

Effects of Therapeutic Ultrasound on Range of Motion and Stretch Pain

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Abstract. [Purpose] This study aimed to clarify the effects of therapeutic ultrasound on range of motion and stretch pain and the relationships between the effects. [Subjects] The subjects were 15 healthy males. [Methods] Subjects performed all three interventions: (1) ultrasound (US group), (2) without powered ultrasound (placebo group), and (3) rest (control group). Ultrasound was applied at 3 MHz with an intensity of 1.0 W/cm² and a 100% duty cycle for 10 minutes. The evaluation indices were active and passive range of motion (ROM), stretch pain (visual analog scale; VAS), and skin surface temperature (SST). The experimental protocol lasted a total of 40 minutes; this was comprised of 10 minutes before the intervention, 10 minutes during the intervention (US, placebo, and control), and 20 minutes after the intervention. [Results] ROM and SST were significantly higher in the US group than in the placebo and control groups for the 20 minutes after ultrasound, though there was no change in stretch pain. [Conclusion] The effects of ultrasound on ROM and SST were maintained for 20 minutes after the intervention. The SST increased with ultrasound and decreased afterwards. Additionally, the SST tended to return to baseline levels within 20 minutes after ultrasound exposure. Therefore, these effects were caused by a combination of thermal and mechanical effects of the ultrasound.

Key words: Ultrasound, Range of motion, Stretch pain

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INTRODUCTION

Therapeutic ultrasound is one of the most widely used physical modalities in the clinical practice of rehabilitation¹⁻⁸⁾. In particular, therapeutic ultrasound in rehabilitation has a number of uses including the treatment of musculoskeletal disorders such as pain, muscle spasm, joint contracture, and tissue injury¹⁻⁸⁾. Therefore, it is now recognized as a major therapeutic method in treating musculoskeletal disorders¹⁻⁸⁾. Essential treatment parameters for therapeutic ultrasound include frequency, intensity, duty cycle, treatment time, and treatment area¹⁾. The frequency for therapeutic ultrasound ranges from 1 to 3 MHz, with 3 MHz used specifically for the treatment of superficial tissues, and 1 MHz is applied to treat deeper tissues¹⁾. In addition, the combination of intensity and duty cycle during ultrasound produces thermal and/or nonthermal (i.e., mechanical) effects¹⁾. Therefore, therapeutic ultrasound

has been used with the aim of having both thermal and mechanical effects¹⁻⁸⁾. The physiological effects of thermal therapeutic ultrasound include increased tissue temperature⁹⁾, increased local blood flow¹⁰⁾, increased extensibility of tissue^{11, 12)}, and reduced viscosity of fluid elements in the tissue¹⁾. Further, the mechanical effects accelerate tissue metabolism by promoting cellular permeability and ion transport¹³⁾. Therefore, therapeutic ultrasound has been used as a treatment method for relief of pain and muscle spasm and for improvement of joint contracture and wounded tissue¹⁻⁸⁾. Previous studies have tended to use pain and/or range of motion as an outcome index²⁻⁸⁾. However, the relationship between the changes in active and passive range of motion and the pain associated with stretching of the muscle (i.e., stretch pain) that are caused by ultrasound is not clear. Stretch pain is defined as pain associated with stretch stimulations in soft tissue such as the skeletal muscles. Therefore, control of stretch pain is necessary to increase the range of motion.

Our previous studies have revealed that therapeutic ultrasound on the upper fibers of the trapezius muscle reduced muscle stiffness and increased the active range of motion^{14, 15)}. However, we have not attempted to distinguish the relationship between the above effects and stretch pain; therefore, the interactions remain unclear. This study aimed to clarify whether therapeutic ultrasound affects active and

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passive range of motion, and stretch pain. A further object of the study was to collate fundamental data on the effects of therapeutic ultrasound for pain, muscle spasm, and joint contracture.

SUBJECTS AND METHODS

The subjects were 15 healthy males with a mean age of 26 years (range; 21–32), mean body height of 171.7 ± 6.0 cm, mean body weight of 62.7 ± 6.9 kg, and mean body mass index of 21.3 ± 2.2 . All the subjects were right handed.

This study was approved by the Koriyama Tohto Academy Educational Foundation Ethics Committee (No. 08-004). All the subjects signed a consent form after being informed of the study purpose and content, and of all the risks involved.

We compared the following 3 interventions in a randomized trial using the same subjects: (1) ultrasound (US group), (2) without powered ultrasound (placebo group), and (3) rest (control group). Each condition was tested 1 week apart. The intervention and measurement sites were defined as the upper fibers of the right trapezius muscle, specifically the midpoint on the C7 spinous process to the acromial end of the clavicle.

We used an ultrasound unit (EU-940, Ito Co., Ltd., Tokyo, Japan) with an effective radiating area of 6.0 cm^2 and a beam nonuniformity ratio of 3.2: 1 (reported by the manufacturer). Ultrasound was applied at 3 MHz with an intensity of 1.0 W/cm^2 and a 100% duty cycle (i.e., continuous mode) for 10 minutes. To denote the ultrasound treatment site, an area twice the size of the ultrasound transducer head was marked on the top of the upper fibers of the right trapezius muscle, and we moved the transducer in a stroking method. Ultrasound transmission gel was used as the conducting medium, and it was applied to the skin after warming to a mean temperature of $33 \text{ }^\circ\text{C}$ for all groups. The placebo treatment was unpowered ultrasound and otherwise was performed using the same method and conditions as those for the US treatment. The control group received application of ultrasound gel and was then instructed to rest.

The measurement indices were the active range of motion (A-ROM) and passive range of motion (P-ROM) of cervical lateral bending to the left, stretch pain (SP) expressed by the visual analog scale (VAS) for P-ROM, and skin surface temperature (SST). In order to standardize the suppress strength in the measurement of P-ROM and SP, a handheld dynamometer was set to push against the subject's right temple, and the cervical vertebra was bent with a suppress strength of 30 N and monitored by the dynamometer. In this position, SP is induced by a stretch stimulation in the upper trapezius muscle. This position also followed the method of active individual muscle stretching (i.e., active ID stretching) for the upper fibers of the trapezius muscle¹⁶. The SP was also confirmed at the end of P-ROM. The subjects also assumed a sitting position with both upper limbs on top of both thighs, with the upper fibers of the trapezius muscle exposed for measurement of the A-ROM and SST. The measurement instruments were a digital inclinometer (MJ-1, Satoshiji Co., Ltd., Tokyo, Japan), handheld dynamometer (μ -Tas MT-1, Anima Co., Ltd., Tokyo, Japan), and an infrared thermometer (THI-700L, Tasco Japan Co., Ltd., Osaka, Japan).

The experimental protocol was executed after a 20-minute acclimation period set for subjects to adapt to the laboratory environment. The protocol included 10 minutes before the intervention (rest), 10 minutes during the intervention (for each condition), and 20 minutes after the intervention (rest). The data collected before and after the interventions were divided into 10-minute intervals for further analysis. The experiment was conducted in a controlled environment with the temperature maintained between $24 \text{ }^\circ\text{C}$ to $26 \text{ }^\circ\text{C}$ and 40% to 60% relative humidity.

Statistical analysis was performed using two-way analysis of variance (ANOVA) with 3×5 (groups \times time) repeated measurements of the change in A-ROM, P-ROM, SP, and SST for comparisons between all groups. Once significant differences were detected by two-way ANOVA, Tukey's post hoc multiple comparison (Tukey-HSD) test was performed. The level of significance was set at $\alpha = 0.05$. All analyses were performed using SPSS for Windows ver. 21.

RESULTS

Tables 1 to 4 show the changes in A-ROM, P-ROM, SP (i.e., VAS), and SST, respectively. The results demonstrate the presence of a significant interaction in A-ROM ($F_{(2,8)} = 11.88, p < 0.01$), P-ROM ($F_{(2,8)} = 5.05, p < 0.01$), and SST ($F_{(2,8)} = 89.18, p < 0.01$), although the SP did not differ statistically between the 3 groups. The Tukey-HSD test revealed that each ROM and SST was significantly higher in the US group than in the placebo and control groups from T3 to T5 ($p < 0.05$). The mean increase in SST from T1 to T3 was $1.6 \text{ }^\circ\text{C}$ in the US group. Whereas the SST increased with ultrasound, it decreased afterwards, and the SST tended to return to baseline levels (i.e., T1 and T2 levels) by T5, which was 20 minutes after ultrasound exposure.

DISCUSSION

In this study, we investigated whether therapeutic ultrasound affects active and passive ROM and SP. Furthermore, we included SST as an assessment criterion to determine how changes in each ROM and SP are related to tissue temperature during therapeutic ultrasound. We compared changes in each ROM, SP, and SST in the US, placebo, and control groups for 20 minutes after the interventions. The present study revealed that each ROM and SST were significantly higher during the 20 minutes after the intervention period in the US group than in the placebo and control groups. However, no change in SP was expressed in a subjective pain assessment, i.e., VAS. These results showed that ultrasound increased the threshold of SP. Given the above, our study revealed that therapeutic ultrasound provided increases in both ROM accompanied by an increased SP threshold for at least 20 minutes after the conclusion of the interventions.

There are primarily two reasons that explain the above findings. Firstly, Mense et al. reported that high threshold mechanoreceptors in skeletal muscle respond to stretch

Table 1. Changes in active range of motion of the three groups

	T1	T2	T3	T4	T5
US	38.5 ± 4.8	38.0 ± 5.6	45.4 ± 7.2**	44.3 ± 7.8**	44.9 ± 8.1**
Placebo	39.4 ± 4.0	39.6 ± 4.1	39.2 ± 3.4	38.8 ± 3.9	39.6 ± 4.0
Control	39.0 ± 5.4	38.0 ± 5.4	37.9 ± 6.0	37.6 ± 6.0	38.3 ± 6.1

Unit: degrees (°) (mean ± SD)

** p < 0.01 (US vs. placebo, control)

The chronological changes in active range of motion in the US, placebo, and control groups are shown. From T3 to T5, active range of motion was significantly higher in the US group than in the placebo and control groups.

Table 2. Changes in passive range of motion of the three groups

	T1	T2	T3	T4	T5
US	41.6 ± 9.1	40.5 ± 8.0	46.8 ± 9.9** †	47.3 ± 9.8** ††	47.0 ± 9.5* ††
Placebo	41.0 ± 8.5	41.7 ± 7.9	40.6 ± 7.1	40.4 ± 5.9	41.2 ± 6.5
Control	39.9 ± 8.7	41.2 ± 8.4	39.6 ± 8.2	41.0 ± 8.5	42.3 ± 8.1

Unit: degrees (°) (mean ± SD)

** p < 0.01 (US vs. control); * p < 0.05 (US vs. control)

†† p < 0.01 (US vs. placebo); † p < 0.05 (US vs. placebo)

The chronological changes in passive range of motion in the US, placebo, and control groups are shown. From T3 to T5, passive range of motion was significantly higher in the US group than in the placebo and control groups.

Table 3. Changes in stretch pain (VAS) of the three groups

	T1	T2	T3	T4	T5
US	51.7 ± 29.5	46.9 ± 29.7	43.7 ± 30.0	45.4 ± 31.5	41.7 ± 31.2
Placebo	48.2 ± 29.7	46.7 ± 29.4	45.5 ± 30.8	44.0 ± 30.6	47.0 ± 33.4
Control	44.1 ± 25.4	46.0 ± 26.5	43.5 ± 28.5	49.1 ± 32.5	48.1 ± 31.3

Unit: mm (mean ± SD)

The results for stretch pain (VAS) in the US, placebo, and control groups are shown. No significant differences were observed between the 3 groups.

Table 4. Changes in skin surface temperature of the three groups

	T1	T2	T3	T4	T5
US	33.5 ± 0.4	33.6 ± 0.4	35.1 ± 0.8**	34.4 ± 0.6**	33.8 ± 0.8**
Placebo	33.4 ± 0.5	33.4 ± 0.6	29.7 ± 1.1	32.4 ± 0.7	33.1 ± 0.5
Control	33.3 ± 0.6	33.2 ± 0.6	29.6 ± 1.5	32.1 ± 0.5	33.0 ± 0.6

Unit: degrees C (°C) (mean ± SD)

** p < 0.01(US vs. placebo, control)

The chronological changes in skin surface temperature in the US, placebo, and control groups are shown. From T3 to T5, skin surface temperature was significantly higher in the US group than in the placebo and control groups.

stimulation¹⁷⁾. Therefore, we hypothesized that ultrasound affected the sensitivity of sensory receptors such as muscle spindle and high threshold mechanoreceptors in skeletal muscle and that this led to the increased ROM. Secondly, ultrasound increases extensibility of the skin and muscle due to the thermal effect that influences tissue viscoelasticity^{11, 12, 18–22)}. Our previous studies have revealed that therapeutic ultrasound on the upper fibers of the trapezius muscle reduced muscle stiffness and increased the active range of motion^{14, 15)}. Based on these two reasons, the effect of therapeutic ultrasound on ROM would be caused by a

combination of the changes in SP threshold and tissue extensibility. One of these changes in the SP threshold and tissue extensibility is due to the thermal effect of ultrasound, and the thermal effect was observed in our study, as the SST was increased. In a previous study completed with the same methods as in our study (i.e., same frequency, intensity, duty cycle, and treatment time), Draper et al.⁹⁾ reported temperature increases of 5.8 °C in tissues at 0.8 and 1.6 cm depths after the application of ultrasound. In our study, the SST increased by a mean of 1.6 °C in the US group after the intervention. The following changes in the biological

reaction resulting from tissue heating have been suggested: an increase in metabolism and a reduction in mild inflammation resulting from a rise of 1 °C in tissue temperature, an increase in blood flow and a reduction of muscle spasm and pain resulting from a rise of 2 to 3 °C, and increases in ROM and tissue extensibility resulting from a rise of 4 °C¹⁾. Therefore, in light of this study and the previous study's results, we considered that the thermal effect of ultrasound influenced the ROM and SP threshold.

Although the increased SST at the conclusion of the intervention indicates the thermal effect in the ultrasound group, the SST gradually decreased afterwards. At 20 minutes after the ultrasound intervention, the SST tended to return to baseline levels (i.e., T1 and T2 levels), which means that the increases in ROM and SP threshold were maintained while the SST exhibited a gradual decrease. This demonstrates a greater presence of mechanical effects on the changes in the ROM and the SP threshold. The mechanical effects were caused by the direct micro vibration effects of ultrasound, which decreases the sensitivity in SP receptor (i.e., high mechanoreceptors and muscle spindles) and change muscle viscoelasticity. Therefore, the present results, i.e., increased ROM and SP threshold, were due to a combined effect of thermal effects and mechanical effects in ultrasound.

In contrast, the SST in the placebo group and control group decreased during the 20 minutes after the intervention period. This decrease could be due to the evaporative cooling of the ultrasound gel. Tissue cooling generally leads to a decrease in pain²³⁾. However, there were no changes in the ROM or the SP threshold, suggesting that the placebo group and control group had no cooling effect on the tissue. In other words, these groups displayed no physiological effects on the tissue; thus, the clinical implication of tissue cooling is not considered to be important. On the other hand, the ultrasound group showed significant influences, such as favorable results in the ROM and SP threshold during the 20 minute period after the intervention. This is clear evidence that ultrasound causes a direct mechanical effect on the skin and muscle. To our knowledge, there has been no previous research studying the relationship between active / passive ROM, SP threshold, and SST in order to observe the prolonged effects of ultrasound^{1-8, 11, 12, 18-22)}. Hence, our findings can be regarded as new evidence.

Clinically, scar tissue and fibrosis cause pain, muscle spasm, and joint contracture. Therefore, increases in tissue viscoelasticity and extensibility caused by an ultrasound application, which improves scar tissue and fibrosis, leads to greater ROM and less pain, and thus it is clinically important. Our results can be used as fundamental data and scientific evidence of the therapeutic effects of ultrasound on pain, muscle spasm, and joint contracture. Furthermore, our results endorse the active application of pain management and therapeutic exercise such as ROM exercises by therapists in the 20 minute window after application of ultrasound^{14, 15)}, since favorable physiological results were shown to be present during this window. This window represents a treatment opportunity, and thus the combined effect with another therapeutic procedure would be greater.

That is, this study suggests that therapeutic ultrasound is possibly an effective treatment method especially when applied with other therapeutic methods. The medical fee system for rehabilitation in Japan classifies 20 minutes as 1 unit; thus, the findings in this study showing that the effect was maintained for 20 minutes suggest that therapeutic ultrasound would be effective and practical in the clinical practice. In this study, we used a handheld dynamometer for the constant suppress pressure of 30N when measuring the P-ROM and SP. Due to the constant pressure, it is considered that the measured values of P-ROM are reliable and objective. Furthermore, because the VAS results were associated with the objective ROM data, the VAS data in the present study could also be clinically important.

Several limitations in this study warrant discussion. Firstly, since this study was done on healthy subjects, care should be taken when applying the findings in our study to practical situations. Secondly, we used the same suppress strength in the assessment of passive ROM to maintain the objectivity of this experiment; however, passive ROM could be assessed by passive torque tissue resistance at a consistent angle instead in order to examine the effects of ultrasound. Therefore, we are now planning to quantitatively evaluate changes in tissue resistance by using a torque machine.

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