The Influence of Thermotherapy on Muscle Elasticity: Measurement of Pennation Angle with the Use of Ultrasound Images

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Abstract. The purpose of this study was to visualize the changes of muscle architecture by measuring pennation angle on ultrasound (US) images, and to examine the influence of thermotherapy on the elasticity of muscles which were stretched passively. Ten healthy male subjects positioned with the ankle joint planterflexed or dorsiflexed were continuously stretched in the dorsiflexion direction for 3 minutes in both positions, and the pennation angle and muscle extensibility were measured. Each subject received the following thermotherapy interventions randomly: Group 1 received continuous US wave (1 MHz, 1.5 W/cm², 5 minutes); Group 2 underwent the same intervention as Group 1 but with no ultrasound output. Subjects of Group 3 were given 20 minutes of moist hot pack; Group 4 stayed still for 20 minutes. All interventions were practiced on the medial gastrocnemius muscle belly. Stretching was given after each intervention. Our study results showed that muscle extensibility did not differ significantly in any group, except for neutral positioning in groups 1 and 4. However, while groups 2 and 4 showed reduction in the pennation angle, it did not change in groups 1 and 3. These results support the hypothesis that thermotherapy is one of the factors which contribute to muscle relaxation. In other words, the measurements of pennation angle enables us to see in vivo effects of thermotherapy on muscle elasticity.

Key words: Pennation angle, Ultrasound images, Thermotherapy

INTRODUCTION

Joint range of motion (ROM) is defined as the range of mobility when one moves the joint actively or when it is moved passively. By measuring ROM in passive motion, one is able to find out structural abnormalities in the soft tissues and the articulations. ROM exercise accounts for a considerably high percentage of physical therapists’ tasks, since ROM is an important indication of motor function, and its limitation brings obstacles in activities of daily living. One of the factors which limits ROM is the contracture resulting from alterations in the soft tissues such as muscle and skin. Trudel et al. suggests that contracture is largely due to muscle alterations, and a number of researchers reported morphological and functional alterations in muscle. Various physiotherapies for ROM improvement exist. Therapists often use passive stretching for muscle shortness, and also
use physical agent modalities for the purpose of improving muscle plasticity\(^2\)\(^{-4}\). Camenon et al.\(^5\) state that thermotherapy, in particular, is effective in extending muscles. Ultrasound (US) is widely used in America and Europe, while hot pack is the chief treatment in Japan.

Recently, a number of researchers, using US imaging and MRI, reported changes in skeletal muscle architecture \textit{in vivo}\(^6\)\(^{-8}\). Investigations with the usage of US images have been drawing considerable attention, for US imaging helps researchers evaluate objectively the changes of muscle architecture in contraction, ligament elasticity as transduction of force, and functions of muscle-tendon unit\(^9\), \(^10\). The angle between the aponeurosis and the fascicles at the points of attachment onto the aponeurosis or so-called pennation angle is often used as indicator of muscle architectural changes\(^11\), \(^12\).

In our previous studies, the occurrence of errors in measuring angle or pennation angle was low, and our measurements of pennation angle and muscle extensibility showed good reproducibility when we examined soft tissue elasticity\(^13\). Thus, we concluded that US imaging is worth using for measuring the pennation angle because of its capability to visualize and quantify it. We also reported that the pennation angle in passive stretching is decreased\(^13\).

The purpose of this study was to visualize muscle architectural changes \textit{in vivo} by measuring the pennation angle on US images, and to examine the influence of thermotherapy on muscle elasticity when it is passively extended.

**METHODS**

**Subjects**

Ten healthy males without any neural or orthopedic disorders were enrolled in this study. We gave all the subjects precise explanations regarding our study, and they all signed an informed consent form. Their mean (\(\pm\) SD) age, height and body mass were 27.3 \(\pm\) 4.2 years, 171.0 \(\pm\) 6.9 cm, 62.9 \(\pm\) 6.1 kg, respectively. We examined the right lower extremity in all subjects.

**Passive stretch**

A Biodex system 3 dynamometer (Biodex System3, Biodex Medical Systems) was used in the present study (Fig. 1). We selected the isometric mode and 30 Nm for torque limit. The subjects were positioned of the ankle joint plantarflexed at 30\(^\circ\), 15\(^\circ\) or 0\(^\circ\), or dorsiflexed at 15\(^\circ\). Each subject stayed static for 180 seconds in all 4 positions to have the ankle plantarflexor muscles to be passively stretched. We regarded the resistance torque of the Biodex as muscle extensibility.

**Ultrasound images**

A linear array probe (EUB415, HITACHI Medical Corporation, Japan) with a scanning frequency of 7.5 MHz was used, and we obtained sagittal plane images of the distal muscle-tendon unit of the medial gastrocnemius muscle. (The direction and distance resolutions of US with this probe were within 1.0 mm.) We selected the real-time B-mode ultrasound apparatus\(^11\). The tested site was proximal 30\% of the medial gastrocnemius muscle belly on a line between the popliteal crease and the lateral malleolus\(^14\). The site was monitored and identified by sagittal US images\(^4\). We moved the probe from the tested site towards the peripheral direction where the distal fascicles of muscle-tendon unit of the medial gastrocnemius muscle intersect with the aponeurosis, in which we were able to see the pennation angle clearly. Using original apparatus, we carefully fixed the probe in a position where it would not push the muscle downward\(^15\). Fixation of the probe enabled us to
measure the same site at any time. We also made a mark on subjects’ skin to confirm all the measurements would be performed on the same spot under any test conditions. Before measurements, we shaved leg where the probe was placed. The scanning head of the probe was coated with gel (ECHO JELLY, Aloka, Japan) to obtain clear images. Images were paused and printed out by connected printer (EZU-VP4, HITACHI Medical Corporation, Japan). The same examiner practiced all measurements.

Image processing by ultrasound scanner

Muramatsu et al.\textsuperscript{12} state that the curve of the fascicle is ignorable when measuring the pennation angle in the rested gastrocnemius muscle. Thus, we considered measurements of the pennation angle to be quantitative. We obtained printed images of US scanner, and then scanned (IPSON SCAN 3000DC, RICHO, Japan) these images into a computer (FMV NH70J, Fujitsu, Japan). The obtained images underwent image processing. With the use of angle measurement software (Scion Image Beta 4.02 for Windows 95, 98, ME, NT2000 and XP, Scion corporation), we identified the pennation angle, which is the intersection of the fascicle and the aponeurosis\textsuperscript{11, 15} (Fig. 2).

Measurement procedure

The subjects were seated on the Biodex dynamometer and the right hip joint was slightly flexed and the right knee joint was flexed to 20°. The right lower extremity was exposed and subjects were secured to the attachment with waist and distal thigh straps. Feet were placed on the footplate and secured with straps. Before starting measurements, the subjects stayed still for 180 seconds with their ankle joint naturally plantarflexed. Flexor muscles of the ankle joint were then passively stretched towards dorsiflexion direction by dynamometer. Images of the ankle joint before stretch and those of after 180-second-stretch were taken and muscle extensibility was measured. The examiner marked the fibular head, the lateral malleolus, the fifth metatarsal base and the fifth metatarsal head to use them as a landmark. The ankle joint ROM in plantarflexion and dorsiflexion were determined at where a line connecting the fibular head and the lateral malleolus intersects with a line connecting the fifth metatarsal head and the fifth metatarsal base. With the use of above measurement method, we set the ankle joint in the neutral position as Biodex ROM 0°. Thereafter, all joint angle measurements were obtained from dynamometer.

Test conditions

The following four types of thermotherapy interventions were given to all subjects in prone. We used active US (US700, Ito Co., Ltd, Japan) for Group 1. Subjects in Group 1 received continuous US wave with a frequency of 1 MHz and an intensity of 1.5 W/cm² for 5 minutes with echo jelly applied over their skin (US group). Group 2 underwent the same intervention as Group 1 but with no ultrasound output (controlled US group). Subjects of Group 3 were given 20 minutes of moist hot pack (HP group). Group 4 stayed still for 20 minutes (controlled HP group). All interventions were practiced on the medial gastrocnemius muscle belly. We randomly scheduled the test sessions at one-week intervals to prevent any residual effects of the initial interventions from contaminating the effect of subsequent interventions.

Data analysis

Comparing between each test condition, we investigated the differences in the pennation angles before and after passive stretch and muscle extensibility. We used the Wilcoxon t-test to analyze the data of pre and post stretch. As for the
data of joint angle, we used Friedman’s test, and then used post hoc test called Wilcoxon t-test with Bonferroni Correction. Analyses of data differences between each test condition were carried out with the Kruskal Wallis H-test, and Mann-Whitney U-test with Boneferroni Correction as post hoc test. Significance for all statistical tests was accepted at the 0.05 level of probability.

RESULTS

Pennation angles before and after passive stretch under diverse test conditions

Pennation angles of pre and post passive stretch under each test condition are shown in Table 1. Pennation angles which were measured before stretch did not show any significant difference under any test condition.

In regard to the pennation angle measured after passive stretch, we found the significant difference in the controlled HP group at 30° planterflexion, neutral position and 15° dorsiflexion (p=0.0022, 0.0052, 0.0299, respectively), and in the controlled US group at 15° planterflexion, neutral position and 15° dorsiflexion (p=0.0476, 0.0374, 0.0052, respectively). In contrast, the HP and US groups did not show significant differences in their pennation angles after stretch.

Muscle extensibility elasticity at each joint angle under various test condition

Muscle extensibility of the ankle joint was measured at 30°, 15°, and 0° planterflexion and 15° dorsiflexion under every test conditions. The 15° dorsiflexed position showed increases in muscle extensibility under all conditions. We found significant difference between the neutral position of the controlled HP and controlled US groups (p=0.0054). However, no other differences were observed (Table 2).

DISCUSSION

Shortened soft tissue, referred to contracture, occurs in contractible or non-contractible tissue, and it brings limitations to ROM. Immobilization causes contracture, and it is assumed that factors causing contracture are 1) abnormal cross-bridge creation between collagen fibers, and 2) loss of body fluid in the fibrous connective tissue such as tendon, articulation capsule or ligament. In terms of histology, it is reported that the collagen fiber, which is the main component of the fascia, alters and causes contracture. Therapists, expecting heat effect, often use physical agent modalities as a treatment for contracture. The physical agent modalities are expected to enhance skin, muscle and joint tissue circulation, to relax muscle tone and to increase muscle and tendon elasticity. Increase of flexibility in the collagen fiber is considered to be another effect of thermotherapy. For instance, Mutungi et al. reported that thermal stimulation increases the elasticity and viscosity of muscles.

Hot pack is the most frequently used thermotherapy intervention in Japan. It is considered that HP increases the extensibility of collagen fibers and thus improves ROM. However, it is reported that thermotherapy itself does not improve collagen fiber extensibility, and only in a combination of thermotherapy and stretching, significant improvement in extensibility can be seen. Since HP is a thermotherapy intervention using conductive heat, consideration of the infiltration is needed.

Ultrasound, on the other hand, is a thermotherapy which uses converted heat energy, it is able to reach the deep connective tissues. Lehmann et al. reported that compared to superficial heat therapy with infrared array radiation, infiltrated thermotherapy with continuous wave at 1.0~2.5 W/cm² was more effective in improving the hip joint ROM. Wessling et al. also stated in their report that a combination of 1 MHz continuous wave at 1.5 W/cm² and static dorsiflexion stretch on the triceps femoris muscle enhanced dorsiflexion ROM. These reports confirm that improvement of ROM by US results from enhanced extensibility of the soft tissues.

Previously it was believed that the myofibril in the resting muscle elongates without any resistance. Muscle elasticity or a parallel elastic component is thought to be related to epimysium, perimysium, and endomysium. While the elasticity coefficient of tendon is high, that of muscle is low. The muscle-tendon unit consists of muscle and tendon, thus its elasticity coefficient is high, low and high in that order. With the static stretching that we practiced in the present study, muscles which had already been stretched passively were extended. It is said that in static stretching, muscle is elongated, whereas elongation of the tendon and muscle-tendon unit is much less because of their high
In our previous studies, we measured muscle elasticity and pennation angle on US images. Our data confirmed that passive stretch with low extension force leads to a decrease in the pennation angle. In contrast, according to Fukunaga et al. and Ito et al., voluntary muscle contraction causes an increase in the pennation angle and physiological cross-section size that subsequently leads to increased muscle extension force.

The major findings of the present study are that: 1) no test condition showed any significant difference in regard to muscle elasticity; 2) in controlled HP and controlled US groups, pennation angles significantly decreased with passive stretch; whereas 3) HP and US groups did not show any changes. These findings support the idea that defensive contraction of muscle does not occur when it is continuously stretched with low extension force, and an unchanged pennation angle reflects the muscle condition of extension by thermotherapy. Therefore, the measurement of the pennation angle enables us to identify a factor to change muscle elasticity in vivo by thermotherapy.

Previously it was considered that muscle in isometric contraction does not change its length. However, Fukunaga et al., using US imaging, reported that the muscle length in isometric contraction does shorten, and leads to extension of the tendon. Thus, compared to static stretching, dynamic stretching accompanied with muscle contraction increases the elasticity coefficient, and the muscle-tendon unit and tendon consequently extend. Fukunaga et al. also report that with actions such as walking and jumping, changes in the length of the muscle-tendon unit and tendon are greater than that of muscle fiber. Physical therapy to improve ROM should be carried out in order to improve ADL. Thus, follow-up studies obviously are needed to investigate muscle architectural changes in dynamic stretching and we will hopefully find proper treatment interventions for limitation of ROM.

There are limitations to this study. The heat effect of HP is superficial, whereas US has deep heat effect. However, the difference in these 2

### Table 1. Pennation angles before and after passive stretch under diverse test conditions

<table>
<thead>
<tr>
<th>Pennation angle</th>
<th>US</th>
<th>Cont. US</th>
<th>HP</th>
<th>Cont. HP</th>
</tr>
</thead>
<tbody>
<tr>
<td>(deg)</td>
<td>Rest</td>
<td>Stretch</td>
<td>Rest</td>
<td>Stretch</td>
</tr>
<tr>
<td>P.F 30°</td>
<td>14.7 ± 3.1</td>
<td>14.8 ± 4.3</td>
<td>12.7 ± 3.0</td>
<td>12.7 ± 3.5</td>
</tr>
<tr>
<td>P.F 15°</td>
<td>14.0 ± 3.3</td>
<td>13.2 ± 3.0</td>
<td>11.3 ± 2.7</td>
<td>10.8 ± 3.1*</td>
</tr>
<tr>
<td>N.P</td>
<td>11.9 ± 2.6</td>
<td>12.1 ± 2.2</td>
<td>10.3 ± 2.8</td>
<td>9.2 ± 3.0*</td>
</tr>
<tr>
<td>D.F 15°</td>
<td>10.6 ± 2.3</td>
<td>10.9 ± 1.9</td>
<td>9.8 ± 2.5</td>
<td>8.4 ± 2.2*</td>
</tr>
</tbody>
</table>

US, ultrasound; Cont. US, controlled US; HP, hot pack; Cont. HP, controlled HP; P.F, plantarflexion; N.P, neutral position; D.F, dorsiflexion.

Rest vs stretch: Wilcoxon t test. *Significant difference (p<0.05).

### Table 2. Muscle extensibility elasticity at each joint angle under various test condition

<table>
<thead>
<tr>
<th>Muscle extensibility (N·m)</th>
<th>US</th>
<th>Cont. US</th>
<th>HP</th>
<th>Cont. HP</th>
</tr>
</thead>
<tbody>
<tr>
<td>P.F 30°</td>
<td>0.6 ± 0.4</td>
<td>1.5 ± 1.0</td>
<td>0.6 ± 0.5</td>
<td>0.6 ± 0.2</td>
</tr>
<tr>
<td>P.F 15°</td>
<td>1.1 ± 0.7</td>
<td>2.0 ± 1.7</td>
<td>0.5 ± 0.4</td>
<td>0.6 ± 0.2</td>
</tr>
<tr>
<td>N.P</td>
<td>2.2 ± 1.0*</td>
<td>3.0 ± 2.2</td>
<td>1.2 ± 0.8</td>
<td>0.8 ± 0.3*</td>
</tr>
<tr>
<td>D.F 15°</td>
<td>4.1 ± 1.9</td>
<td>5.2 ± 3.0</td>
<td>2.7 ± 1.0</td>
<td>2.0 ± 0.9</td>
</tr>
</tbody>
</table>

US, ultrasound; Cont. US, controlled US; HP, hot pack; Cont. HP, controlled HP; P.F, plantarflexion; N.P, neutral position; D.F, dorsiflexion.

US vs Cont.HP: Kruskal-Wallis H test, post hoc test; Mann Whitney U test with Bonferroni correction. *Significant difference (p<0.05).
methods was not examined in the present study for following reasons: 1) the dosage of both interventions, that is the energy amount, was not controlled; 2) the changes in skin temperature differed in both interventions; and 3) the gastrocnemius muscle is relatively superficial.

Compared to microwave apparatus, which has similar effects with US, US has less influence on medical apparatus and human body by electromagnetic wave. Therefore, it is evident that the usage of US will increase in Japan hereafter. Further studies to investigate the effects of US on different muscles and the effects of dynamic stretching are needed.

REFERENCES

