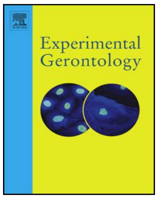
Experimental Gerontology 99 (2017) 127–132

Contents lists available at ScienceDirect

Experimental Gerontology

journal homepage: www.elsevier.com/locate/expgero



Effects of blood flow restricted exercise training on muscular strength and blood flow in older adults

Jahyun Kim, James A. Lang, Neha Pilania, Warren D. Franke*

Department of Kinesiology, Iowa State University, Ames, IA, USA

ARTICLE INFO

Editor: Christiaan Leeuwenburgh

Keywords:
Aging
Sarcopenia
Muscle strength
Vascular reactivity

ABSTRACT

Background: In young adults, blood flow restricted exercise (BFRE) at relatively low intensities can increase muscle strength as effectively as conventional high intensity training. Ischemic exercise can also increase collateral blood flow in skeletal muscle. However, the effects of chronic BFRE on muscle strength and blood flow in older adults remain unknown. The purpose of this study was to compare the effects of 4 weeks of BFRE training on skeletal muscle strength and blood flow between young and older subjects and between older adults performing BFRE and conventional high intensity resistance exercise.

Methods: Maximum voluntary contraction (MVC), forearm girth, peak forearm blood flow (FBF) and forearm vascular conductance (FVC) were assessed before and after 4 weeks of forearm resistance training with BFRE in older adults (O-BFRE, 63 ± 1 y, n = 9) and younger adults (Y-BFRE, 22 ± 1 y, n = 8) and with high intensity training at 75% maximum voluntary contraction in older adults (O-HI, 63 ± 1 y, n = 10).

Results: MVC increased in all groups (O-BFRE, 33.4 ± 4.7 to 36.3 ± 4.7 kg; Y-BFRE, 37.2 ± 4.9 to 43.0 ± 5.0 kg; O-HI, 34.0 ± 4.4 to 39.8 ± 4.4 kg; all $p < 0.05$). Forearm girth increased in O-BFRE (26.3 ± 1.1 to 26.7 ± 1.1 cm; $p < 0.05$) and Y-BFRE (23.9 ± 0.9 to 25.1 ± 1.5 cm; $p < 0.05$) but not in O-HI (25.9 ± 1.0 to 26.1 ± 1.0 cm; $p = 0.26$). Peak forearm vascular conductance increased in Y-BFRE (0.190 ± 0.016 to 0.311 ± 0.031 units; $p = 0.01$) but not in O-BFRE (0.157 ± 0.024 to 0.193 ± 0.029 units; $p = 0.48$) and O-HI (0.188 ± 0.035 to 0.227 ± 0.035 units; $p = 0.18$).

Conclusion: These data suggest that chronic BFRE training is effective in increasing muscular strength, muscle size and vascularity in young adults but, in older adults, increases only muscular strength and size. Longer training durations or higher volumes may be required to evoke similar vascular adaptations in older adults.

1. Introduction

Sarcopenia, or the age-related loss of muscle mass and strength, is generally considered a part of the biological aging process (Marcell, 2003; Baumgartner et al., 1999). Reduced muscle mass and strength can affect quality of life by impairing physical function in older adults (McDermott et al., 2009). To maintain an independent lifestyle, at least 70% of the "normal" muscle mass must be maintained (Bortz, 2002). For this reason, weight training is recommended for older adults as part of a regular exercise program. Unfortunately, only 10 to 12% of older adults perform adequate amounts of resistance exercise (Centers for Disease Control and Prevention, 2001). It is not surprising, then, that over half of all adults older than 60 years are sarcopenic (Janssen et al., 2002). This may exacerbate negative consequences of the physiological aging process via muscle mass losses, bone density decreases, and declines in cardiorespiratory fitness.

The American College of Sports Medicine (ACSM) recommends moderate to high intensity resistance exercise to improve muscle mass and strength (American College of Sports Medicine, 2009). However, this intensity could potentially cause numerous unwanted side effects in older adults, such as orthopedic problems and hypertensive responses (Smolander et al., 1998). A recently developed alternative to conventional high intensity training may be of utility to older adults (Manini and Clark, 2009). This alternative, called *KAATSU* in Japanese, entails performing hypoxic exercise at relatively low exercise intensities. In young adults, blood flow restricted exercise (BFRE) has increased muscle mass and strength more so than high intensity exercise without blood flow restriction (Takarada et al., 2000). It also resulted in increases in muscle mass and strength superior to unrestricted exercise performed at the same low exercise intensities (Abe et al., 2006; Madarame et al., 2008). It is thought to be as safe as conventional resistance training (Clark et al., 2011). However, BFRE research has been primarily performed with younger populations and with acute exercise (Abe et al., 2006; Madarame et al., 2008; Takarada et al., 2000; Reeves

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* Corresponding author at: Iowa State University, 0103J Forker Building, 534 Wallace Road, Ames, IA 50011, USA.
E-mail address: wfranke@iastate.edu (W.D. Franke).

http://dx.doi.org/10.1016/j.exger.2017.09.016
Received 8 March 2017; Received in revised form 5 September 2017; Accepted 25 September 2017

et al., 2006; Yasuda et al., 2012). Few training studies with an older population have been reported (Karabulut et al., 2010; Yasuda et al., 2014; Shimizu et al., 2016). Improved muscle mass and strength were seen in two studies following 6 to 12 weeks of BFRE training (Karabulut et al., 2010; Yasuda et al., 2014). Shimizu et al. (2016) but not Yasuda et al. (2014) saw changes in vascular responses following 3 and 1 months of BFRE training, respectively. However, both studies used indirect measures of vascular responses, the cardio-ankle vascular index and arterial pulse wave amplitude changes in an index finger, and multi-muscle strength training exercises (e.g., leg press and chest press) rather than more focal exercises.

Like sarcopenia, peripheral vascular disease is a common age-related disorder (McDermott et al., 2009; Shammans, 2007). It affects approximately 12 to 20% of adults 75 years or older (Shammans, 2007). Indirect evidence suggests that BFRE training may be of utility in improving this condition. Training in hypoxia has shown an angiogenic response in young animals (Olfert et al., 2001) with increases in skeletal muscle capillary density (Prior et al., 2004). In humans, growth hormone and vascular endothelial growth factor were more elevated after acute BFRE than exercise at a similar intensity (Pierce et al., 2006; Takano et al., 2005; Larkin et al., 2012). Thus, the acute and the long-term training effects of BFRE on angiogenesis may be beneficial to individuals who suffer from low peripheral blood flow perfusion.

In terms of improving muscle strength and mass, previous research suggests that BFRE may be an alternative to conventional resistance training using moderate-to-heavy loads. Ischemic exercise has also been effective at counteracting the effects of peripheral vascular disease (Shimizu et al., 2016; Olfert et al., 2001). Thus, limited research suggests that BFRE may be a useful and simple tool by which to counteract two common issues seen with aging—loss of muscle mass and strength as well as impaired peripheral blood flow—that are precursors to the co-morbidities of sarcopenia and peripheral vascular disease. Consequently, the purpose of this study was to compare the effects of chronic BFRE training on skeletal muscle strength and blood flow across three groups: 1) young adults performing BFRE, 2) older adults similarly performing BFRE, and 3) older adults undergoing a conventional high intensity resistance exercise program. We had two hypotheses with this study. First, we hypothesized that older adults completing the 4 weeks of BFRE training would exhibit greater muscle strength and peak blood flow changes than older adults performing conventional high intensity resistance exercise. Second, we hypothesized that 4 weeks of BFRE would increase peak blood flow and muscle strength in both young and older adults.

2. Materials and methods

2.1. Subjects

Healthy older adults (60–80 years old) and healthy young adults (19–25 years old) were recruited from the local community and screened based on their self-reported medical history. Participants needed to be nonsmokers, not taking either anticoagulants (e.g., Coumadin, Plavix) or antihypertensive medications, and without diagnosed cardiovascular disease, peripheral vascular disease, diabetes, hypertension, or arthritis of the hands. They were allowed to be physically active but could not be engaged in a program of regular resistance exercise or activities involving high forearm strength (e.g., climbing, powerlifting). Fifteen young (Y-BFRE) and thirteen older (O-BFRE) subjects agreed to participate in the BFRE protocol while 10 older subjects agreed to the high intensity resistance training protocol (O-HI). A total of 11 participants dropped out from the BFRE groups (7 young and 4 older). Six of these participants (3 young and 3 older) reported discomfort with the training protocol whereas the remaining five for personal reasons not associated with the study. All experimental procedures were approved by the Institutional Review Board at Iowa State University and conformed to the standards set by the Declaration of Helsinki. Participants were enrolled only after receiving a detailed verbal and written explanation of the experimental protocol and after providing written and verbal informed consent.

2.2. Experimental procedure

A repeated measures research design was used. Two groups of subjects, one being college age and the other older adults, completed 4 weeks of blood flow restricted exercise of the forearm musculature, training 3 times per week at 20% maximal voluntary contraction (MVC). A second group of older adults performed high intensity exercise training at 75% MVC, following an otherwise similar training protocol without blood flow restriction. The older adults were randomly assigned to the two exercise training groups after they passed the screening process. Muscle strength, muscle girth as well as resting and peak forearm blood flow (FBF) were assessed before and after the 4 weeks of training.

The group of young adults performing BFRE training were included to enable the assessment of the effects of age on the vascular responses to BFRE training. The group of older adults performing conventional high intensity resistance exercise were used to assess the effects of different forms of resistance exercise training on vascular responses in older adults.

Upon arrival to the laboratory for either the pre- or post-training assessment, each subject was instrumented for the continuous measurement of heart rate measured by lead II electrocardiography interfaced with a Biopac A/D board (BIOPAC systems, Inc., Santa Barbara, CA) and blood pressure (Dinamap 9300, Critikon, Tampa, FL) with the blood pressure cuff applied to the dominant arm. Resting blood pressure was then assessed to determine the cuff inflation pressure of BFRE. Handgrip strength, taken as the largest of three MVC, was assessed bilaterally using a Jamar-type handgrip dynamometer (Fabrication Enterprises, Inc., Irvington, NY). The subject then assumed a supine posture and was further instrumented for the assessment of FBF of the nondominant arm using venous occlusion strain gauge plethysmography (EC 5R Plethysmograph, D.E. Hokanson, Inc., Bellevue, WA). Forearm girth of the nondominant arm was measured ~1/3 the distance from the olecranon process to the ulnar styloid. This site was used for placement of the strain gauge; changes in forearm girth with training were also used to infer muscle mass changes (Martin et al., 1990). The subject remained supine for 15 min with resting FBF, heart rate and blood pressure measured during the last 5 min of these 15 min. FBF was measured six times per minute while HR and BP were measured every minute. FBF measurements by venous occlusion strain gauge plethysmography are reliable and reproducible (Lee et al., 2004; Proctor et al., 2005). All assessments were conducted and measured by the same investigator.

Maximum FBF was determined next using reactive hyperemia of the nondominant arm via 5 min of blood flow occlusion accompanied by ischemic exercise. This assessment exactly paralleled the protocol used during the BFRE exercise training sessions and consisted of 3 sets of contractions to fatigue completed within the 5 min of occlusion. Here, a blood pressure cuff (straight segmental cuffs SD 10, 11 × 85 cm, D.E. Hokanson, Inc., Bellevue, WA), previously positioned on the upper arm, was inflated to 30% above the subject's systolic blood pressure (young = 150 mmHg, old = 160 mmHg average cuff pressure). Subjects squeezed a handgrip dynamometer following the BFRE exercise training protocol. After these 5 min had elapsed, the pressure in the occluding cuff was released and FBF was assessed six times per minute for the subsequent 5 min. After 4 weeks of exercise training, this assessment was repeated. Post exercise measurements were conducted after at least 24 h, but no later than 48 h, after their last training session.

2.3. Exercise training

The BFRE and high intensity training sessions were initiated no sooner than 1 day after the baseline assessment. The BFRE training protocol was 5 min in duration. It consisted of a maximum of 3 sets of isometric handgrip contractions at 20% MVC to fatigue, with 1 min rest between sets, and with concurrent blood flow occlusion to the exercising limb via a blood pressure cuff inflated to 130% systolic blood pressure (young = 150 mmHg, old = 160 mmHg average cuff pressure, cuff size = 16 × 30 cm). A pressure of 130% of systolic blood pressure has been shown to elicit muscular adaptation and fatigue from BFRE (Cook et al., 2007). It was also felt to be low enough to facilitate participant safety, protocol compliance, and reduce attrition. Contractions were 2 s in duration, separated by 2 s relaxation, with the subject prompted by a metronome. "Fatigue" was defined as the subject volitionally stopping or being unable to produce more than 1/2 of the desired force, or 10% MVC. If the subject did not fatigue during a set, they kept exercising; thus, it was possible that the first set of handgrip contractions could be 5 min in duration. The training session was terminated after 5 min regardless of the number of sets or contractions performed. Blood pressure was assessed on the non-exercising arm before the training session began and 5 min afterward but not during the session.

The high intensity exercise in the older adults consisted of performing handgrip exercise at 75% MVC. Other than the load, the protocol paralleled that of the BFRE training sessions completed by the other two cohorts in this study. Each session consisted of three sets of isometric handgrip contractions to fatigue using the nondominant arm. Volitional stopping or force production of less than half of the desired force, or 37.5% MVC, during the isometric contractions were considered fatigue points. Once a subject reached a fatigue point, a 1 min break was given to the participant before beginning the next set. The training session was terminated after 5 min of exercise regardless of the number of sets or contraction performed. MVC was reassessed after 2 weeks of training and the workload was adjusted as needed.

2.4. Statistical analysis

Mean arterial pressure (MAP) was calculated as the sum of 1/3 pulse pressure and diastolic blood pressure. Forearm vascular conductance (FVC) was calculated as FBF/MAP and expressed as $\text{ml}\cdot\text{min}^{-1}\cdot\text{mmHg}^{-1}$ or units. Resting HR, MAP, and FBF were considered to be the mean of the 5 min of resting data assessed immediately prior to commencing the 5 min of blood flow occlusion. Maximum FBF was the largest FBF measured during the first 3 min after cuff release. To test our first hypothesis, resting and maximum FBF and FVC, HR, BP, muscular strength, and forearm girth before and after training were compared among the two older groups using a group (2) x time (2) mixed repeated-measures ANOVA. To test the second hypothesis, paired *t*-tests with Bonferroni correction were used to assess the effects of exercise training on resting and maximum FBF and FVC, HR, BP, muscular strength and forearm girth in all three groups. Analyses were conducted using SPSS 24 for Windows software. A $p < 0.05$ was considered statically significant. Correlational analyses between strength changes and blood flow changes were also performed. Individual blood flow responses are presented to show the heterogeneity of the responses among participants. Finally, Cohen's *d* effect sizes were calculated to assess the strength of the differences in these physiological variables among the groups by FBF and FVC variables. Data are presented as mean ± SEM.

3. Results

Table 1 summarizes the anthropometric characteristics of the subjects who completed the study (8 Y-BFRE, 9 O-BFRE, 10 O-HI). Strength in all three groups increased significantly with training (Y-BFRE, 37.2 ± 4.9 to 43.0 ± 5.0 kg; O-BFRE, 33.4 ± 4.7 to 36.3 ± 4.7 kg; O-HI 34.0 ± 4.4 to 39.8 ± 4.4 kg; pre- vs. post-training, respectively, $p < 0.05$; Table 1). The increase in forearm girth in the young and old BFRE groups with 4 weeks of training was statistically significant (Y-BFRE, 23.9 ± 0.9 to 25.1 ± 1.5 cm; O-BFRE, 26.3 ± 1.1 to 26.7 ± 1.1 cm; both $p < 0.05$; Table 1) but not in the O-HI group (25.9 ± 1.0 to 26.1 ± 1.0 cm; $p = 0.091$; Table 1).

Neither resting FBF nor resting FVC changed with 4 weeks of BFRE in any group (Figs. 1 and 2; $p > 0.5$). Peak FBF increased significantly in the young group after BFRE training (15.2 ± 1.3 to 23.8 ± 2.1 $\text{ml}\cdot\text{min}^{-1}\cdot\text{mmHg}^{-1}$; $p < 0.05$; Fig. 1), but not in either older group (O-BFRE, 14 ± 2 to 16.7 ± 2.6 $\text{ml}\cdot\text{min}^{-1}\cdot\text{mmHg}^{-1}$, $p = 0.387$; O-HI, 17.1 ± 3 to 18.5 ± 3 $\text{ml}\cdot\text{min}^{-1}\cdot\text{mmHg}^{-1}$; $p = 0.574$; Fig. 1). A similar response was seen for peak FVC (Fig. 2). It increased after 4 weeks of forearm BFRE in the young subjects (0.190 ± 0.016 to 0.311 ± 0.031 units; $p < 0.05$; Cohen's *d*, FBF = 1.94, FVC = 1.76; Fig. 2) but not in either older group (O-BFRE: 0.157 ± 0.024 to 0.193 ± 0.029 units; $p = 0.48$; Cohen's *d*, FBF = 0.32, FVC = 0.33; O-HI: 0.188 ± 0.035 to 0.227 ± 0.035 units; $p = 0.184$; Cohen's *d*, FBF = 0.41, FVC = 0.56; Fig. 2). Thus, neither form of resistance exercise training was effective at increasing peak FBF and FVC among the older groups. The effect sizes for the exercise-associated increases in peak FBF and FVC in the older adults were moderately sized (Cohens's *d*, O-BFRE: FBF = 0.32, FVC = 0.33; O-HI: FBF = 0.41, FVC = 0.56) yet were not statistically significant. There was only a modest association between changes in muscular strength and changes in peak FVC in the two BFRE groups (Y-BFRE, $r = 0.34$; O-BFRE, $r = 0.47$).

Fig. 3 represents individual responses of peak FVC to the chronic exercise training. In both older groups, there was considerable heterogeneity of the response. About half of both the O-HI and O-BFRE groups had either no change or a reduction in peak FVC with training. In contrast, 7 of the 8 members of Y-BFRE group increased peak FVC after training.

4. Discussion

The primary findings of this study are: 1) four weeks of forearm BFRE training increase muscle strength and forearm girth in both young and older adults, 2) BFRE training is superior to conventional high intensity resistance exercise in increasing forearm girth in older adults, but 3) neither training modality increases peak FBF and FVC in older adults. However, BFRE increased peak FVC in the young group.

Several studies have found increased strength and muscle hypertrophy with BFRE training in young healthy adults (Abe et al., 2006; Madarame et al., 2008; Takarada et al., 2000; Reeves et al., 2006; Yasuda et al., 2012). Fewer studies have assessed these responses in healthy older adults (Karabulut et al., 2010; Yasuda et al., 2014; Fahs et al., 2014). To the best of our knowledge, this study is the first to compare the effects of chronic blood flow restricted exercise training on forearm vascular function between older and younger cohorts while also comparing BFRE and "conventional" resistance exercise in older adults.

Previous studies differ from the present one in that blood flow restriction was usually imposed during more aerobic exercise activities such as walking (Abe et al., 2006), only the acute responses were measured (Madarame et al., 2008), and only larger muscle groups were assessed (Takarada et al., 2000). Those studies that assessed BFRE with resistance exercise training supported our finding that BFRE increases muscle strength and size in both young and older adults (Reeves et al., 2006; Yasuda et al., 2012; Karabulut et al., 2010). However, the muscle hypertrophy adaption to conventional resistance exercise training may be impaired in older adults. In older adults, this impairment may be partly due to attenuated muscle neuron activity (Unhjem et al., 2015). Different muscle fiber types (e.g., Type 1 vs. Type 2) respond differently to high intensity resistance training (Verdijk et al., 2009). Verdijk and

Table 1
Participant characteristics.

	O-BFRE		O-HI		Y-BFRE	
	Pre training	Post training	Pre training	Post training	Pre training	Post training
Age (yrs)	63 ± 0.8		62.5 ± 1.1		22 ± 0.6	
Height (cm)	173.5 ± 3.4		167.0 ± 3.6		171.0 ± 3.9	
Weight (kg)	82.0 ± 6.5		81.7 ± 4.5		73 ± 4.9	
HR (beats·min^{-1})	59 ± 3		63.3 ± 3		62 ± 2	
MAP (mmHg)	85 ± 6	84 ± 5	84.3 ± 1.9	83.3 ± 2	78 ± 4	78 ± 2
Strength (kg)	33.4 ± 4.7	36.3 ± 4.7*	34 ± 4.4	39.8 ± 4.4*	37.2 ± 4.9	43 ± 5.0*
Girth (cm)	26.3 ± 1.1	26.7 ± 1.1*	25.9 ± 1.0	26.1 ± 1.0	23.9 ± 1.2	25.1 ± 1.2*

* $p < 0.05$; O-BFRE = older group performing blood flow restricted exercise training; O-HI = older group undergoing conventional high intensity resistance training; Y-BFRE = young group performing BFRE.

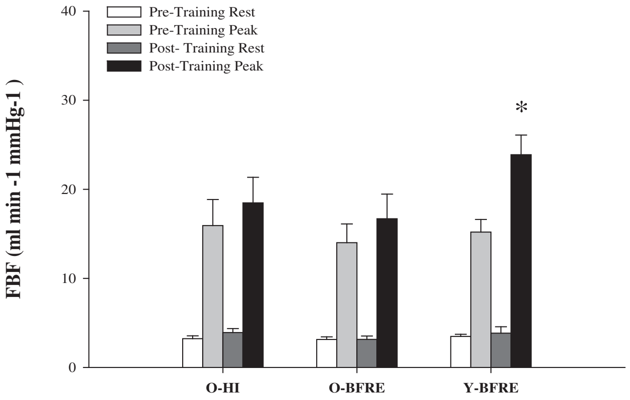

Fig. 1. Peak forearm blood flow changes pre- and post-BFRE training. Resting FBF did not change with four weeks of BFRE in any group. Four weeks of BFRE significantly increased peak FBF only in the Y-BFRE group (*$p < 0.05$, mean ± SE).

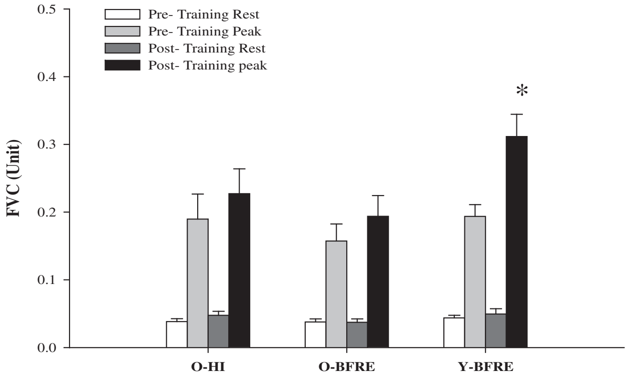

Fig. 2. Peak forearm vascular conductance changes pre- and post-BFRE training. Resting FVC did not change with four weeks of BFRE in any group. Four weeks of BFRE increased peak FVC only in the young group (*$p < 0.05$, mean ± SE).

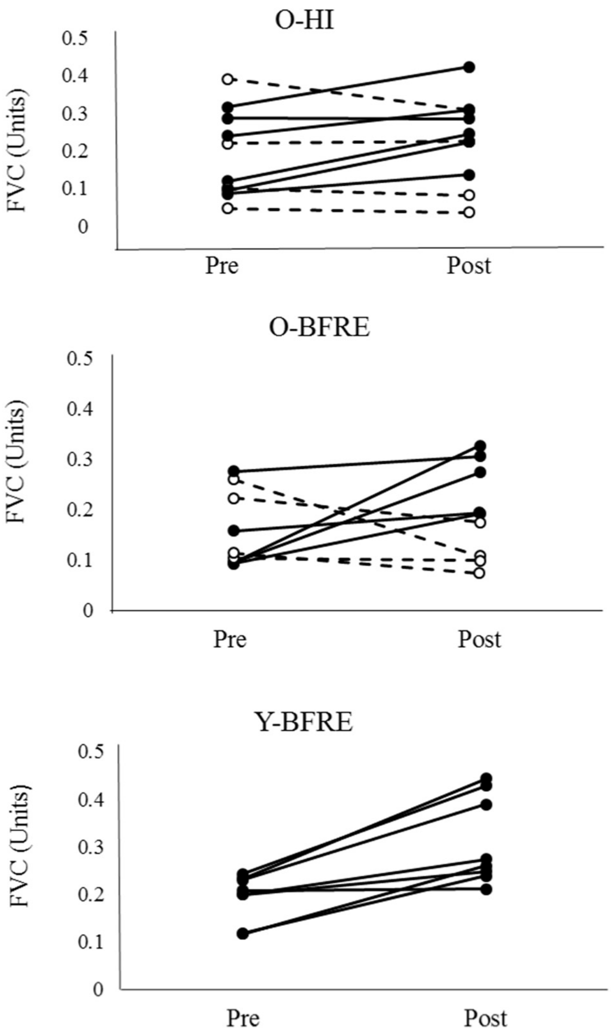

Fig. 3. Individual responses of peak FVC pre- and post-4 weeks of BFRE training. Y-BFRE increased peak FVC in every subject. Several members of the O-HI and O-BFRE groups showed negative responses (O-HI = 4, O-BFRE = 4) with 4-weeks of BFRE (— positive response; – – – negative response).

colleagues found increased satellite cell contents in Type 2 muscle fiber with 12 weeks of resistance training in the older population, but Type 1 muscle fiber did not change satellite cell contents in the same intervention participants. In our study, the training stimulus was specific to the forearm musculature, which is primarily Type 1 fibers (McIntosh et al., 1985). These factors may help explain the current results of attenuated muscle hypertrophy with conventional high intensity exercise in older adults. Thus, compared to high intensity resistance exercise, the benefits of BFRE in an older population are not only increased strength but also muscle hypertrophy.

Abe and colleagues (Abe et al., 2006) used a BFRE protocol employing 6 weeks of walking exercise in an older cohort and found increased leg muscle mass and strength. Yasuda and colleague also reported increased muscle mass following 6 weeks of low intensity (20% of one-repetition maximal) BFRE using knee extension, leg press and upper body exercises (Karabulut et al., 2010). Collectively, these studies suggest that chronic BFRE can increase muscle strength as well as conventional high intensity exercise in older adults.

Muscle blood flow adaptations with exercise training occur to better supply oxygen to exercising muscle in order to match increased metabolic demand (Proctor et al., 2005). Changes in FVC can reflect changes in vascular structure such as increased vascular size and increased number of capillaries (Hodges et al., 2010). In the group of young adults, we found that small muscle group vasculature changes, reflected by increased peak FBF and FVC, occurred after only 4 weeks of resistance BFRE. Although a novel finding in young adults, this result was not seen in the older cohorts. Older adults generally have reduced blood flow responses to acute exercise as well as blunted adaptations to exercise training (Proctor et al., 2005; Lind et al., 1999). Acutely, older adults exhibit a reduced peak reactive hyperemic FBF and attenuated peak cutaneous vasodilation capacity with aging (Hodges et al., 2010; Goldspink et al., 2009; Minson et al., 2002). Minson and colleagues suggested that reduced NO-mediated vasodilation contributes to the attenuated vasodilation responses (Minson et al., 2002). With respect to exercise training, Donato et al. (2005) found a blunted increase in artery diameter and endothelial-dependent dilation after 10 to 12 weeks of treadmill training in older compared to young rats. In the present study, the older adults did not exhibit an increase in peak forearm blood flow following resistance exercise training. This may be due in part to the training stimulus affecting predominantly Type 1 muscle fibers (i.e., forearm muscles) (McIntosh et al., 1985), and thus we might expect blunted increases in vascular diameter with 4 weeks of BFRE in forearm musculature of older subjects. Alternatively, considering that older adults have an attenuated vasodilator response to hypoxic exercise (Casey et al., 2011) and since BFRE is a form of hypoxic exercise, an attenuated vasodilator response in older adults might be one of the reasons for the differing adaptation between the two groups (O-BFRE vs. Y-BFRE) seen here.

The vascular responses to resistance training and BFRE vary in middle-aged and older adults. The findings of Fahs and coworkers parallel our findings in that 4 weeks of BFRE in older adults did not appreciably change blood flow in a small muscle group (Fahs et al., 2014). They found unchanged calf blood flow in middle age subjects following 6 weeks of unilateral knee extensor training with BFRE compared to training without BFRE. In contrast, others reported an increased reactive hyperemia index and peripheral circulation ratio with 4 weeks of low intensity BFRE leg exercise (Yasuda et al., 2014). The present study applied a less intense exercise protocol (20% MVC vs. 30% MVC), considerably shorter exercise protocol (5 min vs. 15 min), different types of exercise (handgrip vs. knee extension exercise with blood flow occlusion) and different sized muscle groups (forearm vs. quadriceps). Thus, the extent to which differences in exercise duration, mode, intensity, or muscle size underlie these disparate results remains uncertain.

In the present study, there were quite divergent individual vascular responses to the BFRE resistance training in the older group that was not seen in the young adults (Fig. 3). Because of this marked variability, a sample size of 28–79 participants would be required to achieve significance (power = 0.80, $\alpha = 0.05$). This disparate response may be somewhat associated with the differences in the gains in muscle strength seen here. The strength gains in the older BFRE group ranged from 0 to 6 kg but from 3 to 12 kg in the younger BFRE group. These changes were moderately correlated to the vascular reactivity responses (young, r = 0.34; old, r = 0.47). Nevertheless, there were moderate effect sizes for the vascular responses, suggesting the presence of a "real" response (Cohens's *d*; O-BFRE, FBF = 0.32, FVC = 0.33; O-HI, FBF = 0.41, FVC = 0.56).

To increase muscle mass, augmented blood flow is required (Heinonen et al., 2015). With traditional training methods, there is an association between training-related changes in blood flow and muscle adaptations (Roth et al., 2001; Hakkinen et al., 1998). Older adults can increase muscle strength and mass with traditional resistance exercise training (Roth et al., 2001), although the rate of this increase is usually blunted compared to younger subjects (Hakkinen et al., 1998). With six weeks of resistance training using BFRE, Karbulut and colleagues found increased strength and muscle mass in older adults (Karabulut et al., 2010). Likewise, Shimizu demonstrated improved vascular function with 12 weeks of lower intensity BFRE (Shimizu et al., 2016). The present study extends these findings to suggest that these adaptations are also seen in older adults performing BFRE.

This study has limitations. First, the final sample sizes of each group limited the statistical power of the study. Unfortunately, 11 participants in both BFRE groups dropped out of the study (Y-BFRE = 7, O-BFRE = 4). Of these 11, 6 (Y-BFRE = 3, O-BFRE = 3) indicated this was due to discomfort associated with BFRE. This discomfiture was somewhat surprising; our pilot work and the work of others (Cook et al., 2007) suggested that this protocol would be well-tolerated. Moreover, the cuff pressure used here has been found to induce greater muscle activation compared to BFRE using lower cuff pressures (Yasuda et al., 2008), suggesting this pressure would be effective at eliciting vascular adaptations. Second, considering that several older adults experienced a decrease in peak FVC following training (Fig. 3), there may be other factors that affect vascular changes with BFRE. These could include the aforementioned heterogeneity of vascular responses in Type 1 muscle in older population and an inhibited anabolic response in older adults. Despite these variable responses, there was a modest association among the strength changes and vascular responses (i.e., FVC) in the BFRE groups (young, r = 0.34; Old, r = 0.47). In other words, BFRE may evoke increases in the vascularity of young and older adults but this increase is associated with strength gains.

5. Conclusion

This study demonstrated that 4 weeks of low intensity BFRE training increases forearm girth and muscle strength in older adults. Although older adults performing BFRE training did not increase FBF and FVC consequent to the training, these older adults exhibited greater increases in forearm girth than older adults performing high intensity conventional resistance exercise training. Further research is needed to determine if longer training durations would elicit different vasculature adaptations to BFRE in older adults.

Acknowledgments

We thank Ekpen Okoruwa, Erin Johnson, and Michael Severin for their assistance on this research project. We also thank the research subjects for their participation.

Conflict of interest

There are no conflicts of interest with this study.

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