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Title	Influence of Constant Torque Stretching at Different Stretching Intensities on Flexibility and Mechanical Properties of Plantar Flexors
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Citation	Journal of strength and conditioning research, 35(3), 709-714 https://doi.org/10.1519/JSC.0000000000002767
Issue Date	2021-03
Doc URL	https://hdl.handle.net/2115/84204
Rights	This is a non-final version of an article published in final form in Oba, Kensuke ¹ ; Samukawa, Mina ² ; Nakamura, Kentaro ² ; Mikami, Kentaro ³ ; Suzumori, Yuki ¹ ; Ishida, Yuko ⁴ ; Keeler, Nathalie ⁵ ; Saitoh, Hiroshi ⁶ ; Yamanaka, Masanori ² ; Tohyama, Harukazu ² Influence of Constant Torque Stretching at Different Stretching Intensities on Flexibility and Mechanical Properties of Plantar Flexors, Journal of Strength and Conditioning Research: March 2021 - Volume 35 - Issue 3 - p 709-714 doi: 10.1519/JSC.0000000000002767.
Type	journal article
File Information	JSCR2_manuscript201805_husca.pdf



Title

Influence of constant torque stretching at different stretching intensities on flexibility and mechanical properties of plantar flexors.

1 **ABSTRACT**

2 The purpose of this study was to examine the effects of constant torque stretching (CTS) at
3 different stretching intensities on the maximal range of motion (ROM) and muscle-tendon unit
4 (MTU) stiffness of plantar flexors. Fourteen healthy men performed four trials of differing stretch
5 intensity: no stretching (control), 50 %, 75 %, and 100 %. Stretch intensity was defined as maximum
6 passive resistive torque predetermined at a familiarization trial. Each stretch trial consisted of five
7 sets of 60-second CTS at the designated stretch intensity. Both maximal ROM and passive resistive
8 torque were assessed during passive dorsiflexion and MTU stiffness was calculated using the
9 torque-angle curves measured before and after CTS. There were no significant differences in
10 maximal ROM or MTU stiffness at the baseline condition. After the intervention, significantly
11 greater maximal ROM and significantly lower MTU stiffness were observed in the 100 % CTS
12 condition than the control condition while there were no significant differences between the
13 submaximal intensity condition (i.e. 50 % or 75 % intensity) and the control condition. Therefore,
14 our findings suggest that maximal intensity stretching is the most effective approach for improving
15 both flexibility and MTU stiffness with CTS.

16

17 **Keywords**

18 Constant torque stretching, stretching intensity, flexibility

19

20

21 INTRODUCTION

22 Stretching exercises are widely used to improve flexibility in the sports and rehabilitation
23 fields. Numerous studies showed that stretching exercises induced acute increases in range of
24 motion (ROM) (1-3) and changes in the stiffness of the muscle-tendon unit (MTU) (1, 4-7).
25 Stretching exercises also enhance athletic performance (8, 9) and reduce the risks of sports-related
26 injury (10).

27 Stretching intensity, duration, frequency, position and technique are all important factors that
28 can influence stretch-induced effects (11, 12). Much research has been conducted in attempt to
29 clarify and establish effective static stretching protocols. Constant angle stretching (CAS) is a
30 stretching technique defined by holding a muscle group at a constant length to maintain a specific
31 joint angle, while Constant Torque Stretching (CTS) is defined by holding passive resistive torque to
32 adjust joint angles. Recent studies have shown that CTS is more effective than CAS for increasing
33 ROM (12, 13) and decreasing MTU stiffness; one of the mechanical properties of the MTU (1, 5,
34 12-14). Yeh et al. (13) reported that CTS produced greater changes in ROM and MTU stiffness than
35 CAS in stroke patients with hypertonic ankle plantar flexors. Similar results were shown by Cabido
36 et al. (12) that the changes in ROM and MTU stiffness in the hamstrings in healthy men were
37 greater with CTS than CAS. Other studies have asserted that the reason passive resistive torque
38 decreases with CAS is due to a stress-relaxation response that occurs when muscles are held at
39 constant stretched lengths. In other words, it is due to the viscoelastic properties of muscle (15, 16).
40 Separate studies have shown that maintaining passive resistive torque can cause small increases in

41 joint angle referred to as muscle creep phenomenon (17, 18). This phenomenon is may also be
42 attributed to muscle viscoelasticity, allowing for muscles to be stretched for greater changes in ROM
43 and MTU stiffness (1, 5, 12-14). As such, CTS can be considered an optimal stretching method to
44 promote flexibility and to change the mechanical properties of MTU.

45 Although a few studies have previously investigated the effects of stretch intensity using CAS
46 (19, 20), none have specifically investigated the influence of CTS on stretch intensity. Freitas et al.
47 (19) compared the influence of different CAS intensities (100 %, 75 %, 50 %) for different lengths
48 of time (5 repetitions of 90 seconds, 135 seconds, and 180 seconds, respectively) on improving peak
49 joint ROM and found that only CAS at 100% for 90 seconds resulted in improved peak joint ROM,
50 while no changes were detected for any of the longer duration submaximal intensity regimes.
51 Recently, the same authors reported that maximum intensity CAS without pain for several 90s
52 repetitions increased maximal ROM, whereas CAS at 50 % intensity for 900 seconds showed no
53 change in maximal ROM (20). The implication of these studies is that CAS at maximum intensity
54 may be the best way to increase joint ROM (19, 20).

55 With CTS, the initial stretch intensity is considered a crucial factor to maintain constant
56 passive resistive torque throughout the duration of the stretching exercise. Therefore, there is a
57 possibility that CTS at submaximal intensity could improve flexibility and change the mechanical
58 properties of the MTU. It is important to determine the influence of CTS intensity in order to create
59 protocols that will yield improved flexibility and changes to the MTU for injury prevention and
60 rehabilitation. We then hypothesize that higher intensity CTS would induce greater increases in

61 maximal ROM and greater decreases in MTU stiffness. The purpose of the present study was to
62 investigate the effects of CTS intensity on maximal ROM and MTU stiffness.

63 **METHODS**

64 **Experimental Approach to the Problem**

65 This randomised crossover study required all participants to perform 5 experimental trials,
66 each 48 hours apart, at the same time of day (± 2 hours) as shown in Figure 1. The first trial
67 orientated and familiarised participants with the instruments throughout the experiment. Passive
68 resistive torque thresholds were then determined. We defined maximal stretch intensity to the point
69 of discomfort but without pain as the passive resistive torque. All participants performed the
70 subsequent four trials, all of which consisted of CTS under the following intensity conditions: no
71 stretching (control), 50 %, 75 %, and 100 % of the passive resistive torque. Each protocol was
72 assigned a number and numbered cards were prepared. Participants were required to pick a card and
73 then perform the protocol corresponding to the number of the card. For the control condition,
74 subjects were instructed to rest for 400 seconds, the duration for all stretching protocols. Maximal
75 ROM and passive resistive torque during passive dorsiflexion of the ankle were measured before
76 and after the CTS for each trial. Participants were asked to relax their ankle plantar flexors during
77 the measurements. Maximal voluntary contraction (MVC) of the ankle plantar flexors was measured
78 after the post-stretching measurements. The temperature in the laboratory room was kept at 25 °C.

79 Figure 1 about here

80

81 **Participants**

82 Fourteen healthy men (age: 22.9 ± 1.0 years (mean \pm SD), height: 174.1 ± 3.9 cm, body
83 mass: 68.6 ± 6.8 kg) with no history of lower-limb injury or neuromuscular disease volunteered for
84 this study through written informed consent. All experiments were conducted on the right plantar
85 flexors of the leg. Participants were asked to refrain from participating in any resistance training or
86 stretching program for twenty-four hours prior to commencement of the interventions and for the
87 entire duration of the study. The ethical committee of a local institutional review board approved the
88 study protocol, and all experimental procedures were performed in accordance with the Declaration
89 of Helsinki.

90

91 Flexibility measurements

92 Maximal ROM and passive resistive torque were determined in pre- and post-stretch
93 protocols using a Biodex System-3 Isokinetic Dynamometer (Biodex Medical System Inc., Shirley,
94 NY, USA) programmed in the passive mode. Participants were secured in the supine position with
95 the right knee in full extension, and the lateral malleolus of the fibula aligned with the axis of the
96 dynamometer. The foot was firmly strapped to a footplate to prevent any movement during ankle
97 dorsiflexion. Investigators used the dynamometer lever arm to dorsiflex passively the ankle from
98 30° plantar flexion at 2° per second until maximal dorsiflexion was reached without pain.
99 Participants hold the safety trigger button, which enabled to stop dynamometer in any time. Before
100 any flexibility measurements were conducted, participants maintained a seated position for 10

121 the first familiarization trial. During the CTS, the dynamometer maintained a constant torque of
122 either 100 % or 75 % or 50 % of the maximal passive resistive torque for 60 seconds and then
123 released to the initial position. A 15-second rest break was taken between each CTS interval. In the
124 control group, the participants were ordered to maintain their leg muscles in a relaxed supine
125 position.

126

127 **Statistical analysis**

128 Two-way repeated-measures analyses of variance (Stretching intensity \times time) were used
129 to determine any significant differences between interventions for maximal ROM and MTU
130 stiffness. Bonferroni's correction was utilized to compare maximal ROM and MTU stiffness
131 between conditions before and after CTS. The significance level was set at $p < 0.05$ and all data
132 were presented as mean \pm SE. For the effect size, partial eta-squared values (η^2_p) for repeated
133 measures were calculated. All statistical analyses were performed using SPSS ver. 19.0 (SPSS, Inc.,
134 Chicago, Illinois, USA).

135

136 **RESULTS**

137 EMG activities of the ankle plantar flexors during the flexibility measurements as well as the
138 stretching protocols exhibited less than 10 % MVC. Therefore, based on a previous study (23),
139 muscle activities seem negligible during each experiment and any voluntary contraction torque
140 could be excluded from passive resistive torque in this study. Consequently, all data were utilized

141 for further analyses.

142 For maximal ROM, a significant two-way interaction (stretching \times time) was found ($p <$
143 0.01 , $\eta^2_p = 0.64$). The maximal ROM increased from pre- to post-stretching for 100 % ($37.2 \pm 6.2^\circ$
144 to $43.3 \pm 6.4^\circ$, $p < 0.01$) and 75 % ($35.2 \pm 5.3^\circ$ to $39.2 \pm 6.7^\circ$, $p < 0.01$), but no significant
145 differences were observed for 50 % ($37.3 \pm 6.8^\circ$ to $37.8 \pm 6.5^\circ$, $p = 0.39$) or the control condition
146 ($36.8 \pm 6.2^\circ$ to $37.5 \pm 5.4^\circ$, $p = 0.14$). In the pre-stretching, no significant differences in maximal
147 ROM were found among any of the interventions or control conditions. However, CTS at 100 %
148 yielded significantly increased maximal ROM compared to 75 %, 50 % and control ($p < 0.01$,
149 respectively) after stretching, although the results for 75 % and 50 % did not significantly differ
150 from the control ($p = 0.94\sim 1.00$) as shown in Figure.4.

151 As for MTU stiffness, a significant two-way interaction (stretching \times time) was observed,
152 ($p < 0.01$, $\eta^2_p = 0.61$). The MTU stiffness decreased from pre- to post- stretching for 100% (1.3 ± 0.4
153 $\text{Nm} / ^\circ$ to $1.1 \pm 0.4 \text{Nm} / ^\circ$, $p < 0.01$), 75% ($1.4 \pm 0.4 \text{Nm} / ^\circ$ to $1.3 \pm 0.4 \text{Nm} / ^\circ$, $p < 0.01$) and 50 %
154 ($1.3 \pm 0.5 \text{Nm} / ^\circ$ to $1.3 \pm 0.5 \text{Nm} / ^\circ$, $p < 0.01$), but no differences were observed for the control
155 ($1.4 \pm 0.5 \text{Nm} / ^\circ$ to $1.4 \pm 0.4 \text{Nm} / ^\circ$, $p = 0.57$). With pre-stretching, no differences were
156 observed among the 100 %, 75 %, 50 % and control conditions. However, CTS at 100 % revealed
157 significantly lower MTU stiffness than 75 %, 50 % and Control ($p < 0.01 \sim 0.05$) after the stretching,
158 whereas no significant differences were found between 75 %, 50 % and Control ($p = 1.00$) as shown
159 in Figure 5.

160 Figure 4 about here

161 Figure 5 about here

162

163 **DISCUSSION**

164 In the present study, we investigated the effects of stretch intensity with CTS on maximal
165 ROM and MTU stiffness to determine whether lower stretch intensity used in combination with a
166 CTS technique could improve flexibility and change the mechanical properties of the MTU. This
167 study showed that CTS at 100 % intensity significantly increased maximal ROM and decreased
168 MTU stiffness in post-stretching compared to CTS at lower intensities and the control condition.
169 While there were no significant differences in maximal ROM and MTU between post-CTS at 50 %
170 or 75 % intensity and the control condition. Therefore, these findings suggested that maximal
171 stretch intensity is required to change both maximal ROM and MTU stiffness of the ankle
172 plantarflexors for CTS techniques.

173 Recently, many studies have reported that CTS was more effective than CAS to increase
174 ROM and decrease MTU stiffness (1, 5, 12-14). CAS and CTS elicit different viscoelastic responses,
175 e.g. stress relaxation and creep behaviors in muscles. In addition, several studies have reported that
176 when in-vitro animal model muscles (24) and human skeletal muscles (15,16) are held at a stretched
177 length under tensile stress using CAS, a stress relaxation response occurs. Magnusson et al. (15)
178 reported that passive resistive torque during CAS decreased by 30.2 % due to the stress relaxation
179 phenomenon in human skeletal muscles (16). They also revealed that stress relaxation in both
180 healthy and spinal cord-injured subjects lead to a 33.2 % and 38.7 % decrease in passive resistive

181 torque respectively. On the other hand, repeated stretching (10 sets \times 30 seconds) in vitro animal
182 models with constant force, increased muscle length and caused creep phenomenon (24). With in
183 vivo testing of skeletal muscles, the majority of muscle creep phenomenon occurred within the first
184 15 - 20 seconds of CTS (17). With repeated CTS (4 sets \times 30 seconds), the extent of the muscle
185 creep phenomenon was the same (18). Therefore, CTS applied at a constant pressure to a muscle
186 causes muscle creep during repeated stretches at the same extent, possibly causing the muscles to
187 work harder than occurs with CAS. Consequently, CTS resulted in greater changes to ROM and
188 MTU stiffness (1, 5, 12-14), implying that CTS is an optimal way of improving flexibility and
189 changing the mechanical properties of the MTU. If considering only MTU work, CTS leads to more
190 work in the same amount of time than CAS, meaning that CTS at submaximal stretch intensities
191 may lead to increased maximal ROM and decreased MTU stiffness. However, whether or not CTS
192 at submaximal intensities affects maximal ROM or MTU stiffness has never been verified and this
193 study is the first to attempt to demonstrate the direct effects of CTS.

194 The present study showed that only CTS at 100 % intensity significantly increased maximal
195 ROM compared to the control for post-stretch measurements. However submaximal stretch
196 intensities (i.e. 75 %, 50 % of the maximal passive resistive torque) had no effect on maximal ROM
197 disproving our hypothesis that submaximal CTS would increase maximal ROM. Freitas et al. (19,
198 20) compared both stretch intensity and duration using a CAS technique, and reported that higher
199 intensity CAS increased peak joint ROM, while submaximal stretch intensity and longer duration
200 did not. These findings suggest that stretch intensity is more important to increase ROM with CAS.

201 Our results were obtained using a CTS technique in accordance with previous studies. Thus, stretch
202 intensity can be deemed an important factor for stretch-induced effects, and this study and others
203 support the idea that the initial torque employed during CTS should be as high as possible.

204 Our data showed a significant decrease in MTU stiffness at 100 % CTS intensity, with no
205 changes at submaximal intensities. To our knowledge, only one other study has investigated the
206 effects of stretch intensity on MTU stiffness with significant decreases resulting from 120 %
207 intensity and not at 80 % (26). Moreover, the change of MTU stiffness at 120 % intensity was
208 greater than at 80 % intensity indicating that higher stretch intensities were necessary to decrease
209 MTU stiffness (26). Many studies reported that longer durations were required to decrease MTU
210 stiffness with CAS whereas CTS decreased MTU stiffness of the calf muscle and hamstring in 30
211 seconds as well as 60 seconds. As such, it is possible that CTS may require shorter durations to
212 reduce MTU stiffness. In this study, submaximal intensity and longer duration CTS were performed,
213 with no significant changes in MTU stiffness. This is a further indication that the initial stretch
214 intensity is an important factor in decreasing MTU stiffness.

215 In this study, we did not attempt to show relationship between stretch intensity and flexibility
216 or stiffness of the MTU, although a previous study has postulated that maximal ROM could be
217 influenced by the physiological and neural properties of the MTU (25). In this study, 100 %
218 intensity was defined as the point of discomfort with no pain, something that has been referred to in
219 previous studies. Submaximal intensity did not provide enough stimuli to influence such
220 physiological and neural factors as pain, stretch feeling, stretch tolerance or reflex activity.

221 Regarding the decrease in MTU stiffness, several studies have investigated the mechanism that
222 decreases MTU stiffness. MTU stiffness decreased after 5 min of stretching due to a decrease in
223 muscle stiffness, not tendon stiffness, estimated by movement of the myotendinous junction (20).
224 Similarly, Kay and Blazevich (27) found that three bouts of 60-second static stretching decreased
225 muscle stiffness while tendon stiffness was unchanged. Therefore, the decrease in MTU stiffness
226 after stretching was due to a decrease in muscle stiffness but not tendon stiffness. Notably, Gajdosik
227 et al. (28) suggested that connective tissues such as the endomysium, perimysium and epimysium
228 could be responsible for any changes in passive stiffness. In the present study, decreases in MTU
229 stiffness might have been caused by increased extensibility in intramuscular connective tissues such
230 as those listed above. Future studies should examine the mechanisms concerned with stretching
231 intensity and the mechanical properties of MTU.

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

240

241 **PRACTICAL APPLICATION**

242 The present study determined that CTS at 100% intensity increased ROM and decreased
243 MTU stiffness compared with the control condition. These findings indicate that the highest
244 stretching intensity is recommended to improve both flexibility and MTU stiffness.
245 Therefore, coaches, trainers and therapists should consider stretch intensities, durations,
246 frequencies, positions and technique could affect stretching results (11, 12).

247

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317

318 **ACKNOWLEDGMENTS**

319 No financial disclosure.

320 **FIGURE LEGENDS**

321 **Figure 1.** Experimental design.

322

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

324

325 **Figure 3.** An example of torque-angle curve and determination of MTU stiffness.

326

327 **Figure 4.** Mean values \pm SE for dorsiflexion angle in pre- and post-stretching with each

328 stretching condition.

329 #: Significant difference from pre- to post-stretching ($p < 0.05$).

330 †: Significant difference from the control, 75%, 50% with post-stretching ($p < 0.05$).

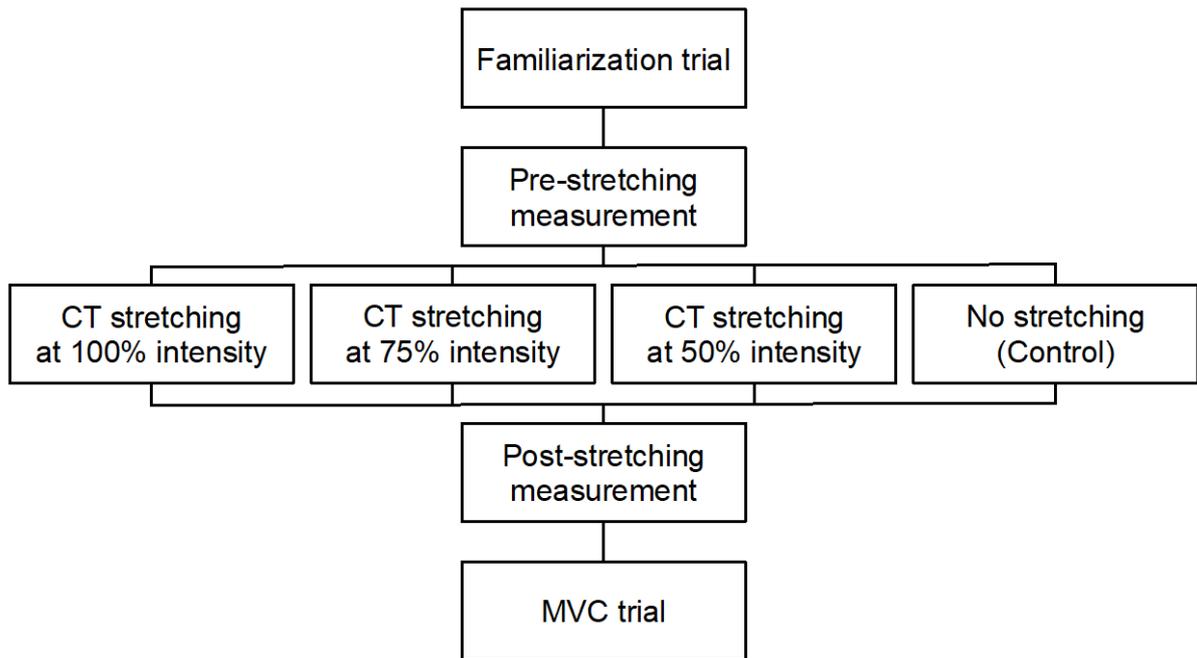
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332 **Figure 5.** Mean values \pm SE for MTU stiffness in pre- and post-stretching with each

333 stretching condition.

334 #: Significant difference from pre- to post-stretching ($p < 0.05$).

335 †: Significant difference from the control, 75%, 50% with post-stretching ($p < 0.05$).



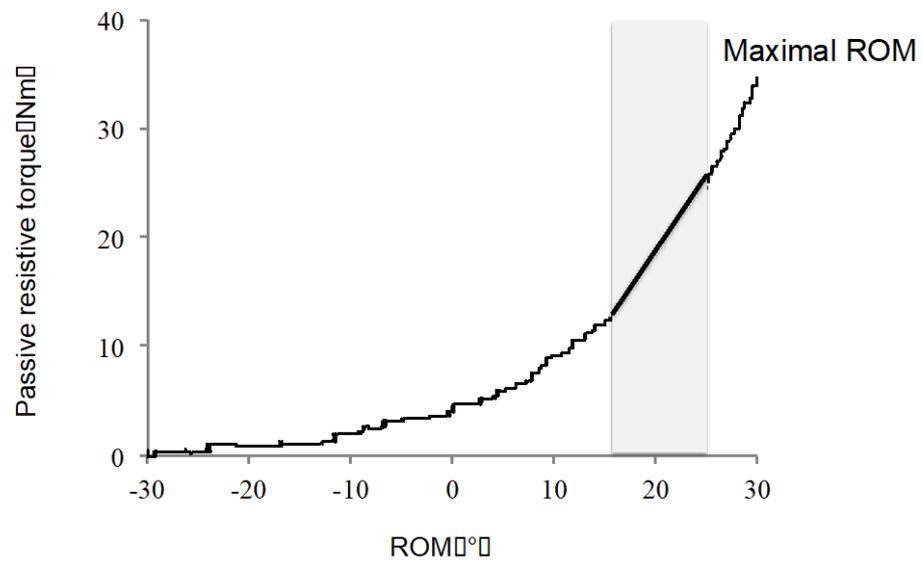
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337 **Figure 1**



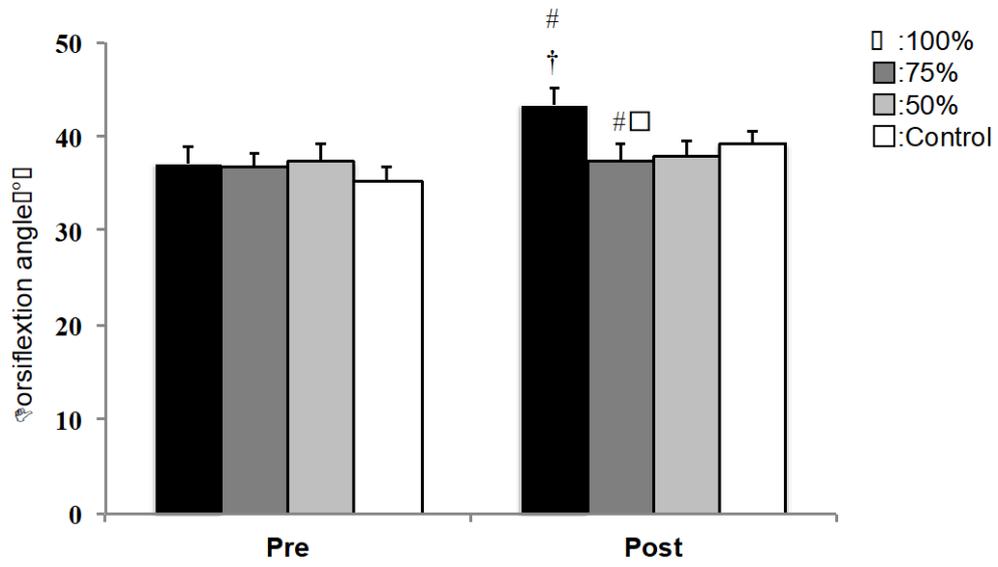
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339 **Figure 2**



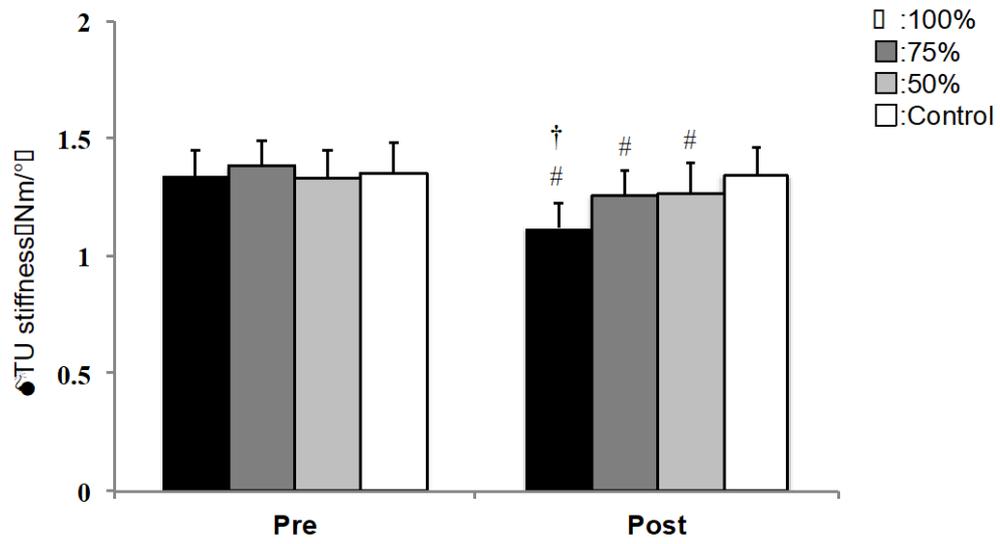
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341 **Figure 3**



342

343 **Figure 4**



344

345 **Figure 5**