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The Effects of High Frequency Transcutaneous Nerve Stimulation on Spasticity, Proprioception, Strength, and Balance in Patients with Stroke : A Randomized Controlled Trial

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This study was conducted to compare the effects of high frequency and low frequency transcutaneous electrical nerve stimulation applied to gastrocnemius muscle on proprioception, spasticity, and dynamic balance of stroke patients. Twenty subjects were randomly assigned to each of 10 experimental and control groups. High frequency transcutaneous electrical nerve stimulation was applied to the experimental group and low frequency transcutaneous electrical nerve stimulation was applied to the control group for 20 minutes per day, 5 times a week for a total of 4 weeks. The subjects were assessed for proprioception by joint position sense in ankle plantarflexion and dorsiflexion, spasticity was assessed using Modified Ashworth Scale (MAS) and amount of resistance, and dynamic balance was assessed using the Timed Up and Go (TUG) test. A significant improvement in joint position sense (plantarflexion, dorsiflexion), MAS, amount of resistance, and TUG was observed after intervention in the experimental group ($p < 0.05$), and there was a significant improvement in all evaluation items compared to the control group ($p < 0.05$). The results of this study suggest that application of high frequency transcutaneous electrical nerve stimulation to the bilateral gastrocnemius muscles of patients with stroke has a positive effect on proprioception, spasticity and dynamic balance.

Keywords : High frequency transcutaneous electrical nerve stimulation, proprioception, spasticity, magnetism, joint position sense

1. Introduction

Stroke is a major disease that causes disability, and it causes movement and sensory disorders, cognitive disorders, and perceptual disorders [1]. Stroke patients have problems with the functional activities of the upper and lower extremities due to damage to the central nervous system, motor nerves, and sensory nerves [2]. In particular, about 72 % of strokes remain deficits in the lower extremities. As a result, the motor control ability is reduced, the balance is reduced due to asymmetric weight support, and the walking ability is limited [3].

Spasticity, which is commonly accompany in stroke patients, causes joint contracture and pain and interferes with rehabilitation [4]. Spasticity is defined as the velocity-dependent increase in muscle tone during passive exercise [5]. Spasticity not only causes severe functional impairment in voluntary movements, gait, balance, but also degrades quality of life [6, 7]. Patients with spasticity were reported to take three times more time to rehabilitate than those who did not [7]. Therefore, it is thought that the treatment of spasticity is important to improve gait training effect in stroke rehabilitation.

Proprioception is the awareness of the orientation of body parts [8]. Position sense is one of the proprioception evaluated for its ability to reproduce a particular location [9]. More than 50 % of stroke survivors were reported to have a negative impact on rehabilitation due to somatosensory deficits. Proprioceptive deficits cause postural instability and safety problems [10].

Stroke patients have increased posture asymmetry due to compensation strategy of lower extremities. Thus, when the weight bearing is biased toward the non-paralyzed lower limb, the movement of the body is also negatively affected. In addition, abnormal muscle tone and movement patterns occur, which makes it difficult to control

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the posture [11]. Stroke patients suffer from postural balance due to lack of these static and dynamic controls [12]. Improper posture control increases the risk of falls in the case of sudden postural fluctuations [13]. Therefore, this lack of balance and posture control can interfere with movements. It causes a fall and causes secondary problems such as fractures [14].

Transcutaneous electrical nerve stimulation (TENS) is a non-invasive electrotherapy intervention that stimulates large sensory fibers, such as Aβ, and is commonly used to reduce pain [15, 16]. TENS increases the cortical-motor excitability of applied body parts, thereby promoting neuroplasticity changes and improving motor recovery after stroke [17]. Recently, however, studies have proved effective in improving motor symptoms [18].

In previous studies using high-frequency TENS, there have been studies in which sensory input stimuli through TENS have improved stroke recovery in stroke patients, and there have been studies that have been effective in reducing spasticity and improving balance when applied to the medial and lateral calf muscles [19, 20]. In another study, the muscle tone and stiffness of the medial part of gastrocnemius were reduced and the BBS scores were improved [21]. A follow-up study of low frequency TENS applied to stroke patients showed a decrease in motor function 3 years later, but the ADL score remained [22].

However, few studies have investigated changes in the proprioception of stroke patients using low frequency TENS, and few studies have compared the differences in the effect of high frequency TENS and low frequency TENS on the prevalence and balance of stroke patients.

The purpose of this study was to compare the effects of high frequency and low frequency TENS on proprioception, spasticity, and dynamic balance in stroke patients.

2. Materials and Methods

2.1. Participants

This study was performed on 20 stroke patients admitted to a rehabilitation hospital. The inclusion criteria for selection were as follows: stroke less than 6 months, Mini-Mental State Examination (MMSE-K) score of 21 points or more, ability to hold for 1 minute in standing position, and independent walking with/without using device.

Exclusion criteria were hemiplegia of flaccid type, orthopedic problems such as joint contracture or fracture, and contraindications of TENS application. In addition, those who had skin problems with electrode application, and hyper sensitivity of electrical stimulation were excluded. Written informed consent according to the ethical standards of the Declaration of Helsinki was provided by all subjects prior to participation. Informed consent was obtained from all patients after sufficient explanation of the procedures.

2.2. Study design

First, the subjects were selected, and the subjects were randomly numbered. We then randomly selected 50 % using the SPSS program's random sampling method. Subjects who were extracted from the program were assigned to the experimental group and the rest to the control group. The experimental group ($n = 10$) received high-frequency TENS and the control group ($n = 10$) received low-frequency TENS. All subjects were blinded to which group they belonged to until the study was completed.

All subjects received neurodevelopmental therapy (NDT) for muscle strengthening and movement re-learning, and TENS intervention was performed after NDT. The intervention was conducted for 30 minutes at a time, five times a week for 4 weeks.

2.3. Intervention

2.3.1. Transcutaneous electrical nerve stimulation (TENS)

TENS was delivered to bilateral gastrocnemius muscles of the subjects using 2-channel TENS (COMBI 500, GymnaUniphy N.V., Belgium). Participants received TENS in prone position on the bed. One of the carbonized gel electrodes was attached to the medial gastrocnemius and the other over the lateral gastrocnemius (Fig. 1).

In order to apply high frequency in experimental group, a biphasic symmetrical stimulus with phase duration of 50 μs and ranging frequency of 70-130 Hz over a five second cycle was used. In order to apply low frequency in control group, the frequency was set at 3 Hz and the pulse duration at 400 μs, and the intensity was adjusted to produce strong and painful sensations [15, 37]. Stimulation intensity was increased until each participant reported a comfortable tingling or buzzing feeling over the site of application [19]. TENS was applied for 20 min in both experimental and control groups.

2.4. Outcome measure

In this study, proprioception was evaluated by determining joint position sense of the ankle in plantarflexion and dorsiflexion. Spasticity was assessed by the grade of Modified Ashworth Scale (MAS) and the amount of resistance. The subjects' dynamic balance ability was assessed by the Timed Up and Go (TUG) test. All measurements were performed before TENS intervention and after TENS intervention for 4 weeks.

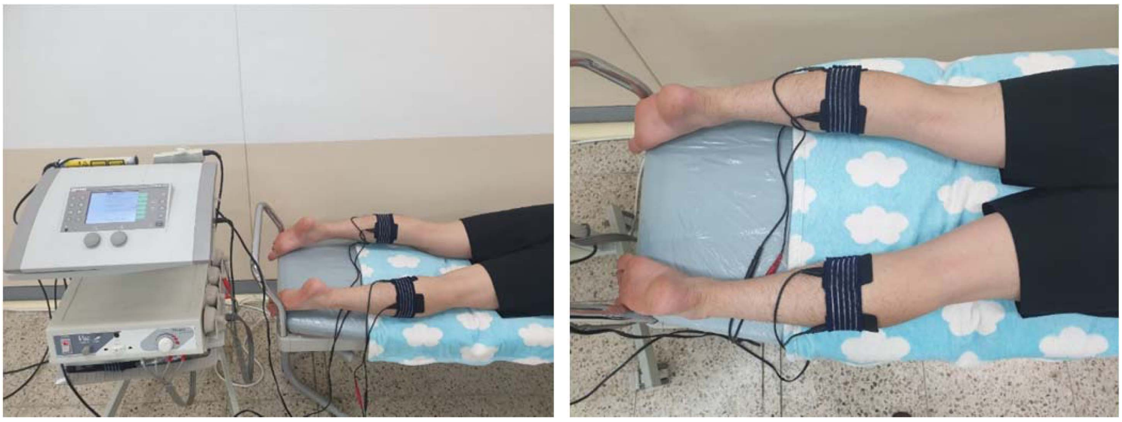

Fig. 1. (Color online) Application of Transcutaneous electrical nerve stimulation (TENS).

2.4.1. Joint position sense of ankle

The joint position sense of ankle was performed on a dynamometer (Biodex Multi-joint System 3; Biodex Medical System Inc., New York, USA). The participants were seated on a Biodex chair with closed eyes to rule out visual clues, and secured with a velcro belt across the chest, pelvis and thigh. The foot of test side was placed on the footplate, and the knee was flexed comfortably. The subject's ankle was passively moved from the neutral position to the plantarflexion or dorsiflexion at 0.25°/s to avoid stretch of the peri-articular structure. The participants were allowed to sense the reference position angle for 10 seconds before the ankle was returned to the start position. The participant then was asked to press the button in his hand to stop the equipment when he felt that the reference position had been reached while the ankle was passively moved again by the dynamometer. The participants were asked to press the button with a non-paretic hand. The equipment then returned the ankle to the neutral position. The error between the reference position and the angle indicated by the participant was calculated, the mean value of three trials was used [23].

2.4.2. Modified Ashworth Scale (MAS)

The amount of resistance was measured by a hand-held dynamometer, it was measured as the amount of resistance when the ankle was passively dorsiflexed in a supine position. MAS was graded by maximum passive stretch of the plantar flexor from ankle plantarflexion to painless range. MAS consists of 6 grades from 0 to 5, and the larger the number means more severe the spasticity [24]. The participant was in relaxed state during the examination of amount of resistance and MAS, and the mean value of three trials was used.

2.4.3. Timed Up and Go (TUG) test

The TUG test measures the time that the subject gets up from a chair with armrests, walks 3 meters as fast as possible, and returns back to sit in the chair [25]. In this study, the mean value was calculated by measuring 3 times at a rest interval of 2 minutes. There are 4 levels of mobility according to the time taken of completion of the test: (1) normal mobility (< 10 sec), (2) good mobility (< 20 sec, can go outside alone or do not need walking aids), (3) limited mobility (< 30 sec, cannot go outside alone or requires walking aids, and (4) dependent mobility (> 30 sec, most of daily activities and mobility are dependent). TUG test has excellent intra-rater ($r = 0.99$) and interrater ($r = 0.98$) reliabilities [26].

Differences in general characteristics between the experimental group and the control group before therapy were compared using independent t-tests and chi-square tests. Paired samples t-tests were performed to assess the before and after effects in each group. Independent samples t-tests were used to assess differences between high frequency TENS and low frequency TENS. For all analyses, p values < 0.05 were considered significant. Data were expressed as the mean ± standard deviation (SD) and statistical analysis was performed using SPSS version 18.0 (SPSS Inc., Chicago, IL, USA).

3. Results

The study and Table 1 summarizes the detailed demographic and clinical information of the subjects. There were no statistically significant differences in general and medical characteristics between the 2 groups. The values of Joint position sense (plantarflexion, dorsiflexion), MAS, amount of resistance and TUG test of the experimental and control groups are summarized in Table 2. There were significant differences between the two groups in the post test of all variance ($p < 0.05$). Further-

Table 1. General and medical characteristics of subjects.

	EG (n = 10)	CG (n = 10)
Age (years)	69.60 ± 3.98[a]	67.70 ± 4.30
Sex (male/female)	6/4	6/4
Duration (month)	4.30 ± .82	4.60 ± .52
Affected side (right/left)	6/4	5/5
Causes (infarction/hemorhage)	7/3	8/2

[a]Mean ± SD, EG: TENS group of high frequency, CG: TENS group of Low frequency

Table 2. Comparison of change in characteristics of the experimental group and control group.

	EG (n = 10)	CG (n = 10)	t	p
Joint position sense plantarflexion (degree)				
Pre-test	6.99 ± .44	7.22 ± .28	-1.39	.18
Post-test	4.20 ± .45	5.55 ± .46	-6.66	.00
t	15.95	8.61		
p	.00	.00		
Joint position sense dorsiflexion (degree)				
Pre-test	6.34 ± .13	6.30 ± .09	.84	.41
Post-test	3.42 ± .22	5.35 ± .11	-24.59	.00
t	28.87	17.79		
p	.00	.00		
Modified ashworth scale (score)				
Pre-test	3.70 ± .67	3.40 ± .70	.98	.34
Post-test	2.50 ± .53	3.20 ± .42	-3.28	.00
t	9.00	1.00		
p	.00	.34		
Amount of resistance (kg)				
Pre-test	12.15 ± 1.73	13.20 ± 2.04	-1.25	.23
Post-test	8.62 ± 1.56	12.30 ± 1.83	-4.85	.00
t	3.85	5.01		
p	.00	.00		
Time up and go test (s)				
Pre-test	26.70 ± 1.77	27.00 ± 1.25	-.44	.67
Post-test	24.00 ± 2.79	26.20 ± 1.23	-2.28	.03
t	2.26	2.75		
p	.05	.02		

[a]Mean ± SD, EG: TENS group of high frequency, CG: TENS group of Low frequency

more, in the experimental groups, significant differences were found in the pre- and post-test for the all variance ($p < 0.05$). Control groups are significant differences were found in the pre- and post-test scores for the Joint position sense (plantarflexion, dorsiflexion), amount of resistance and TUG test ($p < 0.05$).

4. Discussion

This study was conducted to compare the effects of high frequency and low frequency TENS applied to gastrocnemius muscle on proprioception, spasticity, and dynamic balance of stroke patients. As a result, there was no significant change in the spastic score of the MAS using the low frequency TENS in the control group, but there was a significant difference in the joint position sense, amount of resistance, and TUG before and after the intervention in both the experimental group and the control group. In the comparison between groups, there was a significant difference in joint position sense, MAS, amount of resistance, and TUG, indicating that the effect of intervention was greater in the experimental group.

In this study, we conducted a joint position sense test of plantarflexion and dorsiflexion to evaluate proprioception and showed a significant improvement in TENS application. According to previous studies, the application of active TENS via sock electrode showed a significant improvement in proprioception of plantarflexion [27], and some studies showed that proprioception of upper extremity was improved by applying TENS [28]. Because proprioception is affected by bilateral movement of body, the proprioception decrease in the unilateral affected limb after stroke can also cause problems in the non-affected side [29]. Previous studies have reported that the contralateral primary motor and sensory cortex are involved in the integration of sensorimotor information during passive and active movements of the ankle, and premotor cortex, subcortical areas, and cortical associative areas are activated [30]. In previous studies using fMRI, showed the supplementary motor area, the cingulate motor area, basal ganglia, thalamus, primary sensory motor cortex, and cerebellum were activated bilaterally during a proprioceptive activity of knee [31]. Therefore, we suggest that the improvement of proprioception on the affected side through the application of TENS will have a positive effect on recovery of functional movement of stroke patients.

The results of this study showed that the application of TENS reduced spasticity in stroke patients. In previous studies, spasticity was significantly improved compared to the control group with baclofen when the high-frequency TENS was applied to the triceps surae and lateral malleolus of multiple sclerosis patients [32]. Another study reported that the low-frequency TENS applied on gastrocnemius muscle and achilles tendon of CVA patients had a lower MAS score than the sham therapy [33]. These results are consistent with the results of this study which showed the effect of reducing spasticity by applying high and low frequency TENS. This is because TENS increases the pre-synaptic inhibition through activation of the afferent Ia neuron to inhibit the stretch reflex of the spastic muscle [34].

This study showed significant improvement in dynamic balance through the application of TENS, which is consistent with previous studies that reported a decrease in postural sway by applying high frequency TENS to the bilateral gastrocnemius muscle [35]. This suggests that TENS applied to the lower limbs has an effect on the motor cortex through the increase of somatosensory information, thus improving the balance ability [36].

This improvement in balance by TENS is considered to be due to an increase in proprioception input due to somatosensory stimulation of the lower extremities. Since gastrocnemius muscles are very important muscles in the control and maintenance of standing postures, stimulating them would have had a great impact on somatosensory input. Therefore, it is suggested that the increase of somatosensory input by TENS resulted in reorganization of sensory and motor cortex, and thus increased balance [37].

The limitation of this study is that the number of subjects is low and generalization is difficult. In addition, TENS has various effects depending on size and shape of electrode, waveform, frequency, application time, and application site. In this study, we did not include analysis of other variables except frequency.

This study was conducted to compare the effects of high frequency and low frequency TENS applied to gastrocnemius muscle on proprioception, spasticity, and dynamic balance of stroke patients. To compare the effects of TENS, high frequency TENS was applied to the experimental group and low frequency TENS was applied to the control group for 4 weeks.

As a result, the experimental group showed significant differences before and after intervention in joint position sense for evaluation of proprioception, MAS and amount of resistance for evaluation of spasticity, and TUG for evaluation of dynamic balance. In addition, in the joint position sense, MAS, amount of resistance, and TUG, the experimental group showed a significant difference compared to the control group.

Therefore, we suggest that applying high frequency TENS to the gastrocnemius muscle is effective in improving proprioception, spasticity, and dynamic balance in stroke patients.

In order to complement the limitations of this study, we recommend that future studies compare the effect according to size and shape of electrode, type of waveform. This paper was supported by Joongbu University Research & Development Fund, in 2018.

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