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1 **Effects of a Thermal Agent and Physical Activity on Muscle Tendon Stiffness, as Well**
2 **as the Effects Combined With Static Stretching.**

3

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24

25 ABSTRACT

26

27 **Context:** A recent review or article reported that thermal agents (TA) or physical activity
28 (PA) can increase range of motion (ROM), and that the combination of TA with stretching is
29 superior to performing stretching only. However, since ROM is affected by the participants'
30 psychological factors, it is questionable whether these studies measured the effect of these
31 intervention on muscle flexibility. By measuring muscle stiffness, we attempted to evaluate
32 the effect these intervention on muscle flexibility.

33 **Objective:** To compare the individual effects of TA and PA on muscle flexibility, as well as
34 their effectiveness when combined with static stretching (SS).

35 **Design:** Crossover trial.

36 **Setting:** University research laboratory.

37 **Participants:** Fifteen healthy men without a history of orthopedic disease in their lower
38 limbs.

39 **Interventions:** Fifteen minutes of three different conditions: hot pack as TA, pedaling
40 exercise as PA, and the control group with no TA or PA intervention, followed by three
41 minutes of SS for the hamstrings muscles.

42 **Main Outcome Measures:** Joint angle and passive torque of the knee during passive
43 elongation were obtained prior to interventions (pre-intervention), following three kinds of

44 intervention (post-intervention), and after SS (post-SS). From these data, muscle tendon
45 unit (MTU) stiffness of the hamstrings was calculated.

46 **Results:** Although knee joint ROM increased with both TA and PA ($p < 0.05$), there were no
47 significant differences in MTU stiffness between pre- and post-intervention measurements
48 for either of these interventions (TA, $p=0.477$; PA, $p=0.377$; control, $p=0.388$). However,
49 there were similar significant decreases in MTU stiffness between post-intervention and
50 post-SS at all condition ($p<0.01$).

51 **Conclusions:** TA and PA did not decrease MTU stiffness, and combining these
52 interventions with SS did not provide additional decreases in MTU stiffness compared to
53 performing SS alone.

54

Introduction

The effect of thermal agents on muscle flexibility has been well studied using various methods of heat interventions¹⁻⁶. Most of these studies have supported the use of heat intervention for increasing range of motion (ROM)^{1, 2, 5, 7}. A recent review of research with human participants has shown the combination of heat modalities and stretching to be superior to static stretching only for increasing joint ROM but not for lowering the passive stiffness of the muscle at the same joint angle⁸. On the other hand, only a few studies have evaluated the effect of physical activity in improving muscle flexibility^{9, 10}. Williford et al. reported jogging prior to stretching to be effective in improving muscle flexibility, while Demura et al. concluded that 'light exercise' and 'heat' were equivalent for improving ROM, with both light exercise and heat being superior to a placebo.

These studies^{1-3, 9}, however, used joint ROM as an index of muscle flexibility, which is known to be affected by psychological factors, such as pain and stretch tolerance¹¹. Recently, measurement of muscle tendon unit stiffness during passive movement has been shown to be a preferred index of muscle flexibility, as this method excludes the effect of psychological factors. The use of muscle tendon unit stiffness, therefore, would be an effective method to differentiate the underlying mechanism of change in joint ROM, whether it is due to decreased muscle stiffness and/or to a change in muscle stretch tolerance. A study by Kubo et al.¹² did compare the effect of heat and cold water immersion on muscle tendon unit stiffness. However, in their study, Kubo et al. did not examine the effect of physical activity, either alone or in combination with stretching, on muscle tendon unit stiffness. To the best of our knowledge, no study has examined and compared the effectiveness of thermal agent and physical activity interventions, administered prior to static stretching (SS), by using muscle tendon unit stiffness as an index of muscle flexibility.

80 The goals of this study were to examine the effect of thermal agent and physical
81 activity interventions, in combination with SS, on muscle tendon unit stiffness. We
82 hypothesized that thermal agent and physical activity interventions would contribute an
83 additional effect to SS in decreasing muscle tendon unit stiffness, and that the effect of
84 physical activity would be superior to that of thermal agent.

85

86

Methods

87

Design

88 This study used a crossover design. Each subject participated in three sessions, with
89 exposure to all three experimental conditions: the thermal agent condition, in which a hot
90 pack was applied to the hamstring muscles; the physical activity condition, during which
91 subjects performed a pedaling exercise; and the control condition, in which no intervention
92 was provided. Experimental conditions were randomized across subjects to eliminate the
93 effect of order. In each evaluation session, subjects initially underwent either thermal agent,
94 physical activity or rest for the control condition, followed by a period of SS. Measurements
95 of muscle tendon unit stiffness were obtained before thermal agent intervention, physical
96 activity intervention or rest for the control condition (pre-intervention), after the intervention
97 or rest, (post-intervention), and immediately after SS (post-SS). Sessions were held more
98 than two days apart to control for between-condition interactions.

100

Participants

101 Fifteen healthy men (mean age, 23.2 ± 1.9 years; height, 172.9 ± 5.2 cm; weight,
102 68.7 ± 8.0 kg; BMI, 22.9 ± 1.9) volunteered for this study. Subjects with a history of
103 orthopedic impairments to their lower limbs were excluded. Written informed consent was
104

105 obtained from each participant. This study was approved by the ethics committee of Kyoto
106 university hospital (approval number E1936).

107

108 Procedures

109 Measurements of muscle tendon unit stiffness and passive torque of the knee were
110 obtained using the Biodex System 4 (Biodex Medical Systems, Inc.; New York, US).
111 Subjects were seated with a wedge placed under their thigh and another wedge-shaped
112 cushion behind their back, so that the hip and knee joints were flexed to about 120°. The
113 dominant foot was securely attached to the arm of the dynamometer, while the trunk was
114 firmly fixed to the seat with a belt to prevent compensatory pelvic motion (Figure 1). This
115 position was defined as the starting position. Subjects were instructed to remain relaxed
116 during measurements of muscle tendon unit stiffness. To measure the extensibility of the
117 hamstrings, the knee joint was passively extended at a constant velocity of 5°/s from the
118 starting position to the final angle, which was defined as the angle just before subjects
119 reported feeling a strong stretching sensation but no pain. The final angle was expressed
120 as the change in knee angle from the starting position. SS in this study was also performed
121 to this final angle, which was individually determined. Muscle tendon unit stiffness was
122 calculated as the change in passive torque divided by the change in joint angle and,
123 therefore, quantified by the slope of the torque–angle curve over the last 10% of passive
124 knee extension¹³. Passive torque at the final angle was used as an index of stretch
125 tolerance, reflecting the psychological factors (Figure 2).

126 For the thermal agent condition, subjects were required to lie prone for 15 min, with a
127 hot pack applied to their hamstrings. The duration of 15 min was based on previous
128 research^{7, 14}, which we consider to be a typical duration in a clinical setting. Each hot pack
129 (S-PACK: SAKAI Medical Co., Ltd.) was heated to 80°C in a hydro-collator tank

130 (PACKWARMER CL-15: SAKAI Medical Co., Ltd.) and wrapped in double layers with a
131 thick towel. For the physical activity condition, subjects performed a pedaling exercise for
132 15 min, using an Aerobike 75XLIII (Konami Sports & Life Co., Ltd.). Exercise intensity was
133 controlled by cadence or load adjustment, which was self-selected by subjects to maintain
134 their heart rate at 60% of their maximum voluntary exercise capacity, calculated using the
135 Karvonen formula. Subjects increased their heart rate up to their target heart rate over the
136 first 3 min of pedaling, and maintained this target rate for 12 min. In the control condition,
137 subjects were required to lie prone on the bed for 15 min. Immediately after the post-
138 intervention measurement, a 3-min SS was performed at the final angle measured on the
139 dynamometer. The post-SS measurement was obtained at the end of the stretching period.
140 The time between the intervention and SS and that between the SS and post-SS
141 measurement was minimized to 45 s and 15 s, respectively.

142

143 Statistical Analysis

144 SPSS ver. 17 (IBM Japan Ltd.) was used for statistical analysis. A two-way
145 repeated-measures analysis of variance (ANOVA, condition × period) was used to evaluate
146 differences in final angle, muscle tendon unit stiffness, and passive knee joint torque at the
147 final angle. Differences were considered statistically significant at values of $P < 0.05$. When
148 a significant interaction or main effect of the condition was identified, the item was assessed
149 for significant differences using a t-test, with Bonferroni adjustment, as a post-hoc test. A
150 priori power analysis indicated that a sample size of 12 subjects for each group would be
151 required to obtain 80% power, if we estimated an F-statistic of 0.4 for a large effect size
152 with $\alpha=0.05$.

153

154

Results

155 Muscle Tendon Unit Stiffness

156 Two-way ANOVA identified no significant interaction effects between condition and
157 period ($P = 0.97$, $F = 0.14$) on muscle tendon unit stiffness, but did indicate a significant
158 main effect of period ($P < 0.05$). In all conditions, the post-hoc test for period indicated no
159 significant difference between pre- and post-intervention measurements ($P > 0.05$);
160 however, muscle tendon unit stiffness post-SS was significantly lower than post-intervention
161 ($P < 0.05$) (Table 1).

162

163 Final Angle

164 Two-way ANOVA indicated a significant interaction effect between condition and
165 period ($P = 0.03$, $F = 2.71$) on the final angle. In addition, a significant main effect of both
166 condition and period was identified ($P < 0.05$). Post-hoc testing of the period indicated post-
167 intervention final angle to be significantly larger than the angle measured pre-intervention,
168 for both the thermal agent and physical activity conditions ($P < 0.05$). In addition, the final
169 angle measured post-SS was significantly larger than the final angle measured post-
170 intervention for both thermal agent and physical activity ($P < 0.05$). For the control
171 condition, the final angle post-SS was significantly larger than the post-intervention angle (P
172 < 0.05), whereas no significant difference in final angle was identified between pre- and
173 post-intervention measures ($P > 0.05$). Post-hoc testing for the effect of condition indicated
174 that post-intervention final angles for both thermal agent and physical activity were
175 significantly larger than angles for the control condition ($P < 0.05$).

176

177 Passive Torque at the Final Angle

178 Two-way ANOVA indicated a significant interaction between condition and period (P
179 < 0.01 , $F = 5.98$) on passive torque at the final angle. In addition, a significant main effect

180 was identified for both condition and period ($P < 0.05$). Post-hoc testing of the period
181 indicated that the post-intervention passive torque at the final angle for the thermal agent
182 condition was significantly higher than the values measured in the pre-intervention ($P <$
183 0.05), and post-SS was significantly higher than post-intervention ($P < 0.05$). On the other
184 hand, for the physical activity condition, passive torque at the final angle was significantly
185 higher post-intervention than pre-intervention ($P < 0.05$), but there was no significant
186 difference between the post-intervention value and values measured post-SS ($P > 0.05$).
187 For the control condition, there was no significant difference between pre- and post-
188 intervention measures ($P > 0.05$). However, passive torque at the final angle post-SS was
189 significantly higher than at post-intervention ($P < 0.05$). Post-hoc testing of the condition
190 indicated that post-intervention measures of passive torque at the final angle for the thermal
191 agent and physical activity conditions were significantly higher than values for the control
192 condition ($P < 0.05$).

193

194

Discussion

195

196 This study had two objectives. The first was to compare the effect of thermal agent
197 and physical activity on hamstring muscle flexibility, using muscle tendon unit stiffness as
198 an outcome measure. The second was to examine whether thermal agent or physical
199 activity, performed before SS, was more effective at increasing hamstring muscle flexibility
200 than SS alone. To our knowledge, this is the first study to compare the effect of thermal
201 agent and physical activity interventions on muscle tendon unit stiffness, and their
202 combined effects with SS, on muscle tendon unit stiffness.

203

204 For both thermal agent and physical activity conditions, there were no significant

205 changes in muscle tendon unit stiffness measured pre- and post-intervention, in spite of
206 improvements in knee ROM for both interventions. The improvement in ROM is consistent
207 with previous studies having examined the effect of heat on muscle flexibility^{1, 2, 5, 7}. Our
208 study also indicated that there is no difference between thermal agent and physical activity
209 on either ROM or muscle stiffness, post-intervention. Demura et al. (2006) have shown that
210 heat and light exercise (bicycle ergometer) are equally effective and superior to placebo for
211 increasing ROM, which is consistent with our results for ROM. The absence of a significant
212 change in muscle tendon unit stiffness with either the thermal agent or physical activity
213 intervention is in agreement with results from Kubo et al. (2005), who reported that 30 min
214 of hot water immersion yielded no change in the mechanical property of the muscle and
215 tendon. Although *in vitro* studies^{14, 15} have indicated that flexibility can be increased by heat
216 stimulation, there seems to be discrepancy in soft tissue temperatures between these
217 studies and our study. In these studies, the soft tissue was warmed to about 45°C.
218 According to a previous *in vivo* study, which reported that a 15 min of hot pack can increase
219 the soft tissue to only 36–38°C¹⁶, the change in the soft tissue temperature in the thermal
220 agent condition in our study might have been much lower compared to the previous *in vitro*
221 studies, which may have produced different effects on muscle tendon unit stiffness.

222

223 The duration of applying thermal agent and physical activity intervention was set as
224 15 min, following a clinical standard and previous research. In previous research *in vivo*, the
225 application time of hot pack was set at about 15^{7, 16}-20¹ min. Draper et al (1998) described
226 that the application of a hot pack for 15 min raised the body temperature by 3.83 °C at a
227 depth of 1 cm and by 0.74 °C at a depth of 3 cm. Therefore, it is reasonable to assume that
228 the soft tissue temperature in this study was raised to the same extent. However, there is
229 an evident discrepancy in estimates of the tissue temperature attained between research *in*

230 *vivo* and *in vitro*, which could affect muscle tendon unit stiffness.

231

232 Regarding the combination of thermal agent and physical activity intervention with
233 SS, all three conditions, including the control, showed significant decreases in muscle
234 tendon unit stiffness after SS. Moreover, there were no differences between the three
235 conditions, indicating that the combination of thermal agent or physical activity with SS
236 might have no additional effect on muscle tendon unit stiffness compared to SS alone.
237 Again, knee joint ROM increased in all three conditions, compared to both pre- and post-
238 intervention measurements, and there were no significant differences between the three
239 intervention groups.

240

241 These results indicate that thermal agent and physical activity are both effective in
242 increasing joint ROM but not in altering muscle tendon unit stiffness. This indicates that
243 improvements in ROM are likely due to changes in sensory perception or stretch tolerance.
244 The combination of thermal agent and physical activity with SS had no advantage
245 compared to SS alone in improving either ROM or muscle tendon unit stiffness, which
246 contradicts our a priori hypothesis. The result from our study contradict findings in a
247 previous review evaluating the combination of heat modalities (hot pack, ultrasound and hot
248 water immersion, duration 8 to 20min) and stretching ⁸, which reported that the combination
249 of heat and stretching was superior to stretching alone. However, this contradiction in
250 findings seems reasonable when we consider that most of the studies included in this
251 review used ROM as a measure of joint flexibility, instead of muscle tendon unit stiffness as
252 used in our study.

253

254 We used the passive torque at the final angle during passive knee extension as the

255 index of stretch tolerance, with an increase in this index indicating alteration in subjects'
256 sensory perception of muscle elongation¹⁷⁻¹⁹. It is well known that muscle warming
257 modifies this sensory perception. In addition to muscle warming intervention, previous
258 studies have reported that SS provides a 'dulling' of this sensory perception, which may
259 indicate that centripetal input from the muscle and joint, resulting from SS, alters the input
260 from the nociceptive nerve endings and may increase the pain sensation threshold²⁰⁻²². In
261 this study, such changes in threshold may have interacted to increase the passive torque at
262 the final angle after muscle warming intervention and/or SS. The absence of an increase in
263 passive torque at final angle with combined physical activity and SS may be explained by a
264 ceiling effect of physical activity on the modulation of this pain mechanism, presuming that
265 pain threshold differ among intervention methods, and modification of sensation has an end
266 point. The effect of performing physical activity may have been large enough to reach the
267 end point that no additional effect was possible by adding SS. Considering these results,
268 the combined use of muscle warming and SS may have no additional effect on muscle
269 tendon unit stiffness measured by the passive torque at the final joint angle compared to SS
270 only. This theory is based on the hypothesis that modifying sensation has end point which
271 needs further inspection.

272

273 The limitation of this study is that we examined only one method of intervention for
274 both thermal agent and physical activity and only one duration for the heat application.
275 Therefore, it is unknown whether these results apply to other types of thermal agent and
276 physical activity interventions or to longer/shorter heat application times. In addition, there
277 are no data concerning tissue temperature in this study. Therefore, the effect of the
278 interventions on tissue temperature can only be assumed based on previous studies, which
279 used similar protocols. In addition, we did not examine any effects that may have occurred

280 in time after the intervention.

281

282 This result suggests that in the purpose of increasing flexibility, there is no additional

283 benefit on applying thermal agent or physical activity preceding SS in healthy subjects.

284 However, if the patient is too sensitive to perform SS adequately for some reason, it may be

285 a good solution to modify sensation by conducting these interventions prior to performing

286 SS. Similarly, in a situation where increasing ROM is the main aim, it may also be a good

287 solution to apply thermal interventions.

288

289

290

Conclusion

291

292 This study showed that, though thermal agents and physical activity are effective in

293 increasing ROM, this effect is due to change in sensory perception and not to change in

294 muscle tendon unit stiffness. Our results also indicate that performing thermal agent and

295 physical activity intervention prior to SS is not effective in augmenting the effect of

296 stretching, either in terms of ROM or muscle tendon unit stiffness. These findings might be

297 effective in clarifying the mechanism underlying increases in ROM change resulting from

298 thermal agent and physical activity interventions, and to clarify the effect and limit of thermal

299 agents, physical activity and stretching in clinical settings.

300

301

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302

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352

353

354 Table 1. Stiffness, final angle, and passive torque at the final angle

355

| | Stiffness (Nm/°) | | | Final Angle (°) | | | Passive Torque at the Final Angle (Nm) | | |
|-------------------|-------------------|-------------|------------------------------|------------------|--------------------------------|--------------------------------|--|-------------------------------|-------------------------------|
| | Pre | Post | Post-SS | Pre | Post | Post-SS | Pre | Post | Post-SS |
| Control | 1.18 ± 0.22 | 1.18 ± 0.23 | 0.92 ± 0.19 ^{*, ††} | 48.27 ± 11.29 | 44.39 ± 10.62 | 64.70 ± 9.68 ^{*, ††} | 45.12 ± 7.65 | 39.38 ± 4.91 | 52.72 ± 9.54 ^{*, ††} |
| Thermal Agent | 1.19 ± 0.16 | 1.22 ± 0.18 | 0.88 ± 0.26 ^{*, ††} | 49.48 ± 9.20 | 59.29 ± 12.15 ^{*, ††} | 72.49 ± 11.66 ^{*, ††} | 43.57 ± 7.27 | 51.95 ± 7.55 ^{*, ††} | 59.17 ± 8.96 ^{*, ††} |
| Physical Activity | 1.17 ± 0.19 | 1.19 ± 0.18 | 0.86 ± 0.13 ^{*, ††} | 47.11 ± 13.35 | 60.72 ± 9.84 ^{*, ††} | 72.14 ± 8.79 ^{*, ††} | 44.37 ± 7.03 | 56.05 ± 7.13 ^{*, ††} | 58.89 ± 9.38 ^{*, ††} |

Abbreviations: Pre, preintervention; Post, postintervention; SS, static stretching

*P < .05 versus pre.

**P < .01 versus pre.

†P < .05 versus postintervention.

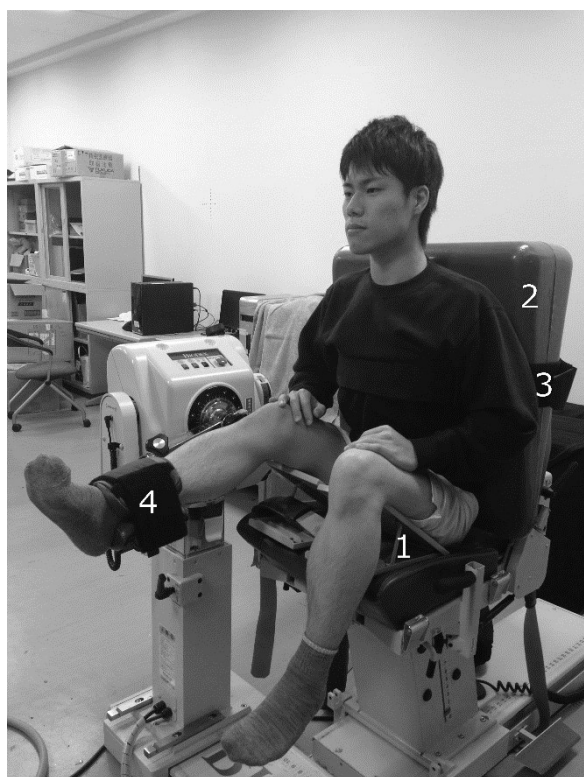
††P < .01 versus postintervention.

‡P < .01 versus control in the same period

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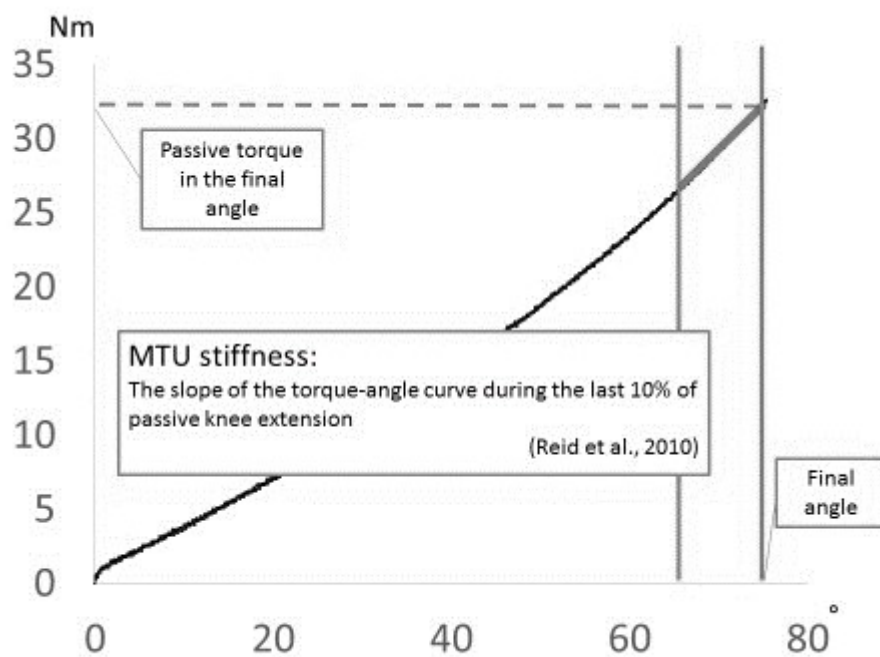
358 Figure1. Measurement position for stretch maneuver: (1) wedge under the thigh;
359 wedge-shaped cushion behind the back; (3) belt stabilizing the trunk; (4) attachment to the load
360 cell.



361

362

363 Figure2. Measurement indices used in this study showing passive torque during passive
364 extension of the knee.



365