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Effects of ESWT, FES, and TENS on the muscle tone and activity functions of stroke patients

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***Abstract*---**This study was conducted to investigate the therapeutic effects of three electrotherapy intervention methods on abnormally elevated muscle tone and reduced functional activities, such as walking, in stroke patients with central nervous system (CNS) injuries. A total of 32 subjects diagnosed with stroke were randomized into three experimental groups: Experimental Group 1 received extracorporeal shock wave therapy (ESWT); Experimental Group 2 received functional electrical stimulation (FES); and Experimental Group 3 received transcutaneous electrical nerve stimulation (TENS). MyotonPRO was used to measure abnormal muscle tone in stroke patients, and the timed up and go test (TUG) was employed to evaluate their functional activity by measuring their gait speed before and after the interventions. All three therapeutic interventions were applied to the triceps brachii, wrist extensors, quadriceps femoris, and tibialis anterior muscles three times a week for six weeks. In this study, decreased muscle tone of the triceps brachii and the wrist and increased gait speed were observed in Experimental Group 1, and decreased muscle tone of the tibialis anterior muscle and increased gait speed were observed in Experimental Group 2. The findings of this study suggest that the selection of an appropriate therapeutic intervention according to the type of stroke patient could have a significant effect on post-stroke rehabilitation, and it would be necessary to apply specialized therapeutic interventions in the treatment of these patients.

Keywords*---electrotherapy, cerebrovascular disease, proprioception, rehabilitation.*

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Introduction

Stroke refers to a cerebrovascular disease caused either by interruption of the blood supply to the brain or by cerebral hemorrhage within the brain tissue, leading to functional loss in the brain, which controls motor and sensory nerves. Although the overall incidence and prevalence of stroke have gradually decreased because of lengthening lifespans, advancements in preventive medicine, and various other factors, the post-stroke disability rate among survivors has increased. Stroke usually results in hemiplegia (Caprio et al., 2019). Although the recovery of lower extremity function in stroke patients is usually effective, the recovery of upper extremity function is not. For this reason, more than 50% of patients with post-stroke hemiplegia suffer from paralysis of the upper extremities, which leads them to have a dysfunctional arm temporarily or even permanently, which prevents them from using the affected arm in daily life (Knight-Greenfield et al., 2019).

The compromised motor function in stroke patients results from paralysis of the contralateral half of the damaged cerebral hemisphere, which leads to motor and sensory impairments. Stroke patients are known to experience various problems in their daily functional activities because of impairments caused by synergic movement patterns or slow responses. Impairments can also be caused by abnormal gross and fine motor functions, which restrict them from normal gait or upper extremity movement. In addition, as one of the diseases that cause long-term disability, stroke reduces mobility and daily living ability (Kimura 2019). Because of the lack of exercise ability in the lower extremities of stroke patients, their walking ability and balance are compromised, which increases the risk of falls. Decreased walking ability and upper extremity activity due to increased spasticity in the upper and lower extremities and sensory dysfunction on the affected side of hemiplegic patients are known to be the main factors that impede their ability to live independently. The gait patterns of stroke patients are characterized by a slow gait cycle and speed, a large difference in stride length between the affected side and the unaffected side, as well as a short stance phase and a long swing phase on the affected side (Iadecola et al., 2020).

In post-stroke rehabilitation, intensive training is essential for the effective recovery of the motor skills of hemiplegic patients and the reorganization of their nervous tissues. In addition, recent treatment strategies have emphasized avoiding learned non-use and increasing the use of the paralyzed upper extremity to facilitate the recovery of upper extremity function in hemiplegic patients after a stroke (Medeiros et al., 2020). Spasticity, weak upper extremity muscle strength, and sensory impairment occurring after a stroke lead to the loss of upper extremity motor control, and as a result, independent activities in daily living, such as dressing, eating, and personal care, become limited. The loss of function in stroke patients hinders their independence in daily activities and increases their dependence, which plays a significant role in lowering their quality of life (Salazar et al., 2019; Lee et al., 2019).

Extracorporeal shock wave therapy (ESWT) is a non-surgical treatment method that can be used as an alternative to surgery for the treatment of various musculoskeletal diseases that are difficult to treat using conventional conservative treatment, including orthopedic diseases such as calcific tendonitis (Auersperg et al., 2020). The shock wave used in ESWT is characterized by the delivery of large pressure energy at supersonic speeds in a short period. When a shock wave is irradiated to the interface between the bone and the soft tissue, the expansion wave is transmitted into the bone, and the pressure wave is deflected to the soft tissue. Similar to sound waves or light, shock waves are characterized by reflection, penetration, and diffraction. Furthermore, these powerful pressure waves are faster than sound waves, and unlike light, they generate a pressure conversion effect that induces the movement of the surrounding fluid or solid material (Simplicio et al., 2020).

ESWT generates high-amplitude pressure from outside the body and then focuses this energy on the diseased treatment area. Various mechanisms of its histological and physical effects have been described, such as the removal of stones. It has been reported that direct stimulation by extracorporeal shock waves (ESW) induces a healing response at the cellular level and activates tissue growth factors, thereby promoting the formation of new blood vessels (Liu et al., 2019). In addition, shock wave stimulation has the effect of increasing the pain threshold by causing a repressive effect on nociceptors. Its various biological effects, including inflammation reduction and wound healing, have also been reported. The therapeutic principle of ESWT is to expose lesions in the musculoskeletal region precisely by transmitting energy to an extent that does not harm the human body, thereby causing physical changes in the cell membrane (Feng et al., 2021).

Functional electrical stimulation (FES) is the most commonly prescribed method in clinical practice to prevent functional and physiological changes caused by muscle paralysis (Jung et al., 2017). While general electrical stimulation focuses on muscle reeducation and muscle atrophy prevention in patients with peripheral nervous system (PNS) lesions or pain, FES applies electrical stimulation to muscles that, because of CNS lesions, cannot be under normal nerve control to enable them to move functionally. A dynamic auxiliary training method, FES provides electrical signals to muscles with motor mobilization impairment to induce functional muscle contraction. Such stimulation can improve the control ability of the stiff extensor through intensive strengthening of the affected upper and lower extremities, thereby increasing coordinated movement in the patient (atkins et al., 2021).

In FES, an electric current is applied to the muscle, and the electric current induces an action potential in the peripheral nerve, which causes muscle contraction. The effects of FES on the lower extremities include activation of the dorsal flexor muscle to reduce foot drag caused by plantar flexor stiffness and increase range of motion, which leads to an increase in gait speed (Sivaramakrishnan et al., 2018). FES applied to the tibialis anterior muscle in stroke patients can improve muscle strength through neurological feedback. A previous study reported that FES combined with gait training improved the strength of the dorsiflexor muscle during the swing phase in stroke patients and reduced unnecessary synergistic movement (Moll et al., 2017).

Transcutaneous electrical nerve stimulation (TENS) therapy, which is applied to patients with pain caused by post-stroke muscle tension, can relieve muscle tension by stimulating peripheral sensory nerves in the skin using a low-frequency current. It is also known to have analgesic effects through pain mechanisms, such as gate control theory and endorphin theory (Zhou et al., 2018; Lee et al., 2020). This treatment method can be applied while freely controlling frequency and stimulation intensity. According to gate control theory, thick nerve fibers are stimulated by transcutaneous nerve stimulation to the extent that no pain is felt, suppressing the delivery of stimulation by the nerve fibers that transmit pain. As a result, pain is controlled by efferent stimulation descending from the brain (Astokorki et al., 2017). In contrast, according to endorphin theory, during electrical stimulation, a large number of endorphins are produced in the spinal fluid and the brain to control pain. Based on these theories, TENS therapy can provide electrical stimulation for cell recovery following cell damage by controlling the period of current flow. It can also promote the movement of important cells required for recovery according to polarity (Elboim-Gabyzon et al., 2019).

When functional movements are performed, a movement pattern combining multiplanar and rotational elements that mobilize gross muscle groups occurs, so muscle weakness due to damage to the nervous system can cause functional limitations in a patient's movement. In other words, in the rehabilitation of patients with nervous system damage, gross motor exercise methods that enhance the mobilization of muscles are required (Segarra et al., 2019). When a patient with functional limitations performs a movement incorrectly, those muscles can help the patient by correcting it through the compensatory action of other muscles. PNF is an appropriate treatment method for use in gross motor exercises. PNF improves function by stimulating proprioceptive groups in muscles and tendons, increasing muscle strength, flexibility, and balance, and enhancing coordination in response to neuromuscular stimuli. Furthermore, PNF is known to be effective in inducing maximal responses by the motor unit (Gunning et al., 2019).

Currently, in clinical practice, treatment using electrical stimulation, which has few side effects and is easy to manipulate and control, is applied in several fields. However, little research has been conducted to determine the most effective and efficient electrical stimulation method for treating abnormal muscle tension and the reduced functional activity that occurs after a stroke. Therefore, in this study, we applied ESWT, FES, and TENS, which are the most commonly, used in clinical practice among post-stroke electrical stimulation treatments, to investigate their effects on the muscle tone and functional activity of stroke patients.

Study methods

Subject

In this study, 32 patients who had been diagnosed with stroke and had visited a rehabilitation hospital were selected as subjects. The inclusion criteria were patients with scores of 24 or higher on the Korean mini mental state examination (MMSE-K), patients with a Bug balance scale (BBS) score of 24 or higher, patients without hypersensitivity to electrical stimulation, patients who had had surgery on an upper or lower extremity more than six months previously, patients who were not taking antidepressants, patients who were not taking anticonvulsants, and patients who could understand the researcher's instructions. The exclusion criteria were patients with severe spasticity, incapable of passive extension of the upper extremity and passive flexion of the lower extremity, patients who were unable to walk or had poor stability while walking, patients with orthostatic hypotension, patients in whom the disease was aggravated by fractures or damage to a joint, and patients who could not continue to participate in the study.

Patients who met all the inclusion criteria were randomly assigned to Experimental Group 1 (11 patients), Experimental Group 2 (10 patients), or Experimental Group 3 (11 patients). After a general explanation of the purpose, procedure, treatment, efficacy, and side effects of the experiment before the start of the study, the subjects signed a written informed consent form before participating in the study. All procedures in this study were conducted according to the regulations on research ethics in compliance with the Declaration of Helsinki. Experimental Group 1 received ESWT, Experimental Group 2 received FES, and Experimental Group 3 received TENS. In this study, the therapeutic intervention method applied to each experimental group was performed three times a week for six weeks, a total of 18 applications. Prior to the experiment, a physical therapist with more than five years of clinical experience conducted pre-evaluations, and the same physical therapist conducted post-evaluations after the final application of the intervention (Figure 1).

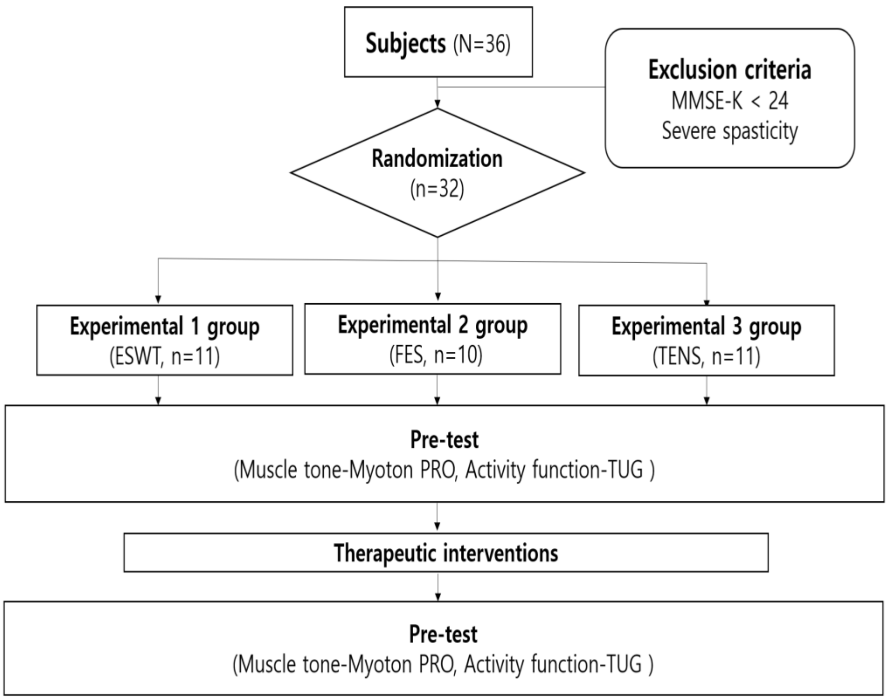

Figure 1. *Flow chart of study*

Evaluation Methods

Muscle tone

Muscle tone is determined by the mechanical stiffness and elasticity elements of the skeletal muscles. Muscle tone provides tension during posture maintenance and active movements. In addition, it enables sufficient movement during muscle contractions without spontaneous movement. The maintenance of muscle tension is achieved neither by reflexes nor by mechanical mechanisms. In this study, the term muscle tone refers to the elasticity and stiffness of a muscle.

Muscle tone was measured using Myoton PRO (Myoton Ltd., UK) in the multi-scan mode, which showed an average value of 10 taps. In the subject's sitting position, muscle tone was measured at the proximal musculotendinous junction on the insertion regions of the triceps brachii and the wrist and finger extensors. In addition, muscle tone was measured at the proximal musculotendinous junction on the insertion region of the quadriceps femoris and at the distal musculotendinous junction at the origin of the tibialis anterior muscle while the subject was in the supine position with the knee joint maintained at 30 degrees of flexion and the tool maintained vertically. The average value of the three measurements for each region was used for the analysis.

Activity Functions

In this study, the TUG test, which simultaneously measures the gait and balance ability of stroke patients, was applied. The TUG test quickly measures basic mobility and balance in the length of time it takes for a subject sitting on a chair with armrests to rise and walk 3m, and return to sit on the chair. If it takes more than 30 seconds, the subject is considered incapable of moving outdoors alone, as basic mobility is dependent. It takes less than 10 seconds for normal adults and 11 to 20 seconds for frail elderly or disabled persons to complete this exercise. If it takes more than 20 seconds, functional motor impairment is indicated. The TUG test is an evaluation tool that has been used to predict the risk of falls by evaluating balance ability and functional movement in the elderly. It has recently been applied to patients with stroke, Parkinson's disease, and arthritis.

Treatments

ESWT

ESWT was applied to a position 1 cm above the lateral epicondyle, which is the origin of the extensor muscles of the hand and wrist joints, and to the musculotendinous junctions on the insertion regions of the triceps brachii, quadriceps femoris, and tibialis anterior muscles. An ESWT machine (Optimus, Salus Talent 3, Korea) that generated shock waves was used to apply ESWT to each site. The patients sat comfortably on a chair with a backrest, and ESWT was applied while they extended their elbow joints as much as possible through a passive assistive exercise.

The same shock wave stimulation was applied to each musculotendinous junction part, 300 times each at a frequency of 2 Hz and a power of level 1, a total of 1,200 times, which was defined as one set. In this study, two sets of ESWT were applied to each of the four regions, and a break of one minute was provided after each region was treated.

FES

In this study, an FES device (Microstim, Germany) was used to apply FES to the triceps brachii, wrist, finger extensors, quadriceps femoris, and tibialis anterior muscles of the patient in a stable sitting position. The intensity of the electrical stimulation was adjusted to the extent that sufficient movement was observed in the upper extremities.

In addition, the intensity was fixed from 15–20 Hz to achieve complete contraction by minimizing fatigue while obtaining the necessary contractile force through repetition of the stimulation wave. Such waveforms reduce pain or discomfort caused by stimulation, reduce muscle fatigue, and help achieve strong contractile force, so they are widely used for the control of paralysis in the upper and lower extremities. The treatment time was set at 25 minutes.

TENS

A TENS treatment device (H-3000, Korea) was used to apply TENS to relieve muscle tone. The voltage and frequency were set at AC 220, 20 Hz, and stimulation was applied to the triceps brachii, wrist, and finger extensors, quadriceps femoris, and tibialis anterior muscles. TENS was regulated to provide low-frequency, high-intensity stimulation, and the treatment intensity was set so that contractions were visible without causing pain. For the position and arrangement of the electrodes of the TENS treatment device, a multichannel arrangement method using eight electrodes from four channels was used, and the treatment time was set at 25 minutes.

Data Analysis

The collected data were analyzed using the statistical processing program SPSS version 18.0, and the mean and standard deviation of the dependent variables were calculated. The difference between the pre-evaluation and the post-evaluation of the experimental groups was investigated using the corresponding sample t-test, and the difference in the size of the treatment effect according to the treatment method was compared using ANOVA. Post hoc tests were performed using Duncan. The statistical significance level α was set at 0.05.

Results

The comparison of the average muscle tone measurements in the muscle tone test before and after intervention yielded the following results: In Experimental Group 1, to which ESWT was applied, a reduction in muscle tone was observed in all regions. The average muscle tone measurements were 14.65 ± 3.45 before the intervention and 12.53 ± 4.19 after the intervention in the triceps brachii; 12.29 ±

2.96 before the intervention and 10.99 ± 3.21 after the intervention in finger and wrist extensors; 17.85 ± 4.15 before the intervention and 16.29 ± 3.19 after the intervention in the quadriceps femoris; and 16.67 ± 3.16 before the intervention and 16.01 ± 3.11 after the intervention in the tibialis anterior muscle (Figure 2).

In Experimental Group 2, to which FES was applied, a reduction in muscle tone was observed in all regions. The average muscle tone measurements were 15.32 ± 4.15 before the intervention and 14.96 ± 3.78 after the intervention in the triceps brachii; 12.97 ± 1.98 before the intervention and 12.01 ± 2.53 after the intervention in finger and wrist extensors; 18.24 ± 5.23 before the intervention and 17.97 ± 4.75 after the intervention in the quadriceps femoris; and 16.12 ± 3.67 before the intervention and 14.22 ± 2.61 after the intervention in the tibialis anterior muscle (Figure 3).

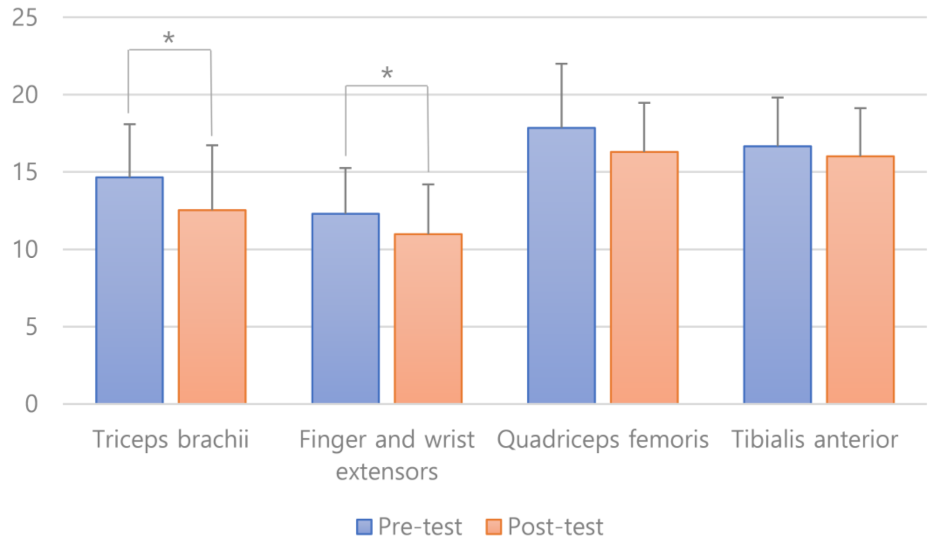

Figure 2. *Comparisons of muscle tone between pre-test and post-test in experimental group 1*
*p<0.05, Mean±SD; Mean±standard deviation

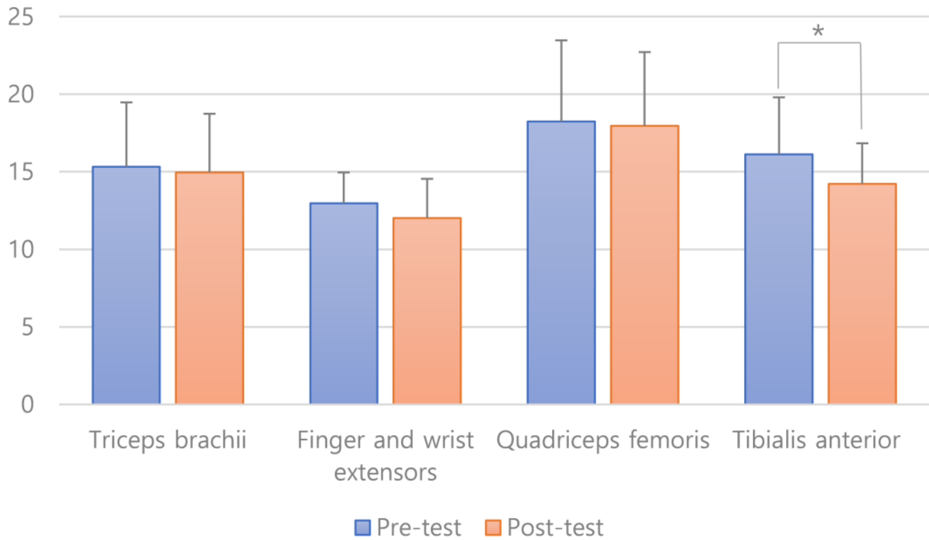

Figure 3. *Comparisons of muscle tone between pre-test and post-test in experimental group 2*
*p<0.05, Mean±SD; Mean±standard deviation

In Experimental Group 3, to which TENS was applied, a reduction in muscle tone was observed in all regions. The average muscle tone measurements were 14.26 ± 3.11 before the intervention and 13.96 ± 4.67 after the intervention in the triceps brachii; 12.78 ± 2.67 before the intervention and 12.78 ± 2.67 after the intervention in finger and wrist extensors; 17.32 ± 4.78 before the intervention and 17.22 ± 4.22 after the intervention in the quadriceps femoris; and 15.85 ± 3.90 before the intervention and 15.25 ± 4.79 after the intervention in the tibialis anterior muscle (Figure 4).

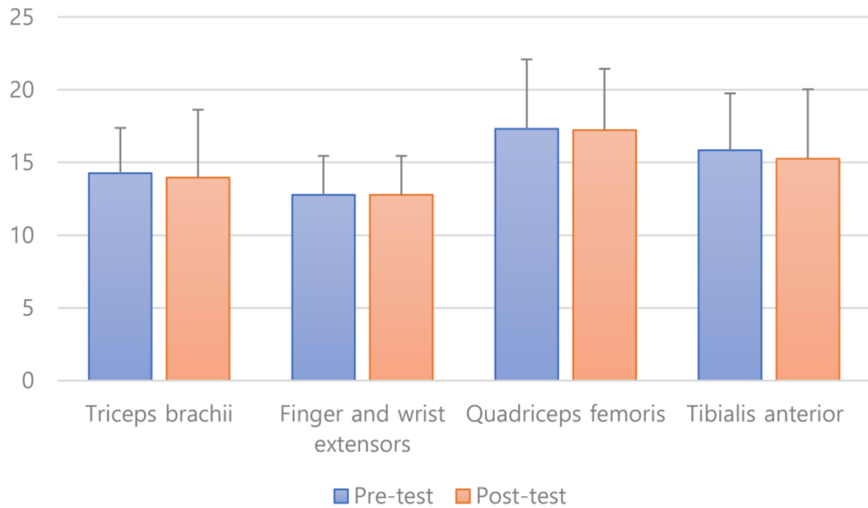

Figure 4. *Comparisons of muscle tone between pre-test and post-test in experimental group 3*
*p<0.05, Mean±SD; Mean±standard deviation

Statistically significant changes in measurements were found after the intervention in the triceps brachii and the finger and wrist extensors in Experimental Group 1 and in the tibialis anterior muscle in Experimental Group 2, compared with the measurements before the intervention. However, no statistically significant change was found in the comparison of the average measurements before and after the intervention in Experimental Group 3.

The comparison of average gait speed measured by the TUG test before and after the intervention showed the following results: In Experimental Group 1, to which ESWT was applied, gait speed increased statistically significantly from 24.54 ± 7.36 before the intervention to 21.57 ± 6.27 after the intervention. In Experimental Group 2, to which FES was applied, the average gait speed increased significantly from 25.34 ± 8.25 before the intervention to 23.11 ± 6.36 after the intervention. However, in Experimental Group 3, to which TENS was applied, the average gait speed was 23.59 ± 8.47 before the intervention and 22.81 ± 6.24 after the intervention, and no statistically significant change was found (Figure 5).

Discussion

The timing of interventions in stroke patients is a critical element in post-stroke rehabilitation. The active treatment of acute-stage patients has a positive effect on their functional recovery after a stroke (Arya et al., 2018). The functional level of most stroke patients recovers within three months after the onset of the disease, gradually improving between three and six months thereafter. In particular, limitations in functional activities that may occur due to motor and perceptual/cognitive impairments in stroke patients hinder the recovery of a patient’s activities after a stroke (Alawieh et al., 2018).

For efficient post-stroke rehabilitation treatment, joint exercise is required to prevent contracture in major joints within a few days of the onset of stroke. In addition, the post-stroke rehabilitation of patients should be aimed at restoring their function and helping them lead independent daily lives. In the course of the functional recovery process of stroke patients, improving walking ability is the main goal of physical therapy (Niu et al., 2019). The gait pattern of stroke patients is characterized by slow speed, excessive effort, and poor coordination. Gait speed is an important element that negatively affects a patient’s walking ability, their ability to function physically, and therefore their ability to live independently (Wonsetler et al., 2017).

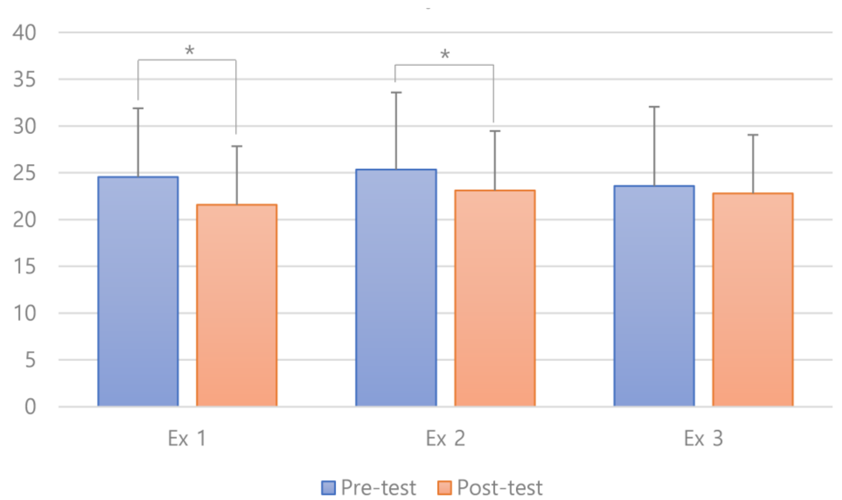

Figure 5. *Comparisons of TUG between pre-test and post-test*
*p<0.05, Mean±SD; Mean±standard deviation

The advantage of ESWT is that it offers non-surgical and non-invasive treatment options. In addition, it can be applied easily to patients with musculoskeletal system disorders (Reilly et al., 2018). Moreover, because the recovery time after treatment is fast, its impact on daily life is minimal. The advantages include the non-requirement of pre-procedural preparations, such as anesthesia. There are few side effects, and compared with the effectiveness of this treatment, the cost is low. It has been reported that ESWT can be used as a therapeutic tool for patients with neurological diseases, such as dystonia and convulsions, in addition to patients with musculoskeletal disorders (Korakakis et al., 2018).

Based on the energy transfer method, there are two types of ESW: concentrated and radial. In radial ESW, the air condensed by the pneumatic device inside the shock wave is instantaneously released and collides with several pendula arranged in a straight line, which generates a pressure wave. As a result, energy is radially diffused. In concentrated ESW, some piezoelectric elements are sporadically arranged on a conical collecting plate inside the shock wave, which concentrates individual shock waves generated by the piezoelectric effect after electrical stimulation at one point (Raza et al., 2017).

In ESWT, a small tensile wave element is represented by one main positive pressure wave that has a frequency range of several kHz to 10 MHz or more. The focal area of ESWT is the position in which the shock wave is focused during treatment, which is reached by 80% of the maximum amount of emitted energy (Gomez-Garcia et al., 2017). The energy in this focal area is defined as the energy density per shock, and the unit area is recorded in joules. The dosage of ESWT is specific to each subject according to their pain level. Therefore, it is important to find the appropriate dosage for each patient and indication. The patient should be closely monitored during treatment, which begins with a low energy level at the site with the severest pain. The energy level is then increased as the treatment progresses (Porst 2021).

In ESWT, changes in pressure are delivered to elastic materials, such as gas, liquids, and solids, at the speed of ultrasound using pressure waves induced by a high-speed oscillation phenomenon. ESWT also increases blood flow by pulverizing bodily deposits, triggers the healing process through an inflammatory response, and controls pain by reducing neurotransmitters (Wang et al., 2018). The hyperstimulation analgesic theory was developed to describe the analgesic effect of ESWT. According to the physical effect theory, changes in cell membrane permeability and the inducted diffusion of radicals facilitate the healing of ruptured tendons (Frassanito et al., 2018).

The physical effect of ESWT is that the mechanical energy of the shock wave is converted into chemical energy in the connective tissue located in the extracellular matrix. With the help of membrane receptors and ion channels containing proteins, this energy is conducted into the nucleus through the cytoskeleton. Then, in the cell nucleus, chain-like signals induce gene transcription and expression to produce mechanosensitive kinases, leading to the enrichment of collagenase (Lee et al., 2021).

In this study, statistically significantly lower muscle tone was observed after intervention in the triceps brachii and wrist extensors of the subjects in Experimental Group 1, to which ESWT was applied. A statistically significant increase in walking ability was also observed in this group after the intervention. These results suggest that ESWT promotes the reconnection and reorganization of motor and sensory nerves by readjusting the microenvironment of the damaged neural circuit, thereby increasing the functional activity of the subject.

Currently, treatments based on motor control reeducation theory allow stroke patients to learn motor functions by creating an environment that helps them to use their upper and lower limbs on the paralyzed side. Functional electrical stimulation (FES) therapy helps patients maximize motor reeducation while performing active, repetitive motor training (Johnston et al., 2021). FES can be applied to the residual nerve conduction pathway downstream of the injury to restore lost function in patients with CNS impairments. Therefore, FES is widely applied to patients with stroke or spinal cord injury for the purpose of strengthening muscle strength, re-educating muscles, and improving paralyzed limb functions (Sharif et al., 2017).

As a tool for providing positive feedback by inducing movement in the paralyzed muscles of patients, FES therapy has positively affected the quality of life of stroke patients for many years. It is also frequently applied in clinical practice as a treatment method to restore lost motor function in patients with neuromuscular damage (Lee et al., 2018). In addition, FES is used to induce muscle strengthening and improve functional movements, such as walking ability. Electrical stimulation is applied to patients suffering from CNS damage, such as stroke, multiple sclerosis, and spinal cord injury. FES therapy has been widely applied to the affected muscles of stroke patients to reduce spasticity, strengthen muscle strength, and improve daily living activities (Alashram et al., 2020).

FES therapy is used in clinical practice to provide electrical stimulation to the affected peripheral motor nerves in order to contract muscles, thereby creating joint movements and, by extension, functional movements. FES therapy can be easily applied in a clinical setting, and it has the advantage that passive or active functional activation training assisted by a therapist can be applied simultaneously (Straudi et al., 2020). FES training induces muscle contraction by applying electrical stimulation to weakened and paralyzed muscles, so effects such as strengthening muscles and preventing muscle atrophy can be expected. The FES training applied in this study differed from conventional FES training, in which muscle contraction was induced only through passive stimulation in an open-chain situation. Active intervention is employed by combining active movements with electrical stimulation, so it is more effective than passive electrical stimulation treatment in recovering the function of stroke patients (McCaughey et al., 2019).

FES can be applied to damaged nerve conduction pathways to restore lost function in patients with CNS impairments. This treatment helps maximize motor reeducation while patients perform active and repetitive movement training. In addition, a previous study reported that FES could improve control ability in areas where non-separated cooperative movements occurred through intensive strengthening of muscles in the paralyzed area and that FES applied to the calf nerve was effective in restoring the muscle strength of the dorsiflexor muscle during the swinging phase, thereby preventing foot drop, and in alleviating stiffness of the plantar flexor muscle, thereby increasing gait speed (Takeda et al., 2017).

The effects of FES are both peripheral and central. Peripheral effects include improvement in muscle strength and endurance, elongation of muscle length and connective tissue, and reduction in muscle stiffness. Central effects include cortical reorganization, the ignition of sensorimotor nerves, and the induction of reorganization of the cortex and segments at the upper level of the spinal cord (Ushiba 2019). In Experimental Group 2, to which FES treatment was applied, statistically significant changes in the muscle tone of the tibialis anterior muscle and in walking ability were found after the intervention.

Transcutaneous electrical nerve stimulation (TENS) has been applied as an electrical treatment to improve pain perception and control pain intensity. However, in some previous studies, it was also applied to control and manage spasticity in patients with CNS damage. TENS has the effect of suppressing abnormal muscle stretch reflex activity. A previous study reported that the experimental group to which high-frequency TENS was applied showed a decrease in spasticity and an increase in postural stability in stroke patients, regardless of whether an exercise was performed in parallel (Fernández-Tenorio et al., 2019). In the present study, the effects of TENS therapy on abnormally elevated muscle tone and decreased functional activity in stroke patients were investigated. Unlike previous studies, the present study failed to find any statistically significant changes in muscle tone and gait speed after the intervention. These results could be attributed to the fact that the sample size was too small and that the application site and duration of TENS used as the therapeutic intervention in this study were inappropriate.

Conclusion

Stroke patients experience a decrease in their ability to perform sophisticated movements, including their balance and gait. As a result, the functional activities necessary for independence in daily life are limited (Zhao et al., 2015). These disabilities are caused by complex functional impairments. Therefore, in this study, the effects of ESWT, FES, and TENS on abnormal muscle tone and decreased functional activity after CNS injury were investigated.

The muscle tone of the triceps brachii and the wrist extensors decreased in Experimental Group 1, to which ESWT was applied, and gait speed increased in this group. In Experimental Group 2, to which FES was applied after the intervention, the measurements showed statistically significant changes in the muscle tone of the tibialis anterior muscle (decrease) and in gait speed (increase) compared with the measurements before the intervention. These results indicate that ESWT and FES applied to stroke patients can improve muscle tone control and functional activity after CNS damage. Moreover, if they are performed in combination with manipulative physical therapy, ESWT and FES could be very effective in the rehabilitation of stroke patients.

This study has the following limitations. The number of subjects was small, and the therapeutic interventions did not have equal degrees of treatment effectiveness. In addition, the patient evaluations were conducted only before and after the intervention, and the period in which the interventions were applied was short (six weeks). Based on the findings of the present study, further research should be conducted to extend the therapeutic evidence by exploring a range of methods that could effectively enhance muscle tone control and functional activity in stroke patients.

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References

Caprio, F. Z. & Sorond, F. A. (2019). Cerebrovascular disease: Primary and secondary stroke prevention. *Med. Clin. North Am*. 103(2), 295–308. doi:10.1016/j.mcna.2018.10.001.

Knight-Greenfield, A., Nario, J. J. Q., & Gupta, A. (2019). Causes of acute stroke: A patterned approach. *Radiol. Clin. North Am.* 57(6), 1093–1108. doi:10.1016/j.rcl.2019.07.007.

Kimura, H. (2020). [Stroke], brain nerve. *Shinkei Kenkyu No Shinpo*. 72(4), 311–321. doi:10.11477/mf.1416201530.

Iadecola, C., Buckwalter, M. S., & Anrather, J. (2020). Immune responses to stroke: mechanisms, modulation, and therapeutic potential. *Clin. Invest.* 130(6), 2777-2788. doi:10.1172/JCI135530.

Medeiros, G. C., Roy, D., Kontos, N., & Beach, S. R. (2020). Post-stroke depression: A 2020 updated review. *Gen. Hosp. Psychiatry*, 66, 70-80. doi:10.1016/j.genhosppsych.2020.06.011.

Salazar, A. P., Pinto, C., Ruschel Mossi, J. V., Figueiro, B., Lukrafka, J. L. & Pagnussat, A. S. (2019). Effectiveness of static stretching positioning on post-stroke upper-limb spasticity and mobility: Systematic review with meta-analysis. *Ann. Phys. Rehabil. Med.,* 62(4), 274–282. doi:10.1016/j.rehab.2018.11.004.

Lee Dae-Hwan and Lee Jung-Ho. (2019). A study on the physical therapy approach for improving the upper extremity function of spastic ischemic stroke patients. *International Journal of Advanced Nursing Education and Research*,.4(3), 7-12. doi:10.21742/IJANER.2019.4.3.02.

Auersperg, V. & Trieb, K. (2020). Extracorporeal shock wave therapy: An update. *EFORT Open Rev.*, 5(10), 584–592. doi 10.1302/2058-5241.5.190067.

Simplicio, C. L., Purita, J., Murrell, W., Santos, G. S., Dos Santos, R. G. & Lana, J. F. S. D. (2020). Extracorporeal shock wave therapy mechanisms in musculoskeletal regenerative medicine. *J. Clin. Orthop. Trauma.* 11(3), S309-S318. doi:10.1016/j.jcot.2020.02.004.

Liu, T., Shindel, A. W., Lin, G. & Lue, T. F. (2019). Cellular signaling pathways modulated by low-intensity extracorporeal shock wave therapy. *Int. J. Impot. Res.* 31(3), 170-176. doi:10.1038/s41443-019-0113-3.

Feng, B. et al. (2021). Li-ESWT treatment reduces inflammation, oxidative stress, and pain via the PI3K/AKT/FOXO1 pathway in autoimmune prostatitis rat models. *Andrology*. 9(5), 1593-1602. doi:10.1111/andr.13027.

Jung, K.-S., In, T.-S. & Cho, H.-Y. (2017). Effects of sit-to-stand training combined with transcutaneous electrical stimulation on spasticity, muscle strength and balance ability in patients with stroke: A randomized controlled study. *Gait Posture*. 54, 183-187. doi:10.1016/j.gaitpost.2017.03.007.

Atkins, K. D., & Bickel, C. S. (2021). Effects of functional electrical stimulation on muscle health after spinal cord injury. *Curr. Opin. Pharmacol.* 60, 226-231. doi:10.1016/j.coph.2021.07.025.

Sivaramakrishnan, A., Solomon, J. M. & Manikandan, N. (2018). Comparison of transcutaneous electrical nerve stimulation (TENS) and functional electrical stimulation (FES) for spasticity in spinal cord injury - A pilot randomized cross-over trial. *J. Spinal Cord Med.* 41(4), 397-406. doi:10.1080/10790268.2017.1390930.

Moll, I. et al. (2017). Functional electrical stimulation of the ankle dorsiflexors during walking in spastic cerebral palsy: A systematic review. *Dev. Med. Child Neurol.* 59(12), 1230-1236. doi:10.1111/dmcn.13501.

Zhou, M., Li, F. Lu, W., Wu, J. & Pei, S. (2018). Efficiency of neuromuscular electrical stimulation and transcutaneous nerve stimulation on hemiplegic shoulder pain: A randomized controlled trial. *Arch. Phys. Med. Rehabil.* 99(9), 1730-1739. doi:10.1016/j.apmr.2018.04.020.

Dae-hwan Lee, Jung-ho Lee and Youn-bum Sung. (2020). Effects of upper limb stabilization exercise on pain control and improvement of function in shoulder dislocation patients. *International Journal of IT-based Public Health Management*. Global Vision Press. 7(2), 7-14. doi:10.21742/IJIPHM.2020.7.2.02.

Astokorki, A. H. Y. & Mauger, A. R. (2017). Transcutaneous electrical nerve stimulation reduces exercise-induced perceived pain and improves endurance exercise performance. *Eur. J. Appl. Physiol.* 117(3), 483-492. doi:10.1007/s00421-016-3532-6.

Elboim-Gabyzon, M., Andrawus Najjar, S. & Shtarker, H. (2019). Effects of transcutaneous electrical nerve stimulation (TENS) on acute postoperative pain intensity and mobility after hip fracture: A double-blinded, randomized trial. *Clin. Interv. Aging.* 14, 1841-1850. doi:10.2147/CIA.S203658.

Segarra, M., Aburto, M. R., Hefendehl, J. & Acker-Palmer, A. (2019). Neurovascular interactions in the nervous system. *Annu. Rev. Cell Dev. Biol.* 35, 615-635. doi:10.1146/annurev-cellbio-100818-125142.

Gunning, E. & Uszynski, M. K. (2016). Effectiveness of the proprioceptive neuromuscular facilitation method on gait parameters in patients with stroke: A systematic review. *Arch. Phys. Med. Rehabil.* 100(5), 980-986, doi:10.1016/j.apmr.2018.11.020.

Arya, K. N., Pandian, S. & Puri, V. (2018). Rehabilitation methods for reducing shoulder subluxation in post-stroke hemiparesis: A systematic review. *Top. Stroke Rehabil.* 25(1), 68–81. doi:10.1080/10749357.2017.1383712.

Alawieh, A., Zhao, J. & Feng, W. (2018). Factors affecting post-stroke motor recovery: Implications on neurotherapy after brain injury. *Behav. Brain Res.* 340, 94-101. doi:10.1016/j.bbr.2016.08.029.

Niu, C. M. et al. (2019). Synergy-based FES for post-stroke rehabilitation of upper-limb motor functions. *IEEE Trans. Neural Syst. Rehabil. Eng. Publ. IEEE Eng. Med. Biol. Soc.* 27(2), 256–264. doi:10.1109/TNSRE.2019.2891004.

Wonsetler, E. C. & Bowden, M. G. (2017). A systematic review of mechanisms of gait speed change post-stroke. Part 2: exercise capacity, muscle activation, kinetics, and kinematics. *Top. Stroke Rehabil.* 24(5), 394-403. doi:10.1080/10749357.2017.1282413.

Reilly, J. M., Bluman, E. & Tenforde, A. S. (2018). Effect of shockwave treatment for management of upper and lower extremity musculoskeletal conditions: A narrative review. *PM R.* 10(12), 1385-1403. doi:10.1016/j.pmrj.2018.05.007.

Korakakis, V., Whiteley, R., Tzavara, A. & Malliaropoulos, N. (2018). The effectiveness of extracorporeal shockwave therapy in common lower limb conditions: A systematic review including quantification of patient-rated pain reduction. *Br. J. Sports Med.* 52(6), 387-4073. doi:10.1136/bjsports-2016-097347.

Raza, A., Harwood, A., Totty, J., Smith, G. & Chetter, I. (2017). Extracorporeal shockwave therapy for peripheral arterial disease: A review of the potential mechanisms of action. *Ann. Vasc. Surg.* 45, 294-298. doi:10.1016/j.avsg.2017.06.133.

Gomez Garcia, S. et al. (2017). Shockwave treatment for medial tibial stress syndrome in military cadets: A single-blind randomized controlled trial. *Int. J. Surg. Lond. Engl.* 46, 102-109. doi:10.1016/j.ijsu.2017.08.584.

Porst, H. (2021). Review of the current status of low intensity extracorporeal shockwave therapy (Li-ESWT) in erectile dysfunction (ED). Peyronie's Disease (PD), and Sexual Rehabilitation After Radical Prostatectomy With Special Focus on Technical Aspects of the Different Marketed ESWT Devices Including Personal Experiences in 350 Patients. *Sex. Med. Rev.* 9(1), 93-122. doi:10.1016/j.sxmr.2020.01.006.

Wang, C.-J., Ko, J.-Y., Chou, W.-Y., Cheng, J.-H. & Kuo, Y.-R. (2018). Extracorporeal shockwave therapy for treatment of keloid scars. *Wound Repair*

Regen. Off. Publ. Wound Heal. Soc. Eur. Tissue Repair Soc. 26(1), 69–76. doi:10.1111/wrr.12610.

Frassanito, P., Cavalieri, C., Maestri, R. & Felicetti, G. (2018). Effectiveness of extracorporeal shock wave therapy and kinesio taping in calcific tendinopathy of the shoulder: A randomized controlled trial. *Eur. J. Phys. Rehabil. Med.* 54(3), 333-340. doi:10.23736/S1973-9087.17.04749-9.

Lee, Y.-C. (2021). Therapeutic effect of low intensity extracorporeal shock wave therapy (Li-ESWT) on diabetic bladder dysfunction in a rat model. *Int. J. Med. Sci.* 18(60), 1423-1431. doi.10.7150/ijms.55274.

Johnston, T. E., Keller, S., Denzer-Weiler, C. & Brown, L. A clinical practice guideline for the use of ankle-foot orthoses and functional electrical stimulation post-stroke. *J. Neurol. Phys. Ther. JNPT*. 45(2), 112-196. doi:10.1097/NPT.0000000000000347.

Sharif, F., Ghulam, S., Malik, A. N. & Saeed, Q. (2017). Effectiveness of functional electrical stimulation (FES) versus conventional electrical stimulation in gait rehabilitation of patients with stroke. *J. Coll. Physicians Surg.--Pak. JCPSP*, 27(11), 703-706, doi: 2747.

Lee, N. G. (2018). Best core stabilization for anticipatory postural adjustment and falls in hemiparetic stroke. *Arch. Phys. Med. Rehabil.* 99(11), 2168-2174. doi:10.1016/j.apmr.2018.01.027.

Alashram, A. R., Annino, G., & Mercuri, N. B. (2020). Changes in spasticity following functional electrical stimulation cycling in patients with spinal cord injury: A systematic review. *J. Spinal Cord Med.* 1-14. doi:10.1080/10790268.2020.1763713.

Straudi, S. et al. Effects of a robot-assisted arm training plus hand functional electrical stimulation on recovery after stroke: A randomized clinical trial. *Arch. Phys. Med. Rehabil.* 101(2), 309-316, doi:10.1016/j.apmr.2019.09.016.

McCaughey, E. J. et al. (2019). Abdominal functional electrical stimulation to augment respiratory function in spinal cord injury. *Top. Spinal Cord Inj. Rehabil.* 25(2), 105-111. doi:10.1310/sci2502-105.

Takeda, K. Tanino, G. & Miyasaka, H. (2017). Review of devices used in neuromuscular electrical stimulation for stroke rehabilitation. *Med. Devices Auckl. NZ.* 10, 207-213. doi:10.2147/MDER.S123464.

Ushiba, J. Brain-machine interface and neuro-rehabilitation. *Brain Nerve Shinkei Kenkyu No Shinpo*. 71(7), 793-804. doi:10.11477/mf.1416201352.

Fernández-Tenorio, E., Serrano-Muñoz, D., Avendaño-Coy, J. & Gómez-Soriano, J. (2019). Transcutaneous electrical nerve stimulation for spasticity: A systematic review. *Neurol. Barc. Spain*. 34(7), 451-460. doi:10.1016/j.nrl.2016.06.009

Yan Zhao, Chi Zhang and Gang Hao. (2015). Comparative study of electromyographic signal in stroke patients. *International Journal of Signal Processing, Image Processing and Pattern Recognition*. NADIA, ISSN:2005-4254 (Print); 2207-970X (Online), 8(5), 267-278. http://dx.doi.org/10.14257/ijsip.2015.8.5.28.