

# The Safety of Blood Flow Restriction Combined with Stepping Aerobic Exercise in Older Adults with Sarcopenia

Hui Zhang<sup>1,2,\*</sup>, Shulian Liu<sup>3,\*</sup>, Zhiyu Mao<sup>2</sup>, Kewen Niu<sup>2</sup>, Xinwei Li<sup>2</sup>, Tongtong Yin<sup>2</sup>, Fangfang Wang<sup>2</sup>, Li Wang<sup>2</sup>

<sup>1</sup>School of Nursing, Suzhou Vocational Health College, Jiangsu, 215009, People's Republic of China; <sup>2</sup>School of Nursing, Suzhou Medical College of Soochow University, Suzhou, Jiangsu, 215006, People's Republic of China; <sup>3</sup>Luoyang Polytechnic, Henan, 471000, People's Republic of China

\*These authors contributed equally to this work

Correspondence: Li Wang, School of Nursing, Suzhou Medical College of Soochow University, No. 1 Shizi Street, Suzhou, Jiangsu, 215006, People's Republic of China, Tel +86-512-6522-1499, Fax +86-512-6512-5097, Email li-wang-l@suda.edu.cn

**Purpose:** This study aimed to explore the safety of blood flow restriction combined stepping aerobic exercise (BFR-SAE) using elastic and non-elastic cuffs at varying pressures in older adults with sarcopenia.

**Methods:** Older adults with sarcopenia were selected by convenience sampling method and underwent BFR-SAE using elastic and non-elastic cuffs at 20%, 40%, and 60% limb occlusion pressure (LOP). Exercise response and adverse events were recorded.

**Results:** Thirty-one participants (84.81 ± 6.19 years old) completed the tests. During the non-elastic cuffs test, 31 participants completed at 20% LOP, and 4 (12.9%) dropped from 40% to 20% LOP. At 60% LOP, 19 (61.3%) and 3 (9.7%) dropped to 40% and 20% LOP, respectively. In the elastic cuffs tests all participants completed at 20% and 40% LOP. At 60% LOP, 9 (29.0%) dropped to the interface pressure corresponding to 40% LOP. General exercise responses were lower with elastic cuffs at 40% LOP (22.6% vs 45.2%) and 60% LOP (41.9% vs 51.6%), with higher completion rate than non-elastic cuffs (40% LOP: 100% vs 87.1%; 60% LOP: 71.0% vs 29.0%). Among the results of systolic and diastolic blood pressure (SBP and DBP), pulse rate (P) and pulse oxygen saturation (SpO<sub>2</sub>), differences were found in BP and P at different time points ( $P < 0.05$ ) within each pressure, but no significant difference between different pressures. Non-elastic cuffs caused significant increases in SBP, DBP, and P from rest, while only SBP and P showed significant increases in elastic cuffs group. Pain scores were 0 for both cuffs after tests, the adverse events rate was 1.1% and rating of perceived exertion all reached moderate-intensity of exercise.

**Conclusion:** Elastic cuffs for BFR-SAE induced milder exercise responses and higher completion rates, suggesting better safety and feasibility than non-elastic cuffs in older adults with possible sarcopenia.

**Keywords:** blood flow restriction, aerobic exercise, sarcopenia, safety, older adults

## Introduction

The worldwide population aged 65 and above is expanding at an unprecedented pace, with projections indicating it will reach 1.6 billion by 2050.<sup>1</sup> The older adults are the main group of chronic diseases, and sarcopenia is one of the common chronic diseases of them. With aging, the prevalence of sarcopenia will also increase sharply, bringing a huge care burden to families and society. The decrease of muscle strength and mass in older adults with sarcopenia significantly reduces the activity ability of daily life.<sup>2</sup> It further aggravates the progression of sarcopenia, resulting in many serious effects, such as falls, fractures, poor quality of life, and disability.<sup>3</sup> Exercise, as a non-drug treatment of sarcopenia, remains a research hotspot.<sup>4,5</sup>

The American College of Sports Medicine (ACSM) and American Heart Association (AHA) recommend the older adults to perform low-intensity aerobic exercise (AE) as transition at the initial stage and take resistance exercise (RE)

based on their exercise and physical condition at a later stage.<sup>6</sup> In addition to significantly improving cardiopulmonary fitness, AE may also improve muscle fitness by reshaping the contraction of muscle fibers.<sup>7</sup>

Blood flow restriction training (BFRT) combines vascular occlusion with concurrent exercise. The exercise is not much fundamentally different from traditional exercise and could be RE or AE.<sup>8</sup> BFRT has been shown to be more effective in improving physical fitness and producing multiple benefits.<sup>9–11</sup> It can achieve similar high-intensity exercise effects at lower intensity,<sup>12,13</sup> producing more optimized exercise effects than simple exercise at the same intensity.<sup>14</sup> Studies have shown that blood flow restriction (BFR) combined with low-intensity AE can more effectively promote muscle hypertrophy and strength than AE alone.<sup>15</sup> BFRT can also better promote hormone release and speed up metabolism,<sup>16</sup> and has achieved good results in improving muscle fitness and cardiorespiratory fitness in some disease groups<sup>17</sup> and athletes,<sup>18</sup> but research in older adults with sarcopenia is still in its infancy.

People with sarcopenia are usually accompanied by other chronic diseases, such as hypertension, diabetes and osteoporosis, and extra care should be taken during exercise training. Although the adverse events of BFRT, such as limb bruising, rhabdomyolysis, numbness and cardiovascular accidents are rarely reported in healthy people and other populations,<sup>19–21</sup> the safety in individuals with sarcopenia is unknown.<sup>22,23</sup>

BFR application reduces blood flow, while its release triggers a rapid rebound increase, resulting in ischemia-reperfusion. It is necessary to consider the possibility of this training causing pressure or muscle damage, cardiovascular adverse events.<sup>24</sup> Current evidence lacks comprehensive documentation of potential BFRT-related adverse events in sarcopenia. Further large-scale studies are required to establish these risks, identify sensitive safety markers, and develop preventive protocols to ensure participant safety during training.

The purpose of this study was to investigate the safety and feasibility of BFR combined with stepping aerobic exercise (BFR-SAE) in older adults with sarcopenia, comparing non-elastic versus elastic cuffs at varying pressures. The findings were expected to provide practical guidance for cuff selection, pressure optimization, and BFRT prescription in this population.

## Materials and Methods

### Participants

Older adults were screened through convenience sampling method at a nursing home from October 2022 to January 2023 in Suzhou. The eligible participants met the following inclusion criteria: conformed to the 2019 Asian Working Group for Sarcopenia (AWGS) diagnostic criteria for sarcopenia, possible sarcopenia, or low muscle mass (pre-sarcopenia), able to communicate, and willing to participate in the study.<sup>25</sup> The exclusion criteria included serious cardiovascular diseases or the acute stage of diseases (such as acute myocardial infarction), lower limb disease (such as deep vein thrombosis or bone and joint surgery within 6 months), using anticoagulant drugs, using the drugs that can affect heart rate (such as  $\beta$ -blocker, anticholinergic drugs, calcium antagonist, etc.), hypertension that cannot be controlled by drugs ( $\geq 150/100$  mmHg), exercise contraindications (such as respiratory failure).

All participants were fully informed of the study content and potential risks before they signed the consent form.

### Procedures

All older adults residing in the nursing home underwent initial screening by researchers through a review of their medical records. Potentially eligible participants then underwent anthropometric and functional assessments, including measurements of height, weight, appendicular skeletal muscle mass index (ASMI), handgrip strength, and the 5 Times Sit-To-Stand test (5TSTS) further eligibility determination. Eligible individuals subsequently completed additional evaluations on a separate occasion, encompassing blood pressure (BP), resting heart rate ( $HR_{rest}$ ), and pulse oxygen saturation ( $SpO_2$ ) measurements. Furthermore, lower limb ultrasound examinations were conducted to rule out lower extremity thrombus, followed by assessments of limb occlusion pressure (LOP) and interface pressure.

After the above measurements, participants received the test of SAE alone for determination of suitable stepping exercise resistance. Based on this, two sessions of tests followed, which were ① BFR with non-elastic cuffs combined

with SAE (abbreviated as non-elastic test) and ② BFR with elastic cuffs combined with SAE (abbreviated as elastic test). In order to avoid bias, participants with odd numbers in their recruiting order accepted the tests with the order of ①-② (group A) and the ones with even numbers had the order of ②-① (group B). BP, heart rate (HR), and SpO<sub>2</sub> were measured before, during (every 5 minutes), and after test (5 minutes later) of each session. Rating of perceived exertion (RPE), pain score and the adverse events were recorded after test.

The study procedure and protocol are summarized in Figure 1.

## Test Protocols

The SAE test consisted of 5 sessions (one session per day, 10 to 20 minutes per session) and lasted for a continuous of 5 days. It was performed with a stepping machine (Jiujian, SCS1, China) and the stepping mileage was automatically recorded. The stepping resistance (ranged from levels 1 to 12, the larger level represented the greater resistance) was adjusted according to the RPE and HR of each participant. According to HR<sub>rest</sub> and age, maximal heart rate (HR<sub>max</sub>), heart reserve rate (HRR) and target heart rate (THR) at low and moderate AE of each participant were calculated.<sup>26</sup> The specific calculation formulas were as follows: HR<sub>max</sub> = 207 - 0.7 × age, HRR = HR<sub>max</sub> - HR<sub>rest</sub>, low-intensity AE: THR = (30%~39%) × HRR + HR<sub>rest</sub>, moderate-intensity AE: THR = (40%~59%) × HRR + HR<sub>rest</sub>.<sup>27</sup> Additionally, RPE was also applied to help maintain the suitable intensity of exercise. RPE was measured immediately after each test using the Borg scale.<sup>26</sup> The scale ranges from 6 to 20, RPE 10~11 stands for low-intensity, 12~13 stands for moderate-intensity, and ≥14 for high-intensity.

In the first day, every participant did a 10-minute test using the stepping machine at a prescribed stepping resistance level (level 2) which was proven properly in previous investigations in our laboratory in healthy population. BP, HR, and SpO<sub>2</sub> were measured before exercise (0 min), during (every 5 mins), and after (5 mins after the test) the exercise. RPE was recorded immediately after the exercise test finished. In the second and third days, tests lasted for 15 and 20 minutes, respectively. During the 5 sessions, the intensity of exercise gradually increased from low to moderate. Based on these tests, the suitable stepping resistance level for each person were determined.

In the BFR-SAE tests, participants put on either non-elastic or elastic cuffs and BFR were performed during the stepping exercise. The non-elastic cuffs were wide rapid-inflation pneumatic tourniquet (Yanling, China; 7.6 cm wide × 120 cm long) and the elastic cuffs were pneumatically controlled cuffs (BStrong, United States; 7.5 cm wide × 105 cm long).<sup>28,29</sup>

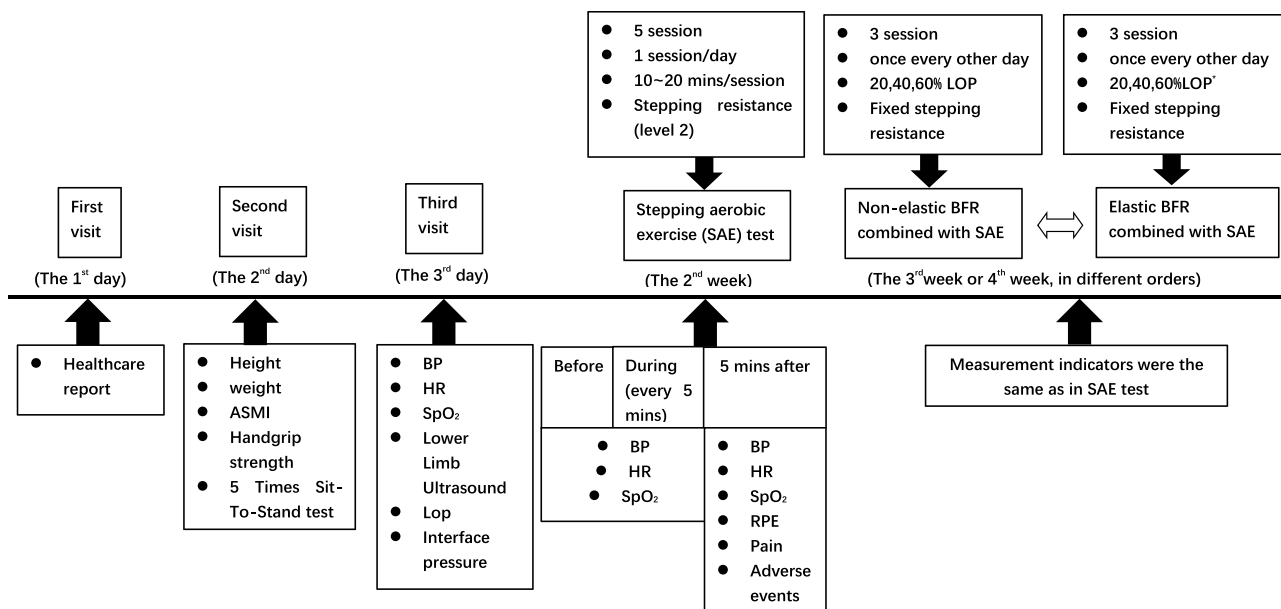


Figure 1 The study procedure and protocol.

The non-elastic test consisted of three 20-minute sessions conducted over a week (every other day), with each session using 20%, 40%, and 60% LOP, respectively. Every participant wore non-elastic cuffs and did SAE at fixed stepping resistance (which was determined based on the SAE alone). The inflation pressure was maintained the same during the test in each session. If the participant felt too tight to continue the test, the researchers would reduce pressure by 20% to ensure the test to be finished.

The elastic cuff protocol comprised three 20-minute sessions administered on alternate days over one week. Each session implemented progressively increasing pressures corresponding to 20%, 40%, and 60% of the non-elastic cuff's LOP (judged by interface pressure), denoted as 20% LOP\*, 40% LOP\* and 60% LOP\* to differentiate from the non-elastic device's pressures. Except for wearing the elastic instead of non-elastic cuffs, all other procedures were the same as the non-elastic test. The parameters measured in both non-elastic and elastic tests were the same as in the SAE alone.

## Measurements

A self-designed questionnaire was used to collect basic characteristics, sarcopenia diagnostic indicators, and other health-related metrics. Basic characteristics include sex, age, height, and body weight. Sarcopenia diagnosis indicators include grip strength, 5TSTS and ASMI. Other health-related metrics included resting BP and HR, the presence of hypertension, and medication which could influence HR.

Before distributing the questionnaire, the researcher provided detailed explanation about the study's purpose to each participant. The questionnaires were completed uniformly by the researcher through direct inquiry and measurement and were collected immediately upon completion. After collection, the researcher thoroughly reviewed each questionnaire to identify and correct any errors or omissions. Any issues found were resolved on the spot.

The diagnostic indicators and criteria for sarcopenia included the following:<sup>25</sup> ① handgrip strength (male < 28 kg, female < 18 kg), ② 5TSTS  $\geq$  12s; and ③ ASMI (male < 7.0 kg/m<sup>2</sup>, female < 5.7 kg/m<sup>2</sup>). Participants meeting criteria ① and ③ or ② and ③ are diagnosed with sarcopenia. Those meeting all three criteria (①, ② and ③) are classified as severe sarcopenia. Meeting either ① or ② suggests possible sarcopenia, while meeting only ③ indicates low muscle mass. The individuals with sarcopenia, severe sarcopenia, possible sarcopenia, or low muscle mass (pre-sarcopenia) were included in our study.

The upper limb muscle strength was assessed using a hand grip dynamometer (Jamar, 563213, USA). Participants sat upright on a 46 cm-high chair with their upper arms in a neutral position and their forearms bent at a 90° angle. After completing two practice trials, participants performed the test by maintaining the grip with their dominant hand in the described position for three seconds. This was repeated three times in total, with a 30-second rest between each attempt. The highest value among the three trials was recorded as the measurement result.<sup>30</sup>

The physical function was assessed using the 5TSTS. The participant sits on a 43 cm-high chair placed against a wall, with their legs naturally apart, arms crossed in front of their chest, and back kept straight. Upon the researcher's prompt to "Start", participant rose from the chair, stand up, and then sat back down. The time (in seconds) required for five full cycles of standing up and sitting down was recorded. A shorter time indicated better lower limb muscle strength.<sup>31</sup>

ASMI was estimated with bioelectrical impedance analysis (BIA) using a portable body composition tester (INBOBY, S10, Korea). Participants were asked to avoid strenuous exercise, excessive water consumption, and eating prior to the test. During the test, they were asked to remove magnetic objects such as metal ornaments and mobile phones, as well as shoes, socks, and heavy clothing. Participants were advised to stay relaxed to prevent muscle hypercontraction. They remained seated position and required to stay silent throughout the procedure.

LOP was measured using an ultrasonic Doppler blood flow detector (Bestman, BV-520T, China) while participants wore non-elastic BFR cuffs. Participants remained seated, and the blood flow probe was placed at a 45° angle on the dorsal foot artery. Non-elastic cuffs were applied to both lower limbs, close to the inguinal region, and gradually inflated. When the waveform displayed on the screen became a straight line and the artery sound disappeared, the cuffs were deflated after 10 seconds. The LOP was determined when the waveform and artery sound reappeared, and the corresponding value on the pressure gauge connected to the cuffs was recorded.

Interface pressure was measured following the method described in previous literature.<sup>32</sup> The participants remained seated, and the pressure test balloon was positioned under the non-elastic BFR cuffs. Interface pressure values were

recorded when the inflation reached 20%, 40% and 60% of the LOP, respectively. These three interface pressure values were then used as reference points for inflating the elastic BFR cuff during the BFR-SAE test, ensuring the interface pressures reached the same levels.

BP and HR were measured using a wrist electronic BP monitor (OMRON, 18F052-21, China) while participants remained seated, ensuring the same arm, instrument, and time were used for consistency. SpO<sub>2</sub> was measured using a finger pulse oximeter (Yuyue, YX102, China).

RPE was assessed immediately after each test. Participants were familiarized with the Borg scale<sup>26</sup> prior to the test and asked to rate their perceived exertion. The scale ranges from 6 to 20, where 10–11 and 12–13 represents low-intensity and moderate-intensity, respectively.

The Numerical Rating Scale (NRS) was used to assess physical pain after exercise. The scale ranged from 0 (no pain) to 10 (the most severe pain). Participants selected a number from 0 to 10 to describe the pain level.<sup>33</sup>

Adverse events were recorded by the researchers, including the time of the occurrence, the methods used to address them. Researchers and medical staff were present during the exercise test to manage any adverse events promptly. Documented adverse events encompassed a range of conditions including: dizziness, vomiting, limb numbness/paresthesia, subcutaneous hemorrhage, rhabdomyolysis, acute heart failure, asthma exacerbation, ecchymoses, falls, and in extreme cases, sudden death.

## Statistical Analyses

Statistical analyses were performed using SPSS software (version 25.0; IBM, United States). The Shapiro–Wilk test was conducted to check the normality of all the parameters. Quantitative variables with normal distributions were presented as means ± standard deviations (s). Qualitative variables were presented as numbers (percentages). Descriptive analysis method was used for exercises completion, adverse reactions under different cuffs and pressures. Repeated measures analysis of variance was used for BP and other indicators during exercise tests with a ball test was performed in advance. When the ball test was not passed, the Green-House correction method was used to analyze the main effects and interaction effects between groups and time, respectively, and then a simple effect analysis between groups and time was performed.  $P < 0.05$  is statistically significant, and this test is a two-sided test.

All the data in this study was restricted to scientific research use only. All the data were recorded and reviewed by two researchers to ensure accuracy.

## Results

A total of 120 individuals aged 60 years and older were recruited. After screening with sarcopenia diagnosis, 40 individuals met the inclusion criteria, and 33 participants who signed informed consent were included in the study. A total of 31 individuals finally completed all the 11 sessions of exercise tests, with a dropout rate of 6.06% (Figure 2).

### General Information of Study Participants

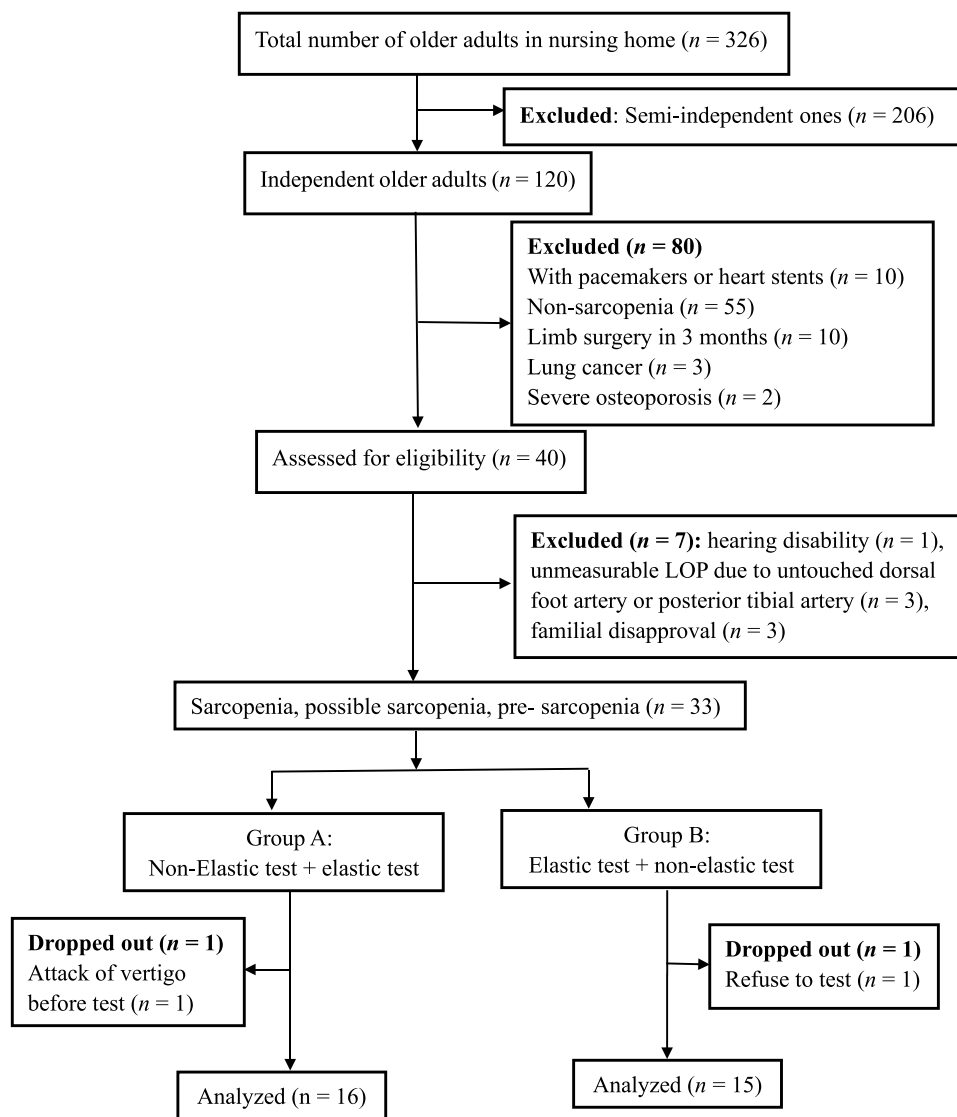
The 31 participants who completed the tests included 5 males (16.13%) and 26 females (83.87%), aged 84.81±6.19 years, and all diagnosed as possible sarcopenia. Among them, 18 had a history of hypertension. None of the participants were taking medications known to affect heart rate, and there were no changes in medication use during the intervention period. Data of participants' basic characteristics, sarcopenia diagnosis indicators, and health-related indicators are shown in Table 1.

### Intervention Completion Status

#### Completion of BFR-SAE with Non-Elastic and Elastic BFR Cuffs Under Different Pressures

The inflation pressures for the non-elastic BFR cuffs were set to be 20%, 40%, and 60% LOP. The corresponded interface pressures at each pressure level were measured and used as the pressures for elastic cuffs (denoted as 20%, 40%, and 60% LOP\*).

In the non-elastic test, all 31 participants successfully completed the trial at 20% LOP. However, at higher pressure levels, some participants required adjustments: at 40% LOP test, 4 participants (12.9%) had their pressure reduced to



**Figure 2** Flow chart of the study.

20% LOP; at 60% LOP test, 19 participants (61.3%) were adjusted to 40% LOP, while 3 (9.7%) were further reduced to 20% LOP. In elastic tests, all 31 participants completed the trials at 20% and 40% LOP\* while 9 participants (29.0%) had their pressure reduced to 40% LOP\* at the 60% LOP\* trial.

In total, 9 participants completed tests under low, medium, and high pressures with non-elastic cuffs, while 22 completed testing with elastic cuffs (Table 2).

### Comparison of Pressures of Different BFR Cuffs Used by Participants

Participants' LOP was  $254.52 \pm 34.37$  mmHg, with the corresponded interface pressure of  $223.81 \pm 28.61$  mmHg. In the intervention trials, the inflation pressure (prescribed) and actual inflation pressure (actually finished) of the elastic cuffs with 20% LOP\*, 40% LOP\*, and 60% LOP\* were higher than those of the non-elastic cuffs (Figure 3).

### Exercise Intensity Achieved by Participants

Exercise intensity was assessed based on the target THR. Twenty-one participants achieved low-intensity, while nine achieved moderate-intensity aerobic exercise. According to RPE, all participants achieved moderate-intensity. Notably, four participants had RPE scores reaching 14 during non-elastic cuff tests.

**Table 1** Participant Characteristics

	<i>n</i> (%) $\bar{x} \pm s$
<b>Basic characteristics</b>	<i>n</i> =31
Gender (male/female)	5(16.13)/26(83.87)
Age (year)	84.81±6.19
Height (cm)	1.56±0.09
Weight (kg)	59.52±10.21
<b>Indicators related to sarcopenia diagnosis</b>	
Grip strength (male/female) (kg)	27.20±7.01/18.24±3.33
5-time chair stand test (s)	13.62±7.86
ASMI (male/female) (kg/m <sup>2</sup> )	9.02±0.52/7.67±0.87
<b>Indicators related to health</b>	
With/without hypertension	18(58.06)/13(41.94)
With/without drugs decreasing or increasing HR	0(0)/100(100)
SBP (mmHg)	135.61±13.98
DBP (mmHg)	76.41±9.60
HR <sub>rest</sub> (beats/min)	74.38±8.70
HR <sub>max</sub> (beats/min)	140.08±4.41
HRR (beats/min)	78.72±9.79
THR at low intensity (beats/min)	93.90±6.85~101.00±6.18
THR at moderate intensity (beats/min)	101.79±6.10~116.76±4.91

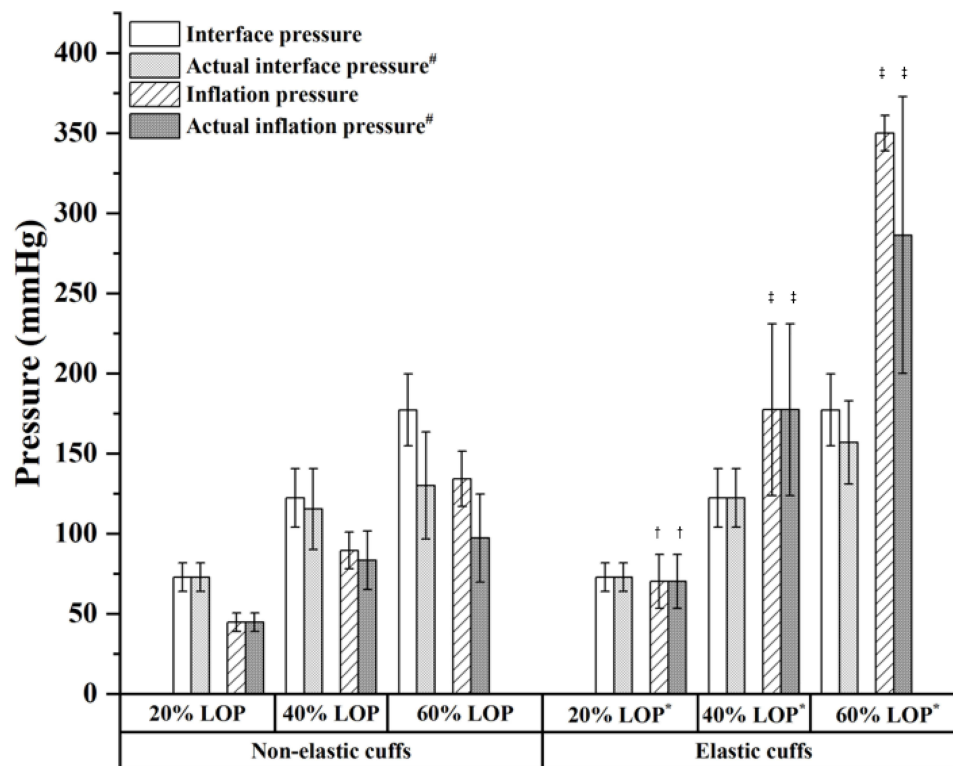
**Abbreviations:** ASMI, appendicular skeletal muscle mass index; HR, heart rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; HR<sub>rest</sub>, resting heart rate; HR<sub>max</sub>, maximal heart rate; HRR, heart reserve rate; THR, target heart rate.

**Table 2** Comparison of the Participants' Exercise Completion Rate Under Different Pressures Using Different BFR Cuffs, *n* (%)

	Non-Elastic Cuffs			Elastic Cuffs		
	20% LOP	40% LOP	60% LOP	20% LOP*	40% LOP*	60% LOP*
Decreased to 20% LOP	31(100)	27(87.1)	9(29.0)	31(100)	31(100)	22(71.0)
Decreased to 40% LOP		4(12.9)	3(9.7)			
Decreased to 40% LOP*			19(61.3)			9(29.0)

**Notes:** \* inflation pressure under interface pressure corresponding to 20%, 40% and 60% LOP of non-elastic cuffs, the same description to all the following tables.

**Abbreviation:** LOP, limb occlusion pressure.



**Figure 3** Comparison of pressures between different BFR cuffs.<sup>#</sup>: During protocol implementation, participants who reported excessive cuff pressure had their inflation levels reduced by 20% LOP while continuing exercise. All participants (100%) successfully completed the 20% LOP trials, confirming that achieved pressures matched target values. However, at higher pressure levels (40% and 60% LOP), a subset of participants required downward pressure adjustments, resulting in actual inflation pressures below the prescribed percentages of their individual LOP measurements; †:  $P < 0.05$ , compared to the corresponding pressure of the non-elastic cuffs; ‡:  $P < 0.01$ , compared to the corresponding pressure of the non-elastic cuffs.

**Abbreviation:** LOP, limb occlusion pressure.

### Stepping Resistance Levels and Power During BFR-SAE

The participants completed 6 exercise tests (three non-elastic and three elastic tests), with an average stepping resistance level of  $4.19 \pm 1.99$ . Using the formula for calculating power ( $P$ ),  $P = FV$  (force  $\times$  velocity), where  $F$  represented the weight corresponding to different resistance levels multiplied by gravitational acceleration ( $9.8 \text{ m/s}^2$ ) and  $V$  was the total distance covered in the six tests (total cycling laps  $\times 0.75 \text{ m}$ )/the total time (20 minutes  $\times 60$  seconds  $\times 6$  tests), the average power during the exercise tests was  $27.24 \pm 9.25$  watts.

### General Exercise Response, Adverse Events, and Pain During BFR-SAE

During the testing, participants reported fatigue in the left leg, right leg, both legs, hips, lower back, and excessive sweating, all of which were considered general exercise responses. The incidence rate of the general exercise response with elastic cuffs (23.7%) was lower than that of non-elastic cuffs (37.6%) (Table 3).

One participant experienced two episodes of palpitations during the highest inflate pressure (once for 60% LOP of non-elastic cuffs and 60% LOP\* of elastic cuffs respectively). During these episodes, the participant's heart rate ranged from 92 to 102 bpm, approaching or reaching the THR range for low-intensity AE (99–110 beats/min), with BP peaking at 180/72 mmHg. No underlying medical conditions were reported, and BP, P, and SpO<sub>2</sub> were normal within 5 minutes post-test. No recurrent palpitation occurred within 48 hours after the exercise. The adverse event incidence rate was 1.1% (2 events among 31 participants across 6 test conditions).

No participants reported pain, with all pain scores recorded as 0.

**Table 3** Incidence and Proportions of Responses During Exercise Tests, *n* (%)

		Muscle Soreness						Other	Subtotal	Total
		Left Leg	Right Leg	Both Legs	Hips	Knees	Lower Back	Heavy Sweating		
Non-elastic cuffs	20% LOP	1(3.2)	2(6.5)	1(3.2)	1(3.2)				5(16.1)	35(37.6)
	40% LOP	1(3.2)	2(6.5)	6(19.4)		1(3.2)		4(12.9)	14(45.2)	
	60% LOP		2(6.5)	8(25.8)				6(19.4)	16(51.6)	
Elastic cuffs	20% LOP*						1(3.2)	1(3.2)	2(6.5)	
	40% LOP*		1(3.2)	3(9.7)	1(3.2)			2(6.5)	7(22.6)	
	60% LOP*	1(3.2)	1(3.2)	8(25.8)				3(9.7)	13(41.9)	

**Notes:** The method for calculating the subtotal ratio was: number of occurrences / 31 (31 was the total number of participants); the method for calculating the total ratio was: number of occurrences / (31×3) (31 was the total number of participants, and 3 was the number of tests performed with the same BFR cuffs).

**Abbreviation:** LOP, Limb Occlusion Pressure.

## Changes in Cardiovascular Response Indicators (BP, P, and SpO<sub>2</sub>) During Exercise

The completion rates for tests of 20% LOP (non-elastic cuff test) and 20% LOP\* (elastic cuff test) were both 100% (31 participants), and for 40% LOP and 40% LOP\* tests were 87.1% (27 participants) and 100% (31 participants), respectively, while for 60% LOP and 60% LOP\* were only 29.0% (9 participants) and 71.0% (22 participants). Statistical comparisons on cardiovascular indicators were performed firstly with the data from all the participants who completed the 20% LOP and 40% LOP or LOP\* ([Supplementary 1](#)), secondly, with the data from the 9 participants and the 22 participants who completed the 60% LOP or LOP\* ([Supplementary 2](#) and [3](#)).

### BP, P, and SpO<sub>2</sub> of All Participants Under 20% LOP, 40% LOP, 20% LOP\* and 40% LOP\*

During the exercise testing at 4 different pressures, significant differences in BP, P, and SpO<sub>2</sub> were found at different time points with both cuffs ( $P<0.05$ ), while no differences were found between trials with the two cuffs ([Supplementary 1](#)).

### Results of the 9 Participants Who Completed Non-Elastic Tests with 60% LOP

Comparative analysis of BP, P, and SpO<sub>2</sub> at 20% and 40% LOP for these 9 participants showed differences at different time points ( $P<0.05$ ), but no differences between the different pressures ([Supplementary 2](#)).

### Results of the 22 Participants Who Completed Elastic Tests with 60% LOP\*

Similar to the non-elastic tests, differences in indicators were found at different time points ( $P<0.05$ ), but no differences between the different pressures ([Supplementary 3](#)).

## Overall Changes in Cardiovascular Response During BFR-SAE with Different Cuffs and Pressures

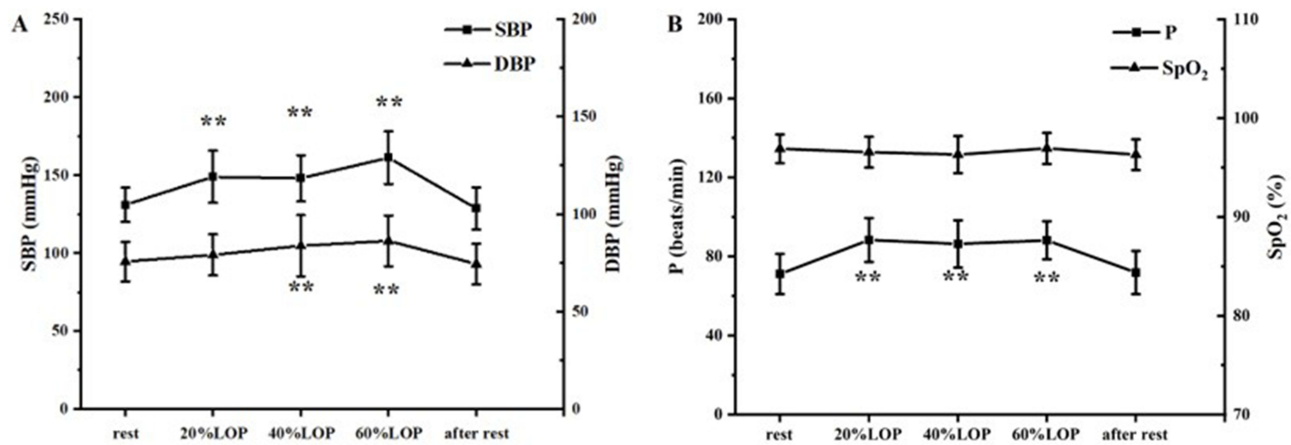
To display the overall changes in cardiovascular indicators, the results from four different time points (5, 10, 15, and 20 minutes) during the intervention were integrated. The results were as follows.

In non-elastic tests, a statistically significant increase was found in SBP, DBP, and P as pressure rose compared to resting levels ( $P<0.05$ ). After 5 minutes rest of exercise, SBP, DBP, and P returned to resting levels ([Figure 4A](#) and [B](#)).

In elastic tests, a statistically significant increase was found only in SBP and P but not in DBP as pressure rose compared to resting levels ( $P<0.05$ ). After 5 minutes rest of exercise, SBP and P also returned to resting levels ([Figure 5A](#) and [B](#)).

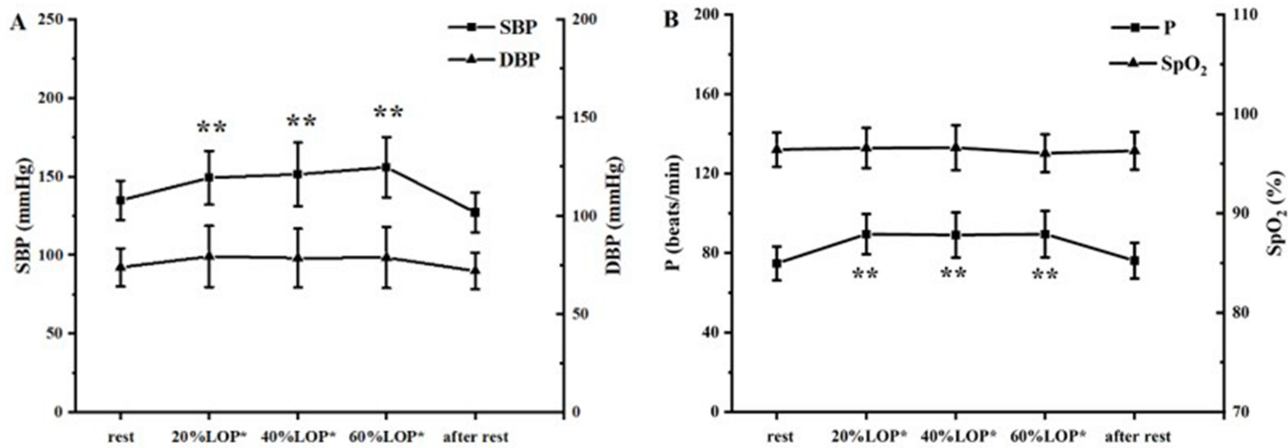
## Discussion

In this study, we explored the safety and feasibility of the program of BFR using different cuffs and under different pressures combined with SAE in older adults with sarcopenia. A total of 33 participants and 11 sessions of exercise tests were conducted over 4 weeks. All testing sessions were conducted indoors with flexible scheduling to accommodate participants' daily routines, which contributed to excellent protocol adherence. Among the enrolled participants (mean age 84.81±6.19 years, 83.87% female), 31 successfully completed all study procedures, resulting in a low dropout rate of 6.06%. These findings demonstrate high feasibility and participant acceptance of the exercise intervention.



**Figure 4** Averaged physiological data under different pressures in non-elastic cuffs of BFR-SAE. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) in (A) and pulse rate (P) and saturation of pulse oxygen (SpO<sub>2</sub>) in (B) \*\*: compared with resting,  $P < 0.01$ .

**Abbreviation:** LOP, limb occlusion pressure.



**Figure 5** Averaged physiological data under different pressures in elastic cuffs of BFR-SAE. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) in (A) and pulse rate (P) and saturation of pulse oxygen (SpO<sub>2</sub>) in (B) LOP\*: the inflation pressure under the interface pressure corresponding to % LOP of non-elastic cuff; \*\*: compared with resting,  $P < 0.01$ .

**Abbreviation:** LOP, limb occlusion pressure.

## The Impact of Non-Elastic and Elastic BFR Cuffs on Exercise Completion and Inflation Pressure

In this study, BFR with both non-elastic and elastic cuffs were tested. To ensure the comparability between the two cuffs, we standardized the pressure between the cuffs through interface pressure assessment. Interface pressure refers to the pressure exerted on the surface of the limb in contact with the BFR cuffs,<sup>32</sup> providing a more accurate representation of the actual pressure level applied to the limb during BFR exercise. The study revealed that after exercise testing with both cuffs, the pain scores were the same (both scored 0). During the tests at 40% and 60% LOP, the proportion of reported general exercise response was lower with the elastic cuffs compared to the non-elastic cuffs (22.6% vs 45.2% at 40% LOP; 41.9% vs 51.6% at 60% LOP), while the exercise completion rate was higher with the elastic cuffs (100% vs 87.1% at 40% LOP; 71.0% vs 29.0% at 60% LOP). These results indicate that, under the same interface pressure, the elastic BFR cuffs demonstrates better exercise adherence, likely due to its multi-chamber design. In contrast with non-elastic

cuffs that has only one chamber, the multi-chamber elastic cuffs provide a gentler compression effect at the same interface pressure, making it more comfortable and requiring less effort during exercise.<sup>34</sup> This suggests that long-term adherence with BFRT using elastic cuffs may be improved, potentially benefiting older adults with sarcopenia in their acceptance and execution of interventions. This is also the first study to compare exercise completion rate between two different cuffs of same width under varying pressures.

Interface pressures for different cuffs in this study were significantly lower than the corresponding inflation pressures, consistent with Hughes et al.<sup>32</sup> At both 40% and 60% LOP, the inflation pressures for the elastic cuffs were substantially higher than those for the non-elastic cuffs at the same interface pressure. Therefore, it is not appropriate to use inflation pressure as a comparative standard between the two cuffs. A review article indicates that 40% to 60% LOP with non-elastic BFR cuffs was beneficial for improving muscular fitness in exercising populations.<sup>35</sup> In older adults, previous study has demonstrated the feasibility and benefit of using pressures around 50% LOP.<sup>36</sup> For the elastic cuffs, it was recommended to use No. 3 cuffs for lower limb (7.5 cm wide) with an inflation pressure of 250 mmHg.<sup>28,37</sup> In our study of BFR-SAE for older adults with sarcopenia, the measured inflation pressure for elastic cuffs was  $177.42 \pm 53.55$  mmHg at 40% LOP and  $286.42 \pm 86.43$  mmHg at 60% LOP. These findings indicate that the commonly recommended inflation pressure of 250 mmHg likely corresponds to a pressure slightly exceeding 50% LOP in this population. Therefore, this pressure aligns with current evidence-based recommendations for both elastic and non-elastic cuffs, supporting its practical utility in developing long-term exercise programs using elastic BFR cuffs for older adults with sarcopenia.

## General Exercise Response, Adverse Events, and Pain During BFR-SAE

BFRT has shown positive effects across various populations, with overall safety being affirmed and rare adverse events during interventions. A national survey involving 105 institutions found that among individuals who had undergone BFRT, the incidence of subcutaneous haemorrhage, limb numbness, and venous thrombosis was 13.1%, 1.3%, and 0.055%, respectively.<sup>20</sup> Moreover, a review article indicated that among 25,813 individuals who had undergone BFRT, 1,672 reported adverse events, such as limb numbness, dizziness, subcutaneous haemorrhage, and rhabdomyolysis, resulting in an adverse events rate of 6.4%. It was noteworthy that the individuals reporting adverse events included patients with hypertension, thoracic outlet syndrome, retinal disease, and Paget's disease, implying that the presence of exercise risks in this population might be a factor.<sup>21</sup> These reports underlined the necessity for a clear definition of adverse event in BFRT to differentiate their severity. It is essential to conduct such training in appropriate populations while using appropriate pressures and modes of exercise, overseen by qualified professionals who can conduct risk assessments prior to exercise and maintain supervision for safety during the training. Current evidence regarding exercise-related adverse events in older adults with sarcopenia remains limited. This knowledge gap underscores the need for comprehensive research to establish evidence-based safety guidelines and develop targeted preventive strategies for this vulnerable population.

This study incorporated multiple safety measures to ensure participant protection, including: firstly, the researcher obtained the certification of international BFRT practice, laying a theoretical and practical foundation for exercise testing; secondly, multiple trained team members managed 1~2 participants during the exercise testing, ensuring detailed observation of their exercise responses and adverse events while tracking these between exercise sessions; and finally, the exercise testing site was equipped with medical emergency equipment and a healthcare professional to address any adverse events promptly and effectively. BP, P, and SpO<sub>2</sub> were measured 5 minutes post-exercise to ensure that participants' metrics recovered to pre-exercise before allowing them to leave.

During exercise testing, general exercise response primarily focused on the soreness of the legs, glutes, and lower back, along with heavy sweating. One participant experienced palpitations while using both non-elastic and elastic cuffs at 60% LOP, likely due to excessive BFR. The palpitations subsided immediately after ceasing exercise. Notably, pain scores following the exercise testing were 0, and the overall adverse event incidence rate was 1.1%, supporting the safety of BFR-SAE for older adults with sarcopenia. The observation of milder physiological responses with elastic cuffs suggests their potential superiority for this vulnerable population.

## The Effects of Non-Elastic and Elastic BFR Cuffs on Cardiovascular Response Indicators (BP, P, and SpO<sub>2</sub>) During Exercise

Given that the exercise pressor reflex is activated during BFRT, stimulating the sympathetic nervous system and further increasing BP, this simulates high-intensity exercise, resulting in a greater cardiovascular response.<sup>38</sup> To ensure the safe application of this training among a broader population, researchers had been seeking ways to reduce cardiovascular risks, such as using lower inflation pressures to mitigate cardiovascular responses. Higher inflation pressures (eg, 90% LOP) did not elicit additional increases in limb circumference and strength compared to lower inflation pressures (eg, 40% LOP), suggesting that a higher degree of BFR may not be necessary for optimal muscle activation and adaptation.<sup>39</sup> Some scholars had proposed guidelines for BFR-AE, recommending pressure settings between 40% and 60% LOP; however, this may not be suitable for older adults with sarcopenia.<sup>40</sup>

The results of this study indicated significant differences in BP, P, and SpO<sub>2</sub> at different time points when using two types of BFR cuffs, with no notable differences between different pressures and cuffs. This implied that the cardiovascular responses during AE were higher than those before and after exercise, and that increases in cuffs pressure did not lead to additional cardiovascular responses. BFRT may therefore serve as a rehabilitative exercise method for older adults with sarcopenia.

A year-long follow-up study found that older adults with sarcopenia had significantly higher rates of cardiovascular adverse events (including non-fatal myocardial infarction, readmission, ischemic stroke, and overall mortality) compared to those without sarcopenia.<sup>41</sup> Multiple meta-analyses indicated that the prevalence of sarcopenia among patients with cardiovascular diseases was about twice that of the general population, demonstrating a positive correlation between cardiovascular diseases and the prevalence of sarcopenia.<sup>42,43</sup> Therefore, the cardiovascular responses experienced by older adults with sarcopenia during exercise remain a key focus for researchers. Stray-Gundersen et al conducted a randomised cross-over experiment using non-elastic cuffs (18 × 108 cm, Hokanson, USA, at a pressure of 160 mmHg) and elastic cuffs (5 × 50 cm, Bstrong, USA, at a pressure of 300 mmHg) involving 15 healthy young individuals. They documented changes in BP and P during single exercise sessions. The results showed that the variations in SBP and DBP during exercises with the non-elastic cuffs were significantly greater than those with the elastic cuffs, which exhibited markedly lower cardiovascular responses in elastic cuffs.<sup>29</sup> However, the inconsistency in cuff widths and inflation pressures, along with the lack of comparative analysis between the BFR degrees induced by the two types of cuffs under different pressures, necessitates further consideration of the reliability of the results. Bordessa et al implemented RE in 34 young individuals with non-elastic cuffs [11.5 × (26~86.5) cm, Delfi, Canada, at a pressure of 160 mmHg] and elastic cuffs [5 × (18~95) cm, Bstrong, USA, pressure auto-adjusted according to limb circumference using an associated app]. They found that the PRE and pain scores during exercise with the non-elastic cuffs were significantly higher than those with the elastic cuffs, potentially inducing a more pronounced cardiovascular response.<sup>44</sup> Citherlet et al compared blood flow changes in arteries under different pressures (0, 40%, 60% LOP, and 200, 250, 300, 350, and 400 mmHg) using non-elastic cuffs (11 × 85 cm, Hokanson, USA) and elastic cuffs [7.5 × (54~79) cm, Bstrong, USA]. They found significant decreases in blood flow at 40% LOP and 350 mmHg, respectively, compared to resting. The two pressures may possible induce cardiovascular responses, and the author recommended these two pressures as suitable cuff inflation settings for combined exercise with different BFR cuffs.<sup>45</sup> However, the above two studies focused on young individuals, and further verification is needed among the older adults.

This study used cuffs of the same width and standardised the inflation pressures among different cuffs. The results indicated that during the BFRT with non-elastic cuffs, both SBP and DBP showed an upward trend with increasing pressure compared to resting. In contrast, only SBP increased with elastic cuffs, while P showed no difference. This suggests that cardiovascular responses induced by non-elastic cuffs are greater, indicating that elastic cuffs may be safer and potentially more suitable for older adults with sarcopenia.

This study has some limitations. First, it was a single-center study with a small sample size. Second, laboratory indicators were not collected, so associated adverse events, such as rhabdomyolysis and thrombosis, could not be collected. Third, these findings are specific to the cuffs used in this study and may not generalize to other cuffs of the same type. Future studies should incorporate larger multi-center cohorts, additional laboratory biomarkers, and diverse cuff types to enhance data reliability and generalizability.

## Conclusions

BFR-SAE is safe for older adults with sarcopenia. Compared with BFR using non-elastic cuffs, using elastic cuffs causes milder cardiovascular responses and better compliance, suggesting that BFR with elastic cuffs is a safer and more practicable method for older adults with sarcopenia.

## Data Sharing Statement

The data will be shared upon reasonable request made to the corresponding author of the manuscript.

## Institutional Review Board Statement

All participants provided informed consent for inclusion before participating in the study, which was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of Soochow University (protocol code SUDA20220723H01 and date of approval July 23, 2022).

## Trial Registration

This study was registered under the accession code ChiCTR2200064080 in the Chinese Clinical Trial Registry on September 26, 2022.

## Acknowledgments

We would like to express our gratitude to all participants in the study for their time and effort.

## Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

## Funding

This work is supported by the The Suzhou Nursing Association Class A Project (SZHL-A-202406, LW), The Key Project of Suzhou Key Laboratory of Geriatric Smart Nursing and Rehabilitation Open Research Program (SZLNKY-A-202404, LW), and The Major Project of Suzhou Vocational Health College (grant number szwzy202303, HZ). The foundations provide funding for research personnel, participants recruitment, participants fees and travel expenses.

## Disclosure

The authors declare that there is no conflict of interest for this work.

## References

1. Ferrucci L, Gonzalez-Freire M, Fabbri E, et al. Measuring biological aging in humans: a quest. *Aging Cell*. 2020 Feb;19(2):e13080. doi:10.1111/acel.13080
2. Yuenyongchaiwat K, Boonsinsukh R. Sarcopenia and Its Relationships with Depression, Cognition, and Physical Activity in Thai Community-Dwelling Older Adults. *Curr Gerontol Geriatr Res*. 2020;2020:8041489. doi:10.1155/2020/8041489
3. Zhang XM, Wang CH, Dou QL, Zhang WW, Yang YZ, Xie XH. Sarcopenia as a predictor of all-cause mortality among older nursing home residents: a systematic review and meta-analysis. *BMJ Open*. 2018;8(11):e021252. doi:10.1136/bmjopen-2017-021252
4. Booth FW, Roberts CK, Laye MJ. Lack of Exercise Is a Major Cause of Chronic Diseases. *Compr Physiol*. 2012;2(2):1143–1211. doi:10.1002/j.2040-4603.2012.tb00425.x
5. Beckwée D, Delaere A, Aelbrecht S, et al. Exercise Interventions for the Prevention and Treatment of Sarcopenia. A Systematic Umbrella Review. *J Nutr Health Aging*. 2019;23(6):494–502. doi:10.1007/s12603-019-1196-8
6. Nelson ME, Rejeski WJ, Blair SN, et al. Physical activity and public health in older adults: recommendation from the American College of Sports Medicine and the American Heart Association. *Circulation*. 2007;116(9):1094–1105.
7. Harber MP, Konopka AR, Douglass MD, et al. Aerobic exercise training improves whole muscle and single myofiber size and function in older women. *Am J Physiol Regul Integr Comp Physiol*. 2009;297(5):R1452–1459. doi:10.1152/ajpregu.00354.2009
8. Lorenz DS, Bailey L, Wilk KE, et al. Blood Flow Restriction Training. *J Athl Train*. 2021;56(9):937–944. doi:10.4085/418-20

9. Rodrigues R, Ferraz RB, Kurimori CO, et al. Low-Load Resistance Training With Blood-Flow Restriction in Relation to Muscle Function, Mass, and Functionality in Women With Rheumatoid Arthritis. *Arthritis Care Res.* 2020;72(6):787–797. doi:10.1002/acr.23911
10. Barbalho M, Rocha AC, Seus TL, Raiol R, Del Vecchio FB, Coswig VS. Addition of blood flow restriction to passive mobilization reduces the rate of muscle wasting in elderly patients in the intensive care unit: a within-patient randomized trial. *Clin Rehabil.* 2019;33(2):233–240. doi:10.1177/0269215518801440
11. Liu Y, Jiang N, Pang F, Chen T. Resistance Training with Blood Flow Restriction on Vascular Function: a Meta-analysis. *Int J Sports Med.* 2021;42(7):577–587. doi:10.1055/a-1386-4846
12. Lixandrão ME, Ugrinowitsch C, Berton R, et al. Magnitude of Muscle Strength and Mass Adaptations Between High-Load Resistance Training Versus Low-Load Resistance Training Associated with Blood-Flow Restriction: a Systematic Review and Meta-Analysis. *Sports Med.* 2018;48(2):361–378. doi:10.1007/s40279-017-0795-y
13. Fabero-Garrido R, Gragera-Vela M, Del Corral T, Izquierdo-García J, Plaza-Manzano G, López-de-Uralde-Villanueva I. Effects of Low-Load Blood Flow Restriction Resistance Training on Muscle Strength and Hypertrophy Compared with Traditional Resistance Training in Healthy Adults Older Than 60 Years: systematic Review and Meta-Analysis. *J Clin Med.* 2022;11(24):7389. doi:10.3390/jcm11247389
14. Tangchaisuriya P, Chuensiri N, Tanaka H, Suksom D. Physiological Adaptations to High-Intensity Interval Training Combined with Blood Flow Restriction in Masters Road Cyclists. *Med Sci Sports Exerc.* 2022;54(5):830–840. doi:10.1249/MSS.0000000000002857
15. Clarkson MJ, Conway L, Warmington SA. Blood flow restriction walking and physical function in older adults: a randomized control trial. *J Sci Med Sport.* 2017;20(12):1041–1046. doi:10.1016/j.jsams.2017.04.012
16. Shimizu R, Hotta K, Yamamoto S, et al. Low-intensity resistance training with blood flow restriction improves vascular endothelial function and peripheral blood circulation in healthy elderly people. *Eur J Appl Physiol.* 2016;116(4):749–757. doi:10.1007/s00421-016-3328-8
17. Wengle L, Migliorini F, Leroux T, Chahal J, Theodoropoulos J, Betsch M. The Effects of Blood Flow Restriction in Patients Undergoing Knee Surgery: a Systematic Review and Meta-analysis. *Am J Sports Med.* 2021;2021:3635465211027296.
18. Wortman RJ, Brown SM, Savage-Elliott I, Finley ZJ, Mulcahey MK. Blood Flow Restriction Training for Athletes: a Systematic Review. *Am J Sports Med.* 2021;49(7):1938–1944. doi:10.1177/0363546520964454
19. Minniti MC, Statkevich AP, Kelly RL, et al. The Safety of Blood Flow Restriction Training as a Therapeutic Intervention for Patients With Musculoskeletal Disorders: a Systematic Review. *Am J Sports Med.* 2020;48(7):1773–1785. doi:10.1177/0363546519882652
20. Nakajima T, Kurano M, Iida H, et al. Use and safety of KAATSU training: results of a national survey. *Int J KAATSU Training Research.* 2006;2(1):5–13. doi:10.3806/ijtr.2.5
21. Anderson KD, Rask DMG, Bates TJ, Nuelle JAV. Overall Safety and Risks Associated with Blood Flow Restriction Therapy: a Literature Review. *Mil Med.* 2022;187(9–10):1059–1064. doi:10.1093/milmed/usac055
22. Loenneke JP, Wilson JM, Wilson GJ, Pujol TJ, Bembem MG. Potential safety issues with blood flow restriction training. *Scand J Med Sci Sports.* 2011;21(4):510–518. doi:10.1111/j.1600-0838.2010.01290.x
23. Pereira-Neto EA, Lewthwaite H, Boyle T, Johnston K, Bennett H, Williams MT. Effects of exercise training with blood flow restriction on vascular function in adults: a systematic review and meta-analysis. *PeerJ.* 2021;9:e11554. doi:10.7717/peerj.11554
24. Zhang XZ, Xie WQ, Chen L, et al. Blood Flow Restriction Training for the Intervention of Sarcopenia: current Stage and Future Perspective. *Front Med Lausanne.* 2022;9:894996. doi:10.3389/fmed.2022.894996
25. Shan J, Lin K, Xiaohong L. Interpretation of Asian Working Group for Sarcopenia:2019 Consensus Update on Sarcopenia Diagnosis and Treatment. *Chin J Geriatr.* 2020;2020(04):373–376.
26. Garber CE, Blissmer B, Deschenes MR, et al. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc.* 2011;43(7):1334–1359. doi:10.1249/MSS.0b013e318213febf
27. Gellish RL, Goslin BR, Olson RE, McDonald A, Russi GD, Moudgil VK. Longitudinal modeling of the relationship between age and maximal heart rate. *Med Sci Sports Exerc.* 2007;39(5):822–829. doi:10.1097/mss.0b013e31803349c6
28. Wooten SV, Fleming RYD, Wolf Jr JS Jr, et al. Prehabilitation program composed of blood flow restriction training and sports nutrition improves physical functions in abdominal cancer patients awaiting surgery. *Eur J Surg Oncol.* 2021;47(11):2952–2958. doi:10.1016/j.ejso.2021.05.038
29. Stray-Gundersen S, Wooten S, Tanaka H. Walking With Leg Blood Flow Restriction: wide-Rigid Cuffs vs. Narrow-Elastic Bands. *Front Physiol.* 2020;11:568. doi:10.3389/fphys.2020.00568
30. Spijkerman DC, Snijders CJ, Stijnen T, Lankhorst GJ. Standardization of grip strength measurements. Effects on repeatability and peak force. *Scand J Rehabil Med.* 1991;23(4):203–206. doi:10.2340/165020021991203206
31. Chen LK, Woo J, Assantachai P, et al. Asian Working Group for Sarcopenia: 2019 Consensus Update on Sarcopenia Diagnosis and Treatment. *J Am Med Dir Assoc.* 2020;21(3):300–307.e302. doi:10.1016/j.jamda.2019.12.012
32. Hughes L, Rosenblatt B, Gissane C, Paton B, Patterson SD. Interface pressure, perceptual, and mean arterial pressure responses to different blood flow restriction systems. *Scand J Med Sci Sports.* 2018;28(7):1757–1765. doi:10.1111/sms.13092
33. Williamson A, Hoggart B. Pain: a review of three commonly used pain rating scales. *J Clin Nurs.* 2005;14(7):798–804. doi:10.1111/j.1365-2702.2005.01121.x
34. Rolnick N, Kimbrell K, de Queiros V. Beneath the cuff: often overlooked and under-reported blood flow restriction device features and their potential impact on practice-A review of the current state of the research. *Front Physiol.* 2023;14:1089065. doi:10.3389/fphys.2023.1089065
35. Chulvi-Medrano I, Cortell-Tormo JM, Hernández-Sánchez S, Picón-Martínez M, Rolnick N. Blood Flow Restriction Training in Clinical Rehabilitation: occlusion Pressure Methods Relative to the Limb Occlusion Pressure. *J Sport Rehabil.* 2023;32(4):361–368. doi:10.1123/jsr.2022-0240
36. Vechin FC, Libardi CA, Conceição MS, et al. Comparisons between low-intensity resistance training with blood flow restriction and high-intensity resistance training on quadriceps muscle mass and strength in elderly. *J Strength Cond Res.* 2015;29(4):1071–1076. doi:10.1519/JSC.0000000000000703
37. Wooten SV, Stray-Gundersen S, Tanaka H. Hemodynamic and Pressor Responses to Combination of Yoga and Blood Flow Restriction. *Int J Sports Med.* 2020;41(11):759–765. doi:10.1055/a-1171-1620
38. Spranger MD, Krishnan AC, Levy PD, O’Leary DS, Smith SA. Blood flow restriction training and the exercise pressor reflex: a call for concern. *Am J Physiol Heart Circ Physiol.* 2015;309(9):H1440–1452. doi:10.1152/ajpheart.00208.2015

39. Counts BR, Dankel SJ, Barnett BE, et al. Influence of relative blood flow restriction pressure on muscle activation and muscle adaptation. *Muscle Nerve*. 2016;53(3):438–445. doi:10.1002/mus.24756
40. Patterson SD, Hughes L, Warmington S, et al. Blood Flow Restriction Exercise: considerations of Methodology, Application, and Safety. *Front Physiol*. 2019;10:533. doi:10.3389/fphys.2019.00533
41. Erkan M, Zengin İ, Bekircavuşoğlu S, Topal D, Bulut T, Erkan H. Effect of Sarcopenia on Coronary Atherosclerotic Burden, Lesion Complexity, and Major Cardiovascular Events in Elderly Patients With Acute Coronary Syndrome: a 1-year Follow-up Study. *Angiology*. 2023;2023:33197231187230.
42. Zuo X, Li X, Tang K, et al. Sarcopenia and cardiovascular diseases: a systematic review and meta-analysis. *J Cachexia, Sarcopenia Muscle*. 2023;14(3):1183–1198. doi:10.1002/jcsm.13221
43. Xue Q, Wu J, Ren Y, Hu J, Yang K, Cao J. Sarcopenia predicts adverse outcomes in an elderly population with coronary artery disease: a systematic review and meta-analysis. *Bmc Geriatr*. 2021;21(1):493. doi:10.1186/s12877-021-02438-w
44. Bordessa JM, Hearn MC, Reinfeldt AE, et al. Comparison of blood flow restriction devices and their effect on quadriceps muscle activation. *Phys Ther Sport*. 2021;49:90–97. doi:10.1016/j.ptsp.2021.02.005
45. Citherlet T, Willis SJ, Chaperon A, Millet GP. Differences in the limb blood flow between two types of blood flow restriction cuffs: a pilot study. *Front Physiol*. 2022;13:931270. doi:10.3389/fphys.2022.931270

### Clinical Interventions in Aging

### Publish your work in this journal

Clinical Interventions in Aging is an international, peer-reviewed journal focusing on evidence-based reports on the value or lack thereof of treatments intended to prevent or delay the onset of maladaptive correlates of aging in human beings. This journal is indexed on PubMed Central, MedLine, CAS, Scopus and the Elsevier Bibliographic databases. The manuscript management system is completely online and includes a very quick and fair peer-review system, which is all easy to use. Visit <http://www.dovepress.com/testimonials.php> to read real quotes from published authors.

Submit your manuscript here: <https://www.dovepress.com/clinical-interventions-in-aging-journal>

**Dovepress**  
Taylor & Francis Group