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Section II - Exercise Physiology & Sports Medicine

Acute Effects of Resistance Training with Blood Flow Restriction on Achilles Tendon Thickness

by

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The Achilles tendon is one of the strongest and thickest tendons of the human body. Several studies have reported an immediate decrease in Achilles tendon thickness after a single bout of resistance training. However, the effects of blood flow restriction training on Achilles tendon thickness have not been investigated. The purpose of this study was to investigate the acute effects of different regimens of resistance training on Achilles tendon thickness. Fifty-two participants (27.3 ± 7 years; 177.6 ± 11 cm; 72.2 ± 13.7 kg) were randomly allocated into one of the three groups: low-intensity exercise without (LI, n = 13) and with blood flow restriction (LI-BFR, n = 24), and high-intensity exercise (HI, n = 15). Participants from LI and LI-BFR groups performed four sets (1 x 30 + 3 x 15 reps) at 30% 1RM, while the HI group performed four sets (1 x 30 with 30% 1RM + 3 x 10 reps with 75% 1RM). All groups performed a plantar flexion exercise. For the LI-BFR group, a blood pressure cuff was placed on the dominant calf and inflated at 30% of the individual´s occlusion pressure (47.6 ± 19.8 mmHg). Sonographic images of Achilles tendon thickness were taken at pre, immediately after, 60 min and 24 h following acute bouts of exercise. Achilles tendon thickness was significantly reduced immediately after, 60 min and 24 h post-LI-BFR exercise (pre: 4.4 ± 0.4 mm vs. IA: 3.8 ± 0.4 mm vs. 60 min: 3.7 ± 0.3 mm vs. 24 h: 4.1 ± 0.3 mm; $p < 0.001$), whereas Achilles tendon thickness was unchanged for HI and LI groups ($p > 0.05$). These results suggest that blood flow restriction training may be an effective strategy to stimulate a positive response in Achilles tendon thickness.

Key words: *tendon morphology, low-load exercise, injury, ultrasonography, occlusion training, rehabilitation.*

Introduction

The Achilles tendon (AT) is one of the strongest and thickest tendons of the human body (Maffulli, 1999), and together with the calf muscles (muscle-tendon complex) allows to perform basic and functional activities such as walking, running and jumping. This is possible not only through its force transmission (Reeves et al., 2003), but also the energy storage and return during locomotion (Ishikawa et al., 2005; Lichtwark and Wilson, 2005). The tendons are stiff and resilient, with high tensile strength (Tai and Williams, 2007). Additionally, the tendons themselves may have an inherent mechanism for regulation of force transmission by an active contraction–relaxation mechanism (O'Brien, 2005). For this reason, the AT is subjected to considerable mechanical stress and, consequently, its vulnerability to injury is higher than other human tendons (Kongsgaard et al., 2005).

Scientific literature has shown that morphological and structural properties of the AT may be altered by the mechanical strain (Obst et al., 2013), since different types and doses of exercise may cause different responses in AT properties (Magnusson et al., 2008; Magnusson and Kjaer, 2018). In this sense, several studies have reported that activities such as running and

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jumping, when performed over a long time, may result in higher AT thickness when compared to regular activities (non-runners and non-jumpers) (Bayliss et al., 2016; Magnusson and Kjaer, 2003; Rosager et al., 2002; Shaikh et al., 2012). In fact, this is correlated with an increase in physio-pathological behavior due to tendon tissue degeneration (e.g. risk of tendinitis, tendon rupture, etc.) (Nehrer et al., 1997; Ying et al., 2003; Sponbeck et al., 2017). Additionally, this morphological change in human tendons is associated with an increase in collagen type I synthesis and fibrocartilage formation (Magnusson and Kjaer, 2003), although more studies are needed to elucidate this claim. In contrast, other studies have reported an immediate and transitory decrease in AT thickness after a single bout of resistance training (RT) (20 to 250% of bodyweight), which is associated with an acute positive response from the tendon (Grigg et al., 2009; Iwanuma et al., 2011; Wearing et al., 2014). These acute changes seem to be associated with the dehydration of the tendon, as well as the movement of fluid in the extracellular matrix of these structures (Cook and Purdam, 2009), as a consequence of the alignment of the collagen fibers that occurs after resistance exercise (Wearing et al., 2008). Thus, the reduction in AT thickness may represent an important marker of tendon adaptation. Likewise, this morphological change may be a positive response of the tendon to inflammation, which may be possible to register by structural changes in the AT measured by ultrasound images (Cook and Purdam, 2009; Kannus, 1997; Maffulli et al., 2003).

A body of evidence has supported that high-load exercise induces mechanical stress which can expose tendon structures to a higher risk of injury than low-load exercise (Magnusson et al., 2008; Milgrom et al., 2014). Therefore, the use of different training regimens with low or moderate loads can attenuate the strain on tendon structures and preserve its components. In recent years, new studies have demonstrated the effectiveness of low-intensity resistance training associated with blood flow restriction (LI-BFR) as an alternative strategy to high-intensity resistance training [>75% of one repetition maximum (RM)] in order to achieve muscle hypertrophy and strength gains (Loenneke et al., 2012a; Scott et al., 2016). In addition, LI-BFR-induced neuromuscular adaptations are superior when compared to LI only (Abe et al., 2005; Slysz et al., 2016; Takarada et al., 2002). However, the acute effects of LI-BFR on AT thickness have not yet been investigated, despite the morphological responses on AT in asymptomatic individuals after this type of training may have important implications for functional performance (daily life activities such as walking or climbing stairs), injury prevention and performance in competitive sports (Wilk et al., 2018). Previous studies have observed that the ischemia caused by LI-BFR exercise provides an adequate stimulus for improving bone metabolic markers due to fluid movement and an increase in intramedullary pressure (Loenneke et al., 2012b, 2013). In this sense, we speculated that the benefits of LI-BFR on bone could be extended to the AT structure. Additionally, given that neuromuscular adaptation induced by LI-BFR is higher than LI only, we believed that a relationship in transmission of force between muscle-tendon may be much more efficient when LI-BFR is being applied, although no study with LI-BFR has been conducted. In addition, some studies have reported that the use of BFR alone attenuated disuse muscle atrophy and the weakness caused by immobilization (Takarada et al., 2000a; Kubota et al., 2008), it has been also used in rehabilitation of the anterior cruciate ligament (Iversen et al., 2016; Ohta et al., 2003). Therefore, the purpose of this study was to investigate the acute responses of different regimens of RT with and without blood flow restriction on AT thickness.

Methods

Participants

Fifty-two recreationally active young subjects (33 men, 19 women; 27.3 ± 7 years; 177.6 ± 11 cm; 72.2 ± 13.7 kg) were recruited to participate in this study. The participants' characteristics are detailed in Table 1. Prior to the commencement of the study, all participants completed a pre-screening questionnaire, and they were instructed to refrain from physical activity and alcohol consumption, caffeine and/or other performance stimulants 48 h before testing. A medical history of diabetes, hypercholesterolemia, neuromuscular disorders and Achilles tendon pain or previous injury in the Achilles tendon were defined as exclusion criteria. All participants completed a medical health history form and provided written informed consent document which described all the procedures of the intervention. This study was carried out in accordance with the Declaration of Helsinki and approved by the Institutional Review Board.

Experimental Design

A familiarization session was completed by all participants one week prior to the experimental trials. During that session, participants were familiarized with the training protocols and sonographic examination of the AT. Then, participants attended the laboratory on three separate visits. During the first visit, following 15 min of rest, anthropometric measurements, arterial occlusion pressure (AOP) and one repetition maximum (1RM) tests in the unilateral calf plantar flexion exercise were performed. Three experimental trials were conducted in particular groups: low-intensity exercise (LI, n = 13); low-intensity exercise with blood flow restriction (LI-BFR, n = 24), and high-intensity exercise (HI, n = 15). Each trial was completed within 72 h after the first visit. Achilles tendon thickness was measured at pre- and post-exercise. Participants were instructed to keep normal hydration and refrain from physical activities 48 h before the experiment.

Exercise Trials

Prior to testing, all participants completed a standardized warm-up that consisted of five minutes on a bicycle ergometer at 70 W, followed by two sets of 15 repetitions of unilateral plantar flexion exercises in the dominant leg, at ≤ 20% 1RM. Thereafter, participants from LI and LI-BFR groups performed four sets (1 x 30 + 3 x 15 reps) at 30% 1RM, with 60 s rest intervals between sets, whereas participants from the HI group performed four 4 sets (1 x 30 at 30% 1RM + 3 x 10 reps at 75% 1RM) with 90 s rest intervals between sets. The exercise trials were performed on a leg press exercise machine. All sets of the exercises were completed with the total phase of the contraction cycle lasting 3 s (1.5 s concentric; 1.5 s eccentric), being monitored by a digital metronome. These protocols have been previously reported in the BFR studies (Martín-Hernández et al., 2013; Picón-Martínez et al., 2018). For the LI-BFR trial, a blood pressure cuff was positioned on the dominant calf and inflated at 30% of the individual AOP (47.6 ± 19.8 mmHg) during the exercise, however, the cuff was deflated during rest intervals between sets.

One Repetition Maximum Test (1RM)

The one-repetition maximum strength (1RM) test of plantar flexion muscles was performed (a leg press exercise) with participants in a seated and horizontal position. Initially, a neuromuscular warm-up was conducted with participants being instructed to perform the movement in a full range of motion and to avoid assistance from any other body part (e.g. the thigh). Then, participants performed eight repetitions with a load estimated to 50% 1RM. Next, participants performed five repetitions at ~75% 1RM. A three-minute rest interval was allowed between sets. Thereafter, the loads were adjusted individually, and participants were instructed to perform repetitions until volitional failure. If more than five repetitions were completed successfully, the load was increased by 5%. If participants were unable to complete the five repetitions, 1RM was estimated by Epley's formula (1RM = load [kg] * [1 + (0.033 * number of repetitions)]), used in previous studies (Martín-Hernández et al., 2013; Picón-Martínez et al., 2018). A five-minute rest interval was allowed between the five attempts.

Determination of Arterial Occlusion Pressure (AOP)

Prior to determining the arterial occlusion pressure, participants rested for ~10 min, in a supine position and in a temperature-controlled room. Following this period, a pneumatic cuff (57 cm length x 9 cm width; Riester Komprimeter, Riester, Jungingen, Germany) was placed on the dominant leg under the knee joint, while the ultrasound probe (US-B, Logiq-e; General Electric Healthcare, Wauwatosa, WI, USA) was positioned over the posterior tibial artery to capture its auscultatory pulse. Then, the cuff was progressively inflated up to the point at which the pulse was interrupted. This point was established as the AOP value [mmHg] (Gualano et al., 2010).

Sonographic Imaging

Sonographic examination of the Achilles tendon from the dominant leg was performed by a specialized physiotherapist in musculoskeletal ultrasound using a 10 MHz linear-array transducer (US-B, Logiq-e; General Electric Healthcare, Wauwatosa, WI, USA) and a standardized imaging protocol. Participants were positioned in a prone position with their ankle passively at 90º to their leg (Wearing et al., 2011). The thickness of the Achilles tendon was scanned transversely with the transducer perpendicular at 3 cm proximal to the insertion of the tendon into the calcaneus, which was coated with conductive gel (Grigg et al., 2009). This point was chosen for measurement in accordance with previous research which indicated that the thinnest and most visible part of the tendon is ~2 to 6 cm above the insertion into the calcaneus (Fredberg et al., 2008). Sonographic images were taken pre, immediately after, 60 min and 24 h post-exercise. Test-retest reliability was examined using intra-class correlation coefficients (ICCs). Twelve images of the Achilles tendon thickness were evaluated by the same researcher and at the same time of day. A one-way intra-class correlation reliability was 0.963.

Statistical Analysis

All data are presented as means and standard deviation (SD) with their respective confidence intervals. The Shapiro-Wilk and Levene's tests were used to evaluate normal distribution and to verify homogeneity of variance. A two-way analysis of variance (ANOVA) with repeated measures for group and time was carried out for dependent variables. Significant interactions between trials were analyzed using a DMS post-hoc test. A t-test for paired samples was used across time within each group. Effect size was calculated using Hedges' G, and the data obtained were categorized as follow: no effect ($d < 0.2$), small effect ($d < 0.5$), medium effect ($d < 0.8$), or large effect ($d > 0.8$). Statistical significance was set at $p < 0.05$. All data were analyzed using SPSS version 17.0 software packages.

Results

There was no significant difference between trials for Achilles tendon (AT) thickness at baseline ($p > 0.05$). There was a time effect ($p = 0.002$) and interaction for AT thickness ($p = 0.0001$) between trials. AT thickness was significantly reduced only in the LI-BFR group from pre- to immediately post-exercise (95% IC: 3.6 to 3.9; ES: $d = 1.54$, $p < 0.001$), post-60 min (95% IC: 3.5 to 4.0; ES: $d = 1.29$, $p < 0.001$) and post-24 h (95% IC: 3.9 to 4.2; ES: $d = 0.85$, $p = 0.002$). In addition, AT thickness was significantly lower in the LI-BFR group when compared to the HI group immediately after ($p = 0.003$) and 60 min post-exercise ($p = 0.012$) (Table 2).

Table 1

Physical characteristics of the participants

	HI	LI	LI-BFR
N	15	13	24
Age (yr)	26.9 (8.5)	27.8 (8.7)	24.4 (3.9)
Height (m)	1.80 (11.0	1.75 (11.0)	1.78 (11.0)
Body mass (kg)	73.4 (12.0)	70.5 (16.2)	72.7 (13.0)
Body mass index (kg·m^2)	23.9 (3.0)	23.8 (3.7)	22.8 (2.7)
Arterial Occlusion pressure (AOP) (mmHg)	-	-	158.8 (66.0
30% of AOP (mmHg)	-	-	47.6 (19.8)

Values are presented as Mean (SD). HI: High-intensity, LI: Low-intensity, LI-BFR: Low-intensity associated with blood flow restriction.

Table 2

Acute effects of resistance exercise groups on Achilles tendon thickness (mm).

Group	**Pre** (mm)	**IA** (mm)	**60 min** (mm)	**24 h** (mm)
HI (n = 15)	4.5 (0.7)	4.5 (0.8) ‡	4.4 (0.9) ‡	4.4 (0.7)
LI (n = 13)	4.0 (0.6)	4.1 (0.8)	4.0 (0.7)	4.2 (0.7)
LI-BFR (n = 24)	4.4 (0.4)	3.8 (0.4) **#	3.7 (0.3) **#	4.1 (0.3) *

*All data are presented as Mean (SD). HI: High-intensity, LI: Low-intensity, LI-BFR: Low-intensity associated with blood flow restriction. IA: Immediately after exercise. ** denotes statistically significant difference from pre value (p<0.001). * denotes statistically significant difference from pre value (p<0.05). #denotes statistically significant difference from the HI protocol (p<0.05). ‡ Significant difference between groups (p<0.05).*

Discussion

The main finding of this study was a statistically significant decrease in AT thickness after the LI-BFR protocol, which remained 24 h post-exercise. However, in HI and LI groups no changes in AT thickness were observed.

Several studies have shown that LI-BFR exercise is able to promote increases in strength and muscle size to the same extent as high-intensity RT (Ellefsen et al., 2015; Karabulut et al., 2010; Laurentino et al., 2012; Martín-Hernández et al., 2013; Takarada et al., 2000b). However, little is known regarding the acute effects of LI-BFR exercise on AT thickness.

Recently, Magnusson et al. (2018) suggested that the human tendon needs a certain magnitude of loading in order to obtain positive changes in the extracellular matrix and, consequently, in its mechanical and morphological properties. For this reason, it is necessary to identify what type of exercise and loading may be most beneficial to reduce the AT injuries incidence rate. Previous research has demonstrated an acute and transitory reduction in AT thickness immediately after a single bout of resistance training using concentric and eccentric exercises with different loads [i.e. between 100 and 150% body weight] (Grigg et al., 2009; Wearing et al., 2008, 2011, 2014). This reduction has been attributed to a positive morphological response from the tendon to mechanical stress. In addition, Maffulli et al. (2003) reported an increase in tendon thickness under a condition of tendinopathy using ultrasound imaging. However, the mechanisms underlying morphological changes in the tendon thickness have not been elucidated. We hypothesized that the alignment of the collagen fibers structure might be forced by a shift of fluid. Similar to the musculoskeletal response, BFR may cause a shift of fluid content from the tendon to myocytes. As collagen presents high affinity with the water, for example water content of tendon has been reported in 62.8% (Thorpe and Screen, 2016), thereby, this change could represent a reduction in its diameter. Probably, the movement of fluid into the tendon would increase the proportion of water bound to the macromolecules and hence, it would reduce the amount of free water (Wearing et al., 2011, 2014). This morphological change in tendon structure can be visualized by ultrasound images from the thinnest and most visible part of the tendon, where the percentage of collagen is the greatest (Mahieu et al., 2006). Nevertheless, in this study molecular changes in the structures of collagen in the tendon (e.g. matrix, types of collagen, structure, metabolites of collagen) were not analyzed and thus, this may be considered as a limitation of this study.

Several studies have reported that the mechanical stress of high-load RT induced an increase in hydrostatic pressure within the tendon matrix, and then, a movement of fluid from the tendon itself to the peritendinous space (Helmer et al., 2006; Magnusson et al., 2018; Obst et al., 2013). In contrast, repeated mechanical stresses of high-load RT on the tendon structure required in sports (i.e. running, jumping, frontal and lateral displacements) over years of practice, may provoke disturbance or rupture in tendon structures and, consequently, increase the incidence of injuries (Cook and Purdam, 2009; Magnusson and Kjaer, 2003). Our data failed to show a reduction in AT thickness following high-intensity resistance exercise. This discrepancy of findings of this study compared to other research may be attributed to different biological factors such as age, hydration status, exercise-induced collagen damage. In this sense, and in accordance with our findings, previous studies have reported no change in AT thickness following resistance training using high load exercise (Fredberg et al., 2008).

Although the role of effects of a single bout of resistance exercise on morphological changes in tendon structure is unclear, its reduction after exercise has been reported as beneficial (Grigg et al., 2009; Wearing et al., 2014). The findings of this study pointed to a significant reduction in AT thickness immediately after the exercise in the LI-BFR trial and it was maintained up to 24 h after exercise. During the last decades, LI-BFR training has been proposed as a more tolerable training methodology to high-intensity RT for elderly individuals, as well as musculoskeletal and joint rehabilitation due to its low-load mechanical stress on joints (Hughes et al., 2018). For example, a recent study highlighted positive effects of LI-BFR on tendon repair after surgery (Yow et al., 2018) and patellofermoral pain (Giles et al., 2017).

These preliminary findings suggest the inclusion of LI-BFR in the *continuum* of tendon pathology rehabilitation strategies because it does not elicit an inflammatory response. We propose two possible mechanisms: first, the strengthening of muscles involved in tendon pathology; and second, the shift of water in the tendon, although this mechanism should be confirmed in future investigations.

We believe that these findings encourage the use of LI-BFR exercise for rehabilitation setting and other conditions where individuals need returning to regular activities of daily life and training conditions as fast as possible. Additionally, the reduction of AT thickness also has positive implications on sport performance since this strategy can be used as a complementary method to conventional and specific training of each sport in order to improve the relationship in transmission of force between muscle-tendon, improving the specific motor abilities related to a particular sport and reducing the risk of injury due to the minor mechanic stress caused by the low-intensity exercise (Wilk et al., 2018, 2020a, 2020b). Whether these positive acute effects of LI-BFR on the morphological properties of AT would extend to long-term adaptations of tendon structures remains unknown.

This study presents some limitations. Firstly, AT thickness was measured only at one specific point (at 3 cm proximal to the insertion of the tendon into the calcaneus) and thus, the results obtained may not be generalized to other locations on the tendon. Second, in the current study, we did not evaluate markers of collagen turnover or peak collagen metabolism to explore possible mechanisms for reduction of AT thickness following resistance training regimens. Finally, the ample size from each group may have decreased statistical power.

Conclusions

The findings of the present study showed that an acute single bout of resistance training with blood flow restriction induced a reduction in AT thickness in asymptomatic individuals, with no morphological changes in AT thickness in the LI and HI groups.

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