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Acute Musculoskeletal Responses to Isometric Blood Flow Restriction Training of the Patellar Tendon in Healthy, Active Young Adults: A Randomized Controlled Trial

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Abstract

Objective: This study aimed to investigate the acute patellar tendon (PT) responses to different isometric resistance training regimens in healthy individuals, with a particular focus on low-intensity blood flow restriction training. Design: Randomized controlled experimental study. Methods: Sixty-six participants (22.3 ± 3 years) were randomly assigned to one of three groups: high-intensity isometric exercise (HI; 70% maximal voluntary isometric contraction [MVIC]), low-intensity isometric exercise with sham blood flow restriction (LI-Sham; 30% MVIC + 20 mmHg), or low-intensity isometric exercise with blood flow restriction (LI-BFR; 30% MVIC + 80% arterial occlusion pressure [AOP]). All participants performed five sets of 30-s isometric knee extensions. Patellar tendon thickness was assessed using ultrasonography at three sites (25%, 50%, and 75% of tendon length) before and immediately after exercise. Vastus medialis thickness and MVIC were also assessed. Results: Patellar tendon thickness decreased significantly over time, with a significant Group × Time interaction ($F(2, 315) = 27.94$, $p < 0.001$). When averaged across measurement sites, the estimated reductions were −0.586 mm in HI, −0.545 mm in LI-BFR, and −0.242 mm in LI-Sham. Reductions were greater in HI and LI-BFR than in LI-Sham (both Holm-adjusted $p < 0.001$), whereas no statistically significant difference was detected between HI and LI-BFR (Holm-adjusted $p = 0.416$). Vastus medialis thickness showed significant Time and Group × Time effects (both $p < 0.001$), with greater increases in HI and LI-BFR than in LI-Sham. No significant Time or Group × Time effects were observed for MVIC ($p = 0.100$ and $p = 0.409$, respectively). Conclusions: A single session of LI-BFR induced an acute reduction in ultrasound-measured PT thickness that was greater than that observed with LI-Sham. No statistically significant difference in tendon-thickness change was detected between LI-BFR and HI; however, this finding should not be interpreted as evidence of equivalence. These findings are limited to immediate responses in healthy young adults and should not be interpreted as evidence of long-term tendon adaptation or clinical benefit.

Keywords: low-intensity resistance exercise; isometric contraction; ultrasonography; rehabilitation; vascular occlusion; tendon morphology

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1. Introduction

The patellar tendon (PT) is essential for knee extension and force transfer during dynamic activities such as walking, running, and jumping [1]. However, athletes frequently experience PT injuries, including patellar tendinopathy ("jumper's knee") and tendon tears, which may be associated with inappropriate or excessive mechanical loading [2].

The patellar tendon, like other soft tissues, exhibits morphological and mechanical adaptations to exercise that vary according to loading intensity and duration [3–7]. For example, long-term changes in tendon morphology may occur in response to repeated mechanical loading through mechanotransduction-related processes [3,8,9]. In contrast, acute decreases in tendon thickness have been associated with short-term physiological responses to loading, including changes in tendon fluid distribution [10–12]. Ultrasonography can be used to assess exercise-related changes in tendon morphology [2].

Higher mechanical loads have also been shown to acutely decrease tendon thickness following exercise [12,13]. However, the clinical or adaptive significance of an acute reduction in tendon thickness remains unclear. Exercise-based loading remains an important component of patellar tendinopathy management, although responses may depend on the type and intensity of exercise [14,15]. Visnes et al. (2005) demonstrated that elite athletes with patellar tendinopathy were unable to endure or advance their rehabilitation programs during competitive seasons due to the excessive loading of the patellar tendon during matches, ultimately leading to suboptimal clinical outcomes [16]. Furthermore, traditional types of dynamic exercises (concentric and eccentric) are still the cornerstone of building tendon endurance and strength, although eccentric exercises may be painful at first [14,17,18]. Therefore, alternative rehabilitation strategies that provide an adequate training stimulus while minimizing symptom aggravation or joint stress may be useful, particularly during early or painful stages of rehabilitation [19,20].

The use of blood flow restriction training (BFRT) has gained increasing attention recently as a rehabilitation technique, utilizing relatively low mechanical loads (e.g., 20–40% of the one-repetition maximum) with partial vascular occlusion [19–21]. One proposed advantage of BFRT is its ability to promote strength and hypertrophy adaptations using lower external loads than traditional high-load resistance training [22–24]. A systematic review with meta-analysis suggested that BFRT may be a useful adjunct in the rehabilitation of painful musculoskeletal disorders, particularly when knee pain is aggravated by conventional strength training exercises [20]. Furthermore, recent reviews indicate the potential benefits of BFRT in both healthy and pathological tendons, with several trials examining its effects [25,26]. More recently, a scoping review of 19 studies involving both healthy individuals and individuals undergoing tendon rehabilitation reported contradictory findings regarding tendon-related outcomes following BFRT, highlighting the need for cautious interpretation of the current evidence [26].

Evidence from knee rehabilitation also provides relevant clinical context. A systematic review and meta-analysis of randomized controlled trials following anterior cruciate ligament reconstruction reported improvements in pain, patient-reported knee function, and isokinetic muscle strength with BFR compared with non-BFR rehabilitation, although effects on quadriceps muscle volume were not significant [27]. More specifically, in males with chronic patellar tendinopathy, a randomized clinical trial reported clinically relevant improvements in pain and VISA-P scores following both low-load BFR training and heavy slow resistance training [19].

BFR has been proposed to influence cellular responses relevant to tendon biology, including fibroblast activity and collagen turnover [19]; however, these mechanisms remain incompletely understood and were not directly assessed in the present study. In addition to eccentric exercise, alternative contraction modalities such as isometric exercise warrant

investigation [28]. In a related context, a single bout of isometric exercise has been reported to provide temporary pain relief and improve strength-related and neural outcomes in individuals with patellar tendinopathy [29,30].

While the acute effect of BFRT on PT thickness remains under-researched, the present study aimed to compare the acute effects of HI, LI-BFR, and LI-Sham protocols on PT thickness in healthy young adults. We hypothesized that LI-BFR would induce an acute reduction in patellar tendon thickness and that the magnitude of this reduction would be greater than that observed following LI-Sham.

2. Methods

2.1. Participants

Sixty-six healthy young adults (36 men and 30 women; age: 22.3 ± 3 years; body mass: 70 ± 11 kg; height: 172 ± 9 cm) with no previous BFR experience were recruited between October 2025 and April 2026 through posters, social media announcements, and email distribution. Participant characteristics are presented in Table 1. Eligible participants were healthy men and women aged 18–40 years. Exclusion criteria included current musculoskeletal injury, cardiovascular disease, inability to complete the experimental protocol, diagnosis of patellar tendinopathy within the previous six months, and contraindications to blood flow restriction, including pregnancy, thrombosis, excessive varicose veins, or a prosthesis in the region to be occluded.

Table 1. Physical characteristics of the participants.

	HI	LI-BFR	LI-Sham
N	22 (10 F,12 M)	22 (11 F,11 M)	22 (9 F,13 M)
Age (yr)	21.9 ± 2.73	22.8 ± 2.92	22.2 ± 3.49
Height (m)	1.71 ± 0.043	1.73 ± 0.055	1.73 ± 0.061
Arterial occlusion pressure (AOP) (mmHg)	-	139.5 ± 22.1	-
Body mass (kg)	70.0 ± 9.73	70.1 ± 11.48	71.0 ± 9.04
Baseline MVIC (N)	504.7 ± 120.1	522.7 ± 102.4	523.3 ± 122.1
BMI (kg/m^2)	23.74 ± 2.42	23.29 ± 2.29	23.36 ± 1.99

Values are presented as Mean ± SD. AOP was determined only for the LI-BFR group because the LI-Sham condition used a fixed cuff pressure of 20 mmHg rather than an individualized pressure relative to AOP. HI: high-intensity, LI-BFR: low-intensity with blood flow restriction, LI-Sham: low-intensity with sham blood flow restriction.

The study was approved by an institutional Human Research Ethics Committee (Ref. 2025-FIS-3834518; 6 October 2025) and was conducted in accordance with the Declaration of Helsinki. Before participation, all participants completed a medical health history form and provided written informed consent.

An a priori power analysis was conducted using G*Power (version 3.1.9.7) for the primary outcome of patellar tendon thickness based on a repeated-measures ANOVA with a within–between interaction. In the absence of suitable prior data from comparable studies on which to base the expected effect, an effect size of f = 0.25 was selected as a conventional medium effect-size assumption for the a priori sample-size calculation; with an alpha level of 0.05, statistical power of 0.95, three groups, two repeated measurements, a correlation of 0.50 among repeated measures, and a nonsphericity correction of 1, the required total sample size was 66 participants. A total of 66 participants were assessed for eligibility, and all met the inclusion criteria. All 66 participants were randomized (22 per group), received the allocated intervention, completed the study protocol, and were included in the final analysis. No participants were excluded or lost to follow-up.

2.2. Experimental Design

The study was conducted by qualified personnel in an appropriately equipped physiotherapy laboratory at the University of Valencia, Valencia, Spain. The study was designed to specifically examine the immediate response to a single isometric exercise session rather than longer-term training adaptations.

The study was retrospectively registered at ClinicalTrials.gov (NCT07848048; protocol ID: UVAL-BFR-2025-01) on 22 September 2026. The research team inadvertently overlooked prospective registration because it initially considered institutional ethics approval sufficient. Following clarification of the journal's requirements, the study was registered to ensure transparency and compliance with publication standards.

The experimental protocol consisted of two laboratory visits separated by 48 h. During the first visit, participants provided personal data and completed baseline assessments. Participants were randomly allocated in a 1:1:1 ratio to three experimental groups (HI, LI-BFR, and LI-Sham) using manual block randomization with a fixed block size of three. For each block, three identical folded paper slips, one per condition, were prepared and mixed in a container one day before allocation. Participant attendance was independently coordinated by a different researcher, who scheduled three participants per day and was not involved in preparing the slips. The three participants simultaneously drew one slip each, and allocations remained concealed from both participants and the examiner until all three participants had completed their selections. This procedure resulted in 22 participants per group ($n = 66$). The CONSORT 2025 checklist and participant flow diagram are provided in Supplementary Files S1 and S2, respectively. These reporting materials follow the CONSORT 2025 guidance [31].

The three experimental conditions were high-intensity isometric exercise (HI; 70% MVIC), low-intensity isometric exercise with blood flow restriction (LI-BFR; 30% MVIC with the cuff inflated to 80% of the individual AOP), and low-intensity isometric exercise with sham BFR (LI-Sham; 30% MVIC with the cuff inflated to 20 mmHg).

Baseline ultrasonographic assessments of patellar tendon and vastus medialis thickness were performed, followed by determination of AOP when applicable and assessment of knee-extension MVIC. Participants were instructed to maintain normal hydration and refrain from physical activity throughout the 48-h period between visits.

Forty-eight hours later, participants returned to the laboratory and completed their assigned exercise protocol. After completing the exercise intervention, post-intervention assessments of patellar tendon thickness, vastus medialis thickness, and MVIC were performed. Ultrasonographic measurements were initiated immediately after exercise, as detailed below. No concomitant interventions were provided during the study. Patellar tendon thickness was the primary outcome, while vastus medialis thickness and MVIC were secondary outcomes.

2.3. Exercise Trials

Before the exercise trials, all participants completed a standardized 5-min warm-up on a stationary bicycle (Technogym Bike, Technogym S.p.A., Cesena, Italy). Participants were then seated on an isometric knee-extension apparatus equipped with an adjustable chair and a 500-kg MuscleLab force sensor (Ergotest Ltd., Oslo, Norway), with the knee flexed to 90°. All exercise trials were performed using the dominant leg, defined as the leg participants preferred to use to kick a ball.

Participants completed five 30-s isometric knee extension contractions, with 60-s of rest between sets. During each contraction, participants viewed real-time force output on a computer screen and adjusted their effort to maintain the prescribed target force. The HI group exercised at 70% of MVIC, the LI-BFR group exercised at 30% of MVIC with the

cuff inflated to 80% of the individual AOP, and the LI-Sham group exercised at 30% of MVIC with the cuff inflated to 20 mmHg. The BFR load and relative occlusion pressure were selected in accordance with established BFR methodological recommendations and previous isometric BFR research [32,33].

For the LI-BFR and LI-Sham conditions, a pneumatic cuff was positioned proximally on the dominant thigh near the inguinal fold. The prescribed cuff pressure was applied during each 30-s contraction and released during the 60-s inter-set recovery periods [20]. Participants were also monitored for adverse events or discomfort during and following the intervention.

2.4. Determination of Maximum Voluntary Isometric Contraction (MVIC)

Maximal voluntary isometric contraction (MVIC) of the knee extensors was assessed on the dominant leg using an isometric knee dynamometer equipped with a force sensor. Force was recorded using a 500-kg MuscleLab force sensor (Ergotest Ltd., Oslo, Norway) at a sampling frequency of 200 Hz, together with the associated MuscleLab software 10.213.98.5188. Before testing, participants completed a standardized 5-min warm-up on a stationary bicycle. Participants were seated and securely stabilized on the dynamometer with the knee flexed to 90°. The resistance pad was positioned against the anterior aspect of the tibia, proximal to the ankle malleoli.

Participants were instructed to exert their maximum possible force against the fixed resistance by performing a maximal isometric knee-extension effort for 3–5 s. Participants performed two MVIC trials separated by 60–90 s of rest. The highest peak force recorded across the two trials was defined as the participant's MVIC and was subsequently used to determine the prescribed exercise intensity for each experimental condition. MVIC was reassessed following completion of the exercise intervention using the same testing procedure.

2.5. Determination of Arterial Occlusion Pressure (AOP)

Arterial occlusion pressure (AOP) was determined using a Samsung HS30 (Samsung Medison Co., Ltd., Hongcheon-gun, Republic of Korea) ultrasound system equipped with an LN5–12 linear-array transducer (Samsung Medison Co., Ltd., Hongcheon-gun, Republic of Korea). Before AOP assessment, participants rested for approximately 10 min in a supine position in a temperature-controlled environment to allow stabilization of vascular tone. A pneumatic cuff (96 × 13 cm; Riester Komprimeter, Riester, Jungingen, Germany), connected to a manometer with a pressure range of 0–700 mmHg, was positioned proximally on the dominant thigh, near the inguinal fold.

Arterial blood flow was monitored over the femoral artery using color Doppler ultrasonography mode (Samsung Medison Co., Ltd., Hongcheon-gun, Republic of Korea). The cuff was progressively inflated until the arterial blood-flow signal was no longer detectable. The pressure at which blood flow disappeared was defined as 100% of the individual AOP and was used to determine the prescribed cuff pressure for the LI-BFR condition. During the exercise trials, the cuff was inflated to 80% of the individual AOP during each 30-s contraction and deflated during the 60 s inter-set recovery periods. In the LI-Sham condition, participants exercised at 30% MVIC with the cuff inflated to 20 mmHg during each contraction and deflated during the inter-set recovery periods. Individualized AOP determination and the use of relative occlusion pressure were performed in accordance with established BFR methodological recommendations [33]. AOP was not determined for the LI-Sham group because the sham pressure was fixed at 20 mmHg rather than individualized relative to AOP.

2.6. Ultrasonography Imaging

Ultrasonographic assessments of patellar tendon and vastus medialis thickness were performed on the dominant leg using a Samsung HS30 ultrasound system equipped with an LN5–12 high-frequency linear-array transducer (5–12 MHz). Ultrasonography has previously been used to assess acute exercise-related changes in Achilles tendon thickness following low-load BFR exercise [11,34]. All ultrasound assessments were performed by the same examiner, a physiotherapist and researcher, who was blinded to group allocation during image acquisition and measurement but was not blinded to the measurement time point.

For patellar tendon assessment, participants were positioned supine with the knee maintained in slight flexion to allow the tendon to remain relaxed. The patellar tendon was visualized longitudinally in B-mode between the inferior pole of the patella and the tibial tuberosity. Total tendon length was defined as the distance between these two anatomical landmarks. At each assessment, one longitudinal image encompassing the patellar tendon was acquired and frozen for measurement. Three separate regional thickness measurements were obtained from the same image at locations corresponding to 25%, 50%, and 75% of the total tendon length to provide standardized assessments across the proximal, middle, and distal tendon regions, respectively. Thus, these measurements represented three distinct locations along the tendon rather than repeated measurements of the same location. A single thickness measurement was obtained at each tendon site; therefore, no within-site averaging was performed. Conductive gel was applied, and minimal transducer pressure was used to avoid compression of the underlying tissue. Thickness was measured perpendicular to the superficial and deep tendon borders using the ultrasound system's built-in electronic calipers.

For vastus medialis assessment, participants were positioned supine with the knee maintained in slight flexion. The transducer was positioned over the anteromedial aspect of the thigh, approximately 3–5 cm proximal to the superior border of the patella. The patella and adjacent quadriceps structures were used as anatomical landmarks to identify the vastus medialis and standardize probe placement. The muscle was initially identified in the transverse plane, and muscle thickness was measured perpendicular to the fascial borders using the ultrasound system's built-in electronic calipers. Conductive gel was applied, and minimal transducer pressure was used to minimize compression of the underlying tissue.

Baseline ultrasonographic measurements were obtained during the first laboratory visit. Forty-eight hours later, participants returned for the second visit and completed their assigned exercise intervention. Post-intervention ultrasonographic measurements were initiated immediately after exercise; participants moved directly from the exercise chair to the examination table located in the same laboratory. No external skin markings were used. At the post-intervention assessment, the measurement locations were re-identified using the same anatomical landmarks and ultrasound-based distance references used at baseline, and the same participant positioning and measurement procedures were reproduced.

All ultrasound assessments were performed by a single examiner; therefore, inter-rater reliability was not applicable. Study-specific intra-rater reliability and measurement error were not formally assessed.

2.7. Statistical Analysis

Descriptive statistics were calculated and are presented as means and standard deviations (SDs), with 95% confidence intervals (CIs) where appropriate. The distribution of the data and homogeneity of variance were assessed using the Shapiro–Wilk and Levene's tests, respectively. Statistical significance was set at $p < 0.05$. All analyses were performed using Jamovi (version 2.6.26).

Patellar tendon thickness was analyzed using a linear mixed-effects model to account for the repeated measurements obtained from each participant across time and tendon measurement sites. Group (HI, LI-BFR, and LI-Sham), time (baseline and post-intervention), and tendon measurement site (25%, 50%, and 75% of tendon length) were included as fixed effects, together with all two-way and three-way interactions. Participant was included as a random intercept.

Overall effects of group, time, site, and their interactions were evaluated using F tests with the Satterthwaite approximation for the denominator degrees of freedom. Estimated changes from baseline to post-intervention were calculated for each group, and direct between-group contrasts of these changes were reported as estimated mean differences with 95% CIs. The *p*-values for the three direct between-group contrasts of change were adjusted using the Holm method to account for multiple comparisons. The absence of a statistically significant difference between groups was not interpreted as evidence of equivalence.

Vastus medialis muscle thickness and MVIC were analyzed using repeated-measures ANOVA, with time (baseline and post-intervention) as the within-subject factor and group (HI, LI-BFR, and LI-Sham) and sex (female and male) as between-subject factors, including their interaction terms. Changes from baseline to post-intervention were estimated for each group, and between-group contrasts of these changes were reported as estimated mean differences with 95% CIs. The *p*-values for the three between-group contrasts were adjusted using the Holm method to account for multiple comparisons.

3. Results

A significant main effect of time was observed for patellar tendon thickness ($F(1, 315) = 498.25$, $p < 0.001$), together with a significant Group × Time interaction ($F(2, 315) = 27.94$, $p < 0.001$), indicating that the magnitude of the acute change in patellar tendon thickness differed among groups. A significant main effect of tendon measurement site was also observed ($F(2, 315) = 55.72$, $p < 0.001$), whereas the main effect of group was not significant ($F(2, 63) = 1.28$, $p = 0.286$). The Group × Site ($F(4, 315) = 0.35$, $p = 0.842$), Time × Site ($F(2, 315) = 0.43$, $p = 0.651$), and Group × Time × Site interactions ($F(4, 315) = 0.06$, $p = 0.994$) were not significant.

When changes were averaged across tendon measurement sites, the estimated reduction from baseline to post-intervention was −0.586 mm (95% CI: −0.656 to −0.516) in the HI group, −0.545 mm (95% CI: −0.615 to −0.476) in the LI-BFR group, and −0.242 mm (95% CI: −0.312 to −0.172) in the LI-Sham group. The difference in change between HI and LI-BFR was −0.041 mm (95% CI: −0.140 to 0.058; Holm-adjusted $p = 0.416$), indicating that no statistically significant difference was detected between these conditions. This finding should not be interpreted as evidence of equivalence. The reduction was greater in HI than in LI-Sham (mean difference: −0.344 mm, 95% CI: −0.443 to −0.245; Holm-adjusted $p < 0.001$) and greater in LI-BFR than in LI-Sham (mean difference: −0.303 mm, 95% CI: −0.402 to −0.204; Holm-adjusted $p < 0.001$).

Vastus medialis muscle thickness showed significant Time and Group × Time effects ($F(1, 60) = 449.52$, $p < 0.001$, $\eta p^2 = 0.882$; $F(2, 60) = 17.77$, $p < 0.001$, $\eta p^2 = 0.372$), with greater increases in HI and LI-BFR than in LI-Sham, while no significant difference was observed between HI and LI-BFR ($p = 0.163$). No significant Time or Group × Time effects were observed for MVIC ($F(1, 60) = 2.79$, $p = 0.100$, $\eta p^2 = 0.044$; $F(2, 60) = 0.91$, $p = 0.409$, $\eta p^2 = 0.029$, respectively). Quantitative changes and 95% CIs are presented in Tables 2–4. No adverse events were reported.

Table 2. Changes in patellar tendon thickness following exercise.

Group	Tendon Site	Baseline Value	Post-Intervention Value	Δ (%)
HI	25%	3.50 ± 0.51	2.90 ± 0.42	−17.14%
	50%	3.33 ± 0.59	2.76 ± 0.54	−17.12%
	75%	3.24 ± 0.54	2.66 ± 0.48	−17.90%
LI-BFR	25%	3.43 ± 0.49	2.85 ± 0.46	−16.91%
	50%	3.22 ± 0.54	2.71 ± 0.45	−15.84%
	75%	3.11 ± 0.54	2.57 ± 0.42	−17.36%
LI-Sham	25%	3.11 ± 0.44	2.84 ± 0.42	−8.68%
	50%	2.98 ± 0.40	2.73 ± 0.34	−8.39%
	75%	2.85 ± 0.36	2.62 ± 0.32	−7.75%

Model-estimated mean tendon changes (95% CI): HI, −0.586 mm (−0.656 to −0.516); LI-BFR, −0.545 mm (−0.615 to −0.476); LI-Sham, −0.242 mm (−0.312 to −0.172). Between-group differences in tendon change: HI vs. LI-BFR, −0.041 mm (95% CI: −0.140 to 0.058; Holm-adjusted $p = 0.416$); HI vs. LI-Sham, −0.344 mm (95% CI: −0.443 to −0.245; Holm-adjusted $p < 0.001$); LI-BFR vs. LI-Sham, −0.303 mm (95% CI: −0.402 to −0.204; Holm-adjusted $p < 0.001$). Note: Data are presented as mean ± SD unless otherwise indicated. Δ% was calculated from the group means as [(post-intervention − baseline)/baseline] × 100 and is presented descriptively. Model-estimated changes and between-group contrasts are presented with 95% CIs.

Table 3. Changes in vastus medialis muscle thickness following exercise.

Group	Baseline Value	Post-Intervention Value	Mean Change (95% CI)
HI	1.043 ± 0.123	1.310 ± 0.115	+0.265 (0.231 to 0.298)
LI-BFR	1.021 ± 0.176	1.252 ± 0.152	+0.231 (0.197 to 0.265)
LI-Sham	1.055 ± 0.160	1.183 ± 0.130	+0.127 (0.093 to 0.161)

Between-group differences in muscle thickness change: HI vs. LI-BFR, 0.034 cm (95% CI: −0.014 to 0.081; Holm-adjusted $p = 0.163$); HI vs. LI-Sham, 0.138 cm (95% CI: 0.090 to 0.186; Holm-adjusted $p < 0.001$); LI-BFR vs. LI-Sham, 0.104 cm (95% CI: 0.056 to 0.152; Holm-adjusted $p < 0.001$). Note: Data are presented as mean ± SD unless otherwise indicated. Mean changes and between-group contrasts are presented with 95% CIs. Vastus medialis muscle thickness is expressed in cm.

Table 4. Changes in maximal voluntary isometric contraction (MVIC) following exercise.

Group	Baseline Value	Post-Intervention Value	Mean Change (95% CI)
HI	504.66 ± 120.14	472.70 ± 94.22	−31.95 (−63.19 to −0.71)
LI-BFR	522.68 ± 102.44	523.41 ± 154.04	+0.73 (−38.83 to 40.29)
LI-Sham	523.30 ± 122.08	505.42 ± 130.76	−17.88 (−50.96 to 15.20)

Between-group differences in MVIC change: HI vs. LI-BFR, −31.52 N (95% CI: −78.72 to 15.68; Holm-adjusted $p = 0.560$); HI vs. LI-Sham, −12.34 N (95% CI: −59.94 to 35.26; Holm-adjusted $p = 0.845$); LI-BFR vs. LI-Sham, 19.18 N (95% CI: −28.33 to 66.68; Holm-adjusted $p = 0.845$). Note: Data are presented as mean ± SD unless otherwise indicated. Mean changes and between-group contrasts are presented with 95% CIs. Abbreviations: HI, high-intensity; LI-BFR, low-intensity with blood flow restriction; LI-Sham, low-intensity with sham blood flow restriction; MVIC, maximal voluntary isometric contraction; CI, confidence interval.

4. Discussion

This is the first study, to our knowledge, to combine isometric exercises with LI-BFR and examine their effects on patellar tendon thickness in a randomized design. The main finding was that all groups demonstrated an acute reduction in PT thickness immediately after exercise. However, the magnitude of this reduction differed among groups, with greater reductions in the HI and LI-BFR groups than in the LI-Sham group. No statistically significant difference in the change in patellar tendon thickness was detected between HI and LI-BFR. Importantly, this non-significant difference should not be interpreted as evidence of equivalence between the two conditions.

Evidence suggests that the human tendon requires a certain magnitude of loading to stimulate changes in the extracellular matrix and its morphological properties [3,9]. The acute reduction in PT thickness may be related to changes in hydrostatic pressure within the tendon's extracellular matrix [10]. Under mechanical loading, fluid, which constitutes

approximately 62.8% of the tendon's composition, may be displaced from the matrix into the peritendinous space [10,11,35]. This fluid redistribution has been proposed as one component of the acute tendon response to mechanical loading [10,11]. However, fluid movement, collagen stress, and cellular responses were not directly measured in the present study, and these mechanisms should therefore be considered potential explanations rather than demonstrated mechanisms.

The greater acute reduction in patellar tendon thickness observed following LI-BFR compared with LI-Sham suggests that the addition of BFR may influence the immediate ultrasound-measured tendon response to low-intensity isometric exercise. One possible explanation may involve the combined mechanical and metabolic environment associated with low-load exercise with BFR. Recent evidence also indicates that BFR can induce distinct acute physiological responses during exercise, including a higher systolic pressor response compared with normobaric hypoxia in healthy young men [36]. Ischemia and lactate accumulation have been suggested to influence collagen metabolism and fibroblast activity. However, these mechanisms were not directly assessed in the present study and therefore remain speculative. Furthermore, although the magnitude of the thickness reduction observed with LI-BFR was numerically similar to that observed with HI, the present findings do not establish equivalence between these conditions.

These findings are consistent with previous studies of the Achilles tendon reporting acute changes in tendon dimensions following mechanical loading [12,13,37,38], suggesting that low-load BFR training may also induce an acute morphological response in the patellar tendon [11,34]. Previous research has also reported significant decreases in Achilles tendon thickness immediately and 24 h after a single LI-BFR exercise session [11,34]. These acute decreases in tendon thickness may reflect fluid redistribution within the tendon following loading [10,11]. However, changes in tendon thickness may have different interpretations and should not, by themselves, be considered evidence of healing or degeneration [2]. More recently, a scoping review of 19 studies reported contradictory tendon-related outcomes following BFR training in both healthy individuals and tendon rehabilitation settings, highlighting the need for cautious interpretation of the current evidence [26]. Research indicates that structural changes may not always accompany clinical improvements, suggesting that functional recovery can occur without morphological adaptations [26]. Nevertheless, the present study measured tendon thickness only and did not assess tendon stiffness, strain, elastic modulus, collagen remodeling, or clinical outcomes. Therefore, the observed acute reduction in thickness should not be interpreted as evidence of tendon healing, long-term structural adaptation, or clinical improvement. Whether these immediate ultrasound-measured changes are associated with longer-term tendon adaptations remains unknown.

Vastus medialis muscle thickness also increased acutely following exercise, with greater increases in the HI and LI-BFR groups than in the LI-Sham group. Acute increases in muscle thickness following a single resistance exercise session have previously been reported [39–42]. Such immediate increases may reflect acute changes in muscle perfusion and swelling rather than muscle hypertrophy [41]. In the context of BFR exercise, increased post-exercise metabolic stress and fluid accumulation have also been proposed to contribute to acute muscle swelling [41,43,44]. Therefore, the increase in ultrasound-measured vastus medialis thickness observed in the present study should be interpreted as an acute morphological response rather than evidence of muscle hypertrophy [45].

In contrast, MVIC showed no significant Time or Group × Time effects. Previous isometric BFR research has shown that acute changes in maximal voluntary force may be transient and dependent on measurement timing [32]. Therefore, the increase in muscle thickness observed in the present study should not be interpreted as a corresponding increase in maximal voluntary force.

Despite the importance of these findings, the present study has several methodological limitations. First, ultrasonography was used to assess tendon and muscle thickness and therefore does not provide direct information regarding tendon mechanical properties such as stiffness, strain, or elastic modulus. Advanced imaging and biomechanical methods may allow a more comprehensive assessment of tendon deformation and mechanical behavior in future studies. Second, the present study investigated only the immediate effects of a single LI-BFR isometric exercise session. Therefore, the findings cannot determine whether the observed acute changes in tendon or muscle thickness translate into long-term structural, mechanical, functional, or clinical adaptations. Future longitudinal studies are needed to address these outcomes.

A further limitation concerns the reliability and precision of the ultrasonographic measurements. Study-specific intra-rater reliability and measurement error were not formally quantified. Although all assessments were performed by the same examiner using a standardized protocol, measurement error was not established using indices such as the standard error of measurement (SEM), typical error, or minimal detectable change (MDC). Therefore, it remains uncertain to what extent the observed millimetre-scale changes in tendon thickness exceeded measurement error. Future studies should report reliability indices and measurement error to facilitate the interpretation of small changes in tendon and muscle thickness. In addition, the exact interval between completion of the exercise protocol and post-exercise ultrasonography was not recorded. Given the acute and potentially time-sensitive nature of tendon-thickness responses, this limits the temporal precision and reproducibility of the post-exercise measurements.

Habitual training characteristics, including weekly training volume, resistance-training experience, and participation in running- or jumping-based sports, were not recorded. Therefore, habitual tendon-loading exposure could not be characterized, which should be considered when interpreting the findings. In addition, caffeine and alcohol consumption, food intake, and time of day were not standardized across testing sessions. These factors may have introduced additional variability in the acute physiological and ultrasonographic responses and should therefore be considered when interpreting the findings. Participant blinding was also not formally assessed; therefore, differences in perception between LI-Sham and LI-BFR cannot be excluded.

5. Practical Implications

A single session of LI-BFR elicited an acute reduction in ultrasound-measured patellar tendon thickness that was greater than that observed with LI-Sham. No statistically significant difference in tendon-thickness change was detected between LI-BFR and HI; however, this finding should not be interpreted as evidence of equivalence between the two conditions. LI-BFR also produced an acute increase in vastus medialis muscle thickness without a significant change in MVIC. These acute findings support further investigation of LI-BFR in longitudinal and rehabilitation studies but should not be interpreted as evidence of long-term tendon adaptation, clinical efficacy, analgesic benefit, or tendon healing. As these findings were obtained in healthy young adults, they cannot be directly extrapolated to individuals with patellar tendinopathy or other tendon pathologies.

6. Conclusions

A single session of LI-BFR induced an acute reduction in ultrasound-measured patellar tendon thickness in healthy young adults. The reduction was greater following LI-BFR than LI-Sham, whereas no statistically significant difference was detected between LI-BFR and HI. However, this finding should not be interpreted as evidence of equivalence between LI-BFR and HI. Vastus medialis muscle thickness also increased acutely, particularly in the

HI and LI-BFR groups compared with LI-Sham, whereas no significant Time or Group × Time effects were observed for MVIC. As this study examined only immediate responses, it remains unclear whether these acute morphological changes translate into long-term structural, mechanical, functional, or clinical adaptations. Further longitudinal research is warranted.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/sports14110508/s1, Supplementary File S1: CONSORT 2025 checklist; Supplementary File S2: CONSORT 2025 flow diagram.

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References

1. Defrate, L.E.; Nha, K.W.; Papannagari, R.; Moses, J.M.; Gill, T.J.; Li, G. The biomechanical function of the patellar tendon during in-vivo weight-bearing flexion. *J. Biomech.* **2007**, *40*, 1716–1722. [CrossRef] [PubMed]
2. Cook, J.L.; Purdam, C.R. Is tendon pathology a continuum? A pathology model to explain the clinical presentation of load-induced tendinopathy. *Br. J. Sports Med.* **2009**, *43*, 409–416. [CrossRef] [PubMed]
3. Bohm, S.; Mersmann, F.; Arampatzis, A. Human tendon adaptation in response to mechanical loading: A systematic review and meta-analysis of exercise intervention studies on healthy adults. *Sports Med. Open* **2015**, *1*, 7. [CrossRef] [PubMed]
4. Reeves, N.D.; Maganaris, C.N.; Narici, M.V. Effect of strength training on human patella tendon mechanical properties of older individuals. *J. Physiol.* **2003**, *548*, 971–981. [CrossRef] [PubMed]
5. Wiesinger, H.-P.; Rieder, F.; Kösters, A.; Müller, E.; Seynnes, O.R. Are Sport-Specific Profiles of Tendon Stiffness and Cross-Sectional Area Determined by Structural or Functional Integrity? *PLoS ONE* **2016**, *11*, e0158441. [CrossRef] [PubMed]
6. Kongsgaard, M.; Reitelseder, S.; Pedersen, T.G.; Holm, L.; Aagaard, P.; Kjaer, M.; Magnusson, S.P. Region specific patellar tendon hypertrophy in humans following resistance training. *Acta Physiol.* **2007**, *191*, 111–121. [CrossRef] [PubMed]
7. Magnusson, S.P.; Kjaer, M. The impact of loading, unloading, ageing and injury on the human tendon. *J. Physiol.* **2019**, *597*, 1283–1298. [CrossRef] [PubMed]
8. Centner, C.; Lauber, B.; Seynnes, O.R.; Jerger, S.; Sohnius, T.; Gollhofer, A.; König, D. Low-load blood flow restriction training induces similar morphological and mechanical Achilles tendon adaptations compared with high-load resistance training. *J. Appl. Physiol.* **2019**, *127*, 1660–1667. [CrossRef] [PubMed]
9. Nakamichi, R.; Asahara, H. The role of mechanotransduction in tendon. *J. Bone Miner. Res. Off. J. Am. Soc. Bone Miner. Res.* **2024**, *39*, 814–820. [CrossRef]
10. Helmer, K.G.; Nair, G.; Cannella, M.; Grigg, P. Water movement in tendon in response to a repeated static tensile load using one-dimensional magnetic resonance imaging. *J. Biomech. Eng.* **2006**, *128*, 733–741. [CrossRef] [PubMed]
11. Picón-Martínez, M.; Chulvi-Medrano, I.; Cortell-Tormo, J.M.; Alonso-Aubin, D.A.; Alakhdar, Y.; Laurentino, G. Acute Effects of Resistance Training with Blood Flow Restriction on Achilles Tendon Thickness. *J. Hum. Kinet.* **2021**, *78*, 101–109. [CrossRef] [PubMed]

12. Obst, S.J.; Barrett, R.S.; Newsham-West, R. Immediate effect of exercise on achilles tendon properties: Systematic review. *Med. Sci. Sports Exerc.* **2013**, *45*, 1534–1544. [CrossRef] [PubMed]
13. Wearing, S.C.; Smeathers, J.E.; Hooper, S.L.; Locke, S.; Purdam, C.; Cook, J.L. The time course of in vivo recovery of transverse strain in high-stress tendons following exercise. *Br. J. Sports Med.* **2014**, *48*, 383–387. [CrossRef] [PubMed]
14. Lim, H.Y.; Wong, S.H. Effects of isometric, eccentric, or heavy slow resistance exercises on pain and function in individuals with patellar tendinopathy: A systematic review. *Physiother. Res. Int. J. Res. Clin. Phys. Ther.* **2018**, *23*, e1721. [CrossRef] [PubMed]
15. Pavlova, A.V.; Shim, J.S.C.; Moss, R.; Maclean, C.; Brandie, D.; Mitchell, L.; Greig, L.; Parkinson, E.; Alexander, L.; Tzortziou Brown, V.; et al. Effect of resistance exercise dose components for tendinopathy management: A systematic review with meta-analysis. *Br. J. Sports Med.* **2023**, *57*, 1327–1334. [CrossRef] [PubMed]
16. Visnes, H.; Hoksrud, A.; Cook, J.; Bahr, R. No effect of eccentric training on jumper's knee in volleyball players during the competitive season: A randomized clinical trial. *Clin. J. Sport Med. Off. J. Can. Acad. Sport Med.* **2005**, *15*, 227–234. [CrossRef] [PubMed]
17. Alfredson, H.; Pietilä, T.; Jonsson, P.; Lorentzon, R. Heavy-load eccentric calf muscle training for the treatment of chronic Achilles tendinosis. *Am. J. Sports Med.* **1998**, *26*, 360–366. [CrossRef] [PubMed]
18. Visnes, H.; Bahr, R. The evolution of eccentric training as treatment for patellar tendinopathy (jumper's knee): A critical review of exercise programmes. *Br. J. Sports Med.* **2007**, *41*, 217–223. [CrossRef] [PubMed]
19. Hjortshoej, M.H.; Juneja, H.; Svensson, R.B.; Herzog, R.B.; Lundgaard-Nielsen, M.; Nielsen, F.K.; Wulff, M.W.; Olsen, A.E.; Nybing, J.D.; Hansen, P.; et al. Effect of Low-Load Blood-Flow Restricted Training Versus Heavy Slow Resistance Training in Unilateral Patellar Tendinopathy: A Randomized Clinical Trial. *Scand. J. Med. Sci. Sports* **2025**, *35*, e70186. [CrossRef] [PubMed]
20. Hughes, L.; Paton, B.; Rosenblatt, B.; Gissane, C.; Patterson, S.D. Blood flow restriction training in clinical musculoskeletal rehabilitation: A systematic review and meta-analysis. *Br. J. Sports Med.* **2017**, *51*, 1003–1011. [CrossRef] [PubMed]
21. Skovlund, S.V.; Aagaard, P.; Larsen, P.; Svensson, R.B.; Kjaer, M.; Magnusson, S.P.; Couppé, C. The effect of low-load resistance training with blood flow restriction on chronic patellar tendinopathy—A case series. *Transl. Sports Med.* **2020**, *3*, 342–352. [CrossRef]
22. Grønfeldt, B.M.; Lindberg Nielsen, J.; Mieritz, R.M.; Lund, H.; Aagaard, P. Effect of blood-flow restricted vs heavy-load strength training on muscle strength: Systematic review and meta-analysis. *Scand. J. Med. Sci. Sports* **2020**, *30*, 837–848. [CrossRef] [PubMed]
23. Lixandrão, M.E.; Ugrinowitsch, C.; Berton, R.; Vechin, F.C.; Conceição, M.S.; Damas, F.; Libardi, C.A.; Roschel, H. Magnitude of Muscle Strength and Mass Adaptations Between High-Load Resistance Training Versus Low-Load Resistance Training Associated with Blood-Flow Restriction: A Systematic Review and Meta-Analysis. *Sports Med.* **2018**, *48*, 361–378. [CrossRef] [PubMed]
24. Scott, B.R.; Loenneke, J.P.; Slattery, K.M.; Dascombe, B.J. Blood flow restricted exercise for athletes: A review of available evidence. *J. Sci. Med. Sport* **2016**, *19*, 360–367. [CrossRef] [PubMed]
25. Bechan Vergara, I.; Puig-Diví, A.; Amestoy Alonso, B.; Milà-Villarroel, R. Effects of low-load blood flow restriction training in healthy adult tendons: A systematic review and meta-analysis. *J. Bodyw. Mov. Ther.* **2024**, *39*, 13–23. [CrossRef] [PubMed]
26. Öberg, S.; von Schewelov, L.; Tengman, E. The impact of blood flow restriction training on tendon adaptation and tendon rehabilitation—A scoping review. *BMC Musculoskelet. Disord.* **2025**, *26*, 503. [CrossRef] [PubMed]
27. Gopinatth, V.; Garcia, J.R.; Reid, I.K.; Knapik, D.M.; Verma, N.N.; Chahla, J. Blood Flow Restriction Enhances Recovery After Anterior Cruciate Ligament Reconstruction: A Systematic Review and Meta-analysis of Randomized Controlled Trials. *Arthroscopy* **2025**, *41*, 1048–1060. [CrossRef] [PubMed]
28. van Ark, M.; Cook, J.L.; Docking, S.I.; Zwerver, J.; Gaida, J.E.; van den Akker-Scheek, I.; Rio, E. Do isometric and isotonic exercise programs reduce pain in athletes with patellar tendinopathy in-season? A randomised clinical trial. *J. Sci. Med. Sport* **2016**, *19*, 702–706. [CrossRef] [PubMed]
29. Rio, E.; Kidgell, D.; Purdam, C.; Gaida, J.; Moseley, G.L.; Pearce, A.J.; Cook, J. Isometric exercise induces analgesia and reduces inhibition in patellar tendinopathy. *Br. J. Sports Med.* **2015**, *49*, 1277–1283. [CrossRef] [PubMed]
30. Rio, E.; van Ark, M.; Docking, S.; Moseley, G.L.; Kidgell, D.; Gaida, J.E.; van den Akker-Scheek, I.; Zwerver, J.; Cook, J. Isometric Contractions Are More Analgesic Than Isotonic Contractions for Patellar Tendon Pain: An In-Season Randomized Clinical Trial. *Clin. J. Sport Med. Off. J. Can. Acad. Sport Med.* **2017**, *27*, 253–259. [CrossRef] [PubMed]
31. Hopewell, S.; Chan, A.-W.; Collins, G.S.; Hróbjartsson, A.; Moher, D.; Schulz, K.F.; Tunn, R.; Aggarwal, R.; Berkwits, M.; Berlin, J.A.; et al. CONSORT 2025 Statement: Updated Guideline for Reporting Randomised Trials. *BMJ* **2025**, *389*, e081123. [CrossRef]
32. Lauber, B.; König, D.; Gollhofer, A.; Centner, C. Isometric blood flow restriction exercise: Acute physiological and neuromuscular responses. *BMC Sports Sci. Med. Rehabil.* **2021**, *13*, 12. [CrossRef] [PubMed]
33. Patterson, S.D.; Hughes, L.; Warmington, S.; Burr, J.; Scott, B.R.; Owens, J.; Abe, T.; Nielsen, J.L.; Libardi, C.A.; Laurentino, G.; et al. Blood Flow Restriction Exercise: Considerations of Methodology, Application, and Safety. *Front. Physiol.* **2019**, *10*, 533, Erratum in *Front. Physiol.* **2019**, *10*, 1332. [CrossRef] [PubMed]

34. Chulvi-Medrano, I.; Picón-Martínez, M.; Cortell-Tormo, J.M.; Tortosa-Martínez, J.; Alonso-Aubin, D.A.; Alakhdar, Y. Different Time Course of Recovery in Achilles Tendon Thickness After Low-Load Resistance Training with and Without Blood Flow Restriction. *J. Sport Rehabil.* **2020**, *30*, 300–305. [CrossRef] [PubMed]
35. Thorpe, C.T.; Screen, H.R.C. Tendon Structure and Composition. *Adv. Exp. Med. Biol.* **2016**, *920*, 3–10. [CrossRef] [PubMed]
36. Vargas, J.; Castillo Paredes, A.; Torres, A.; Lozada, M.; Acha, D.; Montalva Valenzuela, F.; Humeres, G.; Bonilla, D. Effects of High-Intensity Interval Training with Blood Flow Restriction Versus Normobaric Hypoxia on Physiological Parameters in Apparently Healthy Young Men. *Sports* **2026**, *14*, 232. [CrossRef] [PubMed]
37. Iwanuma, S.; Akagi, R.; Kurihara, T.; Ikegawa, S.; Kanehisa, H.; Fukunaga, T.; Kawakami, Y. Longitudinal and transverse deformation of human Achilles tendon induced by isometric plantar flexion at different intensities. *J. Appl. Physiol.* **2011**, *110*, 1615–1621. [CrossRef] [PubMed]
38. Merza, E.Y.; Pearson, S.J.; Lichtwark, G.A.; Malliaras, P. The acute effects of higher versus lower load duration and intensity on morphological and mechanical properties of the healthy Achilles tendon: A randomized crossover trial. *J. Exp. Biol.* **2022**, *225*, jeb243741. [CrossRef] [PubMed]
39. Brancaccio, P.; Limongelli, F.M.; D'Aponte, A.; Narici, M.; Maffulli, N. Changes in skeletal muscle architecture following a cycloergometer test to exhaustion in athletes. *J. Sci. Med. Sport* **2008**, *11*, 538–541. [CrossRef] [PubMed]
40. Csapo, R.; Alegre, L.M.; Baron, R. Time kinetics of acute changes in muscle architecture in response to resistance exercise. *J. Sci. Med. Sport* **2011**, *14*, 270–274. [CrossRef] [PubMed]
41. Hill, E.C.; Housh, T.J.; Smith, C.M.; Keller, J.L.; Anders, J.P.V.; Schmidt, R.J.; Johnson, G.O. Acute changes in muscle thickness, edema, and blood flow are not different between low-load blood flow restriction and non-blood flow restriction. *Clin. Physiol. Funct. Imaging* **2021**, *41*, 452–460. [CrossRef] [PubMed]
42. Martín-Hernández, J.; Marín, P.J.; Menéndez, H.; Loenneke, J.P.; Coelho-e-Silva, M.J.; García-López, D.; Herrero, A.J. Changes in muscle architecture induced by low load blood flow restricted training. *Acta Physiol. Hung.* **2013**, *100*, 411–418. [CrossRef] [PubMed]
43. de Freitas, M.C.; Gerosa-Neto, J.; Zanchi, N.E.; Lira, F.S.; Rossi, F.E. Role of metabolic stress for enhancing muscle adaptations: Practical applications. *World J. Methodol.* **2017**, *7*, 46–54. [CrossRef] [PubMed]
44. Morton, J.P.; Kayani, A.C.; McArdle, A.; Drust, B. The exercise-induced stress response of skeletal muscle, with specific emphasis on humans. *Sports Med.* **2009**, *39*, 643–662. [CrossRef] [PubMed]
45. Brentano, M.A.; Martins Kruel, L.F. A review on strength exercise-induced muscle damage: Applications, adaptation mechanisms and limitations. *J. Sports Med. Phys. Fit.* **2011**, *51*, 1–10.

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