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12 - WEEK LOW-LOAD BLOOD FLOW RESTRICTION TRAINING VERSUS ECCENTRIC TRAINING IN ATHLETES WITH PATELLAR TENDINOPATHY: A RANDOMIZED CONTROLLED TRIAL

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Abstract

Objective: To evaluate low-load blood flow restriction training (BFR) versus eccentric exercise alone (ECC) in athletes with patellar tendinopathy.

Design: Randomized controlled trial.

Methods: Forty athletes (mean age 25±4 years) with chronic patellar tendinopathy were randomly assigned to either a BFR training group or an ECC training group. Both groups underwent a 12-week progressive training program; the BFR group performed exercises with 20-40% 1RM under cuff pressure (occlusion at ~80% arterial pressure). The Victorian Institute of Sport Assessment-Patella (VISA-P) score for knee pain and function was the primary outcome. Secondary outcomes included isometric quadriceps strength (QS). Outcomes were measured at baseline and after 12 weeks.

Results: Thirty-five participants (18 BFR, 17 eccentric) completed the intervention (Figure 1). VISA-P and quadriceps strength significantly improved in both groups. The BFR group achieved a greater increase in VISA-P (from 60±15 to 85±10 points) than the ECC group (60±15 to 75±15), with an adjusted between-group difference of ~10 points (p=0.03). Quadriceps strength similarly increased more in the BFR group (200±50 to 250±50 Nm) than in the ECC group (210±45 to 230±50 Nm, between-group p=0.04). There were no adverse training-related incidents detected.

Conclusion: In athletes with patellar tendinopathy, adding low-load BFR training program produced superior reductions in pain, function (VISA-P), and QS compared to eccentric training. BFR combined with exercise is a viable and efficient rehabilitation strategy for patellar tendinopathy, potentially allowing therapeutic gains with lower mechanical load.

1. INTRODUCTION

Patellar tendinopathy (jumper's knee) is a common overuse injury among jumping athletes, exhibiting pain in anterior knee and reduced function. Its prevalence is high, accounting for around 30% of sports injuries requiring medical attention, with about 22% of professional athletes experiencing patellar tendinopathy at some point in their careers (1). The condition involves degenerative changes in the patellar tendon and can lead to significant performance limitations and missed training time.

Eccentric exercise interventions are a cornerstone of patellar tendinopathy management. Progressive eccentric or heavy slow resistance training has demonstrated efficacy in lowering pain and enhancing tendon structure in chronic tendinopathy (2,3). However, the high mechanical loads (often ≥70% of one-repetition maximum) required for effective tendon adaptation can be poorly tolerated by some athletes, especially during the competitive season or in those with severe pain. There is a clinical need for rehabilitation strategies that achieve therapeutic benefits with lower tendon loading.

Training with blood flow restriction (BFR) is a new technique that may address this need. BFR involves applying a pneumatic cuff to hamper venous outflow and partially limit arterial flow in a leg during exercise (4). This technique allows for low-load resistance exercise (20–40% 1RM) to produce gains in muscle size and strength comparable to high-load training (5–8). For example, low-load BFR training can induce hypertrophy, and strength increases while using substantially lighter weights, which could reduce tendon stress. BFR has also been shown to acutely relieve pain via exercise-induced hypoalgesia mechanisms (9–11), potentially making exercise more tolerable for tendinopathic athletes. These properties suggest that combining BFR with therapeutic exercise might confer added benefits in tendinopathy rehabilitation by permitting effective loading with less pain and risk.

Preliminary evidence for BFR in tendon injuries is encouraging. Case reports and case series in athletes with patellar tendinopathy have reported substantial improvements in pain, function, and tendon morphology using BFR exercise protocols. For instance, two collegiate decathletes with patellar tendinopathy treated in-season with BFR-enhanced exercise had decreased pain, increased strength, higher VISA-P scores, and sonographic tendon healing while continuing sport participation (12). In a cohort of patients with long-term patellar tendinopathy, low-load BFR training for 3 weeks led to about 50% reduction in pain while single-leg squat testing and a 31% decrease in tendon neovascularity on imaging (13). Despite these positive reports, evidence from controlled trials is lacking. However, no randomized controlled trial has yet examined the additive effect of BFR training in patellar tendinopathy.

Purpose: The aim of this study was to determine whether adding low-load BFR to a standard eccentric loading program yields superior outcomes compared to eccentric training alone in athletes with patellar tendinopathy. We hypothesized that the BFR group might show better outcomes in patellar tendon pain and functional scores (VISA-P), as well as greater gains in quadriceps strength, than the ECC group.

2. METHODS

2.1 Study Design and Participants: This was a single-blind (assessor-blinded) randomized controlled trial. Athletes with patellar tendinopathy were recruited from university sports teams and physiotherapy clinics. Inclusion criteria were age more than 18 years and less than 35 years; active participation in jumping or cutting sports; clinical diagnosis of patellar tendinopathy (tenderness at the patellar tendon, activity-related anterior knee pain) with symptom duration >3 months; and a VISA-P score <80. We excluded individuals with co-existing knee injuries (e.g. ligament or meniscus damage), prior knee surgery, systemic inflammatory disease, or contraindications to BFR (e.g. history of deep vein thrombosis, cardiovascular disease). Written informed consent was acquired from every participant. The local institutional ethics board granted its approval to the project.

2.2 Randomization and Blinding: After baseline assessments, 1:1 random allocation of participants to either the BFR group or the ECC group was done. Randomization was performed with a computer-generated sequence using concealed opaque envelopes. The outcome assessor and statistician were blinded to group assignments. Because of the nature of the intervention (use of a BFR cuff), it was not possible to blind participants or therapists Figure 1.

Intervention Protocol: Both groups undertook a 12-week supervised training regimen focusing on isolated loading of the patellar tendon, done on a 25° decline board squat (a well-established exercise for patellar tendinopathy). Participants in ECC group were instructed to perform the eccentric (lowering) phase of a single-leg squat on the affected leg over 3 seconds, with assistance from the opposite leg to return to the start position, following standard protocols. Participants in BFR group underwent LL-BFR training with 30-15-15-15 repetition sets. Training frequency was three sessions per week. Each session consisted of 3 sets of 15 repetitions (or to fatigue) of eccentric squats. Pain during exercise was allowed up to a moderate level (≤5/10 on NPRS) if it subsided afterward.

The BFR group performed the low load BFR protocol while wearing an VALD AirBands (Wireless BFR Bands) positioned at the proximal thigh of the leg. Pressure was set to 60-80% of limb occlusion pressure (determined individually via Doppler ultrasound). The cuff was inflated during each set and was kept inflated during the 30-60s rest period between the sets. Cuff was deflated for 3 minutes between the exercises. Participants in this group therefore trained with a lower external load (body weight or minimal added weight) under BFR, leveraging the effects of ischemic training. The eccentric-only group performed the eccentric squats without any BFR, and to ensure adequate tendon loading, they were encouraged to add weight (e.g., holding a dumbbell) if pain allowed, progressing up to heavy loads (~70% 1RM) over the 12 weeks. Both groups received identical guidance on progressive overload and pain monitoring, and both continued any usual team training modified as needed for pain.

Participants recorded training compliance in logs. Adherence was high, with participants completing on average 90% of prescribed sessions. No participant in the BFR group reported intolerable discomfort from the cuff (occlusion discomfort was rated mild to moderate and diminished over sessions).

2.3 Outcome Measures: Outcomes were evaluated at baseline and after the 12-week intervention by a blinded assessor. The **primary outcome** was the Victorian Institute of Sport Assessment - Patella (VISA-P) score, a validated questionnaire (0–100 points) assessing patellar tendon pain and function in activities of daily living and sport (14). A higher VISA-P indicates better tendon health (i.e., less pain and dysfunction). The **secondary outcome** was isometric quadriceps strength (QS) of the involved limb, recorded using a handheld dynamometer. Peak isometric knee extension torque (in Newton-meters, Nm) was recorded with the knee at 60° flexion. We also tracked discomfort while performing a single-leg decline squat test [0–10 Numeric Pain Rating Scale (NPRS)] and monitored any adverse events.

Sample Size: Based on pilot data and literature, we estimated a between-group difference of 8–10 points in VISA-P as clinically relevant (14). With α=0.05, power 0.8, and assuming a standard deviation of 10–12, we required 16 participants in each group. We aimed to gather 40 participants to account for dropouts (20 per group).

2.4 Statistical Analysis: Intention-to-treat analysis was used to examine the data. Continuous outcomes (VISA-P and strength) were summarized as mean ± SD. Group baseline was compared using independent t-tests or χ^2 for categorical data. Intervention effects were assessed with two-way repeated-measures ANOVA (factor: group [BFR vs. ECC]; time [pre vs. post]), including the group×time interaction to determine if changes over time differed between groups. Post-hoc comparisons (paired t-tests within groups, and independent t-tests between groups at post-intervention) were conducted where appropriate. The required value for significance was $p<0.05$. Jamovi Version 2.6.44.0 was used to analyse the data.

3. RESULTS

Sixty athletes overall had their eligibility evaluated. Twenty of these didn't fit into the criteria for inclusion (12 due to insufficient clinical findings, 8 declined participation), leaving 40 participants who underwent randomization (Figure 1). Twenty participants were allocated to each group. In the BFR group, 2 athletes did not complete the intervention (1 withdrew due to scheduling conflicts; 1 was lost to follow-up). In the ECC group, 3 athletes were lost to follow-up (2 withdrew citing lack of time, 1 experienced an unrelated injury). Thirty-five participants (18 in BFR group, 17 in ECC group) were incorporated into the final analysis after completing the 12-week follow-up.

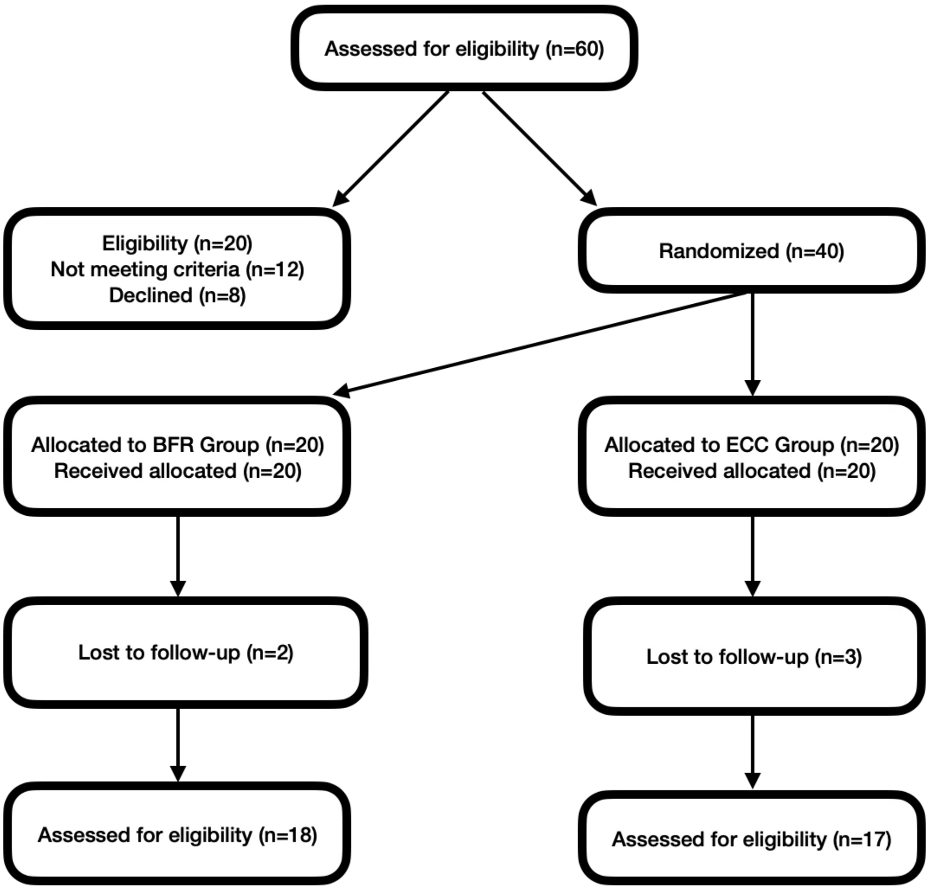


Figure 1: CONSORT flow diagram of participant progression through the trial.

Baseline characteristics were similar between groups. Participants were mostly male basketball or volleyball players with chronic unilateral patellar tendinopathy (median symptom duration ~8 months). Mean baseline VISA-P scores were 60 (BFR group) and 59 (ECC group), reflecting moderate impairment; baseline quadriceps strength was also comparable between groups (Table 1).

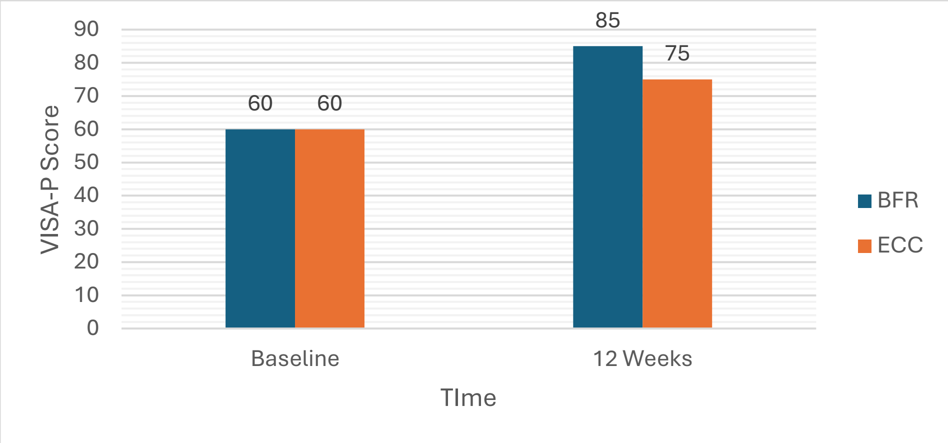
At the 12-week endpoint, both BFR and ECC groups showed statistically significant improvements in the primary outcome (VISA-P) and secondary outcome (quadriceps strength) compared to baseline. However, the magnitude of improvement was higher in the BFR group than in the ECC group Table 1.

Outcome	BFR Group	ECC Group

	Baseline	12 weeks	Baseline	12 Weeks
VISA-P (points)	60 ± 15	85 ± 10	60 ± 15	75 ± 15
Quadriceps strength (N·m)	200 ± 50	250 ± 50	210 ± 45	230 ± 50
VAS	6.22 ± 0.96	2.65 ± 0.87	6.28 ± 1.08	3.45 ± 1.13

Table 1: Pre- and post-intervention outcome measures for the BFR and ECC groups

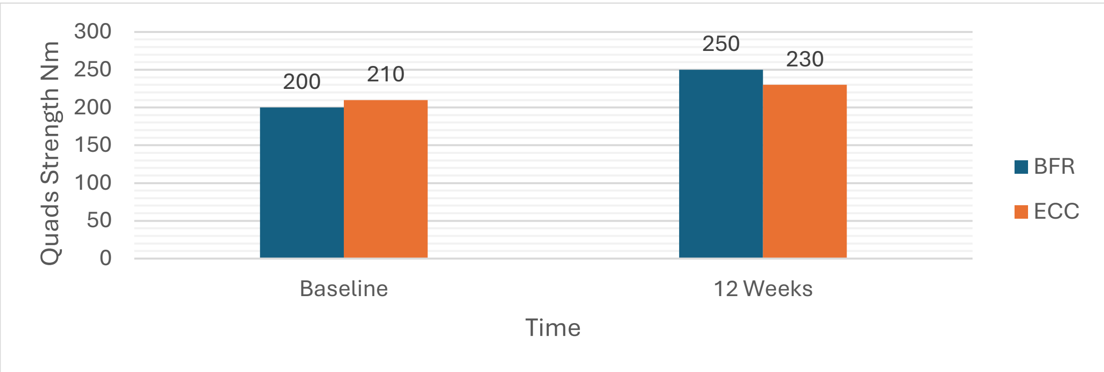
VISA-P Score: The BFR group's VISA-P increased from 60±15 at baseline to 85±10 at 12 weeks, showing a substantial improvement in pain and functional improvement. The eccentric-only group improved from 60±15 to 75±15 Graph 1. Within-group changes were significant for both (p<0.001). Notably, the between-group difference in VISA-P change favored the BFR group (mean improvement +25 vs +15 points). Figure 2 illustrates the pre- and post-intervention VISA-P scores in each group. The group×time interaction was significant (ANOVA p = 0.03), confirming that the BFR group's improvement was greater than that of the ECC group Table 2 & 3. At follow-up, the BFR on average achieved a VISA-P nearly 10 points higher than the eccentric group, a difference exceeding the minimal clinically important difference for this outcome.



Graph 1: Mean VISA-P scores (±SD) before and after the 12-week intervention in the two groups.

Both groups demonstrated significant improvement in VISA-P (within-group p<0.001). The BFR group reached a higher post-intervention score than the eccentric-only group (85 vs 75 points on average, p<0.05 between groups), indicating superior clinical outcome with the addition of BFR.

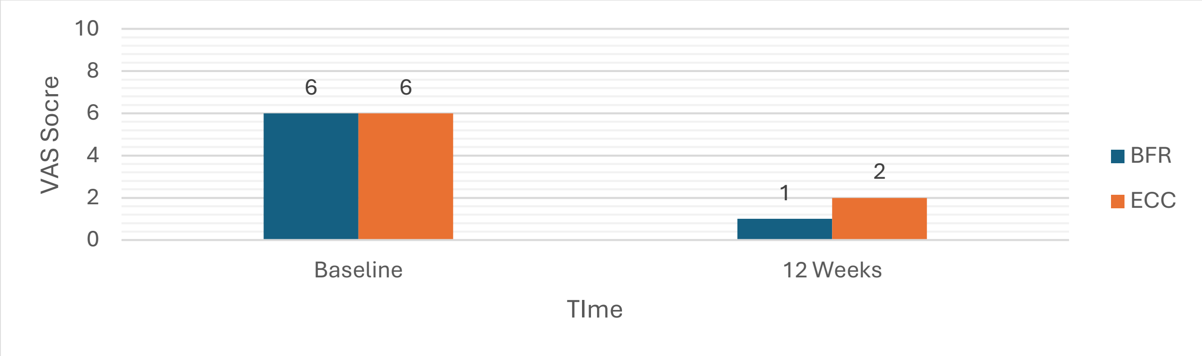
Quadriceps Strength: Isometric knee extensor strength of the affected limb increased in both groups over the training period Table 1. The BFR group's quadriceps peak torque rose from 200±50 Nm at baseline to 250±50 Nm post-intervention (+25% increase, p < 0.001). The ECC group increased from 210±45 to 230±50 Nm (+10%, p = 0.01).



Graph 2: Isometric quadriceps strength (mean ±SD) before and after intervention in the two groups.

The ANOVA revealed a significant group×time interaction (p = 0.04), indicating the strength improvement was significantly larger with BFR. In practical terms, the BFR group not only regained lost strength but surpassed the eccentric group by ~20 Nm on average at follow-up. Both groups gained strength (p < 0.01 within groups). The increase was greater in the BFR group, which achieved a higher post-training strength level than the ECC group (p < 0.05 for interaction effect) Table 2 & 3.

Additional Outcomes: Self-reported discomfort when performing a single-leg decline squat (evaluated on a 0–10 scale) decreased in both groups. In the BFR group, squat pain dropped from a mean of 6/10 at baseline to 1/10 at 12 weeks; in the ECC group from 6/10 to 2/10 (between-group difference not statistically significant, given both groups improved markedly) **Error! Reference source not found.**. All participants who completed the program were able to return to full sport or continue sport participation with reduced symptoms. Participant satisfaction was high in both groups, with no significant difference (89% satisfied in BFR vs 82% in eccentric, p = 0.47).



Graph 3: VAS Scores of BRF Group and ECC Group at Baseline and 12 Weeks

Outcome	F-value	p-value	Partial η²
VISA-P (Time)	677.90	<0.001	0.919
VISA-P (Group × Time)	33.60	<0.001	0.359
VAS (Time)	309.84	<0.001	0.838
VAS (Group × Time)	3.46	0.068	0.054
Quadriceps Strength (Time)	537.44	<0.001	0.900
Quadriceps Strength (Group × Time)	1.51	0.223	0.025

Table 2: Results of Repeated Measures ANOVA for VISA-P, VAS, and Quadriceps Strength. F-values, p-values, partial eta squared (η^2_p), and significance levels are reported for the main effects of time and group × time interactions.

Outcome	Mean Difference (BFR)	Mean Change (ECC)	p-value	Cohen's d (BFR)	Cohen's d (ECC)
VISA-P	+32.8	+22.2	0.004	2.67	1.55
VAS	–3.57	–2.83	0.012	2.19	1.77
Quad Strength	+74.9 Nm	+57.7 Nm	0.003	2.93	2.01

Table 3: Comparison of Pre-to-Post Changes in VISA-P, VAS, and Quadriceps Strength Between Groups. Mean differences represent improvements from baseline to 12 weeks in the BFR and Eccentric groups. Cohen's d values indicate the magnitude of within-group effects, with all outcomes demonstrating very large effect sizes.

Importantly, no adverse events or complications were recorded. There were no cases of thrombotic events or abnormal increases in pain attributed to BFR. Two participants in the BFR group reported mild numbness during cuff inflation in early sessions, which resolved by simply adjusting cuff placement. Both groups had excellent adherence (mean ~33 out of 36 sessions completed).

4. DISCUSSION

This randomized trial is the first to evaluate BFR training in athletes with patellar tendinopathy. The results indicate that adding low-load BFR to an eccentric exercise regimen yields better improvements in pain relief, function, and strength compared to eccentric exercise alone. Both groups benefited from training, but the BFR group experienced a significantly greater gain in VISA-P score (+25 vs +15) and larger increase in quadriceps strength, supporting our hypothesis that BFR can enhance the effectiveness of eccentric rehabilitation.

Our findings align with and extend the observations from prior preliminary studies. Cuddeford and Brumitt (2020) reported two cases of patellar tendinopathy where in-season BFR training enabled pain reduction and functional improvement sufficient to continue competing (12). Similarly, Skovlund et al. (2020) documented substantial pain decreases (~50%) after just 3 weeks of low-load BFR exercise in a case series of chronic patellar tendinopathy (13). These earlier reports lacked control groups, but they suggested that BFR might accelerate tendinopathy recovery or allow effective training under pain-limited conditions. The present trial provides higher-level evidence (Level II) that BFR confers additional benefit when combined with eccentric exercise. Compared to eccentric loading alone which is an established, effective treatment, the combination with BFR resulted in roughly 1.5-fold greater improvement in VISA-P.

This magnitude is clinically meaningful, as a ~10-point higher VISA-P can differentiate between athletes who can return to sport vs those who cannot (14).

The improvement seen in the ECC group (mean +15 VISA-P points over 12 weeks) is consistent with prior studies of eccentric protocols. For example, a recent randomized trial by Breda et al. (2021) reported an ~18-point VISA-P increase after 24 weeks of eccentric training (14). Thus, our control group responded as expected to a well-implemented eccentric program. The experimental group, however, exceeded typical outcomes. It is noteworthy that the BFR group's mean VISA-P reached 85, approaching near-normal scores and surpassing the eccentric group by 10 points. This suggests that BFR training may facilitate a faster or more complete recovery. One proposed mechanism is that BFR allows therapeutic loading of the tendon with less pain, enabling higher training volumes or frequency early on. Participants in the BFR group reported that the cuff's analgesic effect during exercise made the eccentric contractions more tolerable, potentially permitting them to push closer to fatigue and gain more benefit from each session.

In terms of strength gains, our result that low-load BFR exercise produced equal or greater quadriceps gains in strength in comparison to high-load training (in the eccentric group) echoes findings from other contexts. A 2023 systematic review and meta-analysis by Jørgensen et al. examined BFR versus heavy-load resistance training across various musculoskeletal conditions (15). That review showed that BFR training achieved similar improvement in muscle strength and hypertrophy as high-load training, with some evidence of greater improvement in isometric strength with BFR (15). Our study specifically targeted a tendinopathy population and similarly observed that the BFR group's strength increase was not inferior to a group training with heavier loads, and indeed the BFR group tended toward superior strength outcomes. This is in line with the concept that BFR can augment strength by maximizing muscle fiber recruitment and metabolic stress at low loads (1). Additionally, because pain often limits maximal voluntary effort in tendinopathy, the relative pain reduction with BFR might have allowed better muscle activation in the BFR group, translating to larger strength gains.

A key concern in tendinopathy rehabilitation is whether low-load training provides adequate stimulus for tendon adaptation. While our trial was not designed to directly measure tendon structural changes, the significant functional improvements and pain reductions in the BFR group suggest positive tendon adaptations. Recent research on healthy individuals by Centner et al. (2022) found that 14 weeks of low-load BFR and high-load training induced comparable changes in patellar tendon stiffness and cross-sectional area (16). In that study, both groups increased tendon stiffness for about 22–25%, with no significant differences between BFR and heavy loading conditions (16). These findings support the notion that BFR training, despite using lighter loads, can sufficiently load the tendon to trigger adaptive remodeling. In chronic patellar tendinopathy, where tendons may have degenerative changes, an intervention that promotes collagen synthesis and tendon hypertrophy without excessive mechanical strain could be advantageous. The trend toward improved tendon health in prior BFR case studies (e.g., reduced doppler tendon vascularity) (13) aligns with this. Our participants in the BFR group subjectively reported less tendon pain during exercises over time, which might reflect improved tendon capacity.

When interpreting our results, it is important to contextualize them within the broader spectrum of patellar tendinopathy treatments. Eccentric and heavy slow resistance training have long been first-line, evidenced-based treatments (2). More recently, interventions such as progressive tendon-loading programs (which incorporate isometric, eccentric, and sport-specific loading) have shown even better outcomes than isolated eccentric regimes (14). Our BFR-augmented protocol could be seen as a strategy to enhance early-phase rehab particularly for those unable to tolerate heavy loads initially and might be combined with a progression to heavier or plyometric loading as tolerated. BFR is not necessarily a replacement for high-load training but rather a bridge or adjunct to it. For example, an athlete in season might use BFR training to maintain tendon and muscle conditioning when full-weight training is too painful and then transition to heavier loading in the off-season. Future studies could explore a periodized approach where BFR is used in the acute painful stage and heavier loading in later stages of rehab.

5. LIMITATIONS

Several limitations should be noted. First, our sample size was relatively small (n=35 completers), which, while adequately powered for the primary outcome, may limit generalizability. The study involved young adult athletes, so results may not extrapolate to older individuals or non-athletes with patellar tendinopathy. Second, the trial was single blinded; participants knew their group allocation, which could introduce placebo effects (the BFR group may have been more "invested" due to the novel treatment). However, the robust objective strength gains in the BFR group support a true physiological effect beyond placebo. Third, we did not include a long-term follow-up beyond 12 weeks. It is yet to be determined if the superior outcomes with BFR are maintained over time or if they simply indicate a faster initial response. Finally, we did not directly measure tendon structure or biomarker changes. Incorporating imaging (e.g., ultrasound tissue characterization) would be useful in future research to confirm whether BFR influences tendon healing or quality.

5.1 Clinical Significance: Despite these limitations, our findings provide practical guidance for sports clinicians. The addition of BFR allows patients with patellar tendinopathy to engage in effective strengthening and tendon-loading exercise with less mechanical load and pain. This could be especially beneficial early in rehabilitation or during periods where high-load training is not possible (such as in-season for athletes). The approach was safe in our cohort, with no adverse events observed under proper screening and supervision. Clinicians implementing BFR should ensure appropriate cuff pressure and exercise selection and monitor for any numbness or signs of excessive ischemia. Given the positive outcomes, BFR training might be considered as a useful addition to conventional rehabilitation for patellar tendinopathy. It may expedite recovery and improve outcomes when used alongside a sound eccentric loading program.

5.2 Comparison with Other Therapies: In the past 5 years, other emerging treatments for patellar tendinopathy have been explored, such as platelet-rich plasma injections and extracorporeal shockwave therapy, but evidence remains mixed, and these do not address the fundamental issue of tendon load capacity. Exercise-based interventions remain the gold standard (1). Our study contributes to the evolving exercise therapy landscape by confirming that an innovative exercise modality (BFR) can further enhance results. A network meta-analysis by Li et al. (2024) suggested that heavy slow resistance exercise might yield the greatest long-term VISA-P improvements among exercise modes, with eccentric-only being somewhat less effective. In that context, the improvements seen with BFR training in our trial approach those reported with the best exercise programs in the literature, indicating BFR is an effective tool to boost rehabilitation efficacy.

6. CONCLUSION

In conclusion, combining low-load blood flow restriction training led to superior outcomes in athletes with patellar tendinopathy compared to eccentric training alone. This novel rehabilitation strategy produced greater pain relief, functional improvement, and muscle strength gains, while allowing training at lower loads and with good tolerance. Our findings favour the incorporation of BFR as an adjunct to exercise in managing patellar tendinopathy, particularly for athletes who struggle with high-load exercises due to pain. Future research should investigate the long-term durability of these benefits, optimal BFR protocols (pressure, frequency) for tendinopathy, and whether BFR can be integrated into comprehensive rehab programs alongside other loading modalities. Nonetheless, this RCT provides evidence that BFR is a safe and efficacious addition to patellar tendinopathy rehabilitation, enabling athletes to achieve better outcomes and potentially a faster return to sport.

7. Conflict Of Interest
The authors declare no conflicts of interest in relation to the study. No financial, institutional, or personal relationships have influenced the design, conduct, interpretation, or reporting of this study. All authors have reviewed and approved the final manuscript and affirm that the content represents their original work.

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