Energy Consumption in Various Types of Ambulant Cerebral Palsied Children

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ABSTRACT

Purpose: *The purpose of this study was to determine whether a difference exists in energy expenditure during gait between children with CP and normal children as well as between different types of cerebral palsy. Also, to find any possible relationship between energy expenditure and measurements of muscle tone and functional skills in those children.* ***Patients and methods:*** *Eighty-two ambulant children with CP were enrolled (50 males, 32 females; mean age 6 y and 2 months ± 2 y and 2 months). Children were classified according to their clinical diagnoses as follows; spastic diplegia, left sided spastic hemiplegia, right sided spastic hemiplegia, athetoid, and ataxia. A group of 20 normal children (10 males, 10 females; mean age 6 y and 4 months ± 2 y and 3 months) was also tested as a control group for comparison. All CP children were evaluated for their standing and walking skills by the gross motor function measure (GMFM). Muscle tone assessment was conducted only for spastic CP children. The Cosmed K2 system was used to measure oxygen uptake (VO_2) and oxygen cost during walking for all children (CP and normal).* ***Results:*** *Significant differences were found between each of the CP groups and the group of normal children in respect to the energy cost of walking and oxygen uptake (p = 0.000). Children with CP displayed a higher energy cost of walking (mean 0.49±0.08 ml/kg/meter) than the normal children (mean 0.29±0.05 ml/kg/meter). Also, results revealed that the more impaired children with lower standing and walking skills and higher Ashworth score, the greater their metabolic demand and their energy expenditure during walking.* ***Conclusion:*** *The energy expenditure during gait in children with CP is significantly higher than normal children. The highest to the lowest energy cost of walking among the groups of CP was arranged as follows; athetoids; diplegics; ataxic; right sided hemiplegics; left sided hemiplegics.*
Key words: *Cerebral palsy; oxygen uptake; oxygen cost; energy expenditure; gross motor.*

INTRODUCTION

The normal gait pattern is generally considered to be the most energy-efficient means of ambulation. Because there is a dependent relationship between energy conservation and the other parameters of normal gait, improving gait parameters should result in an increased level of energy conservation[1]. Pathological gait is frequently associated with increased energy expenditure. This may limit the ability of an individual with a motor disorder to function in the community. Although three-dimensional kinematics and kinetics describe gait deviations at each joint level in the lower limb and in three anatomical planes, an overall measure of efficiency is difficult to calculate compared with that provided by the measurement of energy expenditure by indirect calorimetry[2].

Over the years, the ability of children with cerebral palsy (CP) to walk has been quantified in various ways, from the relatively simple measures of velocity, step length, and cadence to the more sophisticated measures of kinematics and kinetics, as provided by instrumented three-dimensional analysis. More recently, telemetric oxygen uptake equipment has made it possible to measure the energy efficiency of gait in these children and, thus, provide a measure of walking stamina and endurance[3]. A general measure of energy expenditure may be useful to compare normal gait with pathological gait, to grade the severity of a motor disorder, and to provide an outcome measure to assess the efficacy of intervention. This may be especially important in the evaluation of invasive and irreversible surgical procedures such as selective dorsal rhizotomy and orthopaedic surgery[4].

Measurement of Oxygen Uptake Using Telemetry

Among a number of attempts to evaluate the energy cost of physical movements, oxygen uptake (VO_2) has been shown to be the most accurate and has been widely used[5]. Although protocols vary, most studies that have recorded oxygen uptake focused on the development of a steady state of oxygen consumption after a period of walking at a self-selected speed. The walking time required to achieve steady state varies in the literature from 3 to 10 minutes[6-8], consequently many children with more disabling forms of the cerebral palsy are unable to complete this type of test[3].

In general, VO_2 is measured by the Douglas bag method. This method does not allow totally free movement of the subjects because of the bulky apparatus making it difficult to measure VO_2 on the spot during sport and other physical exercise[5]. Furthermore, many children have difficulty tolerating the equipment, particularly the face mask, for the sustained period required for testing[3]. Attempts have been made to reduce the monitoring apparatus in size and mass so that the subjects can exercise freely[9]. Recently, a new portable apparatus for measuring VO_2 making use of telemetry has been developed. The apparatus has an analytical component for expired air and oxygen concentration which is very much reduced in size and mass, thereby allowing the measurement of VO_2 in various physical activities[10].

The purpose of this study was to determine whether a difference exists in energy expenditure during gait between children with CP and normal children as well as between different types of cerebral palsy. Also, to find any possible relation between energy expenditure and measurements of muscle tone and functional skills in these children.

MATERIAL AND METHODS

Participants

Children with spastic, ataxic, and dyskinetic cerebral palsy were enrolled for the present study. They were managed at the out patient clinics of pediatrics and physical therapy, Jordan university hospital, Amman, Jordan, in the period between may 2000 to may 2002. Eighty six children were recruited to the study their parents gave consent for their children to participate after the initial correspondence. Inclusion criteria included an ability to walk more than 4 minutes without the assistance of another person or assistive devices and were considered to be community ambulators, no significant endurance impairments due to cardiovascular limitations and no surgery within the past year. Exclusion criteria included current ill health, any lower limb surgery, or botulinum toxin injection within the previous 12 months. All subjects were instructed to maintain their typical activity levels in addition to their exercise routine throughout the study. Eighty-two ambulant CP children (50 males, 32 females;

mean age 6 y and 2 months ± 2 y and 2 months) were capable of completing tests involved in the study. Four children were excluded from the study as they were unable to complete all the study tests. Children were classified according to their clinical diagnoses as follows spastic diplegia (n = 29, mean age = 6 y ± 2 y and 1 months), left sided spastic hemiplegia (n = 18, mean age = 6 y and 10 months ± 2 y and 10 years), right sided spastic hemiplegia (n = 11, mean age = 6 y ± 1 y and 8 months), athetoid (n = 18, mean age = 5 y and 9 months ± 1 y and 11 months), and ataxia (n = 6, mean age = 6 y and 7 months ± 2 y and 10 months). Ethical approval was obtained from the local research ethics committee.

A group of 20 normal children (10 males, 10 females; mean age 6 y and 4 months ± 2 y and 3 months) was also selected as a control group and was tested for comparison. Activity level of the normal children ranged from those who were sedentary to those who were active. Subject's weight and height were obtained.

Procedures

1. Muscle tone assessment

Modified Ashworth scale[11] was used to measure the average degree of resistance exhibited to passive movement for the affected lower limb. Tone assessment was conducted only for the spastic CP children (appendix 1).

2. Gross motor function measurements

Dimensions D (standing) and E (walking, running, and jumping) of the GMFM-88[12] were used to assess standing and walking skills for CP children and were performed under the strict guidelines given in the GMFM manual[13.] Scores were computed for the two separate dimensions in percentages. These dimensions were administered for the purposes of analyzing relationships between the energy expenditure values and standing and walking skills.

3. Measurement of Oxygen Uptake

The Cosmed K2 system was used to measure oxygen uptake (VO_2). The K2 has been validated for use in children or disabled. this system was selected because it allows the subjects to be tested while walking on a floor instead of a treadmill and because it is lighter and easier to use than a Douglas bag. The apparatus (K2, Cosmed, Italy) consists of a face mask to sample expired air, a sensor to measure ventilation and oxygen concentration in the air and a transmitter, an electrode to pick up heart rate, a battery, and tubes and cables to connect them to each other, and a receiver. Total mass which the subject carried was about 850g. The VE (ventilation), VO_2, ventilatory equivalent (VE /VO_2), respiration frequency (RF) and heart rate (HR) are calculated, displayed, and printed by the receiver. Intervals of the calculation can be set at 5, 15, 30, 45, and 60 seconds. The telemetry covers a distance over 100m, unless there are no obstacles between the transmitter and the receiver.

Each child practiced walking with the K2 before measurements were taken. Children wore their own clothing and shoes, and were allowed to wear their splints and not to use their walking aids. They were allowed a minimum of 5 minutes rest before starting the test. At the time of the actual test, the child donned the system and was asked to sit quietly until HR and VO_2 reached a steady state. The child was asked to walk inside the outline of a 20-meter level oval track in the gait analysis laboratory at a comfortable speed until the HR and VO_2, reached a steady state that was maintained for one minute (steady state usually occurs at two minutes of walking). They were told that they were not allowed to run. As a subject walked laps around the hallways, an investigator walked behind for safety carrying the Cosmed K2 unit.

The K2 gives HR and VO_2, measures every 15 seconds, and the average of the four values during the third minute of the test was taken as the steady state value for the subject. Distance traveled and time taken for each walk were recorded, and velocity was calculated and recorded as meters/minute. Oxygen consumption was measured as rate of oxygen consumed per unit time (ml/kg/min) and oxygen cost per meter walked (ml/kg/meter).

VO_2 calculation

The VO_2 at standard temperature and pressure, dry (STPD) is calculated from VE and FEO_2 by the following formula:

VO_2 (STPD) = VE (FIO_2-FEO_2) (STPD)

Where FIO_2 is fractional concentration of oxygen in inspired air and is assumed to be 20.9%; FEO_2 is fractional concentration of oxygen in expired air[14].

Statistical Analysis

A descriptive statistics including mean, range, standard deviation and standard error of mean was done for all sets of measurements, in all groups (CP groups and the group of normal children). Least-significant difference (LSD) one way analysis of variance (ANOVA) was used to compare between all sets of measurements among all groups. P-value <0.05 was considered significant. Pearson Bivariate correlation was used with the CP groups to correlate between VO_2 cost, velocity of walking, and GMFM score, as well as between VO_2 cost and Ashworth score (In spastic cases only).

RESULTS

The results of this study revealed that there were no significant differences among different groups of CP as well as between these groups and the group of normal children with regard to age, weight, and height. Also, it revealed no significant difference between the groups of spastic CP with regard to Ashworth score (Table I).

Table (1): Baseline demographic data of CP and normal children.

Variables		Cerebral palsied children					Normal children
		Spastic diplegic	Left spastic hemiplegic	Right spastic hemiplegic	Athetoid	Ataxic	
Patient number	(n)	29	18	11	18	6	20
Gender	(M:F)	18/11	10/8	5/6	13/5	4/2	10/10
Age	Months mean (SD)	72±25.4	82.2±32.1	72±19.8	68.8±23.2	78.8±34.3	75.8±27.4
Weight	Kg mean (SD)	18.4±6.3	21.8±10	19.6±5.4	17.6±5.6	20.3±9.2	21.5±7.8
Height	Cm mean (SD)	109.3±12	114.6±16.3	111.7±6.4	107.1±12.8	113.7±16.7	112.1±13.6
Ashworth scale	Mean (SD)	3.1±1	2.7±1.1	3.2±1	-	-	-

The gross motor function data of CP groups showed that the ataxic cases had the least standing and walking skills with an average percentage of (32.2±8.4 and 38.5±10.4 respectively), followed by the athetoid cases (50.7±19.1 and 54.5±18.5 respectively). On the other hand, the highest skills was for the left sided spastic hemiplegic cases (77.6±16.2 and 71±15 respectively) followed by the right sided spastic hemiplegic cases (61.9±19.9 and 60.1±21.2 respectively). Spastic diplegic cases had an average percentage score of (60.2±18 and 53.5±16.2 respectively) (Table II, figure 1).

Table (2): Measuremnts of gross motor function in CP and normal children.

Variables		Cerebral palsied children					Normal children
		Spastic diplegic	Left spastic hemiplegic	Right spastic hemiplegic	Athetoid	Ataxic	
Standing score	(%) mean (SD)	60.2±18	77.6±16.2	61.9±19.9	50.7±19.1	32.2±8.4	-
Walking score	(%) mean (SD)	53.5±16.2	71±15	60.1±21.2	54.5±18.5	38.5±10.4	-

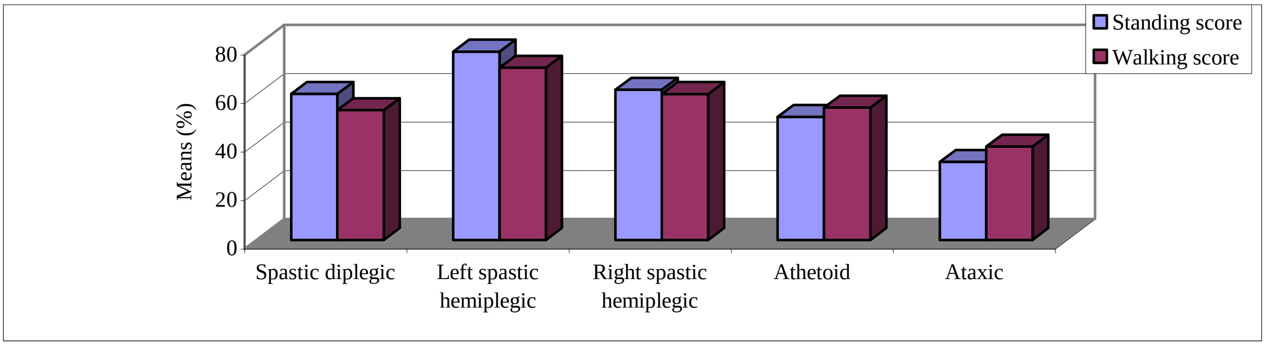

Fig. (1): Comparison between measurement of standing and walking skills in all CP groups.

Least significance post-hoc analyses of variance revealed significant differences between each of the CP groups and the group of normal children in respect to the energy cost of walking and oxygen uptake (p = 0.000). Children with CP displayed a higher energy cost of walking and oxygen uptake (mean 0.49±0.08 ml/kg/meter, 17.8±2.8 ml/kg/minute respectively) than the normal children (mean 0.27±0.05 ml/kg/meter, 9.8±1.7 ml/kg/minute respectively). Results revealed that the highest to the lowest energy cost of walking and oxygen uptake among the groups of CP was arranged as follows; athetoids (mean 0.55±0.05 ml/kg/meter, 20±1.8 ml/kg/minute respectively); diplegics (mean 0.52±0.05 ml/kg/meter, 19.1±2 ml/kg/minute respectively); ataxic (mean 0.52±0.07 ml/kg/meter, 18.8±2.6 ml/kg/minute respectively); right sided hemiplegics (mean 0.44±0.03 ml/kg/meter, 15.9±1.0 ml/kg/minute respectively); left sided hemiplegics (mean 0.39±0.03 ml/kg/meter, 14.4±1.2 ml/kg/minute respectively) (Table III, figure 2).

Table (3): Measurements of oxygen consumption and walking velocity in CP and normal children.

Variables		Cerebral palsied children					Normal children
		Spastic diplegic	Left spastic hemiplegic	Right spastic hemiplegic	Athetoid	Ataxic	
VO_2 uptake	(ml/Kg/min) mean (SD)	19.1±2	14.4±1.2	15.9±1.0	20±1.8	18.8±2.6	9.8±1.7
VO_2 cost	(ml/Kg/meter) mean (SD)	0.52±0.05	0.39±0.03	0.44±0.03	0.55±0.05	0.52±0.07	0.27±0.05
Velocity	(meter/minute) mean (SD)	42.3±3.7	51.2±3.6	49.9±3.5	37.1±2.3	40.2±3.3	57.3±8.5

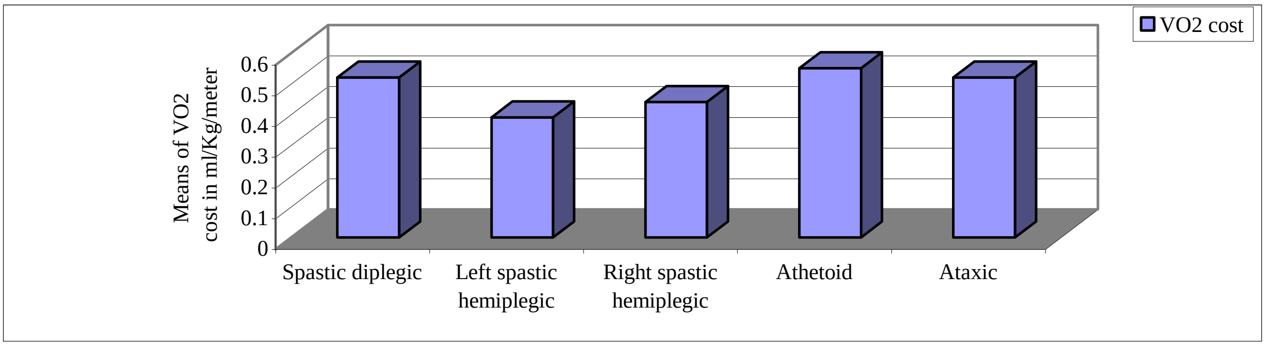

Fig. (2): Comparison between measurement of VO_2 cost in all groups.

On comparing between measurements of velocity of walking among all groups, there was a statistically significant difference between each of the CP groups and the group of normal children (p = 0.000). Normal children revealed a higher velocity (mean 57.3±8.5 meter/minute) than CP children (mean 44.0±6.3 meter/minute). Results revealed that the highest to the lowest velocity of walking among the CP groups was arranged as follows; left sided hemiplegics (mean 51.2±3.6 meter/minute); right sided hemiplegics (mean 49.9±3.5 meter/minute); diplegics (mean 42.3±3.7 meter/minute); ataxic (mean 40.2±3.3 meter/minute); athetoids (mean 37.1±2.3 meter/minute) (Table III, figure 3).

Highly significant negative correlations were found between the energy cost and each of the standing and walking skills as well as the velocity of walking (r = -0.50, r = -0.51, r = -0.89 respectively), while a highly significant positive correlation was detected between the energy cost and Ashworth score (r = 0.52) in spastic cases. (Table IV).

Table (4): Correlation coefficient with oxygen cost (VO_2 cost).

Parameters	Correlation coefficient	
	Cerebral palsied children	
	r	P value
Ashworth scale	0.52	0.00**
Standing score	-0.50	0.00**
Walking score	-0.51	0.00**
Velocity	-0.89	0.00**

** Correlation is significant at the 0.01 level. * Correlation is significant at the 0.05 level.

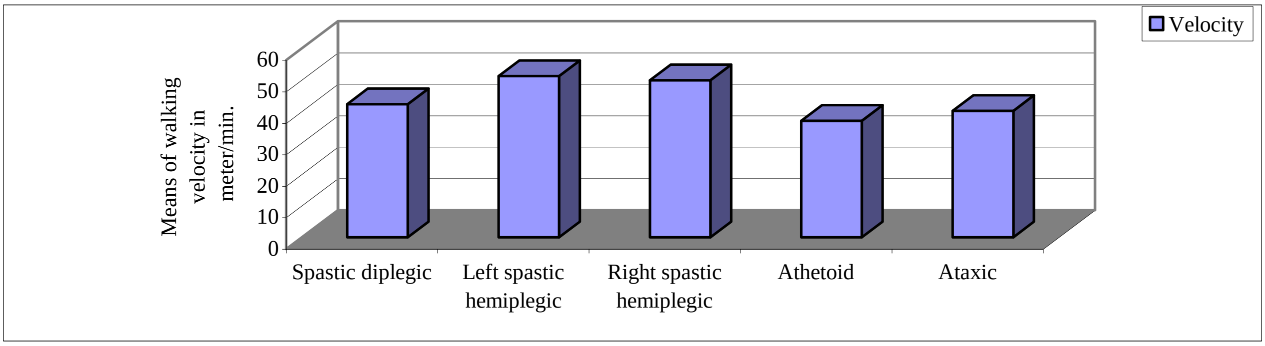

Fig. (3): Comparison between measurement of velocity of walking in all groups.

DISCUSSION

Results revealed that the energy expenditure during gait in all groups of cerebral palsy was significantly higher than normal children (about 1.5 to 2 times). Gage[1] has been reported that the energy demands of walking for adolescents with CP are 1.5 to three times that of healthy adolescents, depending on the degree and type of involvement. Bowen et al[15] reported oxygen cost to be a more reliable oxygen-use measurement of energy expenditure than VO_2 alone. The oxygen cost measure takes into account the oxygen requirement on a per-meter basis and provides a means for comparing individuals or the same individual over time despite differences in walking velocity. The oxygen cost of their ambulating children with CP has been reported to range from 0.42 to 0.64 ml/kg/meter. The calculated oxygen cost measurement for children with CP in our study was 0.39 to 0.55 ml/kg/meter, which is consistent with values reported by other investigators[15,16]. Also Kramer and MacPhail[17] used the Energy Expenditure Index (EEI) as a measure to quantify the energy consumed during walking in children with CP. Their results established energy-inefficient ambulation and correlations between knee extensor strength, velocity of movement and the walking efficiency.

In spastic CP, spasticity and the lack of motor control have long been recognized as sources of energy inefficiencies, especially during gait[18]. Also, Unnithan et al[19] reported that cocontraction may be advantageous during gait because it may be used to achieve joint stability, especially at the ankle. However, when coupled with inadequate force production frequently seen in the gait of individuals with spastic CP, cocontraction has been linked to inefficient energy expediture. Unnithan et al[20] and Stout[21] reported that lower mechanical efficiency during ambulation due to the loss of selective motor control, impaired balance, abnormal tone, weakness, and loss of range of motion contribute to the increased energy cost in children with CP.

A highly significant negative correlation was found between the energy cost and each of the standing and walking skills as well as the velocity of walking. This relation is important because it reflects a difference in metabolic demand during standing and walking among CP children: the more impaired children with lower standing and walking skills place a greater metabolic demand on their systems while standing and walking[22]. Reasons for this negative correlation might include the increasing severity of impairments such as strength, co-contraction, or spasticity and inefficient energy transfers between body segments, all of which have been shown to be related to energy expenditure during walking for children with CP[1,17,19].

Additionally, results showed that the highest oxygen cost was found in athetoid cases followed by the ataxic ones. This might be attributed to alterations in segmental energy transfer because children with athetoid and ataxic CP in particular use atypical patterns of movement, which might interfere with the natural exchange or transfers of potential and kinetic energy between body segments[23]. It has been shown that these deficient energy transfers account for as much as 87% of the variability in the energy cost of walking for children with CP[24]. Also, abnormal equilibrium reactions, which impair balance and speed control might have a role in increasing energy cost in those children[16]. Furthermore, the energy data in our children with spastic CP indicated an association with severity, energy expenditure was found to be higher in those with diplegia than in those with hemiplegia and in right sided hemiplegia than in left sided hemiplegia.

In conclusion the energy expenditure during gait in children with CP is significantly higher than normal children. The highest to the lowest energy cost of walking among the groups of CP was arranged as follows; athetoids; diplegics; ataxic; right sided hemiplegics; left sided hemiplegics. Our findings also demonstrated that the more impaired children with lower standing and walking skills and higher Ashworth score, the greater their metabolic demand and their energy expenditure during walking.

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Appendix 1 Modified Ashworth scale[21] for grading spasticity.

Grade	Description
0	No increase in muscle tone
1	Slight increase in muscle tone, manifested by a catch and release or by minimal resistance at the end of the range of motion when the affected part (s) is moved in flexion or extension.
1+	Slight increase in muscle tone, manifested by a catch, followed by a minimal resistance throughout the remainder (less than half) of the range of motion ROM.
2	More marked increase in muscle tone through most of the ROM, but affected part (s) easily moved.
3	Considerable increase in muscle tone, passive movement is difficult.
4	Affected part (s) rigid in flexion or extension.

الملخص العربي

استهلاك الطاقة في الأطفال القادرين على المشي والمصابين بمختلف أنواع الشلل الدماغي

إن هدف الدراسة الحالية هو تحديد إن كان هناك اختلاف في معدل استهلاك الأكسجين أثناء المشي بين الأنواع المختلفة لمرض الشلل الدماغي وكذلك إن كان هناك علاقة بين معدل استهلاك الأكسجين وكلا من النغمة العضلية ومعدل التطور الحركي لدى هؤلاء الأطفال .
أجريت هذه الدراسة على 82 طفلا من المصابين بالشلل الدماغي (29 شلل تصلبي مزدوج، 18 شلل تصلبي بالنصف الأيسر، 11 شلل تصلبي بالنصف الأيمن، 18شلل الكنع ، 6 شلل الترنح). كذلك تم اختيار عشرين طفلا من الأطفال الأصحاء بهدف المقارنة. تم قياس معدل التطور الحركي في الوقوف والمشي لجميع أطفال الشلل الدماغي . و قياس النغمة العضلية لحالات الشلل الدماغي التصلبي . وقياس معدل استهلاك الأكسجين أثناء المشي لجميع الأطفال (مرضى وأصحاء). أظهرت نتائج الدراسة وجود فروق ذات دلالة إحصائية في معدل استهلاك الأكسجين بين أي من مجموعات الشلل الدماغي ومجموعة الأصحاء وكان أعلى معدل لاستهلاك الأكسجين في حالات شلل الكنع وأقلها في حالات الشلل الدماغي التصلبي في الجانب الأيسر وأظهرت النتائج أيضا وجود علاقة عكسية بين معدل استهلاك الأكسجين أثناء المشي في مرض الشلل الدماغي ومعدل التطور الحركي في الوقوف والمشي وكذلك علاقة طردية مع معدل النغمة العضلية في حالات الشلل التصلبي وعليه يمكننا أن نستنتج أن هناك ارتفاع في معدل استهلاك الأكسجين في أطفال الشلل الدماغي مقارنة بمجموعة الأطفال الأصحاء.