Comparing Changes in the Calf Muscle during Weight-bearing and Non-weight-bearing Stretching

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Abstract. [Purpose] The aim of this study was to investigate and compare changes in muscle fascicle and tendon tissue behavior during stretching between a weight-bearing position and non-weight-bearing position. [Subjects] The study subjects were fifteen healthy individuals. [Method] Changes in the calf muscle after stretching in a weight-bearing and a non-weight-bearing position were compared using ultrasonography. Weight-bearing and non-weight-bearing stretching were performed for 30 seconds, and the medial gastrocnemius (MG) muscle fascicle length, pennation angle, and Achilles tendon length were measured before and after stretching. [Results] The post-stretching results in both positions showed increased fascicle length, decreased pennation angle, and increased Achilles tendon length compared with the pre-stretching results. Significant interactions were found between weight-bearing and stretching as evidenced by MG fascicle length and Achilles tendon length; specifically, the non-weight-bearing position increased the length more than the weight-bearing position. [Conclusion] This study revealed that while both weight-bearing and non-weight-bearing stretching were able to stretch the MG muscle and the Achilles tendon, non-weight-bearing stretching was more effective with regard to extending the MG muscle and Achilles tendon.

Key words: Flexibility, Ultrasonography, Triceps surae

INTRODUCTION

Ankle joint dorsiflexion is necessary for the normal performance of functional activities such as gait, stair climbing, and rising from a chair1,2). In addition, it plays an important role in sporting activities. Limited ankle joint dorsiflexion has been associated with sports injuries of the lower extremity, including ankle sprain3), patella tendon disorder4), Achilles tendon disorder5), plantar fasciitis6), and several overuse syndromes7). Moreover, limited ankle joint dorsiflexion is also related to deformation of the foot8,9). Limited ankle joint dorsiflexion is caused by calf muscle tightness and soft tissue contracture; calf muscle stretching is commonly used in rehabilitation programs and sports activities10). Static or slow stretching methods are thought to be useful for injury prevention and performance by increasing the ankle joint dorsiflexion11).

The development of imaging techniques, such as ultrasonography, allows the determination of the architecture of the muscle tendon unit in humans12,13). This noninvasive method makes it possible to measure changes in muscle fascicle and tendon tissue behavior during stretching. Stretching techniques include weight-bearing or non-weight-bearing stretches with the knee extended14,15). Many recent studies have investigated the detailed changes in muscle fascicle and tendon tissue behavior during stretching using electromyography and ultrasonography16,17). Although weight-bearing stretching is widely used in clinical practice, studies have rarely examined weight-bearing stretching because the amount of resistance must be maintained, and joints other than the ankle joint must remain fixed during image acquisition. Studies have revealed that the kinematics of ankle joint dorsiflexion differs between the weight-bearing position and the non-weight-bearing position18). It has not yet been clarified whether calf muscle stretching differs between the weight-bearing position and non-weight-bearing position. The aim of this study was to investigate and compare changes in muscle fascicle and tendon tissue behavior during stretching between the weight-bearing position and the non-weight-bearing position.

SUBJECTS AND METHODS

The subjects of the study were 15 healthy subjects (10 males, 5 females; mean age 27.4 (5.4) years). All participants signed consent forms after the study procedure was explained to them in detail. The study conformed to the Declaration of Helsinki and was approved by the Gunma University Ethics Committee. To be included in the study,
volunteers met the following criteria: no previous history of trauma to the calf muscle that required surgery and no evidence of lower extremity dysfunction as assessed by visual observation of gait on a level surface.

Stretching in a weight-bearing position was performed using the following protocol. To stretch the calf muscle tendon unit in a weight-bearing position, subjects stood barefoot about 2 or 3 feet from a solid wall. While facing the wall with their right foot perpendicular to it, they were instructed to move the left foot forward while keeping the right foot back, placing their hands against the wall and maintaining their right hip and knee in extension with the right foot kept flat on the floor. Subjects were instructed to move their left foot forward until they felt a substantial pull in the right posterior calf that was just short of being painful or the amount of the load to the foot reached 10 Nm. A hand-held dynamometer (HHD; the Commander Powertrack Dynamometer, J-Tech Medical, Salt Lake City, USA) was placed under the second metatarsal head of the foot to measure the load.

Stretching in a non-weight-bearing position was performed using the following protocol. The subject lay prone on a table with both legs, and the underside of the right foot was attached to a footplate\(^1^9\). The HHD was positioned beneath the second metatarsal head. The ankle acted as the center of rotation for an upwardly applied force to the plantar surface of the foot. The resultant MG fascicle and Achilles tendon behavior was measured and data was recorded only when the upward force on the foot was appropriate for the predetermined torque of 10 Nm. The subject’s foot then pushed the plate from an ankle neutral position until slight discomfort was noted in the posterior calf or the HHD load reached 10 Nm, while maintaining the subtalar joint in an approximately neutral position (Fig. 1).

Stretches were performed for 30 seconds in each position, followed by a three-minute rest period. Each measurement was repeated three times, and weight-bearing and non-weight bearing were performed at random by the subject. It was reported that a stretch of 30 seconds was the most effective for the improvement of range of motion\(^1^5,1^6\). A previous study indicated that ankle dorsiflexion increased over the entire 30-s stretch, while the majority of the increases in position occurred during the first 15–20 s\(^1^6\).

The architectural change in the medial gastrocnemius (MG) muscle and the elongation of the Achilles tendon during stretching were investigated with ultrasonography\(^1^7,2^0\). The MG muscle was measured by obtaining longitudinal images using a real-time B-mode ultrasonographic apparatus (Mylab25; Hitachi Medical Corporation, Japan) with a 10-MHz linear-array probe. The probe was fixed firmly onto the right leg (at 30% of the distance from the popliteal crease to the center of the medial malleolus), over the midbelly of the muscle. A muscle fascicle was clearly identified, and the probe was firmly held in place by the estimator. The fixation ensured constant orientation and pressure of the probe to prevent the muscle shape from changing. Two parameters were measured on each MG ultrasound image: muscle fascicle length and pennation angle. The muscle fascicle was defined as the clearly visible fiber bundle located between the two aponeuroses (superficial and deep). The fascicle length was calculated using trigonometry [total length = \(L_V\) (measured visible fascicle length) + \(L_E\) (estimated fascicle length) = \(L_V + (h/\sin \theta)\), where \(h\) is the height and \(\theta\) is the pennation angle] and assuming a linear continuation of the fascicles. The pennation angle was defined as the angle between the muscle fascicle and its insertion into the deep aponeurosis (Fig. 2). Abellaneda et al.\(^1^7\) reported the coefficients of variation (= SD/mean) were 0.4 and 4.2% for pennation angle and fascicle length. The Achilles tendon length was measured using a B-mode ultrasonographic apparatus (LOGIQ-e; GE Healthcare, USA) with a 7.5-MHz linear-array probe to obtain images of the Achilles tendon and monitor the elongation. The Achilles tendon insertion into the calcaneus notch and the soleus-Achilles muscle tendon junction (MTJ) were located with a probe and...
marked at the corresponding positions on the skin surface. The soleus-Achilles MTJ was defined as the location where the Achilles tendon divided into the soleus aponeurosis and gastrocnemius tendon. The soleus-Achilles MTJ was defined as the intersection between the most distal muscle fascicle of the soleus muscle and the Achilles tendon. A previous study reported the test-retest reliability for tendon length that had been measured based on MTJ and was conducted with 15 subjects within the control condition. Coefficients of variation ranged from 0.4 to 0.5% (13). The ultrasound video data were continuously recorded at 15 frames/s over the entire Achilles tendon length. The obtained motion picture was converted into frame pictures; and a panoramic image was created using the photo merge function of the image analysis software (Adobe Photoshop CS3; Adobe Systems, USA) to connect the frame pictures.

ImageJ (National Institutes of Health, USA) was used to measure the MG muscle fascicle length, the MG muscle pennation angle, and the Achilles tendon length from the soleus-Achilles MTJ to the calcaneus notch insertion along the tendon line of action. It was measured in the pre- and post-stretching positions. The ultrasonographic scan was obtained 3 times, and the values of these measurements were averaged across the scans and used for further analysis. All data are reported as mean (SD).

A two-way (weight and stretching) analysis of covariance (ANOVA) was performed. The repeated factor had two levels (pre and post), and the within subjects factor also had two levels (weight-bearing position and non-weight-bearing position). When significant differences were found, a paired t-test was used to determine the significance of the mean differences. Statistical analyses were performed with statistical software (SPSS version 16.0J for windows; SPSS Inc., USA), and values of $p < 0.05$ were considered significant in all analyses.

### RESULTS

Both stretching positions lengthened the MG muscle fascicle, decreased the pennation angle, and elongated the Achilles tendon. The average length of the MG muscle

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<tr>
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<th>Weight-bearing</th>
<th>Non-weight-bearing</th>
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<tr>
<td></td>
<td>Pre-stretching</td>
<td>Post-stretching</td>
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<tr>
<td>MG muscle fascicle length (mm)</td>
<td>64.0 (6.4)</td>
<td>73.8 (10.4)*</td>
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<tr>
<td>MG muscle pennation angle (degree)</td>
<td>17.1 (2.1)</td>
<td>14.8 (1.8)*</td>
</tr>
<tr>
<td>Achilles tendon length(mm)</td>
<td>72.0(23.0)</td>
<td>74.3(19.7)*</td>
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Mean (SD), *Significant difference ($p<0.01$)
fascicle significantly increased (weight-bearing: from 64.0 (6.4) mm to 73.8 (10.4) mm, p < 0.01; non-weight-bearing: from 62.7 (6.6) mm to 74.9 (10.7) mm, p < 0.01), pennation angle decreased (weight-bearing: from 17.1 (2.1)° to 14.8 (1.8)°, p < 0.01; non-weight-bearing: from 17.0 (2.1)° to 14.2 (1.7)°, p < 0.01), and concurrently Achilles tendon length increased (weight-bearing: from 72.0 (23.0) to 74.3 (19.7), p < 0.01; non-weight-bearing: from 71.4 (23.6) to 78.4 (21.9), p < 0.01) in the stretching position (Table 1).

While no significant interaction between weight and stretching was found with respect to the MG muscle pennation angle, significant interactions were found with respect to the MG fascicle length (p < 0.01) and Achilles tendon length (p < 0.05). Specifically, the non-weight-bearing position lengthened the MG fascicle and the Achilles more than the weight-bearing position did.

DISCUSSION

Muscle stretching is usually used to lengthen the calf muscle tendon unit and improve performance by increasing flexibility. However, the extensive interest in muscle stretching contrasts with the paucity of information regarding the limiting factors of the in vivo muscle-tendon unit (MTU).

In this study, the MG pennation angle decreased and the muscle fascicle length increased as a result of weight-bearing and non-weight-bearing stretching. A similar result was obtained in a previous study of non-weight-bearing stretching. Monte et al. reported that the pennation angle decreased from 30.1° to 19.3°, and the fascicle length increased from 41.1 to 62.6 mm, whereas muscle thickness stayed approximately constant over an ankle dorsiflexion range of 113° to 80°. Another study similarly indicated that the fascicle length increased monotonically as the ankle dorsiflexed and the pennation angle ranged from 41° to 17°, and decreased monotonically as the ankle moved from plantar to dorsiflexion.

This study also revealed that weight-bearing and non-weight-bearing stretching elongated the Achilles tendon. Morse et al. reported that MTU length increased by 22 mm and the elongation of the tendon increased by 12 mm accounting for 53% of the overall change in MTU length during stretching over an ankle dorsiflexion range of 0° to 25°. Extensions of both muscle and tendon components increased linearly with increasing ankle angle during standard stretches. Hoang et al. reported that the mean maximal change in the length of the tendon from the slack length to the longest length was 36 mm, and the maximal strains of the muscle fascicle and tendon were 16% and 9%, respectively. In this study, maximal strains of the muscle fascicle and Achilles tendon in the weight-bearing and non-weight-bearing positions were similar (fascicle strain of weight-bearing: 15%, non-weight-bearing: 19%; tendon strain of weight-bearing: 3%, non-weight-bearing: 10%). It has been shown that prolonged passive stretching induces acute changes in the passive tension–length relationship, related to the viscoelastic properties of the muscle–tendon unit. The increased muscle fascicle length and Achilles tendon length are commonly attributed to changes in the connective tissues and myofibrils.

In this study, we measured the Achilles tendon length using Zhao’s method. In previous studies, the Achilles tendon length was measured using various methods (e.g., Morse et al. measured tendon elongation at the MTU, whereas Kubo et al. measured it at the fascicle insertion into the deep aponeurosis). These methods estimated the length of the Achilles tendon from the movement of the MTU or the aponeurosis. The advantage of the panoramic image method used in this study is that the total length of the Achilles tendon can be clarified. This method is thought to be reliable for measuring the change in the length of Achilles tendon. This study found an interaction between weight and stretching; non-weight-bearing stretching increased fascicle length and Achilles tendon length more than weight-bearing stretching.

In preceding studies about changes in ankle dorsiflexion, weight-bearing stretching did not increase the range of motion. On the other hand, many studies have reported that an effective change was seen as a result of non-weight-bearing stretching. Millington et al. reported that ankle dorsiflexion increased by the talar neck impingement that is in contact with the anterior aspect of the distal tibia. They concluded that the effect of lengthening of the MG muscle and elongation of the Achilles tendon was not achieved by weight-bearing stretching due to the limitation of osseous impingement.

Muscle activity is also thought to influence the weight–stretching interaction. Calf muscle activity varied between the weight-bearing position and non-weight-bearing position because the muscles cannot relax in the weight-bearing position. In a state of muscle strain, sufficient lengthening of the calf muscle is not obtained.

We also revealed that non-weight-bearing stretching was more effective for lengthening the MG muscle and elongating the Achilles tendon than weight-bearing stretching.

The range of ankle dorsiflexion was most influenced by the length of the Achilles tendon. The division of the other tendons and the capsular tissue around the ankle joint did not affect the range of ankle dorsiflexion. There was a mean increase of 12 degrees of dorsiflexion for each centimeter increase in Achilles tendon length. In this study, stretching was found to elongate the Achilles tendon in both positions; thus, elongating the Achilles tendon and lengthening the muscle fascicle increased the range of ankle dorsiflexion.

The range of ankle dorsiflexion was not measured in this study. It is difficult to measure it similarly in a weight-bearing position and non-weight-bearing position because the kinematics of the tarsal bone differs. In future, it will be necessary to combine the measuring methods and to investigate the relationship between the length of the calf MTU and the range of ankle dorsiflexion. The fascicle length and pennation angle were determined to account for 30% of the distance between the popliteal crease and the
center of the medial malleolus. Although it has been shown that there is marked uniformity in fascicle length throughout a muscle, the relationships between joint position and fascicle arrangement might differ in different portions of a muscle. The sample size in the current study was relatively small, although significant differences in biomechanical properties were still observed. Further studies are needed to investigate in detail the passive mechanical properties responsible for improving the range of ankle dorsiflexion in stretching.

In conclusion, this study revealed that weight-bearing and non-weight-bearing stretching were able to stretch the MG muscle and Achilles tendon. Furthermore, non-weight-bearing stretching is particularly effective for lengthening the MG muscle and elongating the Achilles tendon.

ACKNOWLEDGMENT

This work was supported in part by Grants-in-Aid for scientific research from the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT) and the Support Program for Improving Graduate School Education from MEXT.

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