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Effect of Blood Flow Restriction Combined with Low Intensity Resistance Exercise on Cardiorespiratory Aerobic Endurance and Exercise Ability in Adolescent Swimmers

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Abstract

Objective: To compare the effects of blood flow-restricted resistance training (BFR-RT) and conventional resistance training on cardiorespiratory function and exercise capacity in adolescent swimmers. Methods: Sixteen adolescent swimmers were randomly assigned to either the BFR-RT group (n=8) or the conventional resistance training (RT) group (n=8). Both groups underwent 8 weeks of exercise intervention, with comparative analysis of body composition parameters, morphological measurements, cardiopulmonary endurance indices, and exercise performance metrics before and after the intervention. Results: After 8 weeks of training, both groups showed significant changes in body composition ($p>0.05$). However, both groups demonstrated marked improvements in lower limb circumference, underwater breath-hold duration, lung capacity, maximum grip strength, 5x10-meter shuttle runs, and 100m freestyle swimming performance ($p<0.05$), though no statistically significant differences between groups were observed. Conclusion: Both BFR-RT and conventional resistance training effectively enhance cardiorespiratory endurance and exercise capacity in adolescent swimmers over 8 weeks, with no significant difference in efficacy. It is recommended that BFR-RT be adopted as the preferred method for developing strength qualities in adolescent swimmers.

Keywords: *Adolescents, Blood Flow Restriction, Cardiopulmonary Function, Resistance Training, Swimming.*

A. Introduction

As competitive swimming places growing demands on athletes' strength and endurance, traditional resistance training often carries a considerable risk of sports-related injuries, particularly among young athletes in critical stages of growth and development (Yu & Ren, 2015). To address these challenges, blood flow restriction (BFR) training has emerged as a novel and promising method. By applying external pressure to partially restrict blood flow in the limbs, BFR enables athletes to achieve physiological adaptations similar to those produced by high-intensity training, but at a much lower load of only 20–40% of one-repetition maximum (1RM) (Lü et al., 2023). This makes BFR training a safer and more efficient option for adolescents, offering a protective alternative during periods of musculoskeletal vulnerability.

A growing body of evidence indicates that BFR training stimulates anabolic hormonal responses through metabolic stress, including elevated secretion of growth hormone and insulin-like growth factors, which play crucial roles in muscle hypertrophy and repair (Yinghao et al., 2021). Beyond muscular adaptations, the ischemia–reperfusion effects unique to BFR exercise

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have been shown to enhance vascular endothelial function and overall cardiovascular health (Zhao et al., 2021). These findings highlight not only the muscular benefits of BFR but also its systemic advantages, making it highly relevant to sports such as swimming, where both strength and cardiopulmonary efficiency are essential.

Within the specific context of swimming, the integration of BFR training presents dual mechanisms of benefit. On the one hand, it can activate synergistic recruitment of muscle fiber types, thereby improving explosive power crucial for short-distance events. On the other hand, the hypoxic conditions induced by BFR improve microcirculation and oxygen utilization, supporting endurance in long-distance swimming (Wang et al., 2023). The relatively low mechanical load associated with BFR is particularly advantageous for adolescent athletes, as it reduces the risks of growth plate and joint injuries, which are prevalent concerns in traditional high-load resistance training. This dual pathway of muscular and cardiopulmonary enhancement underscores BFR's potential role in designing safe yet effective youth athletic development programs.

In light of these insights, the present study aims to systematically evaluate the effects of an eight-week program of BFR combined with low-intensity resistance training on cardiopulmonary endurance and swimming performance in adolescent athletes. By providing empirical evidence on the efficacy and safety of BFR in this population, the study seeks to contribute to the development of scientific training methods that enhance performance while minimizing injury risks. Ultimately, this research aspires to support coaches, sports scientists, and healthcare professionals in adopting evidence-based approaches for optimizing adolescent swimmers' training programs.

B. Methods

The present study recruited sixteen adolescent swimmers aged 10–13 years from Baoding City who had not previously engaged in weighted resistance training. Before commencing the experiment, all participants underwent thorough health and exercise risk assessments using a standardized health questionnaire. After receiving a full explanation of the trial protocol, participants voluntarily signed informed consent forms, which were also approved by their respective swimming coaches. To ensure objectivity, the subjects were randomly assigned using a digital method into two groups: the Blood Flow Restriction Combined Resistance Training (BFR-RT, n = 8) and the Traditional Resistance Training (RT, n = 8). Their baseline demographic characteristics, including age, years of training, stature, weight, and BMI, showed no significant differences between groups, thereby ensuring comparability.

Table 1. Basic Characteristics of Subjects Included

Variable	BFR-RT group (n=8)	RT (n=8)	*t*	*p*
Age (years)	16.19±0.79	16.04±0.77	0.916	0.362
Years of training	2.33±3.00	2.14±2.54	0.132	0.895
Stature （Cm）	160.37±6.47	161.37±5.18	0.211	0.733
Weight （Kg）	51.58±11.64	51.84±11.22	-0.113	0.902
BMI（kg/m2）	20.80±3.57	20.83±3.79	-0.038	0.969

The experimental design involved an intervention period of eight weeks, during which both groups trained three times per week on non-consecutive days (Monday, Wednesday, and Friday).

Pre- and post-intervention assessments were conducted to measure participants' cardiopulmonary function and physical exercise capacity. This design allowed the study to systematically examine the effectiveness of BFR combined with low-intensity resistance training compared to traditional high-intensity resistance training, particularly in the context of adolescent swimmers whose physiological development remains ongoing.

Prior to the formal intervention, exercise intensity for both groups was determined using the one-repetition maximum (1RM) method. Since direct 1RM testing can impose high physiological stress and safety risks in young athletes, this study applied an established calculation formula (1RM = [1 + (0.0333 × maximum repetitions) × load weight]) to estimate individual values. The testing process was supervised by three professionals, ensuring that all participants demonstrated correct squat techniques and understood exercise execution. A certified instructor further provided guidance to ensure safe use of weight equipment and correct adjustment of resistance settings, thereby minimizing injury risks.

Table 2. Training Programs for Each Group

Group	Exercise Intensity	Training Content	Training Load	Pressure Of Compression
BFR-RT	30%1RM	squatting with weight Negative weighted lunges Dumbbell Bulgarian squats	Perform each exercise 4 times, 8 to 12 times per set, with a 3-minute rest between sets	Tension: 40 mmHg Inflation pressure: 180 mmHg
RT	70%1RM	squatting with weight Weighted lunges Dumbbell Bulgarian squats	Perform each exercise 4 times, 8 to 12 times per set, with a 3-minute rest between sets	not have

The intervention program differed between the two groups. Participants in the BFR-RT group performed resistance training while wearing a pressure band applied to the upper-middle thigh. The band, 5 cm wide with a tension of 40 mmHg and inflation pressure of 180 mmHg, was selected based on Scott et al. (2015) to balance effectiveness and safety. Training intensity was set at 30% of estimated 1RM, performed across four sets: one initial set of 30 repetitions followed by three sets of 15 repetitions, with 60-second rest intervals. In contrast, the RT group performed traditional high-intensity training at 70% 1RM, with four sets of 8–12 repetitions per set and three-minute rest intervals. Both groups performed the same exercises, including weighted squats, lunges, and dumbbell Bulgarian squats, allowing a direct comparison of outcomes between different resistance modalities.

To capture the multidimensional effects of the intervention, several measurement indicators were employed. Body composition was assessed using the InBody370 analyzer, while thigh circumference was measured with a tape measure under standardized conditions. Additionally, lung capacity was evaluated using a high-precision spirometer, and underwater breath-holding time was measured with a stopwatch to reflect aquatic-specific adaptations. Physical performance indicators included a 400 m sprint, a 100 m freestyle swimming test, a 5 × 10 m shuttle run, and maximum grip strength, all administered under strict protocol control to ensure reliability and validity.

Performance assessments were carefully standardized. The underwater breath-holding test was conducted twice for each subject, with averages recorded to minimize measurement error. Lung function testing followed spirometry guidelines, requiring participants to inhale maximally before exhaling forcefully into the device. Similarly, sprint and shuttle run performances were timed by multiple evaluators to ensure accuracy. Swimming performance in the 100 m freestyle was divided into the first and last 50 m segments to provide insights into speed endurance. The inclusion of both land-based and swimming-specific tests enabled a holistic evaluation of the effects of BFR versus traditional resistance training on adolescent athletes' functional capacity.

For statistical analysis, SPSS 27.0 and GraphPad Prism 8.2.1 were utilized. Data were expressed as mean ± standard deviation, and normality was verified using the Shapiro–Wilk test. Since the data met normality assumptions, paired sample t-tests were employed to analyze intra-group differences before and after intervention, while independent sample t-tests were used to evaluate inter-group differences. Statistical significance was set at $p < 0.05$. This rigorous approach ensured that observed changes could be attributed with confidence to the training interventions rather than to random variation or measurement error.

C. Results and Discussion

1. Changes of body composition and morphological indexes of two groups of subjects before and after the experiment

Results (Table 1) showed that after 8 weeks of experimental intervention, compared with the pre-experiment, there was no significant change in weight and BMI of the two groups of subjects (p>0.05), but in the lower limb circumference of the two groups of subjects, the lower limb circumference was significantly increased (p<0.05), but there was no significant inter-group difference (p>0.05).

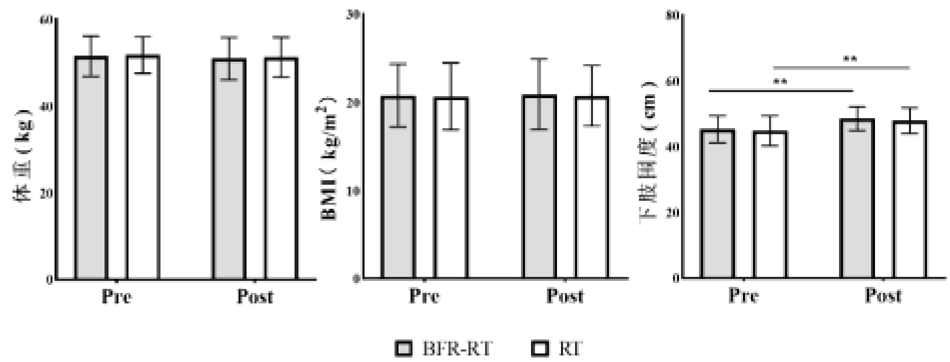

Figure 1. Changes of body composition and lower limb dimensions in two groups of subjects before and after the experiment

2. Changes in cardiopulmonary aerobic endurance in two groups of subjects before and after the experiment

Results (Figure 2) showed that compared with the pre-experiment, the 8-week experimental intervention significantly improved the underwater breath-holding time, lung capacity, and 400m running performance of the two groups of subjects (p <0.05), but there was no significant inter-group difference (p> 0.05).

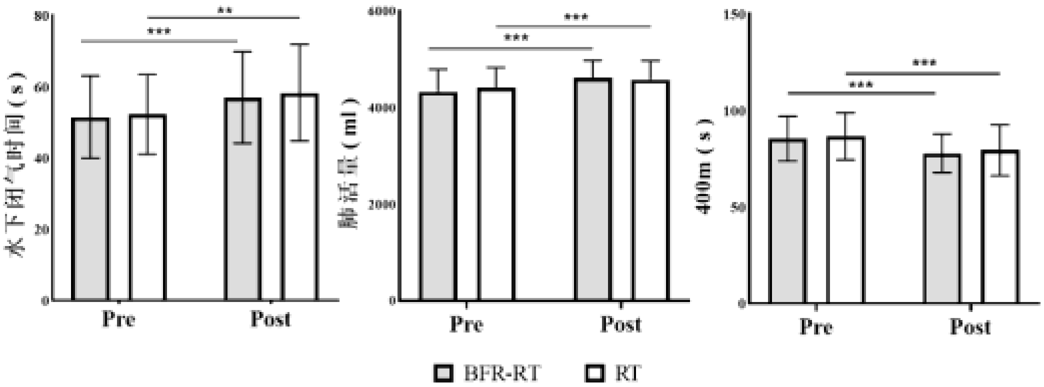

Figure 2. Changes in cardiopulmonary endurance in two groups of subjects before and after the experiment

3. Changes in exercise ability in two groups of subjects before and after the experiment

Results (Figure 3) showed that compared with the pre-experiment, the 8-week experimental intervention significantly improved the maximum grip strength, 5×10m shuttle run and 100m freestyle swimming performance of the two groups of subjects ($p<0.05$), but there was no significant inter-group difference ($p>0.05$).

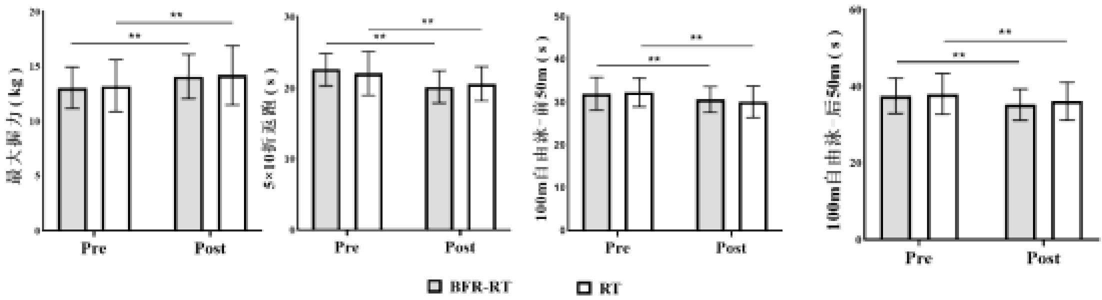

Figure 2. Changes of cardiopulmonary endurance in two groups of subjects before and after the experiment

Strength is often described as the “mother of all sports,” as it provides the foundational capacity upon which athletic performance is built. For young athletes, developing strength qualities is crucial to both physical performance and long-term athletic potential. However, traditional resistance training can present challenges for adolescents due to their unique physiological development characteristics. Excessive or improperly applied loads may negatively impact both physical and psychological growth, as well as compromise athletic longevity (Tian, 2015). To address these concerns, this study designed an eight-week intervention examining the effects of blood flow restriction combined with low-intensity resistance training (BFR-RT) compared with traditional resistance training (RT) among adolescent swimmers. By analyzing the impact of these training methods on cardiorespiratory function and athletic performance, the study aimed to identify safe and effective approaches for strength development in youth athletes.

The study recruited 16 adolescent swimmers, with no significant baseline differences observed between groups prior to intervention, which established internal validity for subsequent comparisons. Throughout the trial period, both groups maintained stable body weight and BMI levels, consistent with their 1–3 years of training history. This suggested that body composition remained largely unaffected by either training protocol. Nevertheless, both groups showed statistically significant increases in lower limb circumference ($p < 0.05$), consistent with well-documented effects of resistance training on muscle hypertrophy. This adaptation occurs as resistance exercise induces micro-damage to muscle fibers, activating satellite cells that repair and regenerate myofibrils (Davids et al., 2023). Concurrently, hormonal responses such as elevated testosterone and growth hormone secretion further accelerate tissue recovery and muscle growth (Luebbers et al., 2024). These outcomes demonstrate that BFR-RT, despite reduced external load, can induce comparable muscle development to traditional RT.

Cardiopulmonary endurance was assessed through three key indicators: underwater breath-hold duration, lung capacity, and 400-meter sprint performance. Each metric provides complementary insights into respiratory and cardiovascular efficiency. Lung capacity reflects oxygen reserve capability, while underwater breath-hold duration indicates tolerance to hypoxia and efficiency of stored oxygen utilization. The 400-meter sprint measures muscular endurance and oxygen uptake, providing a practical evaluation of cardiorespiratory endurance under high metabolic demand (Vinetti et al., 2025). Following the intervention, both groups demonstrated significant improvements in these three indicators, confirming that eight weeks of resistance-based training effectively enhances cardiopulmonary function. These findings are consistent with prior research indicating that resistance training strengthens respiratory muscles, such as the diaphragm and intercostals, thereby increasing lung oxygen reserves (Manifield et al., 2021).

Physiological mechanisms underlying these improvements extend beyond muscular adaptations. Resistance training exerts strong activation effects on the cardiovascular system, particularly vascular endothelial function. This response involves stimulation of the AMPK–PGC-1α signaling pathway, which promotes mitochondrial biogenesis and enhances oxidative metabolism (Mozaffaritabar et al., 2024). Such adaptations improve oxygen uptake, transport, and utilization capacity during exercise. Importantly, this study found no statistically significant differences between BFR-RT and RT groups regarding cardiopulmonary improvements, suggesting that low-load BFR training achieves effects comparable to high-intensity RT. This equivalence highlights BFR-RT's potential as a safer training modality for adolescents while maintaining effectiveness.

Beyond cardiopulmonary endurance, the study also assessed general physical performance, including grip strength, shuttle run performance, and 100 m freestyle swimming times. Both groups demonstrated significant improvements across these indicators ($p < 0.05$), reflecting enhancements in muscular strength, anaerobic endurance, and sport-specific performance. These findings align with earlier reports demonstrating the capacity of BFR to induce localized hypoxia, thereby activating hypoxia-inducible factor (HIF-1α) and the mTOR pathway (Jung et al., 2021). This physiological cascade promotes oxygen efficiency, erythropoietin secretion, and improved blood oxygen-carrying capacity (Nijholt et al., 2021). Together, these mechanisms contribute to sustained energy output and performance improvements in high-intensity swimming efforts.

Overall, the findings validate that both training approaches effectively enhance cardiovascular endurance, general fitness, and swimming-specific performance among adolescent athletes. However, the equivalence of outcomes between groups despite differences in load intensity carries critical implications for training design. By demonstrating that BFR-RT induces similar adaptations to RT, the study highlights its potential role in reducing mechanical stress and injury risks without sacrificing performance outcomes (Scott et al., 2015; Wang et al., 2023). This is particularly valuable for adolescent athletes whose skeletal structures and growth plates remain under development, making them vulnerable to overuse or load-related injuries.

In conclusion, the integration of blood flow restriction into resistance training provides a scientifically grounded, safe, and effective alternative for adolescent swimmers. BFR-RT achieves comparable improvements to traditional RT in terms of muscular development, cardiopulmonary endurance, and performance enhancement, while requiring significantly lower external loads. By mitigating the risks associated with high-intensity training, BFR-RT offers a practical and protective strategy for youth strength development. For coaches and sports scientists, these findings underscore the importance of adopting innovative methods that align with athletes' developmental needs, ensuring both immediate performance gains and long-term athletic sustainability.

D. Conclusion

The findings of this study demonstrate that both eight weeks of blood flow restriction combined with resistance training (BFR-RT) and traditional resistance training (RT) significantly improved the cardiorespiratory endurance and exercise performance of adolescent swimmers. Improvements were observed across key indicators such as lung capacity, underwater breath-hold duration, 400-meter sprint performance, as well as measures of strength and swimming-specific performance. Importantly, no significant difference in training outcomes was found between the two groups, suggesting that BFR-RT can provide physiological and performance benefits comparable to conventional resistance training, despite its lower mechanical load.

Given these results, BFR-RT represents a safe and effective alternative training method for adolescent athletes. Its ability to reduce training intensity without compromising outcomes makes it particularly suitable for young swimmers undergoing critical phases of growth and development. By minimizing the risk of injury while still enhancing strength and endurance, BFR-RT offers coaches and trainers a valuable strategy to optimize athletic performance and ensure long-term physical development. Thus, BFR-RT can be recommended as a reliable option for strength development and performance enhancement in adolescent swimmers.

References

Davids, C. J., Roberts, L. A., Bjørnsen, T., et al. (2023). Where does blood flow restriction fit in the toolbox of athletic development? A narrative review of the proposed mechanisms and potential applications. Sports Medicine, 53(11), 2077–2093. https://doi.org/10.1007/s40279-023-01986-2

Jung, W. S., Kim, S. W., Kim, J. W., et al. (2021). Resistance training in hypoxia as a new therapeutic modality for sarcopenia—A narrative review. Life, 11(2), 106. https://doi.org/10.3390/life11020106

Lü, M., Wang, D., Li, M., et al. (2023). An empirical study on the effectiveness of integrated training for lower limb functional strength and blood flow restriction in male football players. China Sports Science and Technology, 59(10), 22–29.

Luebbers, P. E., Kriley, L. M., Eserhaut, D. A., et al. (2024). Salivary testosterone and cortisol responses to seven weeks of practical blood flow restriction training in collegiate American football players. Frontiers in Physiology, 15, 1507445. https://doi.org/10.3389/fphys.2024.1507445

Manifield, J., Winnard, A., Hume, E., et al. (2021). Inspiratory muscle training for improving inspiratory muscle strength and functional capacity in older adults: A systematic review and meta-analysis. Age and Ageing, 50(3), 716–724. https://doi.org/10.1093/ageing/afab011

Mozaffaritabar, S., Koltai, E., Zhou, L., et al. (2024). PGC-1α activation boosts exercise-dependent cellular response in the skeletal muscle. Journal of Physiology and Biochemistry, 80(2), 329–335. https://doi.org/10.1007/s13105-024-01038-0

Nijholt, K. T., Meems, L. M. G., Ruifrok, W. P. T., et al. (2021). Erythropoietin receptor expression in skeletal muscle is essential for mitochondrial biogenesis and physiological exercise. Pflügers Archiv: European Journal of Physiology, 473(8), 1301–1313. https://doi.org/10.1007/s00424-021-02561-1

Scott, B. R., Loenneke, J. P., Slattery, K. M., et al. (2015). Exercise with blood flow restriction: An updated evidence-based approach for enhanced muscular development. Sports Medicine, 45(3), 313–325. https://doi.org/10.1007/s40279-015-0288-1

Tian, B. (2015). Research on athletic performance and physical fitness of rural youth in Shandong Province. Journal of Sports Culture, (12), 49–52.

VinettI, G., Taboni, A., Fagoni, N., et al. (2025). Energetics of underwater swimming in apnea. Medicine and Science in Sports and Exercise. Advance online publication. https://doi.org/10.1249/MSS.0000000000003517

Wang, Z., Atakan, M. M., Acar, B., et al. (2023). Effects of 4-week low-load resistance training with blood flow restriction on muscle strength and left ventricular function in young swimmers: A pilot randomized trial. Journal of Human Kinetics, 87, 63–76. https://doi.org/10.5114/jhk/167740

Ye, J., Zhang, X., Hu, F., et al. (2017). Exercise intensity monitoring in personalized health management. Journal of Chinese Health Management, 3(03), 265–268.

Yinghao, L., Jing, Y., Yongqi, W., et al. (2021). Effects of a blood flow restriction exercise under different pressures on testosterone, growth hormone, and insulin-like growth factor levels. The Journal of International Medical Research, 49(9), 3000605211039564. https://doi.org/10.1177/03000605211039564

Yu, H., & Ren, Y. (2015). Youth strength training: Mechanisms, methods and trends. Sports Science, 35(08), 76–85.

Zhao, Y., Lin, A., & Jiao, L. (2021). Eight weeks of resistance training with blood flow restriction improve cardiac function and vascular endothelial function in healthy young Asian males. International Health, 13(5), 471–479. https://doi.org/10.1093/inthealth/ihaa098