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Effects of blood flow restriction training using plural parallel cuff on walking functions of older people

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Abstract

OBJECTIVES: Previous studies have shown that older people who usually walk faster have a lower risk of death. The present study investigated the effects of blood flow restriction training using the newly developed plural parallel cuff (multi-cuff training) on psychological and physiological parameters, aiming to improve walking function in older people.
DESIGN, MATERIAL AND METHODS: Forty-two older adults participated in the present study. They were randomly allocated to two groups with the same average age: one group trained with a cuff wrapped on both legs (multi-cuff training) during strength training, and the second group trained without cuffs (control), with training protocols being similar for both groups. This study had a crossover design: after 3 weeks, the training was switched between the groups.
RESULTS: Multi-cuff training significantly rejuvenated the estimated walking age compared to the control.
CONCLUSION: The multi-cuff training program improves the walking function of older people with no major problems.

Abbreviations:

ANOVA	- Analysis of variance
AOP	- Arterial occlusion pressure
BFR	- Blood flow restriction
BMI	- Body mass index
CTR	- Clinical trial registration
LBM	- Lean body mass
MC	- Multi-cuff
MCT	- Multi-cuff training
PPC	- Plural parallel cuff
RM	- Repetition maximum
VRC	- Venous blood return constriction

ORIGINAL ARTICLE

INTRODUCTION

The constant rise in the global average lifespan in recent decades has led to several communities facing a growing older population. This, in turn, comes with a series of health-related challenges in geriatric medicine. Gait speed was reported to be the best predictor of life prognosis in individuals aged >65 years (Studenski *et al.* 2011). In the mentioned report, nine cohort studies, conducted from 1986 to 2000, were pooled to investigate the association between normal gait speed at enrollment and life prognosis during a 6–21-year follow-up period in 34,485 community-dwelling older people. It reported that the higher the gait speed, the lower the risk of death (Studenski *et al.* 2011). Similarly, gait speed reduction in older people might be related to the development of illness (Wei *et al.* 2018) and frailty, as well as handgrip strength/muscle weakness (Soltani *et al.* 2021). For example, recent studies have indicated that gait speed reduction in older adults with blood cancer was independently associated with higher mortality and that patients with fast gait speed might desire or require reduced-intensity therapy, whereas those with slow gait speed might require higher-intensity treatment (Liu *et al.* 2019; Hantel *et al.* 2021).

In general, gait speed decreases with age, and the decrease in skeletal muscle mass in the thigh is a factor contributing to the reduction in gait speed (Beavers *et al.* 2013; Siparsky *et al.* 2014). Sarcopenia has recently become a significant topic of investigation (Siparsky *et al.* 2014). Sarcopenia is a disorder characterized by the loss of skeletal muscle mass and function which commonly occurs with advancing age; it is associated with an increased likelihood of a wide range of adverse outcomes including impaired mobility, increased morbidity, and mortality (Sayer & Cruz-Jentoft, 2022; Smith *et al.* 2022). Mammalian skeletal muscle fibers can be broadly divided into type I fibers, which are small and slow-contracting fibers, and type II fibers, which are much larger and faster-contracting fibers (Siparsky *et al.* 2014). Aging leads to an increased percentage of type I fibers compared with that of type II fibers (Larsson *et al.* 1978; Siparsky *et al.* 2014). Similarly, general muscle strength decreases with age, possibly related to the decreased contribution from progressively smaller numbers of large tension-producing type II fibers (Frontera *et al.* 1988; Siparsky *et al.* 2014). Thus, a decrease in gait speed with age may also be related to the decreasing percentage of type II fibers.

When muscles contract, the small and slow-contracting fibers (type I) are the first to contract. As the required muscle tension increases, the larger and faster-contracting fibers (type II) are gradually contracted (Henneman's size principle) (Henneman, 1957). Commonly, to induce strength and hypertrophy adaptations, individuals may use loads during resistance training corresponding to ≥ 65% of one repetition maximum (RM) (Kraemer *et al.* 2002). Thus, strength training (intensities >60–70% of 1 RM) is beneficial for preserving muscle function throughout the aging process (Nelson *et al.* 2007; Chodzko-Zajko *et al.* 2009). Although the implementation of such high-intensity strength training is not always feasible, particularly in older patients with frailty, recent studies have shown a possible alternative in low-load training, which is expected to have the same effect as that of the former (Yasuda *et al.* 2014; Lopes *et al.* 2019). Previous studies have indicated that low-load strength training with blood flow restriction (BFR) improves muscle strength in older adults (Yasuda *et al.* 2014; Cook *et al.* 2017; Lopes *et al.* 2019). It is possible that BFR training may preferentially recruit type II fibers because it induces early fatigue of type I fibers owing to the lack of oxygen delivery, although further research is needed to confirm this (Hwang & Willoughby, 2019). A previous report has indicated that in addition to the musculoskeletal system, BFR training has beneficial effects on the cardiovascular and endocrine systems as well as on functional exercise capacity (Miller *et al.* 2021). Based on the previous findings, we focused on the BFR training in order to reasonably improve functional walking capacity in older adults without high-intensity exercise.

To perform BFR, blood pressure cuffs are applied as wrapping devices to several body regions, such as the proximal thigh (Hwang & Willoughby, 2019). It is important to note that cuff size and inter-subject differences in limb circumference can potentially reduce the efficacy of BFR training and also present safety issues (Hwang & Willoughby, 2019). Wider cuffs (13.5 cm) have been suggested to induce greater ratings of pain and perceived exertion than narrow cuffs (5.0 cm) during low-load BFR knee extensions at the same restrictive occluded pressure. The arterial occlusion pressure (AOP) is influenced by various factors such as cuff width, material, and shape, body position, and arm circumference (Younger *et al.* 2004; Yasuda *et al.* 2015; Mouser *et al.* 2017; Patterson *et al.* 2019). Therefore, trainers must be highly skilled in order to perform the BFR training in a stable manner.

A plural parallel cuff (PPC® or multi-cuff [MC]; Aichi Electronics Industry Co., Ltd., Aichi, Japan) was recently developed to solve these problems. A PPC is an innovate cuff that can reduce pain and handle inter-subject differences in limb circumference by arranging several narrow cuffs in parallel (Figure 1). Combining the PPC with a computerized venous blood return constriction (VRC®) system (Multi Cuff Care; Aichi Electronics Industry Co., Ltd., Aichi, Japan), BFR training in older people can be performed more safely. In addition, some VRC systems allow for the simultaneous training of two individuals if the load pressure is fixed. Therefore, by using multiple VRCs, it becomes feasible to train several participants simultaneously. BFR training leads to musculoskeletal changes such as muscle hypertrophy and promotes functional improvements in various systems. Therefore, in the present

Fig. 1. Pictures of the plural parallel cuff (PPC)
Left picture shows the PPC and the venous blood return constriction (VRC) system. The right picture shows the PPC wrapped around the thigh.

study, we aimed to investigate the effects of BFR training with the newly developed PPC on walking function and other psychological (well-being) and physiological states in older people.

MATERIALS AND METHODS

Participants

We recruited 42 older adults (6 men and 36 women, mean age = 76.04 years, standard deviation [SD] = 5.49, range = 55–85). Participants met the following inclusion criteria: (1) aged 55–90 years; (2) no contraindications to regular moderate-intensity walking; (3) no diagnosis of deep venous thrombosis; and (4) no diagnosis of malignant or heart diseases. The mean body mass index (BMI) of the participants was 23.36 kg/m^2 (SD = 3.60 kg/m^2, range: 16.0–31.9 kg/m^2). This study was approved by the Ethics Committee of Aichi Medical University (approval number: 2019-062), and the clinical trial registration (CTR) of this study was published on the University Hospital Medical Information Network (UMIN)-CTR (CTR Number UMIN000042185, 2020/10/21). All older adults volunteered to participate in this study (self-selection) and signed an informed consent form prior to participation. After completing the study, the participants were debriefed. The sample size was determined with reference to previous research (Yasuda *et al.* 2014; Lopes *et al.* 2019).

Blood flow restriction training

The PPC used in this experiment had two cuffs lined in parallel. The PPC with a 55-mm-wide blood flow sensor cuff and 100-mm-wide BFR cuff was wrapped on the left leg and that with a 70-mm-wide blood flow sensor cuff and 100-mm-wide BFR cuff was wrapped on the right leg. The cuff position corresponded to the training position of the cuff. In BFR training, it is recommended to first measure the participant's AOP and apply a pressure load approximately 70% of that value. However, in the present study (exercise class for older people), it was necessary to simultaneously train several participants. As the VRC system used in this study (Multi Cuff Care; Aichi Electronics Industry Co., Ltd., Aichi, Japan) enabled the simultaneous training of two individuals when the load pressure was fixed, a load pressure of 200 mmHg was uniformly set for all BFR trainings using the PPC (multi-cuff training [MCT]) sessions. In the present study, we used 5 VRCs, each accommodating 2 individuals, and we conducted the same BFR training for 10 people simultaneously. All prescribed repetitions per set were successfully completed by all participants.

Study design

This research was implemented as an industry-government-academia collaboration project. Participants attended one of two exercise classes for older people held at 1:30 pm and 3:00 pm (once a week for 11 weeks, with a 1-week free interval and the last week reserved for the result report meeting). Owing to the size of the room, only a maximum of 21 people could participate in 1 exercise class. Therefore, a total of 42 participants in the 2 exercise classes were analyzed. There were no young adults participating, as this was an exercise class for older people. These exercise classes were named the "SMART program," which is an acronym for "Social MC Avascularization/Reperfusion Training." Each session consisted of 60 min training divided into three phases: 1) warm-up: low-load rhythmic gymnastics; 2) strength training: 20 squats, 20 lunges, 30 toe raises, and 50 calf raises (first exercise period); 20 times of raising the thighs and stretching the knees using a chair, 30 squats with a chair, and 1 min of toe raises (second exercise period); and 3) cool-down: gradual recovery from the rhythmic gymnastics and strength training. Physical

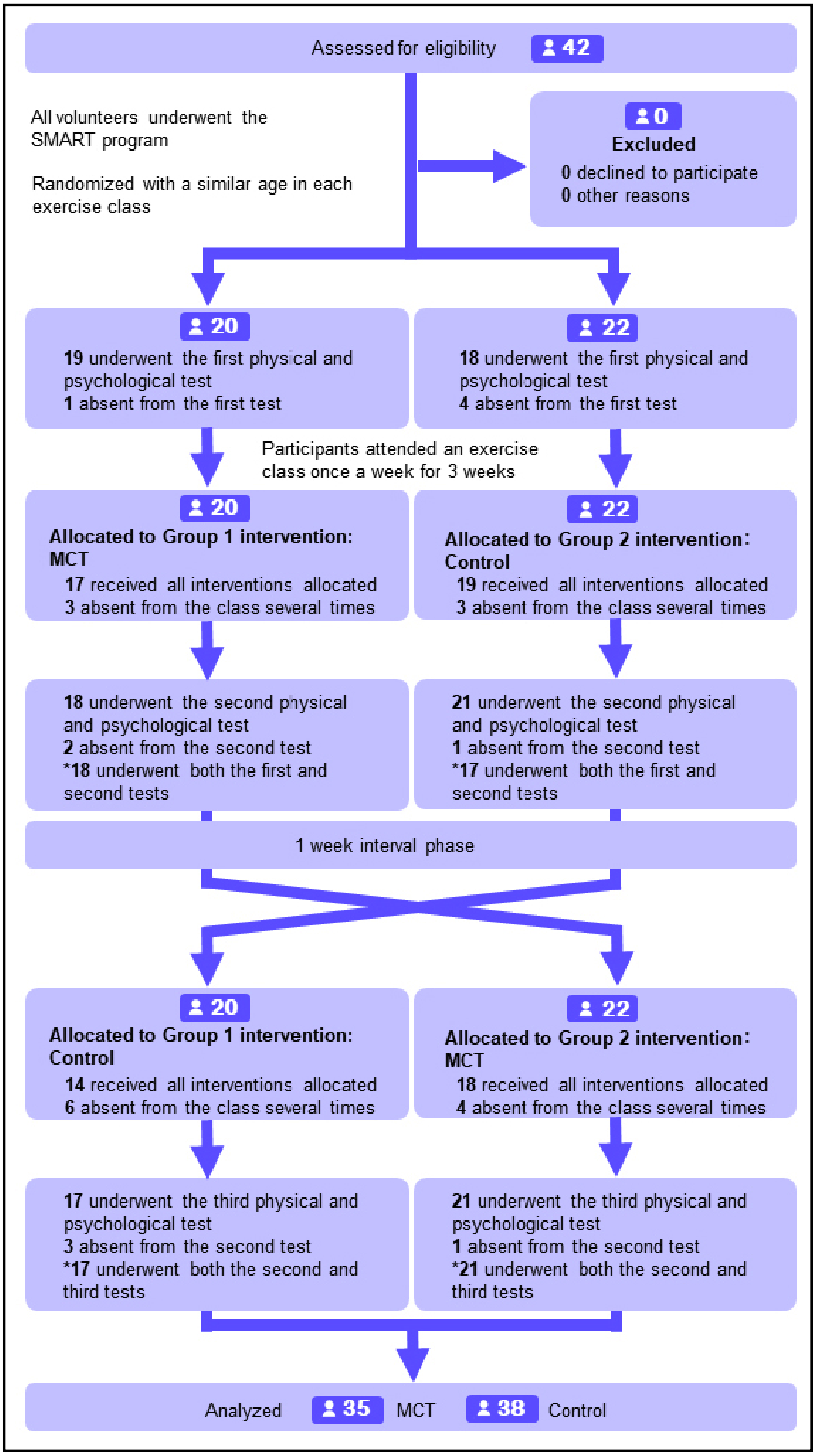

Fig. 2. Graphical scheme of the intervention study design. MCT: multi-cuff training; SMART: Social MC Avascularization/Reperfusion Training.

and psychological tests were administered to all participants thrice within the exercise class, and BFR training was performed using a crossover design (Figure 2). Participants were randomly allocated to two groups with similar average age in each exercise class (Group 1: mean age = 75.75 years, SD = 17.16; Group 2: mean age = 74.81 years, SD = 6.20). On the first day of the exercise class, only psychological and physiological indices were measured without engaging in exercise, and the exercise started the following week. In the first exercise period (once a week for 3 weeks), Group 1 participated in strength training using the PPC (MCT), while Group 2 participated in strength training without the PPC. On the subsequent week, the participants underwent the same psychological and physiological measurements as those conducted on the first day. Thereafter, in the second exercise period (once a week for 3 weeks), Group 2 participated in strength training using the

PPC, while Group 1 participated in strength training without the PPC. Subsequently, in the following week, the participants underwent the same psychological and physiological measurements as those conducted on the first day without engaging in exercises. The crossover design was conducted with a 1-week interval between the two treatment periods owing to room availability. Therefore, the second exercise period commenced 2 weeks after the second physical and psychological test. Data from 35 and 38 participants encompassed the final analytical MCT and final analytical control groups, respectively (Figure 2).

Measurement of psychological well-being

Previous studies have indicated that psychological well-being refers to diverse and interconnected dimensions of physical, mental, and social well-being that extend beyond the traditional definition of health (Naci & Ioannidis, 2015). Based on a previous study (Huber *et al.* 2016), we developed a 10-point evaluation scale (1 point: lowest rating, 10 points: highest rating) encompassing 6 categories (physical condition, mental condition, worth of living, quality of life, social participation, and daily functioning) so that participants could easily answer the questions.

Measurement of physiological parameters

The traditional measurement of walking function is time-consuming and effort-intensive because participants have to wear a marker on their bodies. Thus, in the present study, we used a new walking posture measurement system (NEC Fielding, Ltd., Tokyo, Japan) to make such measurements easier. The function of the Kinect v2 sensor is to measure walking posture. The Kinect v2 sensor is capable of detecting human joints from captured images. In addition, it emits an infrared laser, the reflection of which is captured by a sensor. This enables the calculation of the distance to the target based on the time it takes for the beam to return. Using this function, 20 characteristic points of the human body, such as the head, toes, and joints, are detected, and their movements are captured. The participants' walking function was evaluated using six categories—gait speed, swaying, left-right difference, body axis, arm swing, and foot movement—and displayed by the estimated walking age based on the criteria according to age and sex (Ichikawa *et al.* 2018).

BMI, body fat percentage, and lean body mass (LBM) at the right and left legs were measured using bioelectrical impedance analysis (InBody 270; InBody Japan, Inc., Tokyo, Japan) (McLester *et al.* 2020). The participants' estimated vascular age was evaluated using acceleration plethysmography (Medical Analyzer; P-tech Co., Ltd., Osaka, Japan), which is the second derivative of optical digital plethysmography, based on the criteria according to age and sex (Takada, 2002).

Statistical analyses

All data analyses were conducted using IBM SPSS Statistics (Version 27.0) predictive analytics software. To determine whether the measured walking function was associated with psychological and physiological indices, we first analyzed the correlation between the baseline estimated walking, psychological well-being, and other physiological indices. Subsequently, the effects of attending the SMART program on psychological well-being and physiological functions were analyzed using repeated-measures analysis of variance (ANOVA), followed by a multiple comparisons test with Bonferroni correction. Power was calculated using $\alpha = .05$. Furthermore, to verify the effect of BFR training, we calculated the amount of change in psychological well-being and physiological functions (the difference between the third and second measurements and the difference between the second and first measurements). The effects of BFR training on psychological well-being and physiological function were analyzed using these subtracted values in a 2 (group: control and MCT) × 2 (period: first and second exercise periods) ANOVA followed by Bonferroni-corrected multiple comparisons. The normality of the data was analyzed using the Shapiro–Wilk test, and the sphericity of the data was analyzed using Mauchly's spherical test. Some participants were absent from the exercise classes several times. However, we did not consider the number of exercise classes attended in the present study. Analysis was performed using data from all participants who were able to record changes in the analysis items according to the initially assigned group (intention-to-treat analysis). In addition, some participants were excluded from the analysis owing to incomplete or missing responses to the questionnaire. We calculated two important metrics to evaluate the analysis: the effect size of the multivariate test (ranging from 0 to 1, with lower values indicating less error in the ANOVA) and the observed power (ranging from 0 to 1, with higher values indicating more reliable data analysis). These metrics are referred to as "η^2p" and "power", respectively, in this paper.

RESULTS

Basic analyses of the SMART program

Correlation analysis indicated that the baseline estimated walking age was negatively correlated with the physical condition ($r(29) = -.472$, $p = .010$). The other indices were not significantly correlated with the baseline estimated walking age (Table 1).

Subsequently, we analyzed the effects of attending the SMART program on psychological and physiological parameters (Table 2). Repeated-measures ANOVA revealed significant changes in physical condition [$F(2, 52) = 5.213$, $p < .01$, $\eta^2p = .167$, power = .809], mental condition [$F(1.58, 41.09) = 7.879$, $p < .01$, $\eta^2p = .233$, power = .895], worth of living [$F(1.52, 39.75)$

Tab. 1. Result of the correlation analysis between baseline estimated walking age and other indices

Index	*Correlation coefficient (r)*	p-*value*	*n*
Physical condition	−.472	.010	29
Mental condition	−.323	.087	29
Worth of living	−.251	.188	29
Quality of life	−.267	.162	29
Social participation	−.088	.643	30
Daily functioning	−.121	.532	29
BMI	−.002	.990	37
Percent body fat (%)	.044	.798	37
LBM of the right leg (kg)	−.035	.835	37
LBM of the left leg (kg)	−.043	.800	37
Estimated vascular age	.170	.314	37

Correlation analysis between each item and estimated walking age was performed. The r values represent Pearson's correlation coefficients.
BMI, body mass index; LBM, lean body mass

Tab. 2. Effects of the SMART program on psychological and physiological parameters of older people

Parameter	First test	Second test	Third test	*F-value*	*p-value*	*n*
Physical condition	6.96 (1.84)	7.81 (1.11)	7.74 (1.63)	5.213	.009	27
Mental condition	7.18 (1.81)	7.81 (1.79)	8.03 (1.76)	7.879	.003	27
Worth of living	7.07 (1.68)	7.85 (1.65)	8.00 (1.88)	8.835	.002	27
Quality of life	7.66 (1.86)	8.03 (1.93)	8.18 (1.75)	4.147	.021	27
Social participation	7.59 (1.52)	7.96 (1.95)	8.55 (1.50)	8.029	.001	27
Daily functioning	7.40 (1.64)	8.00 (1.56)	8.59 (1.33)	11.112	<.001	27
Estimated walking age	64.4 (7.47)	64.02 (7.92)	60.29 (8.19)	8.309	.001	34
BMI	23.22 (3.44)	23.21 (3.47)	23.08 (3.40)	3.840	.034	34
Percent body fat (%)	30.16 (7.98)	30.57 (7.56)	29.64 (7.76)	4.349	.017	34
LBM of the right leg (kg)	5.52 (1.00)	5.51 (1.01)	5.54 (1.02)	.750	.476	34
LBM of the left leg (kg)	5.48 (.98)	5.46 (.96)	5.50 (.98)	1.426	.247	34
Estimated vascular age	65.91 (7.00)	67.38 (7.55)	69.00 (8.19)	3.675	.031	34

The results are expressed as means (standard deviations). The variables were compared using repeated-measures ANOVA followed by Bonferroni-corrected multiple comparisons, and the F-value, p-value, and sample size of ANOVA are shown.
BMI, body mass index; LBM, lean body mass

= 8.835, $p < .01$, $\eta^2 p = .254$, power = .920], quality of life [$F(2, 52) = 4.147$, $p = .021$, $\eta^2 p = .138$, power = .707], social participation [$F(2, 52) = 8.029$, $p < .01$, $\eta^2 p = .236$, power = .946], daily functioning [$F(2, 52) = 11.112$, $p < .01$, $\eta^2 p = .299$, power = .989], estimated walking age [$F(2, 66) = 8.309$, $p < .01$, $\eta^2 p = .201$, power = .955], BMI [$F(1.68, 55.65) = 3.840$, $p = .034$, $\eta^2 p = .104$, power = .623], percent body fat [$F(2, 66) = 4.349$, $p = .017$, $\eta^2 p = .116$, power = .735], and estimated vascular age [$F(2, 66) = 3.675$, $p = .031$, $\eta^2 p = .100$, power = .657].

Multiple comparisons showed that the physical condition in the second test was significantly improved than that in the first test ($p = .014$). The mental condition in the third test was significantly improved than that in the first test ($p = .012$). Worth of living in the third test was significantly higher than that in the first test ($p = .012$). Quality of life in the third test was significantly higher than that in the first test ($p = .040$). Social participation in the third test was significantly higher than that in the first ($p < .01$) and second tests ($p = .038$). Daily functioning in the third test was significantly higher than that in the first test ($p < .01$). The estimated walking age in the third test was significantly lower than that in the first ($p < .01$) and second tests ($p = .010$). The percentage of body fat in the third test was significantly lower than that in the second test ($p = .010$). The estimated vascular age in the third test was significantly higher than that in the first test ($p = .041$). There were no statistically significant differences in the BMI.

Tab. 3. Differences in several psychological and physiological parameters between the control and MCT groups

Parameter	Control		MCT			
	Measured value	*n*	Measured value	*n*	*F-value*	*p-value*
Physical condition	.75 (.39)	32	.03 (1.51)	33	3.118	.082
Mental condition	.50 (1.01)	32	.06 (1.05)	33	2.146	.148
Worth of living	.68 (1.06)	32	.18 (1.01)	33	2.857	.096
Quality of life	.29 (1.00)	31	.09 (1.01)	33	.313	.578
Social participation	.22 (1.38)	31	.51 (1.14)	33	.684	.412
Daily functioning	.77 (1.45)	31	.30 (.98)	33	2.143	.148
Estimated walking age	−.38 (6.88)	34	−3.84 (6.26)	39	5.026	.028
BMI	−.003 (.30)	34	−.14 (.31)	39	3.401	.069
Percent body fat (%)	.73 (5.37)	34	−.48 (2.03)	39	1.502	.225
LBM of the right leg (kg)	.02 (.11)	34	−.01 (.15)	39	1.762	.189
LBM of the left leg (kg)	.04 (.12)	34	−.02 (.17)	39	3.528	.065
Estimated vascular age	.55 (6.64)	34	1.35 (7.48)	39	.241	.625

The results are expressed as means (standard deviations). The variables were compared using a 2 (group: control and MCT) × 2 (period: first and second exercise periods) ANOVA followed by Bonferroni-corrected multiple comparisons. The F-value and p-value of ANOVA are shown. MCT, multi-cuff training; BMI, body mass index; LBM, lean body mass

Effects of MCT on psychological and physiological parameters

None of the participants experienced any adverse events or injuries from the MCT. Thus, we performed a 2 (group: control and MCT) × 2 (period: first and second exercise periods) ANOVA using subtracted values of measurements to test our hypothesis that MCT might be effective for walking functions in older people (Table 3). Data regarding changes in the estimated walking age were considered to be normally distributed according to the Shapiro–Wilk test (p = .391). Furthermore, as a result of Mauchly's spherical test (p = .811), the data were determined to be equally distributed. There was no statistically significant interaction between the group and period in the estimated walking age (p = .481) or other indices. However, ANOVA revealed a significant effect of the group on change in the estimated walking age (MCT = −3.84 (SD = 6.26); control = −.38 (SD = 6.88); [$F(1, 69) = 5.026$, $p = .028$, $\eta^2 p = .068$, power = .599]). Multiple comparisons with Bonferroni correction also indicated that the difference in the estimated walking age in the MCT group was significantly greater than that in the control group (p = .028) (Figure 3). A statistically significant main effect of the group was not observed for other indices. Additionally, when analyzing the change in gait speed (raw data), the average gait speed was increased in both groups. However, there was no significant difference (p = .171) between the MCT (7.578 (SD = 10.14)) and control (4.023 (SD = 11.31)) groups.

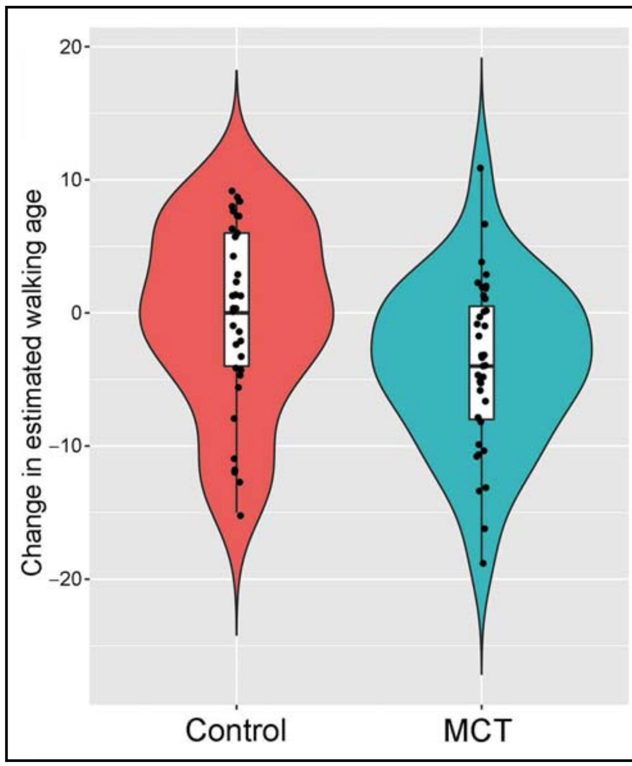

Fig. 3. Violin plot with boxplot representing changes in the estimated walking age between the control and MCT groups. The violin plot lines indicate a kernel density of the distribution (i.e., a smoothed histogram). Boxes span from the first to third quartiles; the horizontal line inside the boxes represents the median, and black dots represent all samples in each group. Endpoints of the axis are labelled by the minimum and maximum values. The control and MCT samples are distinguished by red and blue colors, respectively. MCT, multi-cuff training.

DISCUSSION

General purpose of this study

Previous studies have suggested that gait speed represented the core determinant of physical frailty and sarcopenia, as well as handgrip strength (Studenski *et al.* 2011; Chou *et al.* 2019; Soltani *et al.* 2021). Age-related decline in physiological function is known to be associated with cognitive decline, depressive symptoms, limited social interactions, and reduced engagement in leisure activities (Hsu *et al.* 2014; Chou *et al.* 2019), suggesting that gait speed is a predictor of life prognosis in older people (Studenski *et al.* 2011). Decreased gait speed is thought to be associated with decreased skeletal muscle mass in the thigh (Beavers *et al.* 2013; Siparsky *et al.* 2014). While numerous studies have demonstrated the feasibilities and benefits of muscle trainings for older people (Yasuda *et al.* 2014; Lopes *et al.* 2019), in this study, we focused on BFR training, which is anticipated to have a sufficient effect on muscle strength even during low-load resistance training. Moreover, the PPC and the VRC, which have been recently developed in Japan, do not require specialized technical expertise and can be utilized to train a large number of people, such as in exercise classes for the older people. As previous research indicated that BFR training is expected to increase blood flow and activate the endocrine immune function in addition to increasing muscle strength, we hypothesized that BFR training with the PPC could improve walking function in older people, even with low-load exercises. Therefore, we examined the effect of BFR training with the PPC on the walking function of older people in the exercise classes called the SMART program.

Effects of the SMART program

In the present study, we first analyzed the basic effects of the SMART program on the psychological and physiological parameters of older adults. Previous studies have indicated that psychological well-being includes choices and activities aimed at achieving physical vitality, mental acuity, social satisfaction, a sense of accomplishment, and personal fulfillment (Naci & Ioannidis, 2015). Thus, in the present study, we attempted to assess participants' psychological well-being utilizing a positive health questionnaire from prior research, consisting of 42 questions grouped into 6 categories: "bodily functions," "mental functions and perception," "spiritual dimension," "quality of life," "social and societal participation," and "daily functioning" (Huber *et al.* 2016). To simplify evaluation, we created a questionnaire that rates each of these six items (physical condition, mental condition, worth of living, quality of life, social participation, and daily functioning) on a 10-point scale. In the pre-program test, the estimated walking age was negatively correlated with the rating score of the physical condition (Table 1), suggesting that estimated walking age can be used as one of the physiological indicators related to physiological functions. Further, we analyzed changes in psychological and physiological parameters by participants' enrollment in the SMART program. The scores of all six categories of psychological well-being increased, while estimated walking age, BMI, and percent body fat decreased. These results suggest that this exercise program was a social gathering opportunity for older people and improved their mental and physical health. However, the estimated vascular age also increased. The estimated vascular age is a non-invasive assessment of arterial stiffness using acceleration plethysmography (Takada, 2002). A previous study indicated that chronic sympathetic system activation might increase cardiovascular risk (Holwerda *et al.* 2019), suggesting that the elevation of vascular age might be due to slightly intense exercises. This SMART program increased a modifiable risk factor (vascular age); therefore, it may be necessary to consider modifying our protocol in the future by performing a little less intense exercise.

Effects of MCT

Subsequently, we analyzed the effects of MCT training on psychological and physiological parameters. The estimated walking age was significantly rejuvenated in the MCT group compared with that in the control group ($p < .05$) (Figure 3). This indicates that MCT may effectively improve walking function in older adults. Based on the statistical approach and experimental design, we deem that the crossover design did not influence our findings.

As a previous study indicated that muscle power showed the highest association with thigh muscle volume in healthy older people (Lindemann *et al.* 2016), we initially hypothesized that BFR training with the PPC might be effective for improving walking function in older people. This enhancement may occur through the recruitment of type II muscle fibers, which tend to weaken in older individuals, without necessitating high-intensity exercises (Hwang & Willoughby, 2019). Therefore, in this study, muscle mass was measured in order to clarify the mechanism by which walking function improves; however, unfortunately, our results did not reveal any increase in the LBM of either leg following MCT (Table 3). Therefore, it appears that the enhanced walking function observed in older participants in this study is not attributable to increased muscle strength. Furthermore, given that there were no differences observed between the groups in other physiological and psychological indices measured in this study, it is difficult to speculate on the underlying psychological and physiological mechanisms driving the improvement in walking function in this study. Consequently, further research is required in the future.

Additionally, knee osteoarthritis (KOA) is one of the most common musculoskeletal disorders in older people (Bryk *et al.* 2016; Harper *et al.* 2019; Pitsillides *et al.* 2021), and previous studies have indicated that anterior knee pain decreases in patients with KOA after BFR training (Bryk *et al.* 2016; Ferraz *et al.* 2018; Harper *et al.* 2019; Pitsillides *et al.* 2021). Although the physiological mechanisms underlying pain reduction following BFR training are unclear (Song *et al.* 2021), a previous study showed the involvement of the endogenous opioid system (Hughes and Patterson, 2020). Thus, it is plausible that the pain in the legs may have been alleviated, leading to improved walking function in the present MCT group. Further studies measuring circulating levels of opioids and knee pain are needed in the future to confirm this.

Limitations and future directions

Our study has some limitations. First, as the older people who participated in this SMART program (mean age = 76.04 years) had high walking functions at baseline (mean estimated walking age = 64.4 years) and were able to perform strength training with a relatively high-intensity load, it is unclear whether the present results apply to all older people. In the future, we plan to develop an effective program of MCT for older people with a wide range of walking functions.

Second, it is unclear whether the strength training exercises used in the present SMART program (squat, lunge, toe raise, calf raise, and raise the thighs and stretch the knees using a chair) were appropriate. Strength training did not change the LBM of either leg. For example, previous studies used standard lower limb exercises (leg press, leg extension, calf flexion, and leg curl) (Ferraz *et al.* 2018; Harper *et al.* 2019). Therefore, there may be more appropriate training methods to improve walking function in older people. In addition, although the present MCT did not affect psychological parameters and estimated vascular age, it is possible that there might be other effective MCTs for these psychological and physiological parameters. In the future, it will be necessary to consider appropriate training methods.

Third, the present study indicated that the estimated vascular age of the MCT group tended to be higher than that of the control group, although no significant differences were observed. A previous study suggested that healthy individuals performing resistance training exercises with BFR are potentially at an increased risk of deleterious cardiovascular events (Spranger *et al.* 2015). There were no accidents in this study; however, we need to consider the possibility that MCT might increase the risk of cardiovascular diseases. However, the perception of physiological function, which was the index that correlated with the estimated walking age, did not change with MCT (Table 3). This result is similar to that of a previous study of BFR training, showing no association between improvement in muscle strength and improvement in quality of life in postmenopausal women (Cook *et al.* 2017). The exercises of the SMART program were of somewhat high-intensity; therefore, while the walking functions improved, it was possible that the participants felt stressed. In fact, although there were no statistically significant differences, the estimated vascular age was increased in the MCT group compared with that in the control group (Table 3). Although none of the participants in our study experienced adverse events or injuries from MCT, MCT seems to be slightly more stressful than the control exercise.

Fourth, in this experiment, the pressure during MCT was uniformly set to 200 mmHg; however, it is not clear whether the pressure was appropriate because individual AOP differs from person to person. There may be optimal pressures depending on the individual; therefore, this needs to be explored in the future. In addition, this study was not designed to compare a newly developed cuff (PPC) with a conventional cuff that has been used thus far; therefore, it remains unknown which of the PPC and conventional cuff is preferable for improving walking function in older people. However, as the PPC is easy to handle and the VRC system used in the present study (Multi Cuff Care) is a device that can be operated easily, this VRC system can potentially play a major role in improving the walking functions of older people in the future.

Fifth, intervention studies like the present one typically necessitate randomized controlled trials adhering to the Consolidated Standards of Reporting Trials (CONSORT) 2010 statement (Butcher *et al.* 2022). However, because this study was performed within an exercise class managed by a local government for local older people and there were considerable restrictions imposed by an industry-government-academia collaboration project, full adherence to CONSORT guidelines in certain aspects was not feasible. Therefore, the results of this study may be considered preliminary, and it is considered necessary to conduct further detailed intervention studies in accordance with the CONSORT statement in the future.

CONCLUSION

The present study reported the effects of MCT (BFR with a newly developed cuff [PPC]) on walking function in older people using the walking posture measurement system. Our findings indicate that MCT improves the walking functions of older people with no major adverse events.

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DISCLOSURE OF INTEREST

The authors report there are no competing interests to declare.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to ethical restrictions.

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AUTHORS' CONTRIBUTION

All authors contributed to the study conception and design. Material preparation and data collection were performed by Masahiro Matsunaga, Masahiro Kimura, Junko Hashimoto, and Yusuke Tominari. Data analyses and the first draft of the manuscript was written by Masahiro Matsunaga and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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