

# INFLUENCE OF CONSTANT TORQUE STRETCHING AT DIFFERENT STRETCHING INTENSITIES ON FLEXIBILITY AND MECHANICAL PROPERTIES OF PLANTAR FLEXORS

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## ABSTRACT

Oba, K, Samukawa, M, Nakamura, K, Mikami, K, Suzumori, Y, Ishida, Y, Keeler, N, Saitoh, H, Yamanaka, M, and Tohyama, H. Influence of constant torque stretching at different stretching intensities on flexibility and mechanical properties of plantar flexors. *J Strength Cond Res* 35(3): 709–714, 2021—The purpose of this study was to examine the effects of constant torque stretching (CTS) at different stretching intensities on the maximal range of motion (ROM) and muscle-tendon unit (MTU) stiffness of plantar flexors. Fourteen healthy men performed 4 trials of differing stretch intensities: no stretching (control), 50, 75, and 100%. Stretch intensity was defined as maximum passive resistive torque predetermined at a familiarization trial. Each stretch trial consisted of 5 sets of 60-second CTS at the designated stretch intensity. Both maximal ROM and passive resistive torque were assessed during passive dorsiflexion, and MTU stiffness was calculated using the torque-angle curves measured before and after CTS. There were no significant differences in maximal ROM or MTU stiffness at the baseline condition. After the intervention, significantly greater maximal ROM and significantly lower MTU stiffness were observed in the 100% CTS condition than the control condition, whereas there were no significant differences between the submaximal intensity condition (i.e., 50 or 75% intensity) and the control condition. Therefore, our findings suggest that maximal intensity stretching is the most effective approach for improving both flexibility and MTU stiffness with CTS.

**KEY WORDS** stretching intensity, range of motion, stiffness

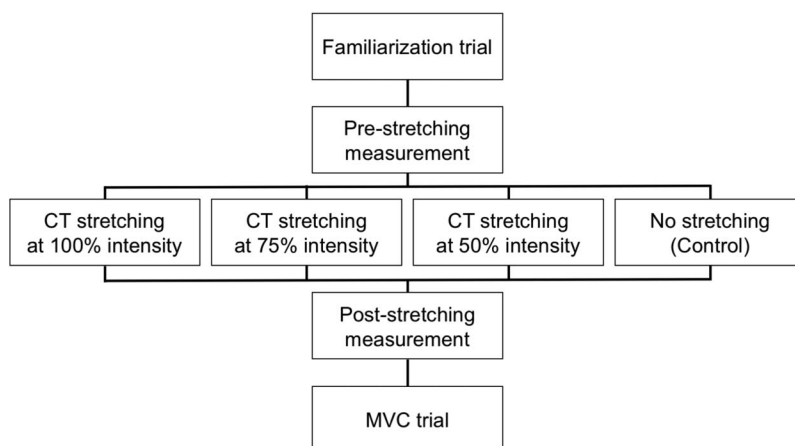
## INTRODUCTION

Stretching exercises are widely used to improve flexibility in the sports and rehabilitation fields. Numerous studies showed that stretching exercises induced acute increases in range of motion (ROM) (2,3,10) and changes in the stiffness of the muscle-tendon unit (MTU) (9,10,17,18,24). Stretching exercises also enhance athletic performance (22,23) and reduce the risks of sports-related injury (21).

Stretching intensity, duration, frequency, position, and technique are all important factors that can influence stretch-induced effects (1,5). Much research has been conducted in an attempt to clarify and establish effective static stretching protocols. Constant angle stretching (CAS) is a stretching technique defined by holding a muscle group at a constant length to maintain a specific joint angle, whereas constant torque stretching (CTS) is defined by holding passive resistive torque to adjust joint angles. Recent studies have shown that CTS is more effective than CAS for increasing ROM (5,28) and decreasing MTU stiffness; one of the mechanical properties of the MTU (5,9,10,27,28). Yeh et al. (28) reported that CTS produced greater changes in ROM and MTU stiffness than CAS in stroke patients with hypertonic ankle plantar flexors. Similar results were shown by Cabido et al. (5) that the changes in ROM and MTU stiffness in the hamstrings in healthy men were greater with CTS than CAS. Other studies have asserted that the reason why passive resistive torque decreases with CAS is because of a stress-relaxation response that occurs when muscles are held at constant stretched lengths. In other words, it is due to the viscoelastic properties of the muscle (13,14). Separate studies have shown that maintaining passive resistive torque can cause small increases in joint angle referred to as muscle creep phenomenon (19,20). This phenomenon may also be attributed to muscle viscoelasticity, allowing for muscles to be stretched for greater changes in ROM and MTU stiffness (5,9,10,27,28). As such, CTS can be considered an optimal

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**Figure 1.** Experimental design. CT = constant torque; MVC = maximal voluntary contraction.

stretching method to promote flexibility and to change the mechanical properties of MTU.

Although a few studies have previously investigated the effects of stretch intensity using CAS (6,7), none have specifically investigated the influence of CTS on stretch intensity. Freitas et al. (6) compared the influence of different CAS intensities (100, 75, and 50%) for different lengths of time (5 repetitions of 90, 135, and 180 seconds, respectively) on improving peak joint ROM and found that only CAS at 100% for 90 seconds resulted in improved peak joint ROM, whereas no changes were detected for any of the longer duration submaximal intensity regimes. Recently, the same authors reported that maximum intensity CAS

without pain for several 90 s repetitions increased maximal ROM, whereas CAS at 50% intensity for 900 seconds showed no change in maximal ROM (7). The implication of these studies is that CAS at maximum intensity may be the best way to increase joint ROM (6,7).

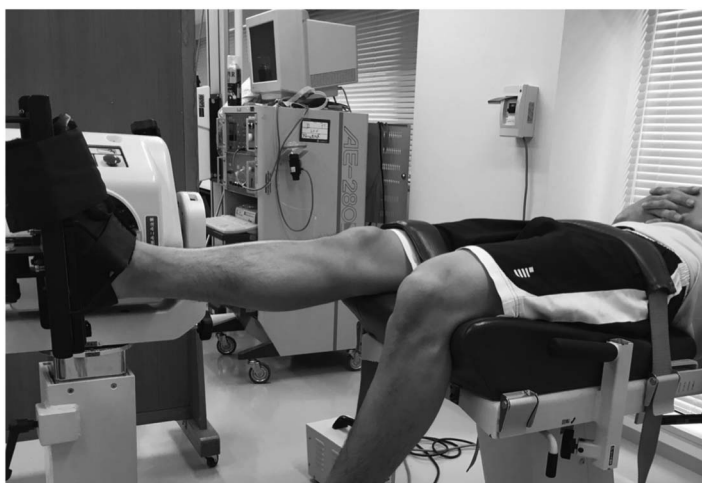
With CTS, the initial stretch intensity is considered a crucial factor to maintain constant passive resistive torque throughout the duration of the stretching exercise. Therefore, there is a possibility that CTS at submaximal intensity could improve flexibility and change the mechanical properties

of the MTU. It is important to determine the influence of CTS intensity to create protocols that will yield improved flexibility and changes to the MTU for injury prevention and rehabilitation. We then hypothesize that higher intensity CTS would induce greater increases in maximal ROM and greater decreases in MTU stiffness. The purpose of the present study was to investigate the effects of CTS intensity on maximal ROM and MTU stiffness.

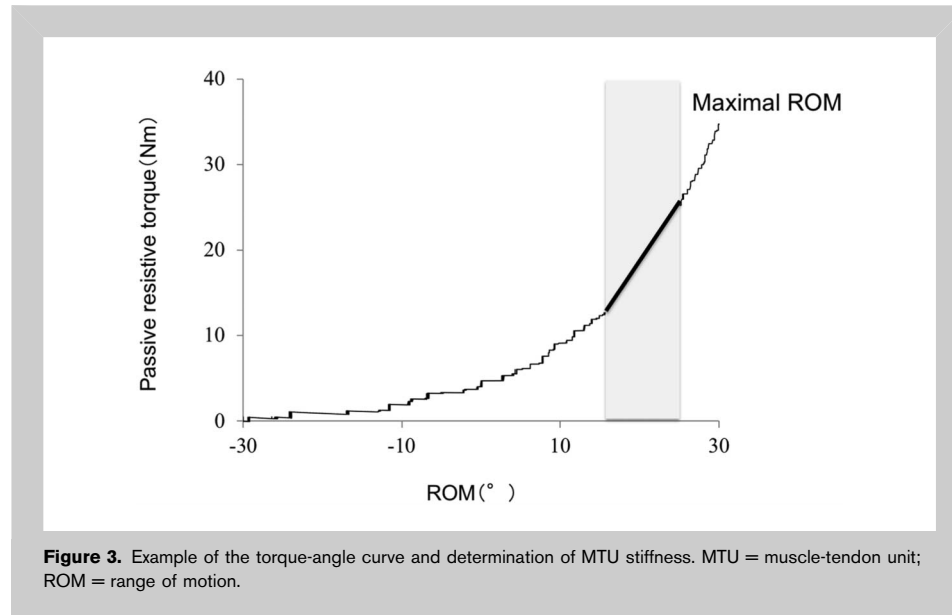
## METHODS

### Experimental Approach to the Problem

This randomized cross-over study required all subjects to perform 5 experimental trials, each 48 hours apart, at the same time of the day ( $\pm 2$  hours) as shown in Figure 1. The first trial orientated and familiarized subjects with the instruments throughout the experiment. Passive resistive torque thresholds were then determined. We defined maximal stretch intensity to the point of discomfort but without pain as the passive resistive torque. All subjects performed the subsequent 4 trials, all of which consisted of CTS under the following intensity conditions: no stretching (control), 50, 75, and 100% of the passive resistive torque. Each protocol was assigned a number, and numbered cards were prepared. Subjects were required to pick a card and then perform the protocol corresponding to



**Figure 2.** Experimental setup for flexibility measurement and stretching protocols.



the number of the card. For the control condition, subjects were instructed to rest for 400 seconds, the duration for all stretching protocols. Maximal ROM and passive resistive torque during passive dorsiflexion of the ankle were measured before and after the CTS for each trial. Subjects were asked to relax their ankle plantar flexors during the measurements. Maximal voluntary contraction (MVC) of the ankle plantar flexors was measured after the poststretching measurements. The temperature in the laboratory room was kept at 25° C.

### Subjects

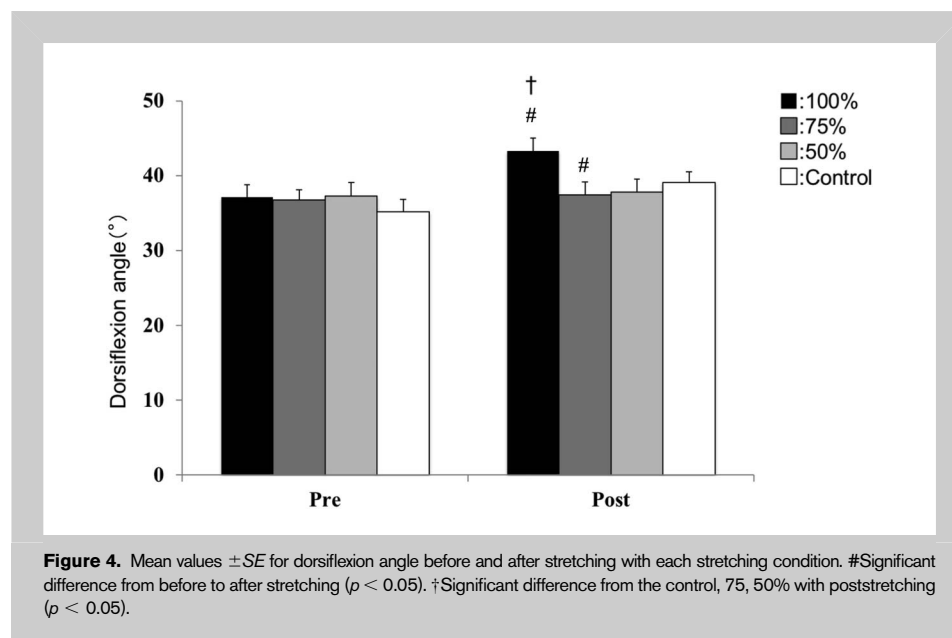
Fourteen healthy men (age:  $22.9 \pm 1.0$  years [range 22 to 24 years], height:  $174.1 \pm 3.9$  cm, body mass:  $68.6 \pm 6.8$  kg, all

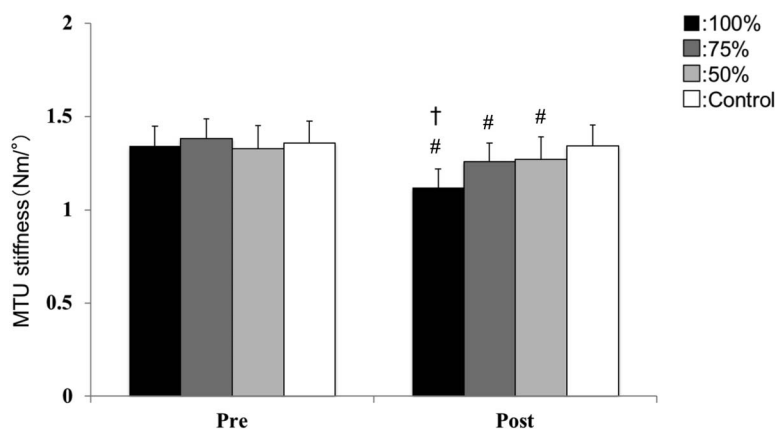
### Procedures

**Flexibility Measurements.** Maximal ROM and passive resistive torque were determined in pre- and poststretch protocols using a Biodex System 3 Isokinetic Dynamometer (Biodex Medical System, Inc., Shirley, NY) programed in the passive mode. Subjects were secured in the supine position with the right knee in full extension and the lateral malleolus of the fibula aligned with the axis of the dynamometer (Figure 2). The foot was firmly strapped to a footplate to prevent any movement during ankle dorsiflexion. Investigators used the dynamometer lever arm to dorsiflex passively the ankle from 30° plantar flexion at  $2^\circ \cdot s^{-1}$  until maximal dorsiflexion was reached without pain. Subjects hold the safety trigger button, which enabled to stop the dynamometer at any time.

Before any flexibility measurements were conducted, subjects maintained a seated position for 10 minutes and were then subjected to 3 passively performed maximal dorsiflexion for practice. For passive resistive torque, a gravity correction of the limb was performed (Figure 2). Based on the methods used in previous studies (15,16), MTU stiffness was calculated from the inclination angles of the torque-angle curve between 15 and 25° of ankle dorsiflexion as shown in Figure 3.

Surface electromyography (EMG) was used to ensure that the ankle plantar flexors were relaxed during the passive





**Figure 5.** Mean values  $\pm$  SE for MTU stiffness before and after stretching with each stretching condition. #Significant difference from before to after stretching ( $p < 0.05$ ). †Significant difference from the control, 75, 50% with poststretching ( $p < 0.05$ ). MTU = muscle-tendon unit.

stretching protocols and the flexibility measurements. The skin surface was cleaned with alcohol before bipolar surface electrodes were placed 20 mm apart on the muscle belly of the middle gastrocnemius and connected to an EMG system (MyoSystem 1200; Noraxon USA, Inc., Scottsdale, AZ). The root mean square of the EMG activity (within 500 ms) was calculated during MVC of the plantar flexors while the ankle was kept in a neutral position. Electromyography measurements were taken for all flexibility measurements and stretching protocols at a sampling rate of 1,000 Hz. The EMG activity was calculated as the percentage of MVC.

**Stretching Protocols.** Similar to the flexibility protocols, 5 sets of CTS exercises were each performed for 60 seconds at different intensities using a Biodex System 3 isokinetic dynamometer set to the passive mode. The stretch intensity was determined using the maximum passive resistive torque measured in the first familiarization trial. During the CTS, the dynamometer maintained a constant torque of either 100 or 75 or 50% of the maximal passive resistive torque for 60 seconds and then released to the initial position. A 15-second rest break was taken between each CTS interval. In the control group, the subjects were ordered to maintain their leg muscles in a relaxed supine position.

#### Statistical Analyses

Two-way repeated-measures analyses of variance (Stretching intensity  $\times$  time) were used to determine any significant differences between interventions for maximal ROM and MTU stiffness. Bonferroni's correction was used to compare maximal ROM and MTU stiffness between conditions before and after CTS. The statistical significance level was set at  $p \leq 0.05$ , and all data were presented as mean  $\pm$  SE. For the effect size, partial eta-squared values ( $\eta_p^2$ ) for

repeated measures were calculated. All statistical analyses were performed using SPSS version 19.0 (SPSS, Inc., Chicago, IL).

#### RESULTS

Electromyography activities of the ankle plantar flexors during the flexibility measurements and the stretching protocols exhibited less than 10% MVC. Therefore, based on a previous study (26), muscle activities seem negligible during each experiment, and any voluntary contraction torque could be excluded from passive resistive torque in this study. Consequently, all data were used for further analyses.

For maximal ROM, a significant 2-way interaction (stretching  $\times$  time) was found ( $p < 0.01$ ,  $\eta_p^2 = 0.64$ ). The maximal ROM increased from before to after stretching for 100% ( $37.2 \pm 6.2^\circ$ – $43.3 \pm 6.4^\circ$ ,  $p < 0.01$ ) and 75% ( $35.2 \pm 5.3^\circ$ – $39.2 \pm 6.7^\circ$ ,  $p < 0.01$ ), but no significant differences were observed for 50% ( $37.3 \pm 6.8^\circ$ – $37.8 \pm 6.5^\circ$ ,  $p = 0.39$ ) or the control condition ( $36.8 \pm 6.2^\circ$ – $37.5 \pm 5.4^\circ$ ,  $p = 0.14$ ). In prestretching, no significant differences in maximal ROM were found among any of the interventions or control conditions. However, CTS at 100% yielded significantly increased maximal ROM compared with 75, 50%, and control ( $p < 0.01$ , respectively) after stretching, although the results for 75 and 50% did not significantly differ from the control ( $p = 0.94$ – $1.00$ ) as shown in Figure 4.

As for MTU stiffness, a significant 2-way interaction (stretching  $\times$  time) was observed, ( $p < 0.01$ ,  $\eta_p^2 = 0.61$ ). The MTU stiffness decreased from before to after stretching for 100% ( $1.3 \pm 0.4$ – $1.1 \pm 0.4$  N·m per degree,  $p < 0.01$ ), 75% ( $1.4 \pm 0.4$ – $1.3 \pm 0.4$  N·m per degree,  $p < 0.01$ ), and 50% ( $1.3 \pm 0.5$ – $1.3 \pm 0.5$  N·m per degree,  $p < 0.01$ ), but no differences were observed for the control ( $1.4 \pm 0.5$ – $1.4 \pm 0.4$  N·m per degree,  $p = 0.57$ ). With prestretching, no differences were observed among the 100, 75, 50%, and control conditions. However, CTS at 100% revealed significantly lower MTU stiffness than 75, 50%, and control ( $p < 0.01$ – $0.05$ ) after the stretching, whereas no significant differences were found between 75, 50%, and control ( $p = 1.00$ ), as shown in Figure 5.

#### DISCUSSION

In the present study, we investigated the effects of stretch intensity with CTS on maximal ROM and MTU stiffness to determine whether lower stretch intensity used in

combination with a CTS technique could improve flexibility and change the mechanical properties of the MTU. This study showed that CTS at 100% intensity significantly increased maximal ROM and decreased MTU stiffness in poststretching compared with CTS at lower intensities and the control condition, although there were no significant differences in maximal ROM and MTU between post-CTS at 50 or 75% intensity and the control condition. Therefore, these findings suggested that maximal stretch intensity is required to change both maximal ROM and MTU stiffness of the ankle plantar flexors for CTS techniques.

Recently, many studies have reported that CTS was more effective than CAS to increase ROM and decrease MTU stiffness (5,9,10,27,28). Constant angle stretching and CTS elicit different viscoelastic responses, e.g., stress relaxation and creep behaviors in muscles. In addition, several studies have reported that when in vitro animal model muscles (25) and human skeletal muscles (13,14) are held at a stretched length under tensile stress using CAS, a stress-relaxation response occurs. Magnusson et al. (13) reported that passive resistive torque during CAS decreased by 30.2% because of the stress-relaxation phenomenon in human skeletal muscles (14). They also revealed that stress relaxation in both healthy and spinal cord-injured subjects lead to a 33.2 and 38.7% decrease in passive resistive torque, respectively. On the other hand, repeated stretching (10 sets  $\times$  30 seconds) in in vitro animal models with constant force increased muscle length and caused the creep phenomenon (25). With in vivo testing of skeletal muscles, most of the muscle creep phenomenon occurred within the first 15–20 seconds of CTS (20). With repeated CTS (4 sets  $\times$  30 seconds), the extent of the muscle creep phenomenon was the same (19). Therefore, CTS applied at a constant pressure to a muscle causes muscle creep during repeated stretches at the same extent, possibly causing the muscles to work harder than CAS. Consequently, CTS resulted in greater changes to ROM and MTU stiffness (5,9,10,27,28), implying that CTS is an optimal way of improving flexibility and changing the mechanical properties of the MTU. If considering only MTU work, CTS leads to more work in the same amount of time than CAS, meaning that CTS at submaximal stretch intensities may lead to increased maximal ROM and decreased MTU stiffness. However, whether CTS at submaximal intensities affects maximal ROM or MTU stiffness has never been verified, and this study is the first to attempt to demonstrate the direct effects of CTS.

The present study showed that only CTS at 100% intensity significantly increased maximal ROM compared with the control for poststretch measurements. However, submaximal stretch intensities (i.e., 75, 50% of the maximal passive resistive torque) had no effect on maximal ROM, disproving our hypothesis that submaximal CTS would increase maximal ROM. Freitas et al. (6,7) compared both stretch intensity and duration using a CAS technique and reported that higher intensity CAS increased peak joint

ROM, whereas submaximal stretch intensity and longer duration did not. These findings suggest that stretch intensity is more important to increase ROM with CAS. Our results were obtained using a CTS technique in accordance with previous studies. Thus, stretch intensity can be deemed an important factor for stretch-induced effects, and this study and others support the idea that the initial torque used during CTS should be as high as possible.

Our data showed a significant decrease in MTU stiffness at 100% CTS intensity, with no changes at submaximal intensities. To our knowledge, only 1 other study has investigated the effects of stretch intensity on MTU stiffness, with significant decreases resulting from 120% intensity and not at 80% (11). Moreover, the change of MTU stiffness at 120% intensity was greater than at 80% intensity, indicating that higher stretch intensities were necessary to decrease MTU stiffness (11). Many studies reported that longer durations were required to decrease MTU stiffness with CAS, whereas CTS decreased MTU stiffness of the calf muscle and hamstring in 30 seconds, as well as 60 seconds. As such, it is possible that CTS may require shorter durations to reduce MTU stiffness. In this study, submaximal intensity and longer duration CTS were performed, with no significant changes in MTU stiffness. This is a further indication that the initial stretch intensity is an important factor in decreasing MTU stiffness.

In this study, we did not attempt to show the relationship between stretch intensity and flexibility or stiffness of the MTU, although a previous study has postulated that maximal ROM could be influenced by the physiological and neural properties of the MTU (4). In this study, 100% intensity was defined as the point of discomfort with no pain, something that has been referred to in previous studies. Submaximal intensity did not provide enough stimuli to influence such physiological and neural factors as pain, stretch feeling, stretch tolerance, or reflex activity. Regarding the decrease in MTU stiffness, several studies have investigated the mechanism that decreases MTU stiffness. Muscle-tendon unit stiffness decreased after 5 minutes of stretching because of a decrease in muscle stiffness, not tendon stiffness, estimated by movement of the myotendinous junction (7). Similarly, Kay and Blazevich (12) found that 3 bouts of 60-second static stretching decreased muscle stiffness, whereas tendon stiffness was unchanged. Therefore, the decrease in MTU stiffness after stretching was because of a decrease in muscle stiffness but not tendon stiffness. Notably, Gajdosik et al. (8) suggested that connective tissues such as the endomysium, perimysium, and epimysium could be responsible for any changes in passive stiffness. In the present study, decreases in MTU stiffness might have been caused by increased extensibility in intramuscular connective tissues such as those listed above. Future studies should examine the mechanisms concerned with stretching intensity and the mechanical properties of MTU.

There were several methodological limitations to this study. First, the present study did not examine the influence of the stretching duration. Future studies should be conducted to clarify the interaction of stretching intensity and duration focusing on the mechanical properties of MTU. Second, in this study, MTU stiffness was calculated based on the torque-angle curve. As such, we could not detect which tissues were affecting stiffness, as the MTU was made up of muscle, tendon, fascia, and connective tissues. Ultrasound images and elastographic techniques would provide more detailed information and might be useful for estimating the effects on mechanical properties of muscle and tendon separately.

# PRACTICAL APPLICATIONS

The present study determined that CTS at 100% intensity increased ROM and decreased MTU stiffness compared with the control condition. These findings indicate that the highest stretching intensity is recommended to improve both flexibility and MTU stiffness. Therefore, coaches, trainers, and therapists should consider that stretch intensities, durations, frequencies, positions, and technique could affect stretching results (1,5).

# ACKNOWLEDGMENTS

The authors have no conflicts of interest to disclose.

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