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Original Research

An Examination of Two Resistance Training Frequency Techniques in Morphological and Functional Adaptations of the Patellar Tendon

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ABSTRACT

International Journal of Exercise Science 15(4): 709-720, 2022. The aim of the present study was to investigate the effects of distinct resistance training frequencies with equated-volume conditions in morphological and functional adaptations of the patellar tendon. Twenty-seven recreationally resistance-trained subjects (men [n=17] and women [n=10]) (age: 20.8 ± 1.9 years [range 18 to 25 years]; height: 1.73 ± 9.8 cm; total body mass = 73.2 ± 11.7 kg; previous RT experience = 3.3 ± 1.6 years) volunteered to participate in this study. A total of 16 training sessions were performed during the study period. Each subject's leg was randomly allocated to one of the following training protocols: 2 training sessions/week (2x) or 4 training sessions/week (4x). Measurements of tendon cross sectional area (CSA) and length were performed through ultrasound imaging. One repetition maximum test was performed to assess patellar tendon force (PTF) unilaterally. For CSA (2x: Δ= -1.3%; 4x: Δ= -0.9%), and length (2x: Δ= -0.4%; 4x: Δ= 1.2%), no significant differences were observed within or between conditions (all $p > 0.05$). For PTF, a significant difference was observed between conditions (mean difference = 0.05 [-125 to 224] p= 0.001). In conclusion, the leg extension exercise performed 2 vs 4x/week induces similar patellar tendon morphological responses. However, the increase in force seems to be enhanced by a lower weekly training frequency associated with a longer intervention period.

KEY WORDS: Strength, training variables, knee, morphology

INTRODUCTION

The main function of the patellar tendon is to transmit the force generated by the quadriceps muscle group to the tibial tuberosity creating leverage for joint movement. Then, the patellar tendon is a crucial factor for human locomotion activities as walking and running (20) and also for several sports-related tasks (e.g., sprinting (17) and jumping (13)). Throughout various phases of movement, tendons are exposed to longitudinal and shearing types forces (12). Indeed, tendinous tissue is highly sensitive to mechanical load, which may lead to deformations in its properties. From a biomechanical standpoint, four different deformation-related factors can affect a tendon´s adaptive response: magnitude, frequency, rate and duration. Among these factors, the combination of high magnitude and low-frequency tension seem to strongly influence deformation-related adaptive responses of the tendon (1,2).

Significant changes in tendon mechanical and structural properties may be induced by resistance training (RT) programs (15,19,32). So, it can be suggested that training interventions that lead to positive morphological responses such as the increase in the cross-sectional area in the tendon may represent an advantage in its mechanical properties (e.g increased stiffnes) (5). The manipulation of RT variables (e.g. volume, intensity, rest intervals, exercise order, range of motion and weekly frequency) can influence the adaptive responses (strength, hypertrophy, power and endurance) of the skeletal muscle (16). However, morphological and mechanical responses may differ from muscle and tendinous tissues over time (17).

Previous meta-analytic data has pointed that effective training interventions for the tendon (e.g. jumping was significantly correlated with tendon stiffness during during parameters of power, force and speed) should apply a high loading intensity (above 70% of one-repetition maximum [1RM]) over a longer intervention duration (>12 weeks) (1,2). However, morphological adaptations of human tendon to distinct RT frequencies are still poorly understood. Therefore, the aim of the current study was to investigate the effects of distinct RT-frequencies with equated-volume conditions in morphological and functional adaptations of the patellar tendon in recreationally resistance-trained subjects. Since the actual work performed by the muscle results in the total stress transmitted to the tendon, our initial hypothesis was that similar results would be observed for the two experimental conditions (low vs high frequency).

METHODS

Participants

Twenty-seven recreationally resistance-trained young subjects (men [n=17] and women [n=10]) (age: 20.8 ± 1.9 years [range 18 to 25 years]; height: 1.73 ± 9.8 cm; total body mass = 73.2 ± 11.7 kg; previous RT experience = 3.3 ± 1.6 years [range 2.6 to 4.0 years]; previous RT frequency = 4.4 ± 0.7 sessions per week) volunteered to participate in this study. The sample size was justified by a priori power analysis based on a pilot study where the tendon length and cross sectional area (CSA) of the patellar tendon (PT) was assessed as the outcome measure for a target effect size difference of 0.75, an alpha level of 0.05, and a power ($1 - \beta$) of 0.80 (7,26). All participants had been performing RT a minimum of 3 days/week and regularly performed (minimum frequency of once a week) the exercise adopted in the training protocol and in the strength tests for at least 1 year before entering the study. The weekly number of sets that each participant usually adopted for the quadriceps muscle prior to the study was reported (27.4 ± 12.3 sets per week). As additional inclusion criteria, the participants had to be free from musculoskeletal disorders that could impair adequate performance of the RT protocols and should not use anabolic steroids. Participants also should answer negatively to all questions on the Physical Activity Readiness Questionnaire (PAR-Q). This study was approved by the University's research ethics committee (protocol 13/19). Procedures conformed with ethics in sport and exercise science (11) ; all subjects read and signed an informed consent document.

Protocol

A randomized, longitudinal within-subject unilateral study design was adopted. All participants completed two familiarization weeks with the knee extension exercise with the cadence and range of motion that they would perform during the intervention period. Afterward, each subject's leg was randomly allocated to one of the following training protocols: 2 training sessions/week (2x) or 4 training sessions/week (4x). Participants' lower limb dominance was balanced in the randomization process. For both conditions, a total of 16 training sessions were performed during the study period. Therefore, for the 2x and 4x conditions, the intervention period lasted 8 and 4 weeks, respectively. All assessments were performed before the training period (Pre) and 72 hours after the last training session (Post), at the same time of the day, by the same researcher.

At the beginning of each training session, subjects performed a specific warm-up of 2 sets of 8 repetitions with a load between 40% and 60% of 10 repetition maximum (RM) obtained in the familiarization week (4). Then, subjects performed 12 sets of 8–12RM in the knee extension exercise. The 2x and 4x groups performed 24 and 48 weekly sets, respectively. To date, this is the first study to implement 48 weekly sets per week for the quadriceps muscles, values similarly adopted (45 sets per week) by a previous study (30). Repetitions were performed to the point of muscular failure (i.e., inability to perform another concentric repetition while maintaining proper form).

The subjects were instructed to perform the leg extension and flexion exercise movements in a range of 90 to 45 degrees with a cadence of 1.5 seconds for concentric phase and 1.5 seconds for eccentric phase. Repetition range was achieved by increasing or decreasing the external load between sets as previously described (3). A 1-minute rest interval was adopted between sets (28). The total load lifted (TLL) performed by 2x and 4x legs over the training period was also calculated. All sessions were supervised by the researchers in order to maintain the proper technique of each exercise. During the intervention period, the participants were asked to not perform any type of physical training.

Measurements of tendon CSA and LENGTH were performed utilizing ultrasound imaging. At the time of the PT assessment, the subjects remained lying on a supine position on a stretcher. For the measures of tendon length and CSA of the PT, the knee was supported on a stabilizer with 30° of flexion (22) (Figure 1A). Two markings were made, one at the apex of the patella and the other at the tibial tuberosity (35). A 4.5mm transducer was used, making it necessary to acquire and combine two images (proximal + distal) to determine the total length of the tendon (33) (Figure 1B). Water-based soluble transmission gel was used. The linear transducer with a frequency of 12MHz was longitudinally oriented in the direction of the sagittal plane to evaluate the length of the tendon and transversely oriented at the midpoint between the apex of the patella and the tibia tuberosity for acquisition of CSA image (Figure 1C).

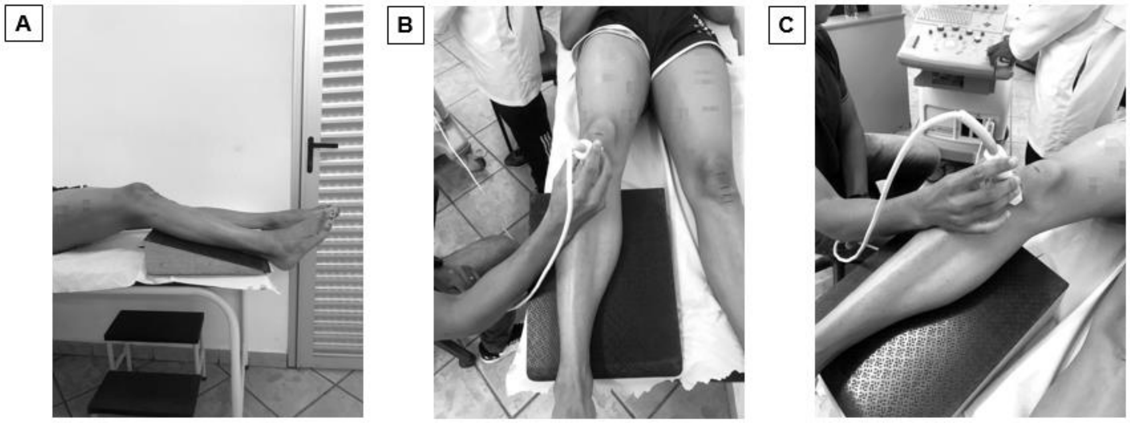

Figure 1. (A) knee was supported on a stabilizer with 30 ° of flexion; (B) transducer longitudinally oriented in the direction of the sagittal plane to evaluate the length of the tendon; (C) transducer transversely oriented at the midpoint between the apex of the patella and the tibial tuberosity for acquisition of CSA image.

The images were collected in duplicate (Table 1) by the evaluator using the equipment LOGIC L3, (General Electric Healthcare®, Wauwatosa). Subjects were instructed to not perform any type of physical activity prior to the collections (72 hours). The measurements of tendon length (cm) and CSA (cm2) were performed using the software ImageJ 1.43u (National Institutes of Health, Bethesda, MD, USA, version 3.0.1), using the "oval-brush" tools for CSA (Figure 2A) and "straight" to determine the length of the tendon after calibration (Figure 2B). The test-retest intraclass correlation coefficient (ICC), coefficient of variation (CV), and the typical error of the measurement (TEM) calculated through the data collected during the familiarization period and the pre-intervention period (5 days between the test-retest) for CSA were 0.881, 3.6%, and 0.02 cm^2, respectively. The ICC, CV, and SEM for LENGTH were 0.989, 2.7%, and 0.02 cm, respectively.

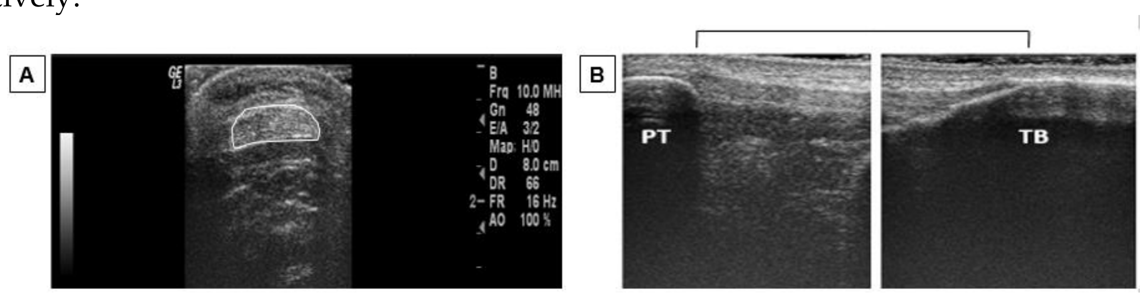

Figure 2. (A) CSA of the patellar tendon; (B) length of the patellar tendon (PT - patella; TB - tibia).

One repetition maximum test (1RM) was performed for the unilateral knee extension exercise in order to assess maximal strength of the lower limbs. Testing was performed according to the recommendations of Brown and Weir (4) and randomized by the dominant hemisphere. Initially, subjects performed a general warm-up in a cycle ergometer at 20 km h^{-1} for 5 min, followed by two sets of specific warm-up. The first set consisted of 8 repetitions with 50% of the estimated 1-RM, and the second set comprised 3 repetitions with 70% of the estimated 1-RM with a 2-min rest between sets. After the warm-up, the 1-RM test was initiated. Each participant was allowed to perform 5 attempts during the test. The individual remained seated with the torso flexed at 60 degrees and legs in 90-degree flexion. The exercise was carried out by leg extension and flexion movement in the range of 90 to 45 degrees.

The patellar tendon force (PTF) was calculated in a relative manner as follows:

*External load in kg (1RM test) divided by the external moment arm ((MA = 25.88 + 0.078 * m - 2.242 * s + 0.128 * h) / 6.5% of the femur length).*

where (m) corresponds to body mass in kilograms; (s) sex (of which: 0 for men and 1 for women); (h) height in centimeters)) (23) divided by the internal moment arm estimated as a percentage (6.5%) of the femur length (8). The femoral length was estimated as the distance from the most lateral point of the greater trochanter to the lateral condyle of the femur. The data were expressed in kilogram-force units (kgf).

The TLL (sets x repetitions x external load) (10) was calculated from training logs filled out by the researchers for every RT session. The weekly TLL was calculated as the values corresponding to the sum of the loads calculated for the RT sessions of each week. Accumulated TLL was calculated as the sum of all 16 training sessions performed in both conditions (2x and 4x). The data were expressed in kilogram-force units (kgf).

Statistical Analysis

The normality and homogeneity of the variances were verified using the Shapiro-Wilk and Levene tests, respectively. Prior to analysis, all data were log-transformed for analysis to reduce bias arising from non-uniformity error (heteroscedasticity). The mean, standard deviation (SD), 90%, and 95% confidence intervals (CI) were used after data normality was assumed. To compare mean values of the total training load lifted in 2x vs 4x a t-test was used (condition effect). A repeated-measures analysis of variance (ANOVA) was used to compare the time effect (pre vs post) and groups (2x vs 4x) in CSA and LENGTH of the patellar tendon and in PTF. Post hoc comparisons were performed with the Bonferroni correction. Assumptions of sphericity were evaluated using Mauchly's test. Where sphericity was violated ($p < 0.05$), the Greenhouse–Geisser correction factor was applied. In addition, effect sizes (ES) in ANOVA were evaluated using a partial eta squared ($\eta 2$ p), with < 0.06, 0.06 - 0.14 and, > 0.14 indicating a small, medium, and large effect, respectively. To assess whether the observed differences could be considered real, changes were compared to their calculated smallest worthwhile change (SWC) for all dependent variables (34). SWC was calculated by the formula (SWC = typical error measurement x 1.96 x $\sqrt{2}$) (36). We defined an individual as "responding" positively to training with a response greater than +1SWC from zero for increases in dependent variables; if not, they were considered as nonresponders. The percentage of subjects exceeding the SWC was calculated for all dependent variables (21). Absolute change analyses (Δ = post – pre) between groups were performed employing unpaired t-tests and ES was calculated using the standardized difference, based on Cohen's d units by means (d value) (6). All analyses were conducted in SPSS-22.0 software (IBM Corp., Armonk, NY, USA). The adopted significance was $P \leq 0.05$. The figures were formatted in GraphPad Prism version 7.0 software (La Jolla, CA, USA) following the assumptions for continuous data (37).

RESULTS

No significant main effect of time to 2x (p= 0.538; Δ= -1.3%) and 4x (p= 0.455; Δ= -0.9%), and group x time interaction ($F_{1, 21}$= 0.206, p= 0.655, η^2_p= 0.010) was observed for CSA (Table 1).

Table 1. Pre and post 16 sessions' measures (mean ± CI 95%).

Variables	Condition	Pre	Post	Δ%	ES (*d*)	MD (CI 95%)	*p*-value
CSA (cm²)							
	2x	1.09 [0.13]	1.07 [0.9]	-1.3	-0.2*	-0.02 (-0.09 to 0.05)	0.53
	4x	1.06 [0.13]	1.04 [0.13]	-0.9	0.0*	-0.03 (-0.12 to 0.05)	0.45
Length (cm)							
	2x	4.57 [0.48]	4.50 [0.48]	-1.4	0.1*	0.00 (-0.32 to 0.33)	0.95
	4x	4.50 [0.43]	4.51 [0.31]	0.2	0.0*	-0.06 (-0.39 to 0.26)	0.68
PTF (Kgf)							
	2x	29.7 [8.7]	39.5 [14.5]$^{A\#}$	36.0	0.9**	9.79 (7.07 to 12.51)	0.01
	4x	31.4 [9.2]	34.2 [8.1]^{A}	12.5	0.2*	2.76 [0.48 to 5.05]	0.01

CSA= cross-sectional area; **PTF** = patellar tendon force; **ES** = effect size small*, moderate**, large***; **MD** =mean difference. ^{A} Significantly greater than the corresponding pre-intervention value ($p < 0.05$). $^{\#}$ significant difference between groups ($p < 0.05$)

No significant main effect of time to 2x (p= 0.955; Δ= -1.4%) and 4x (p= 0.681; Δ= 0.2%) (Table 3), and group x time interaction ($F_{1, 21}$= 1.394, p= 0.251, η^2_p= 0.062) was observed for the LENGTH (Table 1).

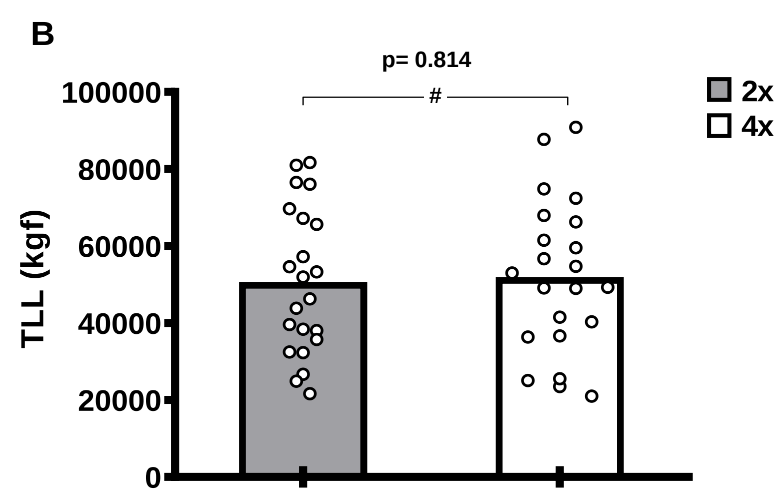

Figure 3. Total load lifted (TLL) during the 8 weeks of training intervention; gray bar (2x) and white bar (4x). # = p > 0.05.

A significant main effect of time to 2x ($p= 0.006$; $\Delta= 36.0\%$) and 4x ($p= 0.014$; $\Delta= 12.5\%$) and group x time interaction ($F_{1, 21}= 14.413$, $p= 0.001$, $\eta^2_p= 0.407$) with significant difference ($p= 0.001$; $\Delta= 23.4\%$) was observed for force (Table 1). No significant difference was observed when comparing both conditions in relation to accumulated TLL throughout the intervention period ($p= 0.814$) (Figure 3).

The individual analyses revealed that CSA increased in 36.36% of the subjects in both conditions (Figure 4A); LENGTH increased in 33.33% of the subjects from the 2x condition, and in 27.27% of the subjects from the 4x condition (Figure 4B); PTF increased in 90.91% of the subjects from the 2x condition, and in 63.64% of the subjects from the 4x condition (Figure 5).

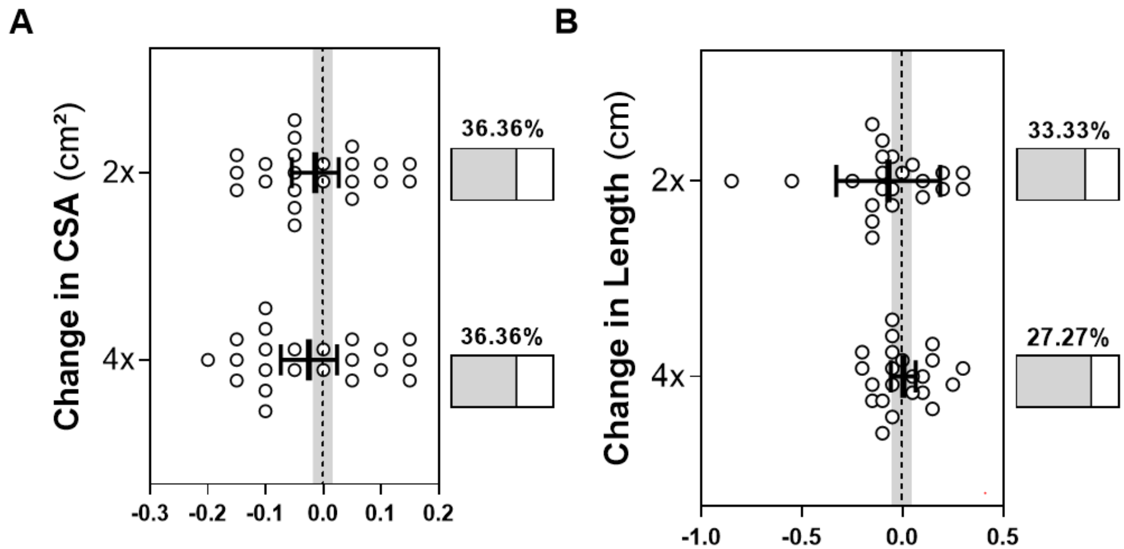

Figure 4. Mean with 95% CI (errors bars) of individual absolute changes in relation to pre values for CSA - cross sectional area (A) length of the tendon (B). Grey area indicates the SWC = see methods. Horizontals columns represent the percentage of subjects responding positively to training.
Legend: 2x = 2 training sessions/week; 4x = 4 training sessions/week; # = p <0.05

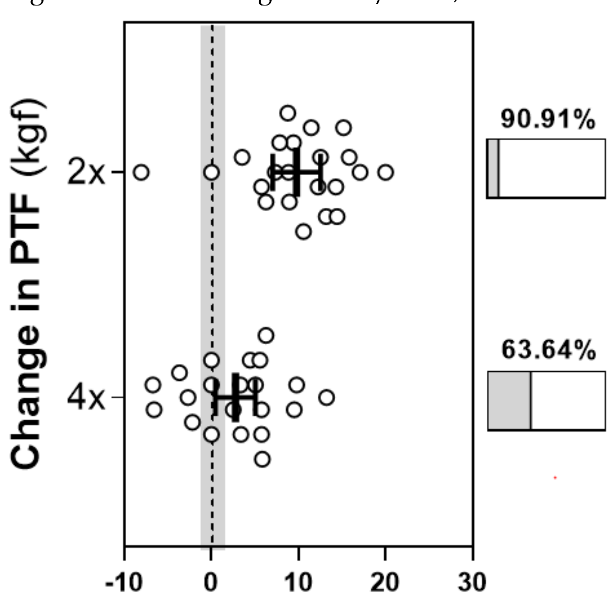

Figure 5. Mean with 95% CI (errors bars) of individual absolute changes in relation to pre values for PTF – patellar tendon force. Grey area indicates the SWC = see methods. Horizontals columns represent the percentage of subjects responding positively to training.
Legend: 2x = 2 training sessions/week; 4x = 4 training sessions/week; # = p <0.05

DISCUSSION

The aim of the present study was to investigate the effects of different RT frequencies on functional and morphological adaptations in the patellar tendon. Confirming the initial hypothesis, no significant differences were observed in morphological adaptations. In contrast, a significant difference was noted between groups in tendon force when comparing 2 vs 4 weekly sessions (8 and 4 weeks, respectively). Different from other investigations regarding training frequency, our study equalized the number of sessions performed for each training condition.

Significant increases in muscle strength and size induced by RT-programs have been widely described (27,29). However, there is still scarce information regarding tendon adaptations induced by distinct manipulations of RT variables. In the present study, both experimental conditions were unable to elicit significant changes in patellar tendon CSA and length. Such results might be attributed to the duration of the protocol adopted, since no tendon CSA and length changes were also reported by longer training interventions consisting of 8 weeks (18) and 12 weeks (19). Kongsgaard et al. (15) was the first study reporting significant increases in tendon CSA (6%) induced by an RT program in humans.

Although the same exercise (knee extension) was adopted in the current study and Kongsgaard et al. (15), 36 training sessions were performed during the latter, which might help to explain these distinct results. In addition, differences regarding the RT intensity must be highlighted when comparing both investigations. Then, an eventual increase in patellar tendon CSA induced by the same research design but with a longer intervention period must not be discarded. Also, one can assume that a longer duration would be more suitable to detect possible differences elicited by distinct training frequencies. In addition, the previous RT experience of the current study’s participants should be considered as intermediate or advanced. As such, an increase in morphological findings may be diminished due to a lower potential for adaptations with the current intensity and load prescribed. In other words, the individuals who participated in the current study may have previously undergone morphological adaptations to their patellar tendon in the early beginner stages of their RT experiences.

For tendon force, both conditions displayed significant increases in the pre to post-intervention moments, although a larger increase in force parameters was noted for the 2x condition. Within an equated-volume condition, the only difference between the 2x and 4x was the intervention time, being 4 weeks (4x) vs 8 weeks (2x). A longer period of mechanical load suffered by the tendon tissue may favor adaptations related to the increase in the synthesis and renewal of matrix proteins, with special emphasis on collagen and consequently inducing greater force production (1,14). However, more studies need to be carried out to investigate the influence of time on the force production of the patellar tendon.

From an individual standpoint, a large number of participants responded above SWC in the 2x than 4x condition. It can be suggested that an eventual higher stress accumulation for tendon tissue in the 4x might have influenced a larger number of individuals in the strength testing. However, such hypothesis requires further investigation with specific analysis. It can also be noted that these significant increases in force were not accompanied by a concomitant tendon morphological adaptation. Indeed, our results confirm previous human studies that have shown that: (i) RT over 12–14 weeks that produces increases in muscle strength of up to 21% did not result in an accompanying increase in tendon CSA (24,25); (ii) a weak and non-significant correlation exits between strength and tendon CSA increases (32). Then, in addition to neural and muscle morphological adaptations, these strength increments may also be justified by changes in tendon increased stiffness as previously described (19).

The absence of further studies investigating the effects of RT frequency on tendinous adaptations limit possible comparisons with our findings. The similar results in tendon CSA and length noted for both conditions might be explained by the same accumulated TLL during the experimental intervention. In fact, different RT frequencies with the same TLL induce similar muscle strength and morphological adaptations (9,31). Then, it can be suggested that tendon CSA tends to respond in a similar fashion that muscle morphological adaptations, although such hypothesis requires further investigations.

The present study has some limitations. First, the 4 and 8-week period adopted might not have been long enough to induce significant differences in the variables assessed. Second, only 1 exercise (knee extension) was performed during the whole intervention period. Then, eventual different responses induced by the addition of other exercises must not be discarded. Third, these results must not be extrapolated to other populations with different characteristics, such as teenagers, which might eventually experience some benefits due to increased hormone levels. Additionally, our sample was considered as being recreationally trained. Future studies with high-level participants may provide further insight in this topic. Although all subjects already performed the knee extension exercise within their usual training routines, further information regarding characteristics of their training programs (e.g. intensity, volume) was not collected, which consists of a relevant limitation of our study. Therefore, it should not be completely discarded that the effects observed in some of the participants are due to the novelty of the stimulus rather than the intervention itself. It is also important to note that the present study limited to assess changes in tendon CSA in only one site (the midpoint between the apex of the patella and the tibial tuberosity). This methodological characteristic should be considered in an attempt to compare these findings with other investigations, since a significant non-uniform morphological adaptation induced by mechanical loading was previously described in human tendons, especially near to the osteo-tendinous junctions (5). In this sense, one can assume that our study examined tendon size in a region that might be unresponsive to training-associated adaptation (5). Therefore, future studies assessing different tendon´s sites must be encouraged in order to better understand eventual morphological adaptations induced by distinct RT frequencies. Finally, no nutritional control was adopted during the intervention period, although participants were asked to maintain their usual nutritional habits.

In conclusion, the findings of the present study suggest that the knee extension exercise performed 2 or 4x/week induces similar patellar tendon morphological responses. Although both training frequencies (2 vs 4 weekly sessions) seem to induce significant improvements in tendon force, a lower training frequency may be more suitable, especially for recreationally trained individuals that cannot be committed to higher-frequency approaches. From a practical standpoint, strength and conditioning coaches should consider adopting both training frequencies to result in tendon morphological outcomes. In addition, practitioners' personal preferences regarding RT frequency can also be considered when designing RT programs.

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