EFFECTS OF LOW INTENSITY RESISTANCE TRAINING WITH BLOOD FLOW RESTRICTION ON ARTERIAL COMPLIANCE AND STIFFNESS INDEX: A NARRATIVE REVIEW

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Abstract

The popularity of resistance training has reached new heights in today's sporting society. It's a well-established and effective practice among various practitioners, including sports scientists, coaches, and medical professionals. Among the available techniques, low-intensity resistance training with blood flow restriction (BFR) is particularly popular, as it offers an alternative to the traditional high-intensity approach. With its many advantages, such as not requiring high-intensity, BFR has picked the interest of practitioners seeking new training methods. This narrative review aimed 1) to increase awareness about the vascular physiological response to BFR training, 2) to compare the effects of training in term of arterial compliance and stiffness between traditional moderate-to-high-intensity resistance training and low-intensity resistance training with BFR from previous studies. Specifically, it examines whether low-intensity resistance training with blood flow restriction produced different vascular function responses, and 3) to provide information for decision-making regarding the use of BFR for individuals who are interested in practicing. The reviewed data was gathered from the previous controlled trial studies based on the literature search in PubMed. The findings indicated a noticeable change in arterial compliance and stiffness subsequent to periods of resistance training using a low-intensity approach with BFR protocol. However, this change was observed to differ from the effects commonly observed in traditional resistance training involving moderate-to-high-intensity protocols. The comparative review provided the insight that arterial compliance was either improved or maintained followed the training protocol of low-intensity resistance training with BFR while high-intensity resistance training could potentially increase arterial stiffness after training instead. Practitioners of low-intensity resistance training with BFR should consider using low training volume (e.g. not train to failure) and low-intensity (e.g. 30 - 50%1RM) as a safe training alternative of high-intensity resistance training regardless of the age of trainee.

Keywords: Blood flow restriction, Arterial compliance, Arterial Stiffness

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Introduction

Since its introduction in the late 1990s (Wortman, Fahs, Rossow & Loenneke, 2021), the **Blood Flow Restriction (BFR)** technique has become overwhelmingly popular. Numerous resistance training (RT) studies have utilized its benefits, allowing low-intensity (30 – 50 % 1RM) training for a variety of purposes, including athletic performance (Wortman et al., 2021), rehabilitation (Killinger, Zaleski, Ebben & Brown, 2019), muscular strength (Lopes, Libardi, Tomeleri, Cavaglieri, Deminice & Damas, 2022), and particularly, as of interest in this study, muscular hypertrophy (May, Carey, Lovalekar & Gerhart, 2022). However, regardless of the application purpose, whether using clinical pneumatic cuffs or practical elastic wraps, BFR equipment must be applied tightly enough to partially restrict arterial inflow and successfully occlude venous outflow (Rolnick & Schoenfeld, 2020). As a result, concerns about physiological responses and risks from BFR application, particularly central cardiovascular responses and vascular functions, have been raised.

In a review of previous studies, researchers conducted a national survey in Japan on the use of **BFR** technique in over 105 facilities where BFR training had been adopted for more than five years (Nakajima, Kurano, Iida, Takano & Oonuma, 2006). They found that at that time 12,642 people, 45.4% male and 54.6% female, had utilized BFR training, and the incidence of **cardiovascular side effects** was surprisingly low with reported side effects of venous thrombus, pulmonary embolism, and rhabdomyolysis at only 0.055%, 0.008%, and 0.008%, respectively (Nakajima et al., 2006). Moreover, in most of the facilities, subjects had done the BFR technique for around 5 - 30 minutes each time. The safety of the application of BFR was not only a concern for normal, healthy adult populations, but also for older populations. In a recent updated meta - analysis that included 12 BFR studies in participants aged over 50 years of any gender for a total of 378 subjects, they found that **low-intensity (20 – 45 % 1RM)** RT with BFR did not result in higher acute hemodynamic responses such as heart rate and blood pressure than **high - intensity RT (> 65 % 1RM)** in this population (Zhang, Chen, Tan, Zhou & Lai, 2022).

However, despite some promising studies suggesting that low-intensity RT with BFR was safe, it was crucial for practitioners and researchers to fully understand the effects of its application. The primary objective of this narrative review aimed to comprehensively examine the potential safety concerns of BFR low-intensity RT, emphasizing the importance of practitioners being fully aware of the vascular function responses, focusing on previous studies measuring arterial compliance and stiffness.

Materials and methods

The present manuscript reviewed the current body of evidence that examined the effect of low-intensity resistance training with blood flow restriction on arterial compliance and arterial stiffness index. The search for articles was carried out using the databases – Pubmed and GoogleSE. The descriptors used as search term were: “Resistance training” OR “Weight training” AND “Blood flow restriction” OR “BFR” AND “Arterial compliance” OR “Arterial stiffness”. Only ten articles that had involved measuring arterial compliance and stiffness as a result of resistance training were selected.

Arterial compliance and stiffness

By definitions, the arterial compliance is a biomechanical characteristic of the arterial wall that measures its ability to expand and increase in volume (Papaioannou, Karatzis, Stamatelopoulos & Zampelas, 2014), while the arterial stiffness refers to the rigidity of the arterial wall (Cheung, et al., 2010). Several studies have demonstrated that arterial compliance decreases with age, including one that found a significant age - related increase in central arterial stiffness among sedentary healthy females (Tanaka, Dinenno. Monahan, Clevenger, DeSouza & Seals, 1998). Moreover, over past 30 years, multiple studies have proposed that the increase in arterial stiffness or decrease in arterial compliance can be potential risk factors for cardiovascular disease (Arnett, Evans, Riley & Barnes, 1994; Hodes, Lakatta, McNeil, & Jinagouda, 1995; Mattace - Raso et al., 2006).

Considering the application of BFR, numerous studies have investigated its effects on training, arterial compliance, and stiffness. Early research studied the impact of BFR RT on arterial compliance (Kim, Kim, Koo & Kang, 2009), with a group of 30 healthy men aged between 18 - 35 participating in the experiment. The training groups included low-intensity BFR RT 20%1RM, high - intensity RT 80%1RM, and BFR only with no training, with both training groups exercising around 20 - 30 minutes per day, three days a week, for three weeks. The exercises consisted of 2 sets of 10 reps of leg press, knee extension, and knee flexion. While the percent changes in arterial compliance and cardiovascular variables after training were not significantly different among the groups, the in - depth analysis revealed that BFR RT increased the large arterial compliance index by an average of 17.9%, while the traditional high load RT showed a slight increase of only 1.4%. Conversely, the BFR RT group showed an increase of 1.4% in small arterial compliance index, while the traditional high load RT group experienced a decrease of 6.41 % (Kim et al., 2009). Previous studies also found that high - intensity RT could reduce arterial compliance after training, such as Miyachi, Donato, Yamamoto, Takahashi and Gates (2004) and Collier et al. (2008). However, Kim et al. (2009) concluded in their study that both large and small arterial compliance were not significantly negatively affected by either BFR or traditional high-intensity RT based on statistical difference. Another study by Tagawa, Ikegawa, Kamijo and Fujita (2018) demonstrated that high - load 75%1RM RT for 5 sets of 10 repetitions, 3 times per week, significantly decreased arterial compliance measured by carotid artery echography by around 13 % after 4 weeks of biceps curl due to the increase in local vasoconstrictive peptide, Endothelia - 1 (ET - 1) around the vessels, which could contribute to the increase in arterial stiffness in the long term.

Until now, two meta-analyses have been mostly cited regarding the effect of RT (RT) on arterial stiffness in healthy individuals (Miyachi, 2013; Ceciliato et al., 2020). The first meta - analysis consisted of eight randomized controlled trials involving 193 subjects, and the results showed that high-intensity RT was significantly associated with an 11.6 % increase in stiffness (Miyachi, 2013). It's worth noting that the high-intensity RT in this study had a cut - off point of intensity at around 80 %, and thus cannot be generalized to lower intensity or BFR RT, since no association was found between an increase in stiffness and moderate intensity in this study. A recent meta - analysis was conducted on the effect of RT on arterial stiffness (Ceciliato et al., 2020).

The study included 10 trials with 310 subjects, and the results showed that RT did not affect arterial stiffness in healthy subjects. However, it's important to mention that the data used in this study included various RT intensities ranging from 20 % to 90 % 1RM, and they were not stratified by intensity when analyzed, as in the previous meta-analysis (Miyachi et al., 2013). Consequently, the researchers reported very high heterogeneity of the data (I2 = 91%; $p < 0.01$) (Ceciliato et al., 2020). Therefore, the results should be interpreted with caution, and it cannot be concluded that RT does not affect vascular function.

In a study conducted by Fahs, Heffernan, Ranadive, Wiksten, Henning and Fernhall (2011), the acute vascular responses to RT at different training intensities were examined in 11 young male subjects with an average age of 25 years. This study was the first of its kind to investigate the acute effect of BFR on RT. The study utilized a randomized cross - over design and the RT regimens included high-intensity at 70%1RM for 3 sets of 10 repetitions, low-intensity with and without BFR at 20%1RM for 1 set of 30 repetitions and 3 sets of 15 repetitions. The total time for each session was around 18 minutes for 4 exercises. The results showed no significant difference in systolic and diastolic blood pressure from pre-training to 15 - and 45 - minutes post - training. However, the large artery elasticity index increased at 15 minutes post - training and returned to baseline after 45 minutes post - training in all groups. The researcher concluded that both traditional high and low load, either with or without BFR, resulted in similar acute post-exercise increases in large arterial compliance.

It's noteworthy that the acute increase in arterial compliance from high - intensity training in Fahs' study (2011) was in contrast with previous studies (Miyachi et al., 2004; Tagawa et al., 2018) that showed traditional high - load RT reduced arterial compliance in chronic adaptation, highlighting the importance of considering the time course of measurement when investigating arterial compliance. A year later, Fahs, Rossow, Seo, Loenneke, Sherk, Kim and Bemben (2012) compared the vascular response effects of low - load BFR, moderate load, high load RT, and a control group using a randomized controlled trial design. The study included 41 healthy young men with an average age of 21 years who performed knee extension and knee flexion exercises 3 times per week for 6 weeks. The high load group performed 3 sets of 10 repetitions at 70%1RM, the moderate load group performed 3 sets of 15 repetitions at 45%1RM, and the low load BFR group performed 1 set of 30 repetitions and 3 sets of 15 repetitions at 30%1RM. The results showed no significant difference from pre to post in large artery elasticity index and small artery elasticity index in all groups. The researcher concluded that when measured in the chronic state, none of the RT regimens in this study negatively affected arterial compliance.

Later, Yasuda, Fukumura, Fukuda, Iida, Imuta, Sato and Nakajima (2014) conducted a study to investigate the impact of RT with BFR on arterial stiffness in older adults, as this population had not been previously examined. The study recruited 21 healthy participants, aged 61 - 84 years, to perform leg press and knee extension exercises using BFR at 20 – 30 % of their one-repetition maximum (1RM) for 4 sets of 75 repetitions with 30 seconds rest between sets, twice per week. The results indicated that arterial stiffness remained stable (90 to 91 m /

sec) in these participants after 12 weeks of training. Yasuda's findings were similar to those found in younger participants, with arterial compliance likely to be maintained or unaffected when training at low-intensity with BFR. Similarly, further study by Ozaki, Loenneke, Thiebaud, Abe and Bemben (2013) investigating the effects of both high and low-intensity BFR RT in 19 young men. Participants performed flat bench press exercises at 75%1RM for 3 sets of 10 repetitions and at 30%1RM for 4 sets of 75 repetitions, respectively, three times per week for six weeks. The results showed no change in resting carotid systolic arterial pressure or brachial systolic arterial pressure in either group from pre to post. However, carotid arterial compliance significantly decreased in the high-intensity group training at 75%1RM (from 0.14 to 0.11 mm^2 / mmHg), while it slightly increased in the low-intensity BFR RT group at 30%1RM (from 0.15 to 0.17 mm^2 / mmHg). The study suggests that the decrease in central arterial compliance was associated with elevations of systolic arterial pressure during the training session, with systolic arterial pressure reaching over 188mmHg in the high-intensity RT group while just 160 mmHg in the low-intensity BFR RT group. Therefore, irrespective of age, the magnitude of changes in blood pressure responses during a workout may be the true influencing factor for RT-induced decreases in arterial compliance, as increases in systolic blood pressure up to 190 mmHg during an exercise session may produce an unfavorable effect on arterial compliance in the high-intensity group.

A more recent study conducted by Yan et al. (2018) investigated the potential benefits of low-intensity RT on arterial compliance in a cohort of 24 healthy men. The participants underwent training sessions consisting of 5 bouts of 1 minute of elbow flexion exercise at 30%1RM with BFR, 5 times per week. Results revealed a significant chronic adaptation of increased aortic arterial compliance ($p < 0.05$) and a decrease in systolic blood pressure at rest after 8 weeks of training. BFR RT also showed a positive influence on cardiac pump function, resulting in an increase in ejection fraction, fractional shortening, and stroke volume. In another study, 11 middle - aged men and 5 women aged 40 - 64 years participated in a 6-week low - intensity knee extension exercise intervention to investigate the effect on calf venous compliance (Fahs et al., 2014). Each limb was subjected to a different condition, with one limb being occluded with a restriction cuff and the other free-flow. Despite differences in total training volume (BFR 8,429 kg vs. free - flow 13,171 kg), both groups showed no significant

Table 1. Effect of blood flow restriction resistance training on arterial compliance and stiffness

Study	Duration	Subject	Intensity	Training intervention	Exercise	Primary outcome
Kim et al., 2009	3 weeks	30 Healthy men	20%1RM 80%1RM	Low-intensity BFR RT High-intensity RT	Leg press Knee extension Knee flexion	Large arterial compliance index increased 17.9% in BFR Low-intensity BFR RT, 1.4% in High-intensity Small arterial compliance index increased 1.4 % in BFR Low-intensity BFR RT, decreased 6.4% in High-intensity
Miyachi et al., 2004	16 weeks	28 healthy men	80%1RM	High-intensity RT	Leg extension Seated chest pressLeg curls Lateral row Squat Sit - ups	Central arterial compliance decreased 19% Arterial stiffness increased 21%
Collier et al., 2008	4 weeks	30 pre - hypertensive men and women	65%1RM	High-intensity RT	Leg press Chest press Leg extension Lat pulldown Leg curls Shoulder press Bicep curl and triceps press Abdominal crunch	Central arterial stiffness increased 14.5% Peripheral muscular arterial stiffness increased 8.7%
Tagawa et al., 2018	4 weeks	14 healthy men	75%1RM	High-intensity RT	Biceps curl	The carotid arterial compliance decreased by 13%
Fahs et al., 2011	Acute effect	11 young healthy men	20%1RM 20%1RM 70%1RM	Low-intensity BFR RT Low-intensity RT High-intensity RT	Supine leg press Seated knee flexion Seated knee extension Seated plantar flexion	Both traditional high load and low load either with or without BFR resulted in similar acute post - exercise increases in large arterial compliance

Study	Duration	Subject	Intensity	Training intervention	Exercise	Primary outcome
Fahs et al., 2012	6 weeks	41 healthy young men	30%1RM 45%1RM 70%1RM	Low-intensity BFR RT Moderate intensity RT High-intensity RT	Knee extension Knee flexion	There was no significant difference from pre to post in large artery elasticity index and small artery elasticity index
Yasuda et al., 2014	12 weeks	21 healthy elder men and women	20 - 30%1RM	Low-intensity BFR RT	Leg press Knee extension	The arterial stiffness was maintained
Ozaki et al., 2013	6 weeks	19 young healthy men	30%1RM 75%1RM	Low-intensity BFR RT High-intensity RT	Flat bench press	The carotid arterial compliance was significantly decreased (27 %) in high-intensity RT and slightly increased (13%) in low-intensity BFR RT
Yan et al., 2018	8 weeks	24 healthy men	30%1RM	Low-intensity BFR RT	Elbow flexion	There is the significant increase in aortic arterial compliance
Fahs et al., 2014	6 weeks	11 middle-age men and 5 women	30%1RM 30%1RM	Low-intensity BFR RT Low-intensity	Unilateral knee extension	The calf venous compliance of both groups did not change significantly from pre to post intervention

changes in calf venous compliance from pre - to post - intervention (BFR 0.0391 to 0.0371, free - flow 0.0362 to 0.0362). This finding contradicts a previous study (Iida et al., 2011), which reported increased venous compliance in older participants after 6 weeks of walking with BFR. The difference in training protocol and duration of applied BFR may account for these results, with the previous study using walking with a BFR duration of 20 minutes per session, 5 days per week (total 100 minutes per week), while the present study used knee extension RT lasting only 3.5 - 7.5 minutes per session (7 - 15 minutes per week), which may have been too short or insufficient to induce positive changes in venous compliance.

According to the evidence presented in Table 1, the data from six chronic studies indicates that low-intensity RT with BFR in healthy individuals, regardless of age, is likely to increase or maintain vascular compliance when measured indirectly through large and small arterial compliance / elasticity index, central arterial compliance, or venous compliance, unlike high-intensity RT. Further research is needed to explore more complex variables such as contraction mode, occlusion time, and other training modalities

Conclusion and practical application

From ten literature reviews, it has been fairly well-documented that low-intensity BFR RT can produce the very satisfying results when considering how low the intensity is. A review of total 7 studies investigating the effects of low-intensity RT with BFR showed that 4 studies (Kim et al., 2009; Fahs et al., 2011; Ozaki et al., 2013; Yan et al., 2018) reported the increase in compliance after training, while 3 of 7 studies (Fahs et al., 2012; Yasuda et al., 2014; Fahs et al., 2014) reported the maintenance of arterial compliance index. As compared to high-intensity protocol that might pose some effects on arterial compliance (Kim et al., 2009; Ozaki et al., 2013), low-intensity RT can be the alternative to high-intensity RT either for young or older participants. However, the side effect on vascular functions should always be one of the main concerns of every practitioner of BFR. From comparing available evidence, it seemed that the effect of low-intensity RT with BFR on arterial compliance and stiffness would be beneficial or at least maintained. The vascular response from high-intensity RT was prone to be more detrimental than low-intensity protocol. Factors such as intensity and volume were the main variables to be concerned when programmed. Practitioners should concern using low volume (e.g., not training to failure) and low to moderate intensity (e.g., 30 - 50%1RM) with BFR RT protocol as it was recognized as a safe training alternative for most practitioners regardless of the age and not be detrimental to vascular functions.

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