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Original Article

Effect of plyometric training on the fascicle length of the gastrocnemius medialis muscle

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Abstract. [Purpose] The present study aimed to determine the effects of eccentric calf raise exercise, which has the characteristics of plyometric training, on the fascicle length and muscle thickness of the gastrocnemius medialis muscle and range of motion of the ankle using ultrasonography. [Participants and Methods] Twenty-one healthy volunteers were randomly assigned to the eccentric calf raise exercise group or normal calf raise exercise group. Measurements were performed before training and at 3, 6, 9, and 12 weeks after training. [Results] In the eccentric calf raise exercise group, the fascicle length significantly increased after 6 weeks compared to that at baseline and at 3 weeks after training. The dorsiflexion angle and muscle thickness after three weeks significantly increased compared to that at baseline, but the pennation angle was not significantly different. The fascicle length, pennation angle, dorsiflexion angle, and muscle thickness showed no significant difference at all time points in the NCR group. [Conclusion] The results of this study showed that continued stretching of the gastrocnemius medialis muscle during eccentric calf raise exercise enhanced the morphological structures, such as the a fascicle length and muscle thickness. Eccentric calf raise exercise training may aid in injury prevention.

Key words: Stretch-shortening cycle, Ultrasonography, Lengthening of fascicle length

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INTRODUCTION

Plyometric training (PT) utilizing muscle elasticity and explosiveness is known as training to improve performance[1–6)]. PT can be divided into a loading phase, coupling period, and unloading phase based on the movement characteristics of the muscles[1)]. PT is considered to use that the stretch-shortening cycle (SSC), in which the muscle contracts sharply during the unloading phase following lengthening of the muscle-tendon unit during the loading phase[2)]. In previous studies on PT, increased peak muscle power output and fiber area[4)], improved elastic energy storage capacity, and increased tendon stiffness and elastic force[6)] have been reported, and Bobbert et al.[7)] described that muscle stretch by SSC enhanced performance. In addition, the coupling phase is the transition between the loading and unloading phases and is characterized by quasi-isometric muscle activity[1)]. A previous report stated that the elastic energy storage decreased when the coupling phase exceeded 0.2 sec[7)]. The shortening of this phase caused an improvement in performance[8)]; it has been reported that continuous and rapid switching behavior induced during PT enhanced energy efficiency[10)]. There were other studies that investigated the relationship between muscle stiffness and muscle strength[11)], or investigated changes in ankle angle[10)], and several other studies[12, 13)]. However, changes in muscle structures such as fascicle length (FL) and pennation angle by PT were not identified[14, 15)]. In many studies[4, 9, 10)], that involved exercises consisting of whole-body training such as a counter-movement jump and depth jump, it was guessed which could easily compensate for weak muscles. Thus, we hypothesized that continuous and

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*Corresponding author. Shintarou Kudo (E-mail: kudo@morinomiya-u.ac.jp) rapid stretching of the localized site may increase FL. A previous study showed that eccentric training led to damage of the muscle fiber, and increased sarcomere number[16)]. Therefore, we focused on the effect of the eccentric calf raise (ECR)[17)]. We previously found that ECR with constant speed and rhythm have a characteristic SSC elements necessary for PT[17)]. In this study, we defined ECR was training localized to the triceps surae as training included in PT. Increasing FL not only increases the range of motion of the muscle parenchyma and improves competition performance, but is also important for injury prevention. The purpose of the present study was to determine the effects of ECR exercise on the FL of the gastrocnemius medialis (GM) muscle.

PARTICIPANTS AND METHODS

Twenty-one healthy, normal volunteers (42 legs) with no injuries in the lower limbs provided informed consent and participated in this study. This study was approved by the ethics committee of Morinomiya Medical University (2016-107). They were randomly categorized into the ECR group (n=11; 8 males and 3 females [22 legs]; mean age, 21.2 ± 3.9 years; mean weight, 57.8 ± 10.2 kg; mean height 164.6 ± 9.4 cm) and the normal calf raise (NCR) exercise group (n=10; 6 males and 4 females [20 legs]; mean age, 19.6 ± 0.7 years; mean weight, 56.1 ± 8.3 kg; mean height, 164.1 ± 7.9 cm). Regarding the frequency of ECR training, we adopted the method described by Alfredson et al[18)]. To equalize the total workouts in the groups, the ECR group was asked to perform 15 × 3 repetitions daily in two sets, seven days/week, and the NCR group was set to perform 20 × 3 repetitions daily in two sets, seven days/week. Both groups perform these respected regiments for 12 weeks based on our pilot study. The starting position was either the normal standing position or standing with the forefoot on a 6-cm pedestal with the ankle in dorsiflexion. Calf raises were performed at 60 beats per minute; this rhythm was controlled using a metronome[17)]. Ultrasound images of the GM muscle were recorded at a height of 25% of the proximal length of the lower thigh, with the ankle at the 0°-position in the prone position, using a B-mode 12-MHz linear transducer ultrasonography device (My Lab. 25, Esaote Corporation). The lower thigh was defined as the lateral knee joint space to lateral malleolus. The pennation angle and muscle thickness of the GM muscle were determined using Image-J (NIH, Washington, DC, USA)[17)], and extended lines that delineate the deep aponeurosis and visible fascicle on each image were used to determine the FL[19)]. The maximum dorsiflexion angle of the ankle was determined with the knee in the fully extended position using a goniometer with the participant in a supine position. All measurements were carried out three times each and performed before training and at 3, 6, 9, and 12 weeks after training. The mean values were calculated. In each group, all measurements at each time point were performed using a repeated analysis of variance (ANOVA). All statistical analyses were performed using IBM SPSS Statistics 24.0 for Windows. Values of $p<0.05$ were considered to indicate statistical significance for all tests.

RESULTS

Sequential changes in each measurement outcome are shown in Table 1. In the ECR group, the FL significantly increased after six weeks compared to that at baseline) and after three weeks of training (68.3 ± 8.1 mm vs. 70.5 ± 9.2 mm; $p<0.01$ [baseline] and $p<0.05$ [3 weeks]). Dorsiflexion angle and muscle thickness after three weeks significantly increased compared to those at baseline (dorsiflexion angle, 12.2 ± 5.2 degrees vs. 14.8 ± 5.8 degrees; muscle thickness, 18.0 ± 2.3 mm vs. 19.5 ± 2.4 mm). Pennation angle showed no significant difference in both groups. In the NCR group, the FL, pennation angle, dorsiflexion angle, and GM muscle thickness showed no significant differences at all time points.

Table 1. Values of fascicle length, dorsi-flex angle, muscle thickness and pennation angle of ECR and NCR groups

	Baseline	3 w	6 w	9 w	12 w
			ECR group (N=22)		
Fascicle length (mm)	68.3 (8.1)	70.5 (9.2)	73.2 (8.8)*†	74.5 (8.3)*††	74.2 (8.0)*††
Dorsi-flex angle (degrees)	12.2 (5.2)	14.8 (5.6)*	15.8 (6.8)*	16.0 (5.3)*	16.2 (7.1)*
Muscle thickness (mm)	18.0 (2.3)	19.5 (2.4)*	19.7 (2.8)*	19.3 (2.2)*	19.6 (2.3)*
Pennation angle (degrees)	17.4 (2.0)	17.6 (2.4)	16.9 (1.3)	16.5 (1.2)	16.9 (1.5)
			NCR group (N=20)		
Fascicle length (mm)	67.4 (8.3)	67.6 (8.2)	70.8 (8.8)	67.7 (9.8)	69.0 (9.1)
Dorsi-flex angle (degrees)	12.6 (4.1)	11.5 (4.0)	11.7 (4.4)	12.1 (3.4)	12.3 (4.7)
Muscle thickness (mm)	18.2 (2.1)	19.1 (2.1)	18.6 (1.7)	18.8 (1.9)	18.8 (2.1)
Pennation angle (degrees)	16.2 (2.4)	16.5 (2.7)	17.0 (2.7)	16.7 (2.9)	16.4 (2.0)

Mean significant difference from results of baseline ($^{*}p<0.01$) and 3 weeks ($^{\dagger}p<0.05$, $^{\dagger\dagger}p<0.01$).
Values: mean (SD); N: participant number; ECR: eccentric calf raise exercise; NCR: normal calf raise exercise.

DISCUSSION

Some evidence for the lengthening of the FL is available[16, 20–26]. However, to the best of our knowledge, this is the first study to show increases in the FL by PT. The results of this study showed that continued stretching of the GM muscle for 6 weeks increased the dorsiflexion angle and enhanced morphological structures such as the FL and muscle thickness. Proske et al.[16] have reported that eccentric exercise has led to an increase in the optimum length of muscle. It was considered that the muscles were damaged by the continuous stretching stimulus and adapted to increasing the sarcomere number in the repair process. Finally, these alterations increased the optimum length of muscle. It was considered that the same process occurred in the lengthening of FL caused by SSC in this study. Incidentally, static stretching has been utilized as an intervention method to promote muscle stretch in a similar manner. Currently, the effects of static stretching are as follows: increased muscle flexibility[27], decreased muscle stiffness[28], increased range of motion[27, 29] and reduced passive joint moment[30]. Regarding increases in FL, the evidence are conflicting. Nakamura et al. showed that continuous static stretching for 4 weeks did not increase the FL, and stated that the increased flexibility of the connective tissue (so-called parallel elastic component) such as the perimysium around the muscle fibers was involved[27]. Conversely, Simpson et al. reported that the FL of the medial and lateral gastrocnemius muscles were increased by continuous static stretching after 6 weeks of training[26]. However, in their study, static stretching was being performed with concurrent resistance training of the gastrocnemius muscle using the leg press exercise. Additionally, they suggested that, to induce muscle adaptations with stretch training, it is necessary to apply the principle of overload to create a sufficient stimulus for adaptations in the skeletal muscle architecture. Based on this, it was suggested that continuous stretch-load stimulated the series elastic components as the contractile component contributed to increases in the FL. In addition, the muscle thickness showed a significant increase, however the pennation angle was not shown significant differences, because the FL were increased too.

Increases in the FL indicate that range of movement of the muscle parenchyma is also increased. This suggested that this was not a temporary increase in the range of motion due to improvement of the tissue flexibility such as fascia; instead, it was effective over a larger range of motion. This is important in improving performance. Increasing the FL by eccentric training is recognized to promote an optimum angle and length[21, 22] shift and improvement in eccentric peak torque[20], which was purported to be related to an increase in elastic energy storage capacity. In addition, it was considered that the increase in FL is important not only for improving performance, but also for the prevention of injuries such as muscle strain, because the muscles can work more efficiently without exposure to overstretching.

This study has some limitations. First, the FL was measured in only one direction. FL change as evaluated in 3D may be different than that evaluated in 2D. Second, passive tension of the tendon was not measured in this study. If there was a change in the muscle structure, there might be a change in the associated tendon structure; it is important to clarify this to understand the change in the gastrocnemius muscle by ECR. However, there is no research on passive tension and increases in the FL. This should be evaluated in future studies. In conclusion, our results revealed that the FL of the GM muscle in the ECR group increased after six weeks.

Conflict of interest

We have nothing to declare for this study.

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