Journal of Frailty, Sarcopenia and Falls

Original Article

Age-Related Differences in Adaptation of Lean Body Mass, Muscle Strength, and Performance Following 6 Weeks of Blood Flow Restriction Training in Young and Older Adults

Julia K. Arnason[1,2], Amy M. Thomson[1,2], Logan E. Peskett[1,2], Dawson A. Nancekievill[1,2], Danielle R. Bouchard[1,2], Martin Sénéchal[1,2]

[1]*Cardiometabolic Exercise & Lifestyle Laboratory, Canada;*
[2]*Faculty of Kinesiology, University of New Brunswick, Canada*

Abstract

Objectives: The primary objective was to test the influence of age on lean body mass (LBM), muscle strength, and isokinetic performance adaptation following a 6-week blood-flow restriction training (BFRT) intervention. **Methods**: A total of 38 young adults (23.5±3.1) and 34 older adults (72.7±5.5) completed a 6-week BFRT program. Exercises were performed three times per week at 30% of 1-repetition maximums (1-RMs) and 60% of each limb's arterial occlusion pressure. Body composition was assessed using dual-energy X-ray absorptiometry, muscle strength was measured using 1-RMs, and muscular performance was measured using an isokinetic dynamometer. **Results**: A significant increase in LBM was observed in young adults (0.9±1.5kg; p<0.001) but not in older adults (0.3±1.3kg; p>0.05) following the intervention. Both age groups significantly improved 1-RMs for knee extension, knee flexion, and chest press, with the young group displaying greater improvements (all ps<0.001). A significant increase in knee flexion torque and power was observed in young adults (all ps<0.001) but not in older adults, while a significant difference between groups was observed (p<0.05). **Conclusions**: The results from our study suggest that young adults improve LBM and muscle performance following 6-weeks of BFRT, while older adults enhance performance, despite a lack of improvement in LBM. Clinicaltrials.gov ID: NCT05615831.

Keywords: Aging, Blood Flow Restriction Training, Body Composition, Lean Body Mass, Resistance Training

Introduction

Sarcopenia refers to the natural loss of lean body mass (LBM) with aging[1], while dynapenia refers the natural loss of strength and power with aging[2]. Although sarcopenia and dynapenia are inter-related, a greater annual decline of muscle strength and power is observed compared to LBM[3]. In fact, peak LBM occurs between 20-30 years of age[4] and then declines by 40% between 20 to 70 years, an average rate of 0.8% per year[5–7], compared to 3.2% yearly decline for muscle strength[3]. Such changes in LBM and its function are not trivial as it increases the risk of falls, physical function limitations, losses of independence, reduces quality of life, increases hospitalizations and health care costs[8], and increases risk of premature mortality[9,10]. Thus, countering the effects of the age-related decline in LBM and function are imperative and resistance training has been found as a preferred intervention[8,11].

For instance, many studies on traditional resistance training in older adults have demonstrated positive effects on LBM and muscle strength[8,12]. Although LBM increases with resistance training in older adults, the effect size is very small. In fact, a meta-analysis revealed that in males

The authors have no conflict of interest.

Corresponding author: *Dr. Martin Sénéchal, Ph.D, CSEP-CEP, Professor, University of New Brunswick, Faculty of Kinesiology, Co-Director of Cardiometabolic Exercise & Lifestyle Laboratory (CELLAB). 90 Mackay Drive, Room 319, Fredericton, New Brunswick, Canada, E3B 5A3*

E-mail: *martin.senechal@unb.ca*

Edited by: *Yannis Dionyssiotis*

Accepted *5 February 2025*

and females aged over 50 years (average= 65.5±6.5years), who trained 2 to 3 times per week (average 2.8±0.4 days/week) at 50 to 80% of 1 repetition maximum (1-RM), an average LBM increase of 1.1kg is usually observed with 20.5 weeks of resistance training[8]. More importantly, a strong inverse association was observed between age and average change in LBM suggesting a weaker association between LBM gain with resistance training in the oldest individuals[8]. These results are also supported by several other studies performed in older adults[13,14], including an interesting review on the impact of resistance training in older adults on body composition[15]. In this review, it was shown that an increase in LBM was only found in approximately 50% of the studies. This is challenging the general belief that resistance training always leads to significant LBM gain in older adults and this was further supported by a recent meta-analysis showing no improvement in LBM in older adults compared to the standard care group[16]. One of the very few studies directly comparing young and older adults showed a significant increase in LBM in the young adults (pre: 39.2±3.7 vs. post: 40.4±3.2 kg, $p<0.05$), while older adults did not significantly increase LBM (pre: 37.3±4.0 vs. post: 38.0±4.3 kg, $p=0.060$) following 6 months of resistance training[17].

As for muscle strength, a meta-analysis of resistance training showed an improvement in muscle strength ranging between 23 and 33% in adults aged over 50 years for leg press, chest press, knee extension, and lat pull down[12]. In young adults, a recent meta-analysis suggests that any traditional resistance training programs is effective in improving muscle strength when compared to no exercise[18,19]. Therefore, the impact of resistance training on muscle strength and function are well-established in both age groups. However, studies suggest significant increases in muscle strength mostly in untrained inidividuals and when performed at high intensity[19]. Interestingly, a systematic review of resistance training in older adults showed that of 121 studies identified ~ 44% provided no comment on adverse events, while from the studies that reported this information, 63% reported musculoskeletal problems or joint pain[20].

Therefore, blood flow restriction training (BFRT), an emerging type of resistance training combining low-load exercises with reduced blood flow, has been proposed as an alternative. In young adults, there is substantial evidence that BFRT can induce muscle hypertrophy[21,22]. BFRT has been shown to induce hypertrophy through the up-regulation of insulin-like growth factor-1, Testosterone, Growth Hormone, and down-regulates muscle growth inhibitors, such as Myostatin[23]. Furthermore, a positive impact on muscle strength has been observed following BFRT[24,25] and is more effective than low-load resistance training[26], which is commonly used for rehabilitation. Increase in muscle strength with BFRT could be explained by the ischemic environment creating a premature fatigue on smaller muscle fibbers (Type 1). This premature fatigue increases recruitment of bigger muscle fibbers (Type II), which then enhance force production with BFRT[27]. Nevertheless, early evidence shows that similar results are observed in older adults, however, no data directly comparing young and older adults in the context of BFRT has been published yet. Therefore, the purpose of this analysis was to determine if adaptations in LBM, muscle strength, and performance following a 6-week BFRT intervention differ between young and older adults.

Methods

Study Design

The current study is a parallel experimental design comparing the impact of a 6-week resistance training intervention in conjunction with partial blood-flow restriction between young (19-30 years) and older (>65 years) adults. Participants underwent a phone screening to assess study eligibility. Following phone screening, participants presented at the Cardiometabolic Exercise and Lifestyle Laboratory at the University of New Brunswick on two non-consecutive days (one-week apart) for baseline testing. Within one week of the last baseline testing visit, participants began the 6-week BFRT. Upon completion of the intervention, follow-up testing was conducted in two sessions no more than one week apart following the last exercise session.

Power sample calculation

A power calculation was performed using G-power software (version 3.1.9.4, Germany) to determine the appropriate sample size for statistical significance. Based on an alpha of 0.05, a power of 0.8, and an effect size of 0.3, we determined the required total sample size to be 24 participants for a repeated measures analysis of variance (ANOVA). To account for a 30% dropout rate and ensure sufficient power to detect interaction and main effects, we aimed to recruit an additional seven participants per group, resulting in a total sample size of 72 participants.

Participants

Participants were recruited in Fredericton, New Brunswick, and surrounding areas from May 2022 until September 2023. Recruitment was done through advertisements on social media, local businesses, markets, and newsletters sent via email to students and staff of the University of New Brunswick.

Inclusion criteria

Inclusion criteria for participants were: 1) aged 19 to 30 years or 65 years or older, and 2) not physically active but otherwise healthy. Participants were considered inactive if they were not meeting the World Health Organization's 2020 physical activity guidelines[30]: 150 minutes of moderate-vigorous physical activity and two muscle-strengthening activities per week. Resistance training frequency was self-reported and moderate-vigorous physical activity was estimated using steps-per-day data from a Fitbit Charge 3. A threshold of 10,000 steps/day was used as a cut-off[31]. Therefore, if participants averaged below 10,000 steps/day over a 4-7 day period and did not participate in resistance training more than twice per week, they were considered inactive and were able to participate in the study.

Exclusion criteria

Exclusion criteria for participants were: 1) aged outside prearranged threshold (19 – 30 or >65 years), 2) the presence of cardiovascular disease such as coronary heart disease, uncontrolled hypertension, peripheral vascular disease, venous thromboembolism, other blood clotting disorders, or hemophilia, 3) surgery, bone fracture, or a skin graft within the last three months, 4) pregnancy, and 5) meeting or exceeding physical activity guidelines. A complete list of the chronic and specific conditions used to excluded participants for BFR is provided in supplementary Table 1.

Primary Exposure – BFRT Exercise Intervention

Participants underwent 6-weeks of low-load resistance training in conjunction with reduced blood flow to their exercising limbs. Participants attended resistance training sessions 3 times per week for 6 weeks, accumulating a total of 18 sessions. The exercises performed included: chest press, seated row, leg press, knee extension, and knee flexion using weight machines. Load was individualized and set to 30% of each 1-RM and participants underwent a 30-15-15-15 repetition scheme for a total of 75 repetitions. This protocol was chosen based on previous literature showing muscle hypertrophy[32,33]. Participants used KAATSU C3 devices (KAATSU Global, Inc., Huntington Beach, CA, USA) with the cuffs worn securely and as proximal as possible on the upper and lower exercising limbs (above the biceps brachii on the arm and near the inguinal crease on the thigh). The KAATSU cuffs were inflated to 60% of arterial occlusion pressure (AOP) for both the arm and leg exercises. One minute of rest with the cuffs inflated was given between sets and 4 minutes with the cuffs completely deflated was given between exercises. At the first session of week 4, all 1-RM's were reassessed, and exercise load was readjusted to 30% if changes occurred, then a set of 30 repetitions and a set of 15 repetitions were performed.

Arterial occlusion pressure (AOP) was calculated according to the following formulas[34]:

Arm arterial occlusion (mmHg) = 0.514 (SBP) + 0.339 (DBP) + 1.461 (Arm circumference) + 17.236

Leg arterial occlusion (mmHg) = 5.893 (Thigh circumference) + 0.734 (DBP) + 0.912 (SBP) - 220.046

Subsequently, 60% of each AOP was calculated for use in the exercise intervention. Arm circumference was measured at halfway between the acromion and olecranon processes. Thigh circumference was measured while seated at 33% distal from the inguinal crease to the top of the patella. Systolic and diastolic blood pressure were taken at rest.

Primary Outcomes

Anthropometric measures and body composition between age groups

Anthropometric measurements were taken at baseline and post-intervention. Participant height, weight, waist circumference, and hip circumference were measured to the nearest 0.5cm and 0.1kg following the Canadian Society for Exercise Physiology (CSEP) protocols[35]. Weight was measured using a calibrated column scale (SECA® model #213) and height was measured using a standardized stadiometer. Waist circumference was measured at the upper lateral border of the iliac crest following a normal exhalation and hip circumference was measured around the widest portion of the buttocks after a normal exhalation.

Dual x-ray absorptiometry (DXA) was used to estimate lean and fat mass using a Hologic Horizon® DXA System (Hologic Canada ULC, Mississauga, ON, Canada). Participants were asked to fast for 12 hours and avoid exercise for 24 hours prior to testing. In addition, participants were asked to avoid clothing that contained metal (metal buckles, zippers, buttons, etc.) and were instructed to lay supine on the DXA table and remain still for the duration of the scan. Arms were placed at the participants' sides with palms facing medially and thumbs pointed upwards. For large individuals, they were positioned with one arm outside of the scan area and results of the scanned arm were duplicated. The coefficient of variation in our lab for LBM is 0.6% and for body fat percentage is 0.7%. This was performed on 33 people (males, n=10) with a mean age of 23.4 years and a mean body mass index (BMI) of 25.6.

Secondary Outcomes

Muscle strength

Strength was assessed by 1-RM for the five exercises used in the intervention, measured at baseline testing, the intervention midpoint, and at follow-up testing. One set of 6-10 repetitions followed by one set of 3-5 repetitions was used as a warm-up. Subsequently, 1-RM's were determined by using incremental increases until failure was observed. Seven attempts were permitted and if the 1-RM was not found in the seven attempts, it was reassessed prior to the next exercise session.

Isokinetic measures

Muscular endurance of the dominant knee extensors and flexors was assessed using a HUMAC® NORM™ isokinetic dynamometer system (Computer Sports Medicine, Inc., Stoughton, MA, USA). Prior to testing, participants walked for 5-minutes as a warm-up. Then, participants were seated, the dynamometer was adjusted to properly align joint angles, and then they were strapped to the device across the chest and

	Total (N=72)	Young (n=38)	Old (n=34)
Age (years)	46.7 ± 25.1	23.5 ± 3.1	72.7 ± 5.5*
Male n (%)	36 (50)	19 (50)	17 (50)
White n (%)	65(90)	31 (82)	34 (100)*
Physical Activity (steps/day)	6526.5 ± 2140.1	6496.2 ± 2198.0	6561.5 ± 2104.8

*Variables are presented as means ± standard deviation. * signifies significant difference between age groups.*

Table 1. General characteristics of the study sample.

thighs. Range of motion was then assessed on an individual basis where 0° corresponded to full knee extension. Before testing, participants performed 5 repetitions at 120°/s for familiarization purposes. Subsequently, participants were given two-minutes of recovery before testing. The testing protocol consisted of 30 consecutive maximal contractions of the knee extensors and flexors at 180°/s[36]. Total work, peak torque, and average power were recorded.

Senior Fitness Test

Chair stands, arm curls, and an 8-foot timed up-and-go test were evaluated pre- and post-intervention. Participants were asked to sit and stand as many times as possible, without the use of their arms, in a 30-second period. Then, in another 30 second period, participants were asked to do as many arm curls as possible while holding a dumbbell in their dominant hand. Dumbbell weight was 5lbs for females and 8lbs for males[37]. Then, participants underwent an 8-foot timed up-and-go test. Participants were directed to stand without using their arms, walk around a marker positioned 8 feet away from the chair, and sit back down as fast as possible without running.

Statistical Analysis

The normality of the data was assessed using the Kolmogorov–Smirnov test and through a visual inspection of the data. Continuous data were presented as mean ± standard deviation and categorical variables were presented as n (%). Paired t-tests were used to analyze the impact of 6-week BFRT, while independent t-tests were used to analyze the group differences on the delta change of each outcome. Furthermore, repeated measures analyses of variance (ANOVAs) were used to adjust for confounders. The significance level was accepted at $p < 0.05$. IBM SPSS statistics version 29.0 was used for all statistical analyses.

Results

Descriptive Characteristics

In total, 72 participants were included in this analysis. There were 38 young adults (19 males and 19 females) and 34 older adults (17 males and 17 females). Baseline characteristics are summarized in Table 1. The average age of the young adults was 23.5 ± 3.1 years and was 72.7 ± 5.5 years for the older adults ($p<0.05$). Although a significant difference for ethnicity was observed between age groups (young: 82% white Caucasian vs. older adults: 100% white Caucasian; $p<0.05$), most participants were white (total sample 90%). There were no significant differences between young and older adults for number of steps per day (p-values >0.05).

Changes in Anthropometric Measures and Body Composition

Table 2 describes the impact of six weeks of BFRT on anthropometrics measures and body composition in young and older adults. Weight significantly increased (weight: 79.5 ± 22.0 kg to 80.5 ± 22.3 kg; p=0.002) in young adults following 6 weeks of BFRT, while no such results were observed in older adults (weight: 81.9 ± 19.9 kg to 82.0 ± 19.7 kg; p=0.598). Significant differences were observed between groups for change in weight (p=0.004) and BMI (p=0.006) after controlling for ethnicity.

In young adults, total LBM significantly increased from 49.3 ± 12.6kg to 50.2 ± 12.2kg; p< 0.001, while no such results were observed for older adults (48.7 ± 11.4kg to 49.1 ± 11.2kg; p=0.158). Relative LBM was significantly increased (16.7 ± 3.2 kg/m^2 to 17.0 ± 3.3 kg/m^2; p<0.001) in young adults, while no increase in relative LBM was observed (17.1 ± 2.8 kg/m^2 to 17.2 ± 2.7 kg/m^2; p=0.125) in older adults following 6 weeks of BFRT. After adjusting for ethnicity, both total (p=0.007) and relative LBM (p=0.012) were significantly different between young and older adults. Both young adults (16.7 ± 4.3 kg to 17.1 ± 4.6 kg; p=0.001) and older adults (15.3 ± 3.5 kg to 15.6 ± 3.4 kg; p=0.009) significantly increased total lower limb LBM, however, no significant differences were observed between age groups even after adjusting for ethnicity.

Changes in 1-Repetition Maximums

Leg press increased in young adults (Figure 1A: 137.4 ± 49.5 kg to 146.7 ± 49.7 kg; p=0.004) and in older adults (Figure 1B: 106.4 ± 45.9 kg to 112.7 ± 44.2 kg;

	Young (n=38)			Old (n=34)		
	Pre	Post	*p*-value	Pre	Post	*p*-value
Anthropometrics						
Weight (kg)	79.5 ± 22.0	80.5 ± 22.3	0.002	81.9 ± 19.9	82.0 ± 19.7	0.598*
Body Mass Index (kg/m^2)	27.0 ± 6.5	27.4 ± 6.6	0.002	28.9 ± 6.6	29.0 ± 6.6	0.506*
Waist Circumference (cm)	91.8 ± 14.6	92.3 ±14.3	0.428	103.9 ± 17.9	103.3 ± 17.8	0.262
Hip Circumference (cm)	105.9 ± 13.0	105.9 ± 12.8	0.999	107.9 ± 13.7	107.7 ± 12.8	0.567
Body Composition						
Body Fat (%)	32.4 ± 9.0	32.1 ± 8.8	0.060	35.2 ± 8.4	34.9 ± 8.5	0.091
Fat Mass (kg)	25.9 ± 11.9	25.9 ± 11.9	0.905	28.5 ± 12.0	28.4 ± 12.2	0.492
Upper Limb Fat Mass (kg)	2.7 ± 1.3	2.7 ± 1.3	0.207	3.0 ± 1.4	2.9 ± 1.2	0.029
Lower Limb Fat Mass (kg)	9.5 ± 4.1	9.4 ± 4.2	0.317	8.5 ± 3.6	8.5 ± 3.7	0.284
Trunk Fat Mass (kg)	12.6 ± 6.9	12.8 ± 6.7	0.128	16.0 ± 7.7	16.0 ± 7.9	0.826
VAT Area (cm^2)	96.1 ± 45.8	97.0 ± 46.9	0.589	201.5 ± 84.4	197.4 ± 88.2	0.113
Lean Body Mass (kg)	49.3 ± 12.6	50.2 ± 12.8	<0.001	48.7 ± 11.4	49.1 ± 11.2	0.158
Lean Body Mass/Height^2 (kg)	16.7 ± 3.2	17.0 ± 3.3	<0.001	17.1 ± 2.8	17.2 ± 2.7	0.125
Upper Limb Lean Body Mass (kg)	5.0 ± 1.7	5.1 ± 1.8	0.010	4.9 ± 1.6	4.9 ± 1.7	0.114
Lower Limb Lean Body Mass (kg)	16.7 ± 4.3	17.1 ± 4.6	0.001	15.3 ± 3.5	15.6 ± 3.4	0.009

*Variables are presented as means ± standard deviation. VAT: visceral adipose tissue. * represents significant difference between groups using an independent sample t-test. Alpha level at 0.05.*

Table 2. The impact of 6-week BFRT on body composition of young and older groups.

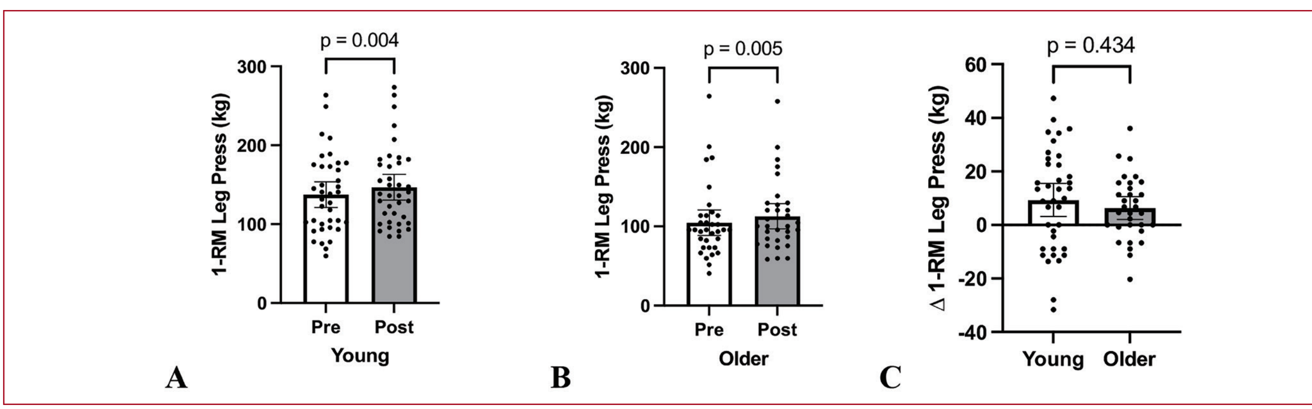

Figure 1. A. 1-RM leg press of young adults at baseline and post-testing. B. 1-RM leg press of older adults at baseline and post-testing. C. Absolute change of 1-RM leg press for young and older adults. Data are presented as mean and 95% confidence intervals with p-values.

p=0.005). Similarly, seated row increased in young adults (Figure 2A: 81.5 ± 23.0 kg to 89.9 ± 29.4 kg; p< 0.001) and in older adults (Figure 2B: 74.9 ± 28.9 kg to 79.5 ± 27.9 kg; p< 0.001) after the intervention. However, no significant differences were observed between age groups (Figure 1C, 2C; p>0.05). Both young (Figure 3A; 64.1 ± 18.7 kg to 81.4 ± 26.9 kg; p<0.001) and older adults (Figure 3B; 46.2 ± 18.7 kg to 55.6 ± 23.7 kg; p<0.001) significantly improved knee extension, however young adults demonstrated a greater increase compared to older adults (Figure 3C; p=0.010) even after adjusting for ethnicity (p=0.010). Similar results were observed for knee flexion

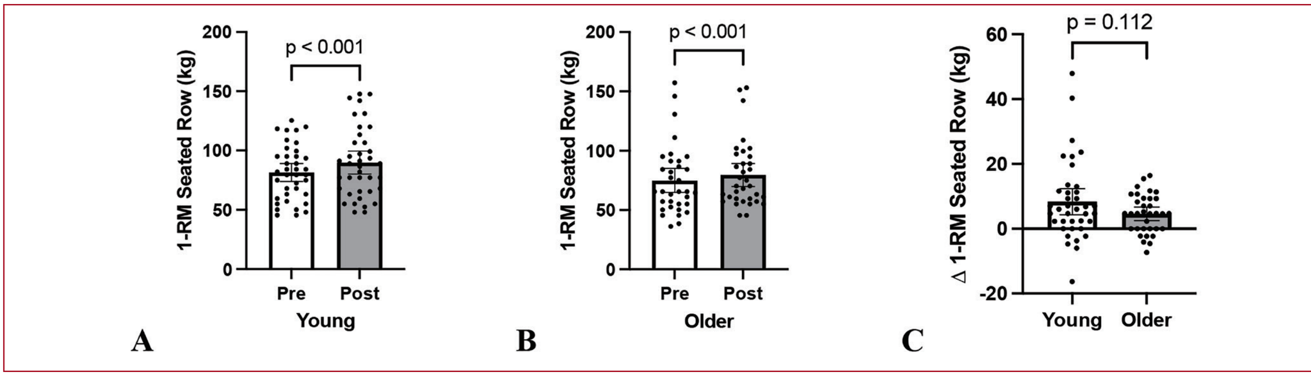

Figure 2. A. 1-RM seated row of young adults at baseline and post-testing. B. 1-RM seated row of older adults at baseline and post-testing. C. Absolute change of 1-RM seated row for young and older adults. Data are presented as mean and 95% confidence intervals with p-values.

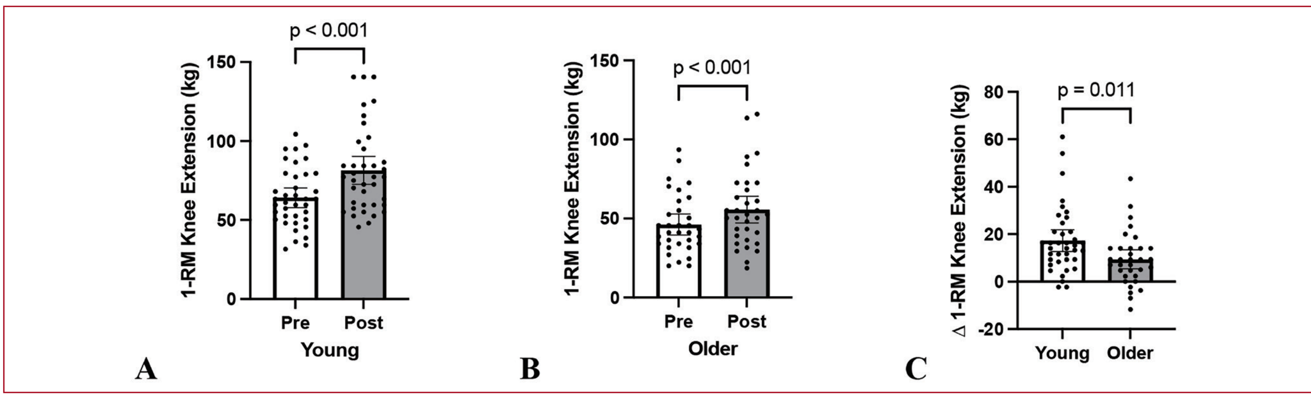

Figure 3. A. 1-RM knee extension of young adults at baseline and post-testing. B. 1-RM knee extension of older adults at baseline and post-testing. C. Absolute change of 1-RM knee extension for young and older adults. Data are presented as mean and 95% confidence intervals with p-values.

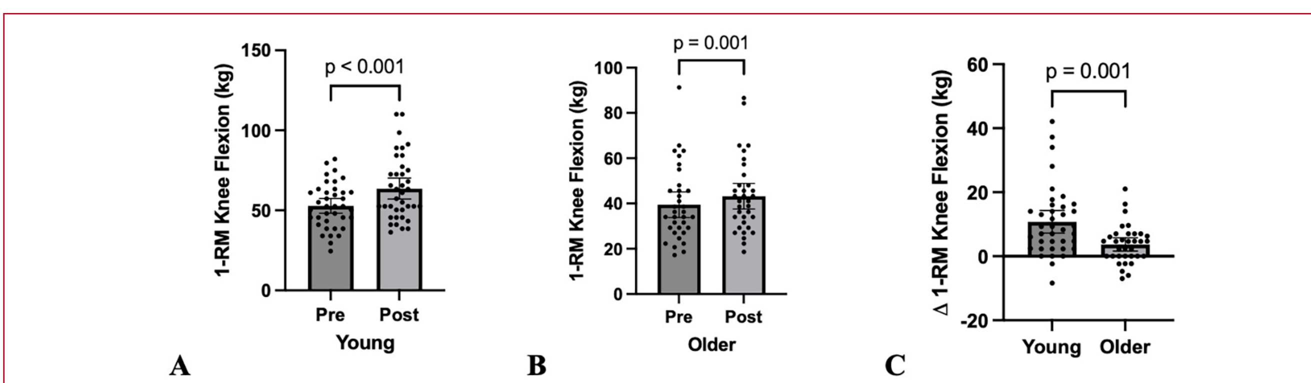

Figure 4. A. 1-RM knee flexion of young adults at baseline and post-testing. B. 1-RM knee flexion of older adults at baseline and post-testing. C. Absolute change of 1-RM knee flexion for young and older adults. Data are presented as mean and 95% confidence intervals with p-values.

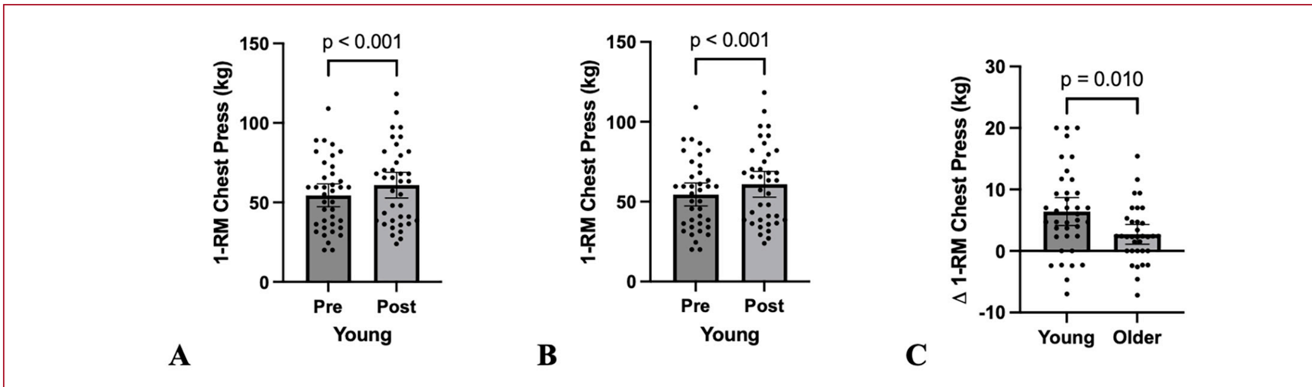

Figure 5. A. 1-RM chest press of young adults at baseline and post-testing. B. 1-RM chest press of older adults at baseline and post-testing. C. Absolute change of 1-RM chest press for young and older adults. Data are presented as mean and 95% confidence intervals with p-values.

	Young (n=38)			Old (n=34)		
	Pre	Post	*p*-value	Pre	Post	*p*-value
Isokinetic Dynamometry						
KE Peak Torque (Nm)	120.3 ± 39.6	128.0 ± 41.9	0.005	74.4 ± 33.1	76.3 ± 29.4	0.355
KF Peak Torque (Nm)	51.1 ± 19.7	59.4 ± 24.8	<0.001	31.9 ± 15.6	34.0 ± 15.2	0.207*
KE Average Power (Watts)	183.8 ± 68.3	204.0 ± 70.8	<0.001	111.1 ± 50.1	116.2 ± 46.6	0.185*
KF Average Power (Watts)	82.0 ± 35.6	97.1 ± 37.8	<0.001	47.6 ± 26.4	51.4 ± 25.8	0.248*
KE Total Work (Nm)	2988.3 ± 1011.8	3358.1 ± 1031.0	<0.001	1819.8 ± 842.5	2028.7 ± 797.7	0.008
KF Total Work (Nm)	1174.4 ± 509.2	1407.8 ± 580.1	<0.001	615.2 ± 428.7	738.3 ± 460.9	0.049
Senior Fitness Test						
Chair Stands (amount/30s)	18.4 ± 5.4	20.8 ± 5.3	<0.001	15.8 ± 5.6	18 ± 5.7	<0.001
Arm Curls (amount/30s)	19.1 ± 4.1	23.6 ± 4.6	<0.001	18.3 ± 3.9	21.3 ± 3.4	<0.001*
8ft TUG (seconds)	5.3 ± 0.8	5.1 ± 0.6	0.025	6.6 ± 1.9	6.4 ± 1.8	0.142

*Variables are presented as means ± standard deviation. KE: Knee Extension, KF: Knee Flexion, Nm: Newton-meter, TUG: Timed Up-and-Go. * represents significant difference between groups using an independent sample t-test. Alpha level at 0.05.*

Table 3. The impact of 6-week BFRT on isokinetic performance and physical function of young and older groups.

(Figures 4A,B,C; all p-values <0.05) and chest press (Figures 5A,B,C; all p-values<0.05).

Changes in Isokinetic Performance

Young adults significantly increased knee flexion peak torque (51.1 ± 19.7 Nm to 59.4 ± 24.8 Nm; p<0.001; Table 3) while no such improvement was observed in older adults (31.9 ± 15.6 Nm to 34.0 ± 15.2 Nm; p=207). Change in knee flexion peak torque was significantly different between age groups (p<0.05). Similarly, knee extension average power (183.8 ± 68.3 watts to 204.0 ± 70.8 watts; p<0.001), and knee flexion average power (82.0 ± 35.6 Nm to 97.1 ± 37.8 Nm; p<0.001) significantly improved in young adults only, and significant differences were observed between age groups (p<0.05). A significant difference was observed between age groups for knee flexion peak torque and knee flexion and extension average power. When adjusting for ethnicity, there was a significant age group difference for knee flexion peak torque (p=0.043) and knee extension average power (p=0.028).

Changes in Senior Fitness Test

Young adults saw a significant improvement in the amount of chair stands (p<0.001) and arm curls (p<0.001) performed in 30 seconds from baseline to post-intervention, as well as a decrease in the 8-foot timed up-and-go test (p=0.025). Older adults saw an improvement in the chair stands (p<0.001) and arm curls (p<0.001), but not the 8-foot timed up-and-go (p=0.142). Changes in arm curls were significantly different between groups (p=0.029), but not after adjusting for ethnicity (p>0.05)

Discussion

The main objective of this study was to investigate age-related differences in adaptation following 6 weeks of BFRT on LBM, muscle strength, muscular performance and physical function. There are several relevant findings from this study to help manage the loss in LBM and functional outcomes in older adults. First, after accounting for potential confounders a significant improvement in LBM was observed in young adults but not in older adults. Second, despite no improvement in LBM in older adults, both young and older adults significantly improved muscle strength, with young adults displaying a greater adaptation. Third, only young adults improved muscular performance with young adults displaying a greater adaptation. Both young and older adults significantly improve physical function without differences between groups. These results are important as they fill a gap in the literature surrounding the impact of BFRT and the age-related differences in adaptation for LBM, muscle strength, muscular performance, and physical function and might help provide better exercise prescriptions for countering or delaying age-related LBM and physical function loss.

Six weeks of BFRT resulted in a significant increase in LBM and relative LBM for young adults, but not for older adults. This result is surprising as previous studies of BFRT have shown increases in LBM following an intervention of BFRT in adults of all ages[28,29,38,39]. The results of the current study might be explained by the selected pressure. In fact, the total AOP was estimated from a formula validated only in young individuals. Nevertheless, our pressure estimates align with what has been reported in the literature of older adults. In addition, a meta-analysis found that a maximum cuff pressure of 200mmHg was ideal to optimize training effect[25], which aligns with our study. Furthermore, we use the KAATSU system, which is different than the tourniquet system used in studies of older adults[29,32]. The tourniquet system allows constant pressure through the whole range of motion, which was not the case with the KAATSU device. Therefore, it is possible that participants in our study did not have enough stress from the device to get a hypertrophic response. However, this hypothesis is unlikely as the KAATSU system actually creates more pressure while moving through the range of motion. Also, many studies using KAATSU devices have observed improvements in LBM and muscle strength following BFRT[40]. In contrast, our results align closely with typical resistance training interventions in older adults, suggesting that increasing LBM in this population only happens in 50% of the studies[15]. The findings of this study are important as they add to the current body of BFRT literature by confirming earlier research on resistance training in older adults, providing a direct comparison among young and older adults, and highlighting the presence of LBM age-related differences following 6 weeks of BFRT.

Following 6 weeks of BFRT, we demonstrated that young and older adults improved their muscle strength, with the young individuals improving to a greater extent than older adults. This result aligns closely with other studies, which have shown that both young and older adults improve muscle strength following BFRT[24,28,29,39,41,42]. Therefore, BFRT has been proposed as an alternative methodology to heavy resistance training[43]. However, studies comparing high-load resistance training and low-load BFRT, confirm that the gain in muscle strength with low-load BFRT is significantly less than high-load resistance training[39,44]. Nevertheless, previous studies that selected individuals aged 50 years and younger that confirmed a meaningful increase in muscle strength with BFRT carried a selection biase . This is important especially if muscle strength is age-dependant. Our study overcomes this bias as our average age for the older adult group was 73 years and we did direct age-group comparisons between young and older adults. As such, our findings continue to add to the current body of literature by demonstrating that BFRT can increase strength in both young and older adults, but young adults may increase strength to a greater extent than older adults.

Our results showed a significant increase in all muscular performance measures for young adults, but only in total work for older adults. These results align with a meta-analysis showing that low-load BFRT is effective in improving knee flexor and extensor peak torque for adults of all ages[25]. Moreover, at 180° per second for 10 repetitions, knee extension and knee flexion peak torque have improved significantly following BFRT[45]; however, participants were all young, male, and physically active. Therefore, our results are consistent with the existing literature for young adults, but add to the whole body of evidence of BFRT in older adults and show inconsistency with other studies of older adults as they did not improve peak torque for knee extension or knee flexion. Although, it appears that the high volume repetition scheme used in our BFRT intervention was sufficient to improve work capacity in older adults for both knee extension and flexion. Our results continue to build on how BFRT impacts knee flexion and extension isokinetic performance, and how age-related adaptations differ between young and older adults.

Strengths and Limitations

The present study has some limitations that need to be highlighted. First, a control group was not included in this study which limits the conclusions that can be drawn. Second, this intervention had a short duration of 6 weeks, and it is possible that different age-related outcomes could have been observed over a longer duration intervention. Third, it is possible that a greater stimulus is require to maximize muscle hypertrophy in older adults, however this studies suggest that resistance training between 20-50% of 1-RM with BFRT provides similar LBM grainas resistance training performed abovbe 70% of 1-RM[46,47]. Finally, although participants were asked to maintain their current lifestyle, food was not provided to control for change in micronutrients and caloric intake. Nevertheless, no participants reported changes in dietary behaviours. Our study was strengthened by the very close supervision from our research staff of each participant during the delivery of the intervention exercise sessions. Also, adherence to the intervention was very high at 94% (17/18 sessions) potentially driven by the flexible schedule and the same research staff supervising the same participants. Furthermore, statistical analyses were adjusted for potential confounders and tools used to quantify primary and secondary outcomes had great metrics ensuring the validity of the observed results.

Conclusion

In summary, our findings highlight the age-specific differences in adaptation following 6-weeks of BFRT with young adults displaying significantly greater improvement for changes in LBM, muscle strength, and performance outcomes compared to older adults. These results are important as they highlight the potential clinical benefits of BFRT in older adults who might present a reduced capacity to adapt to resistance training in terms of strength and LBM when compared to young adults. More studies may want to study the feasibility of BFRT in clinical populations with chronic conditions such as Type 2 diabetes.

Ethics approval

The project was reviewed and approved by the University of New Brunswick Research Ethics Board (REB 2021-124).

Consent to participate

All participants provided freely-given, written informed consent prior to participation.

Authors' contributions

Contribution of the concept and design of the work: Julia K. Arnason, Martin Sénéchal. Data Acquisition: Julia K. Arnason, Amy M. Thomsom, Logan E. Peskett, Dawson A. Nancekievill. Data Analysis and Interpretation: Julia K. Arnason, Martin Sénéchal. Drafting the work or critically reviewing the work: Julia K. Arnason, Amy M. Thomsom, Logan E. Peskett, Dawson A. Nancekievill, Danielle R. Bouchard, Martin Sénéchal. Agreement to be accountable for all aspects of the work: Julia K. Arnason, Amy M. Thomsom, Logan E. Peskett, Dawson A. Nancekievill, Danielle R. Bouchard, Martin Sénéchal. All authors read and approved the final version of the manuscript.

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Absolute contraindications for BFRT	Other conditions requiring precaution
Peripheral vascular disease	Cognitive impairment
Venous thromboembolism	High blood pressure
Blood clotting disorders	Stroke or transient ischaemic attack
Skin graft on arms or legs	Coronary heart disease
Vascular surgery to arms or legs	Diabetes mellitus
Deep vein thrombosis	Sickle cell diseases
Pulmonary embolism	Compartment syndrome
Arteriovenous fistula	Nerve damage
Haemophilia	Cardiopulmonary conditions
	Myocardial ischemia
	Cancer
	Atrial fibrillation
	Heart failure
	High cholesterol
	Varicose veins
	Atherosclerosis
	Rhabdomyolysis

Supplementary Table 1. Conditions screened for prior to participation in the BFR study.