
Cross-Education Effects of Motor-Level Transcutaneous Electrical Nerve Stimulation on Quadriceps Motor Function Recovery Among Stroke Survivors

Ayodele Teslim Onigbinde^{1,*}, Adeola Godwin Olubukola¹, Nwosu Ifeoma Blessing²

¹Department of Medical Rehabilitation, Obafemi Awolowo University, Ile-Ife, Nigeria

²Department of Medical Rehabilitation, Nnamdi Azikiwe University, Nnewi Campus, Awka, Nigeria

Email address:

ayotesonigbinde@gmail.com (A. T. Onigbinde)

*Corresponding author

To cite this article:

Ayodele Teslim Onigbinde, Adeola Godwin Olubukola, Nwosu Ifeoma Blessing. Cross-Education Effects of Motor-Level Transcutaneous Electrical Nerve Stimulation on Quadriceps Motor Function Recovery Among Stroke Survivors. *Pathology and Laboratory Medicine*. Vol. 2, No. 2, 2018, pp. 35-40. doi: 10.11648/j.plm.20180202.12

Received: October 24, 2018; **Accepted:** November 16, 2018; **Published:** December 19, 2018

Abstract: There has been speculation that stronger limbs of stroke survivors can be used to strengthen the homologous muscles on the weaker side through cross education using Motor-level Transcutaneous Electrical Nerve Stimulator (M-LTENS). Recently, there are demonstrations on apparently healthy individuals but there is dearth of empirical data to support this effect in stroke patients. The study aimed to investigate the cross education effects of M-LTENS on the affected knee extensors of stroke survivors when the unaffected homologous muscle group was stimulated. Twenty stroke survivors were recruited using purposive sampling technique. M-LTENS was used to stimulate the quadriceps group of muscles of the unaffected lower extremity for 6 weeks (85Hz and 100 microseconds). Strength values were quantified using the modified sphygmomanometer. The data were analysed using descriptive analysis and Inferential Statistics (paired t-test and Chi-square test of Association). The mean muscle strength of the unaffected quadriceps muscle at baseline was $471.96 \pm 74.70\text{N}$ while that of affected was $167.83 \pm 6.38\text{N}$ and the values significantly increased to $505.40 \pm 83.50\text{N}$ and $191.96 \pm 60.90\text{N}$. ($t=-6.23$, P -value = 0.001; $t=-8.71$; P -value=0.001) respectively at the 6th week. There was also significant difference between the unaffected and affected muscle group strength; both at baseline and after 6 weeks ($t=16.89$; P -value=0.001; $t=14.951$; P -value=0.001). It was concluded that there was cross education effect in contralateral (affected) quadriceps group of muscles in stroke survivors after the unaffected quadriceps muscle group was stimulated using motor-level Transcutaneous Electrical Nerve Stimulator for 6 weeks.

Keywords: Cross-Education, Motor-TENS, Quadriceps Motor Function, Stroke Survivors

1. Introduction

Muscle strength, endurance and power are commonly affected following stroke and this is as a result of decline in the quality and quantity of afferent inputs to the primary sensory cortex [1 - 4]. Evidence suggested that people with stroke have changes in neural and muscle structure; and functional impairments which may contribute to deficits in muscle strength. One of the most prominent impairment is muscle weakness and it is essential to focus appropriate therapeutic interventions in order to improve performance at functional activities [5]. Madhavan had linked cortico-spinal

tract integrity with lower extremity strength, substantiating knee extensor weakness and activation impairments in stroke survivors, and that the weakness develops rapidly after stroke, affecting motor performance that subsequently leads to reduced functional ability [6].

There has been advocacy for strength training for clinically stable stroke survivors [7]. One of the main goals of stroke rehabilitation is training ambulation and this depends to a large extent on the muscle strength of the affected lower limb, asides impairment in balance and presence of moderate extensor pattern [8]. The quadriceps and hamstring group of muscles are of utmost importance for efficient activities of

daily living [9].

In stroke rehabilitation, strengthen exercises are important regimens for walking and endurance training for increasing exercise capacity [10]. Old literature had established that muscle strengthening programmes such as isometric, isotonic, isokinetic muscle settings, weight training and muscle conditioning could improve strength [11]. However, the use of motor-level Transcutaneous Electrical Nerve Stimulator (TENS) is gaining increasing acceptance for muscle building. Safety and rigor of exercise strength training programmes are discouraging factors while improper execution and negligence of appropriate precautions can result in injury [9]. Motor TENS with stimulation parameters is being speculated to improve muscle strength and this suggests that the electro- analgesic modality has other indications other than pain modulation [12]. Hence, TENS has gained recognition as a suitable modality for muscle strengthening, and it is being speculated that it may beneficial to strengthen lower limb muscles of stroke survivors [9]. Previous studies had also established the relevance of different types of TENS in reducing spasticity [13].

Cross-education is a concept that is commonly adopted in kinesiology, motor control, and neurobiology disciplines and its potential clinical applications has been subject of debate, but its clinical applications has not been popular in biomedical engineering and medical rehabilitation [14]. Cross education is the phenomenon in which unilateral strength training induces strength gain, not only in the trained limb but also in the homologous muscle of the contra-lateral limb; and it is a bilateral adaptation after unilateral training that has been acclaimed to be effective in the rehabilitation after one-sided orthopedic injuries, however, limited knowledge exists on its application within the rehabilitation after stroke [9, 15]. It is surprising that cross-education is not currently a rehabilitation strategy for unilateral injury or impairment; aside this, it is limited to only few studies on stroke [16 - 17]. Furthermore, little is known about the cross-education effects of TENS, especially when it is preset to motor stimulation parameters in order to strengthen muscles; hence the need for this study.

2. Materials and Methods

2.1. Participants

Twenty (20) stroke survivors who met the inclusion criteria were recruited at the department of physiotherapy, Obafemi Awolowo University Teaching Hospitals complex, Ile-ife, Osun state, Nigeria.

2.2. Inclusion and Exclusion Criteria

The major inclusion criteria that the participants must have controlled and stable blood pressure; with intact skin sensation and must be ambulant and must have attained quadriceps muscle strength greater than 2 on Oxford muscle grading scale. Excluded were those with metallic implants

and cardiac pacemakers. Patients with other neurological condition aside stroke were also excluded.

2.3. Sampling Technique

The sample size for this study was determined to be 15 considering the standard normal deviate of α at 95% confidence level (probability of making a type 1 and 2 errors) to be 1.96 and 1.64 while prevalent rate of 0.5% [18] was considered in the computation. However, 20 stroke survivors were recruited for the study. Purposive sampling technique was used to recruit the participants based on the selection criteria.

2.4. Research Design

A Pre and post experimental research design was adopted with one lower extremity serving as control for the other. The research Site was the treatment cubicle at the physiotherapy gymnasium of the Department of Medical Rehabilitation, Obafemi Awolowo University Teaching Hospitals Complex, Ile-ife, Osun State.

2.5. Instruments

The major instrument utilized were Transcutaneous Electrical Nerve Stimulator (TENS 7000 TM, Current Solution, LOT NO. 2011-11, LLC 3814, Woodbury, TX, USA), a 9 Voltage stimulator that was used to stimulate the quadriceps group of muscles, modified sphygmomanometer was used to record the strength of the subjects' lower limb knee extensor muscle group. The modified sphygmomanometer was used to assess quadriceps muscle strength while the patient sat at the edge of a resting table using the procedure of Onigbinde et al. [8]. An inelastic measurement tape was used to measure the quadriceps muscle girth in both affected and unaffected limbs of the subjects.

2.6. Procedure

Ethical approval was obtained from the Research and Ethics Committee of the Institute of Public Health, College Of Health Sciences, Obafemi Awolowo University, Ile-ife, Osun state. The purpose and procedure of the study was explained to the participants and written consent was obtained as well. The maximum cooperation of subjects was also solicited, with the assurance that their health would not be adversely affected by the participation in the study. Muscle girth for the quadriceps muscle group of each participant was also taken at the time of preparation for stimulation using the measuring tape and was monitored during the period of stimulation using motor-level TENS. The landmark for quadriceps muscle girth was determined by measuring midway the length of the thigh from the antero-inferior iliac spine to the superior border of the patella.

For muscle strengthening, all subjects were familiarized with TENS prior to application. The participants were kitted in short knickers and were positioned in supine lying for the stimulation of the unaffected quadriceps muscle groups. The

labile method of electrode placement was used to stimulate the quadriceps for a period of 15 minutes using quadripolar technique [10]. Each of the 4 electrodes has an area of $5 \times 5 \text{ cm}^2$ arranged to cover the largest bulk of the anterior thigh of the subject. The TENS was set to strength duration 2 mode (motor stimulation) which consisted of automatic modulation intensity and pulse width of 70% range. Total cycle time was set to 10 seconds. Pulse range was set to 85Hz and pulse width of 100 microseconds. The intensity was increased until there was a significant visible contraction of the quadriceps muscle [8]. Whenever accommodation was observed, the amplitude was further increased to produce a stronger contraction, but was also at a comfortable sensory level for each of the participants.

For each subject, the lower limb quadriceps isometric strength measurement was carried out by two trials but the higher reading was recorded and used for data analysis. Adequate rest intervals were observed for the subjects between each measurement interval. The unaffected lower limb quadriceps muscle group was stimulated for 15 minutes with motor-level TENS twice a week for 6 weeks while the affected, unstimulated limb served as the experimental limb for observation. Muscle strength and girth for both experimental and control limb were measured during the first, third and after the sixth week of motor TENS strengthening. The pre-treatment muscle strength was taken using the modified sphygmomanometer [8]. The subject sat at the edge of table or plinth and the cuffs were put around the shin (around the distal third of the affected leg) to measure the strength of the knee extensors. The modified bladder was put between the cuff and the skin and the subject was asked to extend the knee. They were verbally motivated with the word "PUSH" during knee extension. Before the use of the modified sphygmomanometer, the pressure inside the bladder was increased to 20mmHg to create a baseline for measurement; this meant that a contraction reading 100mmHg was recorded as 80mmHg.

Participants were instructed not to engage in any rigorous physical activities throughout the study period. Both limbs had baseline muscle strengthening exercise, each patient extended both knees (one after the other) until the leg was fully straightened, maintaining quadriceps isometric contraction for 3 to 5 seconds; and then slowly returned to the starting position; 12 repetitions and 3 sets at each

session depending on each individual participant. This was supervised by the principal investigator in-order to prevent potential weakening of the affected quadriceps muscle group.

When analysing data, the muscle strength value was converted from mmHg to the SI unit of force, which is Newton (N). The value of pressure (mmHg) in the modified sphygmomanometer was converted to Pascal (Pa), same as Newton per square meter (Nm^{-2}) and $1\text{mmhg}=133.3\text{Pa}$. The quantity of Force (F) generated in the bladder of the sphygmomanometer was also computed from formula; $F=\text{Pressure} \times \text{Area}$ where the area of the bladder for modified sphygmomanometer was 0.019m^2 ; The Force generated in Newton was $F=0.019 \times P$ or $F=0.019 \times 133.3 \times \text{value of quadriceps pressure in mmHg}$.

2.7. Data Analysis

The data were analysed using descriptive analysis and Inferential Statistics (paired t-test and Chi-square test of Association). The paired t-test was used to compare the muscle strength and girth of the affected (unstimulated) and unaffected (TENS stimulated) limbs.

3. Results

The age height and weight of stroke survivors that participated in the study are presented in table 1. The results of the study showed that the mean muscle strength for the unaffected quadriceps muscle at baseline was $471.96 \pm 74.70\text{N}$ while the muscle strength for the affected quadriceps muscle group at baseline was $167.83 \pm 6.38\text{N}$. The result of the paired t-test showed that there was significant difference between the unaffected quadriceps muscle group strength and the affected quadriceps muscle group strength at baseline ($t=16.89$; $P\text{-value}=0.001$). There was also a significant difference between the affected and unaffected quadriceps muscle strength after 6 weeks of stimulation of the unaffected quadriceps muscle group using motor-level TENS ($t=14.951$; $P\text{-value}=0.001$). Other results are shown in table 2. The result also showed that there was significant difference between the affected quadriceps muscle strength at baseline and after 6 weeks ($t=-8.71$; $P\text{-value}=0.001$). Other results are shown in table 2.

Table 1. Physical Characteristics of the Participants.

Variables	Minimum	Maximum	Mean	SD
Age (Years)	41.00	70.00	55.90	8.55
Height (m)	1.59	1.81	1.70	0.06
Weight (kg)	54.00	80.00	65.08	8.06

Table 2. Comparison of quadriceps muscle strength at baseline and after 6 weeks for affected and unaffected sides.

Quadriceps strength	Mean (N)	SD (N)	t	p-value	
Affected	Baseline	167.83	60.38		
	After 6 weeks	191.96	60.90	-8.71	0.001**
Unaffected:	Baseline	471.96	74.70		
	After 6 weeks	505.40	83.50	-6.23	0.001**

*significant at $P \leq 0.05$ **- significant at $P \leq 0.001$ N= Newton

The mean initial baseline girth of the quadriceps muscle group of the unaffected limb was 49.72 ± 7.31 cm while that of the affected quadriceps muscle group was 49.05 ± 4.46 cm. The girth measurement after 6 weeks of motor-level TENS stimulation of the affected quadriceps muscle group, as well as the unaffected muscle group are presented in table 3. The

result of the paired t-test showed that there was no significant difference between the girth at baseline and after 6 weeks of stimulation using motor M-LTENS in both the affected (unstimulated) and unaffected (stimulated) quadriceps group of muscles.

Table 3. Comparison of the girth in affected and unaffected quadriceps group.

Quadriceps girth		Mean (cm)	SD (cm)	t	p-value
Affected	Baseline	48.52	4.74	-0.27	0.79
	After 6 weeks	48.60	4.22		
Unaffected:	Baseline	49.71	7.31	0.55	0.59
	After 6 weeks	49.05	4.46		

The frequency distribution of side affectation showed that 9 (45%) participants had right sided weakness, while 11 (55%) had left sided weakness. The result of the Chi-Square test of association showed that there was no significant

association between side affected with stroke and muscle strength of either the affected or unaffected quadriceps muscle group at baseline and after six weeks (Tables 4).

Table 4. Association between Side Affected and Quadriceps Muscle Strength (QMS).

	Affectation	Frequency	%	Baseline		After 6 weeks	
				χ^2	p	χ^2	p
Affected QMS	Right side	9	45.0	11.24	0.42	15.29	0.36
	Left side	11	55.0				
Unaffected QMS	Right side	9	45.0	13.26	0.43	10.57	0.56
	Left side	11	55.0				

4. Discussion

There has been increasing advocacy for the use of TENS for other purposes such as reducing spasticity and training muscle balance [19]. This is also evident from report of Kavac et al. [20] on the efficacy of TENS in eliciting muscle contraction and promoting increment in muscle strength. Aside this, it has also been documented that the increment obtained from using TENS was comparable to that of high resistance exercise training [21]. For many individuals who have experienced a stroke, muscle weakness is the most prominent impairment and there is speculation that a cross-training effect can occur from an exercised limb.

This study established that there was significant increase in muscle strength in both the affected and unaffected quadriceps group of muscles despite that it was only the former homologous muscle group that was strengthened using Motor-level Transcutaneous Electrical Nerve Stimulation parameters for 6 weeks. This thus confirmed cross education effects at the contra-lateral, affected quadriceps group of muscles. There were previous reports which had established cross education effects after volition exercise trainings [22]. The strength of the contralateral (affected and un-stimulated) quadriceps muscle group after 6 weeks was significantly than at baseline. Evidence based report of Ehrensberger suggested a moderate level of evidence for the application of cross-education of strength in stroke rehabilitation [15]. There was further corroboration from the reports of Zhou et al.; Miller et al. and Kennedy et al. [23 - 25]. There has been sparse report or documentation on contradictory result on cross-education effects [26].

Attempt had been made to explain the physiology behind cross-education effect. In an extensive review by Zhou [23], he highlighted reports of different authors who offered explanations on changes in neural mechanisms during electrical stimulation for cross education. A study attributed it to bilateral co-activation of the cortico-spinal tract [27]; another study attributed it to the diffusion of impulses between the cerebral hemispheres [28] while a separate study suggested the activation of afferent modulation at the contralateral limb [29].

There was no significant difference between the girth (bulkiness) of the unaffected quadriceps group of muscles at baseline and after 6 weeks of motor-level stimulation (TENS). This might be the reason why there was also no significant difference between the girth (bulkiness) of the affected quadriceps group of muscles. It could be inferred that motor-level stimulation parameters of TENS could not exhibit significant increase in quadriceps muscle bulk after 6 weeks, less transferring effect to the contra-lateral homologous muscle. This result corroborated the findings of Bembem and Murphy [30]. However, several studies had established positive correlation between muscle mass and muscle strength but our current finding has lent credence to the opinion of Chen et al. that 'it is unclear whether higher muscle mass necessarily translates into greater muscle strength or whether gains in muscle strength cannot be achieved without corresponding gains in muscle mass'[31]. There was also no significant association between side of affectation (right or left) and muscle strength of unaffected quadriceps at baseline and after six weeks stimulation. There was however a significant relationship between the muscle

strength of the affected quadriceps at baseline and after 6 weeks motor-level stimulation using TENS.

The clinical implication of these findings is high as the prima fasciae in a successful rehabilitation is to determine the best way to exploit the transfer effects of cross-education to restore symmetry and improve muscle strength in an extremity with unilateral pathology such as stroke. Jonathan and Zehr described the term symmetry in the human motor system to imply that both sides of the body are identical, but rather operate within a range of normal lateralization of function [14]. They opined that neurological impairments would disturb homeostasis thus creating asymmetry while the rehabilitation goal would be attempting to restore the previous symmetry and certain degree of bilateral functional capacity [14]. Russel opined that the study on clinicians' perspectives on cross-education in stroke rehabilitation provided important foundational information about clinician perspectives that would aid effective use of cross-education concept into clinical stroke rehabilitation and practice [17].

5. Conclusion

This study concluded that stronger limbs of stroke survivors induced strength gain in quadriceps, not only in the stimulated limb but also in the homologous muscle of the contra-lateral limb after 6 weeks. This thus established cross training effect. Despite the high clinical importance of this finding, the study has potential limitation as the design was a self-control group, although, such a design has its own positive attribute, especially, eliminating presence of bias between groups. It is in view of this, that we recommend a randomized controlled trial to further support our findings for generalization.

Conflict of Interest

There was no potential conflict of interest in this article.

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