Opto-Electronic Analysis of Pelvic Motion in Stroke Patients During Gait

Hussein A. Shaker, Ph.D., Magdy A. Arafa, Ph.D. and Nevein M.M.Gharib, Ph.D.
Department of Neuromuscular Disorders and its Surgery, Faculty of Physical Therapy, Cairo University.

ABSTRACT

This study was designed to evaluate the abnormalities of pelvic motions during gait in stroke patients compared with that of age matched normal subjects. Thirty stroke patients and ten normal subjects participated in this study. The patients were assigned into two equal groups according to the degree of spasticity of the affected lower limbs (mildly spastic G1 and moderately spastic G2). All subjects were assessed for all components of pelvic motions during gait (including pelvic rotation, tilting and obliquity) by the use of Opto-Electronic Motion Analysis System. The results of this study showed significant decrease in pelvic forward rotation and posterior tilting, as well as unequal obliquity of the pelvis in stroke patients when compared with the normal subjects; with more marked affection in the moderately spastic stroke patients. Therefore, assessment of pelvic motions during gait should be considered in rehabilitation of stroke patients.
Key words: *Stroke – Pelvis – Opto-Electronic – Gait Analysis.*

INTRODUCTION

Stroke is one of the most common neurological disorders that represents a major cause of disability[1]. It is considered as a significant health problem that needs an extensive and continuous rehabilitation[2]. Clinically after stroke, a number of deficits are possible, including impairments of motor, sensory, and perceptual functions. Motor deficits are seen as weakness (hemiparesis) or paralysis (hemiplegia) of one side of the body opposite to the site of the lesion in the brain[3]; both proximal and distal movements are usually impaired[4].

The control of the pelvic motion is vital in maintaining whole body balance in different planes as human trunk including the spine and pelvis acts as a dynamic and stable core from which the upper and lower limbs move[5].

It is not surprising that deformities of the pelvis secondary to stroke have a significant influence on gait patterns. Normally, a dynamic pelvis will respond quickly to changes in postures during all mobility, but poor alignment of the pelvis is causing 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[6].

Before suggesting the suitable plan of treatment and the definitive physical therapy program to improve the gait pattern for stroke patients, it is important to evaluate the proximal malalignment that may cause deviations in the lower extremities. Correction of the distal deviations without consideration of the proximal biomechanical and structural deformities may ultimately create joint pain and limb instability[7].

Stroke patients commonly lose their ability to perform postural adjustments and to maintain postural alignment because of spasticity, weakness, loss of equilibrium and righting reactions. The trunk often assumes an asymmetrical posture. The patient's pelvis and its effect on spinal alignment is considered an important area that should be observed. Patients typically have pelvic obliquity characterized by unequal weight bearing through the ischial tuberosity, which results in lateral spinal flexion[8]. This lateral flexion causes the trunk musculature to become shortened on the non-weight-bearing side and lengthened on the weight-bearing side[9]. On the same time, patients tend to assume a posterior pelvic tilt, which results in spinal flexion and subsequent muscular imbalance[10]. Also, the patient tends to have backward rotation of the pelvis in the horizontal plane (unilateral pelvic retraction)[11].

Although, there are many evaluation techniques available for assessing motor impairment following stroke, little attention has been given to pelvic motion during walking. Also, none of these techniques is sufficient to explain the underlying causes of pelvic instability in such cases[12]. Therefore, it is important to evaluate the abnormalities of pelvic motions during gait after stroke.

SUBJECTS AND METHODS

Thirty stroke patients of both sexes (five females and 25 males) participated in this study. They were selected from the outpatient's clinic of the Faculty of Physical Therapy, Cairo University. The patients were assigned into two equal groups (G1 and G2), according to the degree of spasticity in the affected lower limb. In addition, ten normal age matched subjects (eight males and two females) were selected as a control group (G3).

Age of the subjects ranged from 40 – 66 years, while duration of illness of the patients' groups was from 12 to 18 months. Regarding the patients in G1, seven patients from the fifteen were right sided hemiplegia and the other eight patients were left sided. Two patients were hemorrhagic and 13 patients were thrombotic infarction. Concerning G2, five patients were right sided hemiplegia and the other ten patients were left sided. Five patients were hemorrhagic and 10 patients were thrombotic infarction. All patients were medically stable and had the ability to walk independently for at least 10 meters. None of them suffered from hearing, visual, cognitive impairment or any other neurological disorder. They were able to follow the instructions and had no deep sensory loss.

Procedures

Instrumentations:

Qualisys Motion Capture System was used to measure the angles of the pelvic motion during gait (including pelvic rotation, tilting and obliquity) for all subjects. The system consisted of six ProReflex infrared high speed cameras to perform multi camera measurements and have a capture capability of 120 frames/second. The basic principle of the system was to expose reflective markers to infrared light and to detect the light reflected by the markers. The 2-dimentional (2-D) image of the markers was processed and the 2-D data from the six cameras were combined for calculating the 3-D positions of the markers.

The software programs used to capture the walking subject were Q Gait and Q trac (provided by Qualisys company). Body segment positions were detected using 18 passive reflective markers placed on specific sites on the body. They are small balls that are silver in color and of 8cm^2 surface area. Each marker is capable of reflecting the infrared light sent from the ProReflex Cameras. All markers were placed on all subjects by one individual for placement consistency (according to Rash et al., 1999[13]). These markers were stabilized to the skin by double face adhesive sticker. The position of cameras and their spatial orientation remain unchanged during the study. The markers were placed bilaterally on: superior surfaces of acromion, anterior superior iliac spines, superior edges of the patellae, lateral aspect of the knee joints, tibial tuberosities, lateral malleoli, over both feet between the bases of the 2nd and 3rd metatarsal bones, and over heels (posterior of calcaneus, at the same horizontal plane as the toe markers). Additionally, unilateral application of the markers were put on the spinous process of the 12th thoracic vertebra and the sacrum.

Methodology:

The camera system was calibrated, before any 3D capture was performed, 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. Calibration was set at a volume of 6x2x2 meters for all subjects. The position of cameras and their spatial orientation remain unchanged during the study. Any relocation of the cameras required re-calibration (according to Hsiang et al., 1998[14]). Each subjects was instructed to walk on the walkway bare feet and at what he/she regarded to be a natural or comfortable walking speed (self-selected speed) (according to Lamontagne et al., 2000[15]). Several walks (four times) along the walkway were allowed prior to recording of data, so that acclimatization to the walkway and the recording system could occur. The data were collected from three walking trials and average was taken. Data were analyzed by using Q Gait and Q trac programs which were developed for analyzing the motion pattern of human gait as retrieved by the ProReflex camera system . 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 anterior & posterior pelvic tilting, pelvic obliquity on both sides, and forward & backward pelvic rotation). Also, the maximum angle of pelvic motion can be detected. Statistical package (SPSS) was used to analyze the data (ANOVA test).

RESULTS

Pelvic ROM data during both stance & swing phases of gait (including pelvic tilt, pelvic obliquity and pelvic rotation) were obtained from both normal subjects and stroke patients.

A- Results of pelvic obliquity

In this study, there was a statistical significant difference of the mean values of the peak of upward pelvic tilt among G1, G2 and G3 ($P<0.01$ for both the stance and swing phases). At stance phase, the highest mean values (mean ± SD) of the peak of upward pelvic tilt (degree) were found in G3 (5.62 ± 0.49 degree), and markedly decreased in G1 (2.19 ± 0.2 degree) & in G2 (1.27 ± 0.27 degree). For the swing phase, the mean values (mean ± SD) of the peak of upward pelvic tilt were markedly increased in G2 (6.93 ± 1.03 degree) as compared to G1 (5.44 ± 0.77 degree) and G3 (2.45 ± 0.66 degree).

As regarding to the downward pelvic tilt, there was a statistical significant difference of the mean values of the peak of downward pelvic tilt among G1, G2 and G3 ($P<0.01$ for both the stance and swing phases). The mean values (mean ± SD) of the peak of downward pelvic tilt were (1.42 ± 0.24 degree & 1.12 ± 0.21 degree) for G2, increased in G1 (2.29 ± 0.26 degree & 2.17 ± 0.21 degree), and markedly increased in G3 (4.6 ± 0.93 degree & 5.66 ± 0.46 degree) for stance and swing phases respectively. The changes in the mean values of the peak of upward and downward pelvic tilt among G1 & G2 and G3 are represented in table (1) and illustrated in Fig. (1).

Table (1): Comparison among G1, G2 and G3 mean values of the peak of upward and downward pelvic tilt (degree) at stance and swing phases of gait.

Variable		G1	G2	G3	F-Value	P-value
		Mean ± SD	Mean ± SD	Mean ± SD		
Upward pelvic tilt (degree)	Stance	2.19 ± 0.2	1.27 ± 0.27	5.62 ± 0.49	559.82	0.0001
	Swing	5.44 ± 0.77	6.93 ± 1.03	2.45 ± 0.66	82.06	0.0001
Downward pelvic tilt (degree)	Stance	2.29 ± 0.26	1.42 ± 0.24	4.6 ± 0.93	112.22	0.0001
	Swing	2.17 ± 0.21	1.12 ± 0.21	5.66 ± 0.46	296.29	0.0001

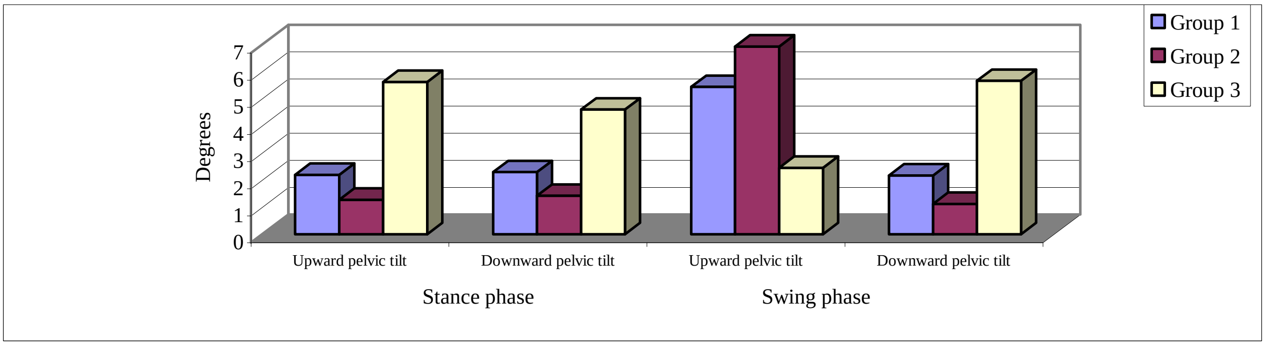

Fig. (1): Changes in the mean values of the peak of upward and downward pelvic tilt (degree) at stance and swing phases of gait for G1, G2 and G3.

B- Results of pelvic tilting data

The peak of anterior pelvic tilting was statistically high in moderately spastic group (G2) as compared to G1 and G3 during both stance and swing phases of gait (P<0.01 for both). As regarding to the peak of posterior pelvic tilting, it was statistically low in G2 as compared to G1 and G3 during both stance and swing phases of gait (P<0.01 for both).

In this study, there was a statistical significant difference of the mean values of the peak of anterior pelvic tilt (degree) among G1, G2 and G3. The mean values (mean ± SD) of the peak of anterior pelvic tilt were (3.55 ±0.25 degree & 3.8±0.29degree) in G2 and decreased in G1 (2.79± 0.17degree & 3.05±0.25 degree) & in G3 (2.77±0.12 degree & 2.77±0.11degree) for the stance and swing phases respectively.

As regarding to posterior pelvic tilt, there was also a statistical significant difference of the mean values of the peak of posterior pelvic tilt among G1, G2 and G3 during both stance and swing phases (P<0.01 for both). The mean values (mean ± SD) of the peak of posterior pelvic tilt were low in G2 (0.54±0.17 degree & 0.43±0.17 degree), and increased in G1 (2.52±0.15 degree & 1.23±0.15 degree) & in G3 (2.73±0.12 degree & 2.74±0.14 degree) for the stance and swing phases respectively. The changes in the mean values of the peak of anterior and posterior pelvic tilt among G1 & G2 and G3 are represented in table (2) and illustrated in Fig. (2).

Table (2): Comparison among G1, G2 and G3 mean values of the peak of pelvic tilting (degree) during stance and swing phases of gait.

Variable		G1	G2	G3	F-value	P-value
		Mean ± SD	Mean ± SD	Mean ± SD		
Anterior pelvic tilt	Stance	2.79± 0.17	3.55 ±0.25	2.77±0.12	73.03	0.0001
	Swing	3.05±0.25	3.8±0.29	2.77±0.11	61.64	0.0001
Posterior pelvic tilt	Stance	2.52±0.15	0.54±0.17	2.73±0.12	847.56	0.0001
	Swing	1.23±0.15	0.43±0.17	2.74±0.14	666.21	0.0001

G1: Mild spasticity stroke patients. G2: Moderate spasticity stroke patients. G3: Normal adult subjects.

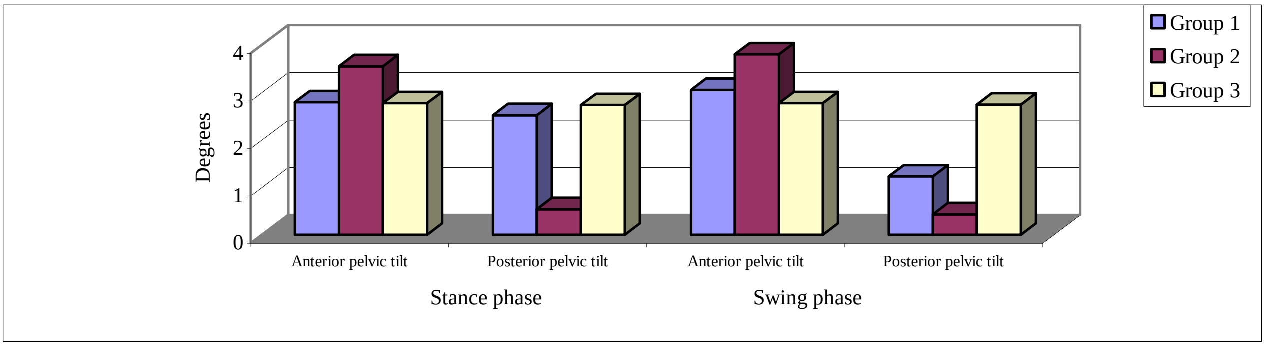

Fig. (2): Changes in the mean values of the peak of anterior and posterior pelvic tilt (degree) at stance and swing phases of gait for G1, G2 and G3.

C- Results of pelvic rotation

In this study, there was a statistical significant difference of the mean values of the peak of forward pelvic rotation among G1, G2 and G3 (P<0.01) for both stance and swing phases. The mean values (mean ± SD) of the peak of forward pelvic rotation were (3.75 ± 0.38 degree & 3.73 ± 0.44 degree) for G3, decreased in G1 (1.7 ± 0.46 degree & 1.87 ± 0.52 degree) and markedly decreased in G2 (0.36 ± 0.19 degree & 0.55 ± 0.32 degree) for the stance and swing phases respectively. As regarding the backward pelvic rotation, there was a statistical significant difference of the mean values of the peak of backward pelvic rotation among G1, G2 and G3 (P<0.01 for both stance and swing phases). The mean values (mean ± SD) of the peak of backward pelvic rotation were (3.35 ± 0.3 degree & 3.6 ± 0.36 degree) in G3, increased in G1 (4.58 ± 0.46 degree & 4.73 ± 0.82 degree) and markedly increased in G2 (6.03 ± 1.38 degree & 6.48 ± 1.23 degree) for the stance and swing phases respectively. The changes in the mean values of the peak of forward and backward pelvic rotation among G1 & G2 and G3 are represented in table (3) and illustrated in Fig. (3).

Table (3): Comparison between G1, G2 and G3 mean values of the peak of forward and backward pelvic rotation (degree) at stance and swing phases of gait.

Variable		G1	G2	G3	F Value	P-value
		Mean ± SD	Mean ± SD	Mean ± SD		
Forward pelvic rotation (degree)	Stance	1.7 ± 0.46	0.36 ± 0.19	3.75 ± 0.38	283.62	0.0001
	Swing	1.87 ± 0.52	0.55 ± 0.32	3.73 ± 0.44	162.08	0.0001
Backward pelvic rotation (degree)	Stance	4.58 ± 0.46	6.03 ± 1.38	3.35 ± 0.3	26.84	0.0001
	Swing	4.73 ± 0.82	6.48 ± 1.23	3.6 ± 0.36	30.74	0.0001

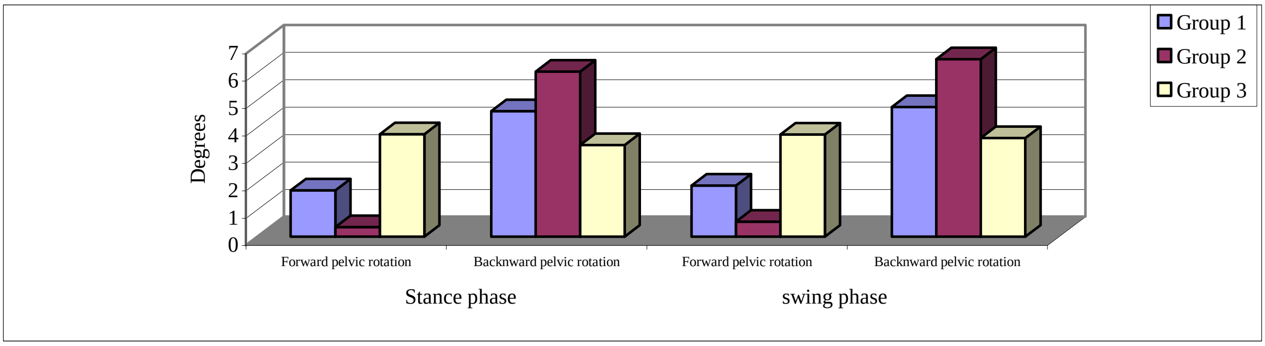

Fig. (3): Changes in the mean values of the peak of forward and backward pelvic rotation (degree) at stance and swing phases of gait for G1, G2 and G3.

DISCUSSION

The present study was conducted to assess pelvic motions during gait in stroke patients and to compare them with normal; age matched; control group.

As regarding to pelvic obliquity, the results of the present study showed significant increase in downward depression of the affected pelvis on the stance limb, additionally, there was a significant increase in upward pelvic tilting on the swing limb. 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 muscles in the lower limb (specially GM muscle)[10,16], 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)[17], and poor single limb balance of the affected side[18]. Such disturbance facilitates the upright abilities but disturbs efficient movement patterns. These problems becomes exaggerated with the increase in the degree of spasticity (as in G2). 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 of the affected side. This comes in agreement with Winstein et al. (1989)[19] 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 in an attempt to free the uninvolved leg for swinging forward more rapidly. This is consistent with the findings of Ounpuu (1995)[16].

Both of excessive lateral trunk lean over the affected leg and positive Trendelenburg's sign indicate weak hip abductors of the stance leg. It is worth mentioning that excessive lateral trunk lean over the stance leg (affected side) is used to compensate the weakness of GM muscle and subsequent pelvic drop on the swing limb. This results in an increase in the downward depression of the affected pelvis on the stance limb. This explanation is consistent with the findings of the study of Kuan et al. (1999)[20] who reported that stroke patients (either with or without a cane) showed downward depression in the affected pelvis throughout stance, followed by marked upward elevation during swing phase.

Additionally, the significant increase in the upward pelvic tilting in the affected side might be attributed to the abnormal use of external and internal obliqus muscles in the affected side as hip hikers (pelvic elevators) in moderately spastic stroke patients (G2) 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)[21]. Also, Wooley (2001)[12] reported that hip hiking (pelvic elevation) is a compensatory mechanism to ensure toe clearance during swinging forward.

Regarding pelvic rotation: It was noticed that there was a statistical significant increase in the mean values of pelvic backward rotation (pelvic retraction) in both G1 and G2 compared with normal subjects in both stance and swing phases. Also, it was noticed that the degree of pelvic retraction of the affected side is increased in moderately spastic patients (G2) compared to mildly spastic stroke patients (G1), and it is increased in swing phase as compared to the stance phase in the same group of patients especially in G2. This might be attributed to the increase in the activity of abdominal muscles especially external obliqus muscle in the affected side[22]. These findings come in agreement with the findings of Kerrigan et al. (2000)[21] who studied pelvic and hip motions (during swing phase) in 23 hemiparetic subjects. They found that the mean values of pelvic retraction (in the affected side) during swing phase was 7.6° (SD 8.1). In the present study, the mean values of pelvic retraction (in the affected side) during swing phase was 6.59° (SD 1.27) in moderately spastic stroke patients. The difference in the degree of pelvic retraction between the present study and there's may be attributed to individual variation among the patients in the two studies in numerous parameters such as joint ranges of motion, muscle strength, degree of spasticity, and different gait habits.

As regarding to pelvic tilt: the results of the present study showed significant increase in the anterior pelvic tilting in G2 as compared to G1 and G3 in both stance and swing phases. Also, the increase in the anterior pelvic tilting was higher in swing 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 (Simoneau, 2002)[23]. These findings are consistent with the results of the study made by Kuan et al. (1999)[20] who reported that stroke patients have sustained anterior tilting of the pelvis through out the gait cycle.

REFERENCES

1- Dally, J.J. and Ruff, R.L.: Electrically induced recovery of gait components for older patients with chronic stroke. Am J Phys Med Rehabil., 79: 349-360, 2000.

2- Mandel, A.R., Nymark, J.R., Balmer, S.J., Grinnell, D.M., O'Riain, M.D.: Electromyographic versus rhythmic positional biofeedback in computerized gait retraining with stroke patients. Arch Phys Med Rehabil., 71: 649-654, 1990.

3- O'Sullivan, S.B. and Schmitz, T.J.: Physical rehabilitation: assessment and treatment. Philadelphia: FA Davis Company, 111-124, 225-250, 327-351, 1994.

4- Dickstein, R. and Abulaffio, N.: Postural sway of the affected and nonaffected pelvis and leg in stance of hemiparetic patients. Arch Phys Ther Rehabil., 81: 364-674, 2000.
5- Hamilton, N. and Luttgens, K.: Kinesiology: scientific bases of human motion. 10th ed. Boston: Mc Graw Hill, 158-180, 470-494, 2002.
6- Hanna, D. and Harvey, R.L.: Review of preorthotic biomechanical considerations. Top Stroke Rehabil 7: 29-37, 2001.
7- Mauritz, K.H.: Gait training in hemiplegia. Eur J Neurol 5: 9 Suppl. 1: 23-29, 2002.
8- Carr, J.H. and Shepherd, R.B.: A Motor relearning programme for stroke. 2nd ed. Oxford: Butterworth-Heinemann, 112-150, 1987.
9- Gillen, G.: Trunk control: a prerequisite for functional independence. In: stroke rehabilitation a function based approach (Gillen G, Burkhardt A, edrs). St. Louis: Mosby, 69-89, 1998.
10- Perry, J.: Gait analysis: normal and pathological function. Thorofare, NJ: Slack, Inc., 185-220, 1992.
11- Fish, D.J. and Kosta, C.S.: Walking impediments and gait inefficiencies in the CVA patients. J Prosthetics and Orthotics, 11: 33-37, 1999.
12- Woolley, S.M.: Characteristics of gait in hemiplegia. Topics in Stroke Rehabil., 7(4): 1-18, 2001.
13- Rash, G.S., Belliapppa, P.P., Wachowiak, M.P., Somia, N.N. and Gupta, A.: Ademonstration of the validity of a 3-D video motion analysis method for measuring finger flexion and extension. J Biomech., 32: 1337-1341, 1999.
14- Hsiang, S.M., Brgmus, G.E., Martin, S.E. and Bezvfrkhny, L.B.: Video based lifting technique coding system. Ergonomics, 41: 239-256, 1998.
15- Lamontagne, A., Richards, C.L. and Malouin, F.: Coactivation during gait as an adaptive behavior after stroke. J Electromyogr Kinesiol, 10: 407-415, 2000.
16- Ounpuu, S.: Clinical gait analysis. In: Evaluation and management of gait disorders (Spivack BS, eds). New York: Marcel Dekker, 1995.
17- Fish, D.J.: Characteristic gait patterns in neuromuscular pathologies. J Prosthet Orthot., 9: 163-167, 1997.
18- Brandstater, M.E., De bruin, H., Gowland, C. and Dark, B.M.: Hemiplegic gait: analysis of temporal variables. Arch Phys Med Rehabil., 64: 583-587, 1983.
19- Winstein, C.J., Gardner, E.R., McNeak, D.R., Barto, P.S. and Nicholson, D.E.: Standing balance training: effect on balance and locomotion in hemiparetic adults. Arch Phys Med Rehabil., 70: 755-762, 1989.
20- Kuan, T.S., Tsou, J.Y. and Su, F.C.: Hemiplegic gait of stroke patients: the effect of using a cane. Arch Phys Med Rehabil., 80: 777-784, 1999.
21- Kerrigan, D.C., Frates, E.P., Rogan, S. and Riley, P.O.: Hip hiking and circumduction gait: quantitative definitions. Am J Phys Med Rehabil., 79: 247-252, 2000.
22- Morris, J.D.: Instructional Course Lectures in: Biomedical Engineering: Human Locomotion. Lecture and supplementary notes on: pelvis and perineum. The Catholic University Of America, 2003.
23- Simoneau, G.G.: Kinesiology of walking. In: Kinesiology of the musculoskeletal system: foundations for physical rehabilitation (Neumann DA, edr). St. Louis: Mosby, 523-569, 2002.

الملخص العربي

التحليل الالكتروني البصري لحركة الحوض في مرضى السكتة الدماغية أثناء المشي

صممت هذه الدراسة لتقييم حركات الحوض أثناء المشي في مرضى السكتة الدماغية مقارنة بأشخاص طبيعيين مناظرين لهم في نفس السن . شارك في هذه الدراسة ثلاثون مريضاً من مرضى السكتة الدماغية وعشرة من الأشخاص الطبيعيين ، وقد قسم المرضى إلى مجموعتين على حسب درجة التوتر في عضلات الطرف السفلي المصاب (مجموعة ذات توتر عضلي بسيط ج 1 ، مجموعة ذات توتر عضلي متوسط ج2) ، 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 مرضى السكتة الدماغية مقارنة مع الاشخاص الطبيعيين مع التأثر الواضح في المرضى ذوي التوتر العضلي المتوسط . وبناءً على هذا فإن تقييم حركات الحوض أثناء المشي يجب أن يؤخذ في الاعتبار أثناء تأهيل مرضى السكتة الدماغية .