

Original article

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Effect of hip abduction orthosis on gait kinematics of children with spastic cerebral palsy

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Abstract

Introduction Adduction or flexion-adduction contracture of the hip joint often causes static and dynamic impairments in children with spastic cerebral palsy that can be corrected with hip abduction orthosis. No reports confirming or rejecting the effectiveness of the method in the gait correction have not found. **The objective** was to explore the effect of the hip abduction orthosis on gait kinematics in children with spastic cerebral palsy. **Material and methods** Twelve biomechanical tests were performed for 6 patients of GMFCS level 3 (6 tests with hip abduction orthosis and 6 tests with no hip abduction orthosis). Gait analysis was produced using the Qualisys Miquis M5 motion capture system (Sweden). Clinical gait analysis was performed with PAF 2.0 of QTM software, Visual3D, Statistica 10 and Excel. **Results** A comparative analysis of the mean values showed differences in the gait parameters depending on test conditions. Improvements in the spatial-temporal parameters ranged between 0.4 % and 23.6 % with use of orthosis. The kinematic analysis of large joints demonstrated a slight positive effect on the hip joint function. There were no significant differences in the function of other joints. The use of orthosis improved the overall gait index score for the left and right lower limbs by 12.5 % and 5.7 %, respectively. A detailed analysis of the gait index for large joints of the lower limbs demonstrated the discrete improvement. **Conclusion** Hip abduction orthosis showed a positive effect on the gait pattern of children with spastic cerebral palsy.

Keywords: gait, orthosis, gait analysis, cerebral palsy, children

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INTRODUCTION

Impaired walking stereotype of patients with spastic cerebral palsy along with orthopaedic disorders, are associated with adduction alignment/contractures of the hip joints [1-3]. Invasive procedures are reported to be mainly used to correct the disorders [4-7]. There is a paucity of publications reporting the role of conservative treatments with the use of hip orthoses [8, 9]. Orthoses are mainly described in the context of the effect on the hip joints in combination with surgery, the use of botulinum toxin type A, etc. [10, 11]. A significant number of patients use hip abduction orthosis to improve the supporting function and ambulation by eliminating the adduction. We have not found any significant publications in the world literature describing the effect of the abduction orthoses on the patient's static and dynamic function

and ambulation stereotype with the exception of the work of a group of scientists [12]. The authors reported a positive effect of the SWASH orthosis on the spatial and temporal characteristics of the gait in a child with cerebral palsy. In our opinion, this work has design limitations since a hardware complex based on the Kinect software (software) was used as an objective tool for assessing the walking parameters that can be used only as a screening method according to Ma Y. et al. [13]. The study of the effect of abduction orthoses on the biomechanical parameters of support and ambulation using a high-precision method – 3D video analysis which is the "gold" standard of assessment abroad [14] is essential. The objective was to explore the effect of the hip abduction orthosis on gait kinematics in children with spastic cerebral palsy.

MATERIAL AND METHODS

A single-stage experimental-analytical controlled quantitative study "case-control" was performed. Patients received comprehensive medical rehabilitation at the Federal State Budgetary Institution "Federal Scientific Center for the Rehabilitation of Disabled named after G.A. Albrecht" of the Ministry of Labor and Social Protection of the Russian Federation. A group of six patients aged 5 to 16 years inclusive (i.e. with already formed walking stereotype) with a confirmed diagnosis

of "cerebral palsy, spastic diplegia" or "cerebral palsy, spastic tetraparesis" with a level of motor activity GMFCS 3 and spasticity level Ashworth scale 2–3 according to physical examination for a biomechanical assessment.

Exclusion criteria were inability of walking even with the use of additional support (crutches, canes, walkers); a significant cognitive impairment or emotional state of the subject which does not allow

contact for a biomechanical examination; history of botulinum therapy less than 6 months before the examination; history of surgical treatment of less than 12 months before examination.

All patients underwent 2 tests with use of hip abduction orthosis and without it. Orthosis requirements included a rigid low-profile corset for the body and cuffs on both hips connected by monolateral femoral rod splints and lockless hinges using Velcro tapes to fasten the corset to the body and cuffs to the hips. A foreign-made design (Sweden) was used as a hip abduction orthosis in four children (Fig. 1a), and a Russian-made device for the hip joints was employed by two patients (Fig. 1, b, c).

The orthosis was used by the patient before the test for at least 4 weeks with the product causing no discomfort. The hip abduction orthosis was purchased by the patient before admission to the hospital or was provided by the hospital for the rehabilitation period. The decision to recommend use of an orthosis was made based on the results of the medical and technical board. The medical

and technical board consisted of three orthopaedic and trauma surgeons (chairman of the MTB, head of the department, attending physician), a researcher at the Institute of Prosthetics and Orthotics, and at least one orthopaedic technician. The abduction of the lower limbs was carried out to the physiological position. Gait analysis was produced using the Qualisys Miquis M5 motion capture system (Sweden). Gait kinematics was recorded by 12 cameras with a resolution of 4 MP and a frequency of 100 Hz. The IOR method was used to place passive markers for the reconstruction of the human skeleton (Fig. 2).

Clinical gait analysis was performed with the QTM (Qualisys), Visual3D (C-Motion) programs and using the clinical PAF Gait module built into the software. The walking index (the gait profile score) was calculated for all joints of the lower limbs and is described in the literature. Experience with the index and the Qualisys clinical system showed that overall values below 8.5 can be considered normal, and higher values of the parameter indicated musculoskeletal dysfunction.

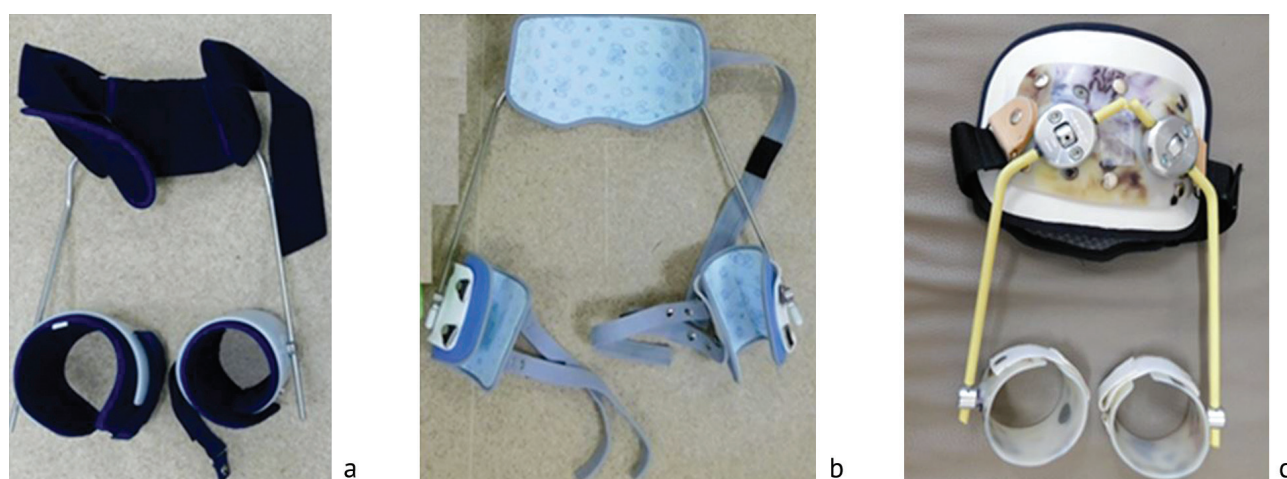


Fig. 1 Samples of hip abduction orthoses used by patients during tests

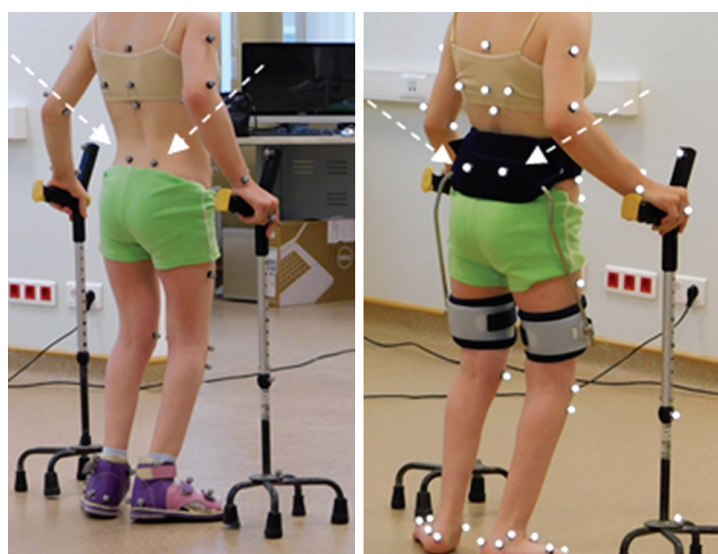


Fig. 2 Markers placed for different test conditions

RESULTS

As part of the study we examined three blocks of basic variables that allowed for a comprehensive assessment of the support and ambulation function: spatial and temporal parameters of walking; kinematics of large joints of the lower limbs; the gait index (GPS) is an integral indicator that is calculated both globally for the right and left lower limbs and separately for the hip, knee and ankle joints. The difference in the median ΔMe_i of the variables was calculated for a more visual representation of the differences in the gait of children using the hip abduction orthosis and not using it (Tables 1 and 2):

$$\Delta Me_i = 100 \% (Me_{i_o} - Me_{i_{n/o}}) / (Me_{i_{n/o}}),$$

where Me_{i_o} – median of the i variable in orthotic patients i , $Me_{i_{n/o}}$ – median of the i variable in non-orthotic patients

Table 1 shows differences in four variables: walking speed, step length and width, and the duration of the

double stance period. Kinematics of the motion of major joints of the lower limbs was performed in three planes: sagittal, frontal and transverse. Flexion and extension in the hip, knee and ankle joints were examined in the sagittal plane, hip abduction explored in the frontal plane, and rotation of the feet examined in the transverse plane (Fig. 3).

Measurements of the integral parameter (gait index) are presented in Table 2

Measurements presented in Table 2 showed that the use of orthosis improved the overall gait index for the left and right lower limbs by 12.5 and 5.7 %, respectively. A detailed analysis of the gait index for the large joints of the lower limbs demonstrated a discrete improvement in the biomechanics of walking, with the exception of the toe-out angle of the right foot.

Table 1

Values of spatial and temporal parameters ($M \pm \sigma$)

Variable	Lower limb	Test option		ΔMe_i
		No orthosis (n = 6)	Use of orthosis (n = 6)	
Speed (m/s)		0.35 ± 0.17	0.38 ± 0.16	6.6
Step width (m)		0.13 ± 0.06	0.16 ± 0.04	23.6
Double stance period (s)		0.88 ± 0.43	0.73 ± 0.32	-17.2
Step length (m)	left	0.32 ± 0.02	0.34 ± 0.02	5.1
	right	0.32 ± 0.07	0.32 ± 0.07	-0.4

Note: n, number of observations; $M \pm \sigma$, mean value with standard deviation.

Table 2

Measurements of the gait index

Parameters/gait index (GPS)	Lower limb	Test options		$\Delta Me (\%)$
		No orthosis (n = 6)	Use of orthosis (n = 6)	
GPS <i>general</i>	left	14.45 ± 2.68	12.65 ± 2.15	-12.5
	right	14.63 ± 2.64	13.80 ± 1.59	-5.7
Hip joint, flexion GPS	left	12.95 ± 2.73	10.23 ± 4.16	-21
	right	14.45 ± 3.38	13.88 ± 4.39	-3.9
Hip joint, adduction GPS	left	5.58 ± 2.19	5.03 ± 2.61	-9.9
	right	6.48 ± 4.68	6.07 ± 2.19	-6.4
Knee joint, GPS	left	20.95 ± 2.60	20.37 ± 4.02	-2.8
	right	22.52 ± 3.29	22.45 ± 4.30	-0.3
Ankle joint, GPS	left	17.75 ± 3.22	14.45 ± 4.49	-18.6
	right	17.85 ± 6.55	16.28 ± 5.77	-8.8
Toe-out angle, GPS	left	17.68 ± 10.28	14.40 ± 8.11	-18.6
	right	14.75 ± 10.31	15.62 ± 7.20	5.88

Note: n, number of observations; $M \pm \sigma$, mean value with standard deviation

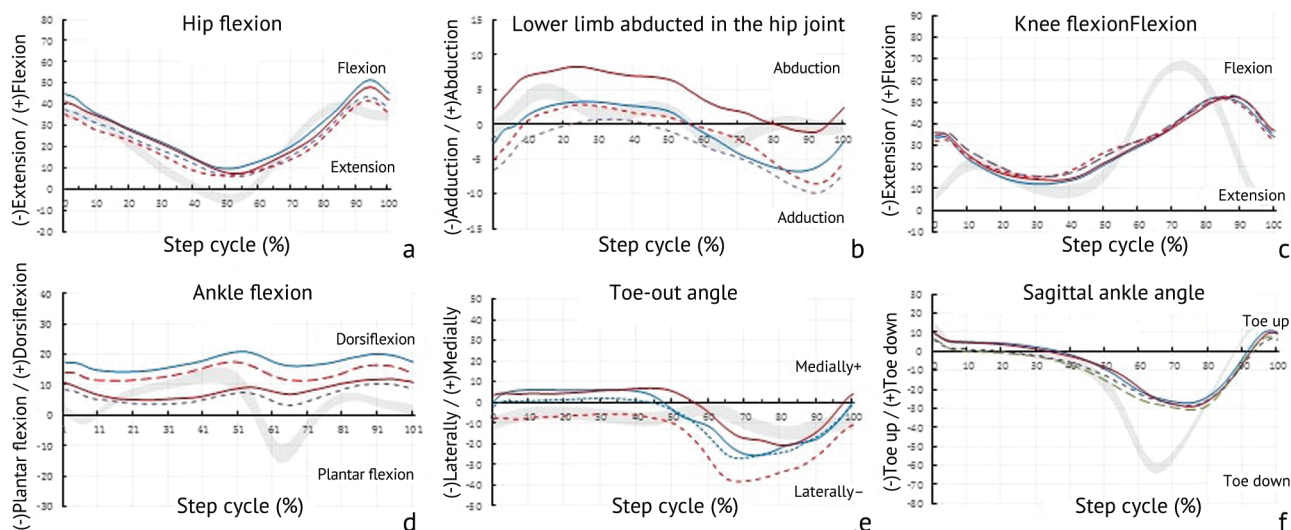


Fig. 3 Goniograms of large joints of the lower limbs. Note: the gray bar is the norm; solid red line showing the left lower limb in orthosis; solid blue line indicating the right lower limb in orthosis; dotted red line showing the left lower limb without orthosis; dotted blue line indicating the right lower limb without orthosis

DISCUSSION

Over the past few decades, abductor orthoses have been used as orthopedic products designed primarily to prevent progression of migration of the femoral head [19, 20]. Few publications described the orthoses in the context of the effect on the hip joints, primarily in combination with surgery and injections of botulinum toxin type A, etc. and less often as a standalone effect [11, 21–24]. There are no convincing data on the effect of abduction orthoses on the hip joints [25]. Both specialists and parents understand that the use of orthoses of this design is practical in reduction of the severity or complete elimination of the adduction alignment of the lower limbs in the hip joints improving the stability of the child at support and the gait. Interestingly, these practical observations are not reported in scientific publications, while this aspect seems to be a priority taking into account such a common manifestation of spasticity as adduction and flexion-adduction alignment or contracture of the lower limbs [6, 26]. We explored spatial and temporal parameters that are evident in visual assessment, along with more subtle and difficult-to-analyze variables as goniograms of large joints of the lower limbs in two planes, and an integral parameter of the gait index. The analysis of spatial and temporal parameters showed their improvement with use of the hip abduction orthosis. The maximum improvement was noted in the step width and the duration of the two-stance period (23.6 and 17.2 %, respectively), the minimum progression was seen in the length and speed of the step (5.1 and 6.6 %, respectively). From biomechanical point of view, the duration of the two-stance period is the key variable that allows for assessment of the stability of the subject, and the decrease in the two-stance characterizes greater stability of the child. This can be caused by a

significantly (23.6 %) increased step width with the orthosis and indirectly confirmed by the literature data reporting that the stability of the human body can change depending on changes in stability factors and can be increased with increased mass, decreased level of the common center of gravity and an increased support area (Fig. 4) [27–29].

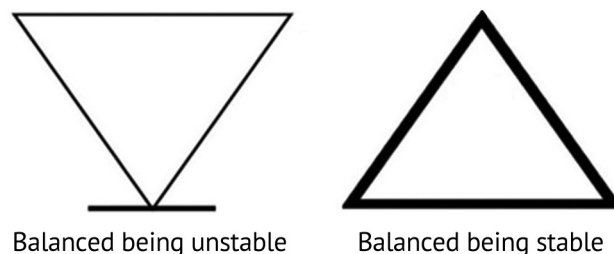


Fig. 4 Schematic representation of the concepts "Stability" and "Balance"

Increased speed and stride length can be considered an attribute of increased stability and balance of the patient's body [29]. The use of an orthosis of any design can be associated with impaired kinematics of adjacent joints. Hip orthosis can lead to excessive flexion of the limbs in the knee joints and/or increased pathological rotation of the lower limbs [12]. We undertook to assess kinematics of the large joints of the lower limbs.

Evaluation of the goniogram of the hip joint showed that the use of the hip abductor orthosis led to optimization of the flexion angle with the foot contacting the supporting surface as compared to no-orthosis test, while the symmetry and amplitude of the joint flexion with and without orthosis were comparable. Analysis of the goniogram describing trajectories of the hip abduction showed that the use of orthosis allowed for

more synchronous function of the right and left lower limbs (this is evidenced by the difference in diastasis between the lines - the right and left lower limb). Analysis of the goniogram of the knee joint showed that patients entered the initial phase of the support period with the knee flexed regardless of the test [30]. Full extension did not occur at the end of the phase; therefore, the transfer period also began with the knee flexed [30]. Analysis of the goniogram of the ankle joint (the relationship between the plane of the plantar surface and the plane of the supporting surface – foot pitch) showed the tendency to normative parameters regardless of the test conditions. The sagittal ankle angle showed improved performance between 0 and 50 % of the gait cycle as compared to the norm with the foot being in full contact with the floor. Analysis of the joint kinematics demonstrated that the use of orthosis had no negative effect on large joints of the lower limbs in children with cerebral palsy and contributed to improved kinematics of the hip joints.

The gait index (GPS) is an important parameter of the gait that is widely used in world clinical practice

to optimize the analysis of a significant amount of data obtained using high-precision research methods and video analysis [16-18]. The index was used in the series for the integral assessment of the gait of patients with and without orthosis. The use of the hip orthosis resulted in improvement of gait index of the left and right lower limbs by 12.5 and 5.7 %, respectively. A more detailed analysis showed a positive effect of the orthosis on the hip (flexion) and ankle (flexion) joints of both lower limbs in the range from 3.9 to 21.0 %. The change in the gait index of the knee with and without use of orthosis demonstrated significant differences. The effect of the orthosis on the intrarotational position of the feet was positive for the left foot (18.6 %) and moderately negative for the right foot (5.9 %). Despite the differences, the symmetry of the feet with orthosis improved.

A more detailed study can be recommended with use of dynamometric platforms to calculate the kinetics of the joints and assess the activity of the major muscles of lower limbs. The work has a design limitation: dynamometer platforms and EMG systems were not employed for the study.

CONCLUSION

1. The use of the hip abductor orthosis had a positive effect on the spatial and temporal characteristics of the gait improving the step width, the length and speed of the step and duration of the two-stance period.

2. The use of orthosis improved the hip function in the frontal and sagittal planes with no negative effect on

the knee and ankle function.

3. Globally, the use of an abductor orthosis had a positive effect on the walking pattern of children with spastic cerebral palsy that was evidenced by the improvement in the variables of the integral parameter of the gait index.

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Contribution of the authors:

Aksyonov A.Yu. – biomechanical examinations, consulting assistance in the processing of digital data, final editing of the article.
Koltsov A.A. – the concept and design of the study, stage and final editing of the article.
Dzhomardly E.I. – literature analysis, physical examination and assistance in biomechanical examinations, processing of digital material, writing the basic text of the article, stage and final editing of the article.

Ethical Conduct of the Study

The studies were approved by the ethics committee of the FGBU FNCRI named after G.A. Albrecht of the Ministry of Labor of Russia and were carried out in accordance with the ethical standards set forth in the Declaration of Helsinki. All patients participating in the study, or their legal representatives, signed an informed consent to conduct the study and publish the results of the study without identifying the person.

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