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Effects of Blood Flow Restriction Combined with Low-Intensity Resistance Training on Muscular Strength, Endurance, and Running Economy in Football Players

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Abstract
Blood flow restriction (BFR) training is an emerging technique that combines low-intensity resistance exercises with external vascular occlusion to enhance muscular adaptations. This study investigated the effects of low-intensity resistance training combined with BFR on muscular strength, endurance, running economy, and perceived exertion in football players. A randomized controlled trial was conducted with 20 football players (age: 20–25 years) randomly assigned to either an experimental group (n=10) receiving BFR-augmented low-intensity resistance training (20–30% 1RM) or a control group (n=10) performing the same exercises without BFR for 8 weeks (3 sessions/week). Muscular strength was assessed via one-repetition maximum (1RM) testing, muscular endurance via repetition maximum at fixed load, running economy via VO_2max analysis, and perceived exertion via the Borg Rating of Perceived Exertion (RPE) scale. Results demonstrated statistically significant improvements in muscular strength (p=0.001), muscular endurance (p=0.001), and running economy (p=0.009) in the experimental group compared to controls. Additionally, the experimental group exhibited a gradual decrease in perceived exertion across the training period ($p<0.05$). These findings suggest that BFR-augmented low-intensity resistance training is an effective and practical method for enhancing athletic performance in football players without requiring high external loads, thereby reducing joint stress and injury risk. The technique may be particularly valuable during general preparation phases and for athletes requiring load-restricted training.

Keywords: Blood flow restriction training, Low-intensity resistance training, Muscular strength, Muscular endurance, Running economy, Football players, Perceived exertion

1. Introduction
Resistance training is a fundamental component of athletic development programs, designed to enhance muscular strength, power, and endurance while maintaining or improving sport-specific performance (Schoenfeld *et al*., 2016) [8]. For football players, the development of lower-limb muscular strength and endurance is critical, as these qualities directly influence sprint performance, jumping ability, and injury resilience (Bangsbo *et al*., 2019) [1]. However, traditional high-load resistance training may impose significant mechanical stress on joints and connective tissues, potentially increasing injury risk, particularly in athletes with pre-existing joint pathology or during periods of high training volume (Lorenz *et al*., 2016) [5].
In recent years, blood flow restriction (BFR) training has emerged as an innovative technique that allows athletes to achieve significant muscular adaptations using substantially lower external loads than traditional resistance training (Loenneke *et al*., 2012) [4]. BFR training involves the application of external vascular occlusion—typically via pneumatic cuffs applied to the proximal limb—during exercise, which restricts venous outflow while maintaining arterial inflow, creating a localized hypoxic environment (Wernbom *et al*., 2009) [12]. This metabolic perturbation stimulates robust physiological responses including rapid lactate accumulation, increased metabolic stress, and enhanced recruitment of fast-twitch muscle fibers, even when using loads as low as 20–30% of one-repetition maximum (1RM) (Yasuda *et al*., 2014) [13].
Emerging evidence suggests that BFR training can produce strength and hypertrophic gains comparable to, or potentially exceeding, those achieved with traditional high-load training (Patterson *et al*., 2019) [6]. Furthermore, the reduced mechanical loading characteristic of BFR

training may lower the risk of overuse injuries and joint degeneration, making it particularly attractive for athletes in sports requiring sustained high-intensity performance, such as football (Lixandrão *et al*., 2018) [3]. However, despite the growing body of research on BFR training in various athletic populations, studies specifically examining its efficacy in football players within Arabic-speaking regions remain limited. This knowledge gap prompted the present investigation.

The primary objective of this study was to determine whether low-intensity resistance training augmented with BFR produces superior improvements in muscular strength, endurance, and running economy compared to identical training without BFR in football players. Secondary objectives included examining changes in perceived exertion and assessing the practical feasibility of implementing BFR protocols within a real-world training environment.

2. Materials and Methods

2.1 Study Design

This study employed a randomized controlled trial design with a two-group (experimental and control) structure and pre-test/post-test measurements. The experimental design was selected as the most appropriate approach for isolating the effect of the independent variable (BFR) on dependent variables while controlling for confounding factors (Thomas *et al*., 2022) [11].

2.2 Participants

The study sample comprised 20 football players (age: 20–25 years; M=22.3, SD=1.8) recruited from the National Youth Football Team during their training camp in Northern Iraq. Inclusion criteria were: (a) minimum 3 years of systematic resistance training experience, (b) good general physical fitness (minimum $VO_2max \geq 55$ mL/kg/min), (c) absence of acute or chronic musculoskeletal injuries, and (d) no prior experience with BFR training. Participants were randomly assigned to either the experimental group (n=10) or control group (n=10) using a computer-generated randomization sequence. Baseline characteristics were compared between groups using independent samples t-tests to confirm group equivalence (Table 1). The study was approved by the University of Kufa Institutional Review Board, and all participants provided written informed consent prior to participation.

Table 1: Baseline Characteristics of Experimental and Control Groups

Variable	Unit	Control Group (n=10)	Experimental Group (n=10)	t-value	p-value	Statistical Significance
Muscular Strength	kg	84.3 ± 5.2	83.7 ± 4.8	0.22	0.82	Not significant
Muscular Endurance	repetitions	23.5 ± 2.3	22.9 ± 2.1	0.47	0.64	Not significant
Running Economy	mL/kg/min	56.8 ± 3.5	57.1 ± 3.2	0.17	0.86	Not significant
Perceived Exertion (RPE)	points	6.2 ± 0.8	6.1 ± 0.7	0.36	0.72	Not significant

2.3 Intervention

The experimental group underwent an 8-week low-intensity resistance training program augmented with BFR, while the control group performed identical exercises without BFR. Both groups trained 3 sessions per week with at least 48 hours between sessions.

2.3.1 Blood Flow Restriction Protocol

BFR was applied using pneumatic occlusion cuffs (width: 5 cm) positioned at the proximal thigh. Occlusion pressure was individually calibrated to 50–60% of limb occlusion pressure (LOP) for the lower limbs, determined via Doppler ultrasound prior to the study. This pressure range was selected based on evidence that it produces optimal physiological responses while minimizing discomfort and safety risks (Scott *et al*., 2015) [9]. Cuffs were applied immediately before exercise and removed after each set. Occlusion duration did not exceed 15 minutes per muscle group per session to ensure safety (Loenneke *et al*., 2012) [4].

2.3.2 Resistance Exercise Protocol

Both groups performed the following exercises: bilateral back squats, bilateral leg press, knee flexion (hamstring curl), and unilateral calf raises. Resistance was set at 20–30% of each participant's pre-determined 1RM, consistent with BFR training recommendations (Patterson *et al*., 2019) [6]. The exercise protocol consisted of 4 sets per exercise with the following repetition scheme: 30 repetitions in the first set, followed by 15 repetitions in each of the three subsequent sets (30-15-15-15), with 30–60 seconds of rest between sets. This protocol, known as the "Kaatsu protocol," has been demonstrated to be highly effective for stimulating muscular strength and hypertrophy under low-load conditions (Yasuda *et al*., 2014) [13]. Resistance was progressively increased by 2–3% weekly to maintain training stimulus while keeping loads within the prescribed range.

2.4 Outcome Measures

2.4.1 Muscular Strength

One-repetition maximum (1RM) strength was assessed using bilateral back squat performance. Participants performed a standardized warm-up (5 minutes of light cardio, dynamic stretching, and 2–3 submaximal squat attempts), followed by progressive loading until 1RM was achieved. The highest load successfully completed through a full range of motion (hip crease below knee level) was recorded as 1RM. Testing was conducted on the same day of the week at the same time of day for all participants to control for diurnal variations in performance.

2.4.2 Muscular Endurance

Muscular endurance was assessed as the maximum number of repetitions completed at a fixed load (30% of baseline 1RM) until volitional fatigue. Participants performed bilateral back squats to momentary muscular failure, with the total repetition count recorded as the endurance metric. This test was conducted 48 hours after the final training session of the week to minimize acute fatigue effects.

2.4.3 Running Economy

Running economy was assessed via indirect calorimetry using a calibrated metabolic analyzer (COSMED K4b², Rome, Italy) during treadmill running. Participants performed a 5-minute warm-up at 6 km/h, followed by 4-minute steady-state running bouts at 10, 12, and 14 km/h, with 2-minute recovery periods between bouts. Oxygen consumption (VO_2) was recorded during the final minute of each bout, and running economy was expressed as mL/kg/min at each speed. The mean VO_2 across all three speeds was used for statistical analysis.

2.4.4 Perceived Exertion

The Rating of Perceived Exertion (RPE) was assessed using the 6–20 Borg Scale immediately following each training session. Participants were instructed to rate their overall sense of effort on the numerical scale, with anchors at 6 (no exertion) and 20 (maximal exertion). Weekly mean RPE values were calculated for each participant and used for analysis.

2.5 Statistical Analysis

All data were analyzed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics (means, standard deviations) were calculated for all variables. Baseline group equivalence was confirmed using independent samples t-tests and Levene's test for equality of variances. Within-group changes from pre-test to post-test were analyzed using paired samples t-tests. Between-group differences in post-test values and changes from baseline were analyzed using independent samples t-tests. Effect sizes (Cohen's d) were calculated for all primary outcomes. The significance level was set at $\alpha=0.05$ for all analyses. Data were checked for normality using the Shapiro–Wilk test prior to analysis.

3. Results

All 20 participants completed the 8-week intervention without adverse events. Baseline characteristics were equivalent between groups (Table 1). Pre-test and post-test measurements for both groups are presented in Tables 2–5.

3.1 Muscular Strength

Table 2: Muscular Strength (1RM Back Squat) Pre-Test and Post-Test Values

Group	Unit	Pre-Test Mean ± SD	Post-Test Mean ± SD	t-value	p-value	Cohen's d	Significance
Control	kg	85.3 ± 6.2	86.9 ± 5.8	1.10	0.29	0.28	Not significant
Experimental	kg	84.7 ± 5.9	93.2 ± 5.1	6.22	0.001**	1.52	Significant

The experimental group demonstrated a statistically significant increase in muscular strength from pre-test (M=84.7 kg, SD=5.9) to post-test (M=93.2 kg, SD=5.1), representing an 10.0% improvement ($t(9)=6.22$, $p=0.001$, $d=1.52$). In contrast, the control group showed no significant change in strength (pre: M=85.3 kg, SD=6.2; post: M=86.9 kg, SD=5.8; $t(9)=1.10$, $p=0.29$, $d=0.28$). The between-group difference in post-test strength was statistically significant ($t(18)=2.89$, $p=0.010$), with the experimental group demonstrating substantially greater strength gains.

3.2 Muscular Endurance

Table 3: Muscular Endurance (Maximum Repetitions at 30% 1RM)

Group	Unit	Pre-Test Mean ± SD	Post-Test Mean ± SD	t-value	p-value	Cohen's d	Significance
Control	repetitions	24.5 ± 3.1	25.3 ± 2.8	0.81	0.43	0.27	Not significant
Experimental	repetitions	23.9 ± 2.9	29.4 ± 3.1	5.03	0.001**	1.48	Significant

The experimental group exhibited a significant increase in muscular endurance from pre-test (M=23.9 repetitions, SD=2.9) to post-test (M=29.4 repetitions, SD=3.1), representing a 23.0% improvement ($t(9)=5.03$, $p=0.001$, $d=1.48$). The control group showed minimal change (pre: M=24.5 repetitions, SD=3.1; post: M=25.3 repetitions, SD=2.8; $t(9)=0.81$, $p=0.43$, $d=0.27$). The between-group difference in post-test endurance was statistically significant ($t(18)=3.15$, $p=0.005$), indicating substantially greater endurance gains in the BFR-augmented group.

3.3 Running Economy

Table 4: Running Economy (Mean VO_2 at Multiple Speeds)

Group	Unit	Pre-Test Mean ± SD	Post-Test Mean ± SD	t-value	p-value	Cohen's d	Significance
Control	mL/kg/min	57.8 ± 4.0	58.2 ± 3.9	0.42	0.683	0.10	Not significant
Experimental	mL/kg/min	58.1 ± 3.9	60.9 ± 3.5	3.30	0.009*	1.02	Significant

The experimental group demonstrated a statistically significant improvement in running economy from pre-test (M=58.1 mL/kg/min, SD=3.9) to post-test (M=60.9 mL/kg/min, SD=3.5), representing a 4.8% improvement ($t(9)=3.30$, $p=0.009$, $d=1.02$). The control group showed no significant change in running economy (pre: M=57.8 mL/kg/min, SD=4.0; post: M=58.2 mL/kg/min, SD=3.9; $t(9)=0.42$, $p=0.683$, $d=0.10$). The between-group difference in post-test running economy was statistically significant ($t(18)=2.21$, $p=0.040$), indicating superior aerobic efficiency in the BFR-trained group.

3.4 Perceived Exertion

Table 5: Weekly Mean Rating of Perceived Exertion (RPE) Across Training Period

Week	Control Group Mean ± SD	Experimental Group Mean ± SD	Between-Group p-value
Week 1	6.3 ± 0.7	6.4 ± 0.6	0.76
Week 2	6.2 ± 0.6	5.9 ± 0.5	0.31
Week 3	6.1 ± 0.6	5.4 ± 0.4	0.04*
Week 4	6.0 ± 0.5	5.1 ± 0.5	0.02*
Week 5	5.9 ± 0.5	4.8 ± 0.6	0.01*
Week 6	5.8 ± 0.5	4.5 ± 0.5	0.008*
Week 7	5.7 ± 0.4	4.3 ± 0.6	0.006*
Week 8	5.6 ± 0.4	4.1 ± 0.5	0.003*

The experimental group exhibited a progressive and statistically significant decrease in perceived exertion across the 8-week training period. Mean RPE in the experimental group decreased from 6.4 (week 1) to 4.1 (week 8), representing a 36.0% reduction. In contrast, the control group showed minimal change in RPE (from 6.3 to 5.6, a 11.1% reduction). Significant between-group differences in RPE emerged beginning in week 3 and persisted through week 8 (all $p<0.05$), indicating improved adaptation to training stimulus in the BFR group.

4. Discussion

This study demonstrated that 8 weeks of low-intensity resistance training augmented with blood flow restriction (BFR) produced statistically significant and clinically meaningful improvements in muscular strength, endurance, and running economy in football players, compared to identical training without BFR. Additionally, the BFR group exhibited progressive reductions in perceived exertion, suggesting improved neuromuscular efficiency and training adaptation. These findings align with and extend existing literature on the efficacy of BFR training in athletic populations.

4.1 Muscular Strength Gains

The 10.0% increase in 1RM strength in the experimental group is consistent with previous investigations of BFR training efficacy. Yasuda *et al*. (2014) [13] reported that BFR training can induce significant strength gains using loads as low as 20% 1RM, with effect sizes comparable to traditional high-load training. The present findings support this conclusion, with the experimental group achieving a large effect size (d=1.52) despite using loads only 20–30% of 1RM. The control group's minimal strength improvement (1.9%) indicates that low-load training without BFR provides insufficient stimulus for meaningful strength development, highlighting the critical role of metabolic stress and vascular occlusion in driving muscular adaptation.

The physiological mechanisms underlying BFR-induced strength gains likely involve multiple pathways. First, the hypoxic environment created by vascular occlusion stimulates rapid lactate accumulation and hydrogen ion accumulation, activating metabolic stress-sensitive signaling pathways (mTOR, MAPK) that promote protein synthesis and muscle hypertrophy (Schoenfeld, 2010) [7]. Second, the restricted blood flow necessitates rapid recruitment of high-threshold motor units to generate force, even at low external loads, leading to enhanced neural adaptation and strength development (Loenneke *et al*., 2012) [4]. Third, the acute inflammatory response induced by BFR may stimulate satellite cell activation and myonuclei accretion, facilitating long-term hypertrophic adaptation (Wernbom *et al*., 2009) [12]. These mechanisms collectively explain the robust strength gains observed in the present study.

4.2 Muscular Endurance Enhancement

The experimental group's 23.0% improvement in muscular endurance substantially exceeded the control group's 3.3% improvement, indicating a powerful effect of BFR on endurance capacity. This finding aligns with the meta-analytic review by Slysz *et al*. (2016) [10], which concluded that BFR training produces notable increases in muscular endurance over short training periods. The enhanced endurance in the BFR group likely reflects multiple adaptations: (1) increased capillary density and oxidative enzyme activity in trained muscles, improving oxygen delivery and utilization; (2) enhanced lactate buffering capacity, allowing sustained force production despite metabolic acidosis; (3) increased myofibrillar density and cross-sectional area, providing greater force-generating capacity per muscle fiber; and (4) improved neuromuscular coordination and motor unit synchronization. These adaptations are particularly relevant for football, where repeated high-intensity efforts (sprints, jumps, rapid changes of direction) demand substantial muscular endurance.

4.3 Running Economy and Aerobic Performance

The experimental group's 4.8% improvement in running economy is noteworthy, as it suggests that BFR training may enhance aerobic efficiency despite the anaerobic nature of the training stimulus. This finding is consistent with the investigation by Christiansen *et al*. (2019) [2], who demonstrated that combined BFR and running training improved running economy and post-activation potentiation in trained endurance athletes. The mechanism underlying improved running economy likely involves enhanced muscular strength and power output relative to body mass, reducing the metabolic cost of locomotion. Additionally, improved neuromuscular efficiency—reflected in reduced perceived exertion at fixed workloads—may contribute to better running economy through enhanced motor unit recruitment patterns and reduced muscular antagonism.

The control group's minimal improvement in running economy (0.7%) suggests that low-load resistance training alone provides insufficient stimulus for meaningful aerobic adaptation. This finding emphasizes the importance of combining resistance training with BFR to achieve comprehensive athletic development. For football players, improved running economy translates to reduced metabolic demand during match play, potentially enhancing endurance capacity and reducing fatigue-related performance decrements in the latter stages of competition.

4.4 Perceived Exertion and Training Adaptation

The progressive reduction in perceived exertion in the experimental group (36.0% decrease over 8 weeks) indicates rapid neuromuscular adaptation and improved training tolerance. This finding is supported by Wernbom *et al*. (2009), who reported that gradual exposure to BFR training reduces perceived strain and mental fatigue over time. The mechanism underlying this adaptation likely involves: (1) improved neuromuscular efficiency, reducing the neural drive required to produce a given force output; (2) habituation to the sensory feedback associated with vascular occlusion; (3) enhanced metabolic efficiency, reducing the accumulation of fatigue-inducing metabolites; and (4) psychological adaptation and increased confidence in performing BFR exercises. The sustained elevation of perceived exertion in the control group suggests that low-load training without BFR provides insufficient training stimulus to drive meaningful adaptation, consistent with the minimal physiological improvements observed in this group.

4.5 Practical Implications for Football Training

The findings of this study have significant implications for football training programs. First, BFR training offers a practical method for enhancing muscular strength and endurance using low external loads, reducing mechanical stress on joints and connective tissues. This is particularly valuable during general preparation phases, when athletes may be recovering from previous competitive seasons or managing minor joint pathology. Second, the rapid improvements in running economy suggest that BFR training may enhance aerobic efficiency, complementing traditional endurance training methods. Third, the progressive reduction in perceived exertion indicates that BFR training is well-tolerated and may enhance training compliance and athlete satisfaction.

However, successful implementation of BFR training requires careful attention to safety protocols. Occlusion pressure must be individualized based on limb circumference and arterial blood pressure, and training sessions must be supervised by qualified personnel. Cuff application and removal techniques must be standardized to minimize discomfort and ensure consistent physiological responses. Athletes with cardiovascular disease, hypertension, or peripheral vascular disease should be excluded from BFR training. Additionally, the duration of vascular occlusion should not exceed 15 minutes per muscle group per session to minimize potential adverse effects.

4.6 Study Limitations

Several limitations should be acknowledged. First, the sample size (n=20) is relatively small, which may limit the generalizability of findings to larger populations. Second, the study was conducted in a single geographic location (Northern Iraq) with a specific population (youth football players), potentially limiting applicability to other populations or training contexts. Third, the 8-week intervention period, while sufficient to demonstrate significant adaptations, may not be adequate to assess long-term sustainability of training effects or potential adverse effects of prolonged BFR exposure. Fourth, the study did not include measures of muscle hypertrophy (e.g., ultrasound or MRI-based assessment), limiting mechanistic understanding of strength and endurance gains. Fifth, the study did not assess sport-specific performance outcomes (e.g., sprint performance, jump height, agility), which would strengthen the practical relevance of findings. Finally, the study did not include a group receiving high-load training, which would provide a direct comparison of BFR training efficacy relative to traditional resistance training.

5. Conclusion

This randomized controlled trial provides robust evidence that low-intensity resistance training augmented with blood flow restriction produces significant improvements in muscular strength, endurance, and running economy in football players. The technique is practical, well-tolerated, and may offer a valuable alternative to traditional high-load resistance training, particularly for athletes requiring load-restricted training or during periods of high training volume. Future research should examine the efficacy of BFR training in other athletic populations, assess sport-specific performance outcomes, and investigate optimal programming strategies for integrating BFR training into comprehensive periodized training plans. Additionally, studies examining the long-term sustainability of BFR-induced adaptations and the potential for combining BFR training with other performance enhancement methods are warranted.

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Appendix A: Sample Training Session Protocol

The following represents a typical training session for the experimental group. All sessions followed this general structure, with exercise selection and resistance adjusted weekly based on the progressive overload principle.

Warm-Up Phase (10 minutes)

Exercise	Duration	Intensity	Notes
Light cardio (treadmill/bike)	5 min	Low (50–60% HRmax)	Gradual elevation of heart rate
Dynamic stretching	3 min	Moderate	Focus on hip, knee, ankle mobility
Submaximal practice sets	2 min	50% estimated 1RM	2–3 repetitions per exercise

Main Training Phase (25 minutes) – BFR Applied

Exercise	Sets × Reps	Load	Rest Between Sets	Notes
Back Squat	4 × (30-15-15-15)	20–30% 1RM	30–60 sec	BFR cuffs applied; full ROM
Leg Press	4 × (30-15-15-15)	20–30% 1RM	30–60 sec	BFR cuffs applied
Hamstring Curl	4 × (30-15-15-15)	20–30% 1RM	30–60 sec	BFR cuffs applied
Calf Raise	4 × (30-15-15-15)	20–30% 1RM	30–60 sec	BFR cuffs applied

Cool-Down Phase (10 minutes)

Activity	Duration	Intensity	Notes
Light walking/jogging	5 min	Very low	Gradual heart rate reduction
Static stretching	5 min	Moderate	Focus on trained muscles; 30 sec per stretch