Three-Dimensional Analysis of Pelvic Motion during Gait in Adolescent Hemiparetic Cerebral Palsy

Moussa A. Sharaf*, Samah A. El-Shemy and Gehan M. Abd El-Maksoud**.**
*Department of Physical Therapy for Neuromuscular Disorders and its Surgery, Faculty of Physical Therapy, Cairo University.
**Department of Physical Therapy for Growth and Developmental Disorders in Children and its Surgery, Faculty of Physical Therapy, Cairo University.

ABSTRACT

Purpose: *This study was carried out to evaluate pelvic motions during gait in adolescent hemiparetic cerebral palsy and to compare these with that of age matched normal subjects.* ***Subjects:*** *Forty adolescent hemiparetic cerebral palsy patients (study group); their age ranged from 15 to 18 years old; and twenty normal subjects (control group); their age ranged from 15.5 to 18 years old; participated in this study.* ***Methods:*** *The patients were selected according to the predetermined criteria from the pediatric outclinic of the faculty of Physical Therapy, Cairo University. All subjects were assessed for all components of pelvic motions during gait (including pelvic tilting, obliquity and rotation) by the use of Opto-Electronic Motion Analysis System.* ***Results:*** *The results of this study showed significant decrease in posterior pelvic tilting, downward pelvic obliquity, forward pelvic rotation during both stance and swing phases and significant decrease in upward pelvic obliquity during stance phase in the study group when compared with the control group. On the other hand, there was significant increase in the anterior pelvic tilting, backward pelvic rotation during both stance and swing phases and significant increase in upward pelvic obliquity during swing phase in the study group when compared with the control group.* ***Conclusion:*** *It can be concluded that patients with cerebral palsy are suffering from abnormal pelvic motion during both stance and swing phases. It is recommended that, abnormal pelvic motions should be considered during rehabilitation of CP.*
Key Words: *Cerebral Palsy – Hemiplegia – Pelvic – Gait – Opto* **-** *Electronic Motion Analysis.*

INTRODUCTION

Cerebral palsy (CP) is a static encephalopathy that can be defined as a motor disorder affecting posture and mobility. It is a manifestation of non progressive brain damage sustained during the period of brain growth or due to a developmental defect of the brain[31]. CP is the most common cause of physical disability in childhood[7,25]. Patients with spastic cerebral palsy frequently demonstrate pathological gait patterns involving abnormal joint motion, muscle timing and temporal-distance characteristics[22].

The older children with cerebral palsy showed disorganized muscle responses and increased frequency of coactivation of both proximal–distal and agonist–antagonist muscles. This coactivation may share in causing gait problems[39,40]. Other major cause of gait disturbances is impairment of standing balance[32].

The human trunk including the spine and pelvis acts as a dynamic and stable core from which the upper and lower limbs move so control of the pelvic motion is vital in maintaining whole body balance in different planes[14]. Deformities of the pelvis have a significant influence on gait patterns. Normally, a dynamic pelvis will respond quickly to changes in postures during different activities. Poor alignment of the pelvis causes loss of maximum dynamic flexibility and stability leading to improper function of the upper and lower limbs that will be reflected on the patient's gait[15].

Assessment of posture including trunk, pelvis and lower extremity posture in static standing and during walking in the different planes will often give insight to areas of weakness, poor motor control and the compensation strategies that the child is using[40]. Gait analysis has been a very useful tool in the assessment of children with CP. It is used both to guide and evaluate treatment[17,42]. Gait analysis by using motion analysis lab is needed because it is so sensitive to show any disturbances in angular excursions in addition to giving some gait parameters[12].

Computerised gait analysis is useful in the individual child with Cerebral Palsy (CP)[12] and is helpful in planning interventions in spastic gait[29,30]. Gait analysis helps to pinpoint the causative impairments. It can document segment and joint motions and allow accurate identification of the location of the abnormalities, including pelvic motion that can be difficult to determine visually or by clinical examinations[12]. Gait analysis will continue to provide clinician with a better understanding of biomechanical and neurophysiologic function, both normal and abnormal. The main goal of gait analysis is to assist in treatment decision-making for the person with complex and not easily understood walking problems[9,24].

Three-dimensional gait analysis is a systematic measurement, description and assessment of human gait. Gait analysis is established as a useful diagnostic tool in patients with gait problems, as it is not possible to obtain an adequate and detailed understanding of such a complex mechanism as gait in a conventional clinical examination. Gait analysis has entailed a change of policy with regard to surgical treatment in this patient group. Gait analysis is recommended in routine diagnostic particularly as a preoperative evaluation, in all children with gait problems and in the follow up after surgery or other treatment[23].

Unfortunately, the treatment of cerebral palsy are not universally effective, outcomes are difficult to predict, and improvements are often minima[l3,10,35]. The treatment of gait abnormalities in persons with cerebral palsy is challenging[2]. This may be because a treatment approach for gait based on a reasonably symmetrical clinical assessment of the abnormalities and visual impression of symmetry in gait that may result in an unexpected treatment outcome. This may help to explain some of the unpredictability in surgical outcomes in the patient with cerebral palsy in which surgical decisions were made without gait analysis. Adding to this, little is known about motor functioning during puberty and adolescence. Information about changes in motor functioning during adolescence and the factors influencing this prognosis is necessary to establish realistic prognosis and treatment goals that will result in effective use of therapeutic resources and prevent loss of functional abilities[1,4,16]. So, the purpose of the present study was to examine ROM of pelvic motions in adolescents with spastic hemiplegic CP during stance and swing phases of gait and to compare these results with age matched normal subjects.

SUBJECTS AND METHODS

Subjects:

Forty adolescent spastic hemiparetic cerebral palsy patients (study group) (18 girls & 22 boys) participated in this study. The patients were selected from the outclinic of the faculty of Physical Therapy. Their age ranged from 15 to 18 years old with a mean of 16.65 ± 0.796. Twenty normal ages matched subjects (control group) (4 girls & 16 boys) participated in this study. Their age ranged from 15.5 to 18 years old with a mean of 16.5 ± 0.745. All patients in study group were diagnosed as spastic hemiparetic CP. They had the ability to stand and walk independently without the use of assistive devices or orthoses (Grades I and II according to the Gross Motor Function Classification System). All patients had no limitation in ROM of the hip joint and didn't receive any surgical interventions during the last year before this study. They had cognitive development that allow them to follow simple requests. All subjects in both study and control groups were assessed for range of motion (ROM) of the pelvis during gait (including upward & downward pelvic obliquity, anterior & posterior pelvic tilting, in addition to forward & backward pelvic rotation) by the use of Opto-Electronic Motion Analysis System.

Methods:

Instrumentations:

Three-dimensional analysis system (Qualisys Motion Capture System) was used to measure ROM of the pelvis during gait (including pelvic obliquity, pelvic tilting and pelvic rotation) for all subjects participated in this study. The system consisted of six ProReflex infrared high speed cameras with a capture capability of 120 frame/sec. The software programs including Q Gait and Q trac (provided by Qualisys company) were used to capture and to analyze gait.

Eighteen reflective markers were used. They were placed on specific sites on the body. These reflective markers are small balls, silver in color and capable of reflecting the infrared light emitted from the ProReflex Cameras. The markers were stabilized to the skin by double face adhesive sticker. These markers were placed bilaterally on: superior surface of the acromion, anterior superior iliac spine, superior edge of the patellae (suprapatellar), lateral aspect of the knee joint, tibial tuberosity, lateral malleolus, over both feet between the bases of the 2^{nd} and the 3^{rd} metatarsal bones, and over heels (posterior of calcaneus, at the same horizontal plane as the metatarsal markers). Additionally, one marker was placed on the spinous process of the 12^{th} thoracic vertebra and another one was placed on the sacrum.

Procedures:

The camera system was calibrated, before any 3-D capture to enable the cameras to pick up the positions of the markers in the trajectory field of the walkway. This was done by using a soft ware calibration technique with a wand. The position of cameras and their spatial orientation remain unchanged during capturing. Any change in the location of the cameras require re-calibration. Each subject was instructed to walk bare feet on the walkway by his/ her self-selected speed (natural or comfortable walking speed). Several walks (four times) along the walkway were allowed prior to recording of data to make the subject familiar with the walkway and the procedures. After being familiar with the walkway, each subject was asked to walk o for three times and data of all measured parameter were collected. Data obtained from the three trials were analyzed by using Q Gait and Q trac programs. The Q trac was used to capture the motion data and then the appropriate part of the data was selected and exported to Q Gait program as TSV (Tab Separated Values) file format for measuring different pelvic angles during the gait cycle (including upward & downward pelvic obliquity, anterior & posterior pelvic tilting and forward & backward pelvic rotation). Then, the average was taken. Statistical package (SPSS) was used to analyze the data (Independent T test). P value of less than 0.05 was considered significant.

RESULTS

All pelvic range of motions during both stance & swing phases of gait (including upward & downward pelvic obliquity, anterior & posterior pelvic tilting; as well as; forward & backward pelvic rotation) were obtained from both normal subjects (control group) and the adolescent spastic hemiparetic CP (study group).

A- Results of pelvic obliquity:

The results concerning ROM of the upward pelvic obliquity showed significant difference between adolescent hemiplegic CP (study group) and the normal subjects (control group) in the peak of upward pelvic obliquity during both stance and swing phases (P=0.0001 for both). The mean values (mean ± SD) of the peak of upward pelvic obliquity were (5.08 ± 0.451 degree & 2.02 ± 0.475 degree) in normal subjects and (1.2 ± 0.462 degree & 4.945 ± 0.812 degree) in CP patients for the stance and swing phases respectively.

Concerning the results of ROM of the downward pelvic obliquity; there was a significant difference between both groups in the peak of downward pelvic obliquity during both stance and swing phases (P=0.0001 for both). The mean values (mean ± SD) of the peak of downward pelvic obliquity were (4.03 ± 0.842 degree & 5.09 ± 0.474 degree) in normal subjects and (1.32 ± 0.439 degree & 1.15 ± 0.461 degree) in CP patients for the stance and swing phases respectively. The changes in the mean values of the peak of upward and downward pelvic obliquity between both groups are represented in table (1) and illustrated in figure (1).

Table (1): Comparison between the mean values of the peak of upward and downward pelvic obliquity (degrees) at stance and swing phases in adolescent CP and normal age matched subjects.

Variable		CP patients (Study group)	The normal subjects (Control group)	t-Value	P-value
Upward pelvic obliquity (degrees)	Stance	1.2 ± 0.462	5.08 ± 0.451	-21.831	0.0001
	Swing	4.945 ± 0.812	2.02 ± 0.475	10.471	0.0001
Downward pelvic obliquity (degrees)	Stance	1.32 ± 0.439	4.03 ± 0.842	-11.677	0.0001
	Swing	1.15 ± 0.461	5.09 ± 0.474	-21.833	0.0001

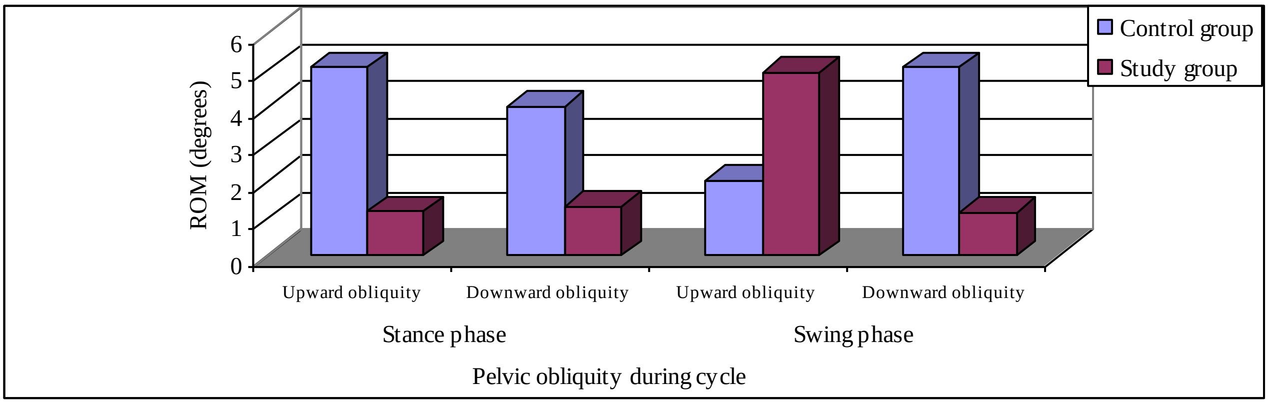

Fig. (1): Changes in the mean values of the peak of upward and downward pelvic obliquity (degrees) at stance and swing phases in adolescent CP patients (Study group) and normal age matched subjects (Control group).

B- Results of pelvic tilting:

Regarding the results of ROM of the anterior pelvic tilting; there was a significant difference between adolescent hemiplegic CP and the normal subjects in the peak of anterior pelvic tilting during both stance and swing phases (P=0.043 & 0.019) respectively. The mean values (mean ± SD) of the peak of anterior pelvic tilting were (2.23 ± 0.346 degree & 2.275 ± 0.108 degree) in normal subjects and (2.47 ± 0.262 degree & 2.595 ± 0.396 degree) in CP patients for the stance and swing phases respectively.

As regarding to ROM of the peak of posterior pelvic tilting; there was a significant difference between both groups in the peak of posterior pelvic tilting during both stance and swing phases (P=0.0001 for both). The mean values (mean ± SD) of the peak of posterior pelvic tilting were (2.305 ± 0.138 degree & 2.275 ± 0.135 degree) in normal subjects and (1.245 ± 0.822 degree & 0.49 ± 0.247 degree) in CP patients for the stance and swing phases respectively. The changes in the mean values of the peak of anterior and posterior pelvic tilt between both groups are represented in table (2) and illustrated in figure (2).

Table (2): Comparison between the mean values of the peak of anterior and posterior pelvic tilting (degrees) at stance and swing phases in adolescent CP patients and normal age matched subjects.

Variable		CP patients (Study group)	The normal subjects (Control group)	t-Value	P-value
Anterior pelvic tilting (degrees)	Stance	2.47 ± 0.262	2.23 ± 0.346	2.12	0.043
	Swing	2.595 ± 0.396	2.275 ± 0.108	2.484	0.019
Posterior pelvic tilting (degrees)	Stance	1.245 ± 0.822	2.305 ± 0.138	-4.01	0.0001
	Swing	0.49 ± 0.247	2.275 ± 0.135	-21.113	0.0001

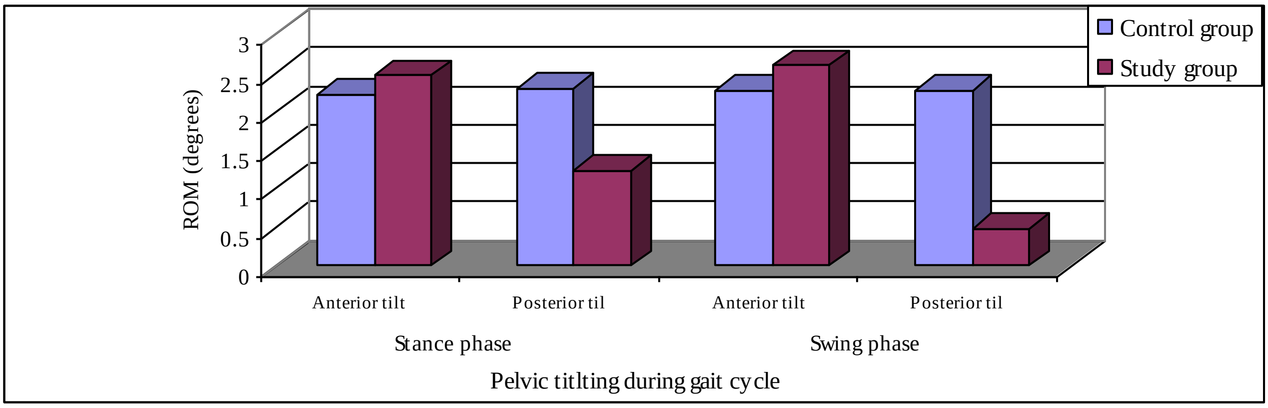

Fig. (2): Changes in the mean values of the peak of anterior and posterior pelvic tilting (degrees) at stance and swing phases in adolescent CP patients (Study group) and normal age matched subjects (Control group).

C- Results of pelvic Rotation:

Concerning the results of ROM of the forward pelvic rotation; there was significant difference between adolescent hemiplegic CP and the normal subjects in the peak of forward pelvic rotation during both stance and swing phases (P=0.0001 for both). The mean values (mean ± SD) of the peak of forward pelvic rotation were (3.245 ± 0.323 degree & 3.25 ± 0.424 degree) in normal subjects and (0.715 ± 0.532 degree & 0.852 ± 0.566 degree) in CP patients for the stance and swing phases respectively.

Regarding the results of ROM of the backward pelvic rotation; there was a significant difference between both groups in the peak of backward pelvic rotation during both stance and swing phases (P=0.0001 for both). The mean values (mean ± SD) of the peak of backward pelvic rotation were (2.845 ± 0.296 degree & 3.07 ± 0.323 degree) in normal subjects and (4.17 ± 0.765 degree & 4.422 ± 0.988 degree) in CP patients for the stance and swing phases respectively. The changes in the mean values of the peak of forward and backward pelvic rotation between both groups are represented in table (3) and illustrated in figure (3).

Table (3): Comparison between the mean values of the peak of forward and backward pelvic rotation (degrees) at stance and swing phases in adolescent CP and normal age matched subjects.

Variable		CP patients (Study group)	The normal subjects (Control group)	t-Value	P-value
Forward pelvic rotation (degrees)	Stance	0.715 ± 0.532	3.245 ± 0.323	-13.735	0.0001
	Swing	0.852 ± 0.566	3.25 ± 0.424	-11.794	0.0001
Backward pelvic rotation (degrees)	Stance	4.17 ± 0.765	2.845 ± 0.296	5.240	0.0001
	Swing	4.422 ± 0.988	3.07 ± 0.323	4.182	0.0001

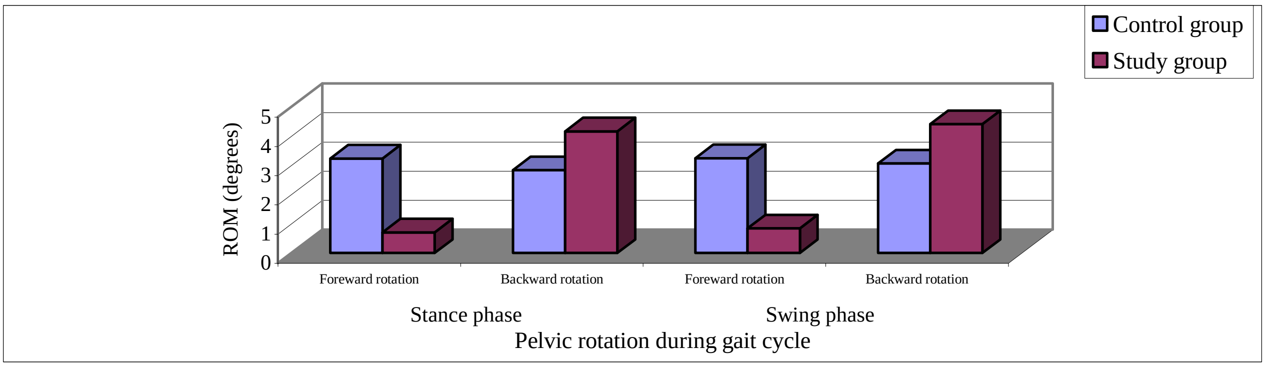

Fig. (3): Changes in the mean values of the peak of forward and backward pelvic rotation (degrees) at stance and swing phases in adolescent CP patients (Study group) and normal age matched subjects (Control group).

DISCUSSION

The aim of this study was to evaluate pelvic motions during gait in adolescent spastic hemiparetic CP (study group) and to compare these with that of age matched normal subjects (control group). The results of this study showed a significant difference in pelvic motions between the adolescent spastic hemiplegic CP and the normal subjects.

Pelvic obliquity:

As regarding to pelvic obliquity, the results of the present study showed significant decrease in downward pelvic obliquity of the affected pelvis in the stance limb and a significant increase in upward pelvic obliquity on the swing limb in the study group when compared with that of the control group. These findings might be justified by the dysfunction of motor control in the affected side such as; lack of awareness in the affected side, spasticity, weakness of the lower limb muscles (specially gluteus medius muscle)[27,28], loss of selective muscle control and release of primitive modes of muscle activation in the form of release of some abnormal reflexes (like positive supporting reaction) and impairment of some normal reflexes (e.g., negative supporting reaction)[11], and poor balance specially single limb balance on the affected side[5,40]. Such disturbance facilitates the upright abilities but disturbs efficient movement patterns. These problems become exaggerated with the increase in the degree of spasticity. As a consequence of these problems, the patient tries to accelerate the swing phase on the non-affected side in an attempt to reduce the stance phase period on the affected side. This comes in agreement with Winstein et al. (1989)[38] who reported that the hemiplegic patient typically demonstrates relatively limited weight transfer to the paretic limb; and stance duration was relatively shorter than for the non-paretic limb. These mechanical and temporal asymmetries were further aggrevated by compensatory changes of the non-paretic limb. This can be performed by making controlled bending of the trunk toward the affected side (during stance phase on the affected side) in an attempt to free the uninvolved leg for swinging forward more rapidly. This is consistent with the findings of Ounpuu (1995)[27].

Both of excessive lateral trunk lean over the affected leg and positive Trendelenburg's sign indicate weak hip abductors of the stance leg (affected limb). The excessive lateral trunk lean over the stance leg (affected side) is used to compensate the weakness of GM muscle (of the affected side) and subsequent pelvic drop on the swing limb. This results in a decrease in the downward pelvic obliquity of the nonaffected side (swing limb) which inturn cause decrease in upward pelvic obliquity of the affected side (stance limb) on the stance limb. This explanation is consistent with the findings of the study of Kuan et al. (1999)[19] who reported that hemiplegic patients showed downward pelvic obliquity in the nonaffected pelvis throughout stance phase on the affected side that causes decrease in the upward pelvic obliquity of the affected side at the same phase. This is followed by marked upward elevation during swing phase (of the affected side).

Additionally, the significant increase in the upward pelvic obliquity in the affected side during swing phase by the affected side might be attributed to the abnormal use of external and internal obliqus muscles of the affected side as hip hikers to allow clearance of the affected foot from the ground. The use of hip hiking in swing phase is a compensatory mechanism to overcome the abnormality of motor control in patients with higher degree of spasticity. These findings are consistent with the conclusion drawn by Kerrigan et al. (2000)[18]. Also, Woolley (2001)[41] reported that hip hiking is a compensatory mechanism to ensure toe clearance during swinging forward.

Pelvic tilting:

Concerning anterior pelvic tilting, the results of the present study showed significant increase in the anterior pelvic tilting in the adolescent CP as compared with normal subjects in both stance and swing phases. Also, the increase in the anterior pelvic tilting was higher in swing phase than in stance phase. These findings might be attributed to two main reasons: (1) pushing of the trunk backward to advance the affected lower limb forward to compansate the weakness of of the hip and knee flexors (during swing phase of the affected side). (2) increased the activity of back muscles that contribute to the increase in the anterior pelvic tilting[34]. These findings are consistent with the results of the study made by Kuan et al. (1999)[19] who reported that hemiplegic patients have sustained anterior tilting of the pelvis through out the gait cycle.

Regarding the posterior pelvic tilting, the results of this study showed a significant decrease in the posterior pelvic tilting during both the stance and swing phases in the study group as compared with the control group. This can be explained by muscle weakness of the muscles that perform posterior pelvic tilting which are the gluteus maximus and the abdominal muscles. This opinion is supported by Wiley and Damiano (1998)[37] who concluded that the strength of the gluteus maximus is particularly reduced in comparison with other lower limb muscles in CP.

Pelvic rotation:

It was noticed that there was a statistical significant increase in the mean values of pelvic backward rotation (pelvic retraction) in adolescent spastic CP compared with normal subjects during both stance and swing phases. This might be attributed to the increase in the activity of abdominal muscles especially external obliqus muscle in the affected side. These findings come in agreement with the findings of Kerrigan et al. (2000)[18] who found increase in pelvic retraction during swing phase.

The results of this study showed that, there is significant increase in backward rotation during both stance and swing phases in the study group when compared with that of the control group. This can be explained as follows; when the non affected side is in stance phase, the CP subject exerts excess effort to start swing phase by the affected limb, this causes increase spasticity in the back muscles which causes retraction of the pelvis (backward pelvic rotation) and decrease in the forward pelvic rotation (protraction). This opinion is supported by Gage (2004)[13] and Brunner et al. (2008) who found that, there is pelvic retraction in CP subjects. Also, O'Sullivan et al. (2007)[26] stated that there was a higher prevalence of retraction among hemiplegic CP.

Regarding the forward rotation, there was a significant decrease of its results in the CP patients that may be attributed to spasticity of the back muscles and weakness of the abdominal muscles. This is supported by the opinion of Ross & Engsberg (2007)[33] who concluded that, spasticity and a lack of muscle strength (weakness) are primary impairments associated with people with cerebral palsy. They considered spasticity as a primary limiting impairment in people with CP.

Also, disturbance in posture and balance may contribute to gait disturbances. This opinion is in agreement with Woollacott and Shumway-Cook (2005)[40] who concluded that disturbance in posture and balance contribute to overall motor dysfunction including gait. This opinion is supported by Rose et al. (2002) who concluded that impairment in standing balance has been suggested to be a major component of gait disorders in cerebral palsy.

The abnormal pattern of muscle activity mainly co-activation of antagonistic leg muscles during the stance phase of a gait cycle and a general reduction in amplitude of EMG activity may contribute to gait disturbances[20,40]. The older children with cerebral palsy showed disorganized muscle responses and increased frequency of coactivation of both proximal–distal and agonist–antagonist muscles[39].

These abnormalities in ROM of the pelvis in CP may be attributed to spasticity that affects the muscle function. This comes in agreement with the opinion of Walton (2003)[36] and Ross & Engsberg (2007)[33] who concluded that spasticity is one of the main symptoms of disturbed muscle function and lead to gait deviations. Other factors that may affect gait in CP include muscle weakness and diminished selective motor control[21,33]. Also, Crenna (1998)[8] concluded that, the pathophysiological profile of what is clinically defined as 'spastic' gait in CP children did not only consist of dynamic spasticity, most often it resulted from the simultaneous contribution of other factors, including paresis, co-contraction, immature and non-neural components.

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الملخص العربي

التحليل ثلاثى الأبعاد لحركة الحوض أثناء المشى لدى المراهقين المصابين بالفالج الشقى

أجريت هذه الدراسة لتقييم حركات الحوض أثناء المشي في المرضى المراهقين المصابين بالفالج الشقى الناتج من الشلل الدماغى ومقارنة تلك النتائج بنتائج أشخاص طبيعيين مناظرين لهم في نفس السن . شارك في هذه الدراسة أربعون من المرضى المراهقين المصابين بالفالج الشقى الناتج من الشلل الدماغى، تراوحت اعمارهم من 15 الى 18 عاما ، وعشرون من الأشخاص الطبيعيين. وقد تم تقييم حركات الحوض في كافة الاتجاهات (دوران الحوض والميل والانحراف) أثناء المشي لكل أفراد العينة باستخدام نظام تحليل الحركة الالكتروني البصري. وقد أسفرت نتائج هذه الدراسة عن وجود قصور ذو دلالة إحصائية في الدوران الأمامي والميل الخلفي للحوض بالإضافة إلى عدم تساوي انحراف الحوض في هؤلاء المرضى مقارنة مع الاشخاص الطبيعيين. ويمكن أن نخلص إلى أن المرضى المراهقين المصابين بالفالج الشقى الناتج من الشلل الدماغى يعانون من اضطراب بحركة الحوض أثناء المشى وبناءً على هذا فإن تقييم حركات الحوض أثناء المشي يجب أن يؤخذ في الاعتبار أثناء تأهيل هؤلاء المرضى .

الكلمات الدالة : الشلل الدماغي - الفالج الشقى – الحوض- المشى - التحليل الالكتروني البصري