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1 **Timing of resistance training during Ramadan fasting and its**
2 **effects on muscle strength and hypertrophy**

3 Submission type: *Original Investigation*

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36 **Purpose:** During Ramadan month Muslims often continue training to maintain their
37 muscle performance. However, trainers should stress the importance of the time of day
38 chosen for practicing resistance training (RT) during the Ramadan fasting (RF) to
39 avoid health and performance alteration. Thus, this study aimed to investigate the
40 effects of the timing of resistance training (RT) while fasting during Ramadan
41 intermittent fasting (RIF) on muscle strength and hypertrophy in healthy male adults.

42 **Methods:** Forty healthy Muslim males were randomly allocated to two matched
43 groups: 20 practicing whole-body RT in the late afternoon in a fasted state (FAST) and
44 20 training in the late evening in a fed state (FED). Both groups performed 4 days/wk
45 of whole-body RT (~75–85% 1RM, 12 repetitions/ 3-4 set) during RIF.

46 Anthropometric measurements, a one-repetition maximum test for the squats ($1RM_{SQ}$),
47 deadlift ($1RM_{DL}$), and bench press ($1RM_{BP}$) were measured. Cross-sectional area
48 (CSA) of the quadriceps and biceps brachii were examined using ultrasound scans. All
49 measurements were taken at four time points: 24 h before the start of Ramadan (T0),
50 on the 15th day of Ramadan (T1), on the 29th day of Ramadan (T2) and 21 days after
51 Ramadan (T3).

52 **Results:** Post-hoc tests indicated significant pre-to-post improvements in FED at T2 for
53 $1RM_{SQ}$ ($p = 0.02$; $ES = 0.21$) and $1RM_{DL}$ ($p = 0.03$; $ES = 0.24$) when compared to T0. No
54 significant changes were observed in the FAST group and for CSA for both groups.

55 **Conclusions:** Practicing RT during RIF appears not to have adverse effects on muscle
56 hypertrophy and strength no matter whether it is practiced in FED or FAST state.
57 However, RT had greater effects on muscle strength when applied in FED state. Our
58 findings suggest that training sessions should be scheduled after breaking the fast-during
59 Ramadan.

60 **Keywords:** Fasting, Ramadan, Exercise training, strength, hypertrophy.

61

Introduction

Ramadan fasting is an Islamic religious obligation requiring healthy pubertal Muslim adolescents and adults to fast from dawn to sunset for approximately 28–30 consecutive days¹. This fasting involves abstaining from food, fluid intake, engaging in sexual activities and smoking for ~12–20 h/day, depending on the geographic location and season of the year².

Changes in mealtimes and the consumption of food and drink is unrestricted only during the hours of darkness³. Caloric restriction during the Ramadan intermittent fasting (RIF) decreases total cholesterol, low-density lipoprotein (LDL), fasting blood glucose levels⁴, and also improves body composition (e.g., lower body fat and higher lean body mass)⁵, possibly by mobilizing saturated fatty acids for metabolic processes.⁷ However, reductions in total energy and water intake, less daily meals (from 3–4 to 2 meals--a late evening meal and/or an early breakfast) and changes in diet composition can induce acute diurnal dehydration⁸, impair sleep quality^{9,10}, reduce total protein synthesis¹¹, and create low energy availability.¹² These changes in terms of food intake and sleep can impact on physiological and psychological functions and may specifically impose major challenges for Muslim athletes who continue training and competitions while fasting³.

Abstaining from eating and drinking for many hours before and during exercise can decrease the availability and utilization of energetic substrates and also cause changes in hormonal and metabolic responses in parallel with dehydration.^{13,14} In addition, sleep deprivation and feelings of malaise, increases in fatigue and perceived efforts in response to the same training volume compared to the non-Ramadan period.^{15,16} Most athletes, experience RIF with a limited loss of physical performance during aerobic^{17,18} and anaerobic exercises.^{19,20}

Resistance training (RT) is an exercise modality commonly used to improve muscular fitness (i.e., muscle strength, power, local muscle endurance) as well as motor skill development in various types of sports including soccer²¹ and martial arts.²² It has further become an increasingly popular mode of physical exercise designed to improve body image and self-rated physical attractiveness by stimulating muscular fitness and muscle cross-sectional area (CSA).^{23,25} Studies of the combined effects of RIF and RT on body composition, muscle hypertrophy and physiological adaptation have produced contradictory findings.^{26,28} For example, while muscle strength and power increased significantly in soccer players after resistance training (8-repetitions × 4-sets with 4-min recovery in between) during Ramadan²⁹, an absence of changes in body mass and body

96 composition have been reported for bodybuilders.³⁰ Moreover, body mass and physical
97 performance declined in male Senegalese runners decreased after RT due to
98 hypoglycemia associated with RIF.³¹

99 These findings suggest that strength and conditioning specialists should choose an
100 appropriate training period to minimize performance degradation and improve / maintain
101 physical outcomes associated with RIF. Some investigators suggest training would be
102 more beneficial after breaking fast (usually 2–3 h after sunset) to prevent dehydration,
103 hypoglycemia and possible decreases in performance^{32,33}, while other studies suggest
104 that training should take place while fasting to improve sleep quality and prevent
105 hormonal disturbances that can alter performance and muscle growth.³⁴

106 Due to contrasting opinions on the timing of RT during RIF, we investigated the
107 effects of RT on strength and muscle hypertrophy in both fasted (training before breaking
108 fast) and fed states (training after breaking fast). We hypothesized that a) RT can be
109 safely practiced during Ramadan in both fed and fasted states while maintaining muscle
110 strength and hypertrophy, and b) there are larger increases in muscle strength and
111 hypertrophy when training in the fed compared with the fasted state.

113 **Materials and methods**

114 **Participants**

115 Forty healthy Muslim recreational males weight lifters volunteered to participate
116 in this study (age= 25.7±5.6 y, mass= 85.1±17.5 kg, height= 175.3±8.9 cm, body-mass-
117 index [BMI]= 28.3±5.7 kg/m²) and were randomly allocated to two groups: 1) Fasted
118 state group (FAST, n=20) practicing RT in the late afternoon 1 hour before breaking fast
119 (between 16h and 18h), and 2) a fed state group (FED, n=20) practicing RT in the late
120 evening after breaking the fast (between 20h and 22h). The study inclusion criteria were
121 healthy males aged 18 to 35 years, two years of RT experience, free from any injuries
122 that could impede or hinder the movements performed, no current or history of
123 cardiometabolic disease, no consumption of supplements other than those provided
124 during the study (*see below*), and self-reported as not having previously used anabolic
125 steroids or related-ergogenic aids. The participants were required to refrain from other
126 non-experimental RT sessions during the study. Participant who did not meet the
127 inclusion criteria was excluded.

128 All participants were informed of the purpose of the study, the experimental
129 procedures, possible discomforts, risks, and benefits of the participation and then signed
130 a written informed consent to participate in the study. The investigation was performed
131 according to the principles outlined in the Declaration of Helsinki and was approved by
132 the local University Ethics Committee on Human Research of the University of la
133 Manouba, Tunisia (Ethics Code: Tn, UM2019-73).

134 **Design**

135 Ramadan began on March 3rd and ended on April 3rd, 2021, with an average duration
136 of the fast being ~ 14 h/d. The study was conducted in Tunisia, where daytime
137 temperatures were $23\pm 4^\circ\text{C}$ and relative humidity was $65\pm 5\%$. Two weeks before the
138 start of Ramadan fasting, volunteers visited the laboratory on three days separated by
139 intervals of 48–72h between visits.

140 Visit 1: Participants signed an informed consent form, answered the physical
141 activity readiness questionnaire (PAR-Q) and the Pittsburgh Sleep Quality Index (PSQI),
142 underwent anthropometric measurements and one repetition maximum (1RM) tests.

143 Visit 2: Participants repeated the 1RM tests to determine the loads to be used for
144 the experimental conditions and to assess the reproducibility of the tests.

145 Visit 3: Ultrasound images were recorded to determine the CSAs of the quadriceps
146 muscle and biceps brachii muscle.

147 After the baseline assessment (T0), all tests (anthropometrics, 1RM, CSAs, PSQI)
148 were conducted on three separate test occasions: during the 2nd week of Ramadan (T1),
149 during the 4th week of Ramadan (T2), and 21 days after the end of Ramadan (T3), with
150 the same order and the same separated days as the previous pre-test procedures (**Figure**
151 **1**).

152 **< ADD FIG 1 NEAR HERE >**

153 **Training program**

154 All participants trained four days per week (Monday, Tuesday, Thursday, and Friday)
155 for 8-weeks (one week before Ramadan, 4 weeks during Ramadan and 3 weeks after the
156 end of Ramadan). Training involved full body RT exercises of 45 to 60 min per session.
157 The exercise sessions of FAST occurred in the late afternoon during Ramadan (between
158 16h and 18h) and those for the FED occurred in the evening (between 20h and 22h) a 1–

159 2 hours after breaking the fast. All sessions started with a general warm-up and cool-
160 down periods of 5–10 min of low-intensity aerobic and dynamic stretching exercises.

161 Five RT exercises were performed in each session, each consisting of four sets.
162 Time under tension was 2 s in concentric mode and 2 s in eccentric mode at an intensity
163 of 75–85% of the 1RM. Two minutes of rest were granted between sets and exercises.
164 Each protocol was repeated twice weekly (Mondays/Thursdays: inclined leg press,
165 parallel squat, deadlifts, calf raise and cable crunches, and Tuesdays/Fridays: bench
166 press, shoulder press, lateral pull-down, barbell curl and obliques raises).

167 During the first session of each intervention week, 1RM tests were performed for
168 all exercises to ensure a relative exercise intensity of 75–85% 1RM throughout the eight
169 weeks of training. The 1RM test and the start of the training session was separated by a
170 10-minute rest interval.

171 Training protocols were started by performing 3 sets of 12 repetitions at 75% of
172 the 1RM during the first week and progressed to 85% of the 1RM during week 6. This
173 progressive overload was monitored by a trained researcher who supervised each
174 workout session to ensure exercises were performed with the correct technique during
175 the concentric and eccentric phases of the movement. The trained researcher also
176 recorded the compliance and individual workout data during each training session so that
177 exercise prescriptions were properly administered (e.g., number of repetitions and sets,
178 rest, velocity of movement, intensity, respiration).

179 **Anthropometric measurements**

180 Body composition was assessed following an overnight fast (12 h) and >72 h following
181 their last exercise bouts at T0, T1, T2 and T3. Body mass was measured to the nearest
182 10 g using a calibrated electronic scale (MEDISANA®, Neuss, Germany), body height
183 was measured to the nearest 5 mm using a stadiometer. BMI was then calculated. In
184 addition, four skinfolds (biceps, triceps, subscapular and suprailium) were measured
185 with a calibrated Harpenden skinfold (Baty International. England) for the evaluation of
186 body fat percentage using a previously published algorithm.³⁵ Lean body mass (LBM)
187 was calculated as body mass minus body fat mass. All measurements were performed
188 by a single evaluator who was experienced in each of the procedures.

189 **Maximum strength tests**

190 Maximum strength (1-RM tests for parallel squat, bench press and deadlift) was
191 performed at T0, T1, T2 and T3 and before the first weekly training session to maintain
192 the relative intensity of each exercise. Participants completed 1RM testing using inclined
193 leg press (Hammer Strength, China), Smith machine squat (Hammer Strength, China),
194 standing calf raise machine (Hammer Strength, China), cable crunches (Hammer
195 Strength, China), machine-guided shoulder press (Hammer Strength, China), pulldown
196 machine (Hammer Strength, China), deadlifts, barbell bench press and barbell curl using
197 a 20 kg Olympic barbell with free-weights.

198 Participants performed 10 repetitions without any extra load on the equipment as
199 described by others.^{36,37} Values for 1RM were determined in a concentric mode with a
200 maximum of 6 attempts, with 5-minutes rest periods between each attempt.³⁷ In addition,
201 a 3-minute rest period was allowed between tests of each exercise.

202 Pilot data were obtained on two test days from 40 participants to determine the
203 reproducibility of the test. Our reliability data revealed the following ICCs at 95%: 1-
204 RM parallel squat (0.929; lower 0.929-upper 0.996), 1-RM bench press (0.779; lower
205 0.581-upper 0.883), 1-RM deadlift (0.886; lower 0.783-upper 0.940), 1-RM CSA
206 quadriceps (0.967; lower 0.938-upper 0.983) and 1-RM CSA biceps (0.782; lower 0.587-
207 upper 0.885).

208 **Muscle cross-sectional areas (CSAs)**

209
210 Ultrasound images were recorded on four different occasions (before Ramadan (T0), on
211 the 15th day of Ramadan (T1), on the 29th day of Ramadan (T2) and 21 days after the end
212 of Ramadan) to analyze the CSA of the quadriceps and biceps brachii muscle. Ultrasound
213 scans were performed using a brightness mode (B-mode) imaging device (Esaote,
214 MyLabTMX8, Florence, Italy) with a multifrequency linear-array probe (4-15 MHz, 60-
215 mm width) using extended-field-of-view mode (EFVO).

216 CSA images of the quadriceps were taken using the EFOV mode.³⁸ Volunteers
217 remained lying in dorsal decubitus position on a stretcher for 15 minutes to allow fluid
218 shifts to stabilize before images were obtained.³⁹ A line from the greater trochanter to
219 the outer femoral condyle was marked to measure the length of the femur. Four axial
220 perpendicular lines were then marked, starting from the proximal extremity at intervals
221 of 20% (proximal), 40% (proximal-middle), 60% (distal-middle) and 80% (distal) of the
222 femur length using a tape measure and a pachymeter positioned parallel to the thigh

223 *(Figure 2A)*. Lines created with a microporous adhesive tape were then positioned 2 cm
224 from each of the four axial perpendicular points to delineate the location for positioning
225 of the ultrasound probe during image acquisition *(Figure 2B)*. It is important to note that
226 CSA measured at a single point on a muscle's length may not adequately represent the
227 entire extent of muscle hypertrophy, thus, CSA analysis using several points provide a
228 more accurate depiction of muscle hypertrophy.⁴⁰

229 <ADD FIGURE 2A NEAR HERE>

230 <ADD FIGURE 2B NEAR HERE>

231

232 The probe was placed transversely on the marked lines across the thigh to allow
233 for a continuous single view, while the mediolateral angle of the probe was changed
234 throughout the experiment so that the probe remained perpendicular to the skin *(Figure*
235 *2C)*.⁴¹ This procedure was performed at constant speed and lasted approximately 4 s in
236 distal regions to approximately 5 s in proximal regions according to the thigh
237 circumference of the participants.

238

239 <ADD FIGURE 2C NEAR HERE>

240

241 A water-based gel was applied between the skin and the transducer to achieve
242 acoustic coupling and avoid any misinterpretation of the images created by the increased
243 pressure when applying the transducer. Participants were asked to remain relaxed during
244 the ultrasound procedures. The panoramic images of the four sits that were created by
245 the moving transducer were digitally stored *(Figure 3)*. Images were analyzed for muscle
246 thickness, fascicle angle, and fascicle length by using specific software (MyLab™Desk,
247 Esaote, Italy).

248

249 <ADD FIGURE 3 NEAR HERE>

250

251 The sum of 4 images of the CSAs were taken at 20, 40, 60, and 80% of femur
252 length on the test day and used to generate a single CSA value per muscle, which was
253 then used for determining the thickness of the rectus femoris and vastus lateralis muscles.

254 The CSA of the biceps brachii was also measured by the EFOV technique with the
255 same device and on the same testing day when images of the quadriceps (T0, T1, T2 and
256 T3) were obtained.⁴² Each individual was seated in a comfortable position with arms
257 resting at 90° shoulder flexion angle, and 0° elbow flexion (i.e., straight arm). A line
258 from the acromion process of the clavicle to the lateral epicondyle of the humerus was
259 marked to measure the length of the upper arm. Two axial perpendicular lines were
260 marked (mid-point of the upper arm: 0 cm, 3 cm below the mid-point: 3 cm) as these
261 two regions provide the largest biceps brachii CSA that generally lies between the two
262 perpendicular markings.

263 EFOV scans were obtained by moving the probe along the two marked lines axially
264 from the medial aspect to the lateral aspect of the upper arm in a continuous single view.
265 Pressure was applied minimally but consistently, avoiding compression of the muscle,
266 with transmission gel applied between the skin and the transducer to aid in acoustic
267 coupling. Images of the biceps brachii taken from each region were traced to calculate
268 CSA using a computer software program (MyLab™Desk, Esaote, Italy).

269 The sum of the two CSAs taken at mid-point of the upper arm was calculated on
270 each testing day at the mid-point of the upper arm: 0 cm, 3 cm below the mid-point: 3
271 cm to generate a single CSA value per muscle, which was then used for data analysis of
272 the biceps brachii muscle thickness.

273 **Dietary habits**

274 Participants were advised to maintain instructed nutritional regimen by a specialist and
275 to avoid taking any supplements other than those provided during the study (*see below*).
276 Dietary adherence was assessed by self-reported food records and analyzed using a
277 nutritional tracking application (<http://www.myfitnesspal.com>) and the food-
278 composition tables of the National Institute of Statistics of Tunis (1978). All food and
279 beverages consumed during the experiment were collected for at least four days a week
280 to offer a reliable estimate of food intake for the entire week. Total water intake was
281 defined as the fluid volume of consumed beverages plus the water content of consumed
282 foods.

283 Individuals were instructed on the correct recording procedures of all food items,
284 including portion sizes. Each item of food was individually entered into the software
285 program to determine total energy consumption, and amount of energy derived from
286 proteins, fats, and carbohydrates for each period analyzed. The mean of nutrient
287 consumed during the intervention was calculated.⁴³ Participants consumed a supplement
288 containing 24 g protein and 1 g carbohydrate before sleeping (Iso100 Hydrolyzed Whey
289 Protein Isolate; Dymatize Nutrition, Dallas, TX) on training days under the supervision
290 of the research staff. The nutrients consumed by participants during the study is shown
291 in *Table 1*, no significant differences between groups and during the experiment were
292 found.

293

294

< INSERT TABLE 1 NEAR HERE >

295

296 **Rating of perceived exertion (RPE)**

297 The Borg scale was used to evaluate the rating of perceived exertion (RPE) during the
298 exercise sessions at 5 min after the end of the training session at T0, T1, T2 and T3.⁴⁴
299 Volunteers were advised to look at the scale and respond immediately after the end of
300 each session to the following prompt: “*Think about your feeling of body effort, how did*
301 *you feel?*” and entered numbers on a sliding scale, where perceived efforts were rated
302 between 0 for "extremely easy" and 10 for "extremely difficult."

303 **Sleep quality**

304 Sleep quality during and after three weeks of Ramadan was assessed using the full
305 Pittsburgh Sleep Quality Index (PSQI)⁴⁵ before Ramadan (T0), on the 15th day of
306 Ramadan (T1), on the 29th day of Ramadan (T2) and 21 days after the end of Ramadan.
307 We used an Arabic validated version of the PSQI.⁴⁶ The global PSQI score is composed
308 of 7 components: subjective sleep quality (sleep quality perception), sleep latency (time
309 between lying on bed and start sleeping), sleep duration (period sleeping reported by
310 subject), habitual sleep efficiency (ratio between time sleeping and time on bed), sleep
311 disturbance (problems to sleep elected by subjects), sleeping medication (use of
312 medication to sleep), and daytime dysfunction (intensity of diurnal somnolence).⁴⁷ The
313 7 domains are each scored from 0 (no difficulty for the component of interest) to 3 (very
314 bad), with a total or global score ranging from 0-21 that reflects sleep quality and

315 disturbances over a 1-month period. A better sleeper would have a lower global PSQI
316 score, while higher score indicates poor sleep quality.

317 **Statistical analyses**

318 The statistical analyses were conducted using the SPSS program version 16.0 (SPSS Inc.,
319 Chicago, IL, USA). Descriptive statistics are presented as means \pm standard deviations
320 ($M \pm SD$). Normal distribution of data was confirmed using the Shapiro–Wilk test. The
321 effects of training times during Ramadan intermittent fasting were evaluated using a
322 mixed model of ANOVA with 2 (groups: FAST, FED) \times 4 (time: T0, T1, T2, T3). If a
323 statistically significant interaction or main effect was found, Bonferroni corrected post-
324 hoc tests were calculated to identify specific differences.

325 Effect sizes (ES) were determined from the output of ANOVA by converting
326 partial eta-squared to Cohen’s d. In addition, within-group ES were computed using the
327 following equation: $ES = (\text{mean post} - \text{mean pre}) / SD$. ES were considered trivial (<0.2),
328 small (0.2-0.6), moderate (0.6-1.2), large (1.2-2, 0) and very large (2.0-4.0).⁴⁸ All
329 statistical analyses were computed at $p < 0.05$.

330 **Results**

331 All participants received treatments as allocated. Adherence to exercise was 100 % for
332 all participants. No training or test-related injuries were recorded. No significant
333 between-group differences were observed for any anthropometric measures, muscle
334 CSA and muscle strength measures at baseline (T0). Dietary intake, RPE values and
335 sleep quality in the FED and FAST groups were recorded at T0, T1, T2, and T3 and are
336 summarized in **Table 2**. The changes in ES ranged from small-to-moderate for all
337 measurements.

338

339 < INSERT TABLE 2 NEAR HERE >

340

341 **Anthropometric tests**

342 Anthropometric and body composition characteristics of participants are presented in
343 **Table 2**. There were no significant group \times time interactions for anthropometric
344 measures. A significant main effect of time was observed for body mass and body fat

345 percentage. Both FAST and FED groups experienced significant decreases in body mass
346 ($p = 0.001$; $ES = 0.44$), BMI ($p = 0.001$; $ES = 0.67$) and body fat percentage ($p = 0.001$;
347 $ES = 0.91$) during Ramadan, with no changes in lean body mass in either group ($p >$
348 0.05).

349

350 < INSERT TABLE 2 NEAR HERE >

351

352 **Hypertrophy and maximal strength**

353 Group \times time interactions are reported in Table 3 for measures of CSA and maximal
354 strength. There were significant group \times time interactions for $1RM_{SQ}$ ($p = 0.001$; $ES =$
355 0.21) and $1RM_{DL}$ ($p = 0.04$; $ES = 0.10$) in favor of the FED group. Post-hoc tests revealed
356 significant increases in $1RM_{SQ}$ and $1RM_{DL}$ at T2 compared to T0 ($p < 0.05$) and at T3
357 compared to T0 and T1 ($p < 0.05$) for FED. No significant group \times time effects were
358 recorded for $1RM_{BP}$, CSA_{QC} , and CSA_{BB} ($p > 0.05$).

359 < INSERT TABLE 3 NEAR HERE >

360

361 **Rating of perceived exertion (RPE)**

362 The RPE among FAST and FED groups at T0, T1, T2 and T3 is summarized in *Figure*
363 *4*, significant group \times time differences between groups for RPE were reported at T1 ($p =$
364 0.02 ; $ES = 0.48$) and T2 ($p = 0.03$; $ES = 0.37$). A significant main effect of time was
365 observed among FAST group with increasing at T1 and T2, while RPE remained
366 unchanged at all time points in the FED state group.

367 < INSERT FIGURE 4 NEAR HERE >

368

369 **The Pittsburgh Sleep Quality Index**

370 Data of the Pittsburgh Sleep Quality Index (mean \pm SD) among FAST and FED groups
371 at T0, T1, T2 and T3 are reported in (*Table 4*).

372 < INSERT TABLE 4 NEAR HERE >

373

374 There was significant group \times time interactions for total score of PSQI, a
375 significant main effect of time was observed among both groups with decreasing of
376 global PSQI at T1 ($p < 0.05$, $d = 6.54$) and at T2 ($p < 0.05$, $ES = 6.54$) compared to T0;
377 and increasing of the total score for the PSQI during the two weeks after RIF. No
378 significant differences between FAST and FED groups were found on any component.

379 **Discussion**

380 This study evaluated the effects of performing RT during Ramadan month on strength
381 and hypertrophy in male athletes with previous RT experience, and also compared the
382 effects of practicing RT during RIF while still fasting (training before breaking fast) with
383 RT in a non-fasting state (training after breaking fast). Our findings indicate that our first
384 hypothesize was confirmed, practicing RT during RIF has no negative effects on
385 muscular performance in either group. However, our results did not support the second
386 hypothesize. Thus, training in a fed state positively affects only maximal strength with
387 no significant development of muscle circumferences compared to the same total
388 training volume while still fasting. Our findings regarding the lack of muscle
389 hypertrophy in fasted state have to be confirmed in future studies using more
390 sophisticated measuring techniques (e.g., magnetic resonance imaging). Our findings
391 regarding the lack of muscle hypertrophy in fasted state have to be confirmed in future
392 studies using more sophisticated measuring techniques (e.g., magnetic resonance
393 imaging).

394 We studied the effects of RT in two well controlled groups (FAST and FED) that : a)
395 had the same training conditions and total volume training before and during Ramadan;
396 b) consumed no medications anabolic steroids, or ergogenic aids either before or during
397 Ramadan; c) maintained the same nutritional regimen with no significant effects on total
398 energy and nutritional intake; d) had reduced sleep schedule that was delayed only
399 slightly (average ~ 1 hr) but with no significant differences between groups.

400 **Muscle hypertrophy**

401 There were neither adverse or beneficial effects of the combination RT and RIF on biceps
402 and quadriceps muscle hypertrophy in the two study groups, and as also reported in
403 previous studies on the effects of RT during other IF protocols. In fact, Moro et al. 2016
404 studied 34 males who performed RT for 8 weeks (3 resistance sessions/week, 6–8
405 repetitions at 85–90% of 1 RM) with restrictive feeding (16h fasting/8h fed , 3

406 days/week) and reported no significant changes in CSA for muscles of the arms and
407 thighs.⁴⁹ However, other studies reported increases in muscle hypertrophy in males
408 following RT in a time restrictive feeding program.^{50,52} The discrepancy between our
409 findings and the latter reports is likely related to conditions of fasting: we studied the
410 effects of food and water deprivation for the entire month of Ramadan IF while the latter
411 studies involved only 3 days/week of time restrictive feeding.^{50,52} The continuous and
412 prolonged fasting period during Ramadan decreases daily energy intake due to the
413 reduction of meal frequency³³ which could hinder gains in muscle mass.

414 However, in this study, we found no significant differences in total energy and
415 protein intake in the two study groups during the experiment, thus, the lack of muscle
416 mass gain here may possibly be explained due to the changing of protein and glucose
417 oxidation during RIF glycogen depletion in the liver. Muscle proteins (and not glucose)
418 were used for the metabolism to sustain energy used by the other organs (heart, brain..)
419 during starvation ^{53,55}. Additionally, cumulative dehydration during fasting can also
420 negatively impact muscle growth, as decreases in fluid consumption can alter serum
421 concentrations of proteins and hormones associated with muscle protein synthesis.⁵⁶

422 **Muscle strength**

423 An important finding of our study is that there was no significant effect of RIF on (1
424 RM_{BP}) in either the FAST or FED study groups. However, there were slight
425 improvements for (1RM_{DL}) and (1RM_{sq}) in the FED group, with no adverse changes in
426 the FAST group. These findings suggest that practicing RT during Ramadan can sustain
427 or improve strength capacity whether it be practiced before or after breaking the fast,
428 which is consistent with other reports indicating no adverse impacts of RIF on (1
429 RM_{BP}).⁵⁷ Furthermore,²⁹ observed a slight improvements in muscle strength capacity
430 during RIF. The authors attributed this unchanged performance despite fasting to a
431 constant total training volume and nutrient intake during RIF, as was the case for our
432 study.

433 However, the improvement was observed just for FED group with increases in
434 (1RM_{DL}) and(1RM_{sq}). Choosing the optimal training conditions, including timing of
435 training, during Ramadan is of great interest to Muslim athletes. Several changes in
436 physiological and psychological parameters during the daytime can impact exercise,
437 including maximal strength performance. For example, the optimal time of day to

438 conduct an acute high-intensity exercise session during Ramadan is after breaking the
439 fast, as performance is negatively impacted in a fasting state (morning and evening
440 sessions).⁵⁸

441 These findings may due to exercise sessions at 21:00 h were performed under
442 favorable circumstances that were similar to those before Ramadan where athletes were
443 able to consume food and liquids before exercise sessions, allowing pre-exercise blood
444 glucose concentration levels and fluid to be within the normal range, whereas training at
445 18:00 h is not advisable as athletes have not consumed food and fluid for >10 h and
446 experience higher levels of fatigue ([1]. Another explanation for the improvement only
447 among FED, that they reached the fatigue sensation more later in comparison with the
448 FAST group. In fact, in our study, RPE levels, recorded post same exercise, were greater
449 in fasting participants compared to the subjects in the fed state, indicating that exercising
450 while fasting may amplify the sensation of physical effort and fatigue independently of
451 the physiological capacity of the muscles for the same training load.⁵⁴

452 **Study limitations**

453 Our measurements were conducted on two different day-time points (in the late
454 afternoon, just before breaking fast and in the evening, after breaking the fast). Future
455 studies should include additionally time points, such as a third time point in the
456 morning to investigate the effects of training shortly after consuming the pre-dawn
457 meal of *suhur*.

458 Additionally, this study was conducted only with young males. Therefore, the
459 observed findings cannot be translated to females. Future studies should examine this
460 research question in female athletes as more women are now engaging in sports and
461 exercise training ⁶⁰.

462 **Practical applications**

463 Muslim recreational weightlifters try to maintain their physical appearance during
464 Ramadan despite the physiological and psychological challenges that occur during this
465 month of daily fasting. Fitness instructors and personal trainers may need to implement
466 strategies to prevent the negative effects of fasting on muscle hypertrophy and strength.
467 Our findings suggest that it is feasible to maintain and increase maximal strength but not
468 muscle circumferences when exercise is performed in the evenings during the fed state.

469 It is possible that the effects we observed may be even more pronounced in geographical
470 areas where the fasting times are even longer (and conversely, less important in areas
471 where duration of fasting is shorter). In addition, some non-Muslim weightlifters
472 followed an intermittent fasting protocol as a nutritional method for muscle toning,
473 however, trainers practicing RT should stress the importance of adopting an appropriate
474 nutritional protocol to reach training goals.

475 **Conclusion**

476 Ramadan fasting and maintaining RT induces favorable changes in body composition
477 (loss of fat, maintain lean tissue) without disturbing total energy and fluid intake.
478 Furthermore, maintaining RT volume during RIF have no negative effect on strength
479 and hypertrophy. Additionally, practicing after breaking fast leads to significant
480 improvement on maximal strength. Thus, choosing the adequate time of training,
481 practicing nutritional strategies and maintaining the same training volume
482 during Ramadan, allows fasting recreational athletes to sustain and improve muscle
483 performance.

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699 **Table 1.** Estimated daily dietary intake recorded (mean \pm SD) of the FAST and FED state groups measured during 1 week before the start of
700 Ramadan (T0), on the 15th day of Ramadan (T1), the day after the end of Ramadan (T2) and 21 days after the end of Ramadan (T3) (n=20 per
701 group).

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		T0	T1	T2	T3	Time	Group	Group \times Time
Protein (% kcal)	FAST	18 \pm 8	19 \pm 1	18 \pm 7	18 \pm 7	0.08 (0.37)	0.06 (0.45)	0.1 (0.57)
	FED	18 \pm 6	18 \pm 2	18 \pm 9	18 \pm 6			
Carbohydrate (% kcal)	FAST	47 \pm 5	45 \pm 8	46 \pm 3	47 \pm 1	0.1 (0.46)	0.08 (0.54)	0.07 (0.55)
	FED	47 \pm 3	46 \pm 5	45 \pm 9	46 \pm 7			
Fat (% kcal)	FAST	35 \pm 8	36 \pm 5	36 \pm 4	35 \pm 7	0.09 (0.45)	0.08 (0.38)	0.08 (0.58)
	FED	35 \pm 9	36 \pm 3	37 \pm 2	36 \pm 4			
Energy (kcal/day)	FAST	3472 \pm 245	3436 \pm 249	3425 \pm 283	3482 \pm 275	0.2 (0.37)	0.08 (0.45)	0.09 (0.51)
	FED	3496 \pm 368	3432 \pm 237	3465 \pm 232	3472 \pm 254			
Total water intake (L/day)	FAST	4.3 \pm 0.5	4.1 \pm 0.4	4.2 \pm 0.3	4.1 \pm 0.7	0.06 (0.57)	0.08 (0.35)	0.2 (0.41)
	FED	4.2 \pm 0.4	4.3 \pm 0.6	4.2 \pm 0.3	4.1 \pm 0.4			

718 **Table 2.** Anthropometric and body composition characteristics (means \pm SD) of the FAST and FED state groups measured during 1 week before
 719 the start of Ramadan (T0), on the 15th day of Ramadan (T1), the day after the end of Ramadan (T2) and 21 days after the end of Ramadan (T3)
 720 (n=20 per group).

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		T0	T1	T2	T3	Time	Group	Group x Time
Body mass (kg)	FAST	79.12 \pm 3.71	76.06 \pm 3.25*	74.19 \pm 3.20*#	77.64 \pm 4.52\$	0.001 (0.44)	0.54 (0.05)	0.09 (0.07)
	FED	80.05 \pm 3.34	79.08 \pm 2.86*	76.23 \pm 3.03*	78.04 \pm 3.52 \$			
BMI (kg/m²)	FAST	24.26 \pm 1.72	23.6 \pm 1.45*	22.35 \pm 1.34*#	23.91 \pm 1.19\$	0.001 (0.67)	0.27 (0.03)	0.13 (0.14)
	FED	24.72 \pm 1.03	24.24 \pm 1.26	23.31 \pm 1.50*	24.01 \pm 1.61\$			
Body fat (%)	FAST	16.66 \pm 1.25	15.31 \pm 1.60*	13.53 \pm 1.55*#	14.84 \pm 1.41*\$	0.001 (0.91)	0.89 (0.00)	0.58 (0.05)
	FED	16.20 \pm 0.57	15.31 \pm 1.59*	13.82 \pm 1.65*#	14.93 \pm 1.47*\$			
LBM (kg)	FAST	66.78 \pm 2.94	65.84 \pm 2.92	64.78 \pm 2.86	65.70 \pm 3.39	0.31 (0.31)	0.10 (0.06)	0.81 (0.01)
	FED	67.24 \pm 1.88	66.72 \pm 2.45	66.57 \pm 2.59	66.98 \pm 2.91			

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BMI: body mass index; **LBM:** lean body mass; *: p< 0.05 compared to T0; #: p< 0.05 compared to T1; \$: p<0.05 compared to T2.

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738 **Table 3:** Maximal strength (1RM) and hypertrophy changes (means \pm SD) of the FAST and FED state groups measured during 1 week before
 739 the start of Ramadan (T0), on the 15th day of Ramadan (T1), the day after the end of Ramadan (T2) and 21 days after the end of Ramadan (T3)
 740 (n=20 per group).

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		T0	T1	T2	T3	Time	Group	Group x Time																																																				
1RM _{SQ} (kg)	FAST	168.75 \pm 13.13	169.50 \pm 11.85	168.45 \pm 11.54	172.25 \pm 11.55*#	0.001 (0.60)	0.04 (0.12)	0.001 (0.21)																																																				
	FED	169.65 \pm 12.09	170.78 \pm 11.15	174.23 \pm 12.08*	177.10 \pm 12.69*#				1 RM _{BP} (kg)	FAST	106.01 \pm 9.50	110.40 \pm 10.54	109.25 \pm 10.33	120.10 \pm 10.09*	0.001 (0.68)	0.63 (0.006)	0.38 (0.08)	FED	105.50 \pm 10.60	107.35 \pm 10.15	109.50 \pm 10.55	116.75 \pm 10.58*	1RM _{DL} (%)	FAST	186.25 \pm 8.13	186.80 \pm 8.88	187.81 \pm 9.38	190.25 \pm 9.88*#	0.001 (0.29)	0.003 (0.12)	0.04 (0.10)	FED	187.50 \pm 8.50	190.85 \pm 8.44	195.40 \pm 9.10*	199.65 \pm 8.39*#	CSA _{QC} (cm ²)	FAST	69.95 \pm 7.14	68.90 \pm 6.98	68.15 \pm 6.58	71.15 \pm 6.27\$	0.94 (0.01)	0.18 (0.12)	0.27 (0.03)	FED	70.60 \pm 6.20	71.90 \pm 6.80	72.80 \pm 6.70	76.45 \pm 6.64*	CSA _{BB} (cm ²)	FAST	20.50 \pm 2.10	21.20 \pm 2.42	20.65 \pm 2.45	22.65 \pm 2.69*\$	0.001 (0.13)	0.88 (0.42)	0.29 (0.32)	FED
1 RM _{BP} (kg)	FAST	106.01 \pm 9.50	110.40 \pm 10.54	109.25 \pm 10.33	120.10 \pm 10.09*	0.001 (0.68)	0.63 (0.006)	0.38 (0.08)																																																				
	FED	105.50 \pm 10.60	107.35 \pm 10.15	109.50 \pm 10.55	116.75 \pm 10.58*				1RM _{DL} (%)	FAST	186.25 \pm 8.13	186.80 \pm 8.88	187.81 \pm 9.38	190.25 \pm 9.88*#	0.001 (0.29)	0.003 (0.12)	0.04 (0.10)	FED	187.50 \pm 8.50	190.85 \pm 8.44	195.40 \pm 9.10*	199.65 \pm 8.39*#	CSA _{QC} (cm ²)	FAST	69.95 \pm 7.14	68.90 \pm 6.98	68.15 \pm 6.58	71.15 \pm 6.27\$	0.94 (0.01)	0.18 (0.12)	0.27 (0.03)	FED	70.60 \pm 6.20	71.90 \pm 6.80	72.80 \pm 6.70	76.45 \pm 6.64*	CSA _{BB} (cm ²)	FAST	20.50 \pm 2.10	21.20 \pm 2.42	20.65 \pm 2.45	22.65 \pm 2.69*\$	0.001 (0.13)	0.88 (0.42)	0.29 (0.32)	FED	20.90 \pm 2.02	20.45 \pm 2.41	20.91 \pm 2.46	22.15 \pm 2.35#										
1RM _{DL} (%)	FAST	186.25 \pm 8.13	186.80 \pm 8.88	187.81 \pm 9.38	190.25 \pm 9.88*#	0.001 (0.29)	0.003 (0.12)	0.04 (0.10)																																																				
	FED	187.50 \pm 8.50	190.85 \pm 8.44	195.40 \pm 9.10*	199.65 \pm 8.39*#				CSA _{QC} (cm ²)	FAST	69.95 \pm 7.14	68.90 \pm 6.98	68.15 \pm 6.58	71.15 \pm 6.27\$	0.94 (0.01)	0.18 (0.12)	0.27 (0.03)	FED	70.60 \pm 6.20	71.90 \pm 6.80	72.80 \pm 6.70	76.45 \pm 6.64*	CSA _{BB} (cm ²)	FAST	20.50 \pm 2.10	21.20 \pm 2.42	20.65 \pm 2.45	22.65 \pm 2.69*\$	0.001 (0.13)	0.88 (0.42)	0.29 (0.32)	FED	20.90 \pm 2.02	20.45 \pm 2.41	20.91 \pm 2.46	22.15 \pm 2.35#																								
CSA _{QC} (cm ²)	FAST	69.95 \pm 7.14	68.90 \pm 6.98	68.15 \pm 6.58	71.15 \pm 6.27\$	0.94 (0.01)	0.18 (0.12)	0.27 (0.03)																																																				
	FED	70.60 \pm 6.20	71.90 \pm 6.80	72.80 \pm 6.70	76.45 \pm 6.64*				CSA _{BB} (cm ²)	FAST	20.50 \pm 2.10	21.20 \pm 2.42	20.65 \pm 2.45	22.65 \pm 2.69*\$	0.001 (0.13)	0.88 (0.42)	0.29 (0.32)	FED	20.90 \pm 2.02	20.45 \pm 2.41	20.91 \pm 2.46	22.15 \pm 2.35#																																						
CSA _{BB} (cm ²)	FAST	20.50 \pm 2.10	21.20 \pm 2.42	20.65 \pm 2.45	22.65 \pm 2.69*\$	0.001 (0.13)	0.88 (0.42)	0.29 (0.32)																																																				
	FED	20.90 \pm 2.02	20.45 \pm 2.41	20.91 \pm 2.46	22.15 \pm 2.35#																																																							

755 **1RM:** one-repetition maximum; **CSA:** cross section area; **SQ:** squat; **BP:** bench press; **DL:** deadlift; **QC:** quadriceps; **BB:** biceps brachii; *: p< 0.05 compared to T0; #: p<
 756 0.05 compared to T1; \$: p<0.05 compared to T2.

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758 **Table 4.** sleep quality recorded (mean \pm SD) of the FAST and FED state groups measured during 1 week before the start of Ramadan (T0), on
 759 the 15th day of Ramadan (T1), the day after the end of Ramadan (T2) and 21 days after the end of Ramadan (T3) (n=20 per group).

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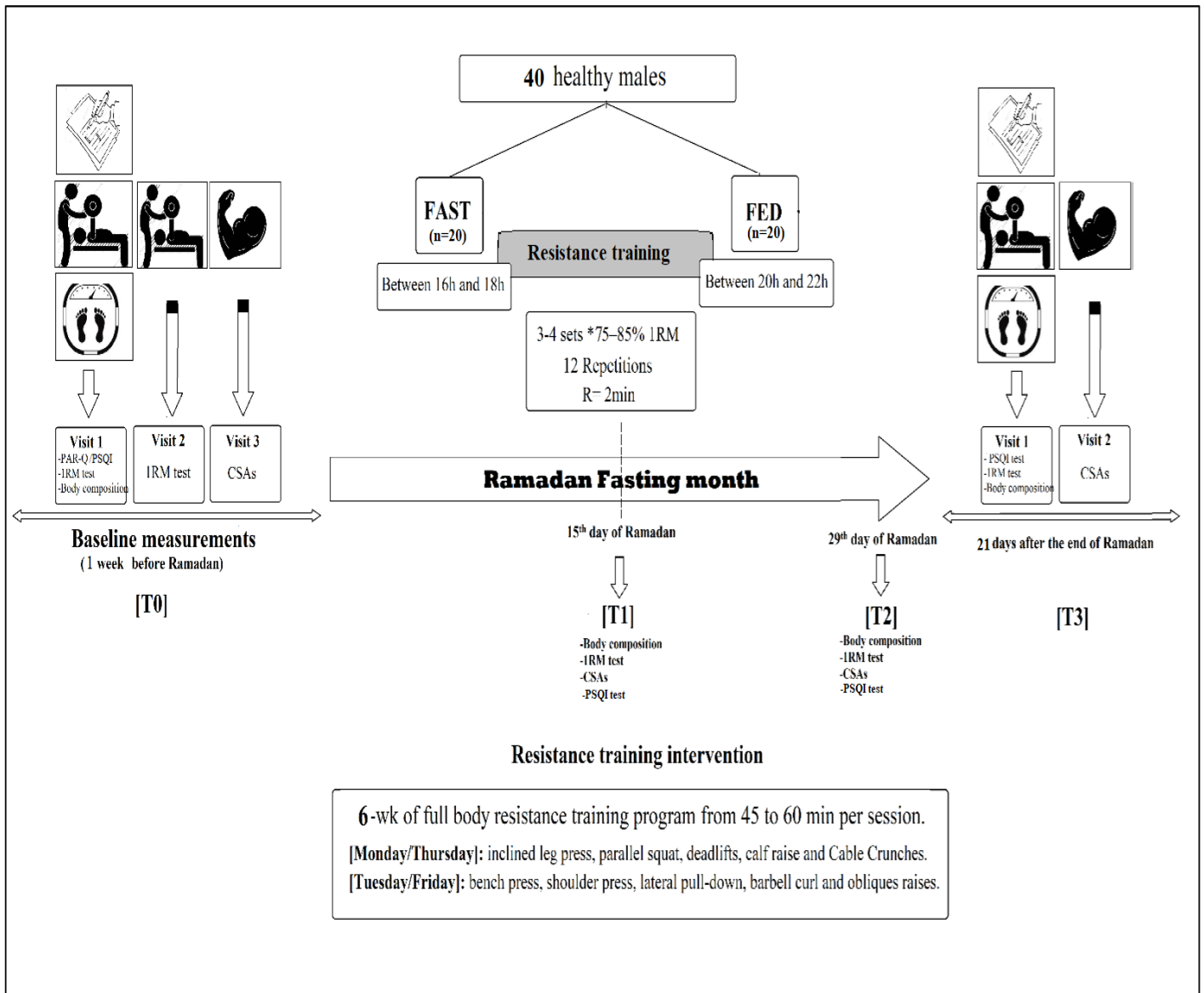
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		T0	T1	T2	T3	Time	Group	Group x Time
sleep quality	FAST	1.2 \pm 0.5	2.4 \pm 0.8*	2.2 \pm 0.7*	1.3 \pm 0.7#S	0.007 (0.48)	0.06 (0.65)	0.1 (0.56)
	FED	1.3 \pm 0.7	2.4 \pm 0.7*	2.3 \pm 0.5*	1.4 \pm 0.6#S			
sleep latency (min)	FAST	17.2 \pm 5.4	17.3 \pm 4.7	16.9 \pm 8.4	16.8 \pm 6.4	0.06 (0.58)	0.07 (0.47)	0.2 (0.56)
	FED	16.9 \pm 6.1	17.5 \pm 6.3	17.1 \pm 7.2	17.1 \pm 5.8			
sleep duration (h)	FAST	7.9 \pm 1.1	6.3 \pm 1.1*	6.7 \pm 1.2*#	7.8 \pm 1.2#S	0.002 (0.69)	0.2 (0.65)	0.06 (0.58)
	FED	8.1 \pm 0.5	6.1 \pm 1.3*	6.6 \pm 1.5*#	7.8 \pm 1.5#S			
sleep efficiency (%)	FAST	98.4 \pm 3.5	95.3 \pm 8.2*	95.2 \pm 7.2*	96.8 \pm 6.5#S	0.005 (0.65)	0.07 (0.37)	0.1 (0.47)
	FED	97.7 \pm 4.1	94.8 \pm 6.7*	95.1 \pm 6.8*	97.1 \pm 7.1#S			
sleep disturbance	FAST	0.7 \pm 0.5	0.7 \pm 0.2	0.6 \pm 0.5	0.6 \pm 0.5	0.07 (0.45)	0.08 (0.45)	0.07 (0.55)
	FED	0.6 \pm 0.3	0.7 \pm 0.5	0.6 \pm 0.4	0.6 \pm 0.4			
daytime dysfunction	FAST	0.4 \pm 0.3	0.4 \pm 0.6	0.4 \pm 0.8	0.5 \pm 0.5	0.07 (0.38)	0.2 (0.38)	0.1 (0.56)
	FED	0.5 \pm 0.6	0.4 \pm 0.7	0.5 \pm 0.6	0.4 \pm 0.3			
Total score of PSQI	FAST	3.4 \pm 2.7	7.2 \pm 2.3*	7.5 \pm 2.1*	3.9 \pm 2.7#S	0.003 (0.47)	0.06 (0.43)	0.08 (0.39)
	FED	3.8 \pm 2.3	7.7 \pm 2.1*	7.3 \pm 2.6*	4.1 \pm 2.1#S			

PSQI: Pittsburgh Sleep Quality Index; *: p< 0.05 compared to T0; #: p< 0.05 compared to T1; S: p<0.05 compared to T2.

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Figure 1. Study design

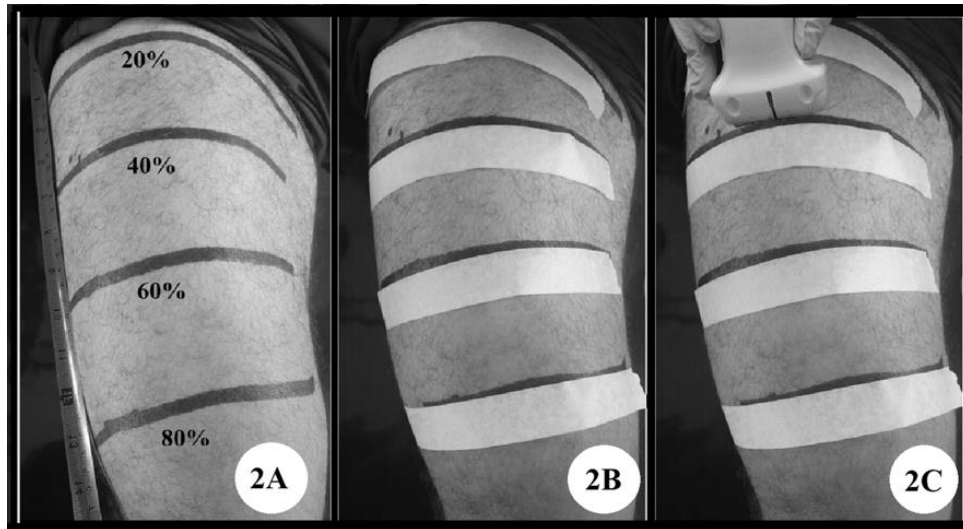
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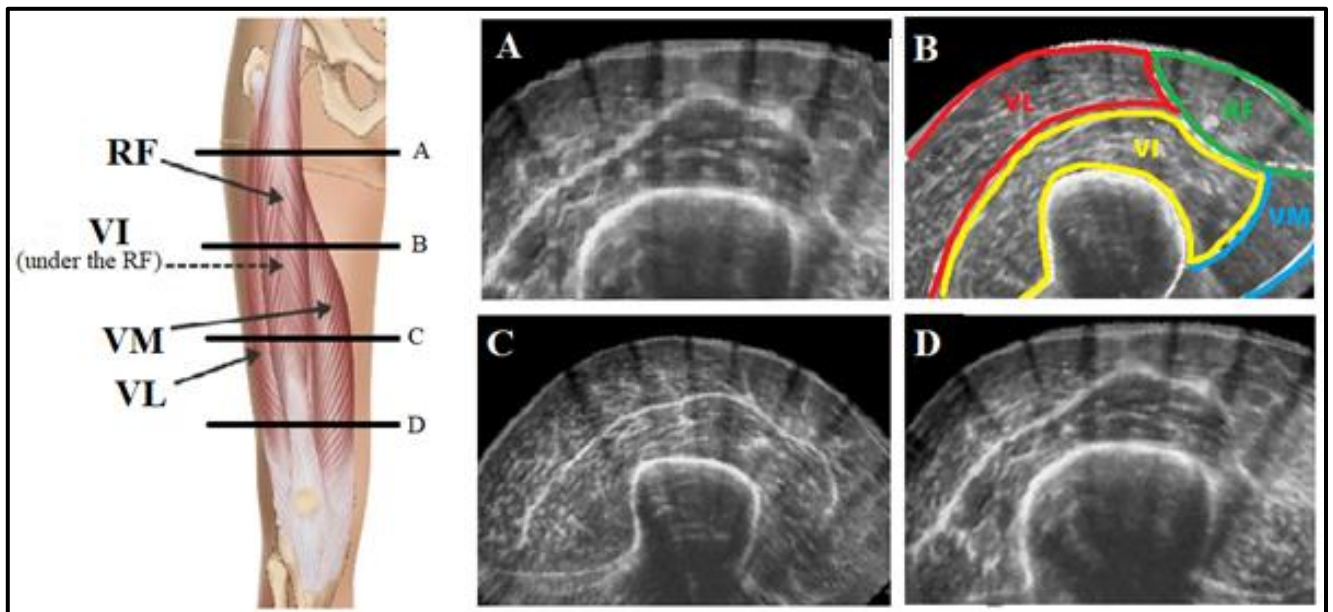


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785 **Figure 2.** Thigh marking procedures (A and B) and ultrasound images acquisition
786 (C).

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790 **Figure 3.** Ultrasound images and cross-sectional areas (CSAs) of quadriceps at 20%
791 proximal (A), 40% (B), 60% (C), and 80% (D) of femur length. RF: rectus femoris;

792 VI: vastus intermedius; VL: vastus lateralis; VM: vastus medialis.

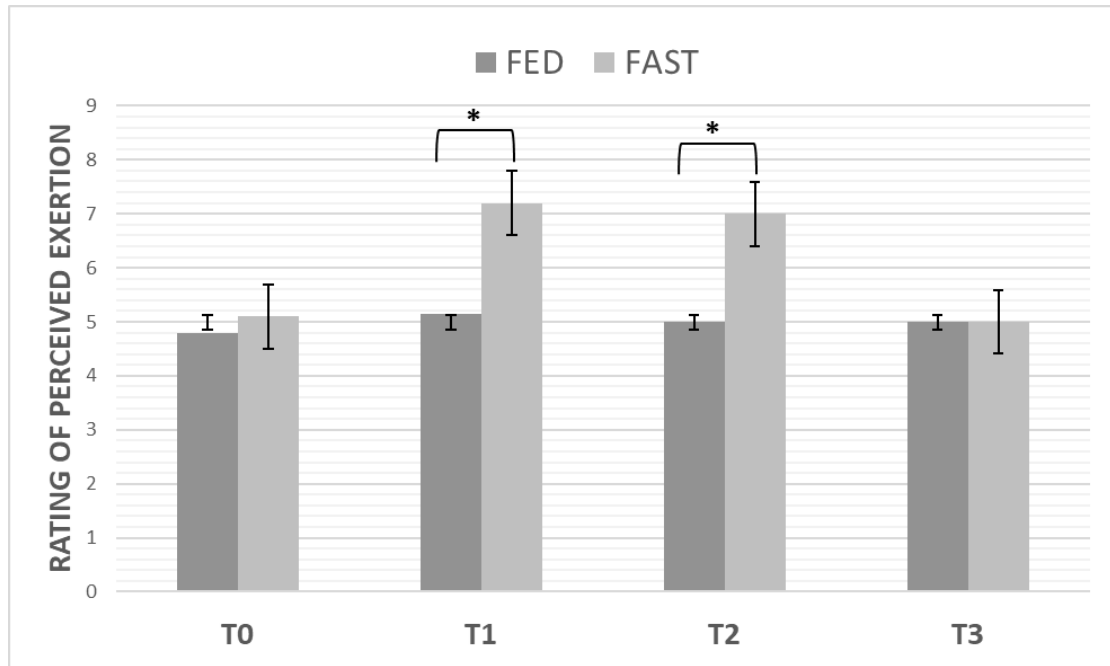
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801 **Figure 4.** Rating of perceived effort (RPE) among FAST and FED state group.

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*: P < 0.05 significant differences between groups.

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