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Immediate Effects of Frequency-dependent Electrotherapy on the Gait and Ankle Range of Motion of Chronic Stroke Patients

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주파수에 따른 전기치료가 만성 뇌졸중 환자의 보행 및 발목 관절가동범위에 즉각적으로 미치는 영향

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Abstract Transcutaneous electrical nerve stimulation and interferential current therapy were applied to the plantar flexor of the stroke patients, and the immediately effects on gait and ankle ROM were investigated. TENS group (n=15) and ICT group (n=15) were applied to the paretic side plantar flexor, respectively. After 60 minutes of application, evaluation of the gait and passive ankle dorsiflexion range of motion (ROM) using smartphone. After 60 minutes of application, immediate post evaluation was carried out. Two electrotherapy methods showed a significant increase in gait speed, cadence, and ankle ROM. Two electrotherapy methods were intervention methods that could increase the gait and ankle ROM of stroke patients. More subjects will be needed to pinpoint differences between the two electrotherapy methods.

Key Words : Gait, ICT, ROM, Stroke, TENS

요 약 본 연구는 발바닥 굽힘근에 저주파 치료인 경피신경전기자극과 중주파 치료인 간섭전류가 뇌졸중 환자의 보행 및 발목 관절가동범위에 즉각적인 영향을 미치는지 알고자 한다. 30명의 연구대상자는 경피신경전기자극군과 간섭전류군으로 동일하게 나누어 마비측 장딴지근에 각각 통전하였다. 60분 통전 직후 스마트폰을 이용한 보행 평가와 발등 굽힘 관절가동범위를 측정하였다. 연구결과 두 전기치료 방법 모두 보행속도, 분속수, 발목 관절가동범위에 유의한 증가를 보였다. 두 전기치료 방법 모두 뇌졸중 환자의 보행 및 발목 관절가동범위를 증가시킬 수 있는 중재 방법이었지만 두 전기치료 방법 간의 차이는 더 많은 대상자 모집을 통해 확인되어야 할 것이다.

주제어 : 보행, 간섭전류치료, 관절가동범위, 뇌졸중, 경피신경전기자극

1. INTRODUCTION

1.1 Introduction

Patients with stroke can recover their physical function to a certain level over time, but the possibility of a complete functional recovery is not clear. Functional gait recovery is one of the most important goals in enabling stroke patients to return to a normal life routine [1-4].

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Decrease in gait velocity in stroke patients is largely associated with leg muscle strength and motor function [5]. Compared to other joints, for joint position sense, the ankle joint position sense affects the variation in stride length and gait velocity [5]. Ankle dorsiflexor strength affects temporal asymmetry and velocity in gait, while spatial asymmetry appears due to spasticity of plantar flexion during gait [6]. Therefore, for gait recovery, the range of motion and function of the ankle joint must be restored.

Although the stiffness of the ankle joint in stroke patients may appear as an extension of resistance during passive movement arising from contracture of plantar flexors muscle, it is better to prevent occurrence of such contracture of the ankle joint than treat it afterward [7]. Although plantar flexion induces muscle stiffness during movement such as gait, [7], electrotherapy or rehabilitation is able to reduce stiffness [8].

Low frequency transcutaneous electrical nerve stimulation (TENS) is a therapeutic method developed to reduce pain [9]; additional therapeutic effect includes reducing spasticity by separating gamma-aminobutyric acid in the dorsal root of the spinal cord [10] when electrical stimulation is conducted at 100 Hz [11]. When combined with exercise, the treatment improves leg function as well as spasticity in patients with stroke [12].

Intermediate frequency interferential current therapy (ICT), in contrast, has less skin resistance compared with low frequency current, with a smaller depth of penetration of the electrical current [13]. ICT stimulates 100 Hz by interfering with 4100 Hz and 4000 Hz[13]. It is reported to improve the ankle range of motion and balance ability when applied to plantar flexor of stroke patients [14].

Despite previous studies showing that electrotherapy reduces spasticity and thus enhances gait ability [11,14], there have been not enough studies comparing the effects of low frequency treatment and intermediate frequency treatment. The purpose of this study is to compare the effects of gait ability and range of joint motion after applying TENS and ICT in stroke patients.

2. METHODS

2.1 Study Participants

This study was carried out on 30 stroke patients admitted to A, J Rehabilitation Hospital in Gyeonggi-do. The inclusion criteria for participants were chronic stroke (of more than six months' duration) diagnosed by a specialist using computerized tomography or magnetic resonance imaging; ability to walk 10 m or more without neurological, orthopedic, or cardiopulmonary problems that may affect gait, other than stroke [15]; no skin disease; and score of at least 24 points on K-MMSEs (Korea version of Mini-Mental State Examination).

The research was explained to potential participants, all participants signed an informed consent form before they were recruited to participate. The study was approved by the Institutional Bioethics Committee (2-1040966-AB-N-01-20-1804-HSR-101-3).

2.2 Study Procedure

The 30 stroke patients in this study were divided into two groups, TENS and ICT groups. An occupational therapist who was not part of this study randomly assigned 15 people each to the two groups by drawing lots. Assessments were conducted by another occupational therapist who was unrelated to the study, after learning the assessment method. Both groups underwent a preliminary evaluation and a post- evaluation was conducted immediately after receiving 60 minutes of electrotherapy.

2.2.1 Measurement Tools

1) Gait Measurement

For gait measurement, a smartphone application 'Gait Analysis Pro' (Gait Analysis Pro, YTA KK, Japan), was used. The principle is that the accelerometer built into the smartphone detects movement in both the x-axis and y-axis and calculates data while walking. The sampling rate was set at 100 Hz and could be automatically analyzed by the smartphone. In this study, the smartphone was placed on the third lumbar vertebra. Participants were prepared for measurement in the standing position, during which the investigator touched the smartphone screen for calibration.

After calibration was completed, the investigator again touched the smartphone screen. Subjects walked along the footpath (10 m) at a comfortable gait speed. After 10 m walk, the results were collected by touching the smartphone screen. This application has a high correlation index with GAIT Rite analysis system in terms of gait speed (r = 0.99) and cadence (r = 0.97) but shows moderate correlation in terms of step length (r = 0.41) [15]. In this study, gait speed and cadence were selected as the outcome measures.

2) Measurement of Range of Motion

The range of motion was measured with a smartphone. The principle is that an angle appears when the smartphone is tilted from a flat surface. In this study, the slope of the paretic heel in contact with the floor was measured from the ground at the lunge position. The smartphone was placed with its base 1 cm above the Achilles tendon. The measurement was conducted on a flat surface. Therefore, the angle of inclination between the Achilles tendon of the paretic lower limb and the level surface was used as the dorsiflexion range of motion. For safety, two study assistants were present, parallel bars were place in front of participants for them to hold on to in the lunge position. Measurements were made before the participants' feet fell to the ground, and if the feet fell to the ground, they were re-measured with the feet back to its original position. The measurement of joint range of motion using the smartphone showed a high reliability of 0.08 [16].

2.2.2 Intervention Methods

1) TENS Group

To investigate the electrostimulation effect of TENS, we applied TENS to medial and lateral paretic planta flexor muscles [17], two channel TENS (TENS-70000, Koalaty products INC, USA) was used. The frequency was fixed at 100 Hz and the pulse width was 200 us. In order to measure the sensory threshold of each subject before stimulation, the threshold of the subject's sense of stimulation was examined, starting from 0.01 mA, and stimulated for 60 min at twice the individual's sensory threshold [17]. Total treatment time was 60 min.

Table 1. General characteristics of subjects

Variable	TENSG(n=15)	ICTG(n=15)	p
Gender (male/female)	6/9	9/6	.273
Paretic side (left/right)	4/11	6/9	.439
Age (years)	65.53±7.73	64.47±8.26	.718
Height (cm)	165.27±6.35	161.80±9.17	.239
Weight (kg)	65.67±8.72	67.33±8.35	.597
Onset time (month)	12.27±2.02	13.07±2.34	.605
K-MMSE (score)	25.20±1.39	25.80±2.34	.379

Mean±SD, *p<.05, **p<.01
TENSG: transcutaneous electrical nerve stimulation group
ICTG: interferential current therapy group
K-MMSE: Korean-mini mental state examination

2) ICT Group

In order to examine the effect of ICT stimulation, an interference suction low frequency stimulator (ProMed III, STI-500, StraTek, Korea) was used. For the ICT application group, four-pole placement method was applied to the paretic side of the plantar flexor using four pads. In order to set the amplitude modulated beat frequency at the treatment site to 100 Hz (using the formula of N = $f1-f2$), one intermediate frequency 'f' was set to 4000 Hz and the frequency of the other intermediate frequency was set to 4100 Hz. In order to apply the maximum interference effect of the intermediate frequency, the intersecting vector direction (45 °) was set according to the driving direction of the plantar flexor muscles by dividing the electric current lines connecting the four electrodes. Total treatment time was 60 min. The duty cycles were set to 50% so that the actual stimulation time was 30 min [18].

2.3 Data Analysis

Statistical analysis was performed with SPSS 20.0 and G power. All participant data were tested for normality of variables using Shapiro-Wilk test, descriptive statistics and chi-squared test were used for subject homogeneity test. To verify the effect of applying ICT or TENS, effect sizes using mean difference from one constant sample were obtained. A paired t-test was used for pre- and post-comparisons within each group, and an independent t-test was used for comparing the different values between groups (post-pre). The statistical significance level was set as α = .05.

3. RESULTS

3.1 General Characteristic of Participants

Table 1 showed that study participants in both groups were homogenous as there was no significant difference in their general characteristics.

3.2 Change of Gait and ROM

Gait speed, cadence, and ankle ROM increased significantly in both the TENS and ICT groups immediately after intervention, and there was no significant difference between the two electrotherapy methods. However, the effect size of the TENS group was 0.67 (gait speed), 0.72 (cadence) and 0.70 (ankle ROM), whereas for the ICT group, the effect size was 1.16 (gait speed), 0.75 (cadence) and 0.89 (ankle ROM).

Table 2. Change of gait and ROM

Variable		TENSG (n=15)	ICTG (n=15)	p
Gait speed(m/min)	Pre	22.11±5.73	22.83±8.09	.779
	Post	24.90±7.74	26.37±9.31	.641
	Post-Pre	2.79±4.15	3.54±3.04	.578
	Effect size	0.67	1.16	
	p	.021*	.001**	
Cadence(step/min)	Pre	109.45±17.81	109.22±22.19	.975
	Post	112.89±19.06	114.57±17.40	.802
	Post-Pre	3.43±4.77	5.35±7.11	.392
	Effect size	0.72	0.75	
	p	.015*	.011*	
Ankle ROM(°)	Pre	2.73±5.65	1.67±4.98	.588
	Post	4.33±4.47	4.07±3.56	.858
	Post-Pre	1.60±2.29	2.40±2.69	.389
	Effect size	0.70	0.89	
	p	.017*	.004**	

Mean±SD, *p<.05, **p<.01
TENSG: transcutaneous electrical nerve stimulation group
ICTG: interferential current therapy group
ROM: range of motion

4. Discussion

Functional improvements such as balance and gait in stroke patients are caused by increased compensatory movement patterns rather than recovery of adjusted motor ability [19]. Therefore, rehabilitation of chronic stroke patients should be immediate and efficient for improvement in movement. In this regard, in order to promote effective functional movement in chronic stroke patients, physical therapy that enhances balance ability immediately and effectively should be given before exercise therapy. TENS and ICT, used as physical therapy, are an effective method for improving the balance ability of patients with central nervous system damage when applied immediately [18, 20]. However, there are few studies confirming gait changes following TENS and ICT treatment, and no comparison between the two interventions. The aim of this study was to determine which electrotherapy method was more effective for improvement in gait and ankle range of motion.

The results showed that both TENS and ICT significantly increased ankle dorsiflexion range of motion and gait. However, there was no significant difference between the two intervention methods.

TENS applied to patients with stroke immediately reduced EMG amplitude [11] and improved leg functional levels when combined with exercise therapy [12]. In this study, ankle range of motion was increased after TENS. Park *et al.* [21] reported a decrease in plantar flexor muscle tone after TENS, and indicated that the result was due to the decrease in spasticity. This resulted in an increase in ankle dorsiflexion mobility, which contributed to improving balance ability, leading to increase in Berg balance scale (BBS) scores. In this study, we think that the improvement in gait velocity was due to the improvement in ankle dorsiflexion mobility.

ICT also decreased the modified Ashworth scale, increased ankle range of motion, BBS, timed up and go scores, and functional reaching test results [14]. In addition, the 10 m walk test results, which shows balance ability, was also improved [18]. However, the improvements in balance ability confirmed in previous studies were measured by simply assessing time for a 10 m walk. This study has clinical significance in that it utilized a smartphone with a built-in gyroscope and accelerometers that can be easily used clinically. In this study, there was no significant difference between TENS and ICT, but the effect sizes in the outcome measures were larger in the ICT group.

Suh *et al.* [18] indirectly compared TENS results from previous studies based on the fact that ICT decreased spasticity when applied to plantar flexor muscles of stroke patients; and found that TENS decreased spasticity by 29% compared to 41% by ICT, indicating that ICT is a better method for reducing spasticity. In this study, we directly compared both methods. Although there was no significant difference between them, ICT showed greater effect sizes than TENS.

The intermediate frequency, which has physiological benefits similar to those of low frequency, interferes with and reinforces the two waves, producing low frequency waves at specific site points [22]. ICT has been reported to have a deeper penetration depth of electric current at specific sites because the skin resistance is less than that of a method using low frequency current. This is due to the characteristics of intermediate frequency electric currents [13]. In a study comparing patients' pain levels, there was no significant difference in pain level after application of TENS and ICT, but ICT further reduced pain than TENS, and ICT was preferred for the comfort and pain relief effect of electrostimulation [23].

Therefore, the increase in effect size seen in this study may be the result of the penetration of higher electric current into the tissues. In addition, intermediate frequency electric current can reduce neural compliance. In this study, the electric current for ICT was applied for 60 min, but the duty cycle was set to 50%, so the actual treatment time was only 30 min. Thus, despite the lower amount of current applied, better effect sizes were

obtained compared to TENS.

This study was designed to determine the immediate effect of electrotherapy while excluding the effect of other modes of therapy; thus, we were unable to confirm long-term effects like effectiveness when combined with continuous exercise therapy. A limitation of this study was the small sample size. Cohen's [24] classification indicates that the minimum number of subjects is 42 when the effect size is large (0.80). The low effect sizes (gait speed = 0.20) and the small number of subjects in this study seemed to make it difficult to differentiate between the two electrotherapy methods. In the future, more studies will be required to compare ICT and TENS effects with a larger sample size and more long-term outcomes.

5. Conclusion

In this study, TENS and ICT were applied to the plantar flexor muscles to identify effective intervention methods to improve gait and ankle range of motion in stroke patients. Both electrotherapy methods had an immediate effect in terms of improving gait and ankle range of motion. However, there was no significant difference between the two interventions, with ICT having larger effect sizes. We conclude that TENS and ICT are effective for improving gait and ankle range of motion in stroke patients and recommend further studies with a larger sample size to confirm the significant difference between the two intervention methods.

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