was 23.1° (range: 16°-36°) at baseline. Initial mean in-brace correction for the primary curve was -40.5%. Brace compliance was 22.2 (0.7) h daily.

Table 1. Demographic and clinical features of the patients

	Mean (SD) (n=21)
Age (years)	13.9 (1.9)
Height (cm)	154.3 (7.0)
Weight (kg)	41.4 (7.7)
BMI (kg/m^2)	17.3 (2.1)
Risser grade	
1 (n)	4
2 (n)	7
3 (n)	10
Curve pattern	
Right thoracic left lumbar (n)	21
Curve magnitude (Cobb angle)	
Thoracic (º)	33.9 (6.7)
Lumbar (º)	23.1 (5.8)
Mean brace wearing time (hours/day)	22.2 (0.7)

Values are frequency or mean (Standard deviation).
Abbreviations: BMI, Body Mass Index

Static baropodometry parameters during standing did not change with bracing ($p>0.05$) (Table 2).

Brace wearing altered dynamic baropodometry parameters during gait. Left foot plantar contact area was greater with bracing compared to without bracing ($p=0.007$). Mean pressure and peak pressures on the left foot were lower with bracing compared to without bracing ($p=0.040$ and $p=0.027$, respectively). Cadence decreased with bracing compared to without bracing ($p=0.010$) (Table 2).

Stabilometry results did not differ with bracing ($p>0.05$) (Table 3).

Discussion

This study demonstrated that bracing produces a more symmetrical pressure distribution pattern between the feet during walking. However, significantly decreased cadence and a trend toward decreased gait speed showed the presence of an adaptation mechanism to the brace during walking. In accordance with our hypothesis, some authors demonstrated that bracing affects gait pattern in idiopathic scoliosis (7,12,13,20).

Stabilometric and baropodometric assessments could help clinicians quantify the effects of braces on load asymmetries, adaptations, or compensations to bracing, and possible alterations in postural control strategies during standing and locomotion in AIS (13). During standing the brace did not alter any baropodometry parameters. However, a more symmetrical plantar pressure pattern between the feet was achieved with bracing during walking. Decreased mean and peak pressures on the left foot with bracing may be related to increased symmetry. Subjects may have engaged a symmetrical loading strategy on the lower extremities with decreased pelvic tilt with bracing. There are many studies that have shown that the pelvis is structurally changed by the spinal change due to scoliosis (21,22). We propose that the 40.5% initial in brace correction may have created a more symmetrical trunk shape and pelvis position. Although pelvic obliquity was not investigated in our protocol, the present findings are consistent with reported correction of pelvic asymmetry. Further studies are needed to clarify the relationship between pelvic obliquity and plantar pressure distribution with bracing. However, these results indicate that improved pressure distribution of body weight with bracing would help provide normal foot biomechanics in the long-term. Asymmetries in plantar pressure distribution may cause

Table 2. Baropodometric outcomes during standing and gait without and with bracing conditions

	Without bracing (n=21)	*With bracing (n=21)*	*P Value*
Baropodometric outcomes	*Mean (SD)*	*Mean (SD)*	
Standing			
Forefoot plantar force percentage (%)			
Left foot	34.07 (9.07)	36.68 (13.87)	0.862
Right foot	39.10 (10.74)	38.28 (12.99)	0.122
Rearfoot plantar force percentage (%)			
Left foot	65.80 (9.10)	62.82 (14.13)	0.862
Right foot	60.90 (10.74)	59.81 (14.59)	0.244
Plantar contact area (cm2)			
Left foot	60.59 (21.04)	61.38 (17.87)	0.639
Right foot	67.80 (20.85)	65.52 (19.74)	0.313
Total plantar force (kg)			
Left foot	21.15 (6.29)	20.40 (4.46)	0.590
Right foot	22.85 (4.44)	22.12 (6.83)	0.339
Foot angle (º)			
Left foot	7.38 (4.75)	9.29 (4.99)	0.360
Right foot	9.99 (4.83)	13.47 (10.77)	0.478
Gait			
Plantar contact area (cm^2)			
Left foot	66.72 (17.94)	76.18 (21.98)	0.007*
Right foot	69.90 (23.33)	75.77 (20.42)	0.289
Total plantar force (kg)			
Left foot	49.72 (6.99)	48.64 (4.78)	0.639
Right foot	50.28 (6.99)	51.36 (4.78)	0.639
Foot angle (º)			
Left foot	11.18 (6.68)	12.50 (6.06)	0.175
Right foot	13.82 (8.71)	14.61 (3.96)	0.130
Mean pressure (kg/cm^2)			
Left foot	640.41 (123.84)	579.77 (92.32)	0.040*
Right foot	676.85 (269.86)	579.70 (112.61)	0.082
Peak pressure (kg/cm2)			
Left foot	1420.88 (1214.03)	1114.35 (368.79)	0.027*
Right foot	1222.63 (402.45)	1141.62 (249.07)	0.339
Step length (cm)			
Left foot	50.38 (6.52)	49.71 (9.30)	0.824
Right foot	48.95 (10.18)	50.29 (9.11)	0.809
Step width			
Left foot	10.57 (6.09)	11.40 (10.30)	0.732
Right foot	11.60 (7.23)	11.65 (10.39)	0.322
Cadence (step/min)	103.53 (13.33)	95.93 (6.75)	0.010*
Gait speed (cm/s)	86.97 (20.94)	81.73 (20.99)	0.170

Values are frequency or mean (Standard deviation).
* $P < 0.05$

Table 3. Results for the stabilometry test, with opened eyes and closed eyes, without and with bracing conditions

	Without Bracing (n=21)	*With Bracing (n=21)*	*P Value*
Stabilometric outcomes	*Mean (SD)*	*Mean (SD)*	
Length of path (mm)			
Opened eyes	241.12 (164.63)	223.35 (86.63)	0.654
Closed eyes	237.84 (69.41)	249.87 (58.64)	0.204
Confidence ellipse area (mm2)			
Opened eyes	182.48 (88.63)	182.54 (61.53)	0.476
Closed eyes	181.19 (76.55)	215.79 (131.11)	0.476
AP CoP sway velocities (mm/s)			
Opened eyes	1.93 (0.78)	2.15 (1.50)	0.972
Closed eyes	2.74 (3.51)	2.71 (1.88)	0.126
LL CoP sway velocities (mm/s)			
Opened eyes	3.48 (1.82)	3.55 (1.37)	0.821
Closed eyes	3.98 (1.71)	4.09 (1.40)	0.281

Values are frequency or mean (Standard deviation).
Abbreviations: AP, Antero-posterior; LL, latero-lateral; COP, center of pressure.

difficulty in controlling foot stability and increase the risk of bone, joint, and muscle traumas and pathologies in the long-term (23). Future biomechanical studies are required to evaluate these changes in foot biomechanics and the relationship with function in scoliosis.

For comfort and maximum energy efficiency in walking, the relationship between step length, cadence, and walking speed is important. These are major determinants of an individual's preferred locomotor pattern (24). Alterations in cadence regulation, step length, or self-selected speed causes increased energy consumption (25) and temporal-spatial gait parameter irregularities (26). In the present study, cadence decreased with bracing. In addition, there was a trend toward decreased gait speed while step length remained similar with bracing. The reduced cadence may be a secondary adjustment to increased trunk stiffness with bracing during walking. Bracing has been reported to increase trunk stiffness and restrict horizontal thorax and pelvis rotations and total spine rotational amplitudes (27). Our results appear to support the hypothesis that bracing stiffened the trunk and thereby disrupted walking, but we did not assess trunk stiffness. Mahaudens et al. found decreased frontal pelvis (39%), hip (23%), and shoulder (30%) motion in bracing, which was associated with reduced pelvis rotation compared to without bracing (20). In addition, neither lumbopelvic muscle activity nor energy expenditure changed with bracing during walking. In agreement with Mahaudens et al., less pelvic obliquity, less pelvis motion, and less rotational movement of the trunk relative to the pelvis was founded previously (11,12). However, no significant changes in foot kinematics were shown by Wong et al. (12). Paolucci et al. found improved gait load symmetry accompanied by reduced walking speed and cadence with the Chêneau brace, which utilized the principle of pressure overcorrection to correct spine deformity (13).

AIS, with three-dimensional deformation of the spine, is known to alter postural orientation and cause a pathological gait. The asymmetries of postural orientation of the shoulder and pelvis, and trunk movement affect the ability to maintain postural balance (28). The goal of bracing for idiopathic scoliosis is to reduce the magnitude of deformity and to maintain spinal balance (5). Therefore, it is important to evaluate postural balance; the functional profile of the feet with bracing should be investigated during standing and gait. In a previous study, we found improved postural stability in terms of increased proprioception, equilibrium performance, and rhythmic movement ability with spinal bracing in patients with AIS (29). However, in the present study, no significant changes were observed in stabilometric outcomes with bracing in patients with double curve pattern scoliosis. These findings may be associated with the patient clinical characteristics regarding curve type, bone maturation, and age. Paolucci et al. found improvement in postural balance in terms of improvement in COP sway length and velocity with a Chêneau brace (13).

Our study has possible limitations: Our findings are pertinent for patients with double curve pattern scoliosis, and cannot be generalized to other scoliosis and brace types. Adding pelvic obliquity and trunk stiffness assessments to outcome measures would have explained clearly the adaptations in plantar pressure, and cadence induced by bracing during walking. Future longitudinal research in different curve pattern scoliosis populations should clarify these aspects.

Conclusion

In conclusion, bracing redistributed foot pressure to be symmetrical during walking in our sample of female adolescents with double curve pattern scoliosis. However, bracing tends to alter temporal-spatial walking parameters as seen by the decreased cadence.

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Conflict of interest statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article.

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