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The effects of 8 weeks isometric resistance training with blood flow restriction on physical performance and muscle damage markers in young men

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Summary. Background. Blood flow restriction (BFR) training is a low-load resistance strategy that promotes muscular adaptations with reduced mechanical stress. However, its effects combined with isometric resistance training on performance and muscle damage markers remain unclear. **Methods**. Twenty physically active young men were randomly assigned to isometric resistance training with BFR (n = 10) or without BFR (CON, n = 10). Both groups completed an 8-week program (two sessions per week) at 50% maximal voluntary contraction. Muscular endurance, anaerobic power, aerobic capacity, and muscle damage markers (creatine kinase [CK] and lactate dehydrogenase [LDH]) were assessed before and after the intervention. Data were analyzed using repeated-measures ANOVA. **Results**. Isometric resistance training significantly improved muscular endurance in both groups ($p < 0.05$), with no additional effect of BFR. Anaerobic power improved only in the CON group ($p < 0.05$), while aerobic capacity remained unchanged. CK levels were significantly lower in the BFR group compared with CON ($p < 0.05$), whereas no between-group difference was observed for LDH. **Conclusion**. Eight weeks of isometric resistance training enhanced muscular endurance regardless of BFR. Although BFR did not further improve performance outcomes, it was associated with reduced CK levels, suggesting a potentially favorable muscle damage response.

Key words. Blood flow restriction, isometric, resistance training, muscle damage, aerobic capacity.

Effetti di un programma di allenamento isometrico di resistenza con limitazione del flusso sanguigno della durata di 8 settimane sulle prestazioni fisiche e sui marcatori di danno muscolare in giovani uomini

Riassunto. **Background**. L'allenamento con restrizione del flusso sanguigno (BFR) è una strategia di resistenza a basso carico che favorisce adattamenti muscolari con uno stress meccanico ridotto. Tuttavia, i suoi effetti, in combinazione con l'allenamento di resistenza isometrica, sulle prestazioni e sui marcatori di danno muscolare rimangono poco chiari. **Metodi**. Venti giovani uomini fisicamente attivi sono stati assegnati in modo casuale a un gruppo sottoposto ad allenamento di resistenza isometrica con BFR (n = 10) o senza BFR (CON, n = 10). Entrambi i gruppi hanno completato un programma di 8 settimane (due sessioni a settimana) al 50% della contrazione volontaria massima. La resistenza muscolare, la potenza anaerobica, la capacità aerobica e i marcatori di danno muscolare (creatina chinasi [CK] e lattato deidrogenasi [LDH]) sono stati valutati prima e dopo l'intervento. I dati sono stati analizzati utilizzando l'ANOVA a misure ripetute. **Risultati**. L'allenamento di resistenza isometrica ha migliorato significativamente la resistenza muscolare in entrambi i gruppi ($p < 0,05$), senza alcun effetto aggiuntivo della BFR. La potenza anaerobica è migliorata solo nel gruppo CON ($p < 0,05$), mentre la capacità aerobica è rimasta invariata. I livelli di CK erano significativamente più bassi nel gruppo BFR rispetto al gruppo CON ($p < 0,05$), mentre non è stata osservata alcuna differenza tra i gruppi per quanto riguarda l'LDH. **Conclusione**. Otto settimane di allenamento di resistenza isometrica hanno migliorato la resistenza muscolare indipendentemente dalla BFR. Sebbene la BFR non abbia ulteriormente migliorato i risultati delle prestazioni, è stata associata a livelli ridotti di CK, suggerendo una risposta potenzialmente favorevole al danno muscolare.

Parole chiave. Restrizione del flusso sanguigno, Isometrico, allenamento di resistenza, danno muscolare, capacità aerobica.

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Introduction and objectives

Resistance training is widely recognized as a fundamental component of physical conditioning due to its beneficial effects on muscular strength, endurance, and overall physical performance[1]. Traditional resistance training protocols typically rely on moderate to high external loads to induce meaningful adaptations; however, such loading strategies may not always be feasible in clinical, rehabilitative, or military settings where minimizing mechanical stress is a priority[2].

Blood flow restriction (BFR) training has emerged as a low-load resistance training strategy capable of eliciting muscular adaptations under reduced mechanical stress. By partially restricting arterial inflow and limiting venous outflow, BFR induces a hypoxic and metabolically demanding intramuscular environment, which may enhance motor unit recruitment and anabolic signaling despite low external loads[3]. Recent evidence suggests that low-load resistance training combined with BFR can result in gains in muscular strength and hypertrophy comparable to traditional high-load training[4].

Most existing BFR research has focused on dynamic resistance exercises involving concentric and eccentric muscle actions[5]. In contrast, relatively little attention has been given to isometric resistance training combined with BFR, despite the widespread application of isometric exercise in rehabilitation and military conditioning programs [6]. Isometric training is characterized by sustained muscle contractions without joint movement, resulting in reduced joint stress and mechanical strain[7].

Concerns remain regarding the effects of BFR on muscle tissue integrity, commonly assessed through circulating muscle damage markers such as creatine kinase (CK) and lactate dehydrogenase (LDH)[8].

While some studies suggest that BFR training performed with low loads may attenuate muscle damage compared with traditional high-load resistance exercise, findings remain inconsistent and appear to be protocol-dependent[9].

Therefore, the purpose of this study was to investigate the effects of 8 weeks of isometric resistance training with and without blood flow restriction on muscular endurance, anaerobic power, aerobic capacity, and muscle damage markers (CK and LDH) in physically active young men.

Materials and methods

Study Design

This study employed a semi-experimental, randomized controlled design with repeated measurements. Participants were randomly assigned to either an isometric resistance training with blood flow restriction group (BFR) or an isometric resistance training without blood flow restriction group (CON). The intervention lasted 8 weeks. Physical performance variables were assessed before and after the training period, while muscle damage markers were additionally assessed at baseline to distinguish resting values from exercise-induced responses.

Participants

Twenty physically active young men (19-22 years) voluntarily participated in the study. All participants were free from cardiovascular, metabolic, neuromuscular, or musculoskeletal disorders. Exclusion criteria included the use of anabolic agents, anti-inflammatory medications, or nutritional supplements during the study period. Participants were instructed to maintain their habitual physical activity and dietary patterns throughout the study. Written informed consent was obtained from all participants prior to participation.

Randomization

Following baseline assessments, participants were randomly allocated to either the BFR group (n = 10) or the CON group (n = 10) using block randomization to ensure equal group sizes.

Training protocol

Both groups completed an 8-week isometric resistance training program consisting of two sessions per week, with a minimum of 48 hours between sessions. Training intensity was set at 50% of maximal voluntary contraction (MVC), which was determined individually using a dynamometer (Back Muscle Isometric Dynamometer, DSI, IRAN) prior to the intervention. Each training session included isometric knee extension and standing calf raise exercises performed on resistance training machines.

Each exercise (Leg Extension Machine, Standing Calf Raise Machine) was performed for three sets, with a contraction duration of 30 seconds per set and 90 seconds of rest between sets. This protocol was designed to provide sufficient neuromuscular and metabolic stimulus while minimizing excessive mechanical loading.

Blood flow restriction application

In the BFR group, blood flow restriction was applied using pneumatic cuffs with a width of 12–13 cm (Richter, Germany) positioned proximally on the lower limbs. Cuff pressure was set within a range of 200 mmHg and remained constant across all training ses-

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sions. This pressure range was selected to partially restrict arterial inflow and substantially limit venous outflow during isometric contractions, in accordance with commonly applied practical BFR protocols reported in the literature[10].

Cuffs remained inflated throughout each isometric contraction and were fully deflated during rest intervals between sets. The CON group performed the same training protocol without blood flow restriction.

Outcome measures

Muscular endurance

Lower-body muscular endurance was assessed using a repetition-to-failure test on a leg extension machine at 70% of one-repetition maximum (1RM). The total number of correctly performed repetitions was recorded for analysis. Anaerobic Power Anaerobic power was assessed using a 30-second Bosco repeated jump test performed on an electronic jump system. Peak power output was recorded and used for statistical analysis. Aerobic Capacity Aerobic capacity was evaluated using the 12-minute Cooper running test. Total distance covered during the test was recorded as an indicator of aerobic performance.

Muscle damage markers

Venous blood samples were collected to determine serum creatine kinase (CK) and lactate dehydrogenase (LDH) concentrations. Samples were obtained at three time points: baseline (prior to any functional testing), immediately after the initial testing session, and 72 hours after the final training session. Blood samples were centrifuged, and serum was stored at −20 °C until analysis. CK and LDH concentrations were measured using commercially available spectrophotometric assay kits (Delta, Iran) according to the manufacturer's instructions, and analyses were performed using an automated biochemical analyzer (ALCYON, USA).

The CK assay had an analytical sensitivity of 1 IU/L, with inter-assay and intra-assay coefficients of variation of 1.04% and 0.7%, respectively; the normal reference range for men is 24-195 IU/L. For LDH, the assay sensitivity was 5 IU/L, with inter-assay and intra-assay coefficients of variation of 1.82% and 2.01%, respectively; the normal reference range for men is 225–500 IU/L. These biomarkers were selected due to their established validity as indicators of exercise-induced muscle damage[8,9].

Statistical analysis

Data are presented as mean ± standard deviation. Normality of data distribution was assessed using the Shapiro–Wilk test. Changes in physical performance variables were analyzed using two-way repeated-measures analysis of variance (group × time). Muscle damage markers were analyzed using repeated-measures analysis of variance across three measurement time points. When significant effects were detected, Bonferroni post hoc tests were applied. Statistical analyses were performed using SPSS 26 software, and statistical significance was set at $p < 0.05$.

Ethical considerations

This study was conducted in accordance with the Declaration of Helsinki. The protocol was approved by the institutional ethics committee (approval code: IR.BMSU.BAQ.REC.1404.069) and was registered in the Iranian Registry of Clinical Trials (IRCTID: IRCT20250629066293N1).

Results

Participant flow and baseline characteristics

A total of 34 participants were initially recruited for the study. During the intervention period, 14 participants withdrew due to non-attendance, personal reasons, or injuries unrelated to the training protocol. Consequently, data from 20 participants (10 in the blood flow restriction group and 10 in the control group) were included in the final analysis.

All remaining participants completed the 8-week training intervention, and no training-related adverse events were reported. Baseline characteristics of the participants are presented in table 1. No significant dif-

Table 1. Participant characteristics at baseline.

Variable	Iso.RT &BFR (n = 10)	Iso.RT (n = 10)	p-value
Age (years)	20.0 ± 0.7	19.4 ± 1.4	>0.05
Height (cm)	180.6 ± 5.0	181.8 ± 4.6	>0.05
Body mass (kg)	75.0 ± 10.4	72.0 ± 12.2	>0.05
BMI (kg/m²)	23.0 ± 3.1	21.7 ± 2.8	>0.05

Data are presented as mean ± standard deviation (SD). BFR: blood flow restriction group; Iso.RT: Isometric resistance training. No significant differences were observed between groups at baseline ($p > 0.05$).

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ferences were observed between groups at baseline for age, height, body mass, or body mass index ($p > 0.05$).

Muscular endurance

Changes in muscular endurance are presented in table 2 and figure 1. Repeated-measures ANOVA revealed a significant main effect of time for muscular endurance ($p < 0.05$), indicating significant improvements following the training intervention in both groups. However, no significant group × time interaction was observed ($p > 0.05$), demonstrating that the magnitude of improvement did not differ between the blood flow restriction and control groups.

Post hoc analyses showed that muscular endurance increased significantly from pre- to post-intervention in both groups ($p < 0.05$).

Anaerobic power

Anaerobic power results are shown in table 3 and figure 2. A significant main effect of time was observed for anaerobic power ($p < 0.05$). Post hoc analysis indicated that anaerobic power increased significantly in the control group following the intervention ($p < 0.05$), whereas the increase observed in the blood flow restriction group did not reach statistical significance. No significant group × time interaction was detected ($p > 0.05$).

Aerobic capacity

Aerobic capacity data are presented in table 4 and figure 3. No significant main effects of time or group × time interactions were found for aerobic capacity ($p > 0.05$), indicating that neither training condition resulted in meaningful changes in aerobic performance.

Muscle damage markers

Creatine kinase

Serum creatine kinase (CK) concentrations across the three measurement time points are presented in table 5 and figure 4. Repeated-measures ANOVA revealed a significant main effect of time ($p < 0.05$) and a significant group × time interaction ($p < 0.05$). Post hoc comparisons demonstrated that CK levels were significantly lower in the blood flow restriction group compared with the control group following the 8-week intervention ($p < 0.05$). No significant between-group differences were observed at baseline or after the initial testing session.

Table 2. Changes in muscular endurance following 8 weeks of isometric resistance training.

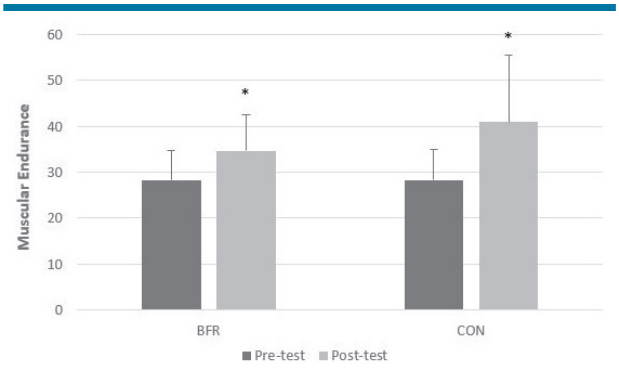
Group	Pre-test (Rep)	Iso.RT (n = 10) (Rep)
Iso.RT &BFR	28.3 ± 6.4	34.7 ± 7.9*

Data are presented as mean ± SD. Muscular endurance was assessed using a repetition-to-failure test at 70% of one-repetition maximum. *Significant difference compared with pre-test within the same group ($p < 0.05$). Iso.RT: Isometric resistance training.

Table 3. Anaerobic power before and after the 8-week training intervention.

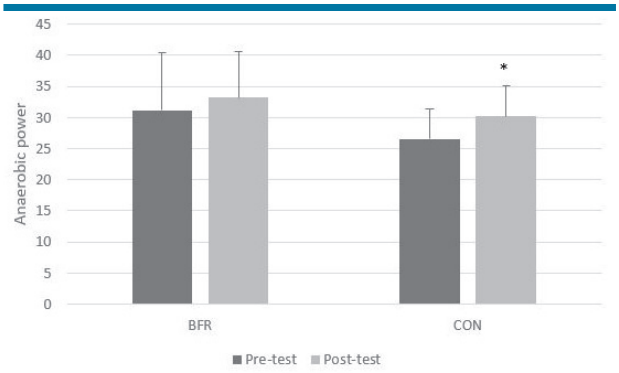
Group	Pre-test	Post-test (8 weeks)
BFR	31.13 ± 9.2	33.2 ± 7.4
CON	26.5 ± 4.9	30.2 ± 4.8*

Data are presented as mean ± SD. Anaerobic power was assessed using a 30-second Bosco repeated jump test. *Significant difference compared with pre-test within the same group ($p < 0.05$). Iso.RT: Isometric resistance training.



Values are presented as mean ± SD. *Significant difference compared with pre-test within the same group ($p < 0.05$).

Figure 1. Changes in muscular endurance following the 8-week training intervention.



Values are presented as mean ± SD. *Significant difference compared with pre-test within the control group ($p < 0.05$).

Figure 2. Changes in anaerobic power before and after the training period.

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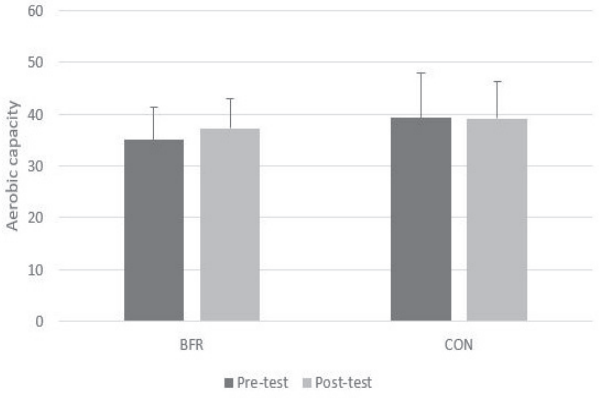
Table 4. Aerobic capacity assessed by the 12-minute Cooper test.

Group	Pre-test	Post-test (8 weeks)
BFR	35.0 ± 6.7	37.3 ± 5.8
CON	39.3 ± 8.7	39.2 ± 7.2

Data are presented as mean ± SD. Aerobic capacity is expressed as total distance covered (meters). No significant within- or between-group differences were observed ($p > 0.05$).



Values are presented as mean ± SD. No significant differences were observed between or within groups ($p > 0.05$).

Figure 3. Aerobic capacity before and after the 8-week training intervention.

Lactate dehydrogenase

Lactate dehydrogenase (LDH) concentrations are reported in table 6 and figure 5. A significant main effect of time was observed for LDH ($p < 0.05$), whereas no significant group × time interaction was detected ($p > 0.05$). Post hoc analysis indicated a significant increase in LDH following the initial testing session in the control group ($p < 0.05$), with no significant differences observed between groups after the training period.

Summary of findings

Overall, analysis of the training outcomes revealed that muscular endurance was enhanced following isometric resistance training, with no additive effect from blood flow restriction. Significant gains in anaerobic power were specific to the conventional isometric training protocol, while aerobic capacity remained stable across both interventions. Notably, the application of BFR conferred a distinct advantage by attenuating the exercise-induced creatine kinase response.Top of Form

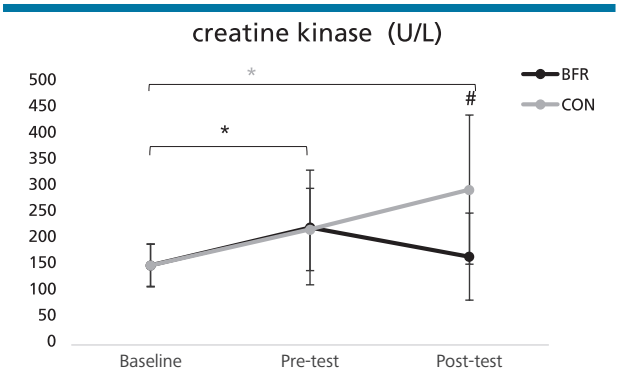
Discussion

The purpose of the present study was to examine the effects of 8 weeks of isometric resistance training with and without blood flow restriction (BFR) on physical performance and muscle damage markers in physically active young men. The main findings indicated that muscular endurance improved significantly in both training conditions, anaerobic power increased significantly only in the control group, aerobic capacity remained unchanged, and isometric training combined with blood flow restriction resulted in a more favorable creatine kinase response compared with conventional isometric resistance training.

Table 5. Serum creatine kinase (U/L) concentrations at baseline, post-test 1, and after 8 weeks of training.

Group	Baseline	Pre-test	Post-test (8 weeks)
BFR	152.3 ± 40.2	224.6 ± 109.7*	168.9 ± 83.3*
CON	152.1 ± 41.2	220.8 ± 78.7	297.0 ± 142.7*

Data are presented as mean ± SD. CK: creatine kinase; BFR: blood flow restriction group; CON: control group. *Significant difference compared with baseline within the same group ($p < 0.05$). # Significant difference between groups at post 8 weeks ($p < 0.05$).



Values are presented as mean ± SD. *Significant difference compared with baseline within the same group ($p < 0.05$).

Figure 4. Serum creatine kinase responses at baseline, post-test 1, and after 8 weeks of training.

Muscular endurance

In the present study, participants performed lower-limb isometric resistance training (quadriceps and standing calf muscles) twice weekly for eight weeks at approximately 50% of maximal voluntary contrac-

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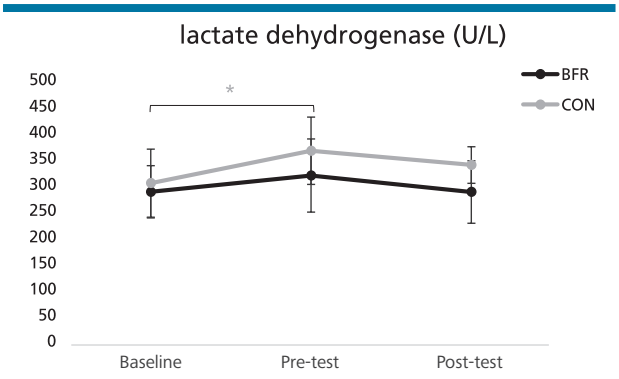
Table 6. Serum lactate dehydrogenase (U/L) concentrations at baseline, post-test 1, and after 8 weeks of training

Group	Baseline	Pre-test	Post-test (8 weeks)
BFR	293.0 ± 50.0	324.1 ± 70.0	292.6 ± 59.8
CON	309.5 ± 65.1	371.5 ± 64.4*	344.2 ± 35

Data are presented as mean ± SD. LDH: lactate dehydrogenase. *Significant difference compared with baseline within the same group ($p < 0.05$).



Values are presented as mean ± SD. *Significant difference compared with baseline within the control group ($p < 0.05$).

Figure 5. Serum lactate dehydrogenase responses at baseline, post-test 1, and after 8 weeks of training.

tion (MVC). Each exercise consisted of three 30-s sustained contractions with 60-s rest intervals, resulting in a moderate training volume primarily targeting the lower extremities. Over the entire intervention period, participants completed a total of approximately 48 minutes of sustained contraction (or ~2880 seconds), providing a quantified overall training volume. This protocol was sufficient to significantly improve muscular endurance in both the BFR and non-BFR groups.

Isometric contractions performed at moderate intensities are known to induce neuromuscular adaptations, such as improved motor unit recruitment, enhanced fatigue tolerance, and increased metabolic efficiency, all of which contribute to local muscular endurance development[6,7]. Under these conditions, the mechanical tension generated by sustained contractions may already approach the threshold necessary to stimulate endurance adaptations, potentially limiting the additional contribution of blood flow restriction.

Previous studies examining low-load resistance training combined with blood flow restriction generally report improvements in muscular endurance and strength comparable to traditional resistance training, particularly when cuff pressures exceed ~160 mmHg and training duration is sufficient to induce metabolic stress[15,17]. However, these adaptations appear strongly influenced by contraction mode, exercise volume, and training intensity.

Furthermore, recent investigations and meta-analytic evidence have demonstrated additional benefits of BFR under specific conditions, indicating that contraction mode, exercise volume, and intensity are key determinants of adaptation. Systematic reviews have reported significant improvements in aerobic capacity and endurance performance following BFR training compared with similar training without BFR in endurance athletes [11] and have highlighted muscle endurance and strength adaptations with BFR across healthy populations[12,13]. Acute studies of isometric BFR exercise also show enhanced neuromuscular and metabolic responses compared with non-restricted exercise[14]. However, the magnitude of these adaptations appears highly dependent on training characteristics such as contraction type, volume, and cuff pressure.

Therefore, the absence of a significant between-group difference in muscular endurance in the present study may be explained by the already adequate neuromuscular stimulus provided by sustained isometric contractions at moderate intensity. The combination of sufficient mechanical tension, localized fatigue, and repeated exposure over eight weeks likely elicited near-maximal endurance adaptations irrespective of blood flow restriction. This suggests that under moderate-intensity, low-volume isometric protocols, BFR may not provide additional endurance benefits.

Anaerobic power

Anaerobic power increased significantly only in the control group, whereas the increase observed in the BFR group did not reach statistical significance. Anaerobic power development relies heavily on rapid force production, high-threshold motor unit recruitment, and dynamic muscle actions. The isometric nature of the training protocol likely limited the development of explosive neuromuscular adaptations necessary for substantial improvements in anaerobic performance[7].

Although BFR training increases metabolic stress and has been shown to enhance muscle strength and hypertrophy under certain conditions, recent evidence suggests that its effects on power-related outcomes are less consistent, particularly when dynamic or high-velocity contractions are absent[17,18]. Thus, the lack of improvement in anaerobic power in the BFR group may reflect the interaction between contraction mode and metabolic stress, whereby isometric exercise does not optimally stimulate the neuromuscular characteristics required for anaerobic power enhancement.

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Aerobic capacity

No significant changes were observed in aerobic capacity in either group following the training intervention. This finding aligns with previous research demonstrating that isometric resistance training does not provide a sufficient cardiovascular or oxidative stimulus to induce meaningful improvements in aerobic performance. Even when combined with blood flow restriction, the localized, intermittent, and low-volume nature of isometric contractions appears insufficient to elicit central or peripheral adaptations associated with enhanced aerobic capacity.

Recent systematic reviews and meta-analyses have reported improvements in aerobic capacity following aerobic or dynamic resistance training with BFR; however, these adaptations are typically observed when training involves rhythmic, continuous muscle activity and a substantial cardiovascular demand[19,20].

Therefore, the absence of aerobic adaptations in the present study is likely attributable to the non-aerobic characteristics of the isometric training protocol rather than an inefficacy of blood flow restriction per se.

Muscle damage markers

One of the most notable findings of the present study was the significantly lower CK response observed in the BFR group following the 8-week training period. Creatine kinase (CK) is a widely used marker of exercise-induced muscle damage and reflects disruption of the sarcolemma and underlying muscle fiber structures[8,9].

The lower CK levels observed in the BFR group likely reflect reduced mechanical strain on muscle fibers despite elevated metabolic stress induced by blood flow restriction. Blood flow restriction training creates a localized hypoxic intramuscular environment characterized by metabolite accumulation, including lactate and hydrogen ions, which promotes muscular adaptations through metabolic signaling pathways while reducing the need for high mechanical loading[10]. Consequently, this approach allowed meaningful muscular adaptations with minimized structural muscle damage.

Recent reviews and meta-analyses have emphasized that BFR training allows individuals to achieve significant muscular adaptations with lower external loads and reduced mechanical stress, which may be particularly advantageous in contexts where minimizing muscle damage is desirable[15,16,19]. In contrast, the higher CK levels observed in the control group following the intervention indicate greater mechanical strain associated with isometric contractions performed without vascular restriction. These findings highlight that the type of contraction and application of BFR directly modulate CK responses, independent of overall training volume or intensity, which were already sufficient to stimulate muscular adaptations.

In contrast to CK, LDH did not differ significantly between groups following the training period. Lactate dehydrogenase (LDH) is considered a less specific marker of muscle damage and may be influenced by systemic metabolic stress rather than localized muscle fiber disruption[9]. The absence of between-group differences in LDH suggests that the effects of BFR in the present study were primarily localized and related to muscle fiber integrity rather than widespread enzymatic leakage.

Practical implications

The findings of the present study have important practical implications for resistance training prescription. Isometric resistance training combined with blood flow restriction appears to be a safe and effective strategy for improving muscular endurance while minimizing muscle damage. This approach may be particularly beneficial in clinical or rehabilitative settings where reducing mechanical stress and muscle damage is a priority.

However, practitioners should not expect additional benefits for anaerobic or aerobic performance when applying blood flow restriction to isometric training protocols. To enhance power or aerobic capacity, dynamic or mixed contraction modes may be required in conjunction with blood flow restriction.

Limitations and future directions

Several limitations should be acknowledged. First, although the sample size was relatively small, it is comparable to previous studies investigating low-load isometric resistance training with blood flow restriction[14]. Nevertheless, this sample size may limit the generalizability of the findings. Second, the study included only physically active young men, and results may not be directly applicable to women, older adults, or clinical populations. Third, several participant-related factors that could influence training adaptations were not controlled, including sleep quality, nutritional status, psychological and mental conditions, and potential genetic differences. Additionally, the use of a fixed cuff pressure range may have influenced individual responses to blood flow restriction.

Future studies should investigate individualized blood flow restriction pressures, longer intervention durations, and the combination of BFR with dynamic or mixed contraction modes. Further research is also warranted to explore the molecular and cellular mechanisms underlying the reduced muscle damage response observed with isometric BFR training.

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Conclusion

The findings of the present study indicate that 8 weeks of isometric resistance training performed at moderate intensity effectively improves muscular endurance in physically active young men, regardless of the application of blood flow restriction. The addition of blood flow restriction did not provide further benefits for anaerobic power or aerobic capacity under the present training conditions.

Importantly, isometric resistance training combined with blood flow restriction was associated with a more favorable muscle damage response, as evidenced by lower post-training creatine kinase levels compared with conventional isometric training. This suggests that blood flow restriction may reduce mechanical stress on muscle fibers while maintaining an effective training stimulus.

Overall, these results support the use of isometric resistance training with blood flow restriction as a safe and practical training strategy when improving muscular endurance with minimal muscle damage is a primary objective. However, blood flow restriction should not be expected to enhance anaerobic or aerobic performance when applied to purely isometric training protocols. Future research should explore individualized blood flow restriction pressures, longer training durations, and the combination of blood flow restriction with dynamic contraction modes to further clarify its performance and physiological benefits.

Conflicts of interest. The authors declare that there is no conflict of interest.

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