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A Study on an Effective Method to Apply Upper Limb Rehabilitation Treatment to Stroke Patients

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Abstract

Patients diagnosed with stroke who were exhibiting motor disorders in their paretic limbs were randomly assigned to an experimental group and a control group. Proprioceptive neuromuscular facilitation (PNF), taping, and extracorporeal shock wave therapy (ESWT) were applied to the experimental group, and general exercise therapy and functional electrical stimulation (FES) were applied to the control group. The treatment program for each group was conducted three times a week for six weeks, 30 minutes per session. Grip strength, shoulder joint muscle strength, functions, and daily living activities were evaluated before and after treatment. The differences in grip strength, shoulder joint muscle strength, functions, and daily activities between before and after treatment in the experimental group were statistically significant. The changes in the muscle strength, and functional activities of the extensor, flexor, adductor, and abductor muscles of the shoulder joint were statistically significantly higher in the experimental group. In conclusion, to increase upper limb grip strength, shoulder joint muscle strength, functional activities, and daily living activities, treatment methods that can be applied simultaneously should be applied, and methods to manage the causes of the patient's limitations should also be applied.

Keywords— Motor disorders, Sensory nerve, Rehabilitation, Activity, Stroke

1. Introduction

In everyday life, upper limb use is one of the most important elements in the performance of functional movements. In general, performing daily living tasks or participating in sports often requires the use of the upper limbs, and muscular strength of the muscles around the shoulder, elbow, and wrist is essential for performing functional tasks [1]. Most activities involve both upper limbs: the dominant limb mainly deals with minute manipulations, and the non-dominant limb plays a role in fixing things. However, in the majority of patients after a stroke, dysfunctions occur in the contralateral upper limb due to damage to the corticospinal tract. This consequently causes limitations in the functional use of the upper limbs and mental and physical pain during daily living activities, which make the patient lose motivation and feel frustrated [2].

In daily life, the upper limbs frequently perform complicated motions, such as functional reaching out, grasping, and lifting. The reaching out motion, for example, is the result of the complex coordination of large movements and delicate movements of various joints. However, damage to the central nervous system or upper limbs can lead to changes in muscle tone and coordination abilities, scapulohumeral rhythm issues, and limitations in the range of motion of the shoulder [3]. The outcome can be pain and adverse effects on the rehabilitation process due to the use of compensatory patterns. The motions of patients with brain injury are more segmented than those of non-injured people, and this is characterized by reduced motion velocity, difficulty with normal joint functions, and deviations from the straight trajectory with high variability [4].

Stroke is a syndrome caused by blood circulation disorders in the brain, such as cerebral hemorrhage and cerebral infarction. Strokes are accompanied by physical disability (e.g., motor paralysis), a decline in cognitive functions (e.g., clouded consciousness), and mental disorders (e.g., depression), often causing a decline in the quality of life. Stroke is also a collective name for the localized symptoms of neurological defects that are suddenly caused by the abnormality of cerebral blood flow [5]. It is a term for symptoms, and the underlying causative condition is cerebrovascular disease. Strokes are largely divided into three types: ischemic strokes, hemorrhagic strokes, and transient ischemic attacks. Ischemic strokes occur when an artery in the brain is blocked, which is clinically termed cerebral thrombosis and cerebral infarction. A hemorrhagic stroke occurs when blood vessels in the brain rupture and blood leaks into the surrounding tissue. A transient ischemic attack is a stroke that lasts only a few minutes and occurs when the blood supply to a part of the brain is temporarily blocked [6].

Following the onset of a stroke, one-third of all patients die, and the survivors live with daily pain because the resultant disabilities, such as hemiplegia, can persist for a long period of time. Since stroke patients recover their daily activities and overall neurological functions in the early stages of onset, an important factor to consider in the recovery of stroke patients is the timing of treatment and therapeutic intervention [7].

The motor abilities and functional levels of stroke patients recover the most within three months of onset, and gradual recovery occurs from three to six months after onset. Therefore, carrying out intensive treatment at an early stage after stroke onset can be a vital element in the recovery of daily living activities and upper limb functions. Thus, various rehabilitation treatments are being researched and developed that focus on helping paretic patients recover their independent daily living activities. Representative methods include drug therapy, ultrasound therapy, and functional electrical stimulation treatments. Among these, physical therapy applied by a physical therapist is the most common [8].

A major symptom of stroke is impairment of motor functions, presenting as hemiplegia, spasticity, aphasia, and gait disturbance. This limits the ability for activities due to muscular weakness, abnormal muscle tone, abnormal movements, and the degradation of voluntary control functions. Most stroke patients continue to use their affected lower limbs when walking. However, in upper limb cases, they rely on the unaffected side, which leads to more severe functional limitations due to the decrease in the use of the affected side [9]. The upper limb muscle weakening, spasticity, imbalance, catatonia, and dysesthesia found in stroke patients bring about a loss of upper limb motor control and cause many limitations in independent daily living activities, such as eating, dressing, and personal care. Therefore, stroke patients develop difficulties in undertaking autonomous activities and become dependent, leading to the degradation of the quality of their lives [10].

As a result of the stroke, and mainly due to the resultant motor function disorder of the paretic side, stroke patients tend to exhibit increases in muscle tone, imbalance, paresthesia, asymmetric postures, and upper limb and hand dysfunctions. In particular, upper limb dysfunction occurs in at least 70% of patients after the onset of stroke. Since sophisticated and large-scale motor skills are complexly used in the upper limb, clinically, upper limb dysfunction becomes a fundamental cause of disabilities that appear after stroke, and acts as a major element that restricts patients with hemiplegia from performing daily living activities and returning to society [11]. Furthermore, dual-task interference is observed more frequently in stroke patients than in the general population; the main cause in stroke patients is a decrease in the ability to simultaneously process motor functions and cognitive functions. Stroke patients also have difficulties in the use of problem-solving strategies, such as prioritizing and distributing attention between two tasks. Consequently, stroke patients show reduced performance on some or all tasks during dual tasks, and the reduced dual task performance exacerbates the decline in their daily living functions [12].

The proprioceptive senses serve several functions. They receive and integrate important kinematic information from muscles, tendons, and joint receptors to help support the body. Such information includes the current positions of joints, the forms of movement of the joints, the ranges and quantities of motion of the joints, the times of the start of the motions, and the velocity and acceleration of the body segments during the motions [13]. In addition, the proprioceptive senses detect the postures of the limbs in stationary states and movements in dynamic states, and recognize the movements of muscles, the postures of the joints, and the object in contact. This mechanism provides information on body movements and postures to allow upright posture, posture control, and the maintenance of constant postures of the limbs, trunk, and head [14].

Feedback, which accounts for the largest proportion of proprioceptive senses, affects learning and performance processes. Hence, the decline of proprioceptive sensory functions in patients with hemiplegia may lead to a decline in joint stability and an increase in the frequency of injuries because of reductions in the efficiency of motions and information on the location of the body in space. Stroke patients may experience falls due to a lack of posture control, reflex abilities, and joint motor ability. It can also be challenging for them to coordinate their hand movements because the affected side (with proprioceptive senses problems) cannot keep up with the unaffected side. Limitations in upper limb movements appear unless there are visual cues [15].

The purpose of upper limb rehabilitation treatment for stroke patients is to improve their quality of life by minimizing the patient's disabilities and maximizing the patient's functions. Upper limb rehabilitation is essential for improving the functions of stroke patients, and treatment techniques implemented in clinical practice include neuromuscular stimulation treatments, task-oriented treatments, constraint-induced movement therapy, electrical treatments, bilateral upper extremity training, strength exercise, robot treatments, virtual reality treatments, and music therapy. Proprioceptive neuromuscular facilitation (PNF) and taping therapy are two examples of neuromuscular stimulation treatments applied in clinical practice [16].

PNF is an exercise therapy that improves function by stimulating proprioceptors for the promotion and suppression of specific muscle groups and is applied to stroke patients to restore and strengthen normal movement patterns, postural responses, and walking ability. In addition, in order to promote functional recovery, patients may be instructed to voluntarily use their paretic limbs to improve their daily living activities. The patients' balance and motor control ability may be improved through weight transfer and load training, and their functional independence may be improved by applying treatments that emphasize the symmetry between the affected side and the unaffected side [17].

Kinesio taping, which is used to stimulate proprioceptive senses, involves applying an adhesive, flexible material directly to the skin. This clinical treatment method has the advantage of not restricting movements during treatment. Taping is used to reduce shoulder pain, soft tissue inflammation, muscle weakening, and postural deformities of stroke patients. Previous studies that examined the effects of taping on the improvement of upper limb functions reported that the application of taping enhanced the stability of the shoulder girdle, improved joint movements, and increased the functional activities of the upper extremities by applying taping to the upper trapezius to suppress the over-tense upper trapezius and activate the under-tense lower trapezius [18].

In clinical practice, extracorporeal shock wave therapy (ESWT) is applied to reduce spasticity that restricts functional activities after stroke. It is based on the therapeutic principle that applying energy, within a range that is not harmful to the human body, to the site of the lesion will cause changes in the cell membrane. ESWT restores damaged areas by controlling the microenvironment; exposing lesion sites to shock waves destroys damaged tissues and cells and promotes neovascularization and an increase in local growth factors [19].

Therefore, the aim of this study was to test and develop a rehabilitation treatment protocol that maximizes the improvement of upper limb muscle strength and functions in stroke patients. ESWT, which can reduce spasticity, was applied before simultaneous PNF and taping, which can stimulate the proprioceptive senses.

2. Study Medthods

2.1 Subjects

In this study, 34 patients who were diagnosed with stroke and exhibited movement disorders in their paretic limbs were randomly assigned (using a lottery format) to an experimental group of 17 persons and a control group of 17 persons. Inclusion criteria were set as those who: had consented to the treatment program; had no cognitive impairment, with a score on the Korean version of the Mini-Mental State Examination (MMSE) not lower than 24 points; had no orthopedic problem, such as fractures or peripheral nerve damage in the upper limbs; had no problems with vision or hearing; and had no subluxation of the shoulder joint on the paretic side. Exclusion criteria were set as those who:

had heart failure; had mental disorders or were taking psychoactive drugs; had vomiting or dizziness; and had any cerebellum-related disease (Figure 1).

Based on the above selection criteria, the experimental group received PNF, taping, and ESWT, and the control group received general exercise therapy and functional electrical stimulation (FES). The treatment program for each group was conducted three times a week for six weeks, and exercise was performed for 30 minutes per session. Evaluation was performed once before the experiment and once at six weeks after the experiment. Finally, subjects with a treatment participation rate of less than 80% were excluded from the study. All study subjects agreed to the experiment after hearing detailed explanations about the contents of the study in advance. All experimental procedures were carried out based on the Declaration of Helsinki.

2.2 Evaluation Methods

2.2.1. Grip Power

The measurement of hand grip strength has been used as a predictive factor for the independent functions and motor performance ability of stroke patients. A comparison of upper limb functions and hand grip strength in subacute stroke patients showed that a deficit in the use of upper limb functions was associated with a failure in the early recovery of grip strength. In general, in subacute stroke patients, grip strength scores improve in parallel with the performance of complex upper limb motor tasks. That is, grip strength acts as a valuable factor in the recovery of upper limb functions. Grip strength was measured with a digital dynamometer.

Before measuring grip strength, the dynamometer and measurement procedure were explained so that the subjects could understand them. Thereafter, the subjects removed accessories and lightly bent and extended all fingers five times as a light warm-up exercise. The subjects were instructed to hold the dynamometer so that the second knuckles were at an angle of 90 degrees to the dynamometer's hand grip, look forward in a standing state, straighten their back, square their shoulders, and put their arms in a natural position. They were instructed not to bend their elbows or wrists and to take an erect posture while preventing their arms from being in contact with their trunk. They were also instructed to position their feet a pelvis-width apart, place the two feet in parallel with each other, and maintain the basic posture while their grip strength was measured.

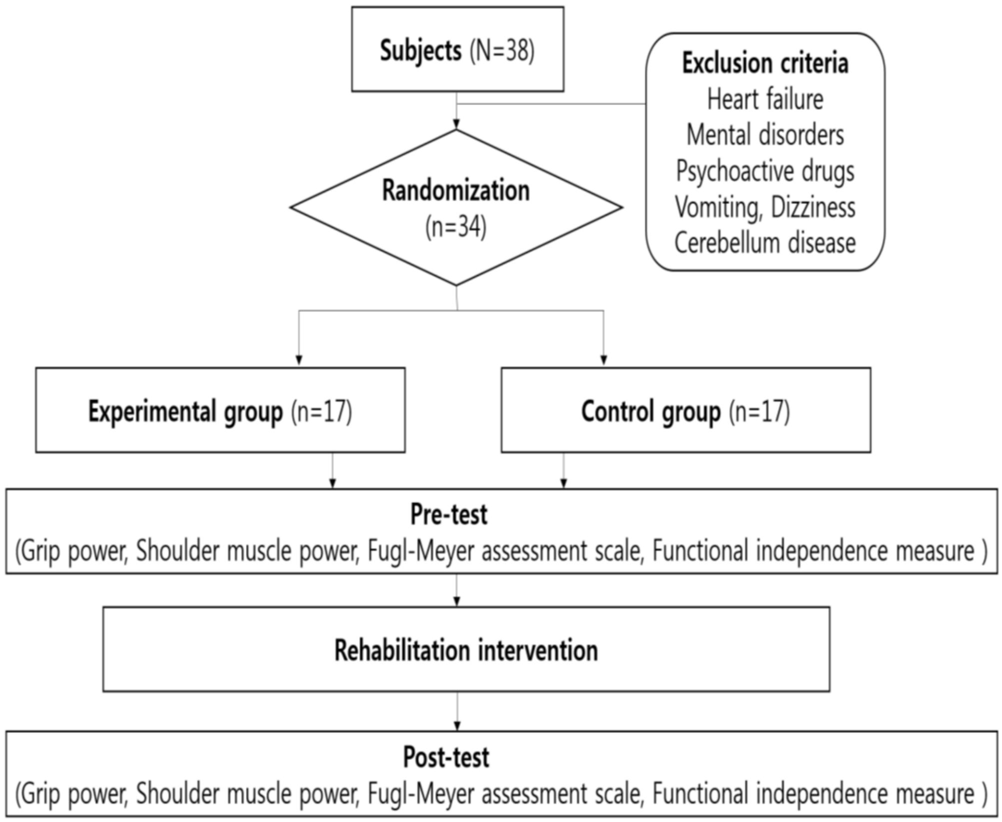

Figure 1. Flow chart of study

They were instructed to maximally grip the dynamometer for no longer than 3 s and maintain the state of exhalation while gripping the dynamometer. The grip strength was measured three times using the dominant hand, and the subjects were instructed to rest for 60 s after each measurement. The researcher checked whether the position of the handle and the posture of the subject were accurate at each time of measurement. The grip strength test value used in this study was defined as the highest measured value of the dominant hand.

2.2.2. Shoulder Strength

To measure shoulder joint muscle strength, the muscular strengths of the flexor, extensor, abductor, and adductor of the paretic shoulder joint were measured using a portable sthenometer (Power Track II Commander hand-held dynamometer, JTech Medical, USA). To measure the muscular strengths, the subjects performed the maximum isometric contraction for 5s in the medium range in the maximum range of active joint motion. The values obtained from three repeated measurements were averaged, and the resultant value was used. The muscular strengths of the shoulder joint flexor, extensor, abductor, and adductor muscles were measured while the upper limbs were supported by a sling in a lateral recumbent position. After each measurement, the subjects rested for 30 s.

2.2.3. Fugl-Meyer Assessment (FMA) Scale

The Fugl-Meyer Assessment Scale was used to evaluate upper limb functions. As a tool used to quantitatively evaluate the degree of functional recovery of stroke patients, it consists of six items, including motor function, balance, sensation, joint range of motion, and pain evaluation. The motor function evaluation consists of 66 points for the upper limbs and 34 points for the lower limbs. The score scale of the evaluation tool consists of three points: 0 points for impossible to perform, 1 point for partially performable, and 2 points for fully performable. A higher score means better functions. In this study, it was used to evaluate upper limb motor functions: the reflexes of the shoulders, elbows, wrists, and hands; voluntary movements; and upper limb coordination.

2.2.4. Functional Independence Measure (FIM)

The FIM was developed by Granger et al. in 1983 and is a method used to objectively evaluate the ability of patients with disabilities to perform daily living activities. It is composed of 18 items in four categories of motor functions (i.e., self-care, bowel/urination control, movements, and walking) and two categories of cognitive functions (i.e., communication and social cognitive domains). The FIM has a 7-point scale for scoring each item according to the degree of help, and the highest total score is 126.

2.3 Treatments

2.3.1. Proprioceptive Neuromuscular Facilitation

For PNF, upper limb patterns and upper/lower limb combination patterns were used. For the upper limb extension/gathering/intorsion patterns among the upper limb patterns, the subjects were instructed to take a hook posture in which the hip and knee joints were bent in a supine position. In the hook posture, the subjects were asked to place the affected arm in the 11 o'clock position in the clockwise direction, place the opposite arm comfortably next to the trunk, and perform the upper extremity extension/gathering/intorsion patterns according to the researcher's instructions.

In the case of the upper limb pounding pattern among the PNF upper limb patterns, the subject was in the hook position. For the leading affected arm, the shoulder joint was in a flexion/gathering/eversion state, the shoulder blade was forward lifted, the elbow joint was extended/supinated, and the wrist was in a flexion/radial leaning state. For the following unaffected arm, the shoulder blade was in a state of flexion/abduction/eversion. The subject then held the left wrist and performed the pounding according to the researcher's instructions (shoulder joint; extension/abduction/ intorsion, scapular; backward lowering, elbow joint; extension-pronation, wrist; extension-ulnar leaning).

For the upper and lower limb combination patterns for PNF, the subjects were instructed to place the left lower limb in the 5 o'clock position in a supine position while keeping the upper limbs in the positions for the upper limb pattern and take the starting postures of the patterns: hip joint extension/abduction/ intorsion, knee extension, and ankle plantar flexion. The subjects were instructed to place both arms comfortably next to the trunk. The movements were performed to take ankle dorsiflexion, knee flexion, and hip joint flexion/collection/eversion, which were the opposite postures to the starting position, in order of precedence, according to the researcher's instructions. To prevent muscle fatigue in the subjects, one-minute breaks were scheduled after every 10 repetitions.

2.3.2. Taping

In this study, taping therapy for the upper limbs was applied by taping for shoulder stability. Elastic taping was applied to the deltoid, supraspinous, and infraspinous muscles. For deltoid taping, an elastic tape was attached in the front from the tuberosity of the humerus to the coracoid process while the upper limb was extended backward and in slight abduction, and an elastic tape was attached to the back on the spine of the scapula after the hand was placed on the opposite shoulder. For supraspinous muscle taping, tape was applied from the greater tuberosity of the affected humerus toward the supraspinous fossa of the humerus. The top of the infraspinous muscle taping began from the medial lower surface of the scapula spine, the bottom began from the angulus inferior scapulae, and the tape was attached to the side of the upper part of the humerus after lifting the ipsilateral shoulder.

2.3.4. Extracorporeal Shock Wave Therapy

ESWT was applied to the myotendinal junction of the affected upper limb to reduce spasticity and improve functions. ESWT was applied to the lower part of the medial epicondyle (the origin of the flexor muscles of the hand and wrist joint), the radial tuberosity of the biceps brachii (the flexor of the elbow and shoulder joints), and the intertubercular groove of the humerus. An ESWT machine that generates shock waves was used to apply ESWT to individual sites.

Each patient sat comfortably in a chair with a backrest, and ESWT was applied while the patient extended the elbow joint to the extent possible through passive assisted movements. The same shock wave stimulation was applied to individual sites, a frequency of 2 Hz was applied, and the power was applied to the myotendinal junction 250 times per step, a total of 750 times. Patients rested for 3 min after the treatment of each site.

2.4 Data Analysis

All statistical analyses were performed using predictive analytics software (PASW)20.0 to calculate the mean values and standard deviations for individual measurement items. Normality was tested using Shapiro-Wilk tests, and the parametric test method was used because all variables were normally distributed in the results. Paired-sample t-tests were conducted to compare the differences in grip strength, shoulder joint strength, upper limb function, and daily living activities of the experimental subjects before and after the experiment, and independent t-tests were conducted to compare the differences in changes between the experimental group and the control group. All statistical significance levels of the data were set to 0.05 or lower.

3. Results

The differences between grip strength before and after treatment in the experimental group and the control group were statistically significant ($P<0.05$). When the effects of the therapeutic interventions were compared, there was no statistically significant difference in the amount of change between the experimental group and the control group (Figure 2) (P>0.05).

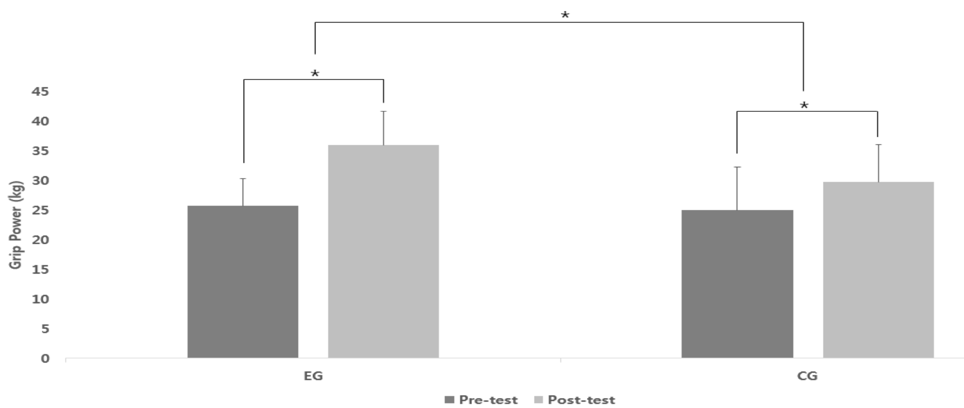

Figure 2. Comparisons of Grip Power Between Groups
***p<0.05, Mean±SD; Mean±standard deviation**

There were statistically significant differences in the muscular strength of the shoulder joint flexor and extensor muscles before and after treatment in the experimental group and control group, respectively (Figure 3) (P<0.05). When the effects of the therapeutic interventions were compared, there were statistically significant differences in the amounts of change between the experimental group and the control group (Figure 4) (P<0.05).

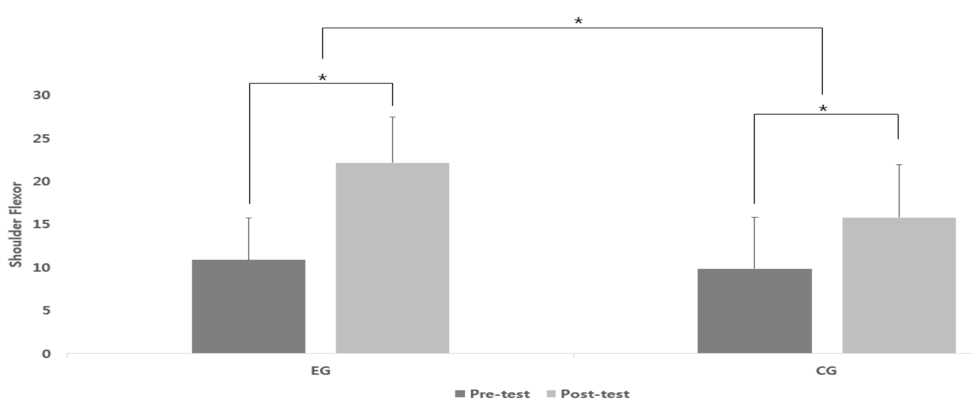

Figure 3. Comparisons of Shoulder Flexor Between Groups
***p<0.05, Mean±SD; Mean±Standard Deviation**

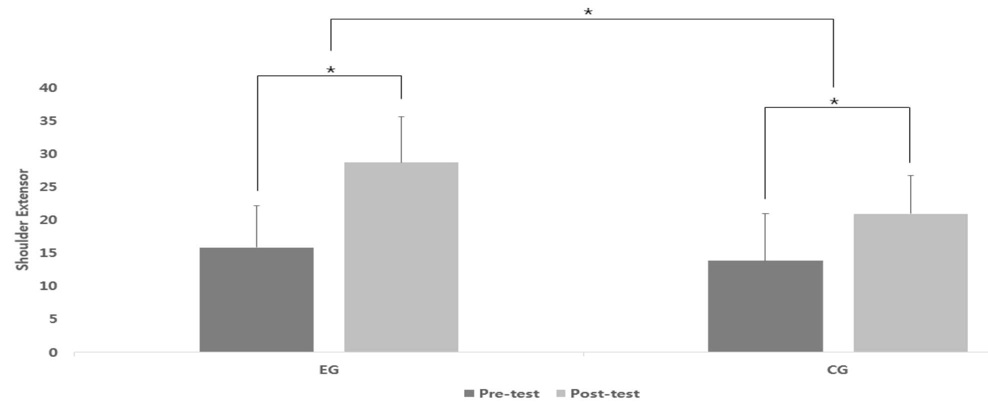

Figure 4. Comparisons of Shoulder Extensor Between Groups
$^{*}p<0.05$, Mean±SD; Mean±standard deviation

In addition, there were statistically significant differences in the muscular strength of the adductor and abductor muscles of the shoulder joint before and after treatment in the experimental group only (Figure 5) (P<0.05). When the effects of the therapeutic interventions were compared, there were statistically significant differences in the amounts of changes in the muscular strength of the adductor and abductor muscles between the experimental group and the control groups (Figure 6) (P<0.05).

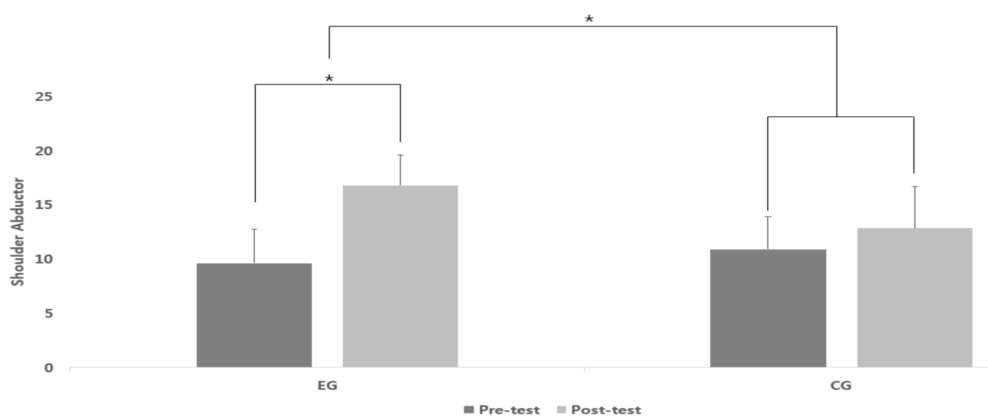

Figure 5. Comparisons of Shoulder Abductor Between Groups
$^{*}p<0.05$, Mean±SD; Mean±Standard Deviation

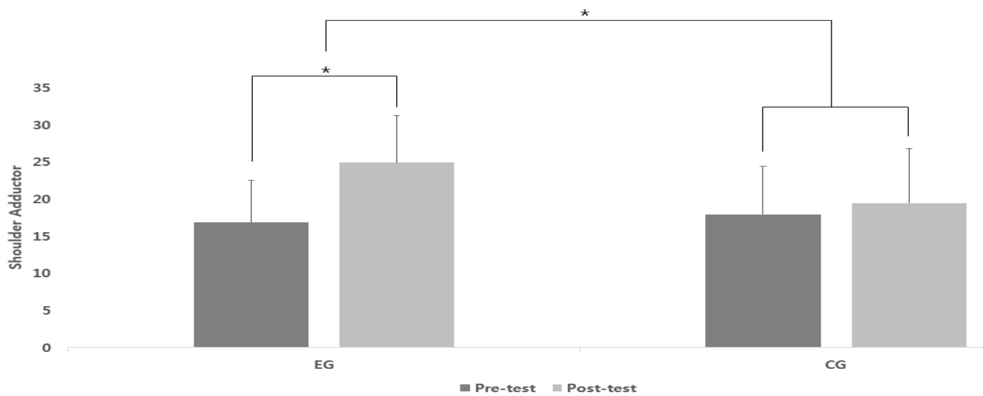

Figure 6. Comparisons of Shoulder Adductor between Groups
***p<0.05, Mean±SD; Mean±Standard Deviation**

There were statistically significant differences in the FMA scores before and after treatment in the experimental group and the control group, respectively (P<0.05). When the effects of the therapeutic interventions were compared, the experimental group showed statistically significantly larger amounts of change compared to the control group (Figure 7) (P<0.05).

There were statistically significant differences in the FIM scores before and after treatment in the experimental group and the control group, respectively (P<0.05). When the effects of the therapeutic interventions were compared, there was no statistically significant difference between the experimental group and the control group (Figure 8) (P>0.05).

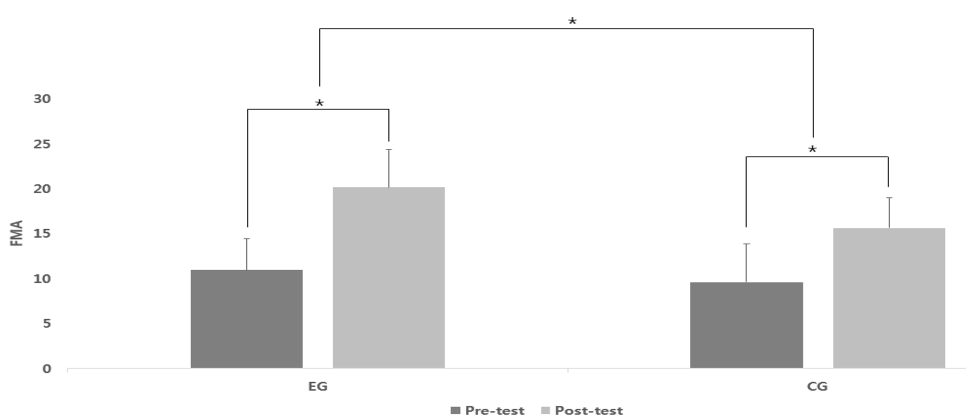

Figure 7. Comparisons of FMA Between Groups
***p<0.05, Mean±SD; Mean±Standard Deviation**

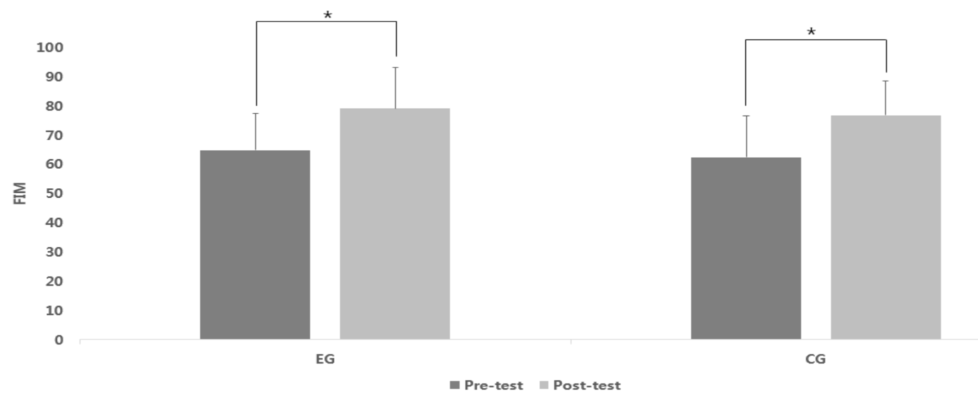

Figure 8. Comparisons of FIM between Groups
***p<0.05, Mean±SD; Mean±Standard Deviation**

4. Discussion

In contrast to the passive interventions mediated by auxiliary tools to reduce functional impairment of the upper limb resulting from various causes, including paralysis due to stroke, muscle strengthening interventions via active assistance or active exercise are an important aspect of rehabilitation of stroke patients. Muscle weakening is the most common symptom after stroke, and muscle weakening accompanied by flaccid palsy occurs in stroke patients in the early stage and thereafter, spasticity gradually increases over time [20]. Repeatedly practicing and training on real-life tasks after stroke can be an important stimulus for creating new or more effective and functional connections within the remaining brain tissue. Therefore, functional recovery of stroke patients requires a training program that enables voluntary use of certain motions and functions and a therapeutic approach to repeat appropriate exercises. To develop an optimized upper limb rehabilitation program, this study investigated the effects of PNF and taping, which are effective for proprioceptive neuromuscular stimulation, and ESWT, which can reduce spasticity, on the muscular strength and functions of stroke patients [21].

The upper limbs of patients with hemiplegia due to stroke have reduced ranges of motion and lack functional movements due to the weakening of shoulder joint muscles and the loss of trunk alignment. The abnormal kyphosis of the thoracic spine in the postures of stroke patients excessively abducts the scapula and increases the abnormal activities of the shoulder joint muscles [22]. The wrong position of the scapula and the wrong activities of the muscles around the shoulder joint interfere with the normal upward rotation of the scapula and cause pain, depending on the movements of the shoulder joint. Eventually, improper alignment and muscle activities bring about frequent shoulder dysfunctions. Therefore, the alignment and activity control of the shoulder joint and scapula intended to improve the shoulder functions of patients with hemiplegia are essential for rehabilitation [23].

Since most upper limb functions occur in combination with lifting and stretching movements, muscular strength and neuromuscular control are required for functional movements against gravity. However, muscle weakening in the hand and shoulder joints and problems in inter-joint coordination and timing after stroke onset cause abnormal flexion synergy during upper limb functions. This reduces the range of active joint motion so that the opportunity for muscle contraction is lost, leading to the aggravation of muscle weakening over time [24].

Long-term non-use of the upper limb due to motor dysfunction may result in the loss of function for performing delicate tasks. Even if the muscular strength of the shoulder joint, elbow joint, and proximal area of the wrist joint is recovered, performing daily living activities will be restricted unless the functions of the finger joints and hand are recovered. Therefore, the recovery of the functions of the finger joints and hand can be said to be an important element of rehabilitation. The performance of upper limb functions is only partially improved after stroke in patients who can voluntarily move the fingers and wrist to some extent, and in order to use the upper limb functionally, a program to develop functional use of the paretic upper limb or hand is required during treatment [22].

The most effective method for activating the proprioceptive senses is the activation of the muscle spindles and the Golgi tendon organ via active muscle contraction. The muscle spindles are located in the intrafusal muscle fibers and deliver information on the length and extension of the muscles to the spinal cord and brain. Whereas the Golgi tendon organ senses the increasing degree of muscle contraction and provides information for the control of muscle tension [25]. The degree of recovery of upper limb motor functions is correlated with the degree of impairment of the joint position senses of stroke patients, and the activation of joint position senses and movement sensations is mostly dependent on the muscle spindles, which are the stretch receptors for most muscles. Therefore, the activation of the muscle spindles by muscle contraction is a vital element in the activation of the proprioceptive senses [26].

PNF can be used when movement or postural patterns have changed or become unnatural due to the lack of neuromuscular mechanisms, and the main goal of treatment is to restore or strengthen normal patterns of movement or postural responses. Special requirements are used to promote direct effects on certain muscle groups or indirect effects on synergistic muscles and antagonists. Those harmonized normal movement patterns that promote strong responses are in the diagonal direction, including spiral elements, and such patterns show the functional relationship between the limbs and the trunk in sports or daily living activities. Diagonal movements are useful when training multiple movements during the treatment process. To achieve the purpose of functional recovery, motor learning should be carried out through repeated practice of training [27].

PNF is used to improve functions by stimulating proprioceptors in muscles and tendons and has been used as a representative therapeutic intervention in rehabilitation to improve the motor performance of patients with movement defects. A variety of therapeutic interventions that use diverse methods have been derived and developed from PNF, including the facilitation of postural reflexes, the use of gravity to promote motions in weak muscles, the use of eccentric contractions to promote agonist activity, and the use of diagonal movement patterns to promote the activity of two joint muscles [28]. PNF has been reported to have positive effects on the improvement of the functional activities of muscles, walking ability, and muscle activity in patients with hemiplegia. It is thought that to maximize the diffusion effect and cross-training through resistance, applying various patterns at the same time will be more effective [29].

Therefore, in this study, PNF and elastic taping were simultaneously applied to stroke patients to increase the activity of the proprioceptive senses, and improvements in muscle strength and functions in stroke patients were examined. Improvement in muscle strength and function of the shoulder joint were observed in the experimental group (in which PNF and taping were applied simultaneously) compared to the control group. These results are thought to be attributable to the overlapping effects of treatment because two therapeutic interventions that can increase the activity of proprioceptive senses were applied simultaneously. However, there was no significant difference between the two groups in the improvement of grip strength and activities of daily living. Therefore, the results contrast with those of previous studies.

Kinesio taping is an elastic taping method used to suppress muscle tension or to promote activity by attaching elastic tapes to the skin above the muscles to facilitate the movement of the agonist [30]. Although the key mechanisms by which Kinesio taping mediates muscle movement have not been clearly reported, it has been suggested that Kinesio taping plays an auxiliary role in improving lymph and blood circulation, relieving pain due to neural inhibition, alleviating abnormal myotonus, and repositioning the joints. Multiple previous studies that applied such mechanisms have reported that taping intervention can bring about muscle strengthening and improvement of joint range of motion and proprioceptive position sensory functions [31].

Kinesio taping is divided into muscle taping and corrective taping methods; they differ in the direction in which the force is applied to the tape and the tape elasticity. Based on the pain causing principle, Kinesio taping is carried out by applying unstretched elastic tapes from the origin to the attachment site of the muscles relevant to the pain site when the relevant skin and muscles have been maximally stretched. The elasticity of the tapes is similar to that of the skin, and when a normal posture is adopted after attaching the elastic tapes, the tapes are wrinkled so that spaces are secured between the skin and the muscles, leading to the enhanced circulation of blood and tissue fluid [32].

Since the taping treatment is simple and has no side effects, it has the advantage of being easily applied at home. However, the biggest advantage is that it can be applied simultaneously with other treatments. Previous studies reported that Kinesio taping was an alternative medicine to obtain therapeutic effects through subcutaneous blood circulation and muscle stimulation, and that if abnormal muscle functions were normalized, and excessive muscle tension and spasm were relieved through the skin stimulation, deformed joints would be corrected, or pain would disappear [33].

In the current study, taping was applied to the deltoid, supraspinous, and infraspinous muscles to strengthen proprioceptive sensory activities and the muscles around joints. The results showed improvements in grip strength ability, shoulder joint muscle strength, and daily living activities after the treatment compared to before the treatment in the experimental group. It is thought that the application of taping relieved pain to a sufficient degree to allow patients to increase their upper limb muscle activities and achieve functional improvement.

ESWT began as a treatment for kidney stones, and interest in its application to musculoskeletal disorders appeared thereafter. It is increasingly used as a non-invasive pain treatment and regenerative treatment method for musculoskeletal disorders [34]. Extracorporeal shock waves are largely divided into a centralized type and a radial type, according to the energy transfer method. In the case of radial extracorporeal shock waves, the air condensed in the pneumatic device is instantaneously released to collide with multiple pendulums arranged linearly so that pressure waves are generated to radially diffuse energy [35].

In the case of centralized extracorporeal shock waves, multiple piezoelectric elements sporadically arranged on a conical dust-collecting plate generate piezoelectric effects by electrical stimulation and focus the individual shock waves generated on one point. ESWT is used for conditions such as fasciitis, tendinitis, arthritis, necrosis, and burns to relieve pain and help the regeneration of damaged tendons, bones, and skin. It has been found to promote blood flow in patients with diabetic foot ulcers or ischemic heart diseases [36-39].

In this study, to reduce spasticity, ESWT was applied to each of the three muscle-tendon junctions before PNF and taping, and the results showed improvements in grip strength, shoulder joint muscle strength, functions, and daily activities. The results are thought to be attributable to the ESWT reducing spasticity, which in turn resulted in pain relief, decreased inflammation, and increased range of motion during the PNF exercise program.

5. Conclusion

The disabilities due to stroke are diverse. It is impossible for one field alone to manage the many symptoms that appear after a stroke, such as disabilities due to a decrease in proprioceptive senses, muscle weakening, dysfunction due to wrong muscle activities, and decreases in daily activities due to the occurrence of pain. In addition, significant amounts of time and money must be allocated to managing the economic and social aspects of stroke patients.

Therefore, based on the results of this study, to improve the grip strength of the upper limb, the muscular strength of the shoulder joints, and functional activities, treatment methods that can be applied at the same time should be applied, along with a method that can manage the causes of patient limitations. In this study, the number of subjects was small, and the duration of the study was short (six weeks). In addition, some of the evaluation methods were not quantified, and pain, which is an important element of rehabilitation, was not evaluated. It is hoped that studies that apply intervention programs to more subjects for longer periods (i.e., exceeding three months) and carry out follow-up evaluations will be conducted.

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