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Research Article

IMPROVED DORSAL BENDING OF THE PARALYZED LEG FOOT IN 14 POST-AVC HEMIPLEGIC SUBJECTS BY CONVENTIONAL REDUCTION AND ELECTROSTIMULATION

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Abstract

This research is implemented to assess the level of improvement in dorsal flexion from a transcutaneous electrostimulation program combined with conventional conventional rehabilitation on the stiffness of the paralyzed leg of the hemiplegic subject post-stroke. This study carried out in the city of Porto-Novo focused on 14 hemiplegic subjects. It is an intervention research carried out in the Sport-Health-Service (3S) fitness center in Porto-Novo and at the Biomechanics and Performance Laboratory (LaBioP) of the National Institute of Physical Education and Sport (INJEPS). The results obtained allow us to affirm that the integration of ES into the therapeutic arsenal of hemiplegic subjects increases the electrical activity of the anterior tibial muscles and common long extensor of the toes; main muscles of the dorsal flexion of the foot. Therefore; it improves flexibility of the ankle. In addition to traditional muscle building techniques, we postulate that electrical stimulation contributes significantly to motor rehabilitation (walking autonomy) of the hemiplegic subject after stroke. Specifically, we note that the strength deficit after the stroke contributes significantly to the limitation of functional capacities. Electrostimulation combined with conventional rehabilitation contributes to limiting the degradation of this by improving muscle strength.

Keywords: Rehabilitation, Electrostimulation, Dorsal flexion of the foot, Hemiplegia, Benin.

INTRODUCTION

The occurrence of cerebrovascular accident (CVA) generates in subjects multiple sequelae which vary according to the location and extent of the lesion. Among these lesions, sensorimotor sequelae, deficiencies of the limbs (lower and upper) are the most commonly encountered and lead to significant limitations in activities of daily living (Azevedo *et al.,* 2007; Hesse *et al.,* 2008). Stroke, which is a sudden interruption of blood supply to the brain, is a source of sudden onset of hemiplegia (Sablot *et al.,* 2007; Bejot *et al.,* 2009). Hemiplegia creates an extremely serious disability these days and poses a major public health problem (Mauritz, 2004; Bejot *et al.,* 2008). It is a common cause of the handicap often acquired in many young and adult subjects. Scientific advances in research, evaluation, imaging and physiotherapy can help improve the techniques used to recover from this disability. The new rehabilitation programs take into account the need to perform electrical stimulation on muscles, or nerves sometimes associated with conventional physical exercises. This new way of re-educating would improve locomotor function and promote a certain muscular and articular movement in hemiplegic subjects. Apparently very few studies in Africa and in Benin in particular are interested in questions of the prevalence, treatment and functional re-education of the hemiplegic by electrical stimulation. Some have been reported by authors (Sagui, 2007) and constitute references for the African continent. To our knowledge in Benin, studies relating to functional rehabilitation of hemiplegic subjects with the electrostimulation method seem to be non-existent.

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In a particular way, we note an absence of study on the reeducation with electrostimulation of the subjects victims of the hemiplegia in the sense of recovering their locomotive function. For our work we will be interested in the question of the use of transcutaneous electrostimulation associated with a conventional rehabilitation program according to the Bobath method (Bobath, 1970). This method will be used as a means of correction of spasticity sometimes observed in the hemiplegic subject after stroke to improve the angle of the dorsal flexion of the ankle of the paralyzed leg. This choice would consist in applying transcutaneous electrical stimulation to the motor points of the main superficial muscles responsible for the dorsal flexion of the foot.

MATERIAL AND METHODS

Experimental setting and type of study

This is an experimental study that took place in the city of Porto-Novo (Benin). The Laboratory of Biomechanics and Performance (LaBioP) of the National Institute of Youth, Physical Education and Sport (INJEPS) and the Center of Sport-Health-Service (3S), served as a support framework for the experiment which lasted a month.

Study population and sample

Our study population consists of 14 hemiplegic post-stroke subjects with stiffness in the foot. They came to register for functional rehabilitation sessions at the 3S center during the period from January 2014 to February 2015. The sample was retained by the non-probabilistic method with a reasoned choice technique. This choice is made to circumscribe our study.

Inclusion criteria

The subjects included in the study sample are:

- Suffering from hemiplegia with an inability to flex the back;
- Apparently not taking any anti-spastic treatment;
- Having given their informed consent to take part in the study.

Non-inclusion criteria

The subjects are not retained in the sample:

- With contraindications to the use of electrostimulation;
- Exempt from physical activity by a specialist doctor;
- Victims of all other muscular or joint pathological affections.

Exclusion criteria

The following are excluded from the study:

- Subjects who missed two or more sessions out of the ten (10) scheduled sessions.

Experimental protocol

The clinical examination was carried out by an attending physician before our intervention. This study took place in three main phases:

- The first phase consisted in collecting data on anthropometric, biomechanical and physiological parameters (size, body mass, surface EMG, etc.);
- During the second phase; subjects are subjected to the classic lower limb rehabilitation program combined with a transcutaneous electrostimulation program;
- Finally the last phase consisted in the evaluation of the stiffness of the ankle and the EMG in order to objectify the effect of the program administered according to the method of Sabut *et al.* (2010)

Specifically in carrying out this study, the conventional conventional rehabilitation program applied to the subjects followed the Bobath recommendations (Bobath, 1970). This rehabilitation program for the lower limbs (paralyzed leg) was carried out with a neuromotor approach, at the rhythm of one session of 45 minutes per day and for ten (10) days. Installation of the EMG: an electromyographic evaluation by the amplitude of the H-reflex made it possible to record the electrical activity of the muscles. To ensure better recording of EMG signals, we have placed the electrodes connected to the surface EMG device via cables in order to have a good connection between the wifi modem and the computer (Photo n° 6). Placement of the EMG electrodes: we used bipolar 10 mm diameter electrodes with a silver cup (SKINTACT model, offering very high sensitivity) which were fixed on each muscle parallel to the muscle fibers precisely at their point of 'innervation (Photo n ° 7 and n ° 8). The inter-electrode distance is two centimeters. The electrical activity of the anterior tibial muscles and common long extensor of the toes was performed.

Recording of EMG signals by the WiFi modem and the computer

Positioning of the electrodes on the anterior tibial and long extensor muscles of the toes

Recording of EMG activity: the electrical activity of the aforementioned muscles was recorded in two stages at the start and end of the experiment. The recording time for each muscle was 30 seconds. Before recording, we first chose the type of test to do (standard SEMG), the channel, the sensitivity (500μV / D) and the scanning speed (0.1s / D). Experimental phase: we were able to work with hemiplegic subjects post-stroke, which were divided into two groups (one group of seven subjects stimulated in a sitting position and the other also of seven subjects stimulated in movement, that is to say during the walk) randomly for ten (10) work sessions.

Intervention: all subjects performed a classic rehabilitation program according to Bobath. They practiced working sessions on the stepper (flexion-extension exercises) for eight (08) minutes and twelve (12) minutes of conventional therapy exercises. A break (recovery time) of five (05) minutes was observed between the classical rehabilitation programs and electrostimulation. These conventional conventional rehabilitation exercises include the following elements:

- Pedaling on ergocycles;
- Balance and stretching exercises in different postures.

This conventional rehabilitation used is combined with a transcutaneous electrostimulation program according to the method of Peurala *et al.* (1986).

Programme de stimulation: 20 minutes d'électrostimulation transcutanée appliquée sur les points moteurs du muscle tibial antérieur et les muscles long extenseurs commun des orteils qui sont des principaux muscles de la loge antérieure (de la jambe responsables de la flexion dorsale du pied). Ce programme a été exécuté sur la jambe paralysée avec une fréquence de 60 Hz ; une largeur d'impulsion de 200 us, pulsé par trains de 2 secondes et suivis d'un temps de repos de 6 secondes. L'intensité a été appliquée relativement à la sensibilité cutanée de chaque sujet. Phase de la stimulation : Le groupe 1 a subi en plus des exercices physiques communs à tous les sujets ; un programme d'électrostimulation en position statique (assise). L'ensemble de l'intervention a duré 10 séances à raison de 20 minutes d'électrostimulation transcutanée par séance. Le groupe 2 l'a reçu en déplacement pendant 20 minutes de marche (position mobile).

The parameters studied

The independent, dependent and confounding variables are taken into account in our study.

The independent variables: the conventional rehabilitation program associated with transcutaneous electrostimulation was used to act on subjects meeting the criteria of our sampling

Dependent variables: these are:

- The electrical activity of the anterior tibial muscles and the long extensor of the toes, recorded by surface electromyography (surface EMG);
- The angle of the dorsal flexion of the foot and the effect of stimulation in the sitting position and the stimulation in the mobile position.

Confounding variables: they are taking antispastic products and carrying out daily activities of life (AQV).

Ethical considerations

Before participating in the study, subjects were made aware of the objectives and interests of the study. On the one hand, written informed consent was obtained from each subject to express their agreement to participate; on the other hand, the approval of the sectoral scientific committee of Sciences and Techniques of Physical and Sporting Activities (CSS / STAPS) of Abomey-Calavi University was requested and granted. No invasive measures were taken on our subjects for data collection.

Statistical analysis

The data collected was analyzed using Statistica software (version 6.10). The tests of normality and homogeneity of the variances verified in the framework of the study were not conclusive (Kolmogorov Smirnov test). The non-parametric test was carried out because we worked with a sample of 14 subjects. The Wilcoxon rank test was carried out to compare the variables (initial and final values) within each group. The Mann-Whitney U test made it possible to appreciate the binary variations (comparison of the means of the variables between groups 1 and 2). The significance threshold was set at $p < 0.05$.

RESULTS

The results of our study are presented in tables.

Characteristics of the subjects of the study

The sample of our study consists of 14 hemiplegic subjects post-stroke, all Beninese of average age 55.5 ± 10.47 years. Their average body mass is 69.21 ± 12.79 kg, with an average height of 1.68 ± 0.07 m and the average body mass index (BMI) which is 24.34 ± 3.42 kg / m2

Intra-group comparison of the electrical activity of the anterior tibial muscles and the long extensor of the toes

Comparison of Mean Root Square (RMS) values of the anterior tibial muscle: The Wilcoxon rank test shows that there is a significant increase ($p = 0.017$) between the mean values of electrical parameter of the anterior tibial muscles and the long common extensor of the toes, in each group at the end of the experiment (Tables I and II).

Table I. Intra-group comparison of RMS values of the anterior tibial muscle

Variables	Group 1 (n = 7)		Group 2 (n = 7)	
	V1 *m ± s*	*V2* *m ± s*	*V1* *m ± s*	*V2* *m ± s*
RMS values of the anterior tibial muscle when seated (µV)	30,4 ±15,39	47,98 ± 29,46* (57,82 %)	38,36 ± 18,65	58 ± 33,94* (51,19 %)
RMS values of the anterior tibial muscle during walking (µV)	30,66 ±14,45	40,43 ± 22,20* (31,86 %)	33,54 ± 18,19	42,92 ± 16,65* (27,96 %)

Group 1: Subjects stimulated while seated; Group 2: Subjects stimulated during the walk; V1: initial RMS value; V2: final RMS value; (µV): microvolt unit of RMS values, n: Number of subjects per group; % Percentage change in muscle electrical activity at the end of the procedure, *: significant difference

Table II. Intra-group comparison of RMS values of the common extensor longus muscle

Variables	GROUP 1 (n = 7)		GROUP 2 (n = 7)	
	V1 *m ± s*	*V2* *m ± s*	*V1* *m ± s*	*V2* *m ± s*
RMS Values of the Common Long Extender of the Toes in a Sitting Position (µV)	18,13 ± 6,43	30,00 ± 12,31* (65,47 %)	29,24 ± 8,37	41,34 ± 12,31* (41,38 %)
RMS values of the Common Long Toe Extender during walking (µV)	24,86 ± 12,29	32,48 ± 17;40* (30,65 %)	25,62 ± 11,58	36,38 ± 11,54* (41,99 %)

n: Number of subjects per group; Group 1: Subjects stimulated while seated; Group 2: Subjects who received stimulation during walking; V1: initial RMS value; V2: final RMS value; (µV): unit in microvolt of RMS values; % Percentage change in muscle electrical activity at the end of the procedure, *: significant difference

Table III. Comparison of the mean values of the angles of dorsal flexion of the foot by group from the start and at the end of the experiment

Variable	GROUP 1 (n =7)		GROUP 2 (n = 7)	
	V1 *m ± s*	*V2* *m ± s*	*V1* *m ± s*	*V2* *m ± s*
Angle of dorsal flexion of the foot (°)	71,42 ± 8,52	60,42 ± 9,77* (15,40 %)	67,28 ± 8,44	52,28 ± 8,97* (22,29 %)

n: Number of subjects per group; Group 1: Subjects stimulated while seated; Group 2: Subjects stimulated during the walk; V1: initial value of the angle of the dorsal flexion of the foot of the paralyzed leg; V2: value of the angle at the end of the intervention; m: average; s: standard deviation; * : significant difference ; (°): degree; :% Percentage decrease in the angle of dorsal flexion of the foot at the end of the intervention.

Comparison of Mean Root Square (RMS) values of the long extensor muscle of the toes: Intra-group comparison of the angle of the dorsal flexion of the foot at the beginning and at the end of the experiment. The analysis in Table III shows that the angle of the dorsal ankle flexion experienced a significant improvement at the end of the experiment in the subjects ($p = 0.017$). This improvement reflects a significant drop in ankle stiffness of 15.40% and 22.29%, respectively in groups 1 and 2.

DISCUSSION

This research focuses on the effect of transcutaneous electrostimulation combined with a classic rehabilitation program in improving gait in hemiplegic subjects after stroke, particularly on the dorsal flexion of the foot of the paralyzed leg. The results obtained provide information on the evolution of the electrical activity of the main muscles of the anterior compartment of the leg in hemiplegic subjects after stroke. These lifting muscles of the foot, retained within the framework of this study (anterior tibial and common extensors of the toes) facilitate the dorsal flexion of the foot during walking. Our study also indicates the different positions in which the subjects received electrical stimulation. During transcutaneous electrostimulation sessions, the intensity of the current applied to the subjects varied between 70 and 100 mA (for a maximum stimulator intensity of 100 mA). This intensity is administered to each subject taking into account their skin sensitivity (Viel *et al.,* 1990). The frequency of the current is set at 60 hertz for all post-stroke hemiplegic subjects concerned. Maximum contraction of the motor units making up a muscle is obtained at a frequency between 50 Hz and 120 Hz during electrical stimulation (Potisk *et al.,* 1995). The pulse duration is set to 200 µs in this work, because the shorter the pulse duration (100 µs to 400 µs), the higher the intensity is necessary to produce maximum muscle contractions (Kramer *et al.,* 1984; Kramer, 1987; Sabut *et al.,* 2011). The pulse duration also affects the comfort of the stimulation, the shorter the stimulation, the more comfortable the stimulation (Peurala *et al.,* 2002; Duchateau, 1992; Portmann and Monpetit, 1991; Lioyd *et al.,* 1986; Alon *et al.,* 1987).

Characteristics of the subjects of the study

The number of subjects in this study was 14 hemiplegic post-stroke subjects with an average age of 55.5 ± 10.47 years (with an age group between 41 and 80 years). This age range of subjects characterizes the heterogeneity of the sample. These subjects have an ineffective ankle movement, i.e. dorsiflexion during the swing phase (drop foot). They do not correctly place the sole on the ground when walking (Burridge *et al.,* 2001). The study subjects are divided into two non-homogeneous groups due to the significant difference in their ages (Sabut *et al.,* 2011). They have had a stroke for at least three (03) months and are suffering from aftereffects such as ankle spasticity. The Modified Ashworth Scale (MAS) was used to assess the stiffness of the foot and to see an improvement in muscle tone. The active or passive movement of the dorsal flexion of the foot and the motor recovery of the lower limbs are measured. This test shows that there is a remarkable increase in muscle tone affecting the range of motion in the subjects' ankles (Sabut *et al.,* 2011; Sheffler *et al.,* 2006; Sheffler *et al.,* 2013; Bakhtiary *et al.,* 2008; De Quervain *et al.,* 1996; Tyson, 1999).

Evaluation of the electrical activities of the main superficial muscles of the dorsal ankle flexion

Electrical activity of the anterior tibial muscle: Electrical activity is considered to be one of the safest ways to check the working or stress state of a muscle. In this study, it made it possible to assess the level of electrical activation of the anterior tibial muscles and the common long extensor of the toes (Fukuda *et al.,* 2010). To assess the level of contraction of the muscles chosen in this study, we recorded the average and maximum RMS values by the EMG. From this recording, we obtained the percentages of evolution of electrical parameters of each of the muscles studied in a given position. The average

RMS values and the percentages of solicitation of the anterior tibial muscles and common long extensor of the toes of the hemiplegic subjects studied show that the electrical activity increases considerably with a transcutaneous electrostimulation program associated with conventional rehabilitation. The results of our experiment showed a significant improvement in RMS value of tibial muscle before the end of the intervention in the two groups and in the different positions. In the group of stimulated subjects sitting without any movement at the ankle we recorded at the end of the program 47.98 µV against 30.4 µV (an increase of 57.82%) while in the group of stimulated during walking we got 58 µV against 38.36 µV (an increase of 51.19%). These values of the anterior tibial muscle recorded by the surface EMG signals (static position), suggest a significant increase in muscle strength in each of the groups. Then the RMS values of the anterior tibial muscle recorded during walking in the two groups of subjects at the end of the experiment (group 1: 40.43 µV versus 30.66 µV; group 2: 42; 92 µV versus 33, 54 µV) indicate an increase in muscle strength of 31.86% and 27.96% respectively. These results are similar to those in the literature (Bakhtiary and Fatemy, 2008; Embrey *et al.,* 2010; Tarkka *et al.,* 2011; Fil *et al.,* 2011; Henneman *et al.,* 1965). Henneman *et al.* (1965) indicate that with one hour of work per day, 5 times per week and for 12 weeks (stimulation associated with a conventional reeducation protocol) the hemiplegic subject increases the muscular force of the anterior tibial, improves the cadence and the length of not (with 66.3% of the root mean square value). Our results also confirm the work of Mesci *et al.* (2009). Who reported that the NMES of the dorsiflector muscles of the foot leads to a significant increase in active joint amplitudes and a decrease in spasticity. The values recorded at the level of each group allow us to deduce that whatever the position in which the subjects were stimulated there is always an increase as regards the gain in muscular strength.

Electrical activity of the common long extensor muscle of the toes: The common long extensor muscle of the toes was also chosen because of its main action in the dorsal flexion of the foot. It is one of the main muscles of the anterior compartment of the leg, the origin of which is located on the lateral condyle of the tibia and on the cranial 2/3 of the medial surface of the fibula (Marieb, 1999). The operation of collecting RMS values performed on this muscle made it possible to record at rest in subjects stimulated in a static position 30 µV against 18.13 µV (or 65.47%) and those stimulated during their walk 41.34 µV against 29.24 µV (or 41.38%). The RMS values recorded in activity on the long extensor muscle of the toes are 32.48 µV against 24.86 µV (or 30.65%) in group 1 and 36.38 µV against 25.62 µV (or 41.99%) in group 2. The results from these recordings of mean RMS values by surface EMG show that there is a significant increase in the electrical activity of the common extensor longus muscle in the two groups of subjects. If the electrical activity of a muscle characterizes its main or secondary action, we can deduce that this muscle has experienced an increase in force allowing it to improve the dorsal flexion or the plantar flexion of the foot; which would lead to a reduction in the stiffness of the ankle (reduction in the action of stepping).

Position of the electrostimulation

The percentages of evolution of the electrical activity of the anterior tibial muscles and long common extensor of the toes obtained in each group in different recording positions show that there is a significant increase in muscle strength. In fact, whatever position (static or mobile) in which the subjects received transcutaneous electrostimulation there is always a gain in muscular strength which is supposed to improve the dorsal flexion of the foot of the paralyzed leg. The values recorded in the mobile position compared to those of the static position in the two groups indicate a trend of a decrease in the percentage of change in the electrical activity of the muscles. This can be justified by the joint action of the other muscles of the leg during walking and would indicate muscular co-contraction (Kramer *et al.,* 1984; Haut conseil de la santé publique, 2004).

Angle of the dorsal flexion of the ankle

The functional anatomy of the foot shows the different possibilities of ankle movement. The ankle joint serves as a transmission of stresses (static role) and allows a perfect adaptation of the foot to the ground during walking, running, jumping (dynamic role). Any damage to each of its structures (bone, joint, ligaments, tendons, etc.) will lead to dysfunction of the entire walking cycle (Kapandji, 1985). This is the case for example with hemiplegic post-stroke subjects who have an absence of flexibility in their ankle. Dorsal flexion or dorsiflexion is the movement that allows the foot or toes to go up by getting closer to the tibia. From the anatomical position, it forms an angle of 0 to 30 degrees at the ankle joint (Dufour and Pillu, 2005). The measurements made on the subjects show that the angle of the dorsal flexion of the foot of hemiplegic subjects after stroke is seriously affected by the stiffness of the ankle joint. The angles of the dorsal flexion of the foot measured in the two groups of subjects (stimulated in sitting position and during walking) were respectively 71 ° ± 8.52 and 67 ° ± 8.44. The results obtained, following our intervention in the groups of subjects stimulated in a sitting position (60 ° versus 71 °) and during walking (52 ° versus 67 °) show a reduction in the stiffness of the ankle. Although the angle measured at the end of the experiment does not exactly approach that of the literature, it experienced a marked improvement which reflects a significant reduction in ankle stiffness of 15% and 22% respectively in the groups 1 and 2. We can explain this high rate (22%) of the group of subjects stimulated during walking, compared to that of 15% (seated position) by the fact that walking would already constitute a gain which is added to electrostimulation to give a better improvement of the angle of dorsiflexion.

Limits and difficulties of the study

The study focused on a small non-homogeneous sample recruited by a non-probabilistic method; which, among other things, is one of its limits. The results obtained cannot be systematically generalized. The study environment and the attachment of our populations to cultural myths and traditional beliefs were also a limit for the constitution of the work sample. Socio-cultural prejudices have not yet given way to modern treatment methods for post-stroke hemiplegia.

Conclusion

The results of this study show that the transcutaneous electrostimulation program combined with a classic rehabilitation program to improve walking in a hemiplegic subject after stroke has given good results. The electrical activity of the anterior tibial muscles and long common extensor of the toes experienced a significant increase and the angle of the dorsal flexion of the foot was reduced in the direction of stiffness or spasticity of the ankle. The values of the electrical activity of the anterior tibial muscles and common long extensor of the toes from this study suggest a gain in muscle strength which translates into improved walking in hemiplegic subjects after stroke. However, we found at the end of the intervention program that regardless of the position in which electrical stimulation was applied, no significant difference in improving the dorsal flexion of the foot was obtained.

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Disclosure of conflict of interest

The authors declare no conflicts of interest.

Abbreviations list

- **AQV**: Carrying out Daily Activities of Life
- **BMI:** Average Body Mass Index
- **CSS / STAPS:** Sectoral Scientific Committee of Sciences and Techniques of Physical and Sporting Activities
- **CVA:** Cerebrovascular Accident
- **EMG**: Electromyographic
- **ES** : Electrostimulation
- **INJEPS :** National Institute of Youth, Physical Education and Sport
- **LaBioP :** Laboratory of Biomechanics and Performance
- **RMS:** Root Mean Square
- **3S:** Center of Sport-Health-Service

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