DOI: 10.37190/abb/205649

Symmetry of Body Posture Among Children with Hemiplegic Cerebral Palsy Using Ankle Foot Orthoses (AFO): a Case – Control Study

Robert Staszkiewicz[1*], Anna Strus[1]

[1]Department of Biomechanics, University of Physical Education in Kraków, Kraków, Poland

[*]Corresponding author: Robert Staszkiewicz, Department of Biomechanics, University of Physical Education in Kraków, Kraków, Poland, e-mail address: Robert.staszkiewicz@gmail.com

Submitted: 27th April 2025

Accepted: 27th May 2025

Abstract

Research objective. The aim of this study was to determine how solid ankle-foot orthoses (AFO) influence the symmetrization of free standing posture in children with hemiplegic cerebral palsy (CP).

Material and methods. In the analysis, we examined the body posture of children (n=43, mean age of 7 years) who did not wear any orthopedic equipment on a daily basis (Group 1). We also studied those who used unilateral (Group 2) or bilateral AFOs (Group 3). The BTS SMART D-140 6 TVC optoelectronic system was implemented in the research.

Results. There were no significant differences between the study groups in terms of obliqueness, rotation or pelvic inclination in standing position, or in hip joint angle on the (un)affected sides with and without AFOs. However, differences could be observed in obliqueness and rotation after applying AFOs ($0.1>p>0.05$). In all study groups, knee flexion angle on the affected side was greater. After putting on the orthoses (Groups 2 and 3), knee joint flexion decreased. Analysis of measurements without orthoses showed significantly less dorsiflexion and greater external rotation of the ankle joint on the affected side ($p<0.05$). After putting on the orthoses (Groups 2 and 3), the differences in dorsiflexion noted in the ankle joints of both feet did not exceed 1°. In such conditions, the rotation in these joints also became equal.

Conclusions. The results of the study allowed to indicate that the use of AFOs in children with hemiplegic CP demonstrates a beneficial effect on the joint to which they are directly applied. They also aid other joints of the lower limbs and pelvis. The use of bilateral AFOs provides greater positive changes in standing symmetry compared to unilateral AFO implementation.

Keywords

cerebral palsy – standing posture – symmetry – ankle-foot orthoses

INTRODUCTION

Cerebral palsy (CP) is a well-recognized neurodevelopmental condition. It begins in early childhood and persists throughout an individual's lifetime. The term is commonly used to describe a variety of motor conditions associated with brain damage, often accompanied by vision, hearing, speech, cognition, communication and perception disorders.

Brain damage in people diagnosed with CP causes disorganization and delay in the development of neurological mechanisms controlling posture, balance and movement [37,37]. The muscles involved in these mechanisms become less efficient. The main cause of this is spasticity. This means excessive, abnormal muscle tension, which induces changes in muscle fibers and connective tissues. Their excessive spasticity further leads to the development of bone and joint deformations. Consequently, muscle contractures become permanent and non-beneficial movement compensations become established [26]. Children with cerebral palsy achieve the consecutive stages of motor development with a delay, and at subsequent levels of maturity, they demonstrate lower levels motor and functional skills compared to their healthy peers [34].

It is estimated that both in Poland and worldwide, the incidence of CP is present in 2-3‰ of the population, which means that it affects between one and two children per 1,000 births [21]. Hemiplegia is one of the most common forms of CP (over 38%) and can be congenital or acquired [20]. It is characterized by paresis, usually spastic, that influences the upper and lower limbs on the same side of the body [35]. This results in asymmetry within the trunk and limbs as well as balance disorders, which cause, for example, incorrect gait patterns [16]. Nonetheless, patients with hemiplegia exhibit high levels of motor functioning [8]. Nonetheless, it should be noted that this is not always the case.

Physiotherapy is one of the main pillars of streamlining and improving quality of life among the aforementioned group of patients. This is the reason why specialists in the field are required to apply more and more innovative methods and technological solutions in the therapeutic process [25]. Orthotic management offers the possibility of treating many diseases that affect both gait and body posture. It is also part of the general physiotherapy program established for CP patients [30]. An orthosis is an element allowing to support and prolong positive effects achieved during physical exercise. In patients with hemiplegic cerebral palsy, lower limb orthoses are usually used: i.e. solid AFOs (ankle-foot orthoses). AFOs include all types that start below the knees, end at the feet, and provide direct control of the foot and ankle joints [37]. These are usually devices that are custom-made as stiff [39], i.e. having no mobility within the ankle joint. Their task is to maintain this joint in an intermediate position. This type of orthopedic equipment is dominant. However, the use of AFOs among children with CP in countries having relatively similar healthcare systems still differ between countries according to age, GMFCS (Gross Motor Function Classification System) level and CP subtype [37].

Although the influence of wearing AFOs on the general kinematics of gait during steady-state walking have been researched to a certain extent, little is known about their application to both limbs simultaneously. The reason for the research being limited only to AFOs is because they have been shown to demonstrate a positive effect on body stability and balance [29]. Static balance is a contribution to more complex motor functions, especially gait. Thus, biomechanical analysis indicates that only one orthosis could negatively affect gait symmetry (different masses of the lower limbs with and without the orthosis). It seems that the above observation is a sufficient premise to use bilateral AFOs in children with CP hemiplegia, especially those with demonstrating low body mass.

Therefore, one of the main objectives of improving mobility among patients with hemiplegia is to achieve symmetry of body posture. The need to perform such an assessment for the affected and unaffected sides of the body among children with CP is supported in the research conducted by Pavao et al. [31]. This study is directly related to difficulties in controlling static position by such patients [6]. At the same time, literature regarding the impact of AFOs on free standing posture in children with CP is sparse; particularly with regard to bilateral implementation. Nevertheless, it should also be added that research is constantly being carried out on so-called static balance in children with CP [7, 22]. Improving the motor skills of such patients, their stable, balanced starting position, e.g. during physical exercises, is crucial. Bahar-Ozdemir et al. [1] proved that the use of AFOs exhibits positive effects. The beneficial effects of orthopedic supplies may find their explanation in the research by Chow [2]. **This author analysed changes in load on individual parts of the feet with regard to the affected and unaffected sides**. It should be mentioned, however, that the cited study included students with CP. This means that comparing it with research conducted in other groups of children has some limitations.

Despite the continuous development of medicine and the provision of increasingly new scientific evidence on cerebral palsy, the high individuality of this disease creates difficulties in selecting a uniform study group. This situation further translates into clear limitations concerning applicability of the obtained results. The present research was carried out to fill this gap, and the globality of observations and conclusions based on it provided the basis for creating practical therapeutic indications.

The main aim of this study is to provide biomechanical, quantitative assessment of symmetry in free standing posture among children with hemiplegic CP. Postural symmetry was assessed on the basis of variables characterizing the position of the pelvis and the static position of the hip, knee and ankle joints. It was decided to solve this problem by conducting research in three groups of young patients: those not using orthopedic equipment, patients using unilateral, solid AFOs on the affected side and individuals provided with solid AFOs simultaneously supporting both lower limbs.

The following research questions were posed: 1) Does the use of AFOs result in improved body posture symmetry?; and 2) Is this process more beneficial when patients use bilateral AFOs?

METHODS

Testing was carried out at the certified (PN-EN ISO 9001:2015) Central Scientific and Research Laboratory of the University of Physical Education in Kraków. The study was approved by the Bioethics Committee at the District Medical Chamber in Kraków (74/KBL/OIL/2015). All study participants and their legal guardians read the provided written information regarding the purpose and course of the study, and gave their informed conscious and voluntary consent to participate in the research project. They were also informed of the possibility to withdraw from the trial at any stage, without providing justification. It should be emphasized that all the adopted research procedures, the created research methodology and measurement tools used in the process of collecting measurement data had no adverse effects on the current health status of the children under study.

Subject characteristics

The study involved 43 children who regularly attended individual physiotherapy sessions twice a week at the Family Medical Centre in Skawina, Poland (the co-author of this study is employed there).

The main inclusion criteria for the study were:

- diagnosis of hemiplegic cerebral palsy;
- spastic unilateral subtype of CP;

- qualification to 1st or 2nd level characterizing quality of locomotion according to GMFCS classification;
- age between five and 10;
- confirmation of so-called intellectual norm, an essential feature for efficient verbal communication between research participants;
- being in the 2nd or 3rd study group using of solid AFO for no less than three months.

Exclusion criteria were:

- mechanical musculoskeletal injuries in the 12 months preceding examination;
- no consent to continue the research procedure.

Three groups were selected:

- Group 1 (n=18; **12 boys and 6 girls**) - hemiplegic children not using lower limb orthopedic equipment on a daily basis;
- Group 2 (n=14; **6 boys and 8 girls**) - hemiplegic children using unilateral AFOs (on affected side) on a daily basis;
- Group 3 (n=11; **5 boys and 6 girls**) - hemiplegic children using bilateral AFOs on a daily basis.

The basic descriptive characteristics of the respondents are presented in Table 1.

Table 1. Patient demographics

	Group 1	**Group 2**	**Group 3**
	M±SD	M±SD	M±SD
Age [years]	7.5±1.7	7.4±1.9	7.2±1.9
Body height [m]	1.19±0.1	1.24±0.12	1.21±0.12
Body mass [kg]	23.8±5.7	26.6±6.3	25±6.2

Research tools

The BTS SMART D-140 6 TVC optoelectronic system (Bioengineering, Italy) was used in the study. Previous reports prove the validity and reliability of this measurement tool for conducting research among children with CP [10, 27]. Therefore, in accordance with the requirements of the system, mandatory anthropometric measurements were taken for each patient. These measurements were carried out by the same trained person each time (a physiotherapist, with many years of experience conducting research in the field of biomechanical analysis; Ph.D.).

In addition to body mass and height, the following variables were measured (using the Sieber Hegner Machines SA and the Holtain caliper; GPM, Switzerland):

- pelvic width (between anterior superior iliac spines) [mm];
- pelvic depth (shortest distance between anterior superior iliac spine and long axis of femur at level of greater trochanter) [mm];
- knee width (between femoral condyles) [mm];
- ankle width (between lateral and medial malleolus) [mm];
- total length of the thigh and shank (from trochanter’s upper edge of greater femur to lateral malleolus) [cm].

The values obtained in this way were of key significance in the further stages of research.

After completing this part of the measurement procedure, retroreflective passive markers were placed at precisely defined locations on the subjects' bodies. This was done according to the Davis measurement protocol [5], dedicated to subjects between the age of five and 10. The reliability of this protocol has been proven by a series of published works, both in basic research and in clinical settings [3, 9, 11].

In this examination, it was decided to slightly change the Davis model and 20 markers were used instead of 22. They were not placed on the external ankle. This modification was made due to: 1) the short length of the children’s lower legs; 2) the remaining markers well-reflecting the course of the lower leg axis; 3) potential difficulties in reflecting the position of the ankle joint axis in the situation of the AFO being worn; 4) the small distance between the markers on the foot and ankle, which could cause difficulties in identifying the path of these markers' movements. As a result, three markers were placed on the pelvis (base of the sacral and posterior superior iliac spine), three on the thighs, two on the shanks (to determine the long axis of these body parts) and two on the feet (5th metatarsal head and heel). In Figure 1, it is demonstrated how the markers were placed during the measurement sessions.

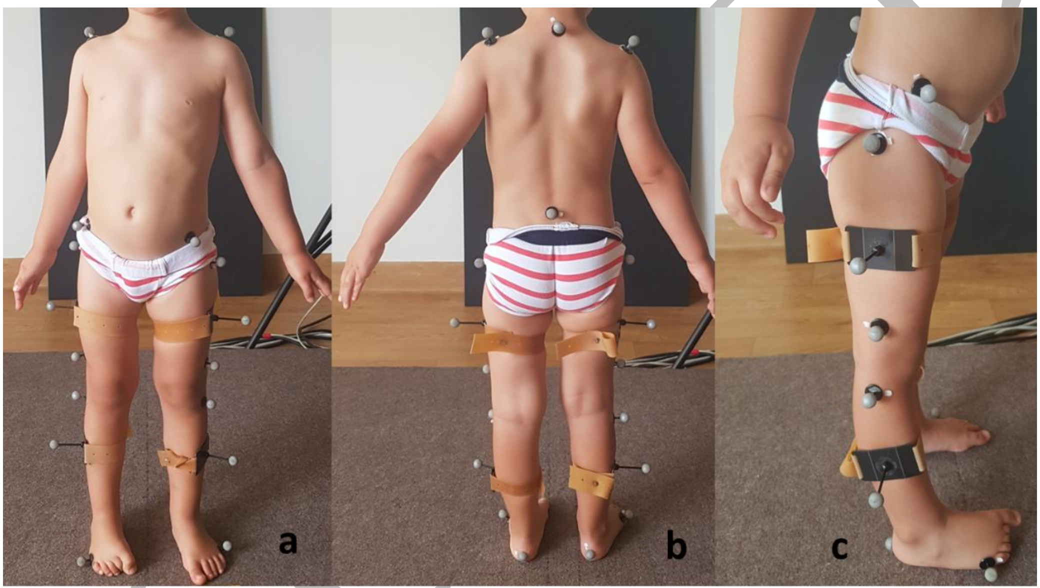

Fig. 1 Placement of markers on the patient's body (a - anterior view, b - posterior view, c - lateral view).

Video recording of standing posture

The next step of the research procedure was registration of free, static standing posture performed for each of the examined children. The duration of recording was approximately 40 seconds, while only the middle, 15-second part of the registration was subjected to analysis (from the 15th to 30th second).

In this way, degree values were established for:

- obliqueness, rotation and tilt of the pelvis in each of the main planes (respectively: frontal, transverse and sagittal);
- values of angles in the joints: hip (abduction/adduction, rotation, flexion), knee (flexion) and ankle (rotation and flexion).

The values of the mentioned variables were determined in barefoot standing position (in each of the groups of examined children) and additionally for Groups 2 and 3 with AFOs. The need to take orthopedic supplies into account was the reason why the markers placed in the area of the lower leg, ankle and foot were moved to the arms of the orthosis and to the worn footwear. The described procedure has already been used in this type of research [17]. In our research, we made sure that the external malleolus, AFO's arm marker (crural marker) and joint space above the fibular head could be seen in the sagittal plane (lateral view, from exterior) and in one straight line. Only this concrete marker placement ensured minimization of errors in mapping angles in the knee and ankle joints. Such a change in conditions caused adjustment of anthropometric measurements regarding the lower limb, above and below the ankle joint. Therefore, the new circumstances were considered, enabling the highest quality of registration in orthoses.

Statistical analysis of results

The measurement data was analyzed using the IBM SPSS Statistics 26 statistical package. Arithmetic means (M) and standard deviations (SD) were implemented for description of the statistics. **The Shapiro–Wilk test was applied in the statistical analysis to verify the assumption of normal distribution. However, not in all cases did the results indicate that the distribution of variables was close to normal.** However, according to current reports, this is not necessary for the analysis of general linear models [19].

At the next stage of evaluation, the differences between the study groups were tested. For this purpose, one-way ANOVA was used. Subsequently, the differences between the affected and unaffected sides were assessed, and it was also determined whether these differences significantly differed between the groups. For this purpose, MANOVA (multivariate analysis of variance) was implemented:

- when children were not wearing orthoses: body side [unaffected vs. affected] with between-group factor [Group 1 vs. Group 2 vs. Group 3];
- when children were wearing orthoses (Group with 1 and 2 orthoses): side of the body [unaffected vs. affected] with between-group factor [Group 2 vs. Group 3];
- in groups of children who wore orthoses (Groups 2 and 3) to investigate the differences between the measurements when the examined children did not wear orthoses compared to the circumstances in which they were worn: measurement [with vs. without orthoses] with between-group factor [Group 2 vs. Group 3].

Statistical calculations were carried out for ANOVA using Levene's test to assess the equality of variances. If the variances were not equal, Welch's ANOVA was applied. In the remaining cases, Fisher's ANOVA was used. For MANOVA, Mauchly's test of sphericity was conducted. When the assumption of sphericity was violated, the Greenhouse-Geisser correction was performed.

Typically, there is an overall F-statistic for the multivariate test in MANOVA and if this F-statistic is significant, then the individual effects for each dependent variable should be reported.

Partial eta squared (η^2_P) was calculated in order to determine the effect strength. The obtained values of >0.01, 0.06 and 0.14 corresponded to small, medium and large effect sizes, respectively [4, 28].

If significant interactions were found, post-hoc probabilities were estimated using Bonferroni's post-hoc test [14].

In all the analyses, the effects were considered significant when the p value was lower than the assumed level of statistical significance adopted at $\alpha=0.05$ ($p<0.05$).

RESULTS

In Table 2, the values of obliqueness (frontal plane), rotation (transverse plane) and pelvic tilt (sagittal plane) are demonstrated for children from the study groups.

Table 2. Obliqueness (positive values - up), rotation (positive values - internal) and pelvic tilt (positive values - anterior) in static, upright standing position

Applied orthosis	**Group 1**	**Group 2**	**Group 3**
	Obliqueness [°]		
	M±SD	M±SD	M±SD
No	2.17±2.00	1.05±2.94	-0.29±3.46
Yes	---	-0.63±2.61	1.01±2.56
	Rotation [°]		
	M±SD	M±SD	M±SD
No	13.75±10.09	13.24±12.44	10.38±15.85
Yes	---	12.29±13.30	2.48±14.92
	Tilt [°]		
	M±SD	M±SD	M±SD
No	21.31±7.86	28.64±34.86	32.65±38.87
Yes	---	21.53±4.91	23.54±3.52

The results of ANOVA and MANOVA did not indicate any statistically significant differences between the study groups in terms of obliqueness, rotation or inclination (p>0.05).

In the case of the interaction: measurement [with vs. without orthoses] × group [Group 2 vs. Group 3], significant differences were indicated in relation to pelvic obliqueness (F(1, 27)=5.033; η^2_P=0.180; p=0.035). The difference between the orthosis vs. no orthosis values was smaller in Group 3 (bilateral orthoses). However, it should be emphasized that the described differences were minimal and within the limits of measurement error.

The characteristics of the examined children regarding the position of the lower limb in the hip joint in free standing position are presented in Table 3. ANOVA did not show any statistically significant differences between the study groups in terms of abduction/adduction, rotation or flexion/extension angles. The lack of differences concerned both the affected and unaffected sides when not wearing orthoses (all groups) and in Groups 2 and 3 when wearing them (p>0.05).

Table 3. Angle in hip joint in static, upright standing position (positive values mean: adduction in frontal, internal rotation in transverse and flexion in sagittal plane)

Applied orthosis	**Group 1**		**Group 2**		**Group 3**	
	Affected s.	Unaffected s.	Affected s.	Unaffected s.	Affected s.	Unaffected s.
	Frontal plane [°]					
	M±SD	M±SD	M±SD	M±SD	M±SD	M±SD
No	**-2.47**±4.33 *	**1.85**±4.78	**-2.23**±4.85	**0.55**±4.29	-1.81±4.97	-1.23±5.51
Yes	---	---	-2.62±6.30	-1.19±4.21	-3.96±5.66	-0.15±4.98
	Transverse plane [°]					
	M±SD	M±SD	M±SD	M±SD	M±SD	M±SD
No	7.87±11.84	1.59±8.90	-0.12±13.88	4.57±14.41	7.88±16.80	9.04±14.96
Yes	---	---	8.57±16.20	5.51±16.21	12.86±11.66	10.58±15.75
	Sagittal plane [°]					

	M±SD	M±SD	M±SD	M±SD	M±SD	M±SD
No	**17.64**±14.43 *	**14.61**±12.61	**23.56**±12.54 *	**18.09**±10.06	**24.77**±14.68 *	**21.48**±9.43
Yes	---	---	26.66±7.08	17.95±10.96	22.52±10.76	21.92±11.08

* - Unaffected vs. affected side; $p<0.05$.

The results of MANOVA demonstrated significant differences in hip abduction/adduction (F(1, 40)=4.378; η^2_P=0.099; p=0.043) and flexion/extension (F(1, 40)=9.589; η^2_P=0.193; p=0.004) when children without orthoses were examined. In Groups 1 and 2, statistically significantly higher abduction values were noted on the unaffected side. However, on the affected side, greater flexion in the hip joint was observed in all groups.

No significant differences were indicated when analyzing the results on the interaction related the side [unaffected vs. affected] × group [1 vs. 2 vs. 3]. A trend was only noted in the case of hip joint rotation (F(2, 40)=2.650; η^2_P=0.117; p=0.083), which may indicate the smallest difference in Group 3 (bilateral orthoses).

There were no statistically significant differences (p>0.05) when the children (Groups 2 and 3) wore orthoses, and similarly, no interactions (unaffected vs. affected sides) were observed.

The results of MANOVA did not show any significant differences between measurements without orthoses compared to those performed with them. However, one trend was observed in hip joint rotation on the affected side (F(1, 27)=3.090; η^2_P=0.118; p=0.092). External rotation was higher in both groups after putting on the orthoses.

There was also no significant interaction between measurements [with vs. without orthoses] × group [Groups 2 vs. 3]. In contrast, a statistical trend was observed in positioning of the hip joint in the frontal plane on the unaffected side (F(1, 27)=3.169; η^2_P=0.121; p=0.088) in Groups 2 and 3 (respectively: unilateral and bilateral orthoses).

In the case of flexion in the knee joint (Table 4), there were no statistically significant differences between the study groups (p>0.05) in any of the measurements (with or without orthoses, neither on the affected or unaffected sides).

Table 4. Knee joint angle for sagittal plane in upright standing position (positive values - flexion, negative - extension)

Applied orthosis	**Group 1**		**Group 2**		**Group 3**	
	Affected s.	Unaffected s.	Affected s.	Unaffected s.	Affected s.	Unaffected s.
	Sagittal plane [°]					
	M±SD	M±SD	M±SD	M±SD	M±SD	M±SD
No	2.68±17.30	-0.06±9.74	13.63±14.45	8.62±13.48	12.65±18.32	10.20±15.86
Yes	---	---	10.86±12.47	3.87±12.60	5.94±15.35	8.07±11.30

The results of MANOVA did not demonstrate any statistically significant differences between the affected and unaffected sides (p>0.05). However, a larger knee joint flexion angle was observed for the affected side in all study groups (F(1, 40)=2.949; η^2_P=0.069; p=0.094).

No statistically significant differences (*p*>0.05) or interactions were indicated for measurements on the affected and unaffected sides (*p*>0.05) or in the case of wearing vs. not wearing orthoses (Groups 2 and 3).The results of ANOVA showed statistically significant differences between Groups 2 and 3 in terms of foot rotation while wearing and not wearing orthoses. They concerned both the affected (F(2, 42)=4.957; *p*=0.036) and unaffected sides (F(2, 42)=5.257; *p*=0.031). In Group 2 (unilateral AFO), the external rotation of the ankle joint was significantly greater than in Group 3 (bilateral AFO). These data, regarding ankle joint characterization in free standing posture assumed by hemiplegic CP children, are presented in Table 5 given below.

Table 5. Ankle joint angle in upright standing position (positive values mean: dorsal flexion in sagittal plane and internal rotation in transverse plane)

Applied orthosis	**Group 1**		**Group 2**		**Group 3**	
	Affected s.	Unaffected s.	Affected s.	Unaffected s.	Affected s.	Unaffected s.
	Sagittal plane [°]					
	M±SD	M±SD	M±SD	M±SD	M±SD	M±SD
No	**6.23**±5.76 *	**9.06**±3.89	**-2.23**±4.85	**0.55**±4.29	-1.81±4.97	-1.23±5.51
Yes	---	---	-2.12±6.30	-1.19±4.21	-0.96±5.66	-0.15±4.98
	Transverse plane [°]					
	M±SD	M±SD	M±SD	M±SD	M±SD	M±SD
No	**-22.26**±10.05*	**-9.43**±7.42	**-17.81**±18.84*	**-8.31**±18.66	**-15.81**±20.79*	**-10.48**±22.69
Yes	---		**-13.01**±9.25*#	**-13.04**±9.30#	**-6.23**±4.50*	**-5.63**±5.96

* - affected vs. unaffected side; *p*<0.05;
\# - Group 2 vs. Group 3; *p*<0.05.

MANOVA for measurements taken without orthoses demonstrated differences between the affected and unaffected sides in ankle dorsiflexion (F(1, 40)=7.941; η^2_P=0.166; *p*=0.007) and foot rotation (F(1, 40))=13.316; η^2_P=0.250; *p*=0.001). In all groups, the mentioned angle values were lower compared to the affected side.

Measurements conducted when the examined children were wearing orthoses (Groups 2 and 3) allowed to note a statistically significant difference regarding flexion angle in the ankle joint on the affected side (F(1, 27)=5.195; η^2_P=0.184; *p*=0.032). The values indicated greater plantar flexion of the foot in relation to the unaffected side

No statistically significant differences were demonstrated for the results of MANOVA concerning angular values in the ankle joint with and without the applied orthosis (*p*>0.05). However, trends were noted on the affected side, both in the case of ankle flexion (F(1, 27)=3.237; η^2_P0.123; *p*=0.085) and foot rotation (F(1, 27)=3.698; η^2_P=0.139; *p*=0.067). After putting on the AFOs, both external rotation and plantar flexion decreased in Groups 2 and 3.

DISCUSSION

Cerebral palsy is one of the most common childhood physical disabilities [13]. Despite the continuous and dynamic development of medicine, a "golden mean" in the treatment of its effects has still not been found. Novak et al. [30] identified available multi-modal interventions to help minimize the symptoms of CP, orthoses use being among them and demonstrating high efficacy as well as significance.

In the present study, we noted that using AFOs (unilateral/bilateral) in children with hemiplegic CP (in static position) induces beneficial changes in the joints of the lower limbs and pelvis. This provides the proper mechanical basis for performing correct functional movements required, for example, in the process of motor improvement. The effect may be favorable for the equal loading of the left and right limbs. This is of significance because children with hemiplegia are characterized by a deficit in strength of the main muscle groups on the affected side of the body [12]. They also demonstrate disturbances in motor planning [36]. For that reason, a stable standing position while performing physical exercise and everyday activities may promote building a correct motor response.

Analysis of the study results for Groups 2 and 3 (using AFOs) showed a statistically significant trend with regard to differences in pelvic obliqueness. At the same time, it was proven that the angular values describing the position in this plane were the lowest in the group using bilateral orthoses. It turned out that in children with hemiplegic CP, AFOs reduce obliqueness of the pelvis while also decreasing its internal rotation. It was further observed that in this group of patients, AFOs had influence on reducing pelvic obliqueness (by approximately 1° and 7°, in Groups 2 and 3, respectively). However, as earlier stated – this observation was not validated in the statistical analysis. The observations concerning the impact of AFOs on the upper levels of the kinematic chain find support in the data provided by Lucareli et al. [24]. This team of researchers also reported indirect effects of orthoses on knee, hip as well as pelvic joint alignment and control. Nonetheless, the discussed issue is still far from being settled, as evidenced in the work by Lidbeck et al. [23]. Its authors, assessing body posture both without and with AFOs, obtained similar results as did we.

In the next analysis, significantly greater flexion was observed in all the examined groups compared to the unaffected side in the area of the hip joint when evaluation was performed in standing position (without AFOs). In patients wearing bilateral AFOs (Group 3), the angle significantly decreased by approximately more than 2°, and this change was statistically significant. In this group, smaller differences in the values recorded on the affected vs. unaffected sides were also observed in comparison to the group of subjects equipped with unilateral orthoses (Group 2). In the children who were given bilateral AFOs, symmetry was noted (differences in both lower limbs did not exceed 1°), while in the unilateral AFO group, these differences reached approximately 9°.

On the other hand, lower flexion values were seen on both the affected and unaffected sides in the area of the knee joint after putting on the orthoses (Groups 1 and 3). These changes were more beneficial in the bilateral AFO group, especially in relation to the affected side of the body. It was found that in upright standing position, the flexion angle decreased by more than 6°. In contrast, the change was twice as small in the unilateral AFO group (approximately 3°).

Finally, plantar flexion and external rotation in the ankle joint on the affected side were constantly greater in all three study groups when orthoses were not applied. The application of orthoses, uni- and bilateral, reduced the angular values mentioned above, and these values were of statistical significance with regard to rotation. What seems to be of greatest importance - the values recorded in both lower limbs were similar. Nevertheless, the described changes in ankle joint symmetrization were more favorable among children from the group provided with bilateral AFOs (Group 3). It was found that dorsiflexion decreased by approximately 1° and external rotation by 5° and 9° (uninvolved and involved sides of the body, respectively). Consequently, in children from Group 3, compared to Group 2, dorsiflexion was smaller by an average of 1° and rotation by approximately 7°.

Our results regarding the impact of AFOs on the hip and knee joints found support in the earlier cited data specified by Lidbeck et al. [23]. At the same time, however, these authors did not record any changes in the ankle joint, which is in contrast to the present research. The described differentiation of the compared results is particularly surprising because the AFOs, due to their construction and location, should first demonstrate their impact on the ankle joint. Pohl and Mehrholz [32] evaluated the effects of unilateral AFOs on the angular values for individual joints of the lower limb in static position. Their subjects comprised neurological patients with hemiparesis. Despite a slightly different research group in relation to this study and due to the disease entity, the scheme of motor improvement was very similar and focused on achieving the greatest possible body posture symmetry. The authors noted significant improvement in the lower limbs after wearing the AFOs.

In research on the issue, the relative ease of assessing body posture symmetry has been demonstrated. This is of great significance in the therapy of hemiplegic patients. At the same time, such an intervention is often omitted in the aforementioned group. Such omission in the environment of people working with cerebral palsy patients should be minimized.

Study limitations

- One possible threat to the validity of the findings is the placement of passive markers on the AFO. Their positioning is the effect of the researcher's experience and not specially-designed detailed scientific protocols with fixed diagnostic value.
- The type of AFO (solid/non-hinged/spring) affects the results.

CONCLUSIONS

The biomechanical evaluation of free-standing posture among children with hemiplegic CP and the obtained results of analysis demonstrated that the AFOs used in this patient group had impact on the joint directly suited with them. These results also influence the remaing lower limb and pelvic joints. In addition, they positively affect angular changes in the knee, hip and ankle joints. AFOs used explicitly on both lower limbs enhance posture symmetry, providing a foundation for accurately targeted movement execution.

Conflict of interest

The authors report that there are no competing interests to declare.

Funding

The publication was financed within the programme of the Minister of Science and Higher Education under the title "Regional Initiative of Excellence" (in Polish: "Regionalna Inicjatywa Doskonałosci") in the years 2024–2027, project no. RID/SP/0027/2024/01.

REFERENCES

[1] Bahar-Özdemir Y., Ünal-Ulutatar C., Karali-Bingül D., Yet al., *Efficacy of foot-ankle orthosis on balance for children with hemiplegic cerebral palsy: An observational study*, Turkish Journal of Physical Medicine and Rehabilitation, 2021, 67:336-343 DOI: 10.5606/tftrd.2021.6906.

[2] Chow T. *Traceable Features of Static Plantar Pressure Characteristics and Foot Postures in College Students with Hemiplegic Cerebral Palsy*. Journal of Personalized Medicine, 2022, 12:394 DOI: 10.3390/jpm12030394.

[3] Cimolin V., Premoli C., Bernardelli G., et al., *ACROMORFO study: gait analysis in a cohort of acromegalic patients.* J Endocrinol Invest., 2024, 47(10):2469-2476 DOI: 10.1007/s40618-024-02340-3.

[4] Cohen J., Cohen P., West S., et al., *Applied multiple regression/correlation analysis for the behavioral sciences.* Third Edition. Routledge: New York, 2003.

[5] Davis R., Õunpuu S., Tyburski D., et al., *A gait analysis data collection and reduction technique*. Human Movement Science, 1991, 10:575-587 DOI: 10.1016/0167-9457(91)90046-Z.

[6] Domagalska-Szopa M., Szopa A., Czamara A., *Dependence of Gait Deviation on Weight-Bearing Asymmetry and Postural Instability in Children with Unilateral Cerebral Palsy*. PLoS One, 2016, 11:e0165583 DOI: 10.1371/journal.pone.0165583.

[7] Domagalska-Szopa M., Szopa A., *Body Posture Asymmetry Differences between Children with Mild Scoliosis and Children with Unilateral Cerebral Palsy*. BioMed Research International 2013:462094 DOI: 10.1155/2013/462094

[8] Dong V., Fong K., Chen Y., et al., *Remind-to-move treatment versus constraint-induced movement therapy for children with hemiplegic cerebral palsy: a randomized controlled trial.* Developmental Medicine & Child Neurology, 2017, 59:160-167 DOI: 10.1111/dmcn.13216.

[9] Donno L., Monoli C., Frigo C., et al., *Forward and Backward Walking: Multifactorial Characterization of Gait Parameters.* Sensors, 2023, *23(10):4671 DOI: 10.3390/s23104671*

[10] Dziuba A., Tylkowska M., Jaroszczuk S., *Index of mechanical work in gait of children with cerebral palsy*. Acta of Bioengineering and Biomechanics, 2014, 16:77-87 DOI: 10.5277/abb140309.

[11] Fiodorenko-Dumas Z., Dumas I., Kowal M., et al., *Using Stubby Prosthesis after Bilateral Transfemoral Amputation: A Biomechanical Case Study*. Applied Sciences, 2021, 11(8):3671 DOI: 10.3390/app11083671.

[12] Fujita H., Fusagawa H., Nishibu H., et al., *Motion analysis and surgical results of anterior transfer of flexor hallucis longus for equinovarus gait in children with hemiplegia.* Journal of Orthopaedic Science, 2021, 26:441-447 DOI: 10.1016/j.jos.2020.08.020.

[13] Galea C., Mcintyre S., Smithers-Sheedy H., Morris C., et al., *Cerebral palsy trends in Australia (1995-2009): a population-based observational study.* Developmental Medicine & Child Neurology, 2019, 61:186-193 DOI: 10.1111/dmcn.14035.

[14] Goeman J., Solari A., *Multiple hypothesis testing in genomics.* Statistics in Medicine, 2014, 33:1946-1978 DOI: 10.1002/sim.6088.

[15] Gulati S., Sondhi V., *Cerebral Palsy: An Overview*. The Indian Journal of Pediatrics, 2018, 85:1006-1016 DOI: 10.1007/s12098-017-2475-1.

[16] Hsue B., Miller F., Su F., *The dynamic balance of the children with cerebral palsy and typical developing during gait. Part I: Spatial relationship between COM and COP trajectories.* Gait & Posture, 2009, 29:465-470 DOI: 10.1016/j.gaitpost.2008.11.007.

[17] Jochymczyk-Wozniak K., Nowakowska K., Michnik R., et al., *Biomechanical analysis of gait in patients with ankle-foot orthoses - preliminary research.* Aktualne Problemy Biomechaniki, 2018, [Current Issues in Biomechanics] 16: 21-26 (in Polish, abstract in English).

[19] Keselman H., Othman A., Wilcox R., et al., *Generalized Linear Model Analyses for Treatment Group Equality When Data Are Non-Normal.* Journal of Modern Applied Statistical Methods, 2016, 15:Article 4 DOI: 10.22237/jmasm/1478002220.

[20] Krägeloh-Mann I., Cans C., *Cerebral palsy update*. Brain & Development, 2009, 31:537-544 DOI: 10.1016/j.braindev.2009.03.009.

[21] Kwolek A., Rehabilitacja medyczna, Elsevier Urban and Partner, Wroclaw 2003 (in Polish).

[22] Leonard R., Sweeney J., Damiano D., et al., *Effects of Orthoses on Standing Postural Control and Muscle Activity in Children With Cerebral Palsy.* Pediatric Physical Therapy, 2021, 33:129-135 DOI: 10.1097/PEP.0000000000000796.

[23] Lidbeck C., Gutierrez-Farewik E., Broström E., et al., *Postural orientation during standing in children with bilateral cerebral palsy.* Pediatric Physical Therapy, 2014, 26:223-229 DOI: 10.1097/PEP.0000000000000032.

[24] Lucareli P., Lima M., Lucarelli J., et al., *Changes in joint kinematics in children with cerebral palsy while walking with and without a floor reaction ankle-foot orthosis.* Clinics (Sao Paulo), 2007, 62:63-68 DOI: 10.1590/S1807-59322007000100011.

[25] McGinley J., Dobson F., Ganeshalingam R., et al., *Single-event multilevel surgery for children with cerebral palsy: a systematic review.* Developmental Medicine & Child Neurology, 2012, 54:117-128 DOI: 10.1111/j.1469-8749.2011.04143.x.

[26] Michlitsch M., Rethlefsen S., Kay R., *The contributions of anterior and posterior tibialis dysfunction to varus foot deformity in patients with cerebral palsy.* The Journal of Bone and Joint Surgery. American Volume, 2006, 88:1764-1768 DOI: 10.2106/JBJS.E.00964.

[27] Michnik R., Nowakowska-Lipiec K., Jurkojc J., et al., *Motor functions assessment method based on energy changes in gait cycle.* Acta of Bioengineering and Biomechanics, 2017, 19:63-75 DOI: 10.5277/ABB-00894-2017-03.

[28] Miles J., Shevlin M., *Applying Regression and Correlation: A Guide for Students and Researchers*. Sage: London, 2001.

[29] Morris C., Bowers R., Ross K., et al., *Orthotic management of cerebral palsy: recommendations from a consensus conference.* NeuroRehabilitation, 2011, 28(1):37-46 DOI: 10.3233/NRE-2011-0630.

[30] Novak I., Morgan C., Fahey M., et al., *State of the Evidence Traffic Lights 2019: Systematic review of interventions for preventing and treating children with cerebral palsy*. Current Neurology and Neuroscience Reports, 2020, 20:3 DOI: 10.1007/s11910-020-1022-z.

[31] Pavão S., Santos A., Oliveira A., et al., *Postural control during sit-to-stand movement and its relationship with upright position in children with hemiplegic spastic cerebral palsy and in typically developing children.* Brazilian Journal of Physical Therapy, 2015, *19*:18-25 DOI: 10.1590/bjpt-rbf.2014.0104.

[32] Pohl M., Mehrholz J., *Immediate effects of an individually designed functional ankle-foot orthosis on stance and gait in hemiparetic patients.* Clinical Rehabilitation, 2006, 20:324-330 DOI: 10.1191/0269215506cr947oa.

[33] Rasmussen H., Pedersen N., Overgaard S., et al., *Gait analysis for individually tailored interdisciplinary interventions in children with cerebral palsy: a randomized controlled trial.* Developmental Medicine & Child Neurology, 2019, 61:1189-1195 DOI: 10.1111/dmcn.14216.

[34] Schwartz M., Rozumalski A., *The Gait Deviation Index: a new comprehensive index of gait pathology*. Gait & Posture, 2008, 28:351-357 DOI: 10.1016/j.gaitpost.2008.05.001.

[35] Sees J., Miller F., *Overview of foot deformity management in children with cerebral palsy*. Journal of Child Orthopaedics, 2013, *7*:373-377 DOI: 10.1007/s11832-013-0509-4.

[36] Steenbergen B., Crajé C., Nilsen D., et al., *Motor imagery training in hemiplegic cerebral palsy: a potentially useful therapeutic tool for rehabilitation.* Developmental Medicine & Child Neurology, 2009, 51:690-696 DOI: 10.1111/j.1469-8749.2009.03320.x.

[37] Stockman J., Eggertsdóttir G., Gaston M., et al., *Ankle-foot orthoses among children with cerebral palsy: a cross-sectional population-based register study of 8,928 children living in Northern Europe*. BMC Musculoskelet Disord, 2023, 24(1):443 DOI: 10.1186/s12891-023-06554-z.

[38] Vitrikas K., Dalton H., Breish D., *Cerebral Palsy: An Overview*. American Family Physician, 2020, *101:213-220 PMID: 32053326.*

[39] Wang X., Wang Y., *Gait analysis of children with spastic hemiplegic cerebral palsy*. Neural Regeneration Research, 2012, 7:1578-1584 DOI: 10.3969/j.issn.1673-5374.2012.20.008.