INTERNATIONAL JOURNAL OF
PHYSICAL THERAPY RESEARCH & PRACTICE
AN OFFICIAL JOURNAL OF SAUDI PHYSICAL THERAPY ASSOCIATION

Original Article

Acute Physiological and Perceptual Responses to Low-Load Blood Flow Restriction vs. High-Load Resistance Exercise: A Randomized Crossover Pilot Study

Abdulaziz A. Masoud[1,2,*]

1. College of Arts and Humanities, Department of Educational Sciences, Jazan University, Jazan, Saudi Arabia.
2. College of Sport Sciences and Physical Activity, Department of Sport Health, Princess Nourah bint Abdulrahman University, Riyadh, Saudi Arabia.

*Corresponding Author: amasoud@jazanu.edu.sa

Article info

Received : **Mar. 08, 2026**

Accepted : **Mar. 26, 2026**

Published : **Mar. 31, 2026**

To Cite: Masoud AA. Acute Physiological and Perceptual Responses to Low-Load Blood Flow Restriction vs. High-Load Resistance Exercise: A Randomized Crossover Pilot Study. International Journal of Physical Therapy Research & Practice, 5(3):193-205. https://doi.org/10.62464/ajqmbj34

Abstract

Objective: To compare the acute physiological and perceptual responses to low-load blood flow restriction (LL-BFR) resistance exercise and traditional high-load (HL) resistance exercise in healthy males. **Methods**: In this randomized crossover pilot study, nine healthy males performed bilateral knee extensions under two conditions: LL-BFR (30% 1RM with blood flow restriction) and HL (80% 1RM without restriction). Each protocol consisted of three sets of eight repetitions. Growth hormone (GH) was measured at rest and 15 min post-exercise, creatine kinase (CK) was assessed at baseline and 48 h post-exercise, and blood lactate was measured at rest, after each exercise set, and 20 min post-exercise. Systolic and diastolic blood pressure (SBP, DBP), and rate of perceived exertion (RPE) were recorded throughout the exercise session. Data were analyzed using two-way repeated-measures ANOVA. **Results:** GH increased significantly following LL-BFR but not HL. CK increased only after HL at 48 h. Blood lactate concentrations increased across sets in both trials but were higher during HL exercise. RPE increased progressively across sets in both conditions with no differences between protocols. SBP increased during exercise in both trials, whereas DBP was higher during LL-BFR, particularly during the final set. **Conclusion:** LL-BFR elicited a greater acute endocrine response with lower indicators of muscle damage compared with HL resistance exercise but was associated with higher DBP during exercise. These findings suggest that LL-BFR may represent a potential alternative when high-load resistance training is not feasible; however, confirmation in larger studies is required.

Keywords: Blood flow restriction, Resistance training, Growth hormone, Muscle damage, Blood pressure.

INTRODUCTION

Resistance training is widely recognized as one of the most effective methods to increase muscle size and strength when performed with proper technique (Lowery et al., 2014). The American College of Sports Medicine (ACSM) has recently updated its recommendations, indicating that

resistance training adaptations are influenced by multiple variables, including load, volume, and effort. Higher loads (≥80% 1RM) are particularly effective for maximizing strength development, whereas muscle hypertrophy can be achieved across a broad range of loading intensities when sufficient training volume and effort are applied (Currier et al., 2026).. However, such high intensities may place excessive stress on the joints and connective tissue and may be unsuitable for older adults, individuals undergoing rehabilitation, or those recovering from injury (Karaismailoglu, 2021; Tøien et al., 2025).

Blood flow restriction (BFR) training involves applying external pressure to a limb to partially restrict venous return while maintaining arterial inflow to the working muscles (Patterson et al., 2019). When combined with low-load resistance exercise (20-30% 1RM), BFR has been shown to elicit muscle hypertrophy and strength adaptations comparable to traditional high-load resistance training (Hughes et al., 2017; Loenneke et al., 2010). Despite these advantages, concerns remain regarding cardiovascular stress and safety. Previous studies report increased systolic and diastolic blood pressure during LL-BFR compared with high-load training (Scott et al., 2018), and recent evidence shows transient increases in vascular resistance and diastolic blood pressure (Huang et al., 2025), although these responses remain within safe limits in healthy individuals.

The endocrine and metabolic responses to BFR are also inconsistent across studies. While some investigations report similar growth hormone (GH) responses between LL-BFR and high-load training (Ellefsen et al., 2015), others suggest that hormonal responses vary depending on cuff pressure, occlusion time, and rest intervals (Kraemer et al., 2017; Sieljacks et al., 2019; Yinghao et al., 2021). Additionally, creatine kinase (CK), a marker of muscle damage, typically increases following high-load resistance training, whereas LL-BFR may induce lower CK responses, potentially reducing muscle damage (Koch et al., 2014).

In addition to endocrine and cardiovascular responses, BFR training induces notable metabolic and perceptual stress. Due to restricted venous blood flow, LL-BFR accelerates metabolite accumulation, resulting in elevated blood lactate levels despite the use of light loads (Takano et al., 2005). Some studies have reported lactate responses comparable to or exceeding those observed during high-load resistance exercise (Suga et al., 2009). Perceptually, rate of perceived exertion (RPE) tends to increase during LL-BFR and may reach levels similar to high-load resistance exercise, although non-failure BFR protocols may reduce discomfort while still promoting muscular adaptations (Sieljacks et al., 2019).

Despite growing evidence on BFR training, few studies have simultaneously examined endocrine, metabolic, cardiovascular, and perceptual responses within the same experimental protocol. This limits the ability to comprehensively compare the acute physiological and perceptual demands of LL-BFR and traditional high-load resistance exercise under controlled conditions.

Therefore, the aim of this study was to investigate growth hormone, CK, blood lactate, RPE, and blood pressure responses to low-load BFR versus high-load resistance exercise in healthy males. It was hypothesized that LL-BFR would: 1) eelicit greater increases in GH and blood lactate compared with HL exercise, 2) result in lower CK levels, indicating reduced muscle damage, 3) induce higher diastolic blood pressure due to vascular occlusion, and 4) result in similar RPE compared with HL resistance exercise.

METHODOLOGY

Study design and Participants

This study was designed as a randomized crossover pilot study to examine the feasibility and acute physiological responses to two resistance exercise protocols. Nine healthy, recreationally active males (age: 29 ± 9.7 years; body mass: 75.3 ± 15.3 kg; height: 175.1 ± 8.6 cm; BMI: 24.4 ± 3.9 kg/m²) volunteered to participate in the study.

Participants were classified as recreationally active, engaging in ≥150 minutes per week of moderate-to-vigorous physical activity; however, they were not resistance-trained, as they had not participated in structured resistance training for at least six months prior to the study. Eligible participants were free of cardiovascular, metabolic, or musculoskeletal disorders, non-smokers, and not taking vasoactive or hormonal medications. All participants refrained from strenuous exercise for two weeks prior to testing.

Sample size estimation

The sample size was determined a priori using a sensitivity analysis in G*Power (version 3.1.9.4) for a within-subject repeated-measures ANOVA (Condition × Time). With $\alpha = 0.05$, correlation among repeated measures $\rho = 0.50$, and a desired statistical power of 0.95, a minimum detectable effect size of $f = 0.43–0.53$ (partial $\eta^2 \approx 0.15–0.22$) was achievable with nine participants. Given the crossover design and controlled laboratory setting, this sample size was considered sufficient to detect moderate-to-large within-subject effects; however, it is acknowledged that the study is exploratory in nature.

Ethical Considerations

Ethical approval was obtained from the Local Committee for Research Ethics at Jazan University (HAPO-10-Z-001), and all participants provided written informed consent prior to participation.

Sample and Randomization

This study used a randomized, counterbalanced crossover design in which participants were randomly assigned to complete two experimental exercise sessions: low-load resistance exercise with blood flow restriction (LL-BFR; 30% 1RM) and high-load resistance exercise without blood flow restriction (HL; 80% 1RM). The randomization was done by using a computer-generated sequence (http://www.randomizer.org), and condition order was placed in sealed opaque envelopes opened before the first session. Sessions were separated by one week to minimize fatigue or carryover effects. This study was conducted and reported in accordance with the Consolidated Standards of Reporting Trials (CONSORT) guidelines for randomized controlled trials.

Study Settings

The one-repetition maximum (1RM) for the bilateral knee-extension exercise was determined at least 48 h before the first experimental session using standard procedures. After a light warm-up (10 repetitions at 50% perceived maximum) and progressive familiarization sets, the load gradually increased until the participant was unable to complete a full repetition through the full range of motion. The 1RM was achieved within 3–5 attempts, with 2–3 min of rest between attempts (Schoenfeld et al., 2017). A standardized metronome was used to maintain a 1-second concentric and 2-second eccentric cadence during knee-extension exercise, in line with previous BFR resistance training research (Takarada et al., 2000).

For the BFR condition, a pneumatic cuff (13 cm width) was placed at the most proximal region of each thigh and inflated to 1.3 × the participant's

resting systolic blood pressure (Takarada et al., 2000). The cuff pressure was continuously monitored and maintained throughout the exercise and rest periods. Baseline measures of serum, blood lactate, and blood pressure (BP) were obtained before the exercise bout.

The one-repetition maximum (1RM) for the bilateral knee-extension exercise was determined at least 48 h before the first experimental session using standard procedures. After a light warm-up (10 repetitions at 50% perceived maximum) and progressive familiarization sets, the load gradually increased until the participant was unable to complete a full repetition through the full range of motion. The 1RM was achieved within 3–5 attempts, with 2–3 min of rest between attempts (Schoenfeld et al., 2017). A standardized metronome was used to maintain a 1-second concentric and 2-second eccentric cadence during knee-extension exercise, in line with previous BFR resistance training research (Takarada et al., 2000).

For the BFR condition, a pneumatic cuff (13 cm width) was placed at the most proximal region of each thigh and inflated to 1.3 × the participant's resting systolic blood pressure (Takarada et al., 2000). The cuff pressure was continuously monitored and maintained throughout the exercise and rest periods. Baseline measures of serum, blood lactate, and blood pressure (BP) were obtained before the exercise bout.

Experimental procedures

To minimize variability and control potential confounding factors, all testing sessions were conducted at the same time of day for each participant (approximately 10:00 AM). Participants were instructed to maintain consistent dietary habits for 24 hours prior to each testing session and to avoid caffeine intake for at least 12 hours beforehand. In addition, participants were asked to maintain their usual hydration status and normal sleep patterns throughout the study period. Due to the nature of the intervention, blinding of participants and investigators was not feasible. However, outcome assessments were conducted by the same trained assessor using standardized protocols and objective instrumentation to minimize measurement variability. Since the assessor was not blinded to the intervention condition, it is acknowledged as a potential source of bias.

During each session, participants completed three sets of eight repetitions at either 30 % 1RM (BFR) or 80 % 1RM (non-BFR), with 60 s rest between sets. Additional resting BP was recorded after cuff inflation in the BFR condition. Participants received standardized verbal encouragement to maintain proper form. BP, Capillary blood lactate concentration was measured using fingertip sampling analyzed by a portable lactate analyzer (Lactate Pro 2, Arkray Inc., Kyoto, Japan). Ratings of perceived exertion (RPE) were recorded using the Borg 6–20 scale (Borg, 1982) immediately after each set and again 20 min post-exercise.

Venous blood samples (~5 mL) were collected at 15 min, and 48 h post-exercise using serum separator tubes. Samples were allowed to clot for 10 min, then centrifuged at 3600 rpm for 10 min. Serum (1 mL) was aliquoted into pre-labeled microtubes containing the participant's ID, condition, and time point, and stored at −20 °C until analysis. Growth hormone (GH) concentration was assessed from the 15-min post-exercise serum sample, whereas creatine kinase (CK) was analyzed from the 48-h sample.

Outcomes measures

Human growth hormone (GH) assay

Serum human growth hormone concentrations were measured via an enzyme-linked immunosorbent assay (ELISA) (EK-310-33, Phoenix Pharmaceuticals, Burlingame, CA) with a

detection range between 1 and 50 ng/ml. Undilute samples were loaded, in duplicate, onto a pre-coated 96-well microplate. All reagents were added and washed according to the manufacturer's recommendations. Absorbance was read at 450nm using a microplate reader (Biorad, Hurcules, CA) and the concentration of human growth hormone in each sample was compared to the absorbance values of a six-point standard curve.

Creatine Kinase (CK) assay

Serum creatine kinase concentrations were measured using a calorimetric assay (C7522, Pointe Scientific, Canton, MI). The creatine kinase reagent and undilute samples were mixed in a 2ml glass cuvette and incubated in a water bath at 37°C according to the manufacturer's recommendations. Absorbance was read at 340nm on a spectrophotometer (DU 520, Beckman-Coulter, Brea, CA) every minute for three minutes. The concentration of creatine kinase in units per liter (U/L) was calculated by multiplying the average change in absorbance per minute by a conversion factor of 6592.

Statistical analysis

Statistical analyses were performed using GraphPad Prism (version 8.0, GraphPad Software, USA). A two-way repeated-measures ANOVA (condition × time) was conducted to assess differences in blood lactate, blood pressure (BP), ratings of perceived exertion (RPE), growth hormone (GH), and creatine kinase (CK) across time points and experimental conditions (LL-BFR vs. HL). For all outcomes, sensitivity analyses were conducted in G*Power (v3.1.9.4) to estimate the minimum detectable interaction effects. Effect sizes are reported as partial eta squared (η^2p) with corresponding interpretation. When significant main or interaction effects were detected, pairwise comparisons were performed using Bonferroni-adjusted post hoc tests. The assumption of sphericity was verified using Mauchly's test, and the Greenhouse Geisser correction was applied when violated. Statistical significance was accepted at $p < 0.05$. Data are presented as mean ± standard deviation (SD).

RESULTS

Participants' flow and recruitment

Nine participants completed both experimental sessions (LL-BFR and HL). No participants were lost to follow-up or excluded from analysis. Figure 1 presents the participant flow throughout the study. Recruitment and data collection were conducted between August and December 2025. The trial ended as planned after all participants completed both conditions; no early termination occurred.

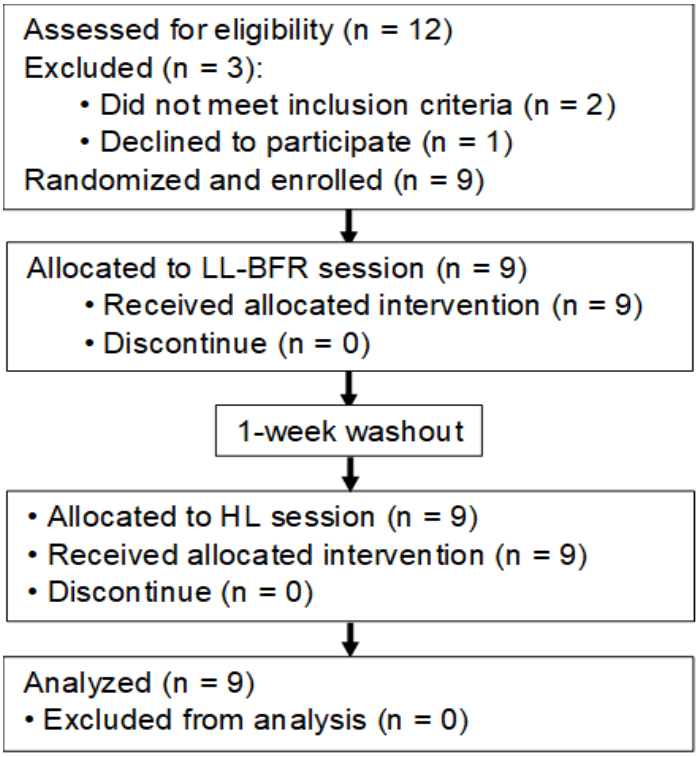

Figure 1. LL-BFR, low-load blood flow restriction; HL, high-load resistance exercise.

Baseline characteristics

Participants were healthy, recreationally active males with an average age of 29 ± 9.7 years, body mass of 75.3 ± 15.3 kg, height of 175.1 ± 8.6 cm, and BMI of 24.4 ± 3.9 kg/m². A summary of the two-way repeated-measures ANOVA results, including effect sizes (partial η²), is presented in Table 1.

Table 1. Summary of two-way repeated-measures ANOVA results for all outcome variables (condition × time).

Variable	Effect	F (df)	p	ηp²	Magnitude
GH	Time	F(1,8)=56.72	<0.0001	0.88	Large
GH	Condition	F(1,8)=64.41	<0.0001	0.89	Large
GH	Interaction	F(1,8)=53.02	<0.0001	0.87	Large
CK	Time	F(1,8)=22.37	0.0015	0.74	Large
CK	Interaction	F(1,8)=14.17	0.0055	0.64	Large
Lactate	Time	F(4,32)=31.79	<0.0001	0.80	Large
Lactate	Condition	F(1,8)=41.30	0.0002	0.84	Large
Lactate	Interaction	F(4,32)=6.77	0.0005	0.46	Moderate
RPE	Time	F(4,32)=217.8	<0.0001	0.96	Large
SBP	Time	F(4,32)=18.79	<0.0001	0.70	Large
DBP	Condition	F(1,8)=33.91	0.0004	0.81	Large
DBP	Interaction	F(4,32)=4.89	0.0034	0.38	Moderate

GH: Growth hormone; CK: Creatinine kinase; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; RPE: Rate of perceived exertion; df: Degree of freedom. p<0.05: Significant value; ηp²: Partial eta square.

Growth Hormone (GH)

A two-way repeated-measures ANOVA revealed significant main effects of time and condition, as well as a significant time × condition interaction (all $p < 0.0001$; see Table 1 for full statistical details and effect sizes). Post hoc analyses showed a marked increase in GH from pre- to post-exercise in the LL-BFR condition ($p < 0.0001$), with no significant change observed in the HL condition ($p > 0.05$). GH levels were significantly higher in LL-BFR compared with HL at post-exercise ($p < 0.0001$), with no difference at baseline (Figure 2).

Creatine Kinase (CK)

A significant main effect of time was observed, along with a significant time × condition interaction (all $p = 0.0055$; see Table 1 for full statistical details and effect sizes), while no main effect of condition was found ($F(1,8) = 0.10$, $p = 0.757$, $\eta^2p = 0.01$). Post hoc comparisons indicated that CK increased significantly from pre- to 48 h post-exercise in the HL condition ($p = 0.0034$), whereas no significant change was observed in LL-BFR ($p > 0.05$). No between-condition differences were observed at 48 h post-exercise (Figure 3).

Blood Lactate

Significant main effects of time and condition were observed, along with a significant time × condition interaction (all $p < 0.001$; Table 1). Blood lactate increased progressively across sets in both conditions ($p < 0.001$), with higher values observed in the HL condition compared with LL-BFR during exercise ($p < 0.05$). No differences were found at rest or 20 min post-exercise ($p > 0.05$). (Figure 4).

Rate of Perceived Exertion (RPE)

A significant large main effect of time was found, with no main effect of condition and no interaction effect (Table 1). RPE increased progressively across sets in both conditions ($p < 0.0001$), with no differences between LL-BFR and HL at any time point (Figure 5).

Systolic Blood Pressure (SBP)

A significant main effect of time was observed ($p < 0.0001$), with no main effect of condition and no interaction effect ($p < 0.05$; Table 1). SBP increased during exercise in both conditions ($p < 0.05$–0.001) and returned toward baseline at 20 min post-exercise, with no differences between LL-BFR and HL (Figure 6).

Diastolic Blood Pressure (DBP)

DBP exhibited significant condition and interaction effects (Table 2), indicating differential responses between LL-BFR and HL conditions. Post hoc analysis showed higher DBP values during LL-BFR compared with HL, particularly at the final exercise set ($p = 0.0275$). DBP returned to baseline levels at 20 min post-exercise in both conditions (Figure 7).

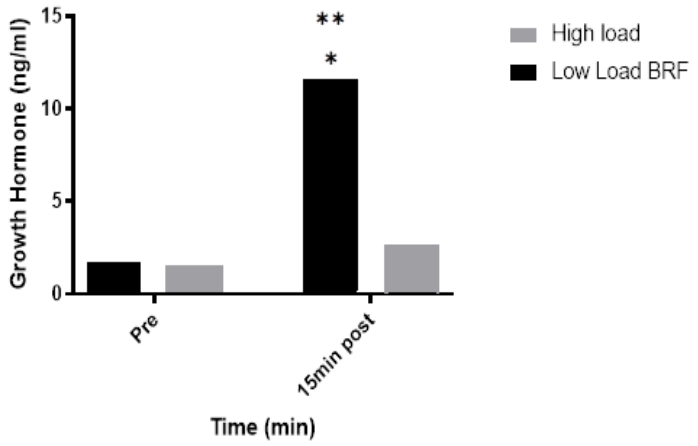

Figure 2. Serum growth-hormone (GH) concentrations before (Pre) and 15 min after (Post) high-load and low-load blood-flow-restriction (BFR) resistance exercise. Bars = mean ± SD (n = 9). * Significant difference from pre-exercise within the same condition ($p < 0.0001$); ** Significant difference between exercise conditions at the same time point ($p < 0.0001$).

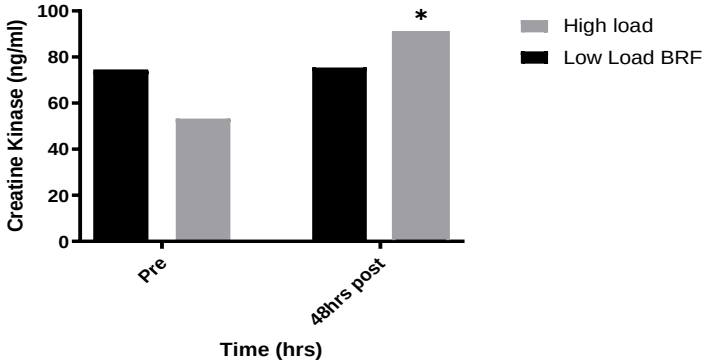

Figure 3. Serum creatine-kinase (CK) concentrations before (Pre) and 48 h after (Post) HL and LL-BFR exercise. Bars = mean ± SD (n = 9). * Significant increase from pre-exercise to 48h post-exercise within the same condition (p = 0.0034).

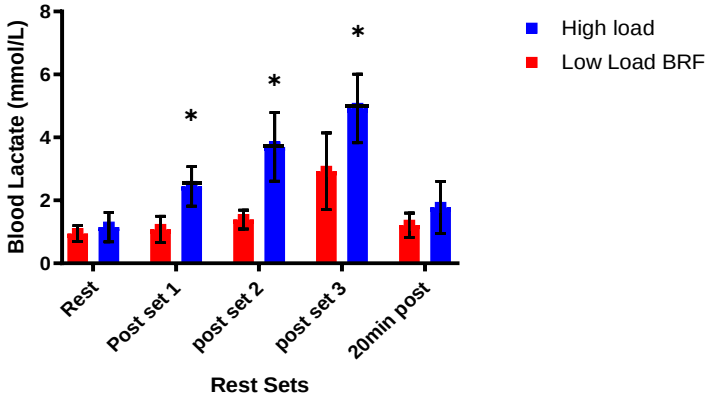

Figure 4. Blood lactate concentrations at rest, after each exercise set (Post Set 1–3), and 20 min post-exercise during HL and LL-BFR resistance exercise trials. Values are mean ± SD (n = 9). * Significant difference between conditions at the same time point (p < 0.05). Blood lactate increased significantly from rest across sets within both conditions (p < 0.001).

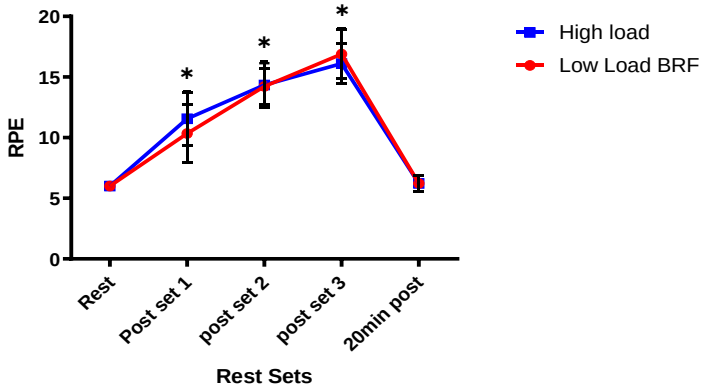

Figure 5. RPE at rest, after each set (Post Set 1–3), and 20 min post-exercise during HL and LL-BFR trials. Mean ± SD (n = 9). RPE increased from rest across sets in both conditions (p < 0.0001), peaking at Set 3 and declining at 20 min post. * Significant difference from rest within condition. No condition or interaction effects were observed.

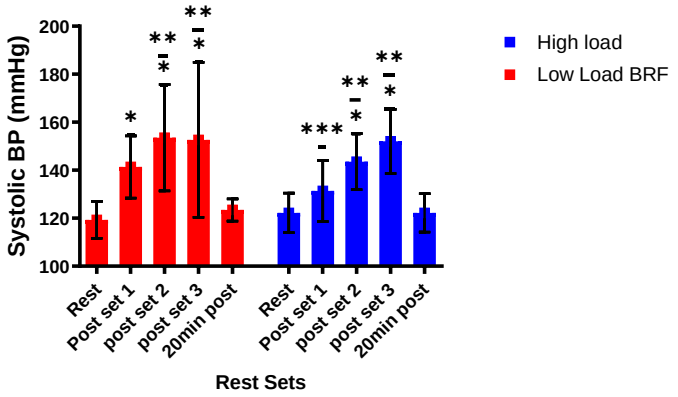

Figure 6. Systolic blood pressure (SBP) at rest, after each set (Post Set 1–3), and 20 min post-exercise during high-load (HL) and low-load blood flow restriction (LL-BFR) resistance exercise trials. Values are presented as mean ± SD (n = 9). SBP increased significantly during exercise, particularly at Post Set 2 and Post Set 3, and returned toward baseline at 20 min post-exercise. *p < 0.05, **p < 0.01, ***p < 0.001 vs. rest within the same condition.

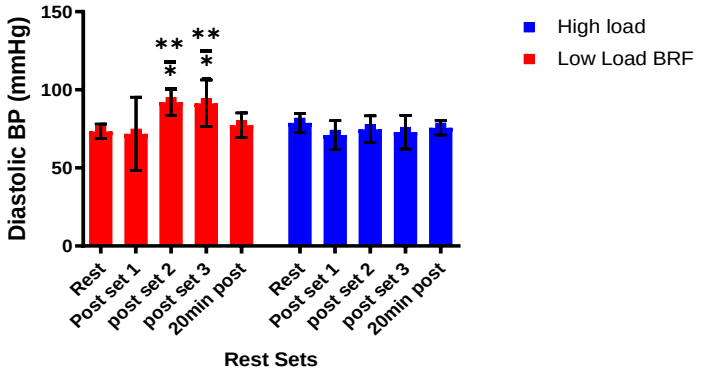

Figure 7. Diastolic blood pressure (DBP) at rest, after each set (Post Set 1–3), and 20 min post-exercise during high-load (HL) and low-load blood flow restriction (LL-BFR) resistance exercise trials. Values are presented as mean ± SD (n = 9). DBP increased significantly during LL-BFR at Post Set 2 and Post Set 3 compared with rest, whereas no significant changes were observed in the HL

condition. *p < 0.05, **p < 0.01 vs. rest within the same condition.

DISCUSSION

The purpose of this study was to compare the acute physiological and perceptual responses to low-load blood flow restriction (LL-BFR) exercise and high-load (HL) resistance training in healthy, recreationally active males. The main findings were that LL-BFR elicited a robust increase in growth hormone (GH), whereas HL training resulted in greater elevations in creatine kinase (CK) and blood lactate. Both exercise modalities produced similar increases in systolic blood pressure (SBP), while diastolic blood pressure (DBP) rose to a greater extent during LL-BFR. Given the pilot nature of this study and the small sample size, these findings should be interpreted with caution.

These findings align with previous research showing that LL-BFR exercise elicits strong endocrine responses despite low mechanical loads. Studies have consistently reported marked increases in GH and other anabolic hormones with BFR, mediated by metabolic stress, hypoxia, and enhanced motor unit recruitment (Pearson & Hussain, 2015; Scott et al., 2018). Such responses may support hypertrophy and strength adaptations comparable to high-load training, making LL-BFR particularly relevant in clinical and rehabilitation contexts (Centner et al., 2019; Lixandrão et al., 2018). Importantly, the present findings reflect acute hormonal responses and should not be directly extrapolated to long-term adaptations without longitudinal evidence.

In contrast, the CK response observed in the HL trial reflects greater muscle damage, consistent with the higher mechanical tension and eccentric loading associated with heavy resistance training (Koch et al., 2014). The lack of significant CK elevation with LL-BFR indicates that this modality may minimize muscle damage while still promoting anabolic signaling. This supports the growing evidence that LL-BFR is a joint-sparing alternative, especially suitable for older adults or clinical populations (Hughes et al., 2017; Sieljacks et al., 2016). However, whether these acute responses translate into equivalent long-term strength and hypertrophy adaptations requires further investigation.

Blood lactate levels were significantly higher with HL compared to LL-BFR, which may be related to differences in absolute load and metabolic accumulation. However, previous studies have shown that when LL-BFR is performed with higher repetitions and shorter rest intervals, lactate responses can approach those of HL training (Pinto & Polito, 2016; Suga et al., 2009). Therefore, protocol design including cuff pressure, set volume, and rest interval strongly influences the metabolic profile of LL-BFR.

The hemodynamic responses observed here highlight both opportunities and cautions. While SBP increased similarly in both LL-BFR and HL, DBP was significantly higher with LL-BFR. This has been noted in prior work, where cuff-induced occlusion augments vascular resistance and elevates DBP (Libardi et al., 2017; Vieira et al., 2013; Winchester et al., 2022). Although such responses are generally well tolerated in healthy populations, these findings represent acute responses and should not be interpreted as indicative of chronic cardiovascular adaptations. Careful monitoring and individualized prescription remain essential, particularly in populations with cardiovascular risk (Patterson et al., 2019).

Limitations and Future Research

Several limitations should be acknowledged. First, this pilot study included a small sample of nine healthy, recreationally active males, which limits the generalizability of the findings and increases the possibility of type II error. Second, female participants were not included, preventing the

assessment of potential sex-based differences in physiological responses to LL-BFR. Third, the study assessed only acute responses, and therefore the findings cannot be generalized to long-term training adaptations. Fourth, potential measurement variability in hormonal assays, particularly GH, should be considered when interpreting endocrine responses. Finally, although a one-week washout period was used, the possibility of residual fatigue or learning effects between sessions cannot be completely excluded.

Future research should include larger, more diverse samples, incorporate female participants, and examine longitudinal training adaptations to better understand the chronic effects of LL-BFR compared with HL resistance training. Additionally, studies exploring different cuff pressures, exercise volumes, and training frequencies are warranted to optimize BFR prescription.

CONCLUSIONS

The present pilot study demonstrates that low-load blood flow restriction (LL-BFR) exercise produces a substantial acute hormonal response, with significantly greater elevations in growth hormone compared with high-load (HL) resistance training. In contrast, HL exercise induced larger increases in creatine kinase and blood lactate, reflecting greater mechanical and metabolic stress. Both exercise modalities increased systolic blood pressure similarly, whereas diastolic blood pressure was elevated to a greater extent during LL-BFR.

LL-BFR may represent a promising alternative to high-load resistance exercise, particularly in contexts where heavy loading is not feasible; however, larger randomized studies are required to confirm these findings and determine their long-term implications.

References

Author Contributions

All authors contributed to the conception and design of the review, literature search, study selection, data charting, and interpretation of findings. All authors drafted or critically revised the manuscript, approved the final version, and agree to be accountable for all aspects of the work.

Ethical Approval and Patient Consent

This study was conducted in accordance with the Declaration of Helsinki and approved by the Local Committee for Research Ethics at Jazan University, Saudi Arabia (Approval No. HAPO-10-Z-001). All participants provided written informed consent prior to participation.

Data Availability Statement

The full study protocol is available from the corresponding author upon reasonable request.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not for profit sectors.

Conflicts of Interest

The author declares no conflicts of interest related to financial or non-financial in this study.

Declaration of generative AI and AI-assisted technologies

The authors used generative AI tools solely to improve language clarity and correct grammatical issues during manuscript preparation. All content was carefully reviewed and revised by the authors, who take full responsibility for the accuracy, integrity, and originality of the final published work.

Borg, G. A. V. (1982). Psychophysical Bases of Perceived Exertion. *Medicine & Science in Sports & Exercise*, *14*(5), 377–381.

Centner, C., Wiegel, P., Gollhofer, A., & König, D. (2019). Effects of Blood Flow Restriction Training on Muscular Strength and Hypertrophy in Older Individuals: A Systematic Review and Meta-Analysis. *Sports Medicine*, *49*(1), 95–108. https://doi.org/10.1007/s40279-018-0994-1

Currier, B. S., D'SOUZA, A. C., Singh, M. A. F., Lowisz, C. V., Rawson, E. S., Schoenfeld, B. J., Smith-Ryan, A. E., Steen, J. P., Thomas, G. A., & Triplett, N. T. (2026). American College of Sports Medicine Position Stand. Resistance Training Prescription for Muscle Function, Hypertrophy, and Physical Performance in Healthy Adults: An Overview of Reviews. *Medicine and Science in Sports and Exercise*, *58*(4), 851. https://doi.org/10.1249/MSS.0000000000003897

Ellefsen, S., Hammarström, D., Strand, T. A., Zacharoff, E., Whist, J. E., Rauk, I., Nygaard, H., Vegge, G., Hanestadhaugen, M., & Wernbom, M. (2015). Blood Flow-Restricted Strength Training Displays High Functional and Biological Efficacy in Women: A Within-Subject Comparison with Wigh-Load Strength Training. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, *309*(7), R767–R779. https://doi.org/10.1152/ajpregu.00497.2014

Huang, R., Ma, Y., Yang, Z., Wang, Z., Zeng, C., Qin, Y., & Jia, M. (2025). Hemodynamic Analysis of Blood Flow Restriction Training: A Systematic Review. *BMC Sports Science, Medicine and Rehabilitation*, *17*(1), 46 https://doi.org/10.1186/s13102-025-01084-8

Hughes, L., Paton, B., Rosenblatt, B., Gissane, C., & Patterson, S. D. (2017). Blood Flow Restriction Training in Clinical Musculoskeletal Rehabilitation: A Systematic Review and Meta-Analysis. *British Journal of Sports Medicine*, *51*(13), 1003–1011. https://doi.org/10.1136/bjsports-2016-097071

Karaismailoglu, B. (2021). High-Intensity Strength Training, Knee Pain, and Knee Joint Compressive Forces in Adults with Knee Osteoarthritis. *JAMA*, *325*(22), 2315–2316. https://doi.org/10.1001/jama.2021.6000

Koch, A. J., Pereira, R., & Machado, M. (2014). The creatine kinase response to resistance exercise. *J Musculoskelet Neuronal Interact*, *14*(1), 68–77.

Kraemer, W. J., Ratamess, N. A., & Nindl, B. C. (2017). Recovery Responses of Testosterone, Growth Hormone, and IGF-1 After Resistance Exercise. *Journal of Applied Physiology*, *122*(3), 549–558. https://doi.org/10.1152/japplphysiol.00599.2016

Libardi, C. A., Catai, A. M., Miquelini, M., Borghi-Silva, A., Minatel, V., Alvarez, I. F., Milan-Mattos, J. C., Roschel, H., Tricoli, V., & Ugrinowitsch, C. (2017). Hemodynamic Responses to Blood Flow Restriction and Resistance Exercise to Muscular Failure. *International Journal of Sports Medicine*, *38*(02), 134–140. https://doi: 10.1055/s-0042-115032

Lixandrão, M. E., Ugrinowitsch, C., Berton, R., Vechin, F. C., Conceição, M. S., Damas, F., Libardi, C. A., & Roschel, H. (2018). Magnitude of Muscle Strength and Mass Adaptations Between High-Load Resistance Training Versus Low-Load Resistance Training Associated with Blood-Flow Restriction: A Systematic Review and Meta-Analysis. *Sports Medicine*, *48*(2), 361–378. https://doi.org/10.1007/s40279-017-0795-y

Loenneke, J. P., Wilson, G. J., & Wilson, J. M. (2010). A Mechanistic Approach to Blood Flow Occlusion. *International Journal of Sports Medicine*, *31*(01), 1–4. https://doi: 10.1055/s-0029-1239499

Lowery, R. P., Joy, J. M., Loenneke, J. P., de Souza, E. O., Machado, M., Dudeck, J. E., & Wilson, J. M. (2014). Practical Blood Flow Restriction Training Increases Muscle Hypertrophy During a Periodized Resistance Training Programme. *Clinical Physiology and Functional Imaging*, *34*(4), 317–321. https://doi.org/10.1111/cpf.12099

Patterson, S. D., Hughes, L., Warmington, S., Burr, J., Scott, B. R., Owens, J., Abe, T., Nielsen, J. L., Libardi, C. A., & Laurentino, G. (2019). Blood Flow Restriction Exercise: Considerations of Methodology, Application, and Safety. *Frontiers in Physiology*, *10*, 533. https://doi.org/10.3389/fphys.2019.00533

Pearson, S. J., & Hussain, S. R. (2015). A Review on the Mechanisms of Blood-Flow Restriction Resistance Training-Induced Muscle Hypertrophy. *Sports Medicine*, *45*(2), 187–200. https://doi.org/10.1007/s40279-014-0264-9

Pinto, R. R., & Polito, M. D. (2016). Hemodynamic Responses During Resistance Exercise with Blood Flow Restriction in Hypertensive Subjects. *Clinical Physiology and Functional Imaging*, *36*(5), 407–413. https://doi.org/10.1111/cpf.12245

Schoenfeld, B. J., Grgic, J., Ogborn, D., & Krieger, J. W. (2017). Strength and Hypertrophy Adaptations Between Low-vs. High-Load Resistance Training: A Systematic Review and Meta-Analysis. *The Journal of Strength & Conditioning Research*, *31*(12), 3508–3523. https://doi: 10.1519/JSC.0000000000002200

Scott, B. R., Peiffer, J. J., Thomas, H. J., Marston, K. J., & Hill, K. D. (2018). Hemodynamic Responses to Low-Load Blood Flow Restriction and Unrestricted High-Load Resistance Exercise in Older Women. *Frontiers in Physiology*, *9*, 1324. https://doi.org/10.3389/fphys.2018.01324

Sieljacks, P., Degn, R., Hollaender, K., Wernbom, M., & Vissing, K. (2019). Non-Failure Blood Flow Restricted Exercise Induces Similar Muscle Adaptations and Less Discomfort Than Failure Protocols. *Scandinavian Journal of Medicine & Science in Sports*, *29*(3), 336–347. https://doi.org/10.1111/sms.13346

Sieljacks, P., Matzon, A., Wernbom, M., Ringgaard, S., Vissing, K., & Overgaard, K. (2016). Muscle Damage and Repeated Bout Effect Following Blood Flow Restricted Exercise. *European Journal of Applied Physiology*, *116*(3), 513–525. https://doi.org/10.1007/s00421-015-3304-8

Suga, T., Okita, K., Morita, N., Yokota, T., Hirabayashi, K., Horiuchi, M., Takada, S., Takahashi, T., Omokawa, M., & Kinugawa, S. (2009). Intramuscular Metabolism During Low-Intensity Resistance Exercise with Blood Flow Restriction. *Journal of Applied Physiology*, *106*(4), 1119–1124. https://doi.org/10.1152/japplphysiol.90368.2008

Takano, H., Morita, T., Iida, H., Asada, K., Kato, M., Uno, K., Hirose, K., Matsumoto, A., Takenaka, K., & Hirata, Y. (2005). Hemodynamic and Hormonal Responses to a Short-Term Low-Intensity Resistance Exercise with the Reduction of Muscle Blood Flow. *European Journal of Applied Physiology*, *95*(1), 65–73. https://doi.org/10.1007/s00421-005-1389-1

Takarada, Y., Takazawa, H., Sato, Y., Takebayashi, S., Tanaka, Y., & Ishii, N. (2000). Effects Of Resistance Exercise Combined with Moderate Vascular Occlusion on Muscular Function in Humans. *Journal of Applied Physiology*, *88*(6), 2097–2106. https://doi.org/10.1152/jappl.2000.88.6.2097

Tøien, T., Berg, O. K., Modena, R., Brobakken, M. F., & Wang, E. (2025). Heavy Strength Training in Older Adults: Implications for Health, Disease and Physical Performance. *Journal of*

Cachexia, Sarcopenia and Muscle, *16*(2), e13804. https://doi.org/10.1002/jcsm.13804

Vieira, P. J., Chiappa, G. R., Umpierre, D., Stein, R., & Ribeiro, J. P. (2013). Hemodynamic Responses to Resistance Exercise with Restricted Blood Flow in Young and Older Men. *The Journal of Strength & Conditioning Research*, *27*(8), 2288–2294. https://doi: 10.1519/JSC.0b013e318278f21f

Winchester, L. J., Blake, M. T., Fleming, A. R., Aguiar, E. J., Fedewa, M. V., Esco, M. R., & Earley, R. L. (2022). Hemodynamic Responses to Resistance Exercise with Blood Flow Restriction Using a Practical Method Versus a Traditional Cuff-Inflation System. *International Journal of Environmental Research and Public Health*, *19*(18), 11548. https://doi.org/10.3390/ijerph191811548

Yinghao, L., Jing, Y., Yongqi, W., Jianming, Z., Zeng, G., Yiting, T., & Shuoqi, L. (2021). Effects of a Blood Flow Restriction Exercise Under Different Pressures on Testosterone, Growth Hormone, and Insulin-Like Growth Factor Levels. *Journal of International Medical Research*, *49*(9). https://doi.org/10.1177/03000605211039564.