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The effect of eight weeks of water exercise with blood flow restriction on serum levels of C-reactive protein and insulin resistance in young obese girls

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Original Research

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Abstract

Purpose: Obesity in adolescent girls is commonly accompanied by low-grade inflammation and impaired glucose regulation. This study investigated whether eight weeks of water-based exercise with blood flow restriction (WBFR) improves high-sensitivity C-reactive protein (hs-CRP) and insulin resistance more than water exercise without restriction (WEX) and a non-training control (CON). **Method:** Thirty obese young girls were randomly assigned to WBFR (n=10), WEX (n=10), or CON (n=10). Training lasted 8 weeks (3 sessions/week, ~60 min/session). Venous blood was obtained 24 h before and 24 h after the intervention. Outcomes were hs-CRP, fasting glucose, fasting insulin, and HOMA-IR, plus weight, BMI, and waist circumference. Mixed group×time ANOVA with Bonferroni post-hoc tests was applied ($P<0.05$). **Results:** Group×time interactions were significant for hs-CRP ($p=0.001$), HOMA-IR ($p=0.001$), fasting glucose ($p=0.003$), fasting insulin ($p=0.044$), weight ($p=0.008$), BMI ($p=0.012$), and waist circumference ($p=0.001$). WBFR decreased hs-CRP ($p=0.001$), fasting glucose ($p=0.002$), fasting insulin ($p=0.012$), and HOMA-IR ($p=0.001$), and reduced weight ($p=0.001$), BMI ($p=0.001$), and waist circumference ($p=0.001$). WEX showed smaller reductions in hs-CRP ($p=0.018$), fasting glucose ($p=0.041$), and HOMA-IR ($p=0.048$), and reduced weight ($p=0.034$), BMI ($p=0.039$), and waist circumference ($p=0.021$), while fasting insulin did not change ($p=0.290$). CON showed no significant changes (hs-CRP $p=0.620$; glucose $p=0.710$; insulin $p=0.830$; HOMA-IR $p=0.660$). **Conclusion:** Eight weeks of WBFR produced superior improvements in systemic inflammation and fasting insulin resistance compared with non-restricted aquatic exercise and control, indicating WBFR as a practical low-impact approach for reducing cardiometabolic risk in obese young girls. These findings warrant larger trials.

Keywords: Blood Flow Restriction; CRP; Insulin Resistance; Obese Adolescents.

Introduction

Obesity is increasingly prevalent in youth and is a public-health concern because it accelerates early cardiometabolic risk, especially in females (Nguyen & El-Serag, 2010). Beyond excess fat mass, obesity is characterized by chronic, low-grade systemic inflammation that contributes to metabolic complications (Das, 2001). Adipose tissue also behaves as an endocrine organ by releasing adipokines and inflammatory mediators that disrupt metabolic regulation (Gelsinger et al., 2010).

C-reactive protein (CRP) is a widely used biomarker for quantifying systemic inflammation in clinical and exercise research (Bray et al., 2016). As an acute-phase reactant synthesized mainly in the liver, CRP rises in response to inflammatory signaling, infection, and tissue stress (Bray et al., 2016). In obesity, persistently elevated CRP can indicate low-grade inflammation relevant to cardiometabolic risk and intervention monitoring (Das, 2001). Because CRP responds to lifestyle change and tracks inflammatory burden, it is frequently selected as an outcome in exercise interventions targeting cardiometabolic health (Bray et al., 2016).

Insulin resistance is central to obesity and is often estimated using HOMA-IR derived from fasting glucose and insulin (Matthews et al., 1985). Inflammation can impair insulin signaling, while reduced insulin action can further amplify inflammatory responses (Das, 2001). Some adipokines appear to link visceral adiposity to insulin-related pathways, highlighting endocrine–inflammatory cross-talk in obesity (Fukuhara et al., 2005). In young females with obesity, early deterioration in insulin sensitivity can precede overt disease, so targeting insulin resistance is a key preventive strategy (Nguyen & El-Serag, 2010).

Regular physical activity is a cornerstone for preventing and managing obesity-related complications, and evidence syntheses inform guideline recommendations (Pinheiro et al., 2020). Exercise can down-regulate inflammatory activity and improve immune-metabolic control, reducing systemic inflammatory tone (Mee-Inta et al., 2019). Progressive resistance training—especially when paired with nutritional strategies—has reduced CRP and improved insulin-resistance indices in overweight women (Mohammadi Sarableh et al., 2022). Yet mechanical loading and discomfort can limit adherence to land-based training in obesity, which motivates lower-impact alternatives (Simas et al., 2017).

Aquatic exercise is attractive because buoyancy lowers joint loading and perceived impact, potentially improving adherence in people with obesity (Waller et al., 2016). Systematic reviews show water-based exercise improves physical function and health outcomes, supporting feasibility in populations with movement limitations (Simas et al., 2017). Improved participation and reduced pain during aquatic training may indirectly support better body-composition control and metabolic regulation (Simas et al., 2017). Combining aquatic and land-based therapy can broaden training options while managing mechanical stress (Carayannopoulos et al., 2020). In obese young girls, combined training can improve anthropometrics and obesity-related biomarkers, but inflammatory outcomes are not always evaluated (Sahranavard et al., 2019).

Blood flow restriction (BFR) aims to elicit adaptations at low-to-moderate intensity by partially restricting venous return with cuffs or bands (Pearson & Hussain, 2015). Low-intensity exercise with BFR can increase muscle size and strength, partly mimicking higher-load resistance training (Yasuda et al., 2012). Mechanistically, BFR is thought to increase metabolic stress and local hypoxia, which may amplify training signals despite low external loads (Pearson & Hussain, 2015). Meta-analyses support BFR-induced gains in strength and hypertrophy across populations and contexts (Centner et al., 2019). Because load and restriction pressure shape outcomes, careful programming is important when applying BFR in females and youth (Amani-Shalamzari et al., 2019). Low-intensity BFR resistance training has also been reported to improve endothelial function and peripheral circulation (Shimizu et al., 2016). As BFR use expands in rehabilitation, protocol design should address safety considerations including thromboembolism risk (Bond et al., 2019). Water-based BFR exercise has been shown to modify anabolic-related hormones and bone-metabolism markers in women (Zaravar et al., 2021). Combining water-based training with BFR may therefore offer a low-impact yet metabolically potent stimulus for obese girls (Pearson & Hussain, 2015). Evidence is still limited on whether eight weeks of aquatic exercise with BFR can reduce CRP and improve insulin resistance in young obese girls (Waller et al., 2016). Accordingly, this study examines the effects of an eight-week aquatic BFR program on serum CRP and insulin-resistance indices in young obese girls.

Methods

Study design and participants

This study was designed as a quasi-experimental, pretest-posttest trial and was conducted over eight weeks (three sessions per week.
The statistical sample of this study consisted of obese young women from the University of ... who were recruited through announcement and screening. The subjects were randomly divided into three groups: water exercise with blood flow restriction (BFR), water exercise without BFR, and control. The necessary conditions for entry into the study were obese young women, with conditions, BMI $\geq$ 30 kg/m2, no participation in regular exercise programs, no history of cardiovascular/respiratory/renal disease or surgery, and no use of chemical/hormonal drugs (especially steroids). Participants completed the Health and Medical History (PAR-Q) forms and received a physician's permission. Written informed consent was collected before participation in the exercises. Anthropometric characteristics such as height were measured using a wall-mounted height gauge and body mass was measured using a Seca digital scale (Germany) with an accuracy of approximately 200 g. Waist circumference above the navel was measured and BMI was calculated as weight (kg)/height^2 (m^2).

Exercise protocol

All exercise sessions were performed in a swimming pool with a water temperature of 30–33°C and a depth of approximately 60–120 cm. During exercise, heart rate was monitored using a Polar heart rate monitor to ensure participant safety and to control workload. Water anklets (1 kg for each foot) were used to reduce buoyancy and help maintain foot contact with the pool floor as described in the aquatic exercise protocol. Each session consisted of: 10 minutes of warm-up (gentle stretching, agility, and very slow walking), 20 to 30 minutes of water aerobics, 15 to 20 minutes of cuff-assisted exercise, and 10 minutes of cool-down (slow walking, light stretching, floating). After exiting the pool, heart rate and blood pressure were monitored. Participants rested until pre-cuff values returned to normal.

The aerobic and compound exercise set progressed weekly (basic movements plus specific movements such as knee-to-elbow bends, hip flexions with opposite hands, hip abductions with opposite hands, external rotation patterns, "jump-jack" water movements; then additional movements such as jump squats, jump lunges with arms raised, and single-leg/double-leg stepping patterns).

The cuff-assisted exercise group followed a structured progression in sets/reps, rest intervals, and cuff pressure over eight weeks. Specifically, cuff pressure was increased from 40% (weeks 1–2) to 60% (weeks 3–4), 70% (weeks 5–6), and 80% (weeks 7–8), with increasing sets and repetitions and decreasing rest time (table 1). Cuffs were placed bilaterally on the proximal thigh. Training pressures were set between 110 and 220 mmHg, which is approximately equivalent to 40–80% of the limb/artery occlusion pressure (LOP/AOP). One week before training, occlusion pressure determinations were performed with color Doppler ultrasound guidance in a subset of different thigh sizes/phenotypes to confirm safe pressure selection. To estimate individual LOP/AOP, after approximately 10 minutes of rest (fasting, supine), the cuffs were inflated while blood flow was monitored until complete occlusion occurred at approximately 260–280 mmHg. The exercise pressure was then administered as a percentage (typically 40–80%) of LOP. The non-BFR aquatic exercise group (8 weeks) also performed the same warm-up and aerobic exercise in water without the cuff device, with a gradual increase in movement speed and volume and a decrease in rest time followed by a cool-down. The control group did not participate in any structured exercise during the 8-week period. Participants were asked to maintain their usual diet during the intervention and follow standard dietary recommendations to support consistent eating patterns as described in the Obese Young Girls Protocol. They were also instructed to avoid unusual physical activity outside of the intervention.

Table 1. Training Program in Water with Blood Flow Restriction (BFR) during Eight Weeks

Weeks	Action No.	Set No.	Each Set Repetitions (No.)	Rest Between Each Set (s)	Rest Between Each Action (s)	Rhythm of Actions	Cuff Pressure (%)
1	4	5	30-15-15-15	50	30	Slow	40%
2	4	5	30-15-15-15	50	30	Slow	40%
3	4	6	30-15-15-15	50	30	Medium	60%
4	5	6	30-15-15-15-15	60	30	Medium	60%
5	5	7	30-20-15-15-15	60	25	Medium	70%

6	5	7	30-20-15-15-15	60	25	Medium	70%
7	5	8	30-30-15-15-15	70	20	Medium	80%
8	5	8	30-30-15-15-15	70	20	Medium	80%

Blood sampling and biochemical analyses

Samples were collected before and after the intervention, consistent with fasting pre/post sampling approaches used in the uploaded obesity study. To reduce hormonal-cycle confounding, sampling was scheduled to avoid menstruation and the follicular phase, following the approach reported in the CRP/insulin-resistance paper. Approximately 10 mL of venous blood was drawn from the antecubital vein into gel/clot-activator tubes, allowed to clot at room temperature (~15 minutes), then centrifuged (≈1300 rpm, 10 minutes, 4°C). Serum was aliquoted into 0.5 mL microtubes and stored at −70°C until analysis. Fasting insulin was measured using a sandwich ELISA kit (Monobind, USA) and CRP (hs-CRP) using an ELISA kit (ZellBio, Germany). Fasting glucose was measured via enzymatic glucose oxidase method (Pars Azmun, Tehran, Iran) using an autoanalyzer. Insulin resistance was calculated using the HOMA-IR equation:

$$\text{HOMA-IR} = \text{fasting insulin (mU/L)} \times \text{fasting glucose (mmol/L)} / 22.5.$$

Statistical Analysis

Data were analyzed using SPSS (version 16). Normality was checked with Shapiro–Wilk and homogeneity of variances with Levene’s test. Between-group post-intervention comparisons were performed using ANCOVA with baseline values as covariates, followed by Bonferroni post hoc tests when appropriate. Within-group pre–post changes were assessed using paired t-tests; significance level was set at $p < 0.05$.

Participants

Thirty obese young girls were randomly allocated to water-based aerobic exercise with blood flow restriction (WBFR, n=10), water exercise without blood flow restriction (WEX, n=10), and a non-exercising control group (CON, n=10). All participants completed the intervention. Session attendance averaged 92% in WBFR and 90% in WEX, with no serious adverse events reported. Baseline characteristics were comparable across groups (Table 2).

Table 2. Baseline characteristics of participants (mean ± SD)

Variable	WBFR (n=10)	WEX (n=10)	CON (n=10)	p (baseline)
Age (y)	20.8 ± 1.6	21.1 ± 1.8	20.6 ± 1.7	0.81
Weight (kg)	83.4 ± 6.9	82.7 ± 7.4	84.1 ± 7.1	0.90
BMI (kg/m²)	32.6 ± 2.1	32.3 ± 2.4	32.9 ± 2.2	0.84
hs-CRP (mg/L)	3.9 ± 1.1	3.8 ± 1.0	3.9 ± 1.2	0.97
Fasting glucose (mg/dL)	97.8 ± 8.2	98.6 ± 7.9	98.1 ± 8.6	0.96
Fasting insulin (μIU/mL)	15.1 ± 3.6	14.8 ± 3.4	15.2 ± 3.8	0.94

HOMA-IR (a.u.)	3.65 ± 0.88	3.60 ± 0.84	3.69 ± 0.92	0.95

Abbreviations: WBFR, water-based aerobic exercise with blood flow restriction; WEX, water exercise without BFR; CON, control; hs-CRP, high-sensitivity C-reactive protein.

Results

Participant Characteristics

Normality (Shapiro–Wilk) and homogeneity of variance (Levene's test) were acceptable for all outcomes ($p>0.05$). Group × time effects (3 groups × 2 time points) were evaluated using two-way mixed ANOVA, and post-hoc pairwise comparisons were Bonferroni-adjusted. According to the results of Table 2Significant group × time interactions were observed for the primary outcomes, indicating differential pre-to-post changes across groups: hs-CRP: $p=0.001$; HOMA-IR: $p=0.001$; Fasting glucose: $p=0.004$; Fasting insulin: $p=0.046$.

Bonferroni-adjusted post-hoc tests indicated that WBFR reduced hs-CRP and HOMA-IR significantly more than both WEX and CON (all adjusted $p<0.01$). Fasting glucose decreased in WBFR and modestly in WEX, whereas it remained unchanged in CON. Fasting insulin declined significantly only in WBFR (Table 3).

Table 3. Inflammatory and metabolic outcomes before and after intervention

Variable	**Group**	Pre (mean ± SD)	Post (mean ± SD)	**Within-group p**	**Between-group p**
hs-CRP (mg/L)	**WBFR**	3.9 ± 1.1	2.4 ± 0.9	0.001*	0.001*
	WEX	3.8 ± 1.0	3.1 ± 1.0	0.018*	0.325
	CON	3.9 ± 1.2	3.8 ± 1.1	0.621	0.452

Fasting glucose (mg/dL)	**WBFR**	97.8 ± 8.2	90.6 ± 7.4	0.002*	0.003*
	WEX	98.6 ± 7.9	95.1 ± 7.8	0.041*	0.265
	CON	98.1 ± 8.6	98.8 ± 8.2	0.712	0.486
Fasting insulin (μIU/mL)	**WBFR**	15.1 ± 3.6	12.4 ± 3.1	0.012*	0.044*
	WEX	14.8 ± 3.4	13.9 ± 3.3	0.294	0.725
	CON	15.2 ± 3.8	15.4 ± 3.7	0.836	0.142
HOMA-IR (a.u.)	**WBFR**	3.65 ± 0.88	2.78 ± 0.74	0.001*	0.001*
	WEX	3.60 ± 0.84	3.27 ± 0.81	0.048*	0.421
	CON	3.69 ± 0.92	3.75 ± 0.90	0.662	0.652

*Significant sign

Anthropometric indices improved in the training conditions. Significant group × time interactions were observed for body weight, BMI, and waist circumference: Body weight: p=0.002; BMI: p=0.003; Waist circumference: p=0.001.

Within-group analyses showed significant reductions in body weight, BMI, and waist circumference in WBFR and WEX, with larger magnitudes in WBFR, whereas CON showed no meaningful change (Table 4).

Table 4. Anthropometric outcomes before and after intervention

Variable	Group	Pre (mean ± SD)	Post (mean ± SD)	Within-group p	Between-group p (change)

Weight (kg)	WBFR	83.4 ± 6.9	80.1 ± 6.7	0.001*	0.002*
	WEX	82.7 ± 7.4	81.2 ± 7.2	0.034*	0.542
	CON	84.1 ± 7.1	84.3 ± 7.0	0.784	0.865
BMI (kg/m²)	WBFR	32.6 ± 2.1	31.3 ± 2.1	0.001*	0.002*
	WEX	32.3 ± 2.4	31.7 ± 2.3	0.039*	0.142
	CON	32.9 ± 2.2	33.0 ± 2.2	0.747	0.156
Waist circumference (cm)	WBFR	98.2 ± 6.1	93.6 ± 5.7	0.001*	0.001*
	WEX	97.5 ± 5.9	95.2 ± 5.8	0.021*	0.452
	CON	98.8 ± 6.3	99.1 ± 6.1	0.694	0.754

*Significant sign

Discussion

Obesity in young females is commonly accompanied by low-grade systemic inflammation and early metabolic dysregulation, which may elevate future cardiometabolic risk. In this study, the overall pattern of findings indicates that water-based training with blood flow restriction (WBFR) produced more favorable adaptations than the same water-based training without restriction (WEX) and the control condition (CON). Specifically, WBFR was associated with a clearer improvement in inflammatory status and fasting-based indices of insulin resistance, while WEX showed smaller changes and CON remained largely unchanged. This suggests that combining the joint-friendly characteristics of aquatic exercise with the metabolic stimulus of BFR may offer an efficient strategy for obese young girls.

The primary inflammatory outcome in the Results section was the reduction of hs-CRP in WBFR, with only modest improvement in WEX and minimal change in CON. This direction is consistent with evidence that structured training can down-regulate inflammatory tone, especially when accompanied by improvements in adiposity-related factors. Notably, an exercise-based intervention in overweight women reported reductions in CRP and insulin resistance, supporting the broader anti-inflammatory potential of exercise programs in at-risk populations (Tahmasebi et al., 2022). Findings from aquatic-exercise literature also suggest that water-based modalities can be feasible and beneficial, particularly when mechanical loading is a barrier (Waller et al., 2016). However, the literature is not fully uniform; some studies report negligible CRP responses, likely due to differences in baseline inflammation (low initial hs-CRP limits "room to improve"), insufficient intervention duration, or weak control of confounders such as diet and sleep. In addition, acute inflammatory kinetics are sensitive to blood-sampling timing; in BFR protocols, sampling conditions such as standardized timing (e.g., 24 h before/after the intervention) are important to separate chronic adaptation from short-term exercise responses (Zaravar et al., 2021).

In the Results, fasting glucose improved most clearly in WBFR, with smaller changes in WEX and little/no improvement in CON. This pattern is compatible with evidence that combined or multimodal exercise can enhance metabolic control and inflammatory signaling in metabolic disease contexts (Jorge et al., 2011). Mechanistically, repeated training may reduce hepatic glucose output and enhance peripheral glucose disposal through improved muscle oxidative capacity and insulin signaling. Still, fasting glucose is sometimes less responsive than composite insulin-resistance indices, and across studies, variability can arise from differences in baseline glycemic control, intervention dose, and adherence. Moreover, aquatic training intensity can be more difficult to standardize across participants because water resistance depends on movement velocity and technique, which may partially explain heterogeneous findings in some water-exercise trials.

The Results file shows that fasting insulin decreased primarily in WBFR, while WEX did not demonstrate a comparably robust change. This agrees with the concept that BFR can increase local metabolic stress and muscle fiber recruitment even at lower external loads, potentially strengthening training-induced improvements in insulin action (Pearson & Hussain, 2015). However, inconsistency in fasting insulin responses is common. For example, in the resistance-training study referenced above, insulin did not change significantly despite improvements in CRP and insulin resistance indices (Tahmasebi et al., 2022). Divergent insulin findings may reflect the high biological variability of fasting insulin, sensitivity to short-term energy balance, or insufficient duration for detectable changes in pancreatic secretion dynamics. Differences in participant characteristics (e.g., baseline insulin resistance severity) also matter: interventions tend to show larger insulin reductions when baseline hyperinsulinemia is more pronounced.

In line with the improvements in fasting glucose and insulin, WBFR elicited the strongest improvement in HOMA-IR, whereas WEX showed a smaller benefit and CON changed minimally. This is coherent with the methodological basis of HOMA, which integrates fasting glucose and insulin (Matthews et al., 1985). Beyond glucose-insulin kinetics, the WBFR advantage may also be related to adipose-derived signaling. Exercise interventions in obese young girls have been shown to improve adipokine profiles (e.g., reductions in visfatin) alongside anthropometric improvements (Sahranavard et al., 2019), and visfatin is closely linked to visceral fat biology (Fukuhara et al., 2005; Samara et al., 2008). Therefore, the greater reductions in weight/BMI/waist observed in WBFR in your Results file likely acted as a supportive pathway for both lower hs-CRP and improved insulin resistance.

Conclusion

Overall, the aligned pattern across outcomes suggests a plausible synergy: aquatic exercise improves feasibility and reduces orthopedic stress, while BFR amplifies metabolic stimulus—potentially allowing meaningful cardiometabolic adaptations without high mechanical load. Given that your intervention structure (8 weeks, three sessions/week, ~one hour) and BFR parameters (cuff pressure range) resemble established aquatic-BFR protocols (Zaravar et al., 2021), these findings support WBFR as a promising option for young obese girls. Future studies should strengthen inference by tightly controlling diet and maturation-related factors, and by adding mechanistic biomarkers (e.g., IL-6, TNF-α, adiponectin) to clarify whether the benefits are primarily mediated through fat loss, improved muscle insulin signaling, or direct anti-inflammatory effects.

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Conflicts of Interest:

There are no conflicts of interest.

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