

Effects of plyometric training with blood flow restriction on body composition, strength, power, and anaerobic performance in soccer players

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Abstract

Background and Study Aim

Soccer performance depends on the ability to combine high levels of strength, power, and endurance within limited preparation time. Plyometric training is widely used to enhance explosive power, but its high-impact nature may increase injury risk. Blood flow restriction (BFR) training can stimulate muscle adaptations with lower external loads, offering a potentially safer alternative. Although both methods are applied in athletic conditioning, their relative effectiveness in improving performance outcomes remains of practical interest. This study aimed to investigate the effects of a six-week combined plyometric and BFR (PLY+BFR) training program on body composition, strength, jump height, and anaerobic power in male collegiate soccer players.

Material and Methods

Twenty-seven male collegiate soccer players (mean age 22.1 ± 0.6 years) were randomly assigned to three groups: control (CON; $n = 9$), plyometric training only (PLY; $n = 9$), and plyometric training with BFR (PLY+BFR; $n = 9$). The two training groups followed an identical plyometric protocol twice weekly for six weeks. The PLY+BFR group applied progressive cuff pressure (160–200 mmHg) to the proximal thighs during exercise. Assessments before and after the intervention included fat-free mass, skeletal muscle mass (via bioelectrical impedance analysis), Muscular strength (1 RM) of knee extension, countermovement jump (CMJ) height, and Wingate anaerobic power test. Data were analyzed using one-way ANOVA with Bonferroni post hoc comparisons.

Results

The PLY+BFR group showed significantly greater gains in fat-free mass (+1.9%), skeletal muscle mass (+1.8%), 1RM strength (+18.7%), CMJ height (+19.5%), and peak anaerobic power (+12.4%) compared to both the CON and PLY groups ($p < 0.05$). The PLY group also demonstrated improvements. However, the magnitude was consistently lower than that of the PLY+BFR group.

Conclusions

The integration of blood flow restriction into plyometric training presents a more effective and time-efficient strategy for improving muscle hypertrophy, strength, power, and anaerobic performance in soccer players. The combined stimulus may enhance both neural and metabolic adaptations. As a result, athletes can achieve pronounced performance gains without the need for excessive mechanical loading. This study provides a feasible and evidence-based approach for coaches and practitioners seeking to enhance key physical attributes during pre-season or other short-term conditioning phases.

Keywords:

plyometric training, blood flow restriction, muscular performance, anaerobic power, soccer conditioning

Introduction

In recent decades, soccer has undergone a profound transformation in both physical intensity and tactical complexity. The modern game is no longer defined only by endurance and technical skill. Players are now required to perform frequent high-velocity sprints, abrupt changes in direction, powerful jumps, and dynamic accelerations within confined timeframes. These demands are particularly pronounced at the collegiate level, where athletes must pursue athletic excellence while also managing academic obligations. As a result, there is increasing emphasis on developing

neuromuscular coordination, lower-limb explosive strength, and anaerobic energy systems to support the rapid and repetitive nature of competitive play [1]. The escalating pace of the game, together with congested training and match schedules, places coaches and performance professionals under pressure to design time-efficient training interventions. Such programs must enhance sport-specific physical qualities while minimizing cumulative mechanical stress and injury risk [2, 3]. These combined challenges have stimulated growing interest in innovative conditioning methods that target both neural and metabolic adaptations while reducing physical loading.

Plyometric training has long been recognized as an effective method for improving stretch-

shortening cycle efficiency, lower-limb explosive power, and change-of-direction ability [4]. The effectiveness of plyometric training in enhancing speed and jump performance is well documented in soccer-specific populations, particularly among youth and collegiate players [5, 6]. However, high-impact ground reaction forces and the associated injury risks limit its applicability during periods of fatigue, growth spurts, or congested match schedules. Blood flow restriction (BFR) training, by contrast, has emerged as a low-load resistance method that promotes muscular strength and hypertrophy through localized hypoxic stress. Numerous studies have demonstrated its effectiveness in enhancing functional capacity while reducing joint stress, making it a viable option for athletes across different age groups [7, 8, 9]. Recent soccer-specific investigations have demonstrated that blood flow restriction training can enhance physical capacities and may support rehabilitation strategies [10].

Although the efficacy of plyometric and BFR training has been well documented individually, their integrated application remains underexplored, particularly regarding combined effects on soccer-specific performance outcomes. While pilot evidence suggests that combining plyometric exercises with blood flow restriction can yield additive benefits in soccer players, large-scale empirical research evaluating structured hybrid protocols that merge the neural benefits of plyometrics with the metabolic stress of BFR remains scarce [11, 12]. This issue is especially relevant in collegiate populations, where time-constrained training environments and elevated injury risk demand innovative approaches to maximize physiological adaptations within limited preparation windows. A recent systematic review and meta-analysis highlighted the limited but growing evidence base on blood flow restriction training in athletes, underscoring the need for further controlled studies in field-based sports [13].

To address this gap, it was hypothesized that the integrated PLY+BFR intervention would generate superior adaptations compared to traditional plyometric training alone by combining neural activation with metabolic overload. The present study aimed to evaluate the effects of a six-week combined plyometric and blood flow restriction (PLY+BFR) training program on body composition, lower-limb strength, vertical power, and anaerobic capacity in male collegiate soccer players.

Materials and Methods

Participants

Twenty-seven male collegiate soccer players (age: 22.1 ± 0.6 years; height: 174.2 ± 2.6 cm; body mass: 69.7 ± 4.2 kg) from Ubon Ratchathani Rajabhat University volunteered to participate. All were in their pre-season phase and trained 4–5 days

per week. Inclusion criteria required the absence of neurological disorders, musculoskeletal injuries, or medical contraindications, as well as a commitment to attend all sessions. Participants were instructed to avoid caffeine, alcohol, and high-intensity activity for 24 hours before testing. Those who failed to meet these criteria or consumed stimulants within 24 hours were excluded. Written informed consent was obtained from all participants, and the study was approved by the Sisaket Rajabhat University Ethics Committee (HE671005). Group allocation was randomized using a computer-generated list, and procedures were overseen by an independent researcher.

Research Design

This randomized controlled trial assigned 27 participants into three equal groups ($n = 9$) using a computer-generated randomization sequence: (1) Control (CON), who maintained regular training; (2) Plyometric training only (PLY); and (3) Plyometric training with blood flow restriction (PLY+BFR). Sample size was calculated using G*Power 3.1, targeting a medium effect size ($f = 0.45$) [12], 80% statistical power, and $\alpha = 0.05$. All pre- and post-intervention assessments were conducted two days before and two days after the six-week training. A blinded evaluator performed all assessments to minimize potential bias.

Intervention Protocol

The intervention lasted six weeks and comprised two training sessions per week (Monday and Thursday), for a total of 12 sessions. Both the PLY and PLY+BFR groups followed an identical plyometric exercise program that progressively increased in intensity and volume over time. Each session began with a standardized 10-minute warm-up followed by dynamic stretching. A one-minute rest was provided between sets and exercises. The program incorporated fundamental lower-body plyometric movements such as squat jumps, lateral bounds, tuck jumps, and depth jumps. The number of repetitions increased from 100 per session in the early weeks to 180 per session in the final weeks, as detailed in Table 1.

In the PLY+BFR group, participants wore pneumatic cuffs (B-Strong, California, USA) applied bilaterally to the proximal thighs throughout each session. Cuff pressure was set at 160 mmHg during the first three weeks and increased to 200 mmHg in the final three weeks, following protocols adapted from Abe et al. [14]. Prior to each session, cuff calibration was performed according to manufacturer guidelines to ensure consistent pressure delivery across participants. Safety monitoring included verbal check-ins before, during, and after each session to assess discomfort, dizziness, numbness, or abnormal cardiovascular symptoms. No adverse events were reported during the intervention. These

Table 1. Structure of the Six-Week Plyometric Training Program

Week	1	2	3	4	5	6
Session	1–2	3–4	5–6	7–8	9–10	11–12
Squat Jump	2×10	2×10	2×12	2×12	–	–
Repeated Tuck Jump	2×10	2×10	2×12	2×12	3×10	3×10
Lateral Bounding – Slalom	2×10	2×10	–	–	–	–
Lateral Jump Over Barrier (30 cm)	2×10	2×10	2×12	2×12	3×10	3×10
Box Lateral Jump (30 cm)	2×10	2×10	2×12	2×12	–	–
Split Jump	–	–	2×12	2×12	3×10	3×10
Single Leg Bounding	–	–	–	–	3×10	3×10
Depth Jumps to Long Jump	–	–	–	–	3×10	3×10
Depth Jumps to Sprint 10 m	–	–	–	–	3×10	3×10
Per session	100	100	120	120	180	180
Per week	200	200	240	240	360	360

Note. Values are presented as sets × repetitions. “Per session” indicates the total number of repetitions per training session, and “Per week” indicates the total number of repetitions per week.

procedures ensured the safe application of BFR during dynamic plyometric activity.

Assessments

Body composition was assessed using a bioelectrical impedance analyzer (Seca mBCA, Hamburg, Germany), which provided values for body weight, body fat percentage, fat mass, fat-free mass, and skeletal muscle mass. Muscular strength was evaluated through a 10-repetition maximum (10RM) knee extension test. The estimated one-repetition maximum (1RM) was calculated using Brzycki’s formula [15]:

$$1RM = \frac{\text{Weight lifted}}{1.0278 - (0.0278 \times X)}$$

where X represents the number of repetitions performed.

Lower-body muscular power was assessed using the countermovement jump (CMJ), measured with a kinematic analysis system (Fitness Technology, Australia). The highest value of three attempts was recorded for analysis. Anaerobic performance was determined using the Wingate Anaerobic Test on a Monark 839E ergometer, with resistance set at 0.087 kg per kilogram of body mass. This followed the standardized protocol described by Bar-Or [16].

Statistical Analysis

All statistical analyses were conducted using IBM SPSS Statistics (Version 21.0). Data normality was verified using the Shapiro–Wilk test, and all variables were normally distributed ($p > 0.05$). Homogeneity of variances was assessed with Levene’s test. This confirmed equal variances across groups ($p > 0.05$). Based on these assumptions, parametric tests were applied. Within-group comparisons were performed using paired-samples t-tests. Between-group differences were analyzed using one-way ANOVA

followed by Bonferroni post hoc tests. Statistical significance was set at $p < 0.05$.

Results

All 27 participants completed the six-week intervention without any dropouts or adverse events. One-way ANOVA indicated no statistically significant differences ($p > 0.05$) among the three groups (Control, PLY, and PLY+BFR) in baseline characteristics such as age, body weight, height, body mass index (BMI), and blood pressure. This baseline homogeneity reinforces the internal validity of the subsequent between-group comparisons (Table 2).

Throughout the intervention period, the PLY+BFR group consistently exhibited higher average heart rate responses after each training session compared to the PLY group. This difference reached statistical significance during the final four sessions (sessions 9 to 12; $p < 0.05$). This indicates an elevated cardiovascular load associated with the application of blood flow restriction. The effect size for this difference was moderate (Cohen’s $d = 0.61$), suggesting meaningful physiological stress induced by the BFR protocol (Figure 1).

After six weeks, the Control group showed a statistically significant increase in body fat percentage (+6.5%, $p < 0.05$). This reflected a negative trend in composition. In contrast, the PLY+BFR group achieved significant improvements in both fat-free mass (+1.9%, $p < 0.05$) and skeletal muscle mass (+1.8%, $p < 0.05$). The corresponding effect sizes were 0.48 and 0.51, respectively, indicating small to moderate practical effects. The PLY group did not demonstrate any significant changes in body composition variables. These results suggest that the addition of BFR to plyometric training contributes more effectively to enhancing lean tissue outcomes than plyometric training alone (Table 3).

Table 2. Baseline Characteristics of Participants in the Control, PLY, and PLY+BFR Groups

Characteristics	Control (n = 9)	PLY (n = 9)	PLY+BFR (n = 9)
Age (years)	21.0 ± 0.9	20.9 ± 0.8	21.0 ± 0.4
Resting heart rate (bpm)	71.1 ± 12.0	73.3 ± 13.5	71.4 ± 10.2
SBP (mmHg)	116.8 ± 10.5	125.3 ± 11.5	125.0 ± 10.1
DBP (mmHg)	71.1 ± 9.2	77.8 ± 7.4	73.9 ± 9.5
Height (cm)	174.0 ± 3.0	172.4 ± 3.2	171.7 ± 4.7
Body weight (kg)	72.9 ± 6.4	66.4 ± 6.5	64.3 ± 5.2
SpO ₂ (%)	97.7 ± 1.4	97.4 ± 1.3	97.9 ± 0.9
BMI (kg/m ²)	24.0 ± 2.1	22.3 ± 2.1	22.0 ± 2.1

Note. Values are mean ± SD. Abbreviations: SBP = systolic blood pressure, DBP = diastolic blood pressure, BMI = body mass index, PLY = plyometric training group, PLY+BFR = plyometric training with blood flow restriction.

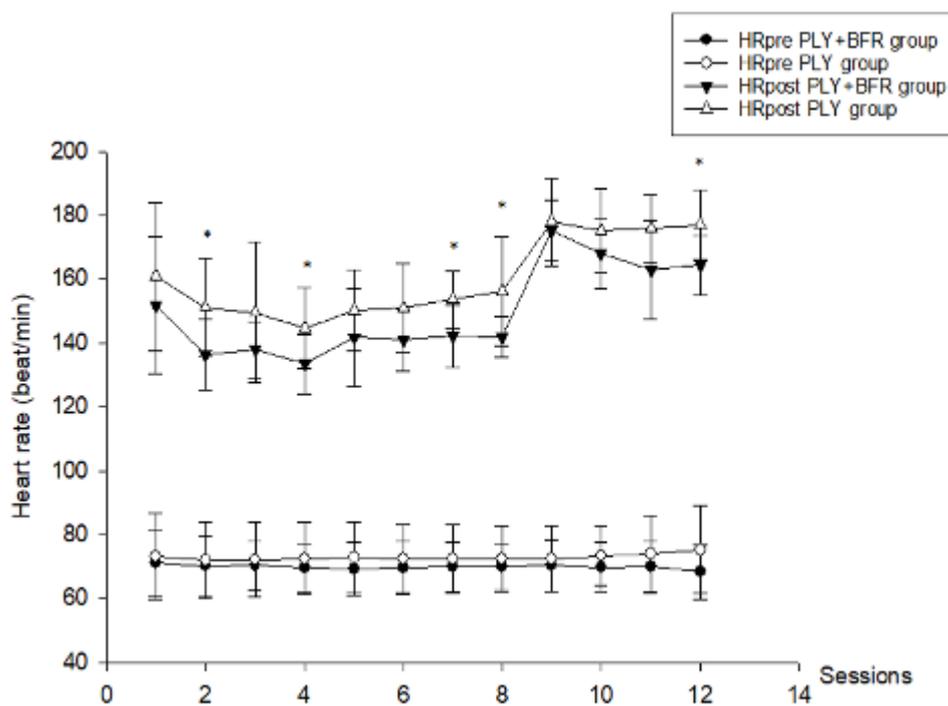


Figure 1. Mean (± SD) heart rate responses during the 12 training sessions in the plyometric training (PLY) and plyometric training combined with blood flow restriction (PLY+BFR) groups. The graph presents data from pre-training and post-training sessions for each group (PLY Pre, PLY Post, PLY+BFR Pre, and PLY+BFR Post). *Indicates significant difference between groups (PLY+BFR vs. PLY, $p < 0.05$), showing that the PLY+BFR group experienced higher heart rates during the intervention period. Data are based on measurements from nine participants per group.

Both intervention groups experienced significant improvements in knee extension strength. The PLY+BFR group showed a greater increase (+18.7%) compared to the PLY group (+9.7%). Similarly, countermovement jump (CMJ) height increased more in the PLY+BFR group (+19.5%) than in the PLY group (+14.5%). In contrast, the Control group experienced a slight decline in both variables. The effect sizes for 1RM strength and CMJ height in the PLY+BFR group were 0.72 and 0.76, respectively. This indicates a large and practically meaningful

impact on muscular performance (Table 4).

Participants in the PLY+BFR group demonstrated the most substantial gains in anaerobic power, with a statistically significant improvement of 12.4% ($p < 0.05$). The associated effect size was moderate (Cohen's $d = 0.67$). In comparison, the PLY group showed only a small and statistically non-significant increase (+2.1%). Both intervention groups improved in anaerobic capacity. However, the practical significance was limited, with small effect sizes recorded in both the PLY group ($d = 0.31$)

Table 3. Changes in Body Composition Following Six Weeks of Training in All Three Groups

Parameters	Control (n = 9)	PLY (n = 9)	PLY+BFR (n = 9)
Body fat (%)	Pre-test: 17.7 ± 7.0	15.6 ± 5.4	14.6 ± 4.0
	Post-test: 18.6 ± 6.9	15.6 ± 5.2	14.2 ± 3.9
	%Change: 6.5 ± 7.7*	1.1 ± 11.5	-1.7 ± 12.2
Fat mass (kg)	Pre-test: 13.3 ± 7.3	10.6 ± 4.4	9.2 ± 3.3
	Post-test: 13.9 ± 7.4	10.7 ± 4.3	9.0 ± 3.4
	%Change: 4.3 ± 8.4	1.4 ± 11.9	-0.6 ± 12.8
Fat-free mass (kg)	Pre-test: 62.5 ± 6.3	54.4 ± 4.5	55.3 ± 2.9
	Post-test: 62.2 ± 6.7	54.5 ± 5.3	56.4 ± 3.6
	%Change: -0.6 ± 1.9	0.2 ± 2.8	1.9 ± 2.4*
Skeletal mass (kg)	Pre-test: 30.2 ± 2.9	26.5 ± 2.2	26.4 ± 1.8
	Post-test: 30.1 ± 3.5	26.2 ± 3.0	26.9 ± 2.2
	%Change: -0.6 ± 2.5	-0.2 ± 5.9	1.8 ± 1.7*

*Values are mean ± SD. $p < 0.05$, Pre-test vs. Post-test.

Table 4. Changes in Muscular Strength and Lower-Body Power Across Groups

Parameter	Control (n = 9)	PLY (n = 9)	PLY+BFR (n = 9)
Muscular strength (1RM)			
Knee extension (kg)			
Pre-test	145.6 ± 10.9	131.8 ± 12.2	124.4 ± 13.8
Post-test	149.9 ± 13.4	144.1 ± 14.6	147.8 ± 23.3
%Change	2.9 ± 3.4	9.7 ± 9.7*	18.7 ± 11.2 ^{b*}
Muscular power			
CMJ (cm)			
Pre-test	38.6 ± 3.3	32.4 ± 2.3	33.4 ± 5.2
Post-test	36.7 ± 3.8	36.9 ± 2.1	39.5 ± 4.8
%Change	-4.7 ± 8.1	14.5 ± 12.8 ^{a*}	19.5 ± 15.6 ^{b*}

Note. Values are mean ± SD. Abbreviations: 1RM = one-repetition maximum; CMJ = countermovement jump. * $p < 0.05$, Pre-test vs. Post-test; ^a $p < 0.05$, change between Control and PLY groups; ^b $p < 0.05$, change between Control and PLY+BFR groups.

and the PLY+BFR group ($d = 0.38$). These findings indicate that the combination of plyometric training with blood flow restriction is more effective in enhancing short-term anaerobic output than plyometric training alone (Table 5).

Discussion

This study aimed to evaluate the effects of a six-week combined plyometric and blood flow restriction (PLY+BFR) training program on body composition, muscular strength, lower-body power, and anaerobic performance in male collegiate soccer players. The results demonstrated that the PLY+BFR program produced greater improvements than plyometric training alone, particularly in fat-free mass, skeletal muscle mass, knee extension strength, countermovement jump height, and anaerobic power.

These results align with Gao et al. [7], who reported that BFR training amplified both strength

and hypertrophy through heightened metabolic stress. However, the PLY group in our study demonstrated significant improvements from baseline in several parameters. This confirms the foundational benefits of traditional plyometric methods as reported by Zheng et al. [3] and Chen et al. [17]. Therefore, while PLY+BFR may accelerate adaptation, conventional plyometric exercises still play a critical role in performance development. This is particularly relevant during phases when equipment for BFR is inaccessible or when training simplicity is preferred.

The integration of BFR may have induced a unique physiological stimulus that contributed to the observed enhancements in power-related outcomes. BFR has been proposed to stimulate muscle protein synthesis and neuromuscular recruitment through increased metabolite accumulation and cellular swelling [8, 18]. These effects might have synergized with the mechanical load of plyometric movements,

Table 5. Changes in Anaerobic Power, Anaerobic Capacity, and Peak Heart Rate Across Groups

Parameter	Control (n = 9)	PLY (n = 9)	PLY+BFR (n = 9)
Anaerobic power (W/kg)			
Pre-test	12.8 ± 0.9	12.3 ± 0.6	12.7 ± 0.8
Post-test	12.7 ± 1.2	12.6 ± 1.1	14.3 ± 1.4
%Change	-1.2 ± 5.7	2.1 ± 5.2	12.4 ± 9.2 ^{bc*}
Anaerobic capacity (W/kg)			
Pre-test	8.5 ± 0.4	8.2 ± 0.3	8.6 ± 0.5
Post-test	8.6 ± 0.5	8.5 ± 0.3	8.7 ± 0.6
%Change	0.4 ± 3.2	3.4 ± 2.8*	2.0 ± 4.0
Peak heart rate (bpm)			
Pre-test	165.4 ± 6.8	177.0 ± 6.5	170.3 ± 5.4
Post-test	165.6 ± 6.0	179.5 ± 9.1	167.0 ± 9.7
%Change	0.1 ± 2.8	1.2 ± 3.8	-1.9 ± 4.0

Note. Values are mean ± SD. Abbreviations: W/kg = watts per kilogram; bpm = beats per minute. ^ap < 0.05, Pre-test vs. Post-test; ^ap < 0.05, change between Control and PLY groups; ^bp < 0.05, change between Control and PLY+BFR groups; ^cp < 0.05, change between PLY and PLY+BFR groups.

generating both neural and metabolic pathways for adaptation. Nonetheless, it is essential to emphasize that our study did not include direct measures of muscle architecture, EMG, or molecular biomarkers. Thus, while the training responses observed are consistent with prior mechanistic hypotheses [9, 19], any inference about underlying mechanisms should be interpreted with caution. These results suggest that the added metabolic stress from BFR may have enhanced neural drive or hormonal signaling. However, further investigation using physiological tools is warranted.

From a pedagogical perspective, the use of BFR in youth athletic training must be approached with deliberate planning. The reduced external load permitted by BFR may be advantageous during recovery cycles, off-season periods, or in athletes with biomechanical limitations. This aligns with injury-prevention strategies [20]. This approach also reflects a modern educational rationale for sport training. Athletes are encouraged to become more aware of internal responses and training efficiency rather than relying solely on volume or intensity. As discussed by Barra-Moura et al. [4], training frequency and load manipulation are critical for maximizing adaptation in youth athletes. BFR may offer an alternative route to stimulate performance without excessive mechanical stress.

In practical terms, the application of PLY+BFR should be integrated strategically into long-term athletic development frameworks. Coaches and sports scientists must consider age, maturation status, and sport-specific demands when selecting between high-impact methods and low-load BFR approaches. The present findings provide initial evidence supporting the periodized use of BFR-

based interventions in adolescent athletes aiming to improve anaerobic capabilities within a limited timeframe. Recent soccer-specific investigations indicate that blood flow restriction training can enhance physical capacities and support rehabilitation strategies, yet individualized programming remains essential to account for inter-athlete variability and ensure safety and effectiveness [5, 10].

Limitations and Future Directions

This study has certain limitations that should be acknowledged. First, the sample size was relatively small and limited to male collegiate soccer players, which restricts the generalizability of the findings. Second, the intervention period lasted only six weeks, preventing conclusions about long-term adaptations or retention of training effects. Third, no direct physiological or biochemical measurements (e.g., EMG, biomarkers, or hormonal assays) were collected, which limits the mechanistic interpretation of the observed outcomes. Future research should examine the applicability of PLY+BFR protocols in female athletes and youth populations, as hormonal responses and neuromuscular adaptations may differ across these groups. Longitudinal studies exceeding 12 weeks, or those with follow-up assessments, are needed to clarify the retention and delayed effects of training adaptations. In addition, incorporating biomarkers, surface electromyography (sEMG), and hormonal profiling would help explain the mechanisms underlying performance improvements. Comparative studies with other low-load resistance strategies are also recommended to determine the relative efficacy and broaden the evidence base for sports performance programming.

Conclusions

This randomized controlled trial demonstrated that a six-week intervention combining plyometric training with blood flow restriction (PLY+BFR) was more effective than traditional plyometric training alone. Significant improvements were observed in body composition, muscular strength, vertical jump performance, and anaerobic power among competitive male collegiate soccer players. These findings suggest a beneficial interaction between neuromuscular and metabolic mechanisms, likely enhancing anabolic adaptations within a relatively short timeframe. The structured progression of cuff pressure in twice-weekly sessions was feasible and well-tolerated, supporting its potential for safe implementation in contexts that require low mechanical load. The results provide practical implications for coaches and conditioning specialists, particularly during pre-season or rehabilitation phases when training intensity must be carefully managed.

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Conflict of Interest

The authors declare no conflicts of interest related to this study.

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