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Immediate and Residual Changes in Dorsiflexion Range of Motion Using an Ultrasound Heat and Stretch Routine

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Objective: With respect to increasing ankle dorsiflexion range of motion, our objective was to examine the influence, if any, of preheating the triceps surae with ultrasound before stretching.

Design and Setting: Subjects were assigned to either group A (ultrasound and stretch) or group B (stretch alone). Group A received 3-MHz ultrasound (1.5 W/cm^2, 4 times effective radiating area) for 7 minutes to the musculotendinous junction of the triceps surae before stretching. Group B rested for 7 minutes before stretching. Both groups then performed identical calf stretches for 4 minutes. Treatment for both groups was conducted at the Brigham Young University Sports Injury Research Laboratory twice daily for 5 days with at least 3 hours between procedures. We analyzed the data with a $2 \times 3 \times 10$ factorial analysis of variance with repeated measures. A Tukey post hoc test was used to identify significant differences in range of motion.

Subjects: Forty college students (male = 18, female = 22, age = 20.4 ± 2.5 years) volunteered for the study.

Measurements: Maximal ankle dorsiflexion range of motion was measured using an inclinometer before and after each treatment.

Results: Immediate effects were that ultrasound and stretch increased mean dorsiflexion range of motion in all sessions significantly more than stretch alone in three treatment sessions. Residual effects were that dorsiflexion range of motion increased 3° in both groups after nine treatment sessions; however, neither group significantly outperformed the other.

Conclusion: As studied, an ultrasound and stretch routine may increase immediate range of motion more than stretch alone, possibly enhancing performance in practice and competition. This increased range of motion, however, is not maintained over the long term and is not more than the range of motion gained from stretching alone. A similar study using subjects with decreased range of motion after immobilization or injury should be conducted to see if the ultrasound and stretch regimen would produce lasting range-of-motion increases.

Key Words: flexibility, modalities, rehabilitation

A main goal in injury recovery is restoring normal joint range of motion. After injury or immobilization, connective tissue progressively shortens, often causing joint contractures and adhesions that restrict joint range of motion.[1-4] If controlled stress is not applied, the collagen fibers interweave and become a dense, limiting structure. This process can be seen after only 1 week of immobilization.[1]

Passive stretch alone has been effective in increasing range of motion in human subjects.[5,6] Very few studies have been performed on humans using heat to improve flexibility. Taylor et al[7] found that hamstring flexibility can be improved by using heat packs before stretching. Wessling et al[8] found that ultrasound applied to the muscle belly before stretching promoted significantly greater immediate gains in ankle dorsiflexion than stretching alone.

Thermal ultrasound is a common therapeutic modality used for treating soft tissue injury,[9] joint dysfunction,[9,10] and other musculoskeletal injuries.[11,12] Heating the tissues with ultrasound before stretching is a common practice thought to improve range of motion.[1-3,8-13] Research performed on rat tail tendons indicates that stretching while the tissue is heated to temperatures between 39°C and 45°C (an increase of 3°C to 8°C over baseline) results in permanent elongation of the tissue.[13-16] In addition, if the stretch is applied at peak temperature, less tissue damage will result.[1,13-16]

We have found that proper application of therapeutic ultrasound can increase temperatures 3°C to 6°C in muscle[9] and 5°C to 8°C in tendons.[17] Because these temperatures are maintained for only a few minutes,[18,19] we believe that the stretch must be applied immediately after the ultrasound treatment to increase connective tissue extensibility. Before our study, this "heat and stretch" theory using correct ultrasound parameters had not been tested on human subjects with 3-MHz ultrasound. The intent of our study was to determine if this method of treatment would improve ankle dorsiflexion range of motion more than stretch alone.

METHODS

Subjects

The procedures for this investigation were approved by Brigham Young University's Institutional Review Board for

Research with Human Subjects. Forty healthy college students (male = 18, female = 22, mean age = 20.4 ± 2.5 years) volunteered for this study. They signed a consent form after being apprised of all risks involved with participation in the research. The subjects followed their normal daily routine without beginning any new exercise or stretching activities during the study.

Instruments

We used an Omnisound 3000C (Accelerated Care Plus-LLC, Topeka, KS) ultrasound unit with a 5-cm^2 transducer and an effective radiating area (ERA) of 4.1 cm^2. This machine provides a beam nonuniformity ratio of 3:1 (measured and reported by the manufacturer), which allowed us to treat at a higher output intensity with decreased risk of tissue damage.[1,13–15] This machine was new and had been calibrated just before our study.

An inclinometer was used to measure joint angle. We tested the reliability of this device in the following manner. Nine subjects were measured daily (to the nearest degree) for 3 days, and the numbers were evaluated using an intraclass correlation coefficient statistic. A correlation of 0.94 was found between measures, with a 95% confidence interval of ± 3.517 and a 68% confidence interval of ± 1.74.

Procedure

We randomly assigned 20 subjects to each group. We measured maximal dorsiflexion range of motion with the inclinometer before all treatments. We measured dorsiflexion range of motion from a standing position in order to replicate the stretches to be used. This was accomplished by placing the device on the posterior aspect of the calf while the subject was standing erect, so that the calf muscle was at a 90° angle to the floor. To insure consistent placement of the inclinometer, a semipermanent mark was drawn on each subject's calf muscle and used throughout the study. While maintaining the knee in full extension and the foot flat on the ground, the subject shifted the body over the foot as far as possible while the needle on the inclinometer moved to measure maximal dorsiflexion range of motion. After measurements were recorded, the subjects in Group A (ultrasound) assumed a prone position on the table. We attached a template cut to four times the size of the soundhead to the musculotendinous junction of the right triceps surae. Ultrasound was applied at the following parameters: 3 MHz, intensity of 1.5 W/cm^2, duration of 7 minutes. We moved the transducer in the template at approximately 4 cm/sec using longitudinal strokes.

Immediately after the ultrasound treatment, each subject stood upright and performed two stretches to the point of discomfort, but avoiding pain. First, a calf stretch was performed for 20 seconds with the knee in full extension, followed by a 10-second rest. The stretch was then repeated for 20 seconds with the knee bent 15° to isolate the soleus muscle. A 10-second rest was given to complete the cycle. This sequence was repeated three more times (4 minutes total). We then measured ankle dorsiflexion again to detect changes possibly attributable to the ultrasound and stretching treatment.

Subjects in Group B underwent the same procedures to determine dorsiflexion range of motion. Subjects then rested in a prone position for 7 minutes, after which they performed the same stretching regimen as Group A. Poststretching dorsiflexion range of motion was measured and recorded. Subjects in both groups received treatments twice daily (>3 hours apart) for 5 consecutive days.

Design and Analysis

We used a 2 × 3 × 10 factorial analysis of variance (ANOVA) with repeated measures to identify differences in the dependent variable (range of motion) between groups (ultrasound and stretching, stretching alone); residual treatment effect (sessions 1 to 10); and immediate treatment effect (before treatment, after treatment). The group factor was a between-subjects factor; the residual and immediate effects were within-treatment factors. We used a Tukey post hoc procedure to identify significant differences. Alpha was set at 0.05 for all comparisons. A separate, single-factor ANOVA with repeated measures was used to identify residual effects for both groups.

RESULTS

Measurements for both groups are displayed in the Table. Both groups began the study with 28° range of motion in dorsiflexion. Range of motion was measured before and after each session to evaluate the change in flexibility due to the treatments. Both groups showed significant improvement in dorsiflexion, measured at about 2° ($F_{1,38}$ =210.340, $P < .001$). When we compared immediate effects between the two groups, we found the average initial increase for Group A was 3°, compared with 2° for Group B. An interaction was found between the two groups (group × immediate $F_{1,38}$ = 8.248, P = .007), and post hoc tests showed that the ultrasound group

Measurements of Mean (±SD) Dorsiflexion ROM by Group and Session

	Group A (Ultrasound + Stretch)		Group B (Stretch Only)	
Session	Pre-	Post-	Pre-	Post-
1	28° ± 4°	32° ± 4°	28° ± 6°	30° ± 7°
2	29° ± 4°	32° ± 4°	29° ± 6°	31° ± 6°
3	28° ± 4°	31° ± 4°	29° ± 6°	31° ± 6°
4	29° ± 4°	32° ± 5°	30° ± 6°	31° ± 7°
5	29° ± 4°	32° ± 4°	30° ± 6°	31° ± 6°
6	30° ± 5°	32° ± 5°	29° ± 6°	31° ± 6°
7	31° ± 5°	33° ± 5°	31° ± 6°	32° ± 6°
8	31° ± 5°	33° ± 5°	30° ± 6°	33° ± 6°
9	30° ± 6°	33° ± 5°	31° ± 6°	33° ± 6°
10	31° ± 5°	33° ± 5°	31° ± 5°	33° ± 6°

achieved significantly greater increases in range of motion than stretch alone in three sessions. Measurements taken before our final session were compared with the first day to determine if any residual lengthening had occurred. After nine treatments, subjects in both groups increased range of motion by about 3°, a significant improvement from baseline measurements ($F_{9,342} = 12.612$, $P < .001$). No interaction, however, was found when the two groups were compared for residual lengthening (group × residual $F_{9,342} = 0.830$, $P = .588$). The residual × immediate effect ($F_{9,342} = 0.924$, $P = .504$) and the group × residual × immediate effect ($F_{9,342} = 1.124$, $P = .345$) also were not significant (group $F_{1,38} = 0.049$, $P = .826$). The results from our single-factor ANOVA on residual lengthening showed that the groups had gained significantly in flexibility after just five treatment sessions.

DISCUSSION

Vigorous heating via ultrasound, combined with stretching, is often used in an effort to lengthen connective tissue. Passive stretching alone has been effective in increasing range of motion in human subjects. Researchers[5,20] found that stretching for as little as 15 seconds can be just as effective as a 2-minute stretch in improving hip abduction and ankle dorsiflexion range of motion. Worrell et al[6] found that four 20-second calf stretches, repeated over 10 treatment sessions, yielded increased range of motion in ankle dorsiflexion.

There is very little evidence that "heat and stretch" procedures are effective in increasing flexibility in humans. Wessling et al[8] found that ultrasound applied to the muscle belly before stretching promoted significantly greater immediate gains in ankle dorsiflexion than stretching alone. Their changes in flexibility, however, were quite small (1° to 2.5°) by clinical standards. They also used only one treatment session; thus, they neglected to evaluate the long-term effect of repeated treatment sessions. In our study, the results from session one indicated a significant difference between the two groups as well. If we had terminated the study here, we would have been able to state, as did Wessling et al[8], that ultrasound assuredly increases flexibility. They also did not use 3-MHz ultrasound, as we did in our study. The 3-MHz frequency is more appropriate than 1 MHz for heating the musculotendinous junction of the Achilles tendon because 3 MHz is better absorbed at this superficial level.[9]

It is known that heat and stretch can effectively lengthen connective tissue permanently in animal tissues.[13–16] Vigorous heating (>3°C) of tissue before stretching is recommended for optimal lengthening.[3,11] The higher the tissue temperature, the more likely the treatment will result in improved flexibility of chronic connective tissue and joint contractures.[13–16] When ultrasound is used to vigorously heat tissues (>3°C), the tissues become more pliable.[11,12] These higher temperatures decrease the viscous properties of collagen and allow us to increase the tissue length more permanently.[2,11,14,15]

Recent research shows that continuous ultrasound can increase temperatures in human muscle[3,9,18,19] and tendon[17] to therapeutic levels. In our study, we used 3-MHz ultrasound to increase the temperature of the musculotendinous junction of the triceps surae muscle. Special attention was paid to treatment size, time, and intensity, all critical when trying to reach peak temperatures.[8,17–19] We used a treatment size of four ERA to enable us to treat the large musculotendinous junction. Based on our previous research,[9,17] we estimate that the temperature increased as much as 3°C in muscle and 8°C in tendon. These therapeutic temperatures should be adequate to allow tissue lengthening, if the tissues are stretched immediately after the treatment. Based on our studies of the stretching window,[17,18] we believe that tissue temperatures remained at therapeutic levels for 2 to 4 minutes, which is why we applied the stretch immediately after the treatment, taking advantage of these higher temperatures.

There were greater immediate effects from the use of ultrasound before stretching in session 1 (ultrasound and stretch = 3°, stretch alone = 2°) and sessions 4 and 5 (ultrasound and stretch = 3°, stretch alone = 1°). However, with alpha set at 0.05, we would expect 1 of 20 sessions to be positive due to chance. These findings may be important in considering the use of ultrasound to treat athletes before practice or competition. By temporarily increasing flexibility in this population, we may reduce the occurrence of injury and improve performance for a given event.

Each subject was treated 10 times over a 5-day period to determine if changes in range of motion would carry over from day to day. Testing for these residual effects was the main focus of our study. We found that both groups increased dorsiflexion about 3° (an 11% increase) over nine treatment sessions. Our results indicated that ultrasound before stretching was not more effective than stretching alone in increasing residual dorsiflexion range of motion in a healthy population.

Limitations

There were a few limitations in our methods. To begin with, we assumed that critical temperatures were reached in the tissues being treated. Since the tissue temperature was not measured, we do not know for certain that these levels were achieved. Very few studies on human tissue have raised tissue temperatures to Lehmann's therapeutic range of 40°C to 45°C.[12] Draper et al[9] increased muscle temperature to the lower end of this range, but human subjects experienced pain before levels >42°C were reached. The cooling mechanism of living tissue may also have prohibited temperature increases of this nature to be reached and maintained. In addition, we also treated a relatively small area. The gastrocnemius-soleus complex is a very large muscle group, and the musculotendinous junction is hard to define and treat with an ERA of four.

We also elected to use a stretch that was not controlled. Subjects were instructed to stretch to tolerance, and, since each subject possessed different size characteristics, this may have affected our results. In future studies, perhaps a percentage of each person's body weight could be used as a control measure.

Finally, the subject sample was conveniently selected from a healthy population of college students and, thus, cannot be generalized to a clinic population. Our subjects already possessed, on average, 28° of ankle dorsiflexion as a baseline measurement, which perhaps left little room for improvement. If our sample had been taken from a population limited in flexibility due to contractures or adhesions, the results might have been different.

Future Research

Further studies should be conducted using a population experiencing tightness due to scarring or other adaptive shortening that limits range of motion. Other joints that allow for greater increases in range of motion, such as the hip or shoulder, could also be evaluated. These studies could also include other common therapies, such as heat packs or cold treatment before stretching. This heat and stretch regimen could also be studied using shortwave diathermy, since this modality heats a larger area than ultrasound.

CONCLUSIONS

According to some researchers, heating tissue before stretching will lead to improved range of motion of chronic connective tissue and joint contractures.[13–16] When ultrasound is used to vigorously heat tissues (>3°C), the tissues become more pliable,[11,12] allowing the tissues to be stretched more effectively.[2,11] Results from our study show that repeated stretching sessions can increase dorsiflexion range of motion. Using ultrasound before stretching might increase immediate dorsiflexion, but residual increases are no different than from stretching alone.

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