Acta of Bioengineering and Biomechanics
Vol. 26, No. 2, 2024
Original paper
DOI: 10.37190/ABB-02442-2024-02

Does the Chêneau brace affect gait pattern and body balance of adolescents with idiopathic scoliosis?

MARIUSZ DRUŻBICKI[1]*, ANNA PUCHALSKA-SARNA[1], OLGA WOLIŃSKA[2], MAGDALENA SZCZEPANIK[1], JOANNA MAJEWSKA[1]

[1] Department of Physiotherapy, University of Rzeszów, Rzeszów, Poland.
[2] Department of Pediatrics, University of Rzeszów, Rzeszów, Poland.

Purpose: This study evaluated changes in selected spatiotemporal and kinematic gait parameters and balance in girls with Adolescent idiopathic scoliosis (AIS) with and without the Chêneau brace. *Methods*: 15 subjects with scoliosis wearing the Chêneau brace and an equal comparative control group underwent objective gait analysis with the 3D BTS motion caption system. Balance assessment was done with the Kistler platform. The analysis was performed at comparison of gait and balance parameters in patients with scoliosis in two conditions: with and without the Chêneau brace during the study. *Results*: Statistically significant differences occurred in many spatiotemporal and kinematic parameters both for the AIS group with and without the Chêneau brace and in the AIS group with and without the Chêneau brace as compared to the control group. When comparing adolescents with AIS with and without the Chêneau brace, statistically significant differences were noted in the COP-X amplitude and in the path length in trials with closed eyes. Compared to the control group the following differences were statistically significant: the value of the COP-Y amplitude during the trial with closed eyes, both with and without the Chêneau brace, and the Equivalent area of the COP during the trial with closed eyes with the Chêneau brace. *Conclusions*: The Chêneau brace in patients with juvenile idiopathic scoliosis affects the level of selected balance and gait parameters.

Key words: *gait analysis, postural balance, Chêneau brace, adolescent idiopathic scoliosis*

1. Introduction

Adolescent idiopathic scoliosis (AIS) is the most common spinal deformity, which occurs with a frequency of 1–4%. This progressive growth disease generates postural changes, standing instability, sensory disturbance, and modification of gait pattern [8], [17], [23], [27]. It has been confirmed in several studies that the step length, cadence, velocity, range of motion of the pelvis, hip, knee, and ankle, muscle efficiency, and energy cost are affected [8], [17], [19], [25], [26]. However, some studies showed that patients with AIS had typically poor balance control, but the gait pattern did not differ from the healthy control group [3]. Bracing is a basic method of treatment, recommended for patients with skeletal immaturity and Cobb angle between 25–40 degrees [14], [20]. Some studies, both with short-term and long-term follow-up, investigated the influence of brace wearing on gait patterns and balance control. In one of them, researchers performed radiological assessment and gait analysis in patients with AIS, first without the brace and 1 hour later in-brace [18]. Another study compared the evaluation of patients with AIS before and after the 6-month-long process of wearing the brace, which included radiological assessment and gait analysis (kinematics, mechanics, electromyography (EMG) as well as the energetics of walking [20]. In most of the studies, patients were treated with Chêneau brace [3], [14], [20], [23], [28]. A few studies focused only on balance assessment in AIS patients wearing the brace. In another study, researchers compared postural control in adolescent girls when wearing the Chêneau brace and

* Corresponding author: Mariusz Drużbicki, Department of Physiotherapy, University of Rzeszów, ul. Warszawska, 35-205, Rzeszów, Poland. E-mail: mdruzbicki@ur.edu.pl
Received: April 23rd, 2024
Accepted for publication: July 9th, 2024

when performing active self-correction during a quiet comfortable stance [22]. Another study showed improvement in postural balance after 4 months of Chêneau brace treatment [21]. However, one of the studies demonstrated a lack of balance changes in a 4-month follow-up, when patients with AIS were wearing the Boston brace [24].

Measuring only static parameters such as the Cobb angle as well as the assessment of balance in static conditions does not describe the dynamic changes of scoliotic deformities in gait. Moreover, to our knowledge, no study has yet investigated the gait of adolescents wearing a cheneau brace and after removing it compared to the control group. Therefore, the study aimed to assess the impact of adolescent idiopathic scoliosis on gait pattern and body balance, but also the impact of using the Chêneau orthosis on the aforementioned factors.

The study aimed to assess the impact of adolescent idiopathic scoliosis on gait pattern and body balance, as well as the impact of using the Chêneau orthosis on the aforementioned factors.

2. Materials and methods

2.1. Participants

Qualification for the study was carried out among children and adolescents referred for treatment and physiotherapy at the Clinical Regional Hospital No. 2 in Rzeszów (KSW). Patients with AIS were referred by orthopedic specialists and rehabilitation specialists. The inclusion criteria were: thoracolumbar/lumbar or lumbar primary structural curve according to Lenke classification [16], age between 10–18, all curve types, and a Cobb angle of 20–40°, Risser stage ≤ 3 [10], who had been prescribed the Chêneau brace, consent to participate in the study. The exclusion criteria were: history of neuromuscular, cardiovascular, pulmonary, vestibular or rheumatological diseases, scheduled for surgery, leg length discrepancy bigger than 1cm, lack of normal vision, back pain or another which could affect gait pattern and balance, lack of consent for participating in this study.

The control group consisted of 15 healthy girls matched in terms of age, height, and weight to the study group (Table 1).

Fiveteen girls with progressive AIS aged 9–15 years were enrolled in the study group. All girls were diagnosed with left thoracolumbar/lumbar or lumbar primary structural curve according to Lenke classification [16]. The value of primary and secondary curves were defined according to the Cobb method and skeletal immaturity was defined with the Risser test. The angle of scoliosis exceeded 20°, but no one was qualified for surgery. The maximum angle of scoliosis was 36°. Patients with leg length discrepancies higher than 1 cm, any locomotor disorders, low back pain, neurological abnormalities observed on clinical examination or with any previous treatment for their scoliosis were not included in this study.

Those who used the brace for more than 12 months were qualified. All patients were wearing the Chêneau brace for 22 hours per day. All girls were patients of the Clinical Regional Centre for Rehabilitation of Children and Adolescents in Rzeszów. All participants have regularly attended physiotherapy. Each participant had one to three individual exercise sessions per week (45 minutes) and individually performed the planned exercises at home. The exercise plan was individual for each and focused on the correction of deformities.

The study was approved by the Bioethics Committee of the Faculty of Medicine of the University of Rzeszów (Resolution No. 1/05/2021/W). All participants were informed about the aim and the course of this study, and they signed a voluntary consent to participate.

2.2. Methods

The cross-sectional study was performed between 2019 and 2021. The assessment was performed in the Movement Analysis Laboratory of the Clinical Physiotherapy Department at KSW in Rzeszów. All of the participants were assessed before starting their first exercises. Gait was assessed using 3D analysis, body balance on a force platform and anterior-posterior spinal curvatures using a digital inclinometer. Gait and balance assessments were performed twice. The first assessment was performed without the brace and the second one after a 30-minute break, with the brace.

Radiological assessment

Full spine and pelvic anteroposterior X-ray in a standing position (without brace) was performed to asses Cobb angle and Risser sign. The anteroposterior curvatures of the spine were measured in all subjects using a Saunders digital inclinometer. In line with Czaprowski's conclusions, the assessment of all participants was performed by the same researcher [4]. The measurements were conducted based on the guidelines of the American Medical Association. To assess the angle of the sacral slope, the inclinometer reader was reset in the horizontal position and then placed on the lumbosacral junction. Measuring the lumbar lordosis angle began by resetting the inclinometer reader at the L5–S1 point, after which it was applied to the thoracolumbar junction (Th12–L1). The angle of thoracic kyphosis was determined after the inclinometer was reset at the Th12–L1 point, and the reading was taken at the cervicothoracic junction (C7–Th1) [4].

Gait assessment

Gait was assessed with the use of a three-dimensional motion analysis system. Spatiotemporal and kinematic data were collected with a six-camera motion capture system (BTS SMART-DX 700, 250 Hz; BTS Bioengineering, Milano, Italy) with software (SMART Capture, Tracker and Analyzer) and two force-plates (AMTI, USA). Passive markers were placed on the subject's skin with the internal protocol of the Davis Marker Placement system on the sacrum, pelvis (the anterior and posterior iliac spine), femur (lateral epicondyle, great trochanter and in the lower one-third of the shank), fibula (lateral malleolus, lateral end of the condyle in the lower one-third of the shank), foot (metatarsal head and heel). Each 3D assessment was preceded by system calibration. Recording process included walking a path of 5 m at least six times. Tests were conducted barefoot. Subjects were asked to walk along this distance at their natural pace. Gait assessment was done when patients were wearing Chêneau brace and without it on the same day. The following data were analyzed [17], [6]: 1) spatiotemporal parameters: step length [m], velocity [m/s], cadence [steps/min], stance phase [s], double stance phase [s]; 2) kinematic parameters: range of motion of the pelvis and the hip on the sagittal, frontal and transversal plane, range of motion of the knee and the ankle on the sagittal plane, position of the pelvis and the hip in the initial contact (IC) and pre-swing (PS).

Balance assessment

For the balance assessment, the AMTI platform was used. The assessment was performed with, and without the Chêneau brace, with eyes both open and closed. Each task took 30 s. The following data were analyzed: amplitude of COP-X [mm], amplitude of COP-Y [mm], trace length [mm] and speed of COP [mm/s] and equivalent area of COP [mm^2] computing sway length, sway ellipse area, and sway velocities [7], [21].

2.3. Statistical analysis

The chosen gait and balance parameters were analyzed for the convex and concave spine curves. All variables were presented in mean (± standard deviation).

A paired Wilcoxon test was used to compare two repeated measures of quantitative variables.

Mann–Whitney test was used to compare quantitative variables between two groups.

The level of statistical significance was assumed at $p < 0.05$. All statistical analyses were performed using Statistica 13.2. software.

3. Results

3.1. Demographic and radiological results

There were no significant differences between AIS and the control group in terms of age, weight and height, but the value of BMI was significantly higher in the control group (Table 1).

Table 1. Participants characteristics

Parameter		Group		*p*
		AIS group (*N* = 15)	Control group (*N* = 15)	
Age [years]	m ± SD	14.83 ± 2.43	14.13 ± 1.64	$p = 0.199$
Weight [kg]	m ± SD	53.07 ± 9.4	57.27 ± 7.81	$p = 0.371$
Height [cm]	m ± SD	1.66 ± 0.09	1.65 ± 0.09	$p = 0.466$
BMI [kg/m^2]	m ± SD	19.21 ± 2.3	20.87 ± 1.54	$p = 0.037$ *
Radiologic: Primery thoracolumbar/lumbar Cobb angle [°]	m ± SD [min–max]	32.1 ± 6,5 [20–36°]	–	–
Risser		2 [2–2]		

m – mean, SD – standard deviation, * statistically significant ($p < 0.05$).

The mean value of the primary curve was 32° Cobb angle (range 20–36°). The mean value of thoracic kyphosis measured with an inclinometer was 28 (range 24–32°) and the angle of lumbar lordosis was 29° (range 24–33°). The mean secondary curve was 19° Cobb angle. The mean value of Risser was 2, 14 girls were post-menarche and one girl was pre-menarche (Table 1). The Chêneau brace was worn on average from 20 to 24 months.

3.2. Gait assessment

Comparison of gait parameter in the AIS group with and without the Chêneau brace

The study showed a decreased step length for both the convex and the concave side of the curve when the patients were wearing the brace while walking, but the result was statistically significant only for the convex side ($p = 0.025$) (Table 2).

Concerning the kinematic gait parameters, the study showed statistically significant differences in both the convex and the concave sides of the curve for the following parameters: pelvic obliquity range of motion and rotation the hip range of motion in frontal plane and hip flexion in IC. Otherwise, the study showed statistically significant parameters only for the concave side for pelvic rotation in IC, hip position in the frontal plane in PS, and rotation in PS (Table 3). In Table 3, the values of only those parameters where differences were statistically significant are collected.

Comparison of gait parameter in the group of AIS without the brace and the control group

According to the comparison of spatiotemporal gait parameters between the AIS and the control group, there were no statistically significant differences (Table 4).

Table 2. Spatiotemporal gait parameters in the AIS group with and without brace

Spatiotemporal gait parameters		No brace	With brace	*p*
Stance phase [%] – convex side	m ± SD	59.64 ± 2.73	60.77 ± 1.69	0.162
Swing phase [%]– convex side	m ± SD	39.25 ± 2.56	39.23 ± 1.69	0.624
Double support [%]	m ± SD	10.62 ± 1.42	11.27 ± 2.74	0.401
Step length [m] – convex side	m ± SD	0.57 ± 0.07	0.55 ± 0.07	0.025*
Stance phase [%]– concave side	m ± SD	60.79 ± 1.52	60.51 ± 1.27	0.249
Swing phase [%]– concave side	m ± SD	39.21 ± 1.52	39.48 ± 1.27	0.249
Double support [%]	m ± SD	10.93 ± 2.52	10.59 ± 1.41	0.783
Step length [m] – concave side	m ± SD	0.58 ± 0.08	0.57 ± 0.07	0.146
Mean velocity [m/s]	m ± SD	0.99 ± 0.17	0.96 ± 0.17	0.092
Cadence [step/min]	m ± SD	110.23 ± 7.14	110.67 ± 7.17	0.754

m – mean, SD – standard deviation, *p* – Wilcoxon paired test, * statistically significant ($p < 0.05$).

Table 3. Kinematic gait parameters in the AIS group with and without the brace

Kinematic gait parameters		No brace	With brace	*p*
Pelvic obliquity ROM– convex side	m ± SD	8.29 ± 2.57	3.6 ± 2.4	0.001*
Pelvic intra-extra rotation ROM	m ± SD	10.21 ± 2.52	7.23 ± 2.08	0.004*
Hip abduction-adduction ROM– convex side	m ± SD	12.52 ± 4.4	9.5 ± 3.17	0.017*
Hip flexion-extension ROM at IC- convex side	m ± SD	32.61 ± 2.85	30.79 ± 2.67	0.014*
Pelvic obliquity ROM– concave side	m ± SD	7.92 ± 3.03	3.03 ± 1.76	0.001*
Pelvic intra-extra rotation ROM– concave side	m ± SD	10.63 ± 3.06	7.24 ± 2.1	0.001*
Hip abduction-adduction ROM– concave side	m ± SD	12.81 ± 3.86	8.61 ± 2.54	0.002*
Pelvic intra-extra rotation at IC – concave side	m ± SD	4.89 ± 2.98	2.79 ± 2.97	0.044*
Hip flexion-extension at IC – concave side	m ± SD	33.12 ± 1.95	30.61 ± 1.62	0.001*
Hip abduction-adduction at PS – concave side	m ± SD	–2.02 ± 3.82	3.41 ± 2.05	0.003*
Hip intra-extra rotation– at PS concave side	m ± SD	4.84 ± 6.36	9.5 ± 3.85	0.045*

ROM – range of motion, IC – initial contact, PS – pre-swing, m – mean, SD – standard deviation, *p* – Wilcoxon paired test, * statistically significant ($p < 0.05$).

The analysis of kinematic gait parameters showed statistically significant differences for both sides of curve in the following parameters: pelvic range of motion in transversal plan, knee and ankle range of motion in sagittal plane and hip position in transversal plane in PS Additionally, on the convex side, statisti-

Table 4. Spatiotemporal gait parameters in the group of AIS without the brace and the control group

Spatiotemporal gait parameters		Control group ($N = 15$)	AIS group (no brace) ($N = 15$)	p
Stance phase [%] – convex side	m ± SD	60.61 ± 1.12	59.64 ± 2.73	0.319
Swing phase [%]– convex side	m ± SD	40.83 ± 5.43	39.25 ± 2.56	0.967
Double support [%]	m ± SD	10.61 ± 0.83	10.62 ± 1.42	0.983
Step length [m] – convex side	m ± SD	0.61 ± 0.05	0.57 ± 0.07	0.13
Stance phase [%]– concave side	m ± SD	60.59 ± 0.87	60.79 ± 1.52	0.506
Swing phase [%]– concave side	m ± SD	38.74 ± 2.04	39.21 ± 1.52	0.901
Double support [%]	m ± SD	10.75 ± 0.72	10.93 ± 2.52	0.708
Step length [m] – concave side	m ± SD	0.61 ± 0.05	0.58 ± 0.08	0.238
Mean velocity [m/s]	m ± SD	1.05 ± 0.12	0.99 ± 0.17	0.248
Cadence [step/min]	m ± SD	111.13 ± 6.97	110.23 ± 7.14	0.819

m – mean, SD – standard deviation, p – Mann–Whitney test, * statistically significant ($p < 0.05$).

Table 5. Kinematic gait parameters in the group of AIS without the brace and control group

Kinematic gait parameters		Control group (N=15)	AIS group (no brace) ($N = 15$)	p
Pelvic intra-extra rotation ROM	m ± SD	8.4 ± 1.47	10.21 ± 2.52	0.034*
Knee flexion-extension ROM – convex side	m ± SD	58.48 ± 2.72	53.94 ± 7.58	0.031*
Ankle flexion-extension ROM – convex side	m ± SD	33.15 ± 3.87	29.17 ± 4.23	0.013*
Hip abduction-adduction ROM at IC – convex side	m ± SD	–3.58 ± 1.63	–0.58 ± 3.46	0.008*
Hip abduction-adduction ROM at PS – convex side	m ± SD	–2.72 ± 2.14	0.8 ± 4.25	0.016*
Hip intra-extra rotation ROM at PS – convex side	m ± SD	10.78 ± 2.74	4.97 ± 3.02	<0.001*
Pelvic intra-extra rotation ROM – concave side	m ± SD	8.46 ± 1.45	10.63 ± 3.06	0.01*
Knee flexion-extension ROM – concave side	m ± SD	59.37 ± 3.7	53.27 ± 7.51	0.022*
Ankle flexion-extension ROM – concave side	m ± SD	34.13 ± 3.72	29.82 ± 3.49	0.007*
Hip intra-extra rotation – at PS concave side	m ± SD	10.53 ± 2.45	4.84 ± 6.36	0.001*

ROM – range of motion, IC – initial contact, PS – pre-swing, m – mean, SD – standard deviation, p – Mann–Whitney test, * statistically significant ($p < 0.05$).

Table 6. Spatiotemporal gait parameters in the AIS group with the brace and the control group

Spatiotemporal gait parameters		Control group ($N = 15$)	AIS group (with brace) ($N = 15$)	p
Stance phase [%] – convex side	m ± SD	60.61 ± 1.12	60.77 ± 1.69	0.983
Swing phase [%] – convex side	m ± SD	40.83 ± 5.43	39.23 ± 1.69	0.693
Double support [%]	m ± SD	10.61 ± 0.83	11.27 ± 2.74	0.967
Step length [m] – convex side	m ± SD	0.61 ± 0.05	0.55 ± 0.07	0.018*
Stance phase [%] – concave side	m ± SD	60.59 ± 0.87	60.51 ± 1.27	0.575
Swing phase [%] – concave side	m ± SD	38.74 ± 2.04	39.48 ± 1.27	0.253
Double support [%]	m ± SD	10.75 ± 0.72	10.59 ± 1.41	0.95
Step length [m] – concave side	m ± SD	0.61 ± 0.05	0.57 ± 0.07	0.133
Mean velocity [m/s]	m ± SD	1.05 ± 0.12	0.96 ± 0.17	0.244
Cadence [step/min]	m ± SD	111.13 ± 6.97	110.67 ± 7.17	0.95

m – mean, SD – standard deviation, p – Mann–Whitney test, * statistically significant ($p < 0.05$).

cally significant differences were observed in the hip position in IC and PS in the frontal plane. The concave side noted statistically significant differences in hip position in the transversal plane in PS (Table 5). In Table 5, the values of only those parameters where differences were statistically significant are presented.

Comparison of gait parameters in the AIS group with the brace and the control group

When the patients were wearing the brace the step length on the convex side was shorter in the AIS group as compared to the control group ($p = 0.018$), which is a statistically significant difference (Table 6).

Concerning kinematic gait parameters, the study showed statistically significant differences for both the convex and the concave side for the following parameters: pelvic range of motion in the frontal plane, range of motion of the knee and ankle and hip position in transversal plane in IC. For the convex side, statistically significant differences were demonstrated in IC for a hip position in the frontal plane, and in PS in pelvic and hip positions in the transversal plane. In Table 7, the values of only those parameters where differences were statistically significant are presented.

3.3. Balance assessment

Comparison of balance parameters in the AIS group with and without the Chêneau brace

Concerning balance parameters the study showed statistically significant differences only for the amplitude of COP-X during the trial with open eyes ($p = 0.045$*) and for trace length with closed eyes ($p = 0.022$) (Table 8).

Comparison of balance parameters in the AIS group without the brace and the control group

When patients were not wearing the brace the amplitude COP-Y was shorter in the control group as compared to the AIS group without the brace during the test with closed eyes ($p = 0.005$), which was a statistically significant difference (Table 9).

Comparison of balance parameters in the AIS group with the brace and the control group

When patients were wearing the brace the amplitude COP-Y with open eyes was shorter in the control group as compared to the AIS group ($p = 0.042$), which was

Table 7. Kinematic gait parameters in the AIS groupwith the brace and the control group

Kinematic gait parameters		Control group ($N = 15$)	AIS group (with brace) ($N = 15$)	p
Pelvic obliquity-ROM – convex side	m ± SD	8.05 ± 1.85	3.6 ± 2.4	<0.001 *
Knee flexion-extension – ROM – convex side	m ± SD	58.48 ± 2.72	54.32 ± 5.37	0.02 *
Ankle flexion-extension – ROM – convex side	m ± SD	33.15 ± 3.87	29.05 ± 3.76	0.006 *
Hip abiduction-adduction at IC – convex side	m ± SD	–3.58 ± 1.63	1.75 ± 3.7	0.001 *
Hip intra-inter rotation at IC – convex side	m ± SD	–3.13 ± 2.42	–0.12 ± 6.01	0.033 *
Pelvic intra-extra rotation at PS – convex side	m ± SD	–4.29 ± 0.8	–2.41 ± 2.58	0.02 *
Hip intra-inter rotation at PS – convex side	m ± SD	10.78 ± 2.74	3.97 ± 7.18	0.001 *
Pevelvic obliquity-ROM – concave side	m ± SD	8.33 ± 1.45	3.03 ± 1.76	<0.001 *
Hip abiduction-adduction – ROM – concave side	m ± SD	11.92 ± 1.76	8.61 ± 2.54	0.001 *
Knee flexion-extension – ROM – concave side	m ± SD	59.37 ± 3.7	51.33 ± 7.81	0.002 *
Ankle flexion-extension – ROM – concave side	m ± SD	34.13 ± 3.72	28.78 ± 3.38	0.001 *
Pelvic tilt at IC – concave side	m ± SD	10.61 ± 1.57	9.28 ± 1.9	0.014 *
Pelvic intra-extra rotation at IC – concave side	m ± SD	4.57 ± 0.81	2.79 ± 2.97	0.044 *
Hip intra-inter rotation at IC – concave side	m ± SD	–3.8 ± 2.41	1.73 ± 6.23	0.001 *
Hip flexion-extension at IC – concave side	m ± SD	32.63 ± 2.82	30.61 ± 1.62	0.024 *
Hip abduction-adduction at PS – concave side	m ± SD	–2.61 ± 2.36	3.41 ± 2.05	<0.001 *

ROM – range of motion, IC – initial contact, PS – pre-swing, m – mean, SD – standard deviation, p – Mann–Whitney test, * statistically significant ($p < 0.05$).

Table 8. Balance parameters in the group of AIS with and without the brace

Parameters		No brace	With brace	*p*
Amplitude COP-X EO [mm]	m ± SD	21.28 ± 11.04	27.84 ± 11.33	0.045 *
Amplitude COP-Y EO [mm]	m ± SD	29.89 ± 13.89	33.98 ± 14.84	0.229
Trace length EO [mm]	m ± SD	489.82 ± 199.16	522.34 ± 158.66	0.315
Equivalent area EO [mmq]	m ± SD	1508.53 ± 2001.91	1411.79 ± 943.97	0.09
Speed EO [mm/s]	m ± SD	16.57 ± 6.58	17.08 ± 6.11	0.66
Amplitude COP-X EC [mm]	m ± SD	25.31 ± 12.2	33.57 ± 29.2	0.303
Amplitude COP-Y EC [mm]	m ± SD	35.47 ± 14.04	44.19 ± 23.26	0.107
Trace length EC [mm]	m ± SD	523.01 ± 142.47	590.07 ± 194.54	0.022 *
Equivalent area EC [mmq]	m ± SD	1821.25 ± 1892.43	1830.2 ± 1589.98	0.561
Speed EC [mm/s]	m ± SD	17.67 ± 4.91	19.4 ± 5.68	0.073

EO – eyes open, EC – eyes closed, m – mean, SD – standard deviation, *p* – Wilcoxon paired test, * statistically significant ($p < 0.05$).

Table 9. Balance parameters in the AIS group without the brace and the control group

Parameters		Control group ($N = 15$)	AIS group (no brace) ($N = 15$)	*p*
Amplitude COP-X EO [mm]	m ± SD	20.95 ± 5.16	21.28 ± 11.04	0.512
Amplitude COP-Y EO [mm]	m ± SD	24.2 ± 7.2	29.89 ± 13.89	0.461
Trace length EO [mm]	m ± SD	485.34 ± 99.46	489.82 ± 199.16	0.148
Equivalent area EO [mm^2]	m ± SD	802.89 ± 350.11	1508.53 ± 2001.91	0.486
Speed EO [mm/s]	m ± SD	16.18 ± 3.32	16.57 ± 6.58	0.325
Amplitude COP-X EC [mm]	m ± SD	23.01 ± 6.29	25.31 ± 12.2	0.967
Amplitude COP-Y EC [mm]	m ± SD	24.52 ± 5.94	35.47 ± 14.04	0.005 *
Trace length EC [mm]	m ± SD	517.06 ± 101.45	523.01 ± 142.47	0.967
Equivalent area EC [mm^2]	m ± SD	884.8 ± 365.22	1821.25 ± 1892.43	0.089
Speed EC [mm/s]	m ± SD	17.24 ± 3.38	17.67 ± 4.91	0.87

EO – eyes open, EC – eyes closed, m – mean, SD – standart deviation, *p* – Mann–Whitney test, * statistically significant ($p < 0.05$).

Table 10. Balance parameters of the AIS group with the brace and the control group

Parameters		Control group ($N = 15$)	AIS group (with brace) ($N = 15$)	*p*
Amplitude COP-X EO [mm]	m ± SD	20.95 ± 5.16	27.84 ± 11.33	0.081
Amplitude COP-Y EO [mm]	m ± SD	24.2 ± 7.2	33.98 ± 14.84	0.042 *
Trace length EO [mm]	m ± SD	485.34 ± 99.46	522.34 ± 158.66	0.806
Equivalent area EO [mm^2]	m ± SD	802.89 ± 350.11	1411.79 ± 943.97	0.019 *
Speed EO [mm/s]	m ± SD	16.18 ± 3.32	17.08 ± 6.11	1
Amplitude COP-X EC [mm]	m ± SD	23.01 ± 6.29	33.57 ± 29.2	0.135
Amplitude COP-Y EC [mm]	m ± SD	24.52 ± 5.94	44.19 ± 23.26	<0.001 *
Trace length EC [mm]	m ± SD	517.06 ± 101.45	590.07 ± 194.54	0.481
Equivalent area EC [mm^2]	m ± SD	884.8 ± 365.22	1830.2 ± 1589.98	0.004 *
Speed EC [mm/s]	m ± SD	17.24 ± 3.38	19.4 ± 5.68	0.436

EO – eyes open, EC – eyes closed, m – mean, SD – standard deviation, *p* – Mann–Whitney test, * statistically significant ($p < 0.05$).

a statistically significant difference. Additionally, the "Equivalent area" parameter, when measured with open eyes, was shorter in the control group as compared to the AIS group ($p = 0.019$) (Table 10).

4. Discussion

Conclusions regarding the findings of gait analysis in patients with AIS are still inconsistent. The present work aimed to compare spatiotemporal, kinematic, and balance variables between AIS patients with and without Chêneau brace and between AIS patients with Chêneau brace and healthy controls. Wu et al. [30], [31] found that the kinematics of the pelvis, and lower extremities differed between concave and convex sides at AIS. The comparative analysis of our study included kinematic and spatiotemporal gait parameters for the concave and convex sides of the primary curvature arc. We also hypothesized that gait pattern abnormalities would affect the poorer body balance control of individuals with AIS.

The study showed that the spatiotemporal parameters of gait of individuals with AIS walking in a Chêneau brace were generally not different from the gait pattern without the brace. The only difference was shown in step length, which was shorter on the convex side during gait in the brace. The step length on the convex side was also significantly shorter during gait in the brace compared to the step length of the healthy group. The difference in stride length was not shown between the gait of individuals with AIS without a Chêneau brace and healthy subjects.

The hypothesis of a difference in the kinematic parameters of individuals with AIS in the study group was confirmed. A decrease in the range of motion of the pelvis and hip joint on the convex side in the sagittal and frontal planes was demonstrated between people with AIS and healthy subjects. Gait in the Chêneau brace was also with reduced pelvic and hip range of motion on the convex side.

Body balance was worse in the group of AIS individuals in the Chêneau brace compared to healthy subjects, while body balance in and out of the brace differed only in terms of anterior-posterior COP sway.

Kim et al. [13] compared the results of gait analysis of adolescent idiopathic scoliosis (AIS) patients and healthy subjects through a meta-analysis of the existing research. They identified and subsequently analyzed six comparative studies published between January 2000 and May 2020 with the findings of AIS including spatiotemporal parameters (walking speed, step length, cadence and stance phase duration), segmental kinematics (frontal, sagittal and transverse pelvic motion), and electromyographic variables (electrical activity of the quadratus lumborum, erector spinae and gluteus medius). Their analysis showed that the stance phase and frontal pelvic motion were significantly reduced in AIS patients compared with healthy controls. No significant differences were observed in the case of speed, step length, cadence, sagittal pelvic motion and transverse pelvic motion. Our results are consistent with those of Kim's meta-analysis, but nevertheless showed a difference in stride length, a shortening on the convex side in those with AIS both in and without a brace. Boulcourt [2] in an analysis of the temporal-spatial parameters of the gait of AIS subjects showed that 46% had asymmetric patterns including asymmetries in stride length.

Daryabor et al. [5] selected 33 studies investigating the effect of scoliosis deformity on gait parameters and energy expenditure during walking. Most of the studies also concluded no significant differences in walking speed, cadence, and step width in scoliosis patients and healthy participants. However, patients showed decreased hip and pelvic motion, excessive energy cost of walking, stepping pattern asymmetry and ground reaction force asymmetry. They lacked consistent evidence of the effect of scoliosis on temporal-spatial and kinematic parameters in AIS patients as compared with healthy individuals.

Moreover, our study showed statistically significant differences in pelvic range of motion in the frontal plane and knee and ankle range of motion in the sagittal plane when comparing scoliosis patients and the control group, both for convex and concave sides. In addition, in our study, hip position in the transversal plane in the initial contact for convex and concave sides was statistically different. Furthermore, on the convex side, there were statistically significant differences in hip position in initial contact in the frontal plane and in pre-swing in the transversal plane and pelvic position in the transversal plane in pre-swing. For the concave side, we noted statistically significant differences in hip range of motion in the frontal plane, hip flexion in initial contact, hip position in the frontal plane in pre-swing, and pelvic position in initial contact in the sagittal and transversal plane.

Concerning spatiotemporal gait parameters with and without the Chêneau brace, our study showed that the only statistically significant parameter was a decreased step length for the convex side of the curve when the patients were wearing the brace while walking ($p = 0.025$).

Mahaudens [18] demonstrated that after 6 months of orthotic treatment, in an out-brace situation, the stride length was found to be increased by 5% compared to those without the brace (without brace: 1.28 m; with brace: 1.38 m). However, the comparison of the immediate in-brace and out-brace situations revealed no significant changes in the length step (without brace: 1.38 m; with brace: 1.40 m) [22]. Karimi [9] detected a significant decrease in the walking speed of subjects with AIS (Milwaukee orthosis: 1.4 m/s) versus no orthosis conditions (1.32 m/s). Paolucci [20] reported a significant reduction in the walking speed between patients with the Chêneau brace (0.57 ± 0.12 m/s) and patients without the brace (0.67 ± 0.13 m/s). Mahaudens [18] and Paolucci [21] showed also a significant reduction in cadence in patients with orthosis compared to those without it. The cadence in the studies by Karimi [8] similar to our research did not significantly differ between the orthosis and no orthosis conditions.

Concerning kinematic gait parameters, our study showed a statistically significant reduction of the range of pelvic motion in the frontal and transverse planes while wearing the brace. The range of hip motion in the frontal plane was also significantly decreased. At the beginning of the gait cycle, the value of hip flexion showed a statistically significant reduction in the Chêneau brace. Statistically significant was also the value of pelvic position in the transverse plane for the concave side and an increase in the value of hip position in the frontal and the transverse plane in the preswing phase, also on the concave side.

Mahaudens [11] demonstrated that compared with an out-brace situation, the immediate in-brace situation in AIS subjects significantly decreased frontal pelvic ($p < 0.001$) and hip ($p < 0.001$) motions with a significant reduction of pelvic rotation ($p = 0.003$) but without any change in the lower limb motions.

Furthermore, Kramers [15] demonstrated that the use of a brace reduced the dynamic range of pelvic motion in the frontal plane in braced condition compared with an unbraced condition. This outcome is consistent with our results.

Our results are also in line with the results of Karimi [9], who showed that the transverse pelvic motion following the use of the orthosis was significantly reduced without any change in the lower limb motions when compared with those patients with no orthosis.

Postural stability is considered as an ability to maintain static body alignment in space and to restore the body balance, lost by the action of destabilizing factors. Structural scoliosis has been claimed to be such a factor [15]. Wiernicka et al. [29] analyzed the postural stability of girls having a progressive form of idiopathic scoliosis compared to the group consisting of healthy girls. They performed a postural stability examination using two stabilometric platforms with visual control (eyes open) at three stages: both legs' stance, left leg stance, and right leg stance. The Center of Pressure (COP) sway path length, the area and the displacement amplitude were compared. For the double stance, they found no difference in postural stability parameters between the groups. However, for the right leg stance, the total sway path length was longer ($p = 0.04$) and the M-amplitude of the lateral COP displacement was increased ($p = 0.03$) in the scoliotic group.

In our study, when comparing the AIS group with and without the Chêneau brace, balance parameters differed significantly only for COP-X amplitude with eyes open ($p = 0.045$) and path length with eyes closed ($p = 0.022$). In contrast, compared to the control group, patients with AIS during the test without the corset had significantly longer COP-Y amplitude ($p = 0.005$) when tested with eyes closed. In the body balance test with the brace, our study showed that the COP-Y amplitude and "Equivalent area" with eyes open were significantly shorter for the control group ($p = 0.042$, $p = 0.019$, respectively). Adler et al. [1] found that scoliosis patients who wore a brace had better balance than patients who did not use the brace. The results suggest that wearing the brace might have a therapeutic effect on balance for patients with AIS and it may cause a long-term learning effect and a gradual improvement in balance performance. However, Sadeghi et al. [24] showed that treatment of scoliosis with a Boston brace did not change medial-lateral COP sway. Khanal et al. [12] found that AIS subjects have poor balance in comparison to healthy subjects. In addition, wearing the brace for a period of 4 months did not cause any improvement in balance parameters in scoliosis subjects. Moreover, when eyes were closed, further more aspects of disbalance was observed. Paolucci [21] examined thirteen patients (11 females and 2 males, mean age 13.3 ± 1.7 years, mean Cobb angle 32 ± 9, median Risser sign 2) and thirteen healthy adolescents (8 females and 5 males, mean age: 13.0 ± 1.6 years) as an age-matched control group. The postural ability of all participants was assessed with stabilometry (with open and closed eyes separately), computing sway length, sway ellipse area, and sway velocities. Static and dynamic baropodometry (open eyes only) was used to measure the limb load and to compute: walking speed, step length, step cadence, and step width. They also evaluated the symmetry of lower limb loading in the standing position. Their results showed that the AIS group was characterized by significantly higher postural instability than the control group ($P < 0.05$) decreased with the brace in terms of limb load symmetry (–12% in eyes open condition), sway length (–12%), velocity in anteroposterior (–16%) and laterolateral directions (–10%). Significant correlations were also found between the changes that occurred when wearing the Chêneau brace in load symmetry while standing and in gait symmetry ($R > 0.5$, $P < 0.05$).

Limitations

Adolescents already using the Chêneau brace were qualified for the study. It can be assumed that bracing has already caused a change in body posture, and removing the Chêneau brace for a short examination will not result in a return to the pre-bracing state. For this reason, the difference in gait and balance parameters assessed with and without the brace may have been smaller than expected. In future studies, we propose examining without the brace when deciding to wear it and after at least 6 months of systematic use. The second limitation is the number of participants, which was too small to separate groups taking into account the size of the curvature, their compensation, or the number of curves.

5. Conclusions

The results of this study may contribute to a better understanding of the characteristics of gait patterns, lower limb kinematics and body balance of people with AIS, especially those treated with a Chêneau brace. Knowledge of asymmetry, shortened stride length on the primary convex side, and reduced pelvic and hip ranges of motion, may help develop rehabilitation and treatment plans for people with AIS.

References

[1] ADLER N., BLECK E., RINSKY L., YOUNG W. et al., *Balance reactions and eye-hand coordination in idiopathic scoliosis*, J. Orthop. Res., 1986, 4, 1, 102–107, DOI: 10.1002/jor.1100040113.

[2] BOULCOURT S., BADEL A., PIONNIER R., NEDER Y., ILHARREBORDE B., SIMON A.L., *A gait functional classification of adolescent idiopathic scoliosis (AIS) based on spatio-temporal parameters (STP)*, Gait Posture, 2023, 102, 50–55, DOI: 10.1016/j.gaitpost.2023.03.002.

[3] CHEN P.Q., WANG J.L., TSUANG Y.H., LIAO T.L., HUANG P.I., HANG Y.S., *The postural stability control and gait pattern of idiopathic scoliosis adolescents*, Clin. Biomech., 1998, 13, 1 (Suppl. 1), S52–S58, DOI: 10.1016/s0268-0033(97)00075-2.

[4] CZAPROWSKI D., PAWŁOWSKA P., GŁĘBICKA A., SITARSKI D., KOTWICKI T., *Intra- and interobserver repeatability of the assessment of anteroposterior curvatures of the spine using Saunders digital inclinometer*, Ortop. Traumatol. Rehabil., 2012, 14 (2), 145–153, DOI: 10.5604/15093492.992283.

[5] DARYABOR A., ARAZPOYR M., SHIRIFI G., BANI M.A., ABOUTORABI A., GOLCHIN N., *Gait and energy consumption in adolescent idiopathic scoliosis: A literature review*, Ann. Phys. Rehabil. Med., 2017, 60 (2), 107–116, DOI: 10.1016/j.rehab.2016.10.008.

[6] DAVIS R.B., TYBURSKI D., GAGE J.R., *A gait analysis data collection and reduction technique*, Hum. Mov. Sci., 1991, 10, 575–587, DOI: 10.1016/0167-9457(91)90046-Z.

[7] GRAFF K., SZCZERBIK E., KALINOWSKA M., JAWORSKI M., SYCZEWSKA M., *Balance assessment in healthy children and adolescents aged 6–18 years based on six tests collected on AMTI AccuSway force platform*, Acta Bioeng. Biomech., 2020, 22 (2), 121–130, DOI: 10.37190/ABB-01497-2019-04

[8] HABER C.K., SACCO M., *Scoliosis: lower limb asymmetries during the gait cycle*, Arch. Physiother., 2015, 5, 4, DOI: 10.1186/s40945-015-0001-1.

[9] KARIMI M.T., KAVYANI M., ETEMADIFAR M.R., *Gait analysis in adolescent idiopathic scoliosis walking with Boston brace*, Scoliosis, 2014, 9 (Suppl. 1), O24, DOI: 10.1186/1748-7161-9-S1-O24.

[10] KARIMI M.T., RABCZUK T., KAVYANI M., *Evaluation of the efficiency of the Chêneau brace on scoliosis deformity: A systematic review of the literature*, Orthopade., 2018, 47 (3), 198–204, DOI: 10.1007/s00132-018-3529-4.

[11] KAROL L.A., VIROSTEK D., FELTON K., JO C., BUTLER L., *The effect of the Risser stage on bracing outcome in adolescent idiopathic scoliosis*, J. Bone Joint Surg. Am., 2016, 3, 98 (15), 1253–1259, DOI: 10.2106/JBJS.15.01313.

[12] KHANAL M., ARAZPOUR M., BAHRAMIZADEH M., SAMADIAN M., HUTCHINS S.W., KASHANI R.V., MARDANI M.A., TARI H.V., ABOUTORABI A., CURRAN S., SADEGHI H., *The influence of thermoplastic thoraco lumbo sacral orthoses on standing balance in subjects with idiopathic scoliosis*, Prosthet. Orthot. Int., 2016, 40 (4), 460–466, DOI: 10.1177/0309364615589466.

[13] KIM D.S., PARK S.H., GOH T.S., SON S.M., LEE J.S., *A meta-analysis of gait in adolescent idiopathic scoliosis*, J. Clin. Neurosci., 2020, 81, 196–200, DOI: 10.1016/j.jocn.2020.09.035.

[14] KOTWICKI T., KINEL E., STRYŁA W., SZULC A., *Discrepancy in clinical versus radiological parameters describing deformity due to brace treatment for moderate idiopathic scoliosis*, Scoliosis, 2007, 3, 2, 18, DOI: 10.1186/1748-7161-2-18.

[15] KRAMERS-DE QUERVAIN I.A., MULLER R., STACOFF A., GROB D., STÜSSI E., *Gait analysis in patients with idiopathic scoliosis*, Eur. Spine J., 2004, 13 (5), 449–456, DOI: 10.1007/s00586-003-0588-x.

[16] LENKE L.G., BETZ R.R., HARNS J., BRIDWELL K.H., CLEMENTS D.H., LOWE T.G., BLANKE K., *Adolescent idiopathic scoliosis: a new classification to determine extent of spinal arthrodesis*, J. Bone Joint Surg. Am., 2001, 83 (8), 1169–1181, DOI:10.2106/00004623-200108000-00006.

[17] MAHAUDENS P., BANSE X., MOUSNY M., DETREMBLEUR C., *Gait in adolescent idiopathic scoliosis: kinematics and electromyographic analysis*, Eur. Spine J., 2009, 18 (4), 512–521.4, DOI: 10.1007/s00586-009-0899-7.

[18] MAHAUDENS P., BANSE X., MOUSNY M., RAISOM M., DETREMBLUER C., *Very short-term effect of brace wearing on gait in adolescent idiopathic scoliosis girls*, Eur. Spine J., 2013, 22 (11), 2399–2406, DOI: 10.1007/s00586-013-2837-y.

[19] MAHAUDENS P., DETREMBLEUR C., MOUSNY M., BANSE X., *Gait in adolescent idiopathic scoliosis: energy cost analysis*, Eur. Spine J., 2009, 18 (8), 1160–1168, DOI: 10.1007/s00586-009-1002-0.

[20] MAHAUDENS P., RAISOM M., BANSE X., MOUSNY M., DETREMBLUER C., *Effect of long-term orthotic treatment on gait biomechanics in adolescent idiopathic scoliosis*, Spine J., 2014, 1, 14 (8), 1510–1519, DOI: 10.1016/j.spinee.2013.08.050.

[21] PAOLUCCI T., MORONE G., DI CESARE A., GROSSO M.R., FUSCO A., PAOLUCCI S., SARACENI V.M., IOSA M., *Effect of Chêneau brace on postural balance in adolescent idiopathic scoliosis: a pilot study*, Eur. J. Phys. Rehabil. Med., 2013, 49, 5, 649–645, PMID: 23820877.

[22] PIĄTEK E., KUCZYŃSKI M., OSTROWSKA B., *Postural control in girls with adolescent idiopathic scoliosis while wearing a Chêneau brace or performing active self-correction: a pilot study*, Peer J., 2019, 29, 7, e7513, DOI: 10.7717/peerj.7513.

[23] ROUBAL P.J., FREMAN D.C., PLACZEK J.D., *Cost and effectiveness of scoliosis screening*, Physiotherapy, 1999, 85, 259–269, DOI: 10.1016/S0031-9406(05)61440-X.

[24] SADEGHI H., ALLARD P., BARBIER F., CHEVET P., GATTO L., RIVARD C.H., SIMONEAU M., *Bracing has no effect on standing balance in females with adolescent idiopathic scoliosis*, Med. Sci. Monit., 2008, 14 (6), CR293–298, PMID: 18509271.

[25] SYCZEWSKA M., GRAFF K., KALINOWSKA M., SZCZERBIK E., DOMANIECKI J., *Does the gait pathology in scoliotic patients depend on the severity of spine deformity? Preliminary results*, Acta Bioeng. Biomech., 2010, 12, 1, 25–28, PMID: 20653321.

[26] SYCZEWSKA M., ŁUKASZEWSKA B., GÓRAK K., GRAFF K., *Changes in gait pattern in patients with scoliosis*, Rehabilitacja Medyczna, 2006, 10, 4, 18–24.

[27] WEINSTEIN S.L., DOLAN L.A., CHENG J.C.Y., DANIELSSON A., MORCUENDE J.A., *Adolescent idiopathic scoliosis*, Lancet, 2008, 371, (9623), 1527–1537, DOI: 10.1016/S0140-6736(08)60658-3.

[28] WENIGER C.D., FUJAK A., HOFNER B., FUCHS M., **F0RST** R., RICHTER R.H., *Long-term Results of Conservative Therapy of Adolescent Idiopathic Scoliosis Using the Chêneau Brace*, Klin. Padiatr., 2019, 231 (5), 248–254, DOI: 10.1055/a-0963-8996.

[29] WIERNICKA M., KOTWICKI T., KAMIŃSKA E., ŁOCHYŃSKI D., KOZINOGA M., LEWANDOWSKI L., KOCUR P., *Stability in Adolescent Girls with Progressive Idiopathic Scoliosis*, Biomed. Res. Int., 2019, 11, 7103546, DOI: 10.1155/2019/7103546.

[30] WU K.W., WANG T.M., HU C.C., HONG S.W., LEE P.A., LU T.W., *Postural adjustments in adolescent idiopathic thoracic scoliosis during walking*, Gait Posture, 2019, 68, 423–429, DOI: 10.1016/j.gaitpost.2018.12.024.

[31] WU K.W., LU T.W., LEE W.C., HO Y.T., WANG J.H., KOU K.N., WANG T.M., *Whole body balance control in Lenke 1 thoracic adolescent idiopathic scoliosis during level walking*, PLoS One, 2020, 6, 15 (3), e0229775, DOI: 10.1371/journal.pone.0229775.