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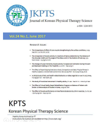

# The Effects of Virtual Reality Based Treadmill Training on the Muscle Architecture of Gastrocnemius in Chronic Stroke Patients

## : Randomized Controlled Trial

KiHun Cho, Ph.D., P.T.

*Dept. of Physical Therapy, Uiduk University*

## Abstract

**Purpose:** The purpose of this study was to investigate the effects of virtual reality based treadmill training on muscle architecture of gastrocnemius in chronic stroke patients. **Methods:** Thirty chronic stroke patients were randomly assigned to either the virtual reality based treadmill training (VRTT) group (n=15) or treadmill training (TT) group (n=15). Both groups participated in a standard rehabilitation program; in addition, the VRTT group participated in virtual reality based treadmill training for 30 minutes per day, three times per week, for 6 weeks, and TT group participated in treadmill walking training for 30 minutes per day, three times per week, for 6 weeks. Ultrasound image was used for measurement of pennation angle and muscle thickness of the medial gastrocnemius muscle at rest and during maximum voluntary contraction. **Results:** In the paretic side medial gastrocnemius muscle, greater improvement on the pennation angle and muscle thickness while resting and maximal voluntary contraction were observed in the VRTT group compared with the TT group. **Conclusion:** Findings of this study demonstrated that the virtual reality based treadmill training has an effect on muscle architecture of medial gastrocnemius in chronic stroke patients.

**Key words** : Gastrocnemius, Stroke, Treadmill, Virtual reality

## Ⅰ. Introduction

A stroke generally causes decline of active motor ability and loss of mobility with the advent of cognitive disorder, sensory disturbance, emotional disorder, functional disorder of upper and lower limbs and balance disorder due to brain damage, although there is difference depending on the degree and parts of brain damage (Jongbloed, 1986). In addition, brain damage affects the pathway of motor nerves and sensory nerves and causes the change of myotonus and the mechanical property of muscles, which leads to weakening of muscular strength due to the decline of voluntary muscle's contractile function (Milot et al., 2008).

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교신저자: 조기훈
주소: 경상북도 경주시 강동면 동해대로 261 위덕대학교 성취관 419, 전화: 054-760-1795, E-mail: mamiya34@gmail.com

There have been many precedent studies on various methods such as feedback training using force plate for recovery of independent walking ability that becomes the ultimate goal of stroke rehabilitation (Yavuzer et al., 2006), task-oriented circuit training (Dean et al., 2000), functional electrical stimulation training (Kottink et al, 2004) and walking training using robot (Mehrholz and Pohl, 2012). Among these, the treadmill training is actively used in clinical environments to improve walking ability of stroke patients who have asymmetrical walking aspects due to hemiparalysis (Polese et al., 2013; Langhorne et al., 2009; Manning and Pomeroy, 2003).

However, the current environment of treatment rooms is very limited, so it is difficult to provide the changing environment, and it is impossible to provide complicated external environment that stroke patients will face when they return to the society, so it is difficult to predict local community walking based on the research results in experiment rooms and treatment rooms (Carvalho et al., 2010).

Therefore, the virtual reality used in various fields due to the development of science is used as a method to provide similar conditions to the external environment for stroke patients (Laver et al., 2012). The virtual reality provides with senses and environments very similar to reality through interaction of computer hardware and software, draws the reaction of users through multisensory feedback stimulation and promotes functional activities by enhancing interest and participation rate of treatment (Laver et al., 2012). Especially combining the virtual reality with treadmill is reported to maximize realtime feedback, interaction, purpose, motivation and achievement that are given to users (Fung et al., 2006).

The improvement of walking ability, balance ability and daily living performance ability of stroke patients is reported by various precedent studies on the virtual reality treadmill training (Kate Laver et al., 2012; Laver et al., 2012; Manning and Pomeroy, 2003), but there are not enough studies on the change of lower limbs muscles' muscle architecture through the virtual reality treadmill training. The paralysis caused by stroke causes behavioral change of muscles' muscle architecture, leading to decline of muscle quantity, shortening of muscular fiber and decrease of the number of motor units, which function as major factors that cause decline of ambulatory function (Narici et al., 2003).

Therefore, this study is intended to observe the change of ultrasonic image about the muscle architecture of medial gastrocnemius closely related to stroke patients' mobile ability through the virtual reality treadmill training, and to provide basic data for stroke rehabilitation.

## Ⅱ. Method

### 1. Subjects

The subjects of this study were 38 stroke patients who were diagnosed with stroke and hospitalized for treatment in B Hospital located in Seoul. To minimize the possibility of natural recovery, we selected those who had stroke over 6 months, those who developed stroke once, those who could communicate and had no cognitive disorder and whose MMSE-K (Mini Mental State Examination-korean) score was over 24, those who were between stage 1 and 4 of Brunnstrom's motor recovery, those who had no apraxia or hemi-neglect, those who had less than 2 MAS (Modified Ashworth Scale) of ankle joint muscle tone and those who were able to walk for over 10 minutes using assistance tool without resting. We excluded those who had heart diseases, uncontrollable high blood pressure, pains, orthopedic problems such as fracture of lower limbs and traumatic damage of peripheral nerves, visual disturbance, visual field defect and auditory disorder and those who had experience to participate in similar experiments recently.

We recruited 38 patients at first, but during the process of selection, 3 patients were excluded due to hemi-neglect and visual field defect, so 35 patients were finally selected for the subjects of this study. We explained necessary matters and the purpose of this study in detail, and received agreement after letting them know that they could be excluded anytime if they want even if the study starts. This study was done with the approval of the research ethics committees in Sahmyook University.

## 2. The procedure of the study

This study consists of two pre-post groups. The 35 patients selected by screening criteria were divided into 18 members of virtual reality treadmill training group and 17 members of treadmill training group through drawing lots one hour before the training started to minimize the prejudice of selection. Both groups received 30 minutes of general exercise treatment (bobath neurodevelopmental treatment, Proprioceptive Neuromuscular Facilitation) and 20 minutes of functional electrical stimulation treatment (Knee Joint Extensor, ankle joint dorsal flexion), so they received total 50 minutes of general rehabilitation treatment once a day and five times a week. The virtual reality treadmill training group additionally performed virtual reality treadmill training for 30 minutes a day and three times a week, and the treadmill training group performed treadmill walking training for 30 minutes a day and three times a week.

During the training session, 3 patients of the virtual reality treadmill training group and 2 patients of the treadmill training group dropped out, so the experiment results of 15 patients of each group were integrated, and statistical analysis was done (Table 1).

## 3. Virtual Reality Based Treadmill Walking Training

For the virtual reality treadmill training environment composition, we used a treadmill (JT-4000, Sehan Medical, Gyeonggi-do, Korea), a suspension system (TA-6000, Gyerim Medical, Gyeonggi-do, Korea), a beam projector, a screen, a speaker and a laptop. The virtual reality images were provided to the screen of 2000mm in width and 1700mm in length located 2m in front of the treadmill through high-resolution beam projector of 1024 × 768 XGA resolution and the laptop, and the audio recorded along with picture was printed out by connecting the lap top with the speaker, auditory feedback was provided. While the virtual reality images were projected to the screen, the subjects walked on the treadmill wearing the suspension system that can't affect gait cycle because they didn't have weight support with the emergency shutdown operated for their safety. The virtual reality images consists of 400m track walking image, weather changing 400m track walking image, obstacle 400m track walking image, obstacle 400m track walking image, local community walking image, nighttime local community walking image and hiking trail walking image. During the virtual reality treadmill training session, 6 real life video images were changed every week increasing the level of difficulty. In the first week, 400m track walking image with clear weather and no obstacle was provided, and in the second week, the changed environment was provided through 400m track walking image with rain. In the third week, obstacle 400m track walking image with flying balls and pedestrians was provided for concentration and posture change. In the fourth week, time factors and congested environments were provided through busy local community walking images with crosswalk, street markets, crowded streets and subways. In the fifth week, the change of lighting was provided through nighttime local community walking image, and in the sixth week, the change of topographical factors was provided through hiking track walking image. During whole session, the difficulty level of the images gradually increased. While the realtime video image was projected to the 2m front screen from the treadmill, the subjects were walking on the treadmill looking at the screen. For the safety of the subjects, an assistant was standing next to the treadmill while the training was done. All the same conditions as the virtual reality treadmill training group's were applied to the treadmill training group except for the virtual reality images.

## 4. Measuring the muscle architecture of medial gastrocnemius

To inspect the structure of medial gastrocnemius, we used a portable ultrasound system (Mysono U5, Samsung Medison, Seoul, Korea). This equipment's range of frequency modulation is 47～63 Hz, and the gain was the fixed value and was applied to all the images equally. The ultrasound images were measured in B-mode with the use of linear prove, and during the measurement of the images, sufficient amount of ultrasound gel was applied between the linear prove and skin to minimize the pressure of skin. The linear prove maintained right angle for consistent measurement.

The paralytic and non-paralytic sides' muscle thickness and pennation angle were filmed in the stable state that the subjects stretched knees facing the ground comfortably and fixed the angle of ankle joint to 90◦ and in the contraction state that the subjects put the pressure plate of the digital sthenometer on the distal part of the sole and did the maximum plantarflexion of ankle (Raj et al., 2012) (Figure 1).

To measure the thickness of muscles, we measured the distance the part that aponeurosis is not included between the superior aponeurosis and the inferior aponeurosis, and filmed the angle that the fascicle and inferior aponeurosis form after confirming the fascicle between the superior aponeurosis and the inferior aponeurosis to measure the right upper angle (Cho et al., 2014; Legerlotz et al., 2010). In addition, we minimized the error of measurement that could occur due to crowded surroundings by doing all the measurement after the end of day (Legerlotz et al., 2010).

Figure 1. Measurement of Medial Gastrocnemius Muscle using Ultrasound

The filmed ultrasound images were stored and the thickness and angle were measured through the caliper program. While the images were filmed, the subjects were laying face down on the bed with the knee joints stretched and with the calves stuck out of the corner of the bed. During the process of measuring through the caliper program, the thickness of muscles was automatically measured when a line was drawn between the upper flap and the lower flap that appeared on the image, and the right upper angle was automatically measured when a line that corresponded with the medial gastrocnemius lower flap was drawn, another line was drawn on the fascicle that changes depending on the degree of contraction of muscles, and the two lines were connected.

The location of the linear prove for ultrasound filming was set in the middle spot between 30% proximal part of calf length (the distance from popliteal wrinkles to the center of external oblique muscle of abdomen) and the posteromedial muscle belly of muscle gastrocnemius (Cho et al., 2014; Raj et al., 2012), and to prevent blurry images caused by pressed muscular fibers, we minimized the pressure between the linear prove and skin, stored the image that showed the right upper angle most clearly, and then measured.

### 5. Method of Analysis

For all work and statistics of this study, we calculated the average and the standard deviation using SPSS (version 18). Because the normal distribution supposition was satisfactory after the test of normality, the general characteristics of the subjects were analyzed with real number, percentage, average and standard deviation, and for the test of homogeneity between the groups, we used independent two-sample t-test and chi-square test. The change of dependent variables before and after training was analyzed with paired t-test, and for comparison of the effects between the groups, independent two-sample t-test was used. The data's level of all the statistical significance (α) was set to be below 0.05.

## Ⅲ. Result

### 1. The change of muscle architecture of medial gastrocnemius on the paralyzed side

Both the experimental group and the comparison group showed significant improvement of the right upper angle and the thickness of muscles on the paralyzed side of medial gastrocnemius muscles at contraction and relaxation of muscles through the 6 week training, and the experimental group had significantly higher improvement than the comparison group (Table 2).

### 2. The change of muscle architecture of medial gastrocnemius on the non-paralyzed side

Both the experimental group and the comparison group showed significant improvement of the right upper angle and the thickness of muscles on the non-paralyzed side of medial gastrocnemius at contraction and relaxation of muscles through the 6 week training, but there was no significant difference between the two groups (Table 3).

## Ⅳ. Discussion

The improvement of hypomotility and hypertonicity muscles caused by paralysis is an essential element for independent walking, which is the ultimate goal of stroke rehabilitation (Kirker et al., 2000). Stroke patients have decreased diameter of muscular fibers, myoatrophy and decreased number and excitement rate of moto units, so effective muscular strength can't be created (Bourbonnais et al., 1989). Therefore, recently, the realtime ultrasound test used for diagnosis or evaluation and analysis of the musculi skeleti function is used to investigate the change of muscular mechanical characteristics and muscle muscle architecture of various neural damage patients as well as musculoskeletal system disorder (Cho et al., 2014). This study observed the change of muscular structures by measuring medial gastrocnemius right upper angle and the thickness of muscles through ultrasound after having chronic stroke patients perform 6 weeks of the virtual reality treadmill walking training. The result of the study showed that both groups showed significant improvement in the medial gastrocnemius right upper angle and the thickness of muscles on the paralyzed and non-paralyzed sides during resting phase and contraction phase after the training ($p < 0.05$), and that the virtual reality treadmill training group had higher improvement in the medial gastrocnemius right upper angle and the thickness of muscles on the paralyzed side during resting phase and contraction phase than the treadmill training group ($p < 0.05$).

The result of the experiment confirmed that the virtual reality treadmill walking training has a positive effect on the medial gastrocnemius in both the paralyzed and non-paralyzed sides, and has a bigger effect on the improvement of the medial gastrocnemius structure in the paralyzed side. There was difficulty in accurate comparison due to lack of studies that observed the change of the medial gastrocnemius structure through intervention via ultrasound, but McNee et al.(2009) performed 10 weeks of intensive ankle joint plantar flexor training(lifting heels, rubber band resistance exercise) on 13 children with spastic cerebral palsy who were able to walk, whose result was that the medial gastrocnemius volume increased by 23.1%.

It was confirmed that real life video fliming based treadmill walking training is the access for the improvement of lower limbs' overall myofunction through the significant improvement of lower limbs' myofunction, but the training of this study wasn't the training only for ankle ankle joint plantar flexor with the medial gastrocnemius included. Nevertheless, through the training, the muscle gastrocnemius, which provide the driving force on the vertical line by connecting the movements of feet and knees during walking cycle, kept contracting, it is thought that there was a change in the muscle architecture. Especially there was increase of weight movement to the paralyzed side in the real life video images that held actual local community environments, so it is thought that there was significant improvement in the paralyzed side.

It was reported that the thickness of muscles and the structural arrangement in the muscles that form specific angle with the direction that muscular strength is conveyed are involved with muscular strength made by muscle cells (Lieber and Friden, 2000), but there is not sufficient research on ultrasound internal body examination until now to equate the function of muscles with the movement of muscle cells that have specific structures in the muscles. In the research on the evaluation of musculi skeleti internal body, the space structure between the relevant muscles and joints and the interaction of muscles and tendon should be considered as well as the thickness and structural arrangement (Lieber et al., 2004). The tendinous tissue is a passive tissue, which interacts with muscles and creates elastic energy (Alexander, 2002), so it is possible that the weight movement through the training of this study affected the tendinous tissue as well as the structure of muscles. Therefore, there is a need for research on myoarchitectonic change through training and additional research on the change of tendinous tissues.

## Ⅴ. Conclusions

This study observed the change of muscular structures by measuring the medial gastrocnemius right upper angle and muscle thickness through ultrasound after having chronic stroke patients receive the virtual reality treadmill walking training for 6 weeks, and the result of this study is as follows.

1. There was significant improvement in the medial gastrocnemius right upper angle and muscle thickness on the paralyzed and non-paralyzed sides during resting phase and contraction period after 6 weeks of training ($p < 0.05$).
2. The virtual reality treadmill training group had higher improvement in the medial gastrocnemius right upper angle and muscle thickness on the paralyzed side during resting phase and contraction period than the treadmill training group ($p < 0.05$).

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## Appendix 1. Table

Table 1. General Characteristics of Subjects

| | VRTT (*n*=15) | TT (*n*=15) |
|---|---|---|
| Gender (M / F) | 7 / 8 | 8 / 7[*] |
| Paralytic Side (Left / Right) | 8 / 7 | 11 / 4[*] |
| Cause of Disease (Infarction / Hemorrhage) | 10 / 5 | 10 / 5[*] |
| Age (year) | 65.86 ± 5.73[a] | 63.53 ± 5.54[*] |
| Height (cm) | 161.33 ± 7.65 | 165.20 ± 5.19[*] |
| Weight (kg) | 60.39 ± 8.96 | 64.66 ± 7.40[*] |
| Duration of Disease (days) | 414.46 ± 150.38 | 460.33 ± 186.78[*] |
| Length of Calf (cm) | 37.73 ± 2.37 | 32.94 ± 2.69[*] |
| MMSE-K (Score) | 26.20 ± 2.27 | 25.20 ± 1.97[*] |
| Brunnstrom stage (2 / 3 / 4) | 2 / 7 / 6 | 4 / 6 / 5 |
| MAS (1 / 1+ / 2) | 5 / 9 / 1 | 6 / 7 / 2 |

[*] $p > .05$

VRTT: Virtual Reality based Treadmill Training group, TT: Treadmill Training group, MMSE-K: Mini Mental State Examination-Korean, MAS: Modified Ashworth Scale

Table 2. Changes in Muscle Architecture of Medial Gastrocnemius on Paralytic side

| | | VRTT ($n$=15) | TT ($n$=15) |
|---|---|---|---|
| Contraction PA (degree) | Pre-Training | 22.54 ± 3.11 | 22.25 ± 1.79 |
| | Post-Training | 27.09 ± 3.99 | 24.39 ± 1.94 |
| | Difference | 4.54 ± 3.70$^{*}$ | 2.14 ± 1.13$^{*+}$ |
| Contraction MT (cm) | Pre-Training | 1.46 ± 0.09 | 1.47 ± 0.07 |
| | Post-Training | 1.61 ± 0.09 | 1.54 ± 0.07 |
| | Difference | 0.14 ± 0.05$^{*}$ | 0.07 ± 0.02$^{*+}$ |
| Relaxation PA (degree) | Pre-Training | 16.03 ± 1.06 | 16.01 ± 0.87 |
| | Post-Training | 17.10 ± 1.02 | 16.55 ± 0.97 |
| | Difference | 1.07 ± 0.38$^{*}$ | 0.54 ± 0.58$^{*+}$ |
| Relaxation MT (cm) | Pre-Training | 1.39 ± 0.12 | 1.39 ± 0.09 |
| | Post-Training | 1.51 ± 0.09 | 1.44 ± 0.08 |
| | Difference | 0.11 ± 0.04$^{*}$ | 0.04 ± 0.04$^{*+}$ |

$^{*}$Intra-group ($p<.05$)

$^{+}$Between-group ($p<.05$)

VRTT: Virtual Reality based Treadmill Training group, TT: Treadmill Training group, PA: Pennation Angle, MT: Muscle Thickness

Table 3. Changes in Muscle Architecture of Medial Gastrocnemius on Non-paralytic side

| | | VRTT ($n$=15) | TT ($n$=15) |
|---|---|---|---|
| Contraction PA (degree) | Pre-Training | 28.08 ± 1.68 | 28.00 ± 2.14 |
| | Post-Training | 30.75 ± 1.69 | 30.53 ± 2.08 |
| | Difference | 2.67 ± 0.80[*] | 2.52 ± 1.05[*] |
| Contraction MT (cm) | Pre-Training | 1.50 ± 0.07 | 1.50 ± 0.70 |
| | Post-Training | 1.58 ± 0.05 | 1.58 ± 0.08 |
| | Difference | 0.08 ± 0.04[*] | 0.07 ± 0.04[*] |
| Relaxation PA (degree) | Pre-Training | 18.10 ± 1.17 | 17.97 ± 1.30 |
| | Post-Training | 18.75 ± 1.18 | 18.60 ± 1.26 |
| | Difference | 0.65 ± 0.40[*] | 0.62 ± 0.22[*] |
| Relaxation MT (cm) | Pre-Training | 1.45 ± 0.07 | 1.45 ± 0.08 |
| | Post-Training | 1.50 ± 0.06 | 1.49 ± 0.08 |
| | Difference | 0.04 ± 0.02[*] | 0.04 ± 0.02[*] |

[*] Intra-group ($p<.05$)

VRTT: Virtual Reality based Treadmill Training group, TT: Treadmill Training group, PA: Pennation Angle, MT: Muscle Thickness