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ORIGINAL RESEARCH

Association Between Calf Muscle Tone, Plantar Surface Area, and Gross Motor Function in Children with Spastic Diplegic Cerebral Palsy

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Background: Children diagnosed with spastic diplegic Cerebral Palsy (CP) usually demonstrate hypertonicity of the lower limb muscles which affects the normal alignments and weight reception by the feet. These impairments could be correlated to the limitations in gross motor function such as standing and walking abilities. Understanding these relationships can contribute to developing more effective rehabilitation strategies and improving overall motor outcomes for affected children.

Objective: The current study was designed to explore the relationship between plantar surface area, weight distribution on the plantar surface, and gross motor function (namely, standing and walking abilities) in spastic diplegic CP children.

Methods: Seventy-one spastic diplegic CP children aged 8–14 years joined this cross-sectional study. The Person's correlation coefficient and regression tests were used to assess the correlation between variables, namely, Gross Motor Function (GMFM), Calf Muscle Tone, Plantar surface area (PSA), and Peak pressure on mid and hind feet (PPMF, PPHF, respectively). These variables were assessed using the GMFM-88 scale, Modified Ashworth scale, and foot scan plantar pressure detection system, respectively.

Results: The correlation analysis demonstrated a strong to moderate positive correlation between PSA, PPMF, PPHF, and GMFM-D and GMFM-E. Additionally, regression model showed prediction levels equal to 0.791 for the GMFM-D and 0.720 for the GMFM-E categories, respectively.

Conclusion: Standing and walking abilities were positively correlated ($r \geq .6$) with the increased plantar surface area and higher peak pressure on mid and hind feet in spastic diplegic CP. Future longitudinal studies should investigate changes in gross motor function in relation to improvement in plantar surface area and peak pressure values.

Keywords: spastic diplegia, gross motor function, calf muscle, plantar surface area

Introduction

Cerebral palsy (CP) is described as non-progressive disruptions to the growing brain that result in a wide variation of dysfunctions such as muscle tone abnormalities, motor dysfunction, and consequently deviations in posture and movement.[1] Worldwide, CP affects around 2.1 out of every 1000 live births.[2] Recent work reported an incidence rate of around 1.6 for every 1000 births in high-income countries, while higher percentages were evident in medium- to low-income countries.[3] For example, 1.8 to 2.3 cases/every 1000 live births were reported in Uganda, while the research carried out in Saudi Arabia, Egypt, and the Sultanate of Oman suggests that the prevalence of CP ranges from 0.7 to 4.07/1000 live births. Nevertheless, epidemiological data are lacking in many other Middle Eastern countries.[4]

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The etiology of the CP is quite variable, and it might be caused by a preterm incident, post-natal events, or injury during the labor. Similarly, many risk factors can be linked to the incidence of CP. Antenatal maldevelopment of the central nervous system, maternal diabetes, hypoxic incidents, and sepsis are among those factors.[5]

The classification of CP is based on motor type, topographic pattern, and gross motor function level. Different motor types were identified, including mixed, ataxic, hypotonic, dyskinetic, and spastic CP. Based on the topographic distribution, spastic patterns were further divided into three main groups: quadriplegia, diplegia, and hemiplegia.[2]

One of the most prevalent types of spastic CP is spastic diplegia, which might be a result of a hypoxic white matter infarct in the periventricular regions. Gait, balance, and coordination problems are the main outcomes, with less involvement of the upper extremities compared to the lower ones. Many foot deformities can be seen in children with spastic diplegic CP such as Hallux valgus, toes overriding, and equinus foot postures.[6]

The equinus foot is characterized by standing and walking on toes and/or the borders of the foot.[6,7] While in normal feet, over 60% of body weight is borne by the heel, approximately 8% by the metatarsal region, and the remaining 32% by the forefoot.[8] The equinus posture leads to the reception of excessive weight on the forefoot, while less or no weight passes through the mid and hind foot.[9] Consequently, the base of support (BOS) decreases considerably which affects certain gross motor functions such as the standing and walking abilities.[10] One of the accurate measures that can determine the distribution of body weight on the feet is using the force plate form to assess the PSA, and the peak pressure on the different parts of the foot, namely, midfoot and hind foot.

Previous work highlighted that the BOS – which we referred to as PSA – is a key factor in the level of static and dynamic balance.[11] Without adequate BOS, walking will require higher muscular work; hence, higher energy expenditure will result. Considering the weakness and spasticity this might further hinder the standing and walking abilities. This can be reflected clinically by the need of the patients to use assistive equipment like forearm crutches or a posterior walker.[12]

Despite the existence of multiple studies about the factors that might affect the standing and walking abilities in children with spastic diplegic CP, no studies used the foot measures as predictors for the standing and walking abilities. Some studies assessed the effect of therapeutic interventions,[13] while others were concerned with factors other than foot measures.[14]

Studying the relationship between the factors that could affect the standing and walking abilities of children having spastic diplegic CP could be beneficial in designing a proper physical therapy rehabilitation program. Focusing on the most related factors and planning the appropriate intervention could speed up the rehabilitation process and achieve better results in a shorter time.

This study aims to assess the relationship between the tone of the calf muscle, plantar surface area, weight distribution on the plantar surface, and gross motor function measures.

Methods

Design

This cross-sectional study was conducted between April and May 2024 in a local rehabilitation center for CP children. The protocol of this study complied with the Declaration of Helsinki and was approved by the University of Ha'il ethical committee under no (H-2024-293). The recruitment process was conducted through written announcements and direct verbal communications with the parents of the eligible child. Before the study, each parent or legal guardian was fully informed about the purpose of the study and signed a consent form on behalf of his/her child to participate in the study.

Participants

Eligible participants were those who met the following criteria (1) were aged between 8 and 14 years; (2) were diagnosed with spastic diplegic CP; (3) were able to stand alone or with assistance; (4) minimum grade of 1 on gross motor function classification scale (GMFCS); (5) at least score 1+ on the Modified Ashworth scale (MAS).

The exclusion criteria were (1) children diagnosed with other types of spastic CP as hemiplegia and quadriplegia; (2) children who received an injection in the calf or any lower extremity muscle during the last six months (botulinum toxin); (3) previous lower extremity surgery; (4) children experiencing pain in the lower limbs; (5) severe associated neurological diseases as epilepsy; (6) medications affecting peripheral muscle tones such as baclofen, clonidine, and tizanidine or antiepileptic such as gabapentin or benzodiazepines;[15] (7) unable to communicate due to low mental functions.

Outcome Measures

All of the following outcome measures were carried out by an experienced pediatric physical therapist. Measures were collected once for all children and reported for further analysis.

Calf Muscle Tone

MAS was used to assess the level of calf muscle spasticity. This method is quite popular and has been used to assess muscle tone in many previous studies. The therapist performed passive ankle ROM at various speeds on the examined limb to identify the right degree of spasticity.[16] The interrater reliability of this scale was reported to be moderate to good in a previous work.[17]

MAS grades have been described as zero (no increase in muscle tone), one (minimal increase in tone) manifested by a catch followed by low resistance throughout less than half of the range, 1+ meant a slight increase in tone with a catch and release felt up to the half of the range, 2 shows a considerable increase in muscle tone over the whole range, grade 3 denotes a considerable increase in the muscle tone with difficulty in passive movement, and grade four if there was flexion or extension rigidity. The minimal clinically important difference was achieved if at least 1-grade change in muscle tone was reported.[18]

Plantar Surface Area, Peak Pressure on Mid and Hind Feet

The plantar surface area and peak pressure on mid and hind feet (PPMF and PPHF, respectively) were determined using a foot scan plantar pressure detection system. The same device was used for the same objective in earlier research,[19] while its reliability has been approved on several occasions.[20,21] This device consists of a force plate (FAS system 1.0 ACP Light, Buratto Advanced Technology, Treviso, Italy), with an active surface (47.5 × 43.0 cm) equipped with 2544 optical sensors distributed along the perimetrical border. For fourteen seconds, the child was asked to stand with their arms hanging down and their back to a fixed location. The entire plantar surface area (expressed in cm^2) and the peak pressure values at the forefoot and hindfoot (expressed in kPa) were included in the quantitative analysis of the pedobarometric evaluation.[22]

Gross Motor Function Measure

The Gross Motor Function Measure (GMFM) comprises (88 components). It is a tool used to evaluate the changes in gross motor function in patients with CP.[23] The GMFM 88 items each scored on a 4-point scale of 0 to 3. Zero indicates the inability to initiate the task; 1 indicates that the child completes <10% of the task); 2 indicates that the child completes from 10 to 99% of the activity; 3 indicates that the child can completely do the task, and NT indicates that the child was not tested. However, the GMFM 88 consists of five dimensions, only two, namely standing, and walking domains were tested in the current study because they are closely related to the challenging tasks of the children at 8–14 years old. In the current study, a maximum of three trials were allowed for each item, and the best trial is recorded.[24]

The GMFM 88 has demonstrated excellent interrater and test–retest reliability and internal consistency in children with CP.[24]

Sample Size

The sample size for correlation was generated using Power Analysis (GPower3.1). Two-tailed tests, a significance level ($p \leq 0.05$), and 80% power were used to calculate the sample size appropriate to detect at least a correlation coefficient of 0.35. The minimal sample size was 71.

Statistical Analysis

SPSS version 27 software was used for the analysis. Data were expressed in the form of means and standard deviation. Data normality was tested using the Kolmogorov–Smirnov test. The Person's correlation coefficient test and regression test were used to assess the correlation between the following pairs of variables: PSA& GMFM-D, PSA & GMFM-E, PPMF & GMFM-D, PPMF & GMFM-E, PPHF & GMFM-D, PPHF & GMFM-E. The significance level was set at $p \leq 0.05$.

Results

A total of eighty-six children with CP were screened for inclusion. Of them, 71 met the inclusion criteria and participated in this study. Girls were 35 representing 49.2% of the total sample, while the boys were 36 representing 50.8%. The characteristics of the participants are summarized in Table 1.

The results of the correlation analysis showed a statistically significant positive correlation between the PSA, PPMF, PPHF, and the GMFM-D. Similarly, statistically significant positive correlation between the PSA, PPMF, PPHF, and the GMFM-E (Table 2).

Regression Analysis for the GMGM-D as an Outcome

The regression model showed a good level (R = 0.791) of prediction of the GMFM-D. Additionally, the adjusted R^2 was 0.594 which means that the independent variables (PSA, PPMF, and PPHF) can explain up to 59.4% of the changes in the GMFM-D.

The ANOVA test showed that the regression model was a good predictor where the independent variables could statistically significantly predict the dependent variable, $F(3, 95) = 20.03$, $p < 0.001$.

Table 1 The Basic Characteristics of the Sample

	Mean	SD	Max	Min
Age (Y)	9.29	1.66	14	8
Weight (kg)	29.87	5.27	42	19
Height (cm)	121.67	7.60	144	103
BMI	23.42	3.76	31.04	16.37

Abbreviations: Y, year; kg, Kilogram; cm, centimeter; SD, standard deviation; Max, maximum; Min, minimum.

Table 2 Pearson's Correlation r Values and the Statistical Significance Between the Independent and Independent Variables

	Statistical values	GMFM-D	GMFM-F
PSA	***r***	0.650	0.600
	p	0.001	0.001
PPMF	***r***	0.714	0.652
	p	0.001	0.001
PPHF	***r***	0.718	0.647
	p	0.001	0.001

Abbreviations: PSA, plantar surface area; PPMF, peak pressure on the midfoot; PPHF, peak pressure on the hindfoot; GMFM-D, gross motor function measure D category; GMFM-E, gross motor function measure E category; *r*, Pearson's correlation coefficient; *p*, statistical value.

Regression Analysis for the GMGM-E as an Outcome

The regression model showed a good level (R = 0.720) of prediction of the GMFM-E. Additionally, the adjusted R^2 was 0.479 which means that the independent variables (PSA, PPMF, and PPHF) can explain up to 47.9% of the changes in the GMFM-E (Figures 1 and 2).

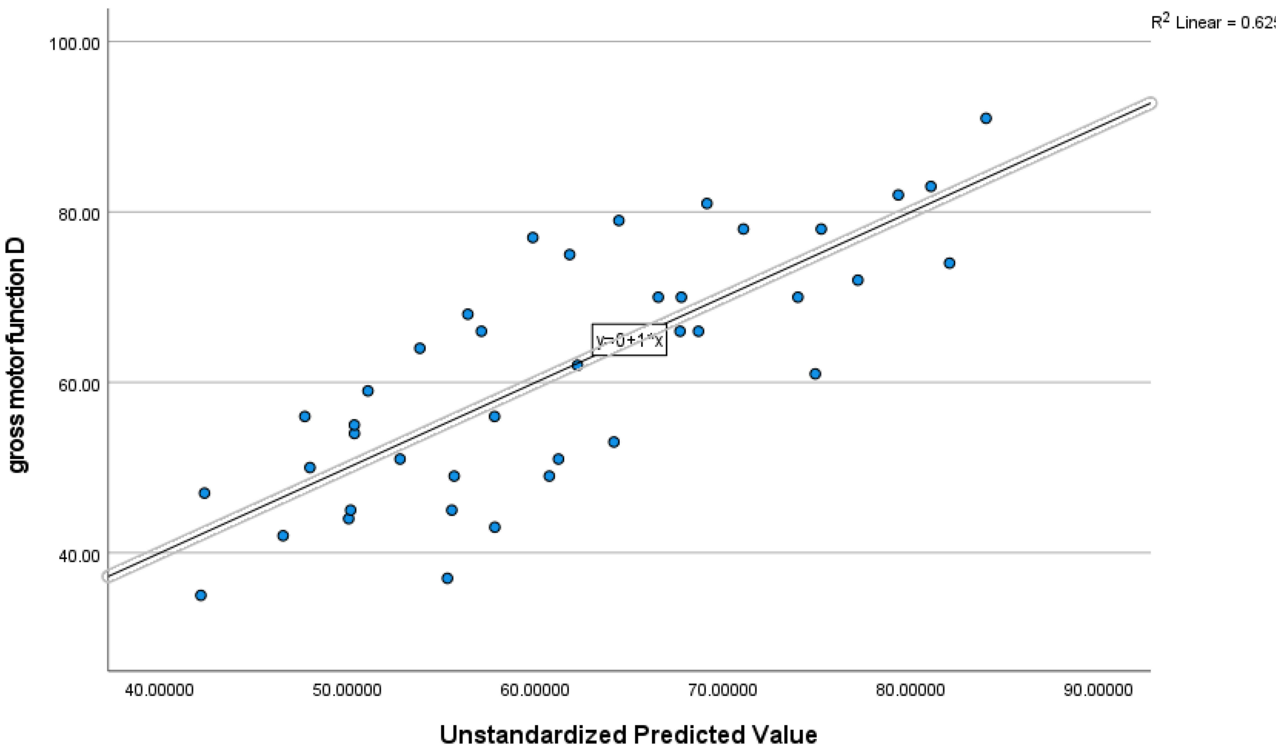

Figure 1 Partial regression plot: independent variables vs GMFM-D.

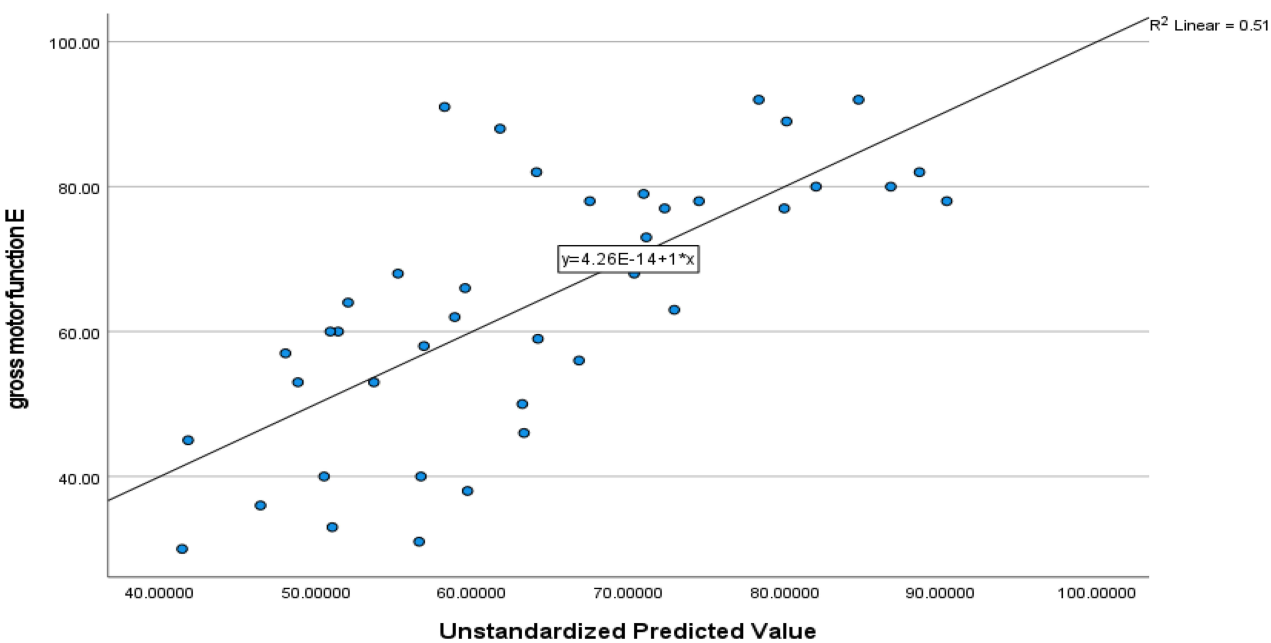

Figure 2 Partial regression plot: independent variables vs GMFM-E.

The ANOVA test showed that the regression model was a good predictor where the independent variables could statistically significantly predict the dependent variable, $F(3, 95) = 12.931$, $p < 0.001$.

Discussion

This study was conducted to determine the relationship between the foot measures such as the PSA, PPMF, and PPHF and the standing and walking tasks of the gross motor function. The current study used the PSA, PPMF, and PPHF values as predictors for the gross motor function abilities, especially those related to standing and walking in children with spastic diplegia CP. Medium to strong positive relationships were demonstrated between the predictors and the standing and walking abilities.

The literature contains multiple research that investigated different predictors of the gross motor function of children having CP. However, the authors claim that no previous studies used PSA and peak pressure distribution on the plantar surface as predictors for gross motor function. This limits the ability to compare the current results with the previous literature.

It is well known that foot behavior and mechanics are crucial for the development of normal standing and walking skills while growing.[25] Feet supports the child during the journey of movement and exploring the surrounding environment. Meanwhile, feet are subjected to continuous change during development and as a response to receiving weight from the upper body.[26] For example, the ossification of the tarsal begins with the calcaneus, the cuboid then the navicular bone. In the early infanthood period, the foot is usually characterized by a flat arch with large contact areas; that area increases as the infant's foot grows.[27] A larger contact area will relatively increase the BOS and enhance stability and balance while standing and walking. It also distributes the body weight on a larger planter area and prevents concentration of weight on certain points. The condition is quite different in children having spastic types of CP, where the increased tone of the calf muscle and other lower limb muscles disturb the normal mechanics of the foot, leading to a more equinus position with decreased PSA and development of excessive pressure points, especially on the forefoot.[28]

The positive relationship reported in the current study can be explained from the perspective of pathomechanics where the abnormal foot placement on the ground will lead to a decrease in the total BOS and consequently, reduce stability.[29] The other factor here is the concentration of body weight on certain points of the plantar surface, while no or minor weight was received by other areas might develop pain in the points with high stress. This pain may hinder the ability to stand and walk for the proper time needed to execute functional tasks. Meanwhile, tissues that receive less pressure may demonstrate slower development of the foot structure.[27]

Although the current work is not a causal effect study, its findings can highlight the importance of evaluating the PSA and the distribution of pressure coming from body weight on different areas of the plantar area such as the mid and hind feet. Such data can give the pediatric physical therapists valuable information about the possible functional abilities, especially standing and walking. It also highlights the importance of addressing foot problems and improving foot mechanics to improve functional gains.

This study has the following limitations; the design of the study is not a causal-effect model, so the results cannot accurately describe the effect of PSA and peak pressure values on the gross motor function. The findings of the current study were limited to the children having diplegia and cannot be generalized to diagnoses such as hemiplegia or ataxia. Moreover, this study did not consider the effect of time on the relationship between variables. Future longitudinal and intervention-based studies should be implemented to assess the effect of time and therapeutic interventions on all variables and their relationships.

Conclusion

Standing and walking abilities were positively correlated ($r \geq .6$) with the increased plantar surface area and higher peak pressure on mid and hind feet in spastic diplegic CP. Future studies should investigate changes in gross motor function in relation to improvement in plantar surface area and peak pressure values.

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Disclosure

We declare that we have no financial or personal relationships among the authors that could potentially influence or bias the content of this study.

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