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Brace Effects on Spatiotemporal Gait Parameters from Pedobarography in Adolescent Idiopathic Scoliosis

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Abstract: Adolescent idiopathic scoliosis (AIS) is a three-dimensional deformation of the spine typically occuring in adolescents, mainly females. Untreated AIS can lead to the need for surgical intervention or to severe back problems later in life. The conventional treatment of AIS involves the use of custom-made braces, combined with physiotherapy. The therapeutic efficiency of the braces is determined using static X-rays. Dynamic evaluations are based on the experience of orthopedic technicians. However, evidence-based knowledge is needed to compare treatment objectively. Gait analysis offers the potential of dynamically assessing the effect of braces without radiation. To evaluate the evidence-based effect of braces using gait analysis, it is first necessary to identify differences between gait with and without brace. Therefore, in this pilot study, pedobarographic gait analyses of nine AIS patients were examined and evaluated. We comprised 199 dynamic gait parameters extracted from pedobarographic measurements covering spatiotemporal gait parameters, pressure and force distributions of foot zones. Logistic regression analysis was used to classify gait with and without brace. A significant model ($p < 0.01$) with two significant coefficients ($p < 0.05$) was revealed covering time to maximum force in relation to segment contact time for left rear and maximum pressure of left toe. Overall classification performance showed an accuracy of 88.9 % to distinguish between with and without brace. Our study demonstrates that there are differences in the gait patterns of AIS patients with and without braces. Further studies, including a more extensive data set, may yield evidence-based findings on the effect of braces on dynamic gait patterns to be used in customized braces for the improved effectiveness in therapy.

Keywords: Scoliosis, Brace, Gait, Pedobarography

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1 Introduction

Adolescent idiopathic scoliosis (AIS) is a disease characterized by the three-dimensional deformation of the spine. Conservative treatment is based on the use of braces and physiotherapy. Standing in-brace and out of brace X-rays are recommended to evaluate the effect of braces on the spine [1].

As the spine is an important component of the musculoskeletal system, gait is affected in patients with AIS. Some studies have investigated the effect of braces on pedobarographic parameters of gait [2–5]. In [2], there was an increase of plantar contact area on the left foot and cadence, and left foot pressure decreased with bracing. Gait wearing a Rigo System Chêneau brace lead to a reduced acceleration and stride length of the left foot, while bracing had no impact on plantar pressure values [3]. Additionally, a study found that gait speed increased with a Sforzesco brace, but the center of pressure (COP) excursion index and maximum pressure point showed no significance [4]. Nevertheless, a further study yielded a contradictory conclusion with Chêneau braces [5]. Thus, the findings indicated changes in COP parameters, and a reduction in both gait speed and cadence while bracing. Additionally, the asymmetry of step length increased in gait with brace [5].

However, the findings in the literature differ, and there is no evidence-based methodology about the brace effect on gait. Thus, the objective of this pilot study is to investigate the differences in gait pattern from pedobarography with and without a Chêneau brace in AIS patients.

2 Method and Materials

To determine the brace effect on dynamic gait parameters of pedobarography, an initial pilot study was conducted to test whether differences in the gait pattern can be determined with and without a brace. The methodology used in this study is presented in Fig. 1. The study has been approved by the ethics committee of Jan Kochanowski University Kielce (Nr 26/2022). Data collection is an ongoing process in the study. In this investigation, we are focusing on a first batch of patients.

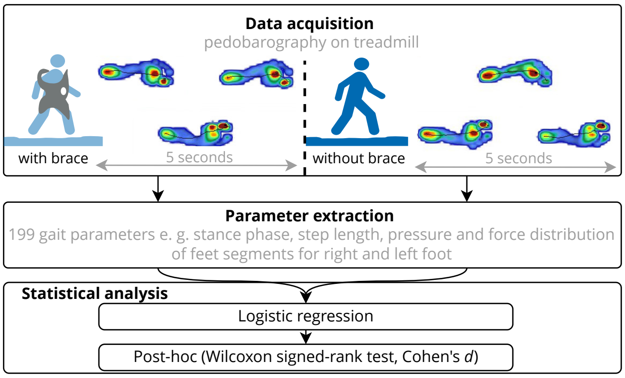

Fig. 1: Methodology used for investigating the difference between pedobarography on treadmill 'with brace' and 'without brace'.

2.1 Study design

In the first study batch 9 patients (7 female, 2 male) were recruited. All patients (Tab. 1) are diagnosed with typical right convex AIS (mean Cobb-angle: $27.44° \pm 7.21°$) and treated with a brace of Chêneau design. The spine of the patients have different shapes and can be grouped in shape C (n=3), S (n=4) and double-S (n=2) form. The severity degrees of the patients' AIS are, according to SOSORT guidelines [1], low (n=3), moderate (n=5) and moderate to severe (n=1).

Tab. 1: Mean, standard deviation (SD) and range of characteristics from 9 (7 female (f), 2 male (m)) AIS patients in the study.

Characteristic, unit	Mean $\pm$ SD [range]
Sex, f / m	7 / 2
Age, years	14.78 $\pm$ 1.55 [13 - 18]
Weight, kg	48.78 $\pm$ 8.46 [29 - 56]
Height, mm	161.89 $\pm$ 9.24 [149 - 184]
Cobb-angle, degree	27.44 $\pm$ 7.21 [17 - 38]

2.2 Data acquisition

For the investigation, pedobarographic measurements were performed on a treadmill. Pedobarographic data was recorded in 2022 and 2023 at Jan Kochanowski University of Kielce and the rehabilitation department of the Pediatric Center in Kielce, Poland with DIERS pedogait from DIERS 4Dmotion® Lab (DIERS International GmbH, Wiesbaden, Germany). The Chêneau braces used in this study were the individual braces worn by the patient for their daily treatment of AIS. The measurements were performed by trained medical staff. A gait analysis was conducted for each patient, both with and without brace support, at a constant velocity of $2\,\mathrm{km} \cdot \mathrm{h}^{-1}$.

In order to achieve the optimum treatment outcome, patients were required to wear their brace for a minimum of 23 hours per day. The precise duration of time the brace is to be worn may vary between individuals. Initially, the measurements 'with brace' were recorded with the brace to ensure a precise representation of the brace effect. To enable the spine to assume the out of brace posture prior to the 'without brace' measurement, patients were requested to not wear the brace for a period of 24 hours before the measurement.

Each measurement took at least seven seconds, of which a period of five seconds was allocated to the calculation of the gait analysis. The initial and final times were automatically determined by the DIERS DICAM 3 software, and the individual foot zones were automatically segmented. The position of the various foot zones determined by the recording system is illustrated in Fig. 2. Timestamps and segmentation were manually checked by an expert afterwards. The software supplies the calculation of 199 gait parameters from pedobarographic measurements. The parameters include well-known spatiotemporal gait characteristics such as cadence, step length, stance phase, foot rotation as well as pressure and force distribution of the foot segments for the right and left foot.

Fig. 2: Definition of foot zones in DIERS pedogait automatically divided by DIERS DICAM 3 software, adapted from [6]. The zones marked in black are selected in the logistic regression model to separate a gait with and without braces.

2.3 Correlation analysis

Initially, a correlation analysis (Spearman) was performed on the extracted gait parameters. Those parameters showing a strong correlation ($|r > 0.5|$) were removed from further analyses, only one parameter in a correlating pair was included.

2.4 Logistic regression analysis

The parameters not excluded by correlation analysis were used for calculation of the logistic regression equation. The aim is to limit the complexity of the regression. We used forward stepwise method with likelihood ratio. Thus, only parameters that significantly ($p < 0.001$) improve the accuracy of the model were used in logistic regression, with all others excluded.

2.5 Post-hoc testing

The parameters in the logistic regression equation are analyzed using a Wilcoxon signed-rank test for differences in gait with and without a brace afterwards. The significance level has been set to $p < 0.05$ (one-sided). The effect size was calculated using Cohen's d. Statistical analyses have been done with Python 3.12.0 and IBM SPSS Statistics 30.0.0.

3 Results

A total of 27 parameters, out of the 199 parameters, showed no strong correlation ($|r > 0.5|$) and are used as input data in the calculation of the logistic regression. Logistic regression analysis revealed a significant ($p < 0.01$) model with the two significant ($p < 0.05$) parameters time to maximum force in relation to segment contact time for left rear and maximum pressure of left toe. Additionally, the parameter force integral of right Metatarsus 1 was used in the model but showed no significance as well as the constant coefficient (Tab. 2).

The logistic regression model achieved an accuracy of $88.9\,\%$ and a model significance of $p = 0.002$. The confusion matrix of the classification is shown in Fig. 3. The two cases of false classification were from two different female patients with moderate and moderate to severe scoliosis. One measurement of each patient from both was correctly classified. The patients with false classifications occuring did not stand out from the collective concerning Cobb angle, scoliosis type, age, sex, height, and weight.

The results of post-hoc Wilcoxon signed-rank test demonstrate that the parameters with significant regression coefficients also show significant differences in gait with and without a brace (Tab. 3). To compare the data of both scenarios, the mean value and standard deviation of the parameters in the logistic regression were included in Tab. 3. It is notable that only the right or left parameter of the two extremities were remained in the logistic regression. Parameters of the other extremity were already excluded during the correlation analysis. In addition to the left maximum pressure of the toes, the right maximum pressure also shows a significant difference between the 'with brace' and 'without brace' measurements. All parameters in the logistic regression showed a strong effect ($|d > 0.5|$) between gait 'with brace' and 'without brace'.

Tab. 2: Revealed coefficients of the logistic regression analysis.

Rank	Parameter	*p*-value
1	Time to maximum force in relation to segment contact time for left rear	0.038
2	Maximum pressure of left toe	0.040
3	Force integral of right Metatarsus 1	0.092
	Constant	0.068
Model accuracy: $88.9\,\%$, model significance $p = 0.002$		

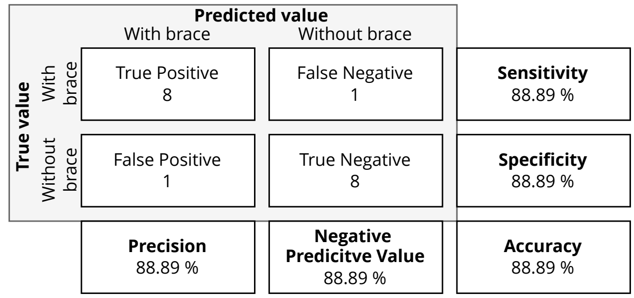

Fig. 3: Confusion matrix as classification result of logistic regression. The classification with logistic regression achieves an accuracy of $88.9\,\%$.

4 Discussion

In the case of right-convex scoliosis, 1) the time to maximum force in relation to the segment contact time for the left rear is significant greater, 2) the maximum pressure load on the left toes is significant reduced, and 3) the force integral of right Metatarsus 1 zone is greater when walking with a brace than without a brace. Post-hoc analyses showed a strong effect ($|d > 0.5|$) of all chosen parameters in logistic regression analysis. Time to maximum force in relation to segment contact time for left rear revealed the strongest effect size ($|d = 1.3|$).

It can be assumed that the corrective effect of the brace on the spine changes the position and load of the body parts involved in gait and thus influences the gait pattern. This can be visualized by dynamically measuring the gait cycle with the foot pressure distribution. In the case of a right-convex scoliosis, the spine is corrected to the left with brace, which means that the left side of the body has a higher time to maximum force and thus leads to a more homogeneous roll-on characteristic. This can be seen at the lower standard deviation (Tab. 3). On the right side this leads to an increased force integral to compensate for the load redistribution. Furthermore, the roll-off characteristic is influenced: The maximum pressure on the left toes is reduced in gait while bracing.

From the literature a reduction of the maximum pressure of the left foot is known [2]. This is consistent with the results in this study, in which the maximum pressure of the left toes is reduced. However, this only concerns the area of the toes and not the whole foot. It can be assumed that this particular area of the foot is the key area in determining the effect of the brace. Due to the substantial differences between the data

Tab. 3: Mean, standard deviation (SD) and range of three gait parameters chosen by logistic regression algorithm (bold). With Wilcoxon signed-rank test, two out of three gait parameters show significant differences ($p < 0.05$) between the gait 'with brace' and 'without brace'. The effect size is based on Cohen's d.

Rank	Parameter, unit	Side	Mean $\pm$ SD [range]		*p*-value	Effect
			With brace	Without brace		size *d*
1	Time to maximum force in relation to segment contact time for rear, %	**left**	**44.63 $\pm$ 8.00 [30.00 - 57.50]**	**29.35 $\pm$ 13.78 [7.41 - 46.30]**	**0.027**	**1.278**
		right	38.68 $\pm$ 12.61 [18.18 - 53.13]	38.37 $\pm$ 11.63 [18.52 - 59.38]	0.326	0.024
2	Maximum pressure of toes, N/cm²	**left**	**5.39 $\pm$ 2.75 [2.50 - 9.50]**	**6.72 $\pm$ 1.96 [3.50 - 9.50]**	**0.025**	**0.527**
		right	5.67 $\pm$ 2.57 [1.00 - 8.50]	7.67 $\pm$ 3.46 [3.50 - 16.00]	0.046	0.618
3	Force integral of Metatarsus 1, Ns	left	7.40 $\pm$ 2.03 [4.92 - 10.90]	6.20 $\pm$ 1.20 [4.15 - 8.19]	0.102	0.678
		right	**7.00 $\pm$ 2.06 [4.34 - 11.15]**	**5.29 $\pm$ 1.87 [2.41 - 8.83]**	**0.064**	**0.818**

recording systems on which the studies in literature are based, the data resulting from the analyses can also differ. A comparable parameter in the literature on the time to maximum force in relation to the segment contact time of rear and the force integral of Metatarsus 1 could not be identified. Compared to the current research findings [3–5], cadence, step length and COP-parameters did not show significant changes in gait with and without bracing. However, cadence and COP-parameters have strong correlations with the parameters used as input for the logistic regression.

The comparability of previous studies is a major challenge. Subject groups are usually very small, and also shape and treatment of AIS are very individualized. Even different types of braces can be cause in different results [4, 5].

The results of the first batch of the pilot study are limited by a small sample size and a high number of parameters. A larger amount of data is required for evidence-based statements and will be recorded in the ongoing study. It is suggested that a larger number of subjects could provide an indication of generally valid statements on the change in gait parameters in AIS patients with conventional brace treatment. However, the results presented in this study demonstrate the potential for distinguishing between patients with and without a brace, based on their gait patterns. So, gait analysis might be a way to quantify the effect of the brace on the dynamic movements. This knowledge could be used to individualize braces, avoiding unnecessary radiation impact, and thus improve the effectiveness of treatment under dynamic conditions.

Author Statement

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