Optoelectronic Analysis of Knee Motions During Gait in Stroke Patients

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ABSTRACT

The purpose of this study was to evaluate EMG activities of quadriceps and hamistring muscles and the knee joint motions of both affected and non-affected sides in stroke patients during gait. Thirty stroke patients participated in this study. Their ages ranged from 47 to 61 years old with a mean of 52.8 ± 3.84. They were complaining from stroke from three to 13 months with a mean of 8.2 ± 2.83. All patients were assessed for range of motion of both knees by the use of Optoelectronic motion analysis system and EMG activities of quadriceps and hamistring muscles of both sides during gait by the use of kinesiological EMG. The results of this study showed a statistically significant difference in the mean peak values of knee flexion between both sides during stance and swing phases and a highly statistically significant difference in the mean values of the least degree of the knee flexion between both sides during stance with a non significant difference during swing phase. Concerning the EMG activity of quadriceps muscles, there was a statistically significant difference between both sides during stance with a non significant difference between them during swing phase. There was a highly statistically significant difference the EMG activity of hamistrings muscles between both sides during stance and swing phases. Therefore, assessment of the knee joint motion synchronized with EMG during gait should be considered in the rehabilitation and prognosis of stroke patients.

Key words: *Stroke – Knee – Opto-Electronic EMG – Gait Analysis.*

INTRODUCTION

Stroke is one of the most common neurological disorders that represents a major cause of disability (Dally and Ruff, 2000). It is a significant health problem that needs an extensive and continuous rehabilitation (Mandel et al, 1990). Stroke can be defined clinically as; a number of deficits are possible after stroke, including impairments of motor, sensory and perceptual functions. Motor deficits are characterized by paralysis (hemiplegia) or weakness (hemiparesis) of the side of the body opposite to the site of the lesion (O'sullivan and Schmitz, 1994); both proximal and distal movements are usually impaired (Dickstein and Abulaffio, 2000).

The kinematic pattern of the knee is a little more complex than that of the hip. Normal function of the knee during gait on a level surface requires range of motion (ROM) from nearly full extension to approximately 60° of flexion. At heel contact, the knee is flexed approximately 5° and it continues to flex an additional 10 to 15° during the initial 15% of gait cycle (GC) through eccentric contraction of the quadriceps. Following initial flexion, the knee extends to nearly full extension until about heel-off (40% of GC). At this point the knee starts flexion, reaching approximately 35° of flexion by the time of toe-off (60% of GC) (Oatis, 2004).

Knee mobility and stability are major factors in the normal pattern of walking. During stance phase the knee is the basic determinant of limb stability. In swing phase, knee flexibility is the primary factor in the limb's freedom to advance. The number of two joint muscles involved in knee control also indicates close functional coordination with the hip and ankle joints (Oatis, 2004).

There is more than one muscle applying force at the knee joint, producing a dynamically indeterminate system. The quadriceps muscles show a high activity during the transition from the swing phase to the stance phase (Kerrigan et al, 2001). The quadriceps starts its activity in terminal swing in preparation for heel contact. The major burst of activity, occurs shortly after heel contact. At this time, it acts eccentrically to control the knee flexion that takes place in the first 10% of GC. The quadriceps then act concentrically to extend the knee and support the weight of the body during midstance (Neumann, 2002).

Also, these muscles begin in terminal swing (90% of GC). Muscle intensity rapidly increases to a peak of 25% of manual muscle testing (MMT) early in loading response. This level of effort is maintained throughout the remainder of the loading response period. The discharge of the VM starts before the heel strike and lasts until the first double-leg support period (Kameyama et al., 1990).

Hamstrings act eccentrically for decelerating the motion of the leg in swing and to facilitate forward momentum greater than that which is provided by the plantarflexors of the limb in the stance phase later on (Kerrigan et al, 2001). The hamstrings muscles are most active from a period just before to just after heel contact to decelerate knee extension in preparation for the placement of the foot on the ground and to assist with hip extension and to provide stability to the knee through co-activation during the initial 10% of the stance phase. The short head of the biceps femoris may also assist with knee flexion during the swing phase. Most of the knee flexion, during preswing and the swing phase of gait results from passive intersegmental dynamics of the limb and a small gastrocnemieus activation (Kerrigan et al., 1991).

Regarding knee joint in stroke patients during gait, three different types of knee patterns during stance have been reported. Some patients have been found to exhibit increased knee flexion during the stance phase, particularly at initial contact. Other patients have been observed to exhibit reduced knee flexion during loading response followed by knee hyperextension in late stance and delayed movement into knee flexion in preparation for swing. The third group of patients exhibited excessive knee hyperextension through out most of the stance phase (Woolley, 2001). Also, it was reported that there is lack of knee flexion which is required for smooth progression of the leg during swing phase (Sawner and LaVigne, 1992).

Analysis of the electromyographic (EMG) data recorded during gait of stroke patients is a useful task to assess, because ambulation is the output of a complex neural system of lower extremity motor control. Analysis of the motor control system for gait includes measuring the timing, sequencing and variability of patterns of muscle activation in different patients and in different phases of gait cycle (Perry, 1999). Before prescribing physical therapy program to improve the gait pattern for stroke patients, it is important to evaluate deviations in the lower extremities (Mauritz, 2002).

SUBJECTS AND METHODS

Subjects

Thirty stroke patients of both sexes (five females and 25 males) participated in this study. They were selected from the outpatient clinic of the Faculty of Physical Therapy, Cairo University. All subjects were assessed for range of motion (ROM) of both knees by the use of Opto-Electronic Motion Analysis System and the electromyographic activities of quadriceps and hamistring muscles by the use of Biopac, TEL100-C, MP system (dynamic electromyography) of both affected and non-affected sides during gait. The patient's ages ranged from 47 – 61 years with a mean of 52.8 years and SD of 3.84. Their duration of illness ranged three to thirteen months with a mean of 8.2 months and SD of 2.83. Fourteen patients were right sided hemiplegia and the other sixteen were left sided. The cause was hemorrhagic in seven patients and thrombotic infarction in 23 patients. All patients were medically stable and had the ability to walk independently for at least 10 meters three times. None of them suffered from hearing, visual, cognitive impairments or any other neurological disorders that may affect gait. They were able to follow the instructions and had no deep sensory loss.

Procedures

Instrumentations:

The following devices were used in this study:

1) Qualisys Motion Capture System was used to measure the angles of both knees during gait for all subjects. The system consisted of six ProReflex infrared high speed cameras with a capture capability of 120 frame/sec. The software programs used to capture the walking subject were Q Gait and Q trac. Body segment positions were detected by using 18 passive reflective markers placed on specific sites on the body and stabilized to the skin by double face adhesive sticker. All markers were placed by one individual for placement consistency.

2) Dynamic EMG unit (kinesiological EMG): Biopac, TEL100-C, MP system was used to assess muscular activities through measuring root mean square (RMS) of quadriceps and hamstrings muscles.

3) Disposable surface EMG electrodes: Bipolar silver/silver chloride (Ag-AgCl) disposable surface electrodes were used to record the EMG activity from the specified muscles. The electrodes were self-adhesive.

Methodology

Before 3-D capture was performed, the camera system was calibrated 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 electrodes were placed as follows; quadriceps: approximately four cm superior to and three cm medial to the superomedial patella border and orientated 55° to the vertical (Cowan et al, 2002). Hamstrings muscles: midway between ischial tuberosity and the popliteal space (Vander Linden et al, 1994). The EMG data collection was synchronized with Qualisys Motion Capture System so that when the Qualisys Motion Capture System works, the EMG apparatus works at the same time.

Subjects were instructed to walk on the walkway inside the lab at their natural or comfortable walking speed (self-selected speed) (Lamontagne et al., 2001). Three to five walks along the walkway were allowed prior to recording of data, so that subjects were familiar to the walkway. All subjects took several steps before recording site to ensure that the available cadence for them had been reached prior to data being recorded. The recording was three times and the average was taken. The EMG activities of the selected muscles were assessed; simultaneously during ROM assessment. Measurements were taken for three consecutive strides for each time and then averaged. 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 knee angles during the gait cycle.

RESULTS

The results of this study showed the following:

<u>1) Regarding the knee joint ROM:</u>

A) The knee joint flexion:

The results of this study showed the peak of knee joint flexion of the non-affected side is statistically significantly higher than that of the affected side during stance phase and during swing phase (P= 0.01 and 0.009 during stance and swing phases respectively). Comparison between mean peak values of knee joint flexion of both affected and non-affected sides (degrees) at stance and swing phases is represented in table (1) and figure (1).

Table (1): Comparison between mean peak values of knee joint flexion of both affected and nonaffected sides (degrees) at stance and swing phases.

Variable			Affected	Non affected	t	P
ROM of knee flexion	Stance	Mean	20.56	25.33	-2.68	0.01
		SD	8.7	4.36		
	Swing	Mean	38.96	45.8	-2.70	0.009
		SD	12.69	5.48		

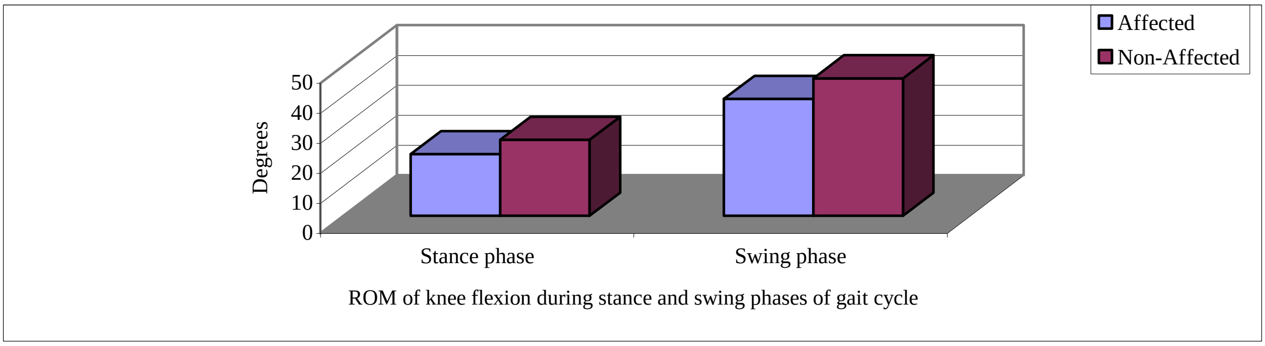

Fig. (1): Comparison between mean peak values of knee joint flexion of both affected and non-affected sides (degrees) at stance and swing phases.

B) The knee joint extension:

The results of this study showed the peak of knee joint extension of the affected side is statistically significantly higher than that of the non-affected side during stance phase and non-significantly higher during swing phase (P= 0.0001 and 0.41 during stance and swing phases respectively). Comparison between mean peak values of knee joint extension of both affected and non-affected sides (degrees) at stance and swing phases is represented in table (2) and figure (2).

Table (2): Comparison between mean peak values of knee joint extension of both affected and non-affected sides (degrees) at stance and swing phases.

Variable			Affected	Non affected	t	P
ROM of knee extension	Stance	Mean	4.4	1.033	6.95	0.0001
		SD	2.49	0.88		
	Swing	Mean	4.36	4.0	0.81	0.41
		SD	1.97	1.46		

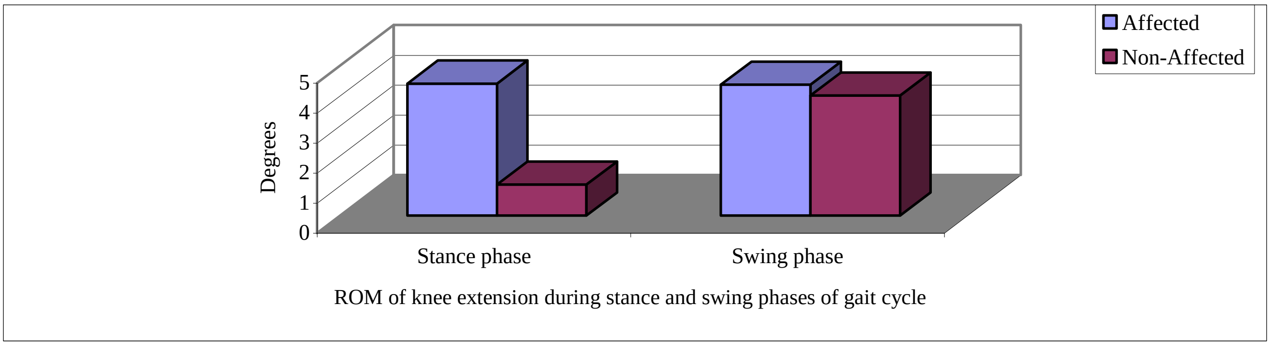

Fig. (2): Comparison between mean peak values of knee joint extension of both affected and non-affected sides (degrees) at stance and swing phases.

2) Regarding the electromyographic (EMG) activities (RMS):

A) EMG (RMS) of quadriceps muscles during stance and swing phase:

The results of this study showed that there is a statistically significant difference in the EMG activity (RMS) of quadriceps muscles between the affected and non-affected sides during stance phase and non-significant difference between them during swing phase (P= 0.02 and 0.14 during stance and swing phases respectively). Comparison between the mean values of the EMG activity (RMS) of quadriceps muscles of both affected and non-affected sides during stance and swing phases is represented in table (3) and figure (3).

Table (3): Comparison between the mean values of the EMG activity (RMS) of quadriceps muscles of both affected and non-affected sides (volts) during stance and swing phases.

Variable			Affected	Non affected	t	P
RMS of quadriceps	Stance	Mean	0.70	0.740	-2.24	0.02
		SD	0.06	0.06		
	Swing	Mean	0.509	0.49	1.48	0.14
		SD	0.04	0.04		

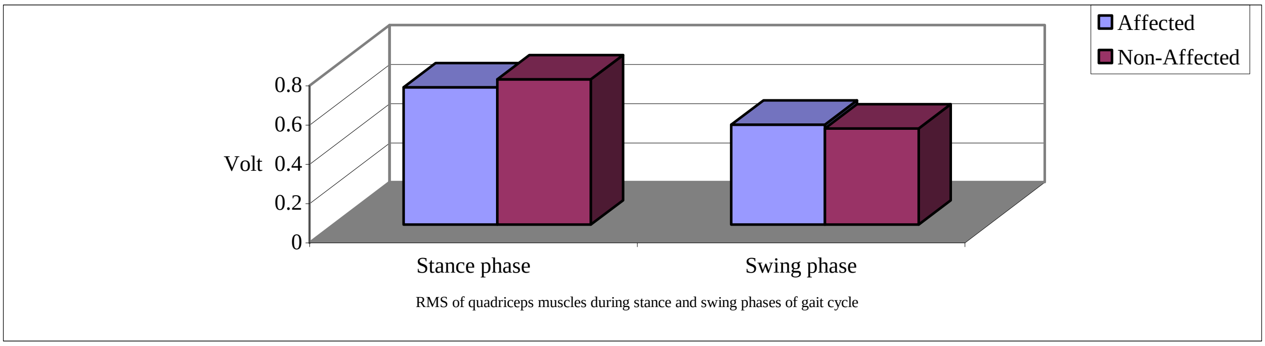

Fig. (3): Comparison between the mean values of the EMG activity (RMS) of quadriceps muscles of both affected and non-affected sides (volts) during stance and swing phases.

B) EMG (RMS) of hamistrings muscles during stance and swing phase:

The results of this study showed that there is a highly statistically significant difference in the EMG activity (RMS) of hamistrings muscles between the affected and non-affected sides during both stance and swing phases (P= 0.0001for both).

Comparison between the mean values of the EMG activity (RMS) of hamistrings muscles of both affected and nonaffected sides during stance and swing phases is represented in table (4) and figure (4).

Table (4): Comparison between the mean values of the EMG activity (RMS) of hamistrings muscles of both affected and non-affected sides during stance and swing phases.

Variable			Affected	Non affected	t	P
RMS of hamistrings	Stance	Mean	0.32	0.44	-11.19	0.0001
		SD	0.043	0.04		
	Swing	Mean	0.50	0.58	-5.25	0.0001
		SD	0.06	0.04		

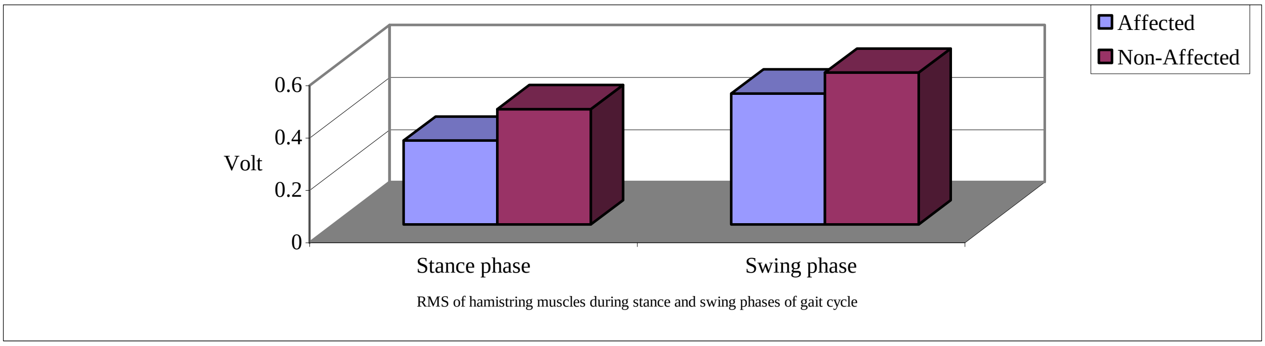

Fig. (4): Comparison between the mean values of the EMG activity (RMS) of hamistrings muscles of both affected and nonaffected sides during stance and swing phases.

DISCUSSION

Regarding EMG activity of quadriceps muscles during stance and swing phases:

At the stance phase, there was a statistically significant increase in the mean values of the activity of these muscles of the affected side during stance phase. This can be justified as follows: during the stance phase of the affected lower limb and in the presence of many problems that limits normal stable stance such as: muscle weakness, joint instability, alterations of normal muscle functions, sensory impairment and loss of normal balance mechanisms of the affected leg (Turnbull et al., 1996), the patient exerts high effort to carry his body weight over the affected side (which is difficult). This increased effort in turn increases spasticity in the affected side specially the extensors such as quadriceps muscles. This is consistent with the findings of Perry (1993) who reported that all of the stroke patient's extensor muscles are active at the onset of stance. This constitutes normal timing to provide stability of weight acceptance. Also, it might be justified as quadriceps muscles are antigravity muscle where spasticity increases specially with increasing effort In addition, appearance of the positive (+ve) supporting reaction may contribute in this increase as it causes increase in the extensor muscle activity. The activities in the nonaffected side increased more than those of the affected side. This may be due to the over load on the nonaffected side as quadriceps muscles are antigravity muscle needed to support the knee and prevent giving way to give a chance for advancing the affected side. The over load as a result of more weight on the nonaffected side may be the cause of the significant difference between the affected and the nonaffected sides.

At the swing phase, there was a

nonsignificant increase in the mean values of the EMG activity of quadriceps muscles of the affected side in stroke patients as compared to the nonaffected one. It can be explained as follows: when the patient starts to raise his affected limb to initiate swing phase, there is a delay in the release of extensor tension in the affected limb (Sawner and LaVigne, 1992; Kerrigan et al., 2001). This abnormal pattern of muscle activation appears more as the degree of spasticity increases. Therefore, the patient exerts high effort to swing the affected limb forward, which in turn causes more increase in the degree of spasticity that means increase in the EMG activity of the spastic muscles. The activities in the nonaffected side increased as patients tried to carry moreweight on the nonaffected side to clear the affected foot from the ground.

Regarding EMG activity of hamistrings muscles during stance and swing phases:

At the stance phase, there was a statistically significant difference in the mean values of the activity of these muscles during both stance and swing phases. This might be attributed to the increased activity of the quadriceps muscles together with inadequate and delay of the action of the hamstrings. This explanation might justify the significant decrease in the mean values of the peak of the knee joint flexion of the affected side as compared to the nonaffected one during stance phase. This is consistent with the findings of Perry (1993). Additionally, Chapman and Wiesendanger (1982) reported that; in UMNL, the inhibitory effects from extensors onto flexors are relatively much more powerful than the reverse. This pattern is similar to that seen in normal man (but more exaggerated). This exaggeration might be due to reduced Renshaw cell recurrent inhibition of extensor Ia inhibitory interneurons, leading to increased reciprocal inhibition of antagonistic (flexor) Ia inhibitory interneurons. The activities in the nonaffected side increased more than that of the affected one. This may be due to the over load on the nonaffected side as the patient needs to put his weight on this side and exert effort to swing the affected one. There is contraction of both quadriceps and hamstring of the nonaffected side to ensure the extension of the knee to give a chance for advancing the affected limb. This may explain the significant difference between the affected and the nonaffected sides.

At the swing phase, the mean values of the EMG activity of hamistrings muscles were statistically significantly lower in the affected side in stroke patients as compared to the nonaffected side. This might be justified as follows: during this phase, there is difficulty in producing adequate knee flexion as the result of the frequent concomitant activity by the quadriceps muscles and the unavailability of the hamstring muscles (weakness). Additionally, stroke patients lack the ability to modify muscle action. Muscle timing and force are determined by the strength and completeness of patterns and not by the need to respond to changing conditions (Ozer et al, 1994). This is consistent with findings of Burdett et al (1988) who reported that hemiplegic gait is characterized by decreased knee and hip flexion during swing phase. Additionally, Sawner and LaVigne (1992) who documented that there is lack of knee flexion which is required for smooth progression of the leg during swing phase in stroke patients because the required cessation of activity of the hip and knee extensor muscles is absent or too slow to allow flexion at these joints. The activities of hamistrings muscles in the nonaffected side increased slightly more than that of the affected one. This may due to the acceleration of the swing phase of the nonaffected side. The nonsignificant difference may be explained as; at this phase; this muscle is not needed for stability but it acts for a short time to clear the nonaffected foot from the ground and the load after that is on the knee extensors as a preparation for initial contact.

Regarding knee joint flexion and extension during stance and swing phases:

Concerning knee flexion:

At stance phase, there was a significant decrease in the peak of the knee joint flexion of the affected side. This may be due to the increased activity of the quadriceps muscles and delay of the action of the hamstring. This opinion is in accordance with Kerrigan et al., 2001.

There was a significant decrease in the peak of the knee joint flexion of the nonaffected side. This may be due to the decreased period of the swing phase of the nonaffected side as the patient feels no stability when he at SLS on the affected side so, he accelerate the nonaffected side to contact the ground i.e., does not give it a chance to complete its normal range.

At swing phase, there was a significant decrease in the peak of the knee joint flexion of the affected side. This may be due to the delayed relaxation of quadriceps, delayed action of hamstrings and weakness of the hamstrings muscles. Muscular activities may show the explanation for changes in the peak of the knee joint flexion.

Concerning knee extension:

At stance phase, the least degree of knee extension decreased in the affected side. This may due to spasticity of the quadriceps, weakness of the hamstrings and appearance of the +ve supporting reaction. In addition the presence of genu recurvatum in some of stroke patients causes the least angle to be decreased in those patints. At swing phase, the least degree of knee extension increased in the affected. This may be due to the presence of flexor synergy.

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الملخص العربي

التحليل الالكتروني البصري لحركات الركبة أثناء المشي في مرضى السكتة الدماغية

لقد أجرى هذا البحث على ثلاثين مريضا من مرضى السكتة الدماغية بهدف دراسة النشاط العضلي للعضلة ذات الأربعة رؤوس والعضلة ذات الثلاثة رؤوس أثناء المشي مصحوبا بدراسة المدى الحركي للركبة وذلك للساقين المصابة والغير مصابة على السواء باستخدام جهاز تحليل الحركة ثلاثي الأبعاد . وقد أوضحت المعالجة الإحصائية لنتائج هذا البحث وجود اختلاف واضح ذو دلالة إحصائية بين لركبتين المصابة والغير مصابة في حركة ثنى الركبة وذلك أثناء مرحلة الثبيت وأثناء مرحلة عدم التحميل. كما أظهرت النتائج وجود اختلاف واضح ذو دلالة إحصائية في حركة فرد الركبة وذلك أثناء مرحلة الثبيت . كذلك وجود اختلاف واضح ذو دلالة إحصائية في النشاط العضلي للعضلة ذات الأربعة رؤوس بين الساقين المصابة والغير مصابة أثناء م رحلة الثبيت مع عدم وجود اختلاف واضح ذو دلالة إحصائية أثناء مرحلة عدم التحميل . كما أسفرت النتائج عن وجود اختلاف واضح ذو دلالة إحصائية في النشاط العضلي للعضلة ذات الثلاثة رؤوس بين الساقين المصابة والغير مصابة أثناء مرحلتي الثبيت و عدم التحميل. وبناءا" على هذا فإن تقييم حركة الركبة مصحوبا بدراسة المدى الحركي للركبة أثناء المشي يجب أن يؤخذ في الاعتبار أثناء عملية التأهيل لمرضي السكتة الدماغية .