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Research article

Effect and Mechanism of a New Method of Low-Intensity Resistance Training Combined with Blood Flow Restriction on Sports Biomechanics of Young People

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Abstract

High-intensity resistance training is effective in improving muscle strength but poses a higher risk of atherosclerosis. Combining high-intensity resistance training with aerobic exercise can reduce atherosclerosis levels. Low-intensity resistance training combined with blood flow restriction does not require high-load force to stimulate muscles and may improve muscle strength and maintain arterial elasticity. The objective of the study was to investigate the effects of 12 weeks of low-intensity resistance training combined with blood flow restriction on body composition, muscle strength, and arterial elasticity in young people. The primary aim is to clarify whether the low-intensity resistance training combined with blood flow restriction training is a scientific training method to improve muscle strength and maintain arterial elasticity, and providing theoretical support for the scientific implementation of blood flow restriction training and the development of individualized training programs. Fifty-five college students were randomly divided into three groups: high-intensity resistance training, high-intensity resistance training combined with aerobic exercise, and low-intensity resistance training combined with blood flow restriction. Each group underwent 12 weeks of their respective training programs, and the effects on body composition, muscle strength, and arterial elasticity were examined. After 12 weeks, lean body mass significantly increased in both the high-intensity resistance training and low-intensity resistance training combined with blood flow restriction groups ($P < 0.05$). 1RM and knee isometric muscle strength significantly increased in all three groups ($P < 0.05$). Arterial elasticity significantly improved in both the high-intensity resistance training combined with aerobic exercise group and the low-intensity resistance training combined with blood flow restriction group ($P < 0.05$). Twelve weeks of high-intensity resistance training and low-intensity resistance training combined with blood flow restriction significantly improved body composition. All three training methods increased muscle strength. Low-intensity resistance training combined with blood flow restriction was more effective in improving arterial elasticity than high-intensity resistance training combined with aerobic exercise. Therefore, low-intensity resistance training combined with blood flow restriction is recommended as the preferred method to improve body composition, muscle strength, and arterial elasticity, reducing the risk of atherosclerosis.

Key words: High intensity resistance training, aerobic exercise, blood flow restriction training, body composition, muscle strength, arterial elastic function.

Introduction

Moderate physical activity improves physical health, but different training methods may produce different effects. The effectiveness of strength training in improving muscle strength, delaying muscle atrophy, and preventing injuries has been recognized by many studies (Kraemer et al., 2017). Nystoriak and Vina showed that high intensity resistance training (HIRT) has a positive effect on improving body composition, increasing muscle strength, and reducing fall-related dysfunction all have positive effects (Nystoriak and Bhatnagar, 2018; Vina et al., 2012). However, Miyachi et al pointed out that HIRT training can trigger a series of negative effects due to its relatively high load (Miyachi et al., 2004). For example, Suga et al and Ozaki et al showed that although HIRT was effective in improving muscle mass and strength, arterial stiffness was significantly increased after prolonged HIRT, which could be attributed to the intermittent elevation of blood pressure during weight lifting, which led to changes in arterial structure and consequently increased the risk of atherosclerosis (Suga et al., 2012; Ozaki et al., 2013). Studies have shown that people who regularly perform HIRT exhibit higher levels of atherosclerosis than sedentary people, and that reduced arterial elasticity is highly correlated with the incidence of cardiovascular disease (Zoungas and Asmar, 2007). Consequently, while we recognize the efficacy of HIRT in enhancing muscle mass and strength, the discovery of a more optimized alternative training regimen capable of maintaining arterial elasticity and mitigating arterial stiffness would hold significant importance for the prevention of cardiovascular complications. Studies have shown that aerobic exercise is effective in reducing arterial stiffness (Kawano et al., 2006). Kawano et al showed that arterial stiffness significantly improved after 30 min of high intensity resistance-aerobic exercise training (HIR-AET) per week. Blood flow restriction training (BFRT) is a type of training in which the limb is externally pressurized by a special pressurization device during exercise to restrict blood flow in order to improve the training effect (Ozaki et al., 2013; García-Rodríguez et al., 2023; Ferraz et al. 2018). Javorsk and Lowe demonstrated that BFRT in combination with low-intensity strength training was able to elicit muscle hypertrophy and strength gains similar to traditional strength training (Javorský et al., 2023; Lowe et al., 2023). Since BFRT does not require high-load force stimulation of the muscles, the trainer's blood pressure can remain stable throughout the exercise. Therefore, low intensity resistance-blood flow restriction training (LIR-BFRT) may be an effective training modality to maintain arterial elasticity.Curty found that, compared with HIRT, the Joint range of motion was significantly increased and recovery from muscle injury was more efficient compared to HIRT (Curty et al., 2018). Vechin showed that LIR-BFRT had similar effects as HIRT in increasing muscle mass and strength, but HIRT was more effective than LIR-BFRT in increasing muscle strength (Vechin et al., 2015).

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Therefore, this study aimed to investigate the effects of 12 weeks of LIR-BFRT on body composition, muscle strength and arterial elasticity function in young people, and to provide theoretical support for the scientific implementation of BFRT and the development of personalized training programs. The hypotheses of this study were: (1) body composition after HIRT, HIR-AET, and LIR-BFRT were significantly improved; (2) muscle strength after HIRT, HIR-AET, and LIR-BFRT were significantly increased; (3) arterial stiffness was increased after HIRT, and arterial elasticity function after HIR-AET and LIR-BFRT was maintained better, and the arterial elasticity function of LIR-BFRT was better than HIR-AET. function was superior to HIR-AET.

Methods

Subjects

G*Power3.1 was used to calculate the sample size required for the test, referring to previous studies (Huang et al., 2021; Kang, 2021), the effect size was set to 0.55, the test efficacy was set to 0.8, the significance level was set to 0.05, and the sample size required for the calculation was 36. Considering the subject attrition and the validity of the experimental data, 20 subjects were recruited in a single group for this study. College students without regular exercise habits were randomly recruited from the local university as study subjects, and a total of 60 subjects with good quality of life and above, physical activity readiness questionnaire (PAR-Q), and chronic venous disease quality of life questionnaire (CIVIQ-20) were screened for past medical history and determined to be eligible by using the health status questionnaire (SF-36). Subjects were then randomized by lottery into 3 groups (HIRT group, HIR-AET group, LIR-BFRT group) of 20 each. During the intervention, 1 person withdrew for medical reasons and 4 were lost through absence, totaling 55 subjects included in the final study, as shown in Table 1 and Figure 1. Inclusion criteria: age between 18-35 years old, no regular exercise habits. Exclusion criteria: those with pulmonary or cardiovascular diseases, those with musculoskeletal disorders that impair exercise performance, and those with a history of thrombosis, varicose veins, or other disorders that impede venous return. All subjects were aware of the trial process and signed an informed consent form. The study was conducted in accordance with the relevant ethical requirements of the Ethics Committee of Jiangsu College of Health and Wellness Professions (Ethics Approval No. 2022076).

Table 1. Basic information of subjects.

Group	n	Age (years)	Height (cm)	Body mass (kg)	Body mass index (kg/m2)
HIRT group	18 (9 men, 9 women)	21.05 ± 0.84	174.2 ± 1.57	77.69 ± 5.39	24.68 ± 1.35
HIR-AET group	17 (10 men, 7 women)	20.90 ± 1.02	172.98 ± 1.29	78.19 ± 4.32	25.20 ± 1.04
LIR-BFRT group	20 (10 men, 10 women)	21.14 ± 0.58	174.84 ± 1.97	75.89 ± 3.23	25.94 ± 0.96
***P* value**	/	0.356	0.782	0.074	0.103

HIRT-High Intensity Resistance Training, HIR-AET-High Intensity Resistance Combined with Aerobic Exercise, LIR-BFRT-Low Intensity Resistance Combined with Blood Flow Restriction Training. Repetition Maximum.

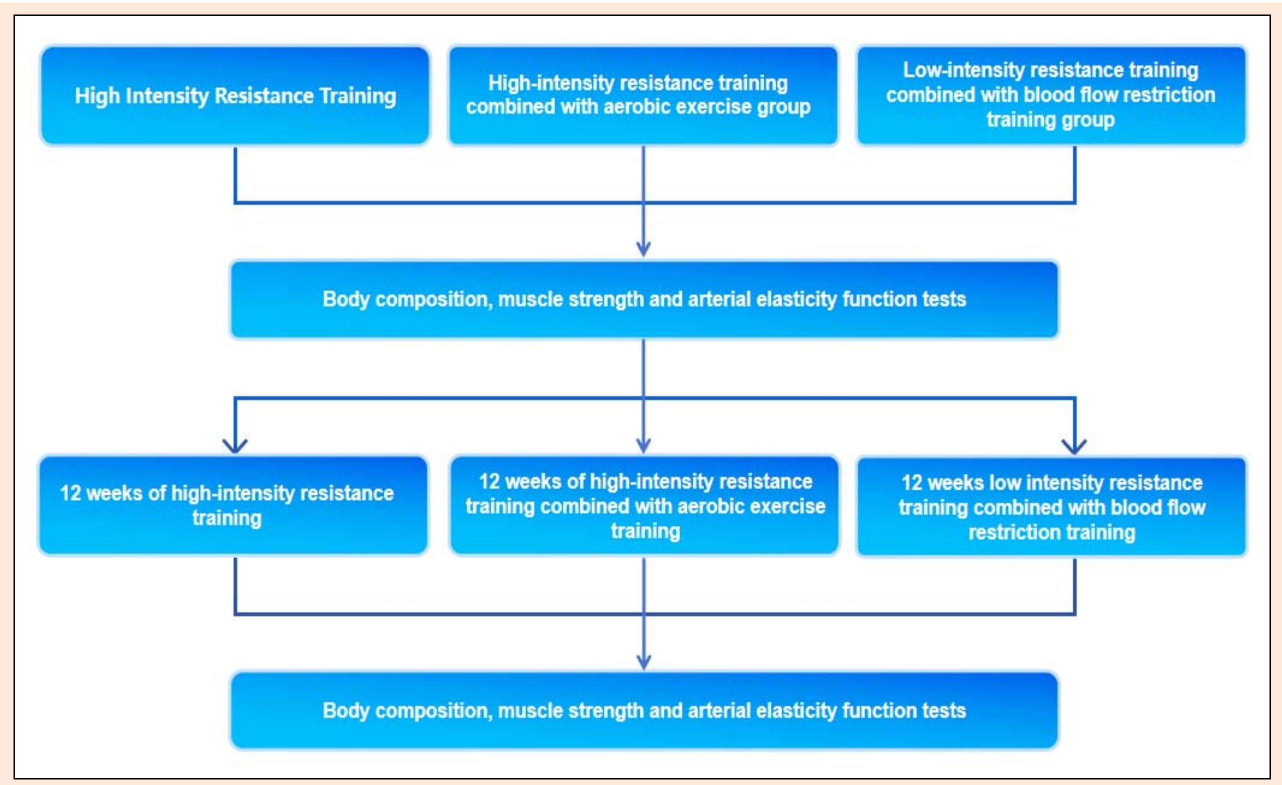

Figure 1. Experimental flowchart.

After the subjects came to the laboratory, they were first collected the basic information and 1RM (Repetition Maximum, RM) test, and then the professional staff introduced the whole test procedure. The study required 12 weeks of HIRT, HIR-AET and LIR-BFRT training, and body composition, 1RM, knee isometric muscle strength and arterial elasticity function tests were performed before and after the training in randomized order, respectively.

Intervention protocol

The metabolic equivalents recommended by ACSM were used to control the training intensity (de Oliveira et al., 2007). Based on the physical activity compilation, we found the corresponding values of high-intensity resistance training and aerobic exercise, and calculated the total metabolic equivalents from 60 min of high-intensity resistance training plus 15 min of aerobic exercise in the HIR-AET group, and then extrapolated the training time of the HIRT group to about 70 min. The specific training programs were as follows:

i) HIRT group: before the intervention, subjects first warmed up by walking on a treadmill for 5 min at a self-selected speed, and then performed high pull-downs, shoulder presses, upward inclined barbell bench presses, leg raises, seated leg curls, and seated leg bends and extensions at 70% of the intensity of 1RM, 3 times per week for about 70 min each time;

ii) HIR-AET group: before the intervention, subjects first warmed up by walking on a treadmill for 5 min at a self-selected speed, then performed high-intensity resistance training for 60 min at 1RM for 70% of the intensity of 1RM. performed 5 min of walking for warm-up, and then performed high pull-down, shoulder press, overhead barbell bench press, leg raises, seated leg curls and seated leg bends and extensions at 70% of the intensity of 1RM, 3 times per week, 4 sets of 4 repetitions of 10 repetitions each for a total of about 60 min, and after the completion of the HIRT training, the subjects performed 15 min of jogging at an intensity of 60% of their peak oxygen uptake;

iii) the LIR-AET group. BFRT group (Harper et al., 2019): before the intervention, subjects first warmed up by walking on a treadmill for 5 min at a self-selected speed, then a compression band was strapped around the subject's upper arms and thighs, and the compression was performed based on 0.5 × diastolic blood pressure + 2 × limb circumference + 5 to set the amount of compression, and after the completion of the compression, they performed a high pull-down, a shoulder push-up, an upward-inclined barbell press, and a leg curl at 30% of their intensity of 1RM, seated leg curl and seated leg flexion, 3 times a week, 4 sets each time, 10 repetitions per set, 3 min intervals for loosening the pressurized band after completion of each set of training.

Body composition test

Based on the principle of bioelectrical impedance, the Inbody 270 (Inbody Systems, Biospace, Korea) was used to collect the body composition data of the subjects, which mainly included body mass, lean body mass, fat mass, and other body composition indicators (Chen et al., 2019).

Knee joint isokinetic muscle strength test

The peak moments of flexion/extension of the knee joint of the dominant leg of the subjects were measured and evaluated using a Biodex isokinetic muscle strength tester (Biodex Medical Systems, Biodex, Inc., USA) at angular velocities of 60°/s and 180°/s. The flexion/extension of the knee joint was repeated 10 times at an angular velocity of 60°/s and 180°/s for each subject. and 30 repetitions of knee flexion/extension at an angular velocity of 180°/s (Coban et al., 2021).

Arterial elasticity function test

The systolic blood pressure, diastolic blood pressure, arm and ankle pulse wave conduction velocity, ankle-arm index, and reflection wave enhancement index were collected before and after the intervention by using a desktop sphygmomanometer (Yuwell, Jiangsu Yueyue Company) and an arterial elasticity function tester (CVProfilor DO-2020, HDI Company, USA), respectively.

Main observational indexes

Body composition before and after the intervention modality was assessed using body mass, lean body mass and fat mass in the three groups; muscle strength before and after the intervention modality was assessed using 1RM of high pull-down, 1RM of shoulder push-up, 1RM of upward-inclined barbell push-up, 1RM of leg raise, 1RM of seated leg curl, 1RM of seated leg flexion, maximal voluntary contraction, and peak knee flexion-extension moments at angular velocities of 60°/s and 180°/s in the three groups. Muscle strength before and after the intervention modality; arterial elasticity function before and after the intervention modality of the three groups was evaluated using systolic blood pressure, diastolic blood pressure, arm and ankle pulse wave conduction velocity, ankle-arm index, and reflection wave enhancement index.

Statistical analysis

The experimental data were statistically analyzed using SPSS 22.0 statistical software, and the data were expressed as mean ± standard deviation. Shapiro-Wilk was used to test the normal distributability of the data. If the data conformed to normal distributability, one-way ANOVA was applied to compare the differences in pre-training body composition, muscle strength and arterial elasticity indexes between groups; if there was no difference in pre-training indexes between groups, two-way Repeated Measures ANOVA was applied to compare the group effects (HIRT HIRT, HIR-AET and LIR-BFRT groups), time effect (pre-training and post-training) and the interaction effect between the two were tested for body composition, muscle strength and arterial elasticity, and if there was a significant difference, post hoc tests were performed using LSD; if there was no difference in pre-training indexes between the groups, Analysis of Covariance (ANCOVA) was performed. ANCOVA) was used to compare the indicators. If the data did not conform to normal distributability, Kruskal-Wallis nonparametric tests were used. The significance level was set at $P < 0.05$.

Results

Effects of different training programs on body composition

As shown in Table 2, lean body mass increased significantly after HIRT (P = 0.000) and LIR-BFRT (P = 0.036) compared to pre-training, whereas no significant differences were seen in the comparison of indicators between groups before and after training.

Effects of different training protocols on 1RM and knee muscle strength

As can be seen in Figure 2, compared with the pre-training period, high pull-down (P = 0.023, P = 0.019, P = 0.044), shoulder press (P = 0.010, P = 0.022, P = 0.029), upward-inclined barbell bench press (P = 0.031, P = 0.028, P = 0.067), leg raises (P = 0.000, P = 0.000, P = 0.014), seated leg bends (P = 0.000, P = 0.000, P = 0.000), and seated leg curls (P = 0.042, P = 0.034, P = 0.047) 1RMs showed varying degrees of increase, while the training No significant differences were seen in the comparison of the indexes between the groups before and after.

As shown in Table 3, compared with the pre-training period, the maximal voluntary contraction (P = 0.046), peak knee extension moment at 180°/s angular velocity (P = 0.011), and knee flexion moment (P = 0.000) were significantly increased after HIRT, the maximal voluntary contraction (P = 0.034), peak knee flexion moment at 180°/s angular velocity (P = 0.023) were significantly increased after LIR-BFRT, and maximal voluntary contraction (P = 0.039), peak knee extension moment at 180°/s angular velocity (P = 0.000), and knee flexion moment (P = 0.020) were significantly increased after LIR-BFRT, whereas no significant differences were seen in the comparison of the indexes between the groups before and after training.

Effects of different training programs on arterial elastic function

As shown in Table 4, compared with the pre-training period, systolic blood pressure (P = 0.032), diastolic blood pressure (P = 0.040) and brachial-ankle PWV (P = 0.017) were significantly decreased after HIR-AET, and brachial-ankle PWV (P = 0.026) was significantly decreased after LIR-BFRT, whereas brachial-ankle PWV after HIRT, although there was no significant difference in the values of However, a numerical increase of 2.45% was observed; systolic blood pressure (P = 0.030) was significantly lower after HIR-AET compared with HIRT; and systolic blood pressure (P = 0.028) was significantly higher after LIR-BFRT compared with HIR-AET.

Table 2. Impact of different training programs on the body composition of subjects (mean ± standard deviation).

Indicators	HIRT group (n = 18)		HIR-AET group (n = 17)		LIR-BFRT group (n = 20)	
	Pre-training	Post-training	Pre-training	Post-training	Pre-training	Post-training
Body Mass	77.69 ± 5.39	75.28 ± 5.33	78.19 ± 4.32	76.75 ± 3.85	75.89 ± 3.23	74.60 ± 4.45
Lean Body Mass	47.50 ± 2.58	50.17 ± 2.91**	52.18 ± 1.94	52.94 ± 2.15	48.84 ± 2.06	51.72 ± 2.33*
Fat mass	24.51 ± 2.48	24.16 ± 2.86	24.04 ± 3.03	23.37 ± 2.67	20.37 ± 1.56	20.65 ± 1.49

*P < 0.05, **P < 0.01 compared to pre-training.

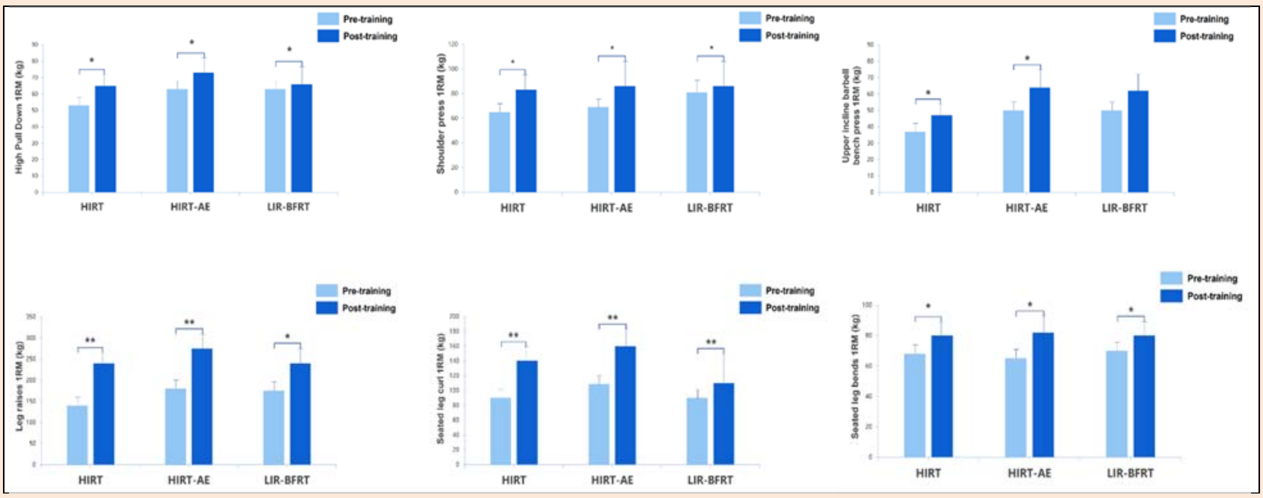

Figure 2. **Impact of different training programs on the 1RM of subjects.** HIRT: High Intensity Resistance Training, HIR-AET: High Intensity Resistance Combined with Aerobic Exercise, LIR-BFRT: Low Intensity Resistance Combined with Blood Flow Restriction Training, RM: Repetition Maximum. *P < 0.05, **P < 0.01 compared to pre-training.

Table 3. Impact of different training programs on the arterial elasticity of subjects (mean ± standard deviation).

Indicators		HIRT group (n=18)		HIR-AET group (n=17)		LIR-BFRT group (n=20)	
		Pre-training	Post-training	Pre-training	Post-training	Pre-training	Post-training
MaxAutCont (Nm)		207.32 ± 41.55	219.67 ± 45.09*	210.90 ± 40.20	227.99 ± 51.62*	198.05 ± 30.80	214.23 ± 35.19*
60°/s	Peak KExtM (Nm)	190.97 ± 37.35	199.23 ± 31.58	202.31 ± 42.88	206.40 ± 39.71	193.83 ± 40.14	195.09 ± 37.97
	Peak KFlexM (Nm)	90.24 ± 22.25	104.16 ± 27.63	110.78 ± 30.82	117.54 ± 34.98	98.78 ± 20.46	108.17 ± 35.45
180°/s	Peak KExtM (Nm)	129.46 ± 25.73	150.54 ± 32.41*	148.64 ± 29.01	159.65 ± 37.22	140.92 ± 29.34	157.63 ± 25.98**
	Peak KFlexM (Nm)	74.23 ± 19.52	96.91 ± 17.97**	84.31 ± 20.16	101.10 ± 23.98*	80.28 ± 18.65	92.34 ± 13.69*

MaxAutCont: Maximum Autonomous Contraction; Peak KExtM: Peak knee extension moment; KFlexM: Peak flexion moment. *P < 0.05, **P < 0.01 compared to pre-training.

Table 4. Impact of different training programs on the Arterial elasticity of subjects (mean ± standard deviation).

Indicators	HIRT group (n = 18)		HIR-AET group (n = 17)		LIR-BFRT group (n = 20)	
	Pre-training	Post-training	Pre-training	Post-training	Pre-training	Post-training
SBP (mmHg)	118.71 ± 7.20	123.84 ± 9.56	123.15 ± 8.14	116.94 ± 10.87*&	124.12 ± 7.43	123.98 ± 8.20#
DBP (mmHg)	66.00 ± 7.24	66.23 ± 7.02	66.43 ± 7.97	60.27 ± 7.03*	69.10 ± 8.20	66.98 ± 7.21
BrAnk PWCV (cm/s)	1101 ± 120	1128 ± 116	1186 ± 122	1114 ± 108*	1104 ± 120	1026 ± 124*
AnkBrIndex	1.20 ± 0.13	1.06 ± 0.09	1.17 ± 0.10	1.06 ± 0.12	1.27 ± 0.18	1.14 ± 0.13
RefWEnh index	77.62 ± 8.72	83.09 ± 10.41	78.64 ± 9.23	75.16 ± 11.52	78.47 ± 10.24	73.64 ± 8.87

SBP: Systolic blood pressure; DBP: Diastolic blood pressure; BrAnk: Brachial and ankle; PWCV: pulse wave conduction velocity; AnkBrIndex: Ankle-Brachial Index; RefWEnh index: Reflected wave enhancement index. * $P < 0.05$ compared to pre-training, & $P < 0.05$ compared to HIRT group, # $P < 0.05$ compared to HIR-AET group.

Discussion

This study aimed to investigate the effects of 12 weeks of LIR-BFRT on body composition, muscle strength and arterial elasticity function in young people, and to provide theoretical support for the scientific implementation of BFRT and the development of individualized training programs. The results of the study showed that: (1) body composition significantly improved after HIRT and LIR-BFRT; (2) 1RM and knee isometric muscle strength significantly increased after HIRT, HIR-AET, and LIR-BFRT; and (3) arterial elasticity function remained better after HIR-AET and LIR-BFRT.

Body composition significantly improved after HIRT and LIR-BFRT. Numerous studies have shown that resistance training is effective in improving body composition by increasing lean body mass or decreasing fat mass (Wang et al., 2024). The results of this study showed a significant increase in lean body mass after HIRT and LIR-BFRT training compared to pre-training, which is consistent with previous studies (Ozaki et al., 2013; Vechin et al., 2015).Vechin investigated the effects of HIRT and LIR-BFRT interventions on lower limb muscle strength and mass, and the results showed that even when BFRT was combined with low-intensity resistance training, both groups of post-intervention significant increases in lower limb muscle strength and mass were also observed, speculating that the increase in muscle strength after the HIRT intervention may be due to the mechanical tension generated in the muscles while performing resistance training, leading to muscle adaptations, which was also demonstrated in a study by Schoenfeld et al. (2010). In contrast, the increase in muscle strength after LIR-BFRT intervention may be caused by exercise-induced metabolic stress in the muscles (Takada et al., 2012). With the accumulation of metabolites, the activation of afferent nerves inhibits the movement of slow muscle fibers, thus forcing the recruitment of fast muscle fibers (Slysz et al., 2016). Since fast muscle fibers are more adaptable to muscle mechanical tension, they are able to produce an increase in muscle mass similar to that seen after HIRT intervention.The results of Farup showed a significant increase in upper limb muscle mass in both the conventional resistance training group and the LIR-BFRT group of subjects after 6 weeks of intervention training (Farup et al., 2015). The results of this study showed that in contrast to HIRT and LIR-BFRT, there was no significant difference in lean body mass after the HIR-AET intervention, which may be due to the phenomenon of inhibition of muscle growth (Docherty and Sporer, 2000). Lundberg showed that simultaneous training in both modalities might have a negative impact on muscle mass, and that this negative impact might be due to a significant increase in adenylate activated protein kinase significantly increased (Lundberg et al., 2022). Adenylate-activated protein kinase has been shown to inhibit mammalian target of rapamycin pathway signaling (Kishton et al., 2016). The activation of adenylate-activated protein kinase is intensity-dependent, and it is activated at an intensity of about 60% of maximal aerobic capacity. The results of this study showed that there was no significant difference in fat mass after HIRT, HIR-AET, and LIR-BFRT compared to the pre-training period, with changes of -1.45%, -2.77%, and 1.37%, respectively.Wewege demonstrated that resistance training reduces fat mass by about 1.4% compared to a no-exercise intervention, which is not consistent with this study's results were inconsistent (Wewege et al., 2022). Although a training duration of 6 - 12 weeks is commonly selected in most experiments (Vechin et al., 2015), the authors speculated that it may be possible that a longer period of training would be required to significantly reduce fat mass in the absence of an intervention diet. In summary, both HIRT and LIR-BFRT at 12 weeks significantly improved body composition, and body composition did not significantly improve after HIR-AET, possibly due to the presence of muscle growth inhibition.

1RM and knee isometric muscle strength increased significantly after HIRT, HIR-AET, and LIR-BFRT. The National Academy of Sports Medicine recommends a lifting intensity of 60-70% of the 1RM to elicit adaptive increases in muscle mass and strength. In contrast, Yasuda showed that BFRT combined with 20% of 1RM intensity can induce an increase in muscle strength, so BFRT may be the preferred training modality for special populations (Yasuda et al., 2011). The results of this study showed that compared with the pre-training period, the 1RM of HIRT, HIR-AET, LIR-BFRT post-high pull-down, shoulder press, upward inclined barbell bench press, leg raises, seated leg bends and seated leg curls increased to varying degrees, but there was not any significant difference between the groups at the same point in time, which is basically in line with the previous studies (García-Rodríguez et al., 2023; Harper et al., 2019). However, it has also been shown that muscle strength was significantly reduced after HIR-AET compared to HIRT (Sillanpää et al., 2009).Wilson speculated that it may be that the addition of aerobic high intensity training to HIRT exceeded the body's tolerance, resulting in a decrease in muscle adaptive capacity (Wilson et al., 2012). It is important to note that this study did not examine the effects of different intensities of BFRT on muscle strength.Ozaki and Yasuda found that both low-intensity BFRT and high-intensity BFRT caused an increase in muscle strength (Ozaki et al., 2013; Yasuda et al., 2011), but a study by Vechin came to the opposite conclusion, that HIRT significantly increased muscle compared to BFRT strength (Vechin et al., 2015). The two results may be due to the frequency of training, duration of training, and cuff stress. The results of this study showed a significant increase in maximal voluntary contraction after all three training interventions, which is consistent with previous findings. Scott found a significant increase in maximal voluntary contraction after BFRT training compared to pre-training (Scott et al., 2016), while Andersen showed a significant increase in maximal voluntary contraction after HIR-AET training (Andersen et al., 2010). All of these results suggest that BFRT elicits similar increases in isometric muscle strength even without isometric training. The results of this study showed a significant increase in lower knee isometric muscle strength at 180°/s, while at 60°/s, although no significant difference was seen, both tended to increase. This is in general agreement with the results of a previous study by Ferrari (Ferrari et al., 2016), which showed that isometric testing has become the gold standard for assessing muscle strength in both clinical and experimental settings, and that both resistance and aerobic training showed varying degrees of increase in isometric strength at both 60°/s and 180°/s velocities. In summary, 12 weeks of HIRT, HIR-AET, and LIR-BFRT all increased muscle strength.

Arterial elastic function was better maintained after HIR-AET and LIR-BFRT. Previous studies have shown that HIRT is associated with an increase in arterial stiffness (Miyachi et al., 2004; Ozaki et al., 2013), but Fahs showed that no significant difference in arterial stiffness was found in subjects after resistance training (Fahs et al., 2012). This study used arm-ankle pulse wave conduction velocity, ankle-arm index and reflection wave augmentation index to reflect arterial elasticity function, which are known as the gold standard for arterial stiffness measurement. The greater the brachial-ankle pulse wave conduction velocity, the poorer the arterial elasticity and the higher the degree of atherosclerosis; the ankle brachial index, which is the ratio of peak ankle arterial systolic blood pressure to peak upper brachiocephalic arterial systolic blood pressure, is clinically used as an indicator for determining the stenosis and blockage of arteries caused by atherosclerosis; the reflected wave augmentation index mainly reflects the augmentation of arterial pressure waves by pressure reflective waves, whose increase suggests the early damage of the arteries, and therefore can be used to predict the occurrence of adverse cardiovascular events (Han et al., 2021). The results of this study showed that compared with the pre-training period, the arm and ankle pulse wave conduction velocities after HIR-AET and LIR-BFRT showed significant decreases of 6.46% and 7.60%, respectively, whereas the arm and ankle pulse wave conduction velocities after HIRT did not show a significant difference, but showed a numerical increase of 2.45%. This suggests that HIR-AET and LIR-BFRT effectively improve arterial elastic function, and LIR-BFRT is more effective for arterial elastic function. Atherosclerosis is a risk factor for hypertension and high prevalence of cardiovascular disease, so reducing arterial stiffness is essential to minimize the prevalence of cardiovascular disease (Fahs et al., 2012). Studies have shown that aerobic exercise significantly reduces arterial stiffness (Kawano et al., 2006). Therefore, most current studies recommend >30 min of aerobic exercise per day at a heart rate reserve of 40% - 60%. In this study, the reduction in brachial-ankle PWV after HIR-AET may be attributed to the 15 min of aerobic exercise performed after HIRT, which effectively improved systolic and diastolic blood pressure after HIRT, which in turn led to the reduction in brachial-ankle PWV (Otsuki et al., 2020). Whereas the absence of significant difference in brachial-ankle PWV before and after HIRT may be due to the fact that the number of HIRTs per week was not sufficient to cause significant changes in arterial stiffness, the same result was obtained in the study by Rakobowchuk (Rakobowchuk et al., 2005). Whereas the number of groups of weekly HIRT was higher in the study that showed a significant increase in arterial stiffness after HIRT, the 12 groups of weekly HIRT performed in that study may not have been sufficient to cause a significant effect on brachial-ankle pulse wave conduction velocity. It is important to note that the 3 groups of ankle-brachial index and reflex wave enhancement index in this study did not show significant differences before and after training. On the one hand, the reason for no significant difference in ankle-brachial index may be that the subjects selected in this study were all healthy young people, and the global consensus defines ankle-brachial index ≤0.9 as the gold standard for atherosclerosis (Litwin et al., 2019); on the other hand, the reason for no significant difference in the reflex-wave augmentation index may be due to the fact that the reflex-wave augmentation index is not only affected by the large arteries, but also by the changes in the elastic function of the small arteries, and therefore it is not the same as the arm-ankle pulse-wave conduction velocity. changes, so it does not have a significant correlation with brachial and ankle pulse wave conduction velocity (Han et al., 2021). However, it is not difficult to see from the results of this study that the trends of brachial-ankle pulse wave conduction velocity and reflection wave enhancement index are basically the same. In conclusion, both 12-week HIR-AET and LIR-BFRT can improve arterial elasticity function, and the effect of LIR-BFRT is better than that of HIR-AET.

The findings of this study can be applied in various practical settings, particularly in rehabilitation programs and optimized exercise training regimens. For instance, low-in LIR-BFRT can be incorporated into post-injury rehabilitation plans to enhance muscle strength and improve arterial elasticity without placing excessive stress on healing tissues. In athletes' training schedules, LIR-BFRT can serve as a supplementary method to boost performance while reducing the risk of cardiovascular complications associated with high-intensity resistance training. For cardiovascular disease patients, LIR-BFRT offers a safer alternative to traditional resistance training, facilitating muscle strengthening without exacerbating arterial stiffness. Moreover, the study highlights the importance of personalized training programs, encouraging practitioners to tailor exercise regimens according to individual health status and goals, thus maximizing the benefits while minimizing potential risks.

Our study has the following limitations. Firstly, the participants in this study were limited to young adults aged 18-35. Future research should expand the age range and sample size for further exploration. Secondly, this study did not consider factors such as participants' diet, sleep, and mental health, which may have had certain impacts on the results of body composition and other outcomes. Future studies should control for potential confounding factors such as diet to exclude their influence on the experimental results. Lastly, although this study controlled the training loads of HIRT and HIR-AET, there might still be differences compared to LIR-BFRT. Future research could precisely control the three intervention methods using methods such as calorie expenditure and maximal oxygen uptake, and conduct in-depth exploration by stratifying training frequencies.

Conclusion

12 weeks of HIRT and LIR-BFRT were effective in improving body composition; 12 weeks of HIRT, HIR-AET, and LIR-BFRT all increased muscle strength; and 12 weeks of HIR-AET and LIR-BFRT all improved arterial elasticity function, and LIR-BFRT was more effective than HIR-AET. Therefore, LIR-BFRT is recommended as the preferred training modality to improve body composition and increase muscle strength to improve arterial elasticity and reduce the risk of atherosclerosis.

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Key points

- Both high-intensity resistance training (HIRT) and low-intensity resistance training combined with blood flow restriction (LIR-BFRT) significantly improved lean body mass after 12 weeks.
- No significant changes were observed in fat mass across the groups, suggesting that the primary impact was on muscle mass rather than fat reduction.
- All three training protocols (HIRT, HIR-AET, and LIR-BFRT) resulted in significant increases in 1RM (one-repetition maximum) and knee isometric muscle strength.
- LIR-BFRT and HIR-AET (high-intensity resistance training combined with aerobic exercise) were more effective in improving arterial elasticity compared to HIRT alone.
- The combination of low-intensity resistance with blood flow restriction provides a safer alternative to high-intensity training in terms of cardiovascular health.

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