Focal Muscle Vibration Changes the Architecture of the Medial Gastrocnemius Muscle in Persons With Limited Ankle Dorsiflexion

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Article Info

Received December 31, 2021

Revised January 18, 2022

Accepted January 19, 2022

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Key Words

Gastrocnemius

Muscle tonus

Ultrasonography

Vibration

Background: The gastrocnemius tightness can easily occur. Gastrocnemius tightness results in gait disturbance. Thus, various interventions have been used to release a tight gastrocnemius muscle and improve gait performance. Moreover, focal muscle vibration (FMV) has recently been extensively researched in terms of tight muscle release and muscle performance. However, no study has investigated the effects of FMV application on medial gastrocnemius architectural changes.

Objects: In this study, we aimed to investigate the effects of FMV on medial gastrocnemius architecture in persons with limited ankle dorsiflexion.

Methods: Thirty one persons with $<10^\circ$ of passive ankle dorsiflexion participated in this study. We excluded persons with acute ankle injury within six months prior to study onset, a history of ankle fracture, leg length discrepancy greater than 2 cm, no history of neurological dysfunction, or trauma affecting the lower limb. The specifications of the FMV motor were as follows: a fixed frequency (fast wave: 150 Hz) and low amplitude (0.3–0.5 mm peak to peak) of vibration; the motor was used to release the medial gastrocnemius for 15 minutes. Each participant completed three trials for 10 days; a 30-second rest period was provided between each trial. Medial gastrocnemius architectural parameters [muscle thickness (MT), fiber bundle length (FBL), and pennation angle (PA)] were measured via ultrasonography.

Results: MT significantly decreased after FMV application ($p < 0.05$). FBL significantly increased from its baseline value after FMV application ($p < 0.05$). PA significantly decreased from its baseline value after FMV application ($p < 0.05$).

Conclusion: FMV application may be advantageous in reducing medial gastrocnemius excitability following a decrease in the amount of contractile tissue. Furthermore, FMV application can be used as a stretching method to alter medial gastrocnemius architecture.

INTRODUCTION

The gastrocnemius is essential for walking and posture, and thus gastrocnemius tightness can easily occur [1]. A tight gastrocnemius results in gait disturbance and loss foot energy absorption [2]. Moreover, the medial gastrocnemius that contains more fibers per unit volume exerts a greater contribution to gait performance than the lateral gastrocnemius [3]. Various interventions, such as stretching [4], massage [5], and vibration [6] have been used to release gastrocnemius tightness and improve gait performance [7]. Moreover, recently, the effect of focal muscle vibration (FMV) application on gastrocnemius

tightness release, and muscle performance has been extensively investigated [8].

FMV, a non-invasive technique through which targeted vibration is easily applied to specific muscles, facilitates the proprioceptive nervous system [9]. A vibration motor and actuator drive were used to operate the FMV device. The vibration motor, connecting the eccentric load to the rotor of the motor, generates an unbalanced rotation force [10]. This rotation force can be easily controlled using a fixed frequency and amplitude of the FMV device. Due to these advantages, many therapists use the FMV device to prolong the exposure of specific muscles to vibrations to reduce muscle tightness [11,12].

Ultrasonography is a useful tool for assessing muscle architectural properties, such as muscle thickness (MT), fiber bundle length (FBL), and pennation angle (PA). Muscle architecture can be used to determinate muscle function and force-generating capacity, which forms the basis for physiological movement [13]. Thus, the use of ultrasonography to measure muscle architectural changes is an important factor for enhancing human performance [14].

Few studies have compared the effects of FMV in exercise performance; further, other studies have examined the changes in muscle properties based on the joint angle [15,16]. However, no study has investigated the effects of FMV application on medial gastrocnemius architectural changes. Therefore, in this study, we aimed to assess, using ultrasonography, the medial gastrocnemius architecture via FMV application in participants with limited ankle dorsiflexion.

MATERIALS AND METHODS

1. Participants

A priori power analysis using G-power software (ver. 3.1.9.4; Franz Faul, Kiel University, Kiel, Germany) was used to estimate the sample size (Wilcoxon signed-rank test; effect size = 0.5, alpha level = 0.05, power = 0.80), the estimated sample size was 31. We included active participants who volunteered to participate in this study and had a passive ankle dorsiflexion range of motion (ROM) < 10°. Novacheck [17] demonstrated that a passive ankle dorsiflexion ROM of at least 10° is required for sufficient ambulation. Moreover, we excluded patients who presented with acute ankle injury within six months prior to the study onset, a history of ankle fracture, leg length

discrepancy greater than 2 cm [18], no history of neurological dysfunction, or trauma affecting the lower limb [19]. All volunteered participants provided written informed consent, and the study was approved by Institutional Review Board of the Graduate School, Yonsei University, Wonju (IRB no. 1041849-202103-BM-042-01).

2. Focal Muscle Vibration Therapy

In this study, a custom-made FMV device (UVTEC Inc., Incheon, Korea), using an eccentric rotor vibration motor, was used to release medial gastrocnemius tightness for 15 minutes (the ratio between right and left medial gastrocnemius was 29 to 2). Each participant completed three trials for 10 days, and a 30-second rest period was provided between each trial. The medial gastrocnemius architectural parameters were measured via ultrasonography. The specifications of the vibration motor for FMV application were as follows: a fixed frequency (fast wave: 150 Hz) and low-amplitude (0.3–0.5 mm peak to peak) (Figure 1). The FMV device was placed on the medial gastrocnemius, around the upper third of the posterior lower leg (Figure 2). The directions of the anchor and strap were perpendicular to the shaft of the motor, and the vector of the vibratory stimulus was parallel to the muscle fiber.

3. Outcome Measures

1) Medial gastrocnemius architecture

An ultrasound scanner with a 7.5-MHz linear transducer (SonoAce x8, Samsung Medison Co., Ltd., Seoul, Korea) was used

Figure 1. Specification of the focal muscle vibration motor with a fixed high frequency (fast wave: 150 Hz) and low amplitude (0.3–0.5 mm peak to peak).

Figure 2. Focal muscle vibrator device placement on the medial gastrocnemius.

to measure the medial gastrocnemius architectural parameters. Using the protocol provided by a previous study, medial gastrocnemius architectural images were obtained [20]. To ensure the consistency of the measurements, all images were obtained by a physical therapist, who was trained to administer the medial gastrocnemius ultrasound imaging protocol. The ultrasound probe was placed on a quarter proximal to the distance between the popliteal crease and the center of the lateral malleolus (Figure 3). Image acquisitions from medial gastrocnemius architecture were used in the mean value of three trials. The intra-reliability of the ultrasound used in our study was calculated for comparison with previous studies [20,21].

MT was measured as the longest distance between the superficial and deep fascias of the medial gastrocnemius. The PA was defined as the angle made by the insertion of the muscle fiber fascicles into deeper aponeurosis (Figure 4). The FBL was defined as the length of the fascicular path between the superficial and deep muscular fascias and was estimated using the following mathematical formula [21].

$$FBL = \frac{MT}{\sin(PA)}$$

4. Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics for Windows version 24.0 (IBM Co., Armonk, NY, USA) and the level of statistical significance ($\alpha = 0.05$). The Wilcoxon signed-rank test was performed to compare the dependent variables (MT, PA, and FBL) before and after FMV application.

RESULTS

1. Participants' Demographics

Thirty one healthy university participants (age = 23.9 ± 3.74 years; height = 171.6 ± 7.19 cm; body mass index = 70.9 ± 14.23 kg/m²) were included in this study.

2. Muscle Architecture

The medial gastrocnemius architectural changes evaluated using ultrasonography are shown in Figure 5. MT significantly

Figure 3. Ultrasound probe positioning for the medial gastrocnemius.

Figure 4. Ultrasound image of the medial gastrocnemius.

Figure 5. Ultrasonographic data for medial gastrocnemius architecture. Error bars indicate standard deviation. FMV, focal muscle vibration. * $p < 0.05$.

Table 1. Wilcoxon signed-rank test between before and after FMV application

Variable	Before FMV	After FMV
Muscle thickness (mm)	24.38 ± 4.50	22.90 ± 4.63*
Fiber bundle length (mm)	81.73 ± 14.45	88.66 ± 15.76*
Pennation angle (°)	19.12 ± 3.35	17.02 ± 3.76*

Values are presented as mean ± standard deviation. FMV, focal muscle vibration. * $p < 0.05$.

decreased from 24.4 ± 4.49 to 22.9 ± 4.63 mm ($p < 0.05$) after FMV application. The FBL significantly increased from 81.7 ± 14.45 to 88.7 ± 15.76 mm ($p < 0.05$) after FMV application. The PA significantly decreased after FMV application from $19.1 \pm 3.35^\circ$ to $17.0 \pm 3.76^\circ$ ($p < 0.05$) compared with the baseline value (Table 1).

DISCUSSION

This is the first study to quantify changes in muscle architectural parameters (MT, FBL, and PA) using an FMV device in participants with limited ankle dorsiflexion. Significant differences were found in MT, FBL, and PA after applying FMV. These findings indicate that FMV application may be advantageous in altering the amount of contractile tissue in the medial gastrocnemius.

In this study, MT significantly decreased after FMV application. This implies that FMV application allowed for medial gastrocnemius release by decreasing MT compared with the initial position. MT is commonly used for predicting the maximum force-generating capacity, which is defined by muscle activity; moreover, MT has been significantly correlated with the anatomical cross-sectional area [22]. Hebert et al. [23] reported a positive linear relationship between MT and abdominal electromyographic (EMG) activity during ultrasound imaging. Hides et al. [24] showed good to high correlation between MT and abdominal EMG activity in a magnetic resonance imaging study. Thus, MT is often used as an index of muscle activity. A fixed high-frequency (fast wave: 150 Hz) and low-amplitude (0.3–0.5 mm peak to peak) FMV was used to reduce the muscle excitability and to restrict the stimuli to specific muscles [25]. The stimuli provide the proprioceptive input by activating the neural pathway from the muscle spindle [8]. This proprioceptive input adjusts the intra-cortical inhibitory and facilitatory networks, thereby altering the excitability of the corticospinal pathway. Therefore, a localized application of FMV to the me-

dial gastrocnemius reduces the focal muscle excitability.

The FBL is the most important muscle architectural parameter and indicates the number of sarcomeres in a series [26]. Thus, a decrease in muscle contraction velocity or range of muscle fiber excursion influences the FBL [27]. An increase in FBL indicates a decrease in the amount of contractile tissue. Ribot-Ciscar et al. [28] reported that FMV application on specific muscles creates centrally localized neural changes that may decrease the spontaneous firing rate in the muscle spindle of primary sensory nerve endings, thereby changing the length-tension property of the muscle. In this study, FBL significantly increased after FMV application. This result is clinically useful, as it shows that FMV application is effective in releasing the medial gastrocnemius, and thus may effectively influence gastrocnemius stiffness.

The larger the PA, the greater the muscle contractility, and this increases the physiological cross-sectional area of the muscle [29]. Thus, an increase in PA indicates an increase in the muscle's capacity to produce force. In our study, the PA significantly decreased from the baseline value after FMV application. Therefore, applying FMV on the medial gastrocnemius may decrease the muscle's capacity for force productivity. Pilch et al. [30] reported that vibration application on a muscle plays a significant role in increasing tissue temperature. This tissue temperature alteration may be associated with improved blood flow and reduced muscle viscosity [31]. Malanga et al. [32] demonstrated that an increased local blood circulation reduces muscle spasm or muscle activity. Considering a heating mechanism, the local application of heat to a muscle is commonly recommended to strengthen the efficacy of muscle stretching [33]. Thus, FMV application can be used as a means to enhance the efficacy of muscle stretching using a neural pathway mechanism and heating effect.

This study has a few limitations. First, the study participants were generally vicenarians. This limited age group impedes the generalizability of the results. In further studies, a variety of age groups would be required to evaluate the muscle architectural properties. Second, we only investigated muscle architecture; functional or motion analysis (such as ROM, balance, or walking) was not performed. Further research will focus on the abovementioned variables.

CONCLUSIONS

In the present study, we investigated muscle architectural properties (MT, FBL, and PA) after FMV application in participants with limited ankle dorsiflexion. The findings suggest that FMV may have an advantage in reducing the medial gastrocnemius excitability following a decrease in the amount of contractile tissue. Furthermore, FMV application can be used as a stretching method for altering medial gastrocnemius architecture.

ACKNOWLEDGEMENTS

This study was supported by the “Brain Korea 21 FOUR Project”, the Korean Research Foundation for Department of Physical Therapy in the Graduate School of Yonsei University.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

AUTHOR CONTRIBUTIONS

Conceptualization: IYM, CHY. Data curation: IYM, JSL, IWP. Formal analysis: JSL, IWP. Funding acquisition: JSL, CHY. Investigation: IYM, JSL, IWP, CHY. Methodology: IYM, JSL, IWP, CHY. Project administration: CHY. Resources: IYM, IWP. Software: IYM. Supervision: IWP, CHY. Validation: IYM, JSL. Visualization: IWP, CHY. Writing - original draft: IYM, JSL. Writing - review & editing: IWP, CHY.

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