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Original Article

Factors associated with gait efficiency in children with cerebral palsy: association between gait abnormality and balance ability

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Abstract. [Purpose] Children with cerebral palsy require more gait energy than healthy children. The association between gait abnormalities and gait efficiency remains unclear. We investigated the association between gait abnormalities, balance, and maximum step length to determine contributors to gait efficiency in children with cerebral palsy. [Participants and Methods] The study included 33 patients with cerebral palsy, who could walk without the use of walking aids. All participants were instructed to walk for 6 min, and the Total Heart Beat Index was calculated as a measure of walking efficiency. The Edinburgh Visual Gait Score was used to assess gait abnormalities. Additionally, the maximum step length was recorded, and all participants performed the Berg Balance Scale. Correlation analysis and stepwise multiple regression analysis were used to confirm the association between the aforementioned parameters and the Total Heart Beat Index. [Results] The Edinburgh Visual Gait Score was correlated with the heel lift during the stance, knee position during the terminal swing of gait as factors associated with the Total Heartbeat Index. The Berg Balance Scale was correlated with turning 360°, standing with feet together. [Conclusion] Our findings emphasize the need for treatment strategies focused on gait abnormalities and balance.
Key words: Gait efficiency, Gait analysis, Balance ability

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INTRODUCTION

The Gross Motor Function Classification System (GMFCS) has been used to predict the prognosis of children with cerebral palsy (CP). GMFCS Level III patients show a decline in gross motor function beginning at 7 years and 11 months of age. However, Level I and II patients do not lose gross motor function with advancing age[1, 2)]. In clinical practice, however, we see cases that show a sense of gait difficulty as they approach adulthood. This is the case for many adults with CP who experience a decline or loss of the ability to walk[3)]. In adults with CP, gait deterioration is reportedly caused by decreased physical activity, endurance and balance[3–5)]. Children with CP who walk at the same speed as healthy children have a higher energy requirement. Therefore, it is vital to improve the walking efficiency of these children[6)]. It has also been shown that low gait efficiency may lead to activity limitation and reduced participation in daily life[7)]. The Physical Cost Index (PCI) is often used as a measure of gait efficiency. It is known that the reproducibility of PCI in children with CP is also low due to the low reproducibility of resting heart rate in children with CP. Therefore, the Total Heart Beat Index (THBI) is used to demonstrate gait efficiency without decreasing resting heart rate and THBI is highly reproducible in children with CP[8)]. To increase gait efficiency, it is important to increase gait speed and step length; Abel et al. reported that children with CP have a lower ability to lengthen their step length than normal children[9)]. In addition, THBI and maximum step length (MSL) are significantly correlated[10)]. Gait abnormalities are reportedly correlated with decreased gait efficiency in children with CP[11)].

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Kimoto et al. calculated gait efficiency from the heart rate using THBI; they reported that if the gait of a child with CP was within the normal range even in one limb, the gait efficiency was good[12)]. However, the specific aspects of gait abnormalities related to gait efficiency have not yet been reported. In the relationship between gait efficiency and balance ability, it has been reported that the gait efficiency of CP children is closely related to their balance ability[13)]. Balance ability includes static balance, dynamic balance and coordinated movement. However, it is not clear which parameters of standing balance correlate with gait efficiency. Investigation of these factors would be helpful for treatment programs when improving gait efficiency. These studies calculated gait efficiency using expiratory gas analysis devices and gait assessment was performed using three-dimensional motion analysis devices. However, such devices are expensive and their use is limited. Therefore, in this study, as a more clinical approach, gait efficiency was calculated using THBI and the Edinburgh visual gait score (EVGS) was used to evaluate gait abnormalities. We also aimed to determine which factors among gait abnormalities, balance capacity, endurance and step length reported in previous studies had the greatest influence on gait efficiency.

PARTICIPANTS AND METHODS

Participants were recruited from among those with spastic CP attending our hospital who were able to understand verbal instructions and walk without the use of walking aids. Potential research collaborators were screened in consultation with the physician in charge and informed consent was obtained verbally and in writing from the participants and their guardians after an appropriate explanation of the study content by the Declaration of Helsinki. Exclusion criteria included past orthopedic treatment within the past 6 months. Video cameras (Panasonic DMC-GF7, Osaka, Japan) were placed on the frontal and sagittal planes. A 6-minute walk test (6MWT) along a 30-m one-way walking path was performed using an arm-mounted optical heart rate sensor (Polar Verity Sense, Kempele, Finland). The THBI was calculated by dividing the total heart rate during walking by the total distance walked using the 6-minute walk distance (6MWD). EVGS was used to assess gait. The EVGS was scored using Kinovea video analysis software (Ver. 0.9.5, Retrieved from https://www.kinovea.org/, Bordeaux, France) based on sagittal and frontal videos taken during the 6MWT. Subsequently, MSL and BBS were performed. In the MSL test, the lower limbs moved significantly forward from the starting position. The distance from the most distal point of the forelimb was measured. The maximum step lengths of the left and right sides were summed and normalized by dividing by the sum of the left and right spino-malleolus distance. We examined the correlation between THBI and gait parameter variables by utilizing Spearman's rank correlation coefficient. Multiple regression analysis using the stepwise method was then conducted to determine the variables that influence THBI with THBI as the dependent variable and the other variables (EVGS, BBS, MSL) as independent variables. The number of independent variables was taken from Peter et al[14)]. In addition, sample size and statistical power were calculated using G power Ver 3.1 (α error: 0.05, Power: 0.8, Effect size Cohen f^2: 0.35, sample size:31) (Düsseldorf, Germany). The residuals' normality was examined for all variables utilized in the multiple regression analysis. It was found to be linear in the Q-Q plots, and a reasonable factor for analysis. IBM SPSS Statistics for Windows (Ver. 28. IBM Corp., Armonk, NY, USA) was used for statistical analysis. The significance level was set at 5%. This study was approved by the Research Ethics Review Committee of the International University of Health and Welfare (Approval No.: 22-Ig-243).

RESULTS

This study included 33 children with GMFCS level I and II CP who attended our hospital and had not received Botulinum Toxin A (BTA) or undergone orthopedic surgery within 6 months. Of these, 21 patients were GMFCS level I and 12 patients were GMFCS level II, with a mean age of 14.8 years (Table 1). We identifiend significant correlations between THBI and distribution of paralysis, GMFCS, EVGS, BBS, MSL and 6MWD as presented in Table 2. Variables from Table 3 of the correlation matrix were included in the analysis, except for the variable 6MWD, which has | r |>0.8. Multiple regression analysis, with the THBI as the dependent variable, identified EVGS and BBS as significant gait parameters. Within the EVGS, specific items chosen were heel lift in the stance phase, knee position in the terminal swing. For the BBS, the selected gait parameters included performing a 360° turn, maintaining a standing position with the feet together (Table 3).

DISCUSSION

We aimed to determine the relationship between gait efficiency and gait abnormalities, balance, and step length using EVGS and BBS. Multiple regression analysis with the THBI as the dependent variable identified EVGS and BBS as the significant gait parameters. For each item, the EVGS selected heel lift in the stance phase, knee position in the terminal swing, while the BBS selected turning 360°, standing with the feet together. Wren et al. reported 14 specific gait abnormalities in children with CP[15)], which were also observed in the present study, suggesting an effect on gait efficiency. In terms of detailed items, the timing of heel elevation resulted in a correlation with gait efficiency. The timing of heel elevation affected gait efficiency. Overactivity and weakness of the gastrocnemius muscle affected early and delayed heel elevation, resulting in a forward shift of the center of gravity and decreased stride length on the opposite side[16)]. Changes in the timing of heel elevation may affect gait efficiency. In addition to heel elevation, the knee joint angle at the end of the swing phase was

Table 1. Characteristics of participants and subgroups

	All participants (n=33)
Gender (n)	Male 18, Female 15
Age (years)	14.8 ± 6.7 (3.0–27.9)
Height (cm)	141.1 ± 22.2 (85.0–173.4)
Weight (kg)	37.8 ± 15.6 (12.0–84.0)
GMFCS (n)	I: 21, II :12
Distribution of paralysis (n)	Hemiplegia 15, Diplegia 10, Triplegia 1, Quadriplegia 7
THBI	2.43 ± 1.03 (0.99–5.04)
EVGS	15.4 ± 10.8 (0–50)
BBS	44.4 ± 9.8 (9–56)
Total maximum step length/Total spino-malleolus distance	0.91 ± 0.34 (0.30–1.63)
6MWD (m)	383.7 ± 113.9 (113–540)

GMFCS: Gross Motor Function Classification System; THBI: Total Heart Beat Index; EVGS: Edinburgh Visual Gait Score; BBS: Berg Balance Scale; 6MWD: the total walk distance in 6 minutes.

Table 2. Correlation analysis between THBI and each gait parameter

	Distribution of paralysis	GMFCS	EVGS	BBS	Total maximum step length/ Total spino-malleolus distance	6MWD
THBI	0.72**	0.72**	0.73**	−0.76**	−0.60**	−0.90**

*p<0.05, **p<0.01.
THBI: Total Heart Beat Index; GMFCS: Gross Motor Function Classification System; EVGS: Edinburgh Visual Gait Score; BBS: Berg Balance Scale; 6MWD: 6-min walk distance.

Table 3. Multiple regression analysis with THBI as dependent variable

Walking parameters		B	SE	β	95% CI	VIF
(Constant)		4.13	0.68		2.74 to 5.52	
EVGS**		0.04	0.01	0.45	0.02 to 0.07	1.45
BBS**		−0.05	0.01	−0.50	−0.08 to −0.03	1.45
Adjusted R^2=0.69						
EVGS	(Constant)	1.57	0.18		1.21 to 1.93	
	Heel lift in stance**	0.66	0.11	0.67	0.47 to 0.93	1.01
	Knee position in terminal swing**	0.29	0.08	0.40	0.13 to 0.46	1.01
	Adjusted R^2=0.62					
BBS	(Constant)	4.73	0.31		4.09 to 5.36	
	Turning 360 degrees**	−0.46	0.11	−0.57	−0.68 to −0.25	1.59
	Standing with feet together**	−0.24	0.09	−0.34	−0.43 to −0.05	1.59
	Adjusted R^2=0.65					

*p<0.05, **p<0.01.
THBI: Total Heart Beat Index; EVGS: Edinburgh Visual Gait Score; BBS: Berg Balance Scale; B: unstandardized coefficients; SE: standard error; β: standardized coefficients, 95% CI: 95% confidence interval for unstandardized coefficients, VIF: variance inflation factor.

also selected in this study. During walking in normal participants, the leg moves like a pendulum during the swing phase, exchanging kinetic energy and potential energy to conserve total energy during locomotion. Normally, at the end of the swing phase, the hip joint is flexed and the knee is extended at the same time. However, it has been reported that in CP patients, there is no pendulum motion in the lower leg during walking[17)]. The increased knee flexion angle at the end of the swing phase caused by the absence of pendulum motion of the lower leg in CP patients is attributed to the shortness of the hamstrings, which causes a decrease in step length and an increase in knee flexion at initial contact[18)]. This decreases gait efficiency due to the lack of pendulum motion. Other previous studies have reported that the energy conversion efficiency of children with CP is lower than that of normal children[19)]. In the present study, apart from gait abnormalities, balance ability was selected as a contributing factor. Previous studies have shown that abnormal gait patterns in children with CP may be associated with unstable postural control[20]. Walking efficiency in children with CP was correlated with balance ability, similar to previous studies[13]. For each of the balance ability items relevant to this study, a 360° turning was defined as completing a full rotation while taking small steps on the spot. Because dynamic balance was significantly correlated with gait function in children with CP, we emphasized the need to promote rhythmic weight-shifting training to improve the gait ability in children with CP[21]. Dynamic balance is reportedly less efficient in weight transfer than healthy children, manifesting a narrower range of motion of the foot's center of pressure and slower displacement speed during weight transfer[22]. These factors potentially exert a strong influence on gait efficiency. While most previous studies focused on a single factor affecting gait efficiency, we considered the factors related to gait efficiency from multiple perspectives and employed a more comprehensive clinical evaluation. Our results show that gait abnormalities and balance ability are affected, which may help consider specific training programs and analyze the results of interventions to improve gait efficiency in children with CP. Research limitations of this study. Walking efficiency is influenced by various factors, and previous studies suggested that age[11] and weight[23] were related and confounding factors. However, correlation analysis showed that weight and age were not correlated with gait efficiency. Due to the difference in the number of participants and the range of ages covered in the previous study and the difference in study design, we believe that these weight and age factors could not be completely excluded in this study and that a correlation cannot be ruled out. In addition, we were unable to eliminate the confounding factor of lower limb length for normalization, although we believe that lower limb length and other factors may also affect THBI. In a study design closer to the purpose of this study, we would like to set cutoff values for dividing the participants into two groups, one with good gait efficiency and the other with poor gait efficiency, and to conduct statistical analyses to examine the correlation between THBI and secondary items in each group. However, the sample size is small, which we believe is a limitation of this study. In conclusion, this study examined gait efficiency in children with CP by considering multiple factors, including gait abnormalities and balance ability. The findings underscore the significance of addressing the knee flexion angle during the swing phase, the timing of heel lift in stance during the stance phase, and weight transfer in enhancing gait abilities. Our innovative approach to assessing gait efficiency from a comprehensive clinical perspective highlights the need for further investigation and tailored interventions to optimize gait outcomes in this population. Specific methods include stretching and orthopedic treatment of the hamstrings and triceps muscles to maintain the knee joint extension angle at the end of the swing phase and to prevent early heel elevation during the stance phase. In addition, triceps strengthening exercises and center-of-gravity shifting exercises for dynamic balance should be performed to prevent delayed heel elevation during the stance phase.

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Conflicts of interest

The authors declare no conflict of interest.

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