Enhancing muscle strength and body composition after low-load resistance with blood flow restriction and hypoxia in untrained males

Mejora de la fuerza muscular y la composición corporal tras entrenamiento de resistencia de baja carga con restricción del flujo sanguíneo e hipoxia en varones no entrenados

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Abstract

Introduction: High-intensity resistance training may elevate the risk of musculoskeletal injuries and hinder optimal performance execution.
Objective: This study compared the effects of low-load resistance training under blood flow restriction (BFR) and hypoxia (HYP) on body composition, strength, and endurance in untrained male college students.
Methodology: Forty-five male college students from Ubon Ratchathani Rajabhat University were purposively sampled and matched into three groups (n = 15): 1) high-load resistance training (HLRT), 2) low-load resistance combined with blood flow restriction training (LLBFR), and 3) low-load resistance combined with hypoxic training (LLHYP). All groups trained three times weekly for five weeks.
Results: After five weeks of training, all groups showed significant improvements in fat-free mass, skeletal muscle mass and performance outcome ($p < 0.05$). The LLHYP group also exhibited significantly reduced skinfold thickness and greater arm circumference ($p < 0.05$). All groups improved strength and endurance, but LLHYP demonstrated significantly greater endurance than HLRT in both exercises ($p = 0.021$ and 0.003, respectively) and outperformed LLBFR in the dip machine ($p = 0.032$).
Discussion: Findings support that LLBFR and LLHYP can produce similar strength and body composition outcomes as HLRT over a short term. LLHYP, in particular, showed superior benefits in endurance, possibly due to hypoxia-related physiological adaptations.
Conclusions: Low-load resistance training with BFR and HYP effectively enhanced body composition, strength, and endurance of the biceps and triceps. This approach may offer a safer alternative for untrained male students.

Keywords

Blood flow restriction; body composition; hypoxia; low-load resistance training; muscular strength and endurance.

Resumen

Introducción: El entrenamiento de resistencia de alta intensidad puede aumentar el riesgo de lesiones musculoesqueléticas y dificultar la ejecución óptima del rendimiento.
Objetivo: Este estudio comparó los efectos del entrenamiento de baja carga con BFR e hipoxia sobre la composición corporal, fuerza y resistencia en varones universitarios no entrenados.
Metodología: Cuarenta y cinco estudiantes varones de la Universidad Rajabhat de Ubon Ratchathani fueron asignados intencionalmente a tres grupos (n = 15): 1) alta carga (HLRT), 2) baja carga con restricción del flujo sanguíneo (LLBFR), y 3) baja carga con hipoxia (LLHYP). Todos entrenaron tres veces por semana durante cinco semanas.
Resultados: Después de cinco semanas de entrenamiento, todos los grupos mostraron mejoras significativas en la masa libre de grasa, la masa muscular esquelética y el rendimiento ($p < 0.05$). El grupo LLHYP también presentó una reducción significativa en el grosor del pliegue cutáneo y un mayor perímetro del brazo ($p < 0.05$). Todos los grupos mejoraron en fuerza y resistencia, pero el grupo LLHYP demostró una resistencia significativamente mayor que el grupo HLRT en ambos ejercicios ($p = 0.021$ y 0.003, respectivamente), y superó al grupo LLBFR en la máquina de fondos ($p = 0.032$).
Discusión: Los resultados indican que el LLBFR y el LLHYP pueden igualar al HLRT en fuerza y composición corporal a corto plazo. Además, el LLHYP destacó en resistencia, posiblemente por adaptaciones fisiológicas a la hipoxia.
Conclusiones: El entrenamiento de baja carga con BFR e hipoxia mejoró eficazmente la composición corporal, fuerza y resistencia de bíceps y tríceps, siendo una alternativa segura para varones no entrenados.

Palabras clave

Restricción del flujo sanguíneo; composición corporal; hipoxia; entrenamiento de resistencia con baja carga; fuerza y resistencia muscular.

Introduction

Resistance training (R_T) is widely recognized as an effective method for enhancing muscle size, strength, and overall physical fitness. Traditional R_T protocols typically employ moderate to high intensities, generally ranging from 70% to 80% of one-repetition maximum (1RM), to facilitate muscular adaptations (Prieto et al., 2022). However, high-load R_T is not appropriate for all individuals. Those with specific medical conditions, musculoskeletal injuries, or individuals engaged in rehabilitation may find it unsafe to participate in high-intensity training due to the increased risk of muscle strain and joint stress (Kim & Yoon, 2021).

In response to this limitation, alternative low-load training strategies have been developed to elicit similar adaptations. One such method is low-load resistance training combined with blood flow restriction (BFR). BFR involves the application of external pressure to proximal limbs to partially restrict venous return while maintaining arterial inflow (Patterson et al., 2019). This restriction results in blood pooling and localized hypoxia within the working muscles, creating a metabolic environment that promotes physiological adaptations, including muscle hypertrophy and strength gains (Bennett & Slattery, 2019; Kacin & Strazar, 2011). Numerous studies have shown that low-load resistance training with BFR can significantly improve muscle strength, endurance, and aerobic capacity across diverse populations (Centner et al., 2019; Cook et al., 2018; Manimmanakorn et al., 2013). Training at 20%-40% 1RM with BFR has been show to induce muscle hypertrophy and improve muscle size, strength, and performance, similar to high-load resistance training without BFR (Centner et al., 2019; Kim et al., 2017; Lixandrão et al., 2018; Piskin et al., 2025). Notably, even at 40% 1RM, BFR training has proven effective in promoting muscle growth and strength, particularly in overweight adolescents (Huntula & Nuttouch, 2023). This training method has been found to elicit muscular adaptations comparable to those achieved with traditional high-load resistance training (Jacobs et al., 2013). Moreover, BFR has been shown to elevate levels of vascular endothelial growth factor (VEGF), indicating its role in improving muscle perfusion and vascular adaptations, especially in older adults (Ramadhan et al., 2025). Therefore, low-load resistance training combined with BFR offers an alternative for individuals who cannot tolerate high-load resistance training due to medical conditions or other limitations.

Hypoxic training (HYP) is another emerging and widely used method in combination with low-load resistance training. This approach involves reducing the oxygen content of inspired air (hypoxia), simulating high-altitude conditions and resulting in the inhalation of oxygen-deprived air. The reduced oxygen availability leads to a drop in blood oxygen levels (hypoxemia), triggering various physiological responses (Mazzeo, 2008; Park et al., 2019; West, 1996). Evidence suggests that low-load R_T (30%–50% 1RM) performed under hypoxic conditions for 4–6 weeks can improve muscle strength, power, and VO_2 max, comparable to conventional high-load RT under normoxia (Namboonlue et al., 2020; Thuwakum et al., 2017). Additionally, improvements in body composition have been observed following hypoxic R_T, particularly in fat mass reduction and lean mass preservation (Yuyongsin et al., 2022). A meta-analysis by Feriche et al. (2017) concluded that R_T under HYP can lead to greater hypertrophy and strength gains than normoxic R_T, particularly when combined with appropriate training volume and intensity (Feriche et al., 2017).

Despite the growing interest in BFR and R_T, most existing studies have focused primarily on lower-body musculature, particularly the quadriceps and hamstrings. Research involving upper-body muscles remains limited, and upper-limb protocols are significantly underrepresented in the current literature (Rodríguez-Zamora et al., 2019). This gap is particularly relevant for populations that depend heavily on upper-body strength and endurance, such as racquet sport athletes, swimmers, or individuals with mobility impairments who rely on their arms for daily activities. To address this limitation, low-load resistance training under HYP has emerged as a promising alternative to improve muscle performance while minimizing the risk of training-related injuries. However, to optimize the effectiveness of this training method, factors such as the appropriate training duration, movement speed, load progression (Törpel et al., 2020), and the optimal dose of training intensity for R_T under HYP should be carefully considered (Rodríguez-Zamora et al., 2019).

Therefore, the researcher team aimed to investigate and compare the effects of low-load resistance training on biceps brachii and triceps brachii muscles combined with blood flow restriction and hypoxic condition training on body composition, muscle strength, and muscular endurance among untrained male college students.

Method

Study Design

Forty-five untrained male college students from Ubon Ratchathani Rajabhat University (mean age: 19.58 ± 0.85 years) volunteered for this study. The inclusion criteria included untrained male college students, aged 19-24 years, studying at Ubon Ratchathani Rajabhat University, with a body mass index (BMI) between 18 and 30 kg/m^2; being in good health with no existing health issues and not living at an altitude higher than 1,000 meters in the three months prior to the study. The exclusion criteria included those missing more than 20% of the program, having health issues such as respiratory diseases, allergies, asthma, hypertension, or any other conditions that might affect participation, such as dizziness, light-headedness, or chest pain during exercise. Written informed consent was obtained from all participants after they were fully informed of the study's objectives, procedures, and other relevant details. The study employed experimental research design and was approved by the Ubon Ratchathani University Ethics Committee for Human Research (UBU-REC-97/2024), in accordance with the principles of the Declaration of Helsinki.

Participants

The sample size was calculated using the WinPepi program version 11.65, based on the study by Manimmanakorn et al. (2013). An effect size of 18.3 was used, with a confidence level of 95% ($\alpha = 0.05$) and a statistical power of 80% ($\beta = 0.20$). The standard deviation for the experimental group was 17.9, while that of the control group was 7.0. Based on these parameters, the minimum required sample size was determined to be 9 participants per group. To account for a potential dropout rate of 10%, the adjusted sample size was increased to at least 15 participants per group. Therefore, the study included a total of 45 participants, dividing them into three groups. A single-blind design was used to compare muscle strength, endurance, and changes in body composition, arm circumference, and skinfold thickness of the biceps brachii and triceps brachii muscles after five weeks of low-load resistance training with either blood flow restriction or hypoxia or high-load resistance training. The participants were selected using purposive sampling and were divided into three groups using the matched group method. The average score for hand grip strength was used as the criterion for group assignment. Following this, the participants were randomly allocated to one of three groups: high-load resistance training (HLRT, n = 15), low-load resistance combined with blood flow restriction training (LLBFR, n = 15), and low-load resistance combined with hypoxic training (LLHYP, n = 15). The experiment was conducted three times a week (Monday, Wednesday, and Friday). The research instrument was a resistance training program consisting of three plans: a warm-up exercise, two resistance training exercises (biceps curl and dip machine), and a cool-down exercise. The training program had an Item Objective Congruence (IOC) value of 0.95. All participants were measured at baseline and again after five weeks of training (within 2 days before and after the final training session) (figure 1).

Procedure

Training program

The HLRT group performed a high-load resistance training using two exercises: biceps curl (Nautilus impact strength S5301, USA) and dip machine (Nautilus impact strength S5303, USA) at an intensity of 80% 1RM. Each exercise consisted of 3 sets of 6 repetitions, with a 1-minute rest between sets and a 1-minute rest before moving on to the next exercise. The participants breathed normal ambient room air ($F_iO_2 = 20.9\%$), equivalent to sea level altitude. However, the LLBFR and LLHYP groups performed a resistance training program consisting of biceps curls and dip machines at 50% 1RM, with 3 sets of 15 repetitions, 1-minute rest between sets, and 1-minute rest before transitioning to the next exercise. The LLBFR group performed low-load resistance combined with blood flow restriction using the cuffs (Vald Performance: AirBands, Australia) to wrap around the mid-upper arm circumference at 60% of cuff pressure (60% of each individual's arterial occlusion). The LLHYP group performed low-load resistance combined with hypoxic training using Hypoxicator (Hypoxicator: altitude training systems-hypoxic unit, Australia) and maintained an oxygen saturation of 15.8% (F_iO_2 = 15.8%), equivalent to an altitude of ~2200 meters above sea level. All groups performed the training three times a week for five weeks. Throughout the training period, oxygen saturation and heart rate were measured using a pulse oximeter (Pulse oximeter by beurer model: PO30) and recorded during both the testing and training sessions. A 10-minute warm-up and stretching routine preceded all training sessions.

Measures

Exercise testing

All participants completed two tests: the first test before the first week of the experiment (pre-test) and the second test after the fifth week of the experiment (post-test). The following data were collected:

Body composition, including body weight, BMI, fat percentage, fat mass, fat-free mass, and muscle mass was measured. The participants were asked to stand on the machine (Body composition; seca mBCA, Germany) without their shoes for approximately 5 minutes.

Arm circumference was measured using a tape measure at the mid-upper arm in a relaxed condition. The distance from the acromion process to the olecranon process on the arm was measured, and a mark was made at the 50% position, measured distal to the acromion process in centimeters (cm).

Body fat was measured using a skinfold caliper (Lange skinfold caliper; Beta technology, USA). The measurement was taken at the biceps and triceps, ensuring the skinfold caliper passed through the subcutaneous layer. During measurement, the participants' hands and arms were in a relaxed condition. The same measurer performed the measurements both before and after the experiment. The right hand of the measurer held the skinfold caliper, while the left hand grasped the subcutaneous fat (between the thumb and index finger, approximately 1 inch apart) without pinching the tissue. During measurement, the tip of the skinfold caliper was positioned about 1 cm away from the tip of the left finger. The values were recorded in millimeters (mm) after allowing the skinfold caliper to press on the skin for approximately 2 seconds.

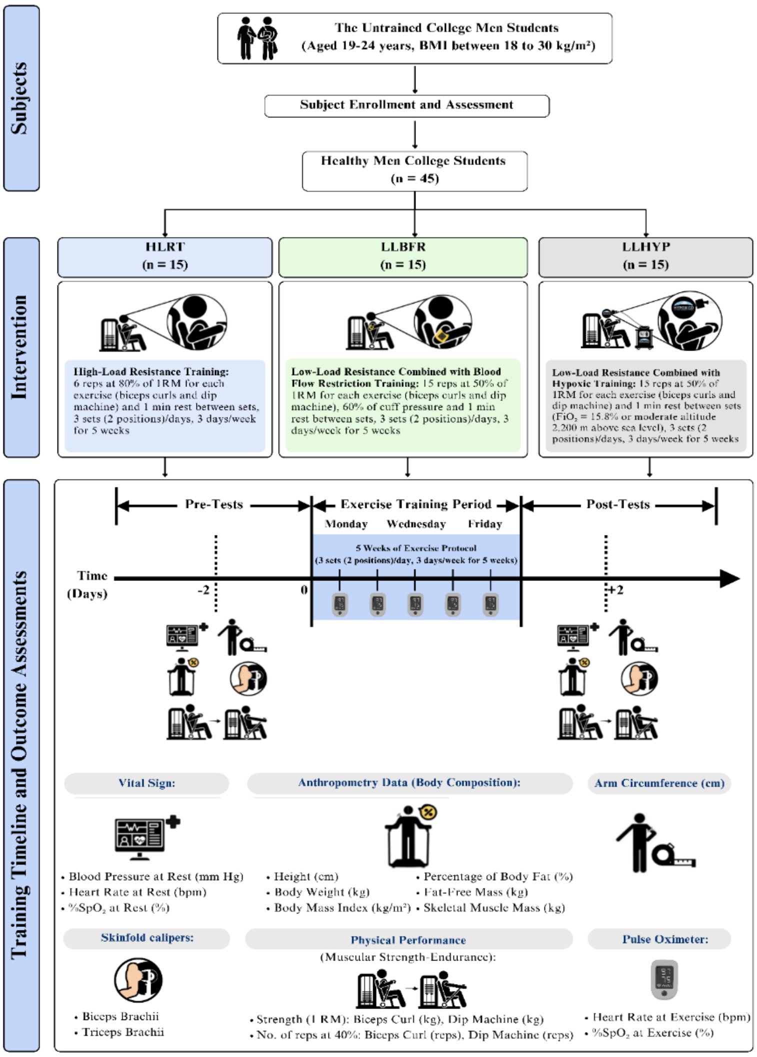
Muscular strength was measured using a stationary machine for biceps curl (Nautilus impact strength S5301, USA) and dip machine (Nautilus impact strength S5303, USA). The participants completed both exercises, and the weight lifted was then calculated using an indirect method. The predicted 1RM was determined using the equation: 1RM = weight lifted / (1.0278 - 0.0278 × reps) (Brzycki, 1988). The session took approximately 20 minutes.

Muscular endurance was measured using a stationary machine for biceps curl (Nautilus impact strength S5301, USA) and dip machine (Nautilus impact strength S5303, USA). The participants performed both exercises at 40% 1RM, repeating each movement until they could no longer continue. The number of repetitions completed was recorded. The entire session took approximately 20 minutes.

Data analysis

Statistical analyses were performed using SPSS 26 (IBM Corp. IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp). The normality of the data was assessed using the Shapiro-Wilk test. The mean values of the variables before and after the experiment within the group were analyzed using a paired t-test. Additionally, the mean values of the variables before and after the experiment between groups were analyzed using one-way ANOVA, with a statistical significance level set at 0.05 (p-value < 0.05).

Figure 1. Outline the training and testing schedule. Abbreviations: reps, repetitions; SpO_2, resting arterial oxygen saturation.



Results

Table 1 presents the participants' characteristics and baseline measurements from the three training groups. No substantial differences were seen across the groups (HLRT, LLBFR, and LLHYP) for any variable.

Table 1. Characteristics of participants in the three training groups.

Characteristics	HLRT (*n* = 15)	LLBFR (*n* = 15)	LLHYP (*n* = 15)	p-value
Age (y)	19.92±0.95	19.27±0.70	19.60±0.83	0.063
Weight (kg)	67.69±12.29	66.46±10.36	64.91±8.57	0.452
Height (cm)	173.69±6.10	174.13±3.89	172.60±5.33	0.353
BMI (kg/m²)	21.87±4.17	21.87±3.19	21.90±2.68	0.481
Resting heart rate (b/m)	73.91±7.26	74.55±8.20	72.08±7.27	0.361
S_pO_2 (%)	98.67±0.49	98.87±0.35	98.47±0.64	0.057
SBP (mmHg)	121.44±5.39	124.85±8.42	122.75±7.42	0.278
DBP (mmHg)	78.45±7.70	80.08±7.53	78.83±7.41	0.429

Table note: HLRT: high-load resistance training; LLBFR: low-load resistance combined with blood flow restriction training; LLHYP: low-load resistance combined with hypoxic training; BMI: body mass index; S_pO_2 = resting arterial oxygen saturation; SBP = systolic blood pressure; DBP = diastolic blood pressure; Values are mean ± SD.

After five weeks of training, the mean fat-free mass, subcutaneous fat of the right triceps brachii, subcutaneous fat of the left triceps brachii, skeletal muscle mass, skeletal muscle mass of the right arm, and skeletal muscle mass of the left arm in both the HLRT and LLBFR groups showed significant differences from the baseline at the 0.05 level. However, the LLHYP group exhibited a more pronounced trend in changes. The mean fat-free mass, subcutaneous fat of right biceps brachii, subcutaneous fat of left biceps brachii, subcutaneous fat of right triceps brachii, subcutaneous fat of left triceps brachii, skeletal muscle mass, skeletal mass of right arm, skeletal muscle mass of left arm, right arm circumference, and left arm circumference showed significant differences from the baseline at the 0.05 level. (p = 0.006, p = 0.006, p = 0.001, p = 0.006, p = 0.004, p = 0.001, p = 0.001, p = 0.001, p = 0.037, and p = 0.021, respectively). Nevertheless, when comparing between groups, no significant differences were found in body composition across all variables at the 0.05 level (p > 0.05) (table 2).

Table 2. Mean changes in body composition observed in all three training groups after five weeks of training.

Body composition	HLRT (*n* = 15)			LLBFR (*n* = 15)			LLHYP (*n* = 15)			p-value
	Pre-test	Post-test	%change	Pre-test	Post-test	%change	Pre-test	Post-test	%change	
Weight (kg)	67.69 ±12.29	68.25 ±12.12	0.83	66.46 ±10.36	66.55 ±10.06	0.14	65.70 ±9.11	66.34 ±8.99	0.97	0.240
BMI (kg/m²)	21.87 ±4.17	22.05 ±4.11	0.82	21.87 ±3.19	21.88 ±3.08	0.07	22.23 ±2.76	22.38 ±2.62	0.71	0.270
Fat-Free mass (kg)	55.81 ±5.65	56.61 ±5.87	1.43 *(p=0.005)	55.99±5.55	56.67 ±5.33	1.22 *(p=0.001)	55.82 ±5.21	57.27 ±5.21	2.59 *(p=0.006)	0.136
Fat mass (%)	14.22 ±8.41	13.80 ±8.23	-2.92	14.09 ±3.87	13.67 ±3.64	-2.98	14.06 ±5.81	13.68 ±6.43	-2.73	0.367
Skinfold calipers of right biceps brachii (mm)	3.91 ±1.22	3.45 ±0.69	-11.63	4.91 ±1.22	4.36 ±1.03	-11.11	4.50 ±0.90	3.75 ±0.45	-16.67 *(p=0.006)	0.273
Skinfold calipers of left biceps brachii (mm)	4.73 ±1.27	4.45 ±0.82	-5.77	4.75 ±1.29	4.33 ±1.15	-8.77	4.50 ±0.67	3.75 ±0.62	-16.67 *(p=0.001)	0.240
Skinfold calipers of right triceps brachii (mm)	5.64 ±2.16	4.91±1.45	-12.90 *(p=0.027)	6.56 ±5.33	5.78 ±1.56	-11.86 *(p=0.022)	6.38 ±1.71	5.46 ±1.39	-14.46 *(p=0.006)	0.455
Skinfold calipers of left triceps brachii (mm)	6.33 ±1.22	5.56 ±1.01	-12.28 *(p=0.022)	6.63 ±1.41	5.75 ±1.58	-13.21 *(p=0.003)	6.45 ±1.69	5.59 ±1.59	-13.38 *(p=0.004)	0.453
Skeletal muscle mass (kg)	26.93 ±3.60	27.42 ±3.62	1.80 *(p=0.005)	27.45 ±3.35	27.74 ±3.27	1.06 *(p=0.025)	26.83 ±3.03	27.40 ±3.18	2.12 *(p=0.001)	0.244
Skeletal muscle mass of right arm (kg)	1.68 ±0.16	1.75 ±0.15	3.74 *(p=0.001)	1.62 ±0.19	1.67 ±021	3.21 *(p=0.012)	1.60 ±0.22	1.67 ±0.24	4.54 *(p=0.001)	0.343
Skeletal muscle mass of left arm (kg)	1.63 ±0.19	1.68 ±0.20	3.25 *(p=0.006)	1.54 ±0.18	1.57 ±0.17	2.15 *(p=0.011)	1.55 ±0.18	1.61 ±0.21	3.97 *(p=0.001)	0.260
Right arm circumference (cm)	26.22 ±2.73	26.44 ±2.13	0.85	26.67 ±1.83	27.04 ±1.89	1.36	26.78 ±2.05	27.39 ±1.98	2.29 *(p=0.037)	0.392
Left arm circumference (cm)	26.00 ±2.71	26.40 ±2.22	1.54	26.65 ±2.32	26.98 ±2.11	1.26	26.70 ±2.11	27.20 ±1.97	1.88 *(p=0.021)	0.486

Table note: *Significant p<0.05 (pre vs post).

After five weeks of training, the changes in maximum muscle strength showed that the HLRT, LLBFR, and LLHYP groups exhibited an increasing trend in the mean 1RM for the biceps curl (48.42%, 50.88%, and 55.79%, respectively) and the dip machine (34.12%, 33.53%, and 37.76%, respectively) compared to the baseline. Similarly, changes in muscular endurance were observed in all groups after five weeks of training. The mean muscle endurance in both the biceps curl and dip machine showed significant differences from the baseline at the 0.05 level (table 3).

In particular, the LLHYP group exhibited significantly different mean muscle endurance scores on the biceps curl and dip machine compared to the HLRT group at the 0.05 level (p = 0.021 and p = 0.003, respectively). Additionally, the LLHYP group showed significantly different mean muscle endurance scores on the dip machine compared to the LLBFR group at the 0.05 level (p = 0.032) (figure 3-4).

Table 3. Mean changes in muscular strength and endurance observed in all three training groups after five weeks of training.

Variables	HLRT (*n* = 15)			LLBFR (*n* = 15)			LLHYP (*n* = 15)			p-value
	Pre-test	Post-test	%change	Pre-test	Post-test	%change	Pre-test	Post-test	%change	
Maximum strength (1RM)										
Biceps curl (kg)	22.68 ± 1.86	33.66 ± 4.65	48.42 *(p=0.001)	24.81 ± 8.63	37.44 ± 11.13	50.88 *(p=0.001)	22.25 ± 1.83	34.66 ± 4.23	55.79 *(p=0.001)	0.390
Dip machine (kg)	54.15 ± 12.78	72.63 ± 11.47	34.12 *(p=0.001)	53.32 ± 14.33	71.19 ± 13.89	33.53 *(p=0.001)	55.21 ± 9.50	76.05 ± 20.32	37.76 *(p=0.001)	0.494
Muscular endurance (Number of reps at 40% 1RM)										
Biceps curl (reps)	25.40 ± 7.63	38.80 ± 9.55	52.76 *(p=0.001)	25.67 ± 5.24	44.33 ± 7.11	72.73 *(p=0.001)	24.42 ± 4.44	47.50 ± 9.47	94.54 *(p=0.001), †(p=0.021)	0.023
Dip machine (reps)	42.82 ± 7.25	56.00 ± 11.70	30.79 *(p=0.001)	44.11 ± 8.46	60.11 ± 8.52	36.27 *(p=0.001)	42.94 ± 7.99	69.83 ± 17.89	62.72 *(p=0.001), †(p=0.003), ‡(p=0.032)	0.003

Table note: *Significant p<0.05 (pre vs post); #Significant p<0.05 (HLRT vs LLBFR); †Significant p<0.05 (HLRT vs LLHYP); ‡Significant p<0.05 (LLBFR vs LLHYP).

Figure 2. Changes in muscular strength (A: 1-RM biceps curl and B: 1-RM dip machine) before and after five weeks of the training period. Values are presented as mean ± SD. *Significant p<0.05 (pre vs post).

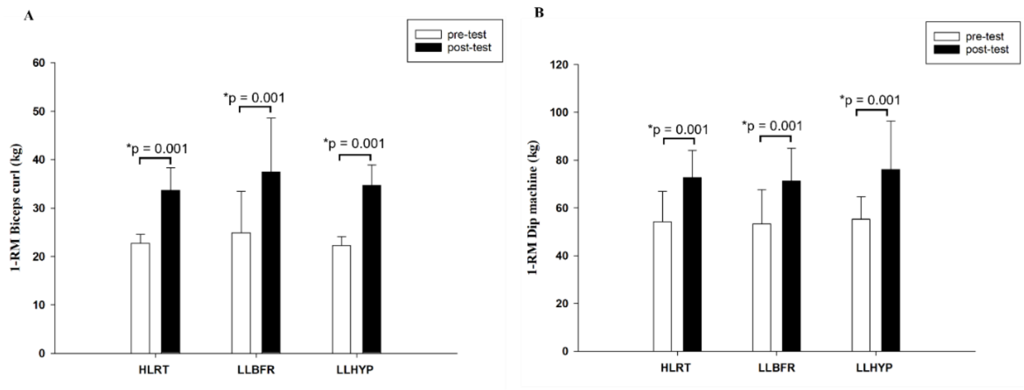
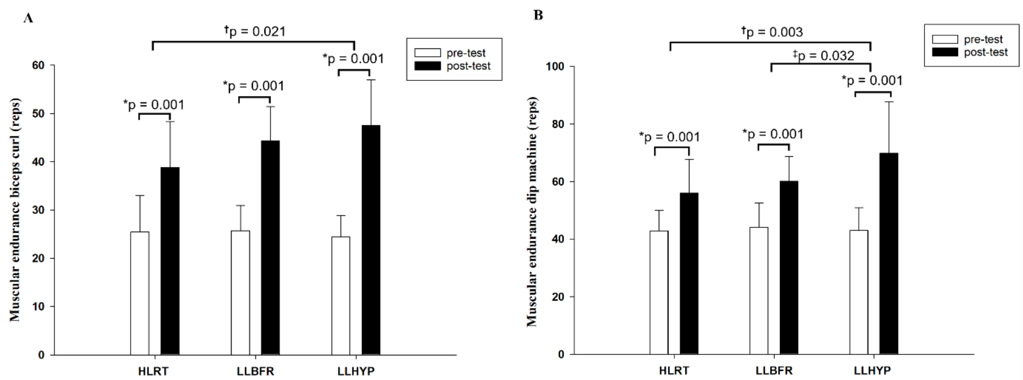


Figure 3. Changes in muscular endurance (A: Muscular endurance biceps curl and B: Muscular endurance dip machine) before and after five weeks of the training period. Values are presented as mean ± SD. *Significant p<0.05 (pre vs post), #Significant p<0.05 (HLRT vs LLBFR), †Significant p<0.05 (HLRT vs LLHYP), ‡Significant p<0.05 (LLBFR vs LLHYP).



Discussion

This study found that after five weeks of resistance training, all training groups (HLRT, LLBFR, and LLHYP) showed improvements in muscle strength and endurance, as well as favorable trends in body composition, such as an increase in fat-free mass and muscle mass, and a decrease in skinfold thickness of the biceps brachii and triceps brachii, compared to baseline values (p<0.05). However, no statistically significant differences were observed between groups, possibly due to the short training duration, small sample size, and the fact that all participants were untrained young males who may exhibit rapid initial adaptations.

This finding is consistent with previous studies indicating that low-load blood flow restriction (LLBFR) training can stimulate muscle growth similar to HLRT through metabolic stress (Pearson & Hussain, 2015). Meanwhile, low-load hypoxic training (LLHYP) may promote muscle adaptations via hypoxia-related pathways, such as increased expression of hypoxia-inducible factor 1-alpha (HIF-1α). Although previous studies suggest that LLBFR may stimulate muscle growth through mechanisms such as metabolic stress and LLHYP may promote adaptations potentially involving pathways like increased expression of HIF-1α (Feriche et al., 2017), these mechanisms were not directly measured in the current study and should therefore be interpreted with caution.

The lack of differences between groups may be attributed to the short training duration (only 5 weeks) (Plotkin et al., 2022) or the rapid initial response of previously untrained participants. Despite these limitations, the results suggest that LLBFR and LLHYP training may have the potential to serve as suitable alternatives for beginners, showing promising trends in improving body composition similar to traditional resistance training (Soares Fernandes Jacomo da Silva et al., 2024; Vechin et al., 2015). However, further research with longer training durations and larger sample sizes is essential to validate these findings. Supporting this, a study by Piskin et al. (2025), using ultrasound measurements found similar increases in muscle thickness in both BFR and traditional training groups (Piskin et al., 2025).

Regarding changes in muscle strength and endurance, after five weeks of LLBFR and LLHYP (50% 1RM), improvements in maximal strength of the biceps brachii and triceps brachii were observed, with gains approaching those seen in HLRT (80% 1RM); however, the short duration and small sample size limit definitive conclusions. All groups showed significant increases in strength compared to the baseline. This is consistent with a study by Jessee et al. (2018), which revealed that LLBFR training produced strength in a manner similar to traditional training (Jessee et al., 2018). The LLHYP group demonstrated a clear advantage in muscular endurance, showing significantly higher muscular endurance in the biceps curl and dip machine compared to the HLRT group ($p = 0.021$ and $p = 0.003$, respectively), as well as higher muscular endurance in the dip machine compared to the LLBFR group ($p = 0.032$). Similarly, a study by Piskin et al. (2025) found that BFR training at 20-40% of 1RM for 8 weeks effectively increased muscle strength, comparable to high-load resistance training (60-80% of 1RM)(Piskin et al., 2025). This finding aligns with the results of the present study, which indicated that the LLBFR group led to strength gains similar to those of the HLRT group. These findings support the concept that BFR training can activate high-threshold motor units comparable to high-load resistance training, primarily through metabolic stress; however, this mechanism remains speculative as it was not directly measured in the present study. This effect may also be linked to adaptations to hypoxia, such as increased mitochondrial density and improved muscle oxygen consumption efficiency (Feriche et al., 2017). In addition, the results align with those of Manimmanakorn et al. (2013), who found that training in HYP can enhance muscle performance more effectively than training normoxic conditions (Manimmanakorn et al., 2013). While all groups demonstrated improvements in muscle strength and endurance, the LLHYP group tended to exhibit greater muscle endurance development. These findings suggest that LLHYP training may be an effective option for novice training seeking to improve both strength and endurance while potentially reducing injury risk associated with high-load resistance training (Vechin et al., 2015); however, such conclusions should be considered preliminary. Limitations of this study include the short training duration of five weeks and the inclusion of untrained male youth with no prior R_T experience. Further studies with larger, more diverse populations and longer training periods are needed to confirm these results and clarify underlying mechanisms (Plotkin et al., 2022).

This study revealed findings that are both consistent with and contradictory to previous research. Specifically, the results demonstrated that LLBFR and LLHYP training can increase muscle strength similarly to HLRT, consistent with a study by Loenneke et al. (2012), who reported that low-load resistance training at 20–30% 1RM combined with BFR produced similar strength gains as traditional high-load resistance training at 70% 1RM in novice subjects (Loenneke et al., 2012). However, the results of this present study, which found no significant difference in body composition between groups, contradict the findings of Fujita et al. (2007), who reported that BFR training led to a significantly greater increase in muscle mass compared to traditional resistance training (Fujita et al., 2007). These contradictory findings may be explained by several methodological differences. For instance, Fujita et al. (2007) employed a longer intervention period and included different training frequencies and intensities, which may have contributed to more pronounced hypertrophic adaptations (Fujita et al., 2007; Raharjo et al., 2024). Additionally, their participants had different baseline training experience, and muscle mass was assessed using more sensitive imaging techniques that may have detected changes.

In terms of muscle endurance, the LLHYP group showed better development than the other groups, likely due to the effects of hypoxia on muscle performance adaptation and endurance development (Manimmanakorn et al., 2013; Thuwakum et al., 2017). However, Scott et al. (2014) reported no difference in muscle endurance between hypoxic and normoxic training groups in highly trained athletes (Scott et al., 2014). These discrepancies may be attributed to several methodological and population-related factors. For example, differences in participant training status (trained vs untrained), intervention duration (e.g., 5 vs 8 weeks), training intensity, and methods of assessing muscle mass (e.g., calipers vs imaging techniques) could have influenced the observed outcomes across studies.

Several limitations to this study should be considered. Firstly, the training duration was relatively short (only five weeks), which may not have been sufficient to elicit measurable changes in muscle mass or body composition (Plotkin et al., 2022). In comparison, Piskin et al. (2025) used an eight-week training and assessed muscle thickness using ultrasound, which may have allowed for more precise detection of morphological adaptations (Piskin et al., 2025). Therefore, further studies should consider longer training durations and the use of more sensitive and standardized measurement techniques to accurately capture muscle adaptations. Secondly, the participants were limited to young, untrained male students, so the results may not be generalizable to other groups of the population, such as women, older adults, or athletes (Loenneke et al., 2012). Thirdly, this study did not include a non-training control group, limiting our ability to isolate the intervention effects. The non-blinded design may also have introduced performance or assessment bias. Additionally, although mechanistic explanations such as increased HIF-1α expression and metabolic stress are often cited in the literature, we did not measure any physiological markers (e.g., hormonal, inflammatory, or molecular responses) to support these assumptions (Scott et al., 2014). Lastly, although LLBFR and LLHYP are often proposed as safer alternatives to HLRT, this study did not evaluate safety outcomes such as muscle soreness, cardiovascular responses, or injury rates. Future studies should incorporate longer training durations, more diverse populations, control groups, blinded assessments, and physiological and safety monitoring to confirm and extend the present findings.

In terms of practical application, the results of this present study suggest that LLBFR and LLHYP training may serve as potential alternatives for beginners, particularly those who are unable to train with high-load resistance training due to health limitations or injury risks (Vechin et al., 2015). For trainers and sports scientists, LLHYP training could be considered specifically for enhancing muscular endurance, while LLBFR training may be more suitable for focusing on strength gains with a lower injury risk and greater ease. However, considering the limitations of the study, further research with longer durations, larger sample sizes, and diverse populations is necessary to establish the most appropriate protocols and evaluate the long-term sustainability of these training effects (Fujita et al., 2007). Additionally, changes in other aspects of muscle performance with resistance training combined with BFR and HYP should be explored.

Conclusions

Low-resistance training (50% 1RM) combined with blood flow restriction (60% of the occlusion cuff) and hypoxic training (F_iO_2 = 15.8%) can improve the body composition, maximum strength, and endurance of the biceps and triceps brachii muscles in untrained male college students, similarly to high-resistance training (80% 1RM). It is another option to train with resistance that reduces the risk of possible injury. This approach is beneficial for beginner exercise, as it allows them to plan their training together more effectively.

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Conflict of interest

The authors declare that they have no conflict of interest.

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