Acute effects of anterior thigh foam rolling on hip angle, knee angle, and rectus femoris length in the modified Thomas test

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Background: Foam rolling has been shown to acutely increase range of motion (ROM) during knee flexion and hip flexion with the experimenter applying an external force, yet no study to date has measured hip extensibility as a result of foam rolling with controlled knee flexion and hip extension moments. The purpose of this study was to investigate the acute effects of foam rolling on hip extension, knee flexion, and rectus femoris length during the modified Thomas test.

Methods: Twenty-three healthy participants (male = 7; female = 16; age = 22 ± 3.3 years; height = 170 ± 9.18 cm; mass = 67.7 ± 14.9 kg) performed two, one-minute bouts of foam rolling applied to the anterior thigh. Hip extension and knee flexion were measured via motion capture before and after the foam rolling intervention, from which rectus femoris length was calculated.

Results: Although the increase in hip extension (change = +1.86º (+0.11, +3.61); $z(22)$ = 2.08; p = 0.0372; Pearson's r = 0.43 (0.02, 0.72)) was not due to chance alone, it cannot be said that the observed changes in knee flexion (change = -1.39º (-5.53, +2.75); $t(22)$ = -0.70; p = 0.4933; Cohen's d = -0.15 (-0.58, 0.29)) or rectus femoris length (change = -0.005 (-0.013, +0.003); $t(22)$ = -1.30; p = 0.2070; Cohen's d = -0.27 (-0.70, 0.16)) were not due to chance alone.

Conclusions: Although a small change in hip extension was observed, no changes in knee flexion or rectus femoris length were observed. From these data, it appears unlikely that foam rolling applied to the anterior thigh will improve hip extension and knee flexion ROM, especially if performed in combination with a dynamic stretching protocol.

1   **Acute effects of anterior thigh foam rolling on hip angle, knee angle, and rectus femoris**

2   **length in the modified Thomas test**

3   Running Head: FOAM ROLL

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Introduction

37

38   Foam rolling (FR) is a ubiquitous intervention, performed by athletes during both

39   preparation for and following physical activity. FR is postulated to be a form of self-myofascial

40   release, despite no research investigating whether FR directly influences fascia. Therefore, it is

41   perhaps presumptuous to refer to the fascia in its name, let alone as its mediator. For the

42   purposes of this study, FR and similar modalities, such as massage sticks, will be referred to as

43   self-manual therapy. Previous self-manual therapy and FR work has been shown to increase

44   range of motion (ROM) (Behara & Jacobson 2015; Halperin et al. 2014; Jay et al. 2014;

45   MacDonald et al. 2013; Schroeder & Best 2015; Škarabot et al. 2015; Sullivan et al. 2013),

46   attenuate delayed onset muscle soreness (DOMS) (Macdonald et al. 2014; Pearcey et al. 2014),

47   reduce arterial stiffness (Okamoto et al. 2013), and improve vascular endothelial function

48   (Okamoto et al. 2013). Importantly, FR has also been shown not to have detrimental effects on

49   physical performance (Behara & Jacobson 2015; Halperin et al. 2014; Healey et al. 2013;

50   MacDonald et al. 2013; Sullivan et al. 2013).

51   Quadriceps injuries are a commonplace in sport (Orchard & Seward 2002), and the rectus

52   femoris is the most commonly injured quadriceps muscle (Cross et al. 2003; Speer et al. 1992).

53   Risk factors for injury appear to be multifactorial (Mendiguchia et al. 2012). Of particular

54   interest are hip flexor strength and flexibility, as these can be modified through training and

55   warm-up (Mendiguchia et al. 2012). Should FR be an efficacious methodology for increasing

56   rectus femoris extensibility, it may allow athletes to train through a greater ROM. Training

57   through a greater ROM would allow athletes to not only see greater gains in strength throughout

58   a greater ROM, but also increase their total ROM (Hartmann et al. 2012; McMahon et al. 2014;

59   Morton et al. 2011; Wyon et al. 2013). Because both strength and flexibility are risk factors for

60   rectus femoris strain injury, doing so may reduce risk of injury (Mendiguchia et al. 2012).

61   The effectiveness of self-manual therapy in increasing ROM is of particular interest, as

62   flexibility appears to be a risk factor for muscle strain injury (Mendiguchia et al. 2012). As noted

63   by Schroeder & Best (2015), despite the heterogeneity of previous studies, FR does appear to be

64   an efficacious intervention for increasing flexibility. Only a couple of studies have investigated

65   the effects of self-manual therapy on hip flexor – namely, rectus femoris – extensibility, as

66   measured by either knee flexion or hip extension. The first to do so was MacDonald et al. (2013),

67   who found that two, one-minute bouts of FR applied to the anterior thigh increased knee flexion

68   ROM by 10º and 8º at 2 and 10 minutes post-intervention, respectively. More recently, Bushell

69   et al. (2015) investigated the effects of three, one-minute bouts of FR applied to the anterior

70   thigh on hip extension angle during a dynamic lunge. The intervention was completed once per

71   week for three weeks. The only increase in hip extension noted was during the second week; no

72   changes were found in the first or third weeks. Investigators did report a slight increase in hip

73   extension from the first to second week (3.7º vs. 0.34º (control)), but it cannot be said that this

74   increase was not due to chance alone. The effects of FR on static measures of hip extension, knee

75   flexion, and consequently, rectus femoris length have not yet been investigated. Therefore, the

76   purpose of this study was to investigate the effects of two, one-minute bouts of FR of the anterior

77   thigh on acute hip extension ROM, knee flexion ROM, and rectus femoris length. It was

78   hypothesized that FR of the anterior thigh will acutely increase hip extension ROM, knee flexion

79   ROM, and rectus femoris length.

80

81   **Methods**

82　*Study Design*

83　　　This study used a within-subject repeated measures design. Data was collected during

84　one experimental session. Hip extension and knee flexion were measured both before and after

85　one bout of FR, which was carried out by FR the hip flexor muscle group on the anterior thigh.

86　*Participants*

87　　　As per an *a priori* power analysis ($\alpha = 0.05$; $\beta = 0.80$; expected difference = 2.95°;

88　Cohen's *d* = 0.54) for an increase in hip extension using G*Power (Faul et al. 2007), 23

89　participants (male = 7; female = 16) were recruited from a student population via flyers placed

90　on a University campus and presented to Kinesiology and Exercise and Wellness classes.

91　Participants would have been excluded only if they currently had a back or lower extremity

92　musculoskeletal or neuromuscular injury or pain, but no participants reported such an injury.

93　Before each participant was scheduled for testing, the participants were asked about their current

94　injury status. Participants were provided a verbal explanation of the study, and read and signed

95　an Informed Consent and Physical Activity Readiness Questionnaire (PAR-Q) before beginning.

96　Any participant that would have answered "Yes" to any of the questions on the PAR-Q would

97　have been excluded, but none did. Participants' age, height, and weight were then measured. The

98　study was approved by the Institutional Review Board at Arizona State University (IRB ID:

99　STUDY00001660).

100　*Procedures*

101　　　A ten minute standardized warm up procedure followed. This warm up consisted of five

102　minutes on an Airdyne bike, two sets of 20 body weight squats, two sets of 10 leg swings in both

103　the frontal and sagittal planes, and two sets of 10 body weight lunges.

104   Once the aforementioned 10-minute warm-up was completed, reflective markers were

105   adhered to participants' skin or tight fitting garments on the lateral femoral epicondyle, greater

106   trochanter, lateral malleolus, and iliac crest, halfway between the PSIS and ASIS and spaced

107   10cm apart. These methods differ slightly from those presented by Kuo et al. (2008), as the PSIS

108   and ASIS markers were placed closer to the midaxillary line so they would not be blocked from

109   the camera by the table. Once placed, the markers were not removed until after the final (post-

110   FR) testing procedure. Should the participant's tight fitting garment have had any potential

111   marker distractions (e.g., reflective logos), they were covered with masking tape.

112   Participants then performed one FR intervention, utilizing a 91.44 (L) x 15.24 (D) cm

113   polypropylene foam roller (Perform Better, West Warwick, RI) directed at the right anterior

114   thigh for two, 60-second bouts. While lying prone, participants were instructed to place their

115   body weight on the foam roller, starting at the proximal aspect of the thigh (just inferior to the

116   ASIS) and rolling down the thigh in a kneading-like fashion, slowly reaching the knee (Figure

117   1). Once the foam roller reached the superior knee, participants were instructed to return the

118   roller to the starting position and continue the sequence for the remainder of the 60 seconds

119   (MacDonald et al. 2013). Participants were instructed to complete the intervention at a slow pace

120   (seconds/repetition). Following a thirty-second break, the participant repeated this intervention.

121

122   Figure 1 about here.

123

124   Within one minute of completing the second bout of FR, participants' hip extension and

125   knee flexion ROM were re-tested.

126

127   *Testing and Analysis*

128   Hip extension and knee flexion were measured as the participant performed the modified

129   Thomas test. Hip extension values were calculated by subtracting the four-point angles that the

130   four markers create from 90º. Knee flexion values were calculated by subtracting the three-point

131   angles that the three markers create from 180º. Two-dimensional sagittal plane motion capture

132   were obtained using a 120Hz camera, set to 30Hz (Basler Scout scA640-120, Basler Vision

133   Technologies, USA), and motion analysis software (MaxTRAQ 2D, Innovision Systems Inc.,

134   USA). Marker digitization was also completed in MaxTRAQ, using auto-digitization and auto-

135   tracking, as to prevent investigator bias. These methods (motion capture) differ substantially

136   from those previously described (Harvey 1998) in that the hip angle was measured relative to the

137   pelvis rather than the plinth (Figure 2). This prevented lumbopelvic movement from confounding

138   the results of the modified Thomas test, which can severely impact the test's reliability (Kim &

139   Ha 2015). Furthermore, measuring these angles via motion capture presumably allows for more

140   reliable and objective measures, as the same points are being utilized to calculate the angle with

141   each measurement trial. Doing so has demonstrated very high levels of reliability for knee

142   flexion (ICC = 0.98; SEM = 1.0º) (Peeler & Leiter 2013) and hip extension (ICC = 0.90–0.95;

143   SEM = 2.0º) (Wakefield et al. 2015). The average of three tests was used for each participant's

144   reported measure. Rectus femoris length was estimated using the regression equations and

145   coefficients provided by Hawkins & Hull (1989), and is presented relative to length at neutral

146   (that is, hip and knee at 0º) (Eq. 1); for example, 1.020 would represent a 2% increase from

147   resting length, or 102% of resting length. Similar methods and presentation of data were utilized

148   by Thelen et al. (2004) and Vigotsky et al. (2015).

149

150
$$l_{RF} = \frac{1.107 - \left(1.50 \cdot 10^{-3}\right)\theta_{hip} + \left(1.99 \cdot 10^{-3}\right)\theta_{knee}}{1.107}$$
(Eq. 1)

151

152   Figure 2 about here.

153

154

155   The averages of the three pre- and post-FR measures of hip extension ROM, knee flexion

156   ROM, and calculated rectus femoris length were entered into Stata 13 (StataCorp, LP, College

157   Town, TX). Shapiro-Wilk tests were performed to ensure normality. For normal data, paired

158   samples *t*-tests were performed. Any data found to be non-parametric were compared using

159   Wilcoxon paired-samples signed-rank tests. Alpha was set to 0.05. Parametric effect sizes (ES)

160   were calculated by Cohen's *d* using the formula $d = \frac{M_d}{s_d}$, where M_d is mean difference and s_d is

161   the standard deviation of differences (Becker 1988; Morris 2007; Smith & Beretvas 2009). This

162   method is slightly different than the traditional method of calculating Cohen's *d*, as it calculates

163   the within-subject effect-size rather than group or between-subject effect sizes. Cohen's *d* was

164   defined as small, medium, and large for 0.20, 0.50, and 0.80, respectively (Cohen 1988). Non-

165   parametric ES were reported in terms of Pearson's *r*. Pearson's *r* was defined as small, medium,

166   and large for 0.10, 0.30, and 0.50, respectively (Cohen 1988). 95% confidence limits (95% CL)

167   for effect sizes were also calculated. Because a small number of preplanned comparisons were

168   made, no correction was employed.

169

170   **Results**

171   Twenty-three healthy participants (Table 1) were recruited and underwent two, 1-minute

172   bouts of FR the anterior thigh. Measures of hip extension did not meet parametric assumptions,

173   but knee flexion and rectus femoris length did. Although the increase in hip extension (change =

174   +1.86º (+0.11, +3.61); $z(22) = 2.08$; $p = 0.0372$; Pearson's $r = 0.43$ (0.02, 0.72)) was not due to

175   chance alone, it cannot be said that the observed changes in knee flexion (change = -1.39º (-5.53,

176   +2.75); $t(22) = -0.70$; $p = 0.4933$; Cohen's $d = -0.15$ (-0.58, 0.29)) or rectus femoris length

177   (change = -0.005 (-0.013, +0.003); $t(22) = -1.30$; $p = 0.2070$; Cohen's $d = -0.27$ (-0.70, 0.16))

178   were not due to chance alone (Table 2).

179

180   Table 1 about here.

181

182   Table 2 about here.

183

184   **Discussion**

185   The purpose of this study was to determine if FR applied to the anterior thigh increases

186   hip extension, knee flexion, and rectus femoris length during the modified Thomas test. It

187   appears that the moderate to large effect observed for hip extension was not due to chance alone.

188   However, it cannot be said for certain that this increase was not at the expense of a decrease in

189   knee flexion, especially since no real change in rectus femoris length was observed. Although

190   prior research would consider the observed increase in hip extension to be clinically relevant – as

191   the observed 45.24% increase in hip extension exceeds the 10% threshold (Roach & Miles 1991)

192   – one cannot truly compute a relative change of joint kinematics, as joint angles are an interval

193   scale, and not ratio scale (O'Donoghue 2014). Additionally, and perhaps more importantly, the

194   increase in hip extension did not exceed the previously-reported SEM of 2.0° (Wakefield et al.

195   2015), implying that the mean change observed in this trial would not be clinically detectable

196   within or between individuals.

197   Of interest is the inter-individual variability to the FR intervention, as there were

198   responders, non-responders, and even decreases in rectus femoris length observed in individuals

199   (Table 2). For example, participant #1's rectus femoris length increased by 3.9%, while

200   participant #23's rectus femoris length decreased by 3.1%, and participant #11 nearly did not

201   experience any change (-0.1%). Furthermore, those who had similar changes in rectus femoris

202   length did not necessarily experience those changes from the same place; participant #22

203   experienced a large increase in hip extension with a decrease in knee flexion, while participant

204   #23 experienced a small increase in hip extension and a large decrease in knee flexion, but both

205   participants saw similar decreases in rectus femoris length (-0.029 and -0.031, respectively).

206   Interestingly, there did not appear to be differences in responses between genders (Table 2).

207   These results differ slightly from MacDonald et al. (2013), who found an increase in knee

208   flexion with the hip fixed in extension. However, it should be noted that MacDonald and

209   colleagues' ROM testing utilized a less objective protocol because the participants' passive range

210   of movement was measured while the experimenter actively applied a force to flex their knee.

211   Our protocol involved two 1-minute bouts FR on the anterior thigh, which was identical

212   to the dosage investigated by both MacDonald et al. (2013) and Markovic (2015), who each

213   assessed changes in knee flexion angle following FR of the anterior thigh and reported

214   significant increases. However, it was smaller than the dosage assessed by Bushell et al. (2015),

215   who investigated changes in hip extension angle during a lunge movement following three 1-

216   minute bouts of FR on the anterior thigh and reported significant increases. Given that our

217   protocol involved dosages at the lower end of what has previously been utilized in the literature,

218   it is possible that it could potentially have been insufficient to bring about changes in flexibility.

219   However, since similar protocols have reported increases in flexibility and since no previous trial

220   has yet identified a dose-response effect following self-manual therapy (Bradbury-Squires et al.

221   2015; Sullivan et al. 2013), this would seem unlikely. Furthermore, several other trials making

222   use of smaller dosages of FR, albeit in other muscle groups, have all reported significant

223   increases in flexibility (Halperin et al. 2014; Škarabot et al. 2015; Sullivan et al. 2013). Together,

224   these factors suggest that the dosage used in our protocol was likely sufficient.

225   The only external force applied to the thigh, resulting in a hip extension moment, was the

226   weight of the participants' lower extremity. Also, since the setup for the modified Thomas test is

227   nearly identical each time, the moment arm about each segment (thigh and leg) is likely similar

228   on each setup. However, it is possible that these moment arms change depending on the

229   compliancy of the rectus femoris. The constant external force and presumably moment arm, and

230   thus external hip extension moment, may provide insight into the mechanisms of self-manual

231   therapy. If FR's effectiveness is a result of an increase in tissue extensibility, an increase in

232   muscle-tendon unit length (with a related decrease in tissue stiffness) with the same applied

233   moment would have been observed due to a shift in the length-tension curve (Weppler &

234   Magnusson 2010). However, a similar applied moment alone was not enough to elicit observable

235   changes in rectus femoris length. Following these outcomes, it is proposed that self-manual

236   therapy may work through an increase in stretch tolerance rather than an increase in tissue

237   length, as an increase in tissue length or decreased stiffness would have resulted in increased

238   rectus femoris length with the same applied tension. This is certainly possible, as potential

239   mechanisms for manual therapy have been described to be primarily neurophysiological in

240   nature (Bialosky et al. 2009). Recently, Eriksson Crommert et al. (2014) described similar effects

241 after a seven-minute massage; a decrease in muscle stiffness, measured via elastography, was

242 observed immediately following intervention, but there was no observed effect at three minutes.

243 These findings are similar to ours, in that no changes in stiffness were observed shortly following

244 intervention. This warrants further research utilizing dynamometry, elastography, or similar

245 methods to measure passive joint or muscle stiffness before and following a FR protocol.

246   The mechanism by which FR of the anterior thigh increases flexibility at the hip or knee

247 might inform an understanding of similar interventions intended to reduce rectus femoris strain

248 injury risk. Reviewing rectus femoris strain injury in soccer, Mendiguchia et al. (2012) suggested

249 that the reduced capacity for using the stretch-shortening cycle during the kicking action that

250 might follow from less hip extension ROM, resulting from less hip flexor extensibility, could be

251 key for an increased risk of strain injury. Reduced capacity for using the stretch-shortening cycle

252 could require the rectus femoris to produce more muscle force for each kicking action, thereby

253 increasing the rate of fatigue and consequently the risk of injury. It has been suggested that

254 increasing muscle compliance could reduce muscle strain injury risk in the stretch-shortening

255 cycle in general by enhancing the ability of the muscle-tendon unit to store energy (Witvrouw et

256 al. 2004). Similarly, it has been argued that since strain injuries occur in stretch (Mendiguchia et

257 al. 2012), a stiffer, less flexible muscle might be less likely to incur a strain injury than a

258 compliant one (Gleim & McHugh 1997; Noonan & Garrett 1999; Safran et al. 1989). Since the

259 findings of our investigation indicate that FR might exert its effects through an increase in stretch

260 tolerance rather than biomechanical mechanisms (as no change in muscle length was observed

261 and the test did not require additional tension) an increase in flexibility following FR may not

262 provide the purported benefits that could reduce rectus femoris strain injury risk through

263 increases in muscle compliance.

264   Several limitations should be noted in relation to this study. First, of worthy mention is

265   the warm-up participants endured during this study, which was assumed to more closely mimic

266   the warm-up that athletes would typically undergo. The warm-up protocol employed was longer

267   than that of MacDonald et al. (2013), who only had participants perform five minutes on a cycle

268   ergometer. It is possible that the participants in our study had already maximized the potential

269   acute rectus femoris extensibility gains before testing began (O'Sullivan et al. 2009), especially

270   since it been shown that FR and dynamic stretching may elicit similar gains in hip flexion ROM

271   (Behara & Jacobson 2015). Therefore, the extensive warm-up protocol must be taken into

272   account when interpreting these results. Second, the pace at which participants completed the FR

273   intervention was not recorded, and this might have had an effect on individual outcomes (i.e.,

274   pace-dependent outcomes). Thirdly, the only external force applied to the thigh, resulting in a hip

275   extension moment, was the weight of the participants' lower extremity. Therefore, it is difficult

276   to form conclusions as to whether FR of the anterior thigh would allow a patient or athlete to

277   move through a greater ROM, as the external moment of force during exercise may allow the

278   athlete to increase his or her ROM.

279

280   **Conclusions**

281   Although a small change in hip extension was observed, no changes in knee flexion or

282   rectus femoris length were observed. From these data, it appears unlikely that FR applied to the

283   anterior thigh will improve passive hip extension and knee flexion ROM, especially if performed

284   in combination with a dynamic stretching protocol.

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Starting (A) and ending (B) position of the foam roll protocol.

Figure 2(on next page)

Hip and knee joint calculations.

The illustrated participant would have a hip extension angle of 8.1º (98.1º−90º) and a knee flexion angle of 53.2º (180º−126.8º). Illustration credit: Ji Sung Kim
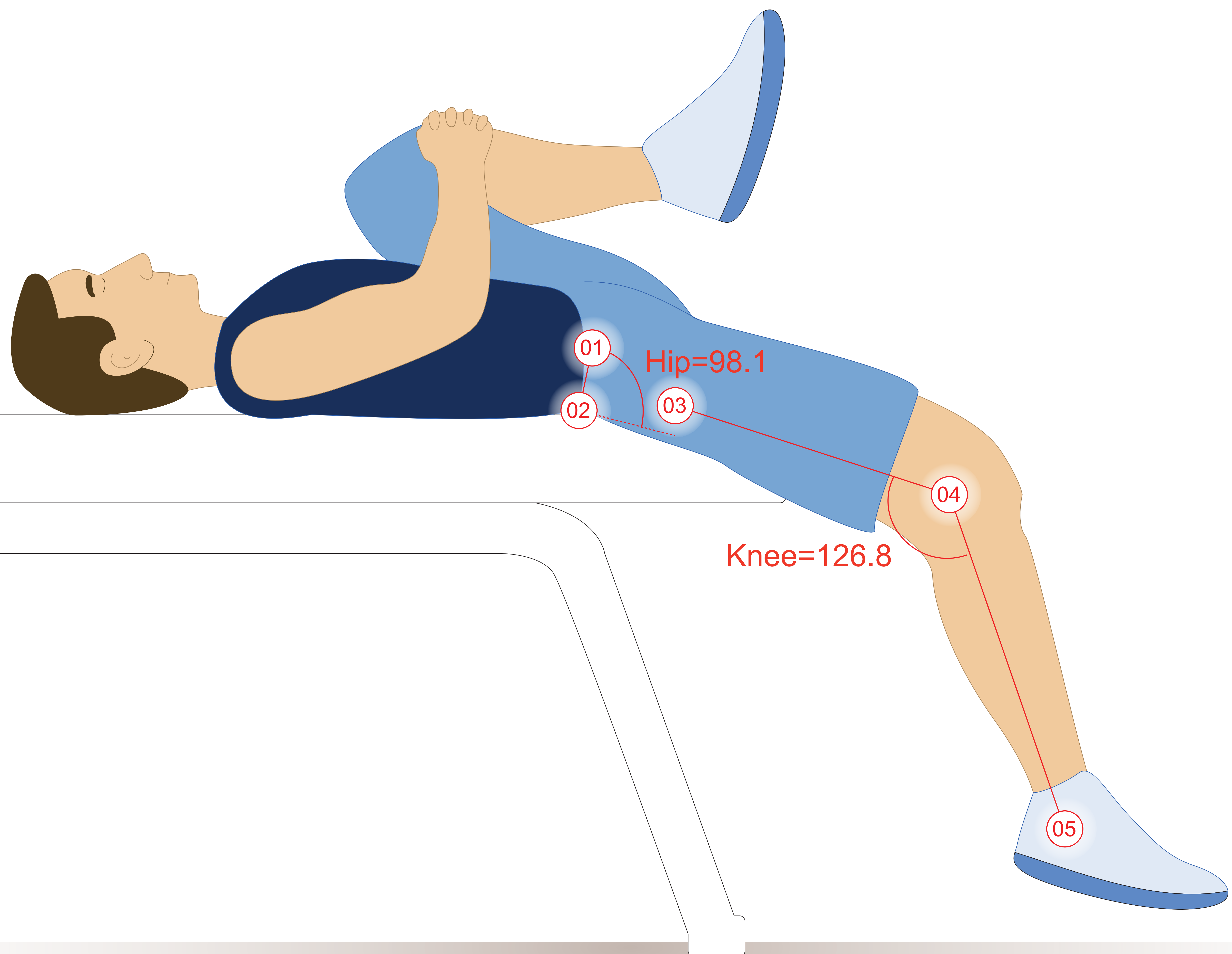
Table 1(on next page)

Descriptive statistics of participants.

1

2 **Table 1.** Descriptive statistics of participants

Sex	n	Age (years)	Height (cm)	Body mass (kg)
Male	7	21.00 ± 1.63	179.54 ± 6.90	83.24 ± 11.25
Female	16	22.06 ± 3.84	165.74 ± 6.53	60.91 ± 10.64
Total	23	22.00 ± 3.30	169.95 ± 9.18	67.71 ± 14.90

3

Table 2(on next page)

Individual and mean (± SD) changes in hip extension ROM, knee flexion ROM, and calculated rectus femoris length pre- and post-FR.

1   **Table 2.** Individual and mean (± SD) changes in hip extension, knee flexion, and calculated rectus femoris length pre- and post-FR.

	Sex	Hip extension (º)			Knee flexion (º)			Rectus femoris length		
		Pre-	Post-	Δ	Pre-	Post-	Δ	Pre-	Post-	Δ
1	M	17.0	16.5	-0.5	40.9	62.5	21.6	1.051	1.090	0.039
2	F	-4.5	-6.7	-2.1	48.1	58.9	10.8	1.093	1.115	0.022
3	F	8.9	10.1	1.2	53.5	62.7	9.2	1.084	1.099	0.015
4	M	4.0	4.5	0.4	49.4	57.8	8.4	1.083	1.098	0.015
5	F	-1.1	0.9	2.0	24.8	33.2	8.4	1.046	1.059	0.012
6	M	20.5	18.6	-1.8	47.6	51.1	3.5	1.058	1.067	0.009
7	F	-3.6	-1.7	1.9	53.4	59.5	6.1	1.101	1.109	0.008
8	F	16.3	17.2	0.9	50.6	53.1	2.5	1.069	1.072	0.003
9	F	10.2	10.4	0.2	53.4	55.2	1.8	1.082	1.085	0.003
10	F	12.1	14.9	2.7	55.9	59.2	3.3	1.084	1.086	0.002
11	M	-5.5	-6.1	-0.6	49.1	48.0	-1.1	1.096	1.094	-0.001
12	F	-5.3	-9.8	-4.5	64.7	57.0	-7.7	1.124	1.116	-0.008
13	F	10.8	13.0	2.2	58.6	54.5	-4.1	1.091	1.080	-0.010
14	F	2.7	1.8	-0.9	49.9	43.8	-6.1	1.086	1.076	-0.010
15	M	-3.1	4.0	7.2	49.1	48.5	-0.6	1.093	1.082	-0.011
16	F	5.2	8.6	3.4	53.6	45.2	-8.4	1.089	1.070	-0.020
17	F	2.7	5.0	2.3	58.3	47.4	-11.0	1.101	1.078	-0.023
18	F	5.3	5.8	0.5	57.6	45.1	-12.5	1.096	1.073	-0.023
19	M	-4.5	4.8	9.4	39.2	32.4	-6.8	1.077	1.052	-0.025
20	F	3.6	1.2	-2.5	55.0	38.8	-16.2	1.094	1.068	-0.026
21	F	9.2	13.8	4.6	59.2	46.9	-12.3	1.094	1.066	-0.028
22	M	-3.5	10.6	14.0	55.6	49.9	-5.7	1.105	1.075	-0.029
23	F	-0.6	2.2	2.9	56.0	40.8	-15.2	1.102	1.070	-0.031
$\bar{x}$		4.2 ± 7.8	6.1 ± 7.8	1.9 ± 4.0	51.5 ± 8.2	50.1 ± 8.7	-1.4 ± 9.6	1.087 ± 0.018	1.082 ± 0.017	-0.005 ± 0.019