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Research Article

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Comparison of inspiratory muscle strength and aerobic exercise training and detraining on blood pressure in hypertensive patients

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Abbreviations
AE, aerobic exercise; BMI, body mass index; BP, blood pressure; CI, confidence interval; DBP, diastolic blood pressure; HRR, heart rate reserve; IMST, inspiratory muscle strength training; MAP, mean arterial pressure; PI_{max}, maximal inspiratory pressure; PP, pulse

ABSTRACT

Background: This study evaluated the effectiveness of inspiratory muscle strength training (IMST) as a time-efficient alternative to widely recommended aerobic exercise (AE) for reducing and maintaining blood pressure in hypertensive patients.
Methods: Twenty-eight hypertensive patients (aged 61 ± 7 years) were randomly assigned to IMST (n = 14) and AE (n = 14) groups. The IMST performed 30 breaths/session at 75% of maximal inspiratory pressure (PI_{max}), totaling about 8 minutes, 5 days/week. The AE group exercised at 70% of heart rate reserve for 30 minutes/session, 5 days/week. Both supervised interventions lasted 8 weeks, followed by a 4-week detraining period. Brachial and central systolic blood pressure (SBP) were taken at baseline, 8-week post-intervention, and post-detraining.
Results: The mean (standard deviation) change in brachial SBP from baseline to 8 week post-intervention significantly decreased in both the IMST group [−9.1 (12.1) mmHg, P = 0.01] and the AE group [−6.2 (7.2) mmHg, P = 0.01], with no significant difference between groups (P = 0.46). Central SBP also significantly reduced in the IMST group [−9.0 (11.9) mmHg, P = 0.01] and in the AE group [−5.7 (6.2) mmHg, P = 0.01], with no significant difference between groups (P = 0.37). However, the IMST group did not show significant persistence in SBP reduction, whereas the AE group did.
Conclusions: Both IMST and AE effectively reduced brachial and central BP after 8-week interventions in hypertensive patients. While IMST presents a time-efficient adjunctive option to AE, its long-term effectiveness remains uncertain.

Keywords: Inspiratory muscle strength training; Aerobic exercise; Blood pressure

BACKGROUND

Moderate-to-vigorous-intensity aerobic exercise (AE) is widely recommended as an effective non-pharmacological strategy for reducing blood pressure (BP) in patients with hypertension [1]. Regular AE exercise not only lowers BP but also reduces the risk of cardiovascular mortality in patients with hypertension [2-4]. Despite the benefits of AE interventions, adherence to AE recommendations of more than 150 minutes per week is challenging for pressure; SBP, systolic blood pressure; SD, standard deviation; VO_{2peak}, peak oxygen consumption.

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Competing interest
The authors declare that they have no competing interests.

Availability of data and materials
Datasets may be made available from the corresponding author on reasonable request.

Ethics approval and consent to participate
Ethical approval for this study was obtained from the Institutional Review Board of the University of Seoul (IRB File No. 2023-02-003-001).

Consent for publication
Not applicable.

Authors' contributions
Conceptualization: Jae SY, Choi TG; Data curation: Choi TG, Kim HJ, Kunutsor SK; Formal analysis: Choi TG, Kim HJ, Kunutsor SK; Investigation: Choi TG, Kim HJ, Kunutsor SK; Methodology: Jae SY, Choi TG; Project administration: Jae SY; Resources: Choi TG, Kim HJ, Kunutsor SK; Supervision: Jae SY; Writing - original draft: Jae SY, Choi TG; Writing - review & editing: Jae SY, Choi TG, Kim HJ, Kunutsor SK.

some individuals, primarily due to time constraints and mobility limitations [5,6]. Therefore, alternative exercise interventions that are time-efficient, broadly applicable, safe, and adaptable to diverse mobility requirements are needed for effective BP reduction.

Recent research has highlighted high-resistance (intensity) inspiratory muscle strength training (IMST) as a time-efficient exercise modality and a potential alternative approach to lowering BP [7-10]. Despite the established benefits of IMST, only a limited number of studies have investigated whether the effectiveness of IMST is comparable to that of AE [11]. Furthermore, few studies have examined the detraining effects of IMST on BP reduction [8,11]. Therefore, it remains unclear whether the short-term comparative efficacy of IMST and AE in reducing and maintaining BP in hypertensive patients is significant. In addition, previous studies on BP reduction through IMST have predominantly focused on brachial BP measurements, whereas data concerning central BP [12], an emerging measure of cardiovascular health [13], remain sparse. This study aimed to evaluate the effectiveness of IMST as a time-efficient alternative to the widely guideline recommended AE for reducing and maintaining BP in hypertensive patients.

METHODS

Study design

This study was conducted as a randomized, single-blinded, parallel-group clinical trial. Participants were randomly assigned to either the IMST group or the moderate-to-vigorous-intensity AE training group. The 8-week exercise programs were conducted as the primary intervention to lower BP, followed by a 4-week detraining period to assess the sustainability of the effects, resulting in a total duration of 12 weeks. The flowchart of the overall study design is presented in **Fig. 1**. All study processes were approved by the Institutional Review Board of the University of Seoul (UOS 2023-02-003-001).

Participants

Participants were patients with hypertension and the inclusion criteria were: 1) aged 50 or older; 2) diagnosed with hypertension and receiving antihypertensive medication for more than 4 months or having a BP of 140/90 mmHg or higher after quiet rest measurement; 3) not participating in regular exercise; 4) able to provide informed consent and willing to voluntarily participate in the study. Participants underwent a screening process, including health and medical history questionnaires, and were excluded if they had cardiovascular, musculoskeletal, metabolic, inflammatory diseases, or any medical/physical limitations that restrict participation in the exercise program or uncontrolled BP despite antihypertensive medication. Participants meeting the criteria were included in the study after providing a detailed explanation of the study's content and purpose and signing the informed consent. Participants who changed or discontinued prescribed antihypertensive medications during the study were excluded. Initially, 58 participants were recruited through community online boards and flyers posted at local community centers. Twenty-eight were excluded during pre-screening and baseline measurement, resulting in 30 participants assigned to the exercise interventions.

Measurements

All variables were measured at baseline, after the exercise intervention (follow-up), and after the detraining intervention using consistent standard operating procedures. All participants visited

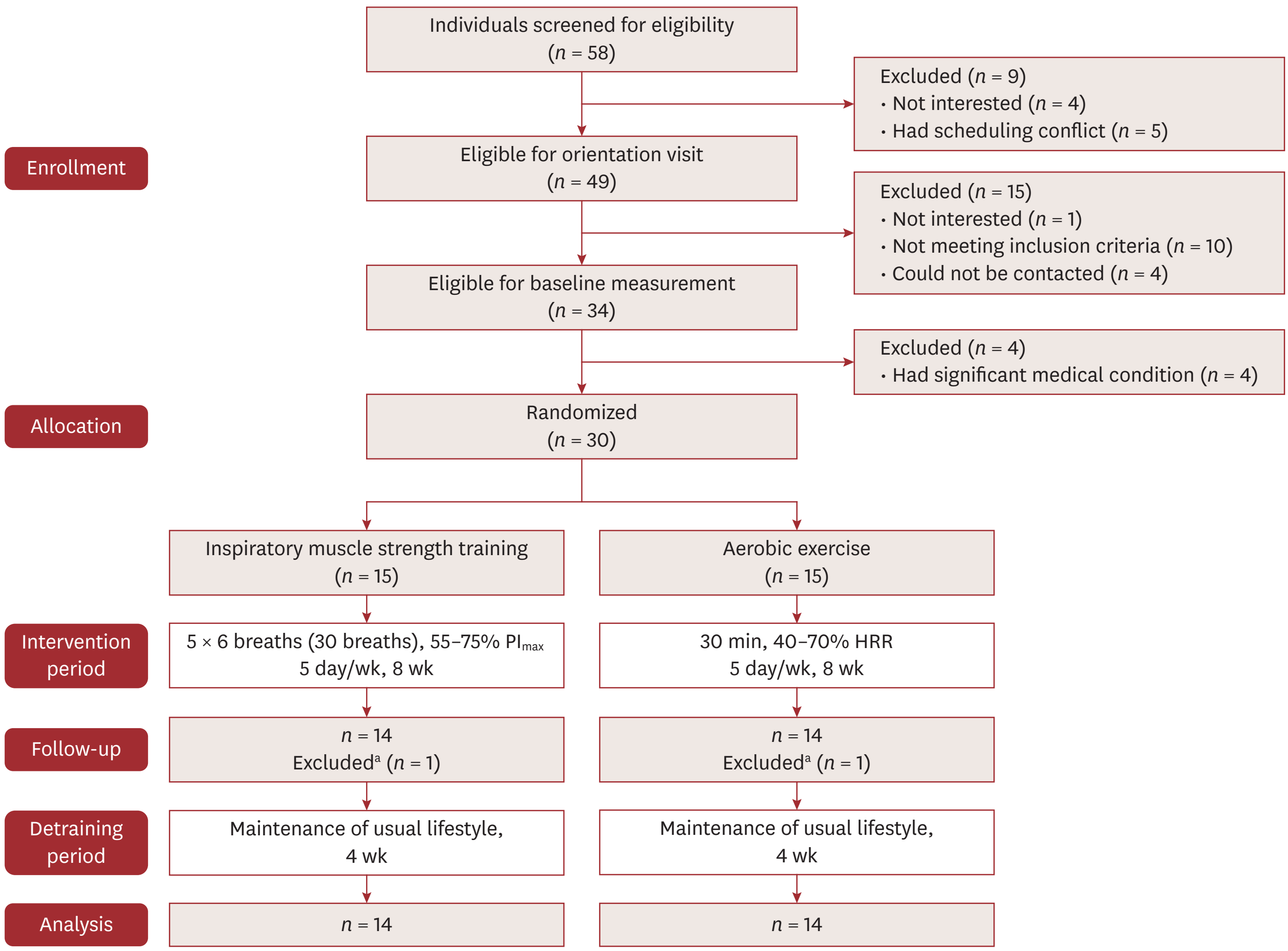

Fig. 1. Flow diagram of the experimental design.
[a]Excluded due to change or withdrawal of antihypertensive medication during intervention period.

the laboratory in the morning, refraining from vigorous physical activity, smoking, alcohol consumption, and food intake prior to measurements. Participants on any medications took them at their usual times. Follow-up measurements were conducted at least 48 hours and within 7 days after the last exercise session, considering acute effects. As all female participants were postmenopausal, menstrual cycles were not considered. Anthropometrics were measured using an automatic extensometer (BSM330, Inbody, Seoul, Korea) and a bioelectrical impedance analyzer (InBody620, Inbody) to assess height, weight, body mass index, body fat percentage, and skeletal muscle mass.

BP

Brachial BP was measured on the right arm using an automated oscillometric device (Mobile-O-Graph NG, IEM, Aachen, Germany). Measurements were taken twice at 1-minute intervals, after 10 minutes of supine rest, and the mean value was used. An additional measurement was taken if the difference between the two readings exceeded 10 mmHg, and the average of the two closest values was used.

Central BP was measured using SphygmoCor System (AtCor Medical, Sydney, Australia) with an applanation tonometry probe (SPT-304, Millar Instruments, Pearland, TX, USA) on the right radial artery. The radial pulse waveform was recorded continuously for 12 seconds, and transformed into the aortic waveform using a generalized transfer function. Brachial BP values were input into the software's built-in calculation formula to derive the central BP. Measurements were considered valid if the quality index was above 80% and intra-measurement error was below 5%.

Other measurements

Cardiorespiratory fitness was assessed using a graded maximal exercise test on a cycle ergometer (Corival, Lode BV, Groningen, Netherlands) to measure peak oxygen consumption (VO_{2peak}). Participants wore an ECG monitor (Quinton, Everett, WA, USA) and a gas analyzer (TrueOne 2400, ParvoMedics, Salt Lake City, UT, USA) for continuous monitoring. The ramp protocol was used, maintaining 50–60 RPM until exhaustion. Criteria for maximal exercise included two of the following: 1) perceived exertion above 18; 2) respiratory exchange ratio above 1.15; 3) predicted maximal heart rate above 90%; 4) plateau or decrease in oxygen consumption despite increased exercise intensity [14]. VO_{2peak} was determined at the highest oxygen consumption value recorded during the test.

Maximal inspiratory pressure (PI_{max}) was measured using the POWERbreathe K5 (POWERbreathe, England, UK) device in TEST mode. Participants performed maximal inspiratory efforts while seated, and the average of three values within a 5% error range was calculated.

IMST and AE interventions

IMST followed a protocol demonstrated to effectively reduce BP [8], using the handheld inspiratory resistance device (POWERbreathe K5, POWERbreathe) (**Supplementary Fig. 1**). Participants performed IMST once per day, 5 days per week for 8 weeks. Each daily session consisted of 5 sets, with each set comprising 6 inspiratory efforts, totaling 30 inspiratory efforts per day. Each inspiratory effort lasted approximately 2 seconds, followed by a 1-minute rest between sets. Each IMST session lasted about 8 minutes per day. The intensity of inspiratory resistance was set at 55–75% of their PI_{max}: 55% during the first week, 65% during the second week, and 75% for the remainder of the intervention period. From the 4 week onward, retested PI_{max} was reassessed during the first session of each week to progressively adjust the training intensity. The training intensity was continuously monitored through a computer software program connected to the device.

AE followed guidelines from the Korean Society of Hypertension [15], performed 5 days per week for 8 weeks on a treadmill at 40–70% of heart rate reserve (HRR) for 30 minutes. Intensity started at 40–50%, increasing weekly by 10%, and maintained at 60–70% from the 3rd week. HRR was calculated using the Karvonen formula based on maximal heart rate measured from maximal exercise test. Participants wore a wearable heart rate monitor (Fitbit Charge 2, Fitbit, USA) for intensity monitoring. AE included a 5-minute warm-up and cool-down before and after the main session.

Both IMST and AE sessions were supervised by the researchers and adherence of less than 80% (32 out of 40 sessions) was defined as incomplete data. After the exercise intervention, a 4-week detraining period was implemented, during which participants ceased IMST or AE and maintained their usual lifestyle.

Randomization and sample size

Participants were randomly assigned to IMST or AE groups using a simple randomization allocation method based on a random number table at a 1:1 ratio. As no prior studies have compared IMST and AE for BP reduction, the sample size was determined based on the initial study by Vranish and Bailey [16] reporting IMST's BP-lowering effect (Cohen's d = 1.12). Using G*Power 3.1.9.2, a sample size of 13 for the IMST group was calculated for an effect size of 1.12, a significance level (α) of 0.05, and power (1-β) of 0.95. Considering a dropout rate of 10%, the total sample size was set at 30 participants (15 participants per group).

Statistical analysis

All data were presented as frequencies, means (standard deviation [SD]), and means (95% confidence intervals [CIs]). Normality was assessed using the Shapiro-Wilk test. To evaluate the effects and sustainability of IMST and AE interventions, paired *t*-tests were conducted within each group (baseline vs. follow-up, baseline vs. detraining). To compare the effects between the interventions, mean between-group differences in change (IMST - AE) were assessed using independent *t*-tests on the changes (Δ) in each variable. All statistical analyses were performed using SPSS-PC version 28.0 (IBM Corporation, Armonk, NY, USA), with the significance level (α) set at < 0.05.

RESULTS

Of the 30 participants initially assigned to the interventions, one participant from the IMST group was excluded due to changes in antihypertensive medication, and one participant from the AE group withdrew from the study. Consequently, 28 participants (IMST: $n = 14$; AE: $n = 14$) completed the intervention and were included in the final analysis.

Baseline characteristics of the participants are presented in **Table 1**. There were no significant differences between the groups for most variables at baseline. No exercise-related injuries or adverse events were reported. The adherence rates for the IMST and AE groups were 97% and 94%, respectively. VO_{2peak} and PI_{max} changes at follow-up and after detraining are presented in **Figure 2**. VO_{2peak} showed no significant changes in the IMST group at follow-up ($P = 0.49$) or after detraining ($P = 0.87$). In the AE group, there was a marginal increase at follow-up (1.32 ± 2.0 mL/min/kg, $P = 0.06$), with a significant increase after detraining (1.95 ± 2.9 mL/min/kg, $P = 0.05$). Both IMST and AE groups showed significant increases in PI_{max} at follow-up (both, $P < 0.01$) and after detraining (both, $P < 0.01$).

Effects of interventions

The changes in brachial and central BP at follow-up and after detraining are presented in **Table 2** and **Fig. 3**. The mean (± SD) change in brachial systolic blood pressure (SBP) from baseline to post-intervention significantly decreased in both the IMST group (−9.1 ± 12.1 mmHg, $P = 0.02$) and the AE group (−6.2 ± 7.2 mmHg, $P = 0.01$), with no significant difference between groups (−2.9 mmHg; 95% CI, −10.6 to 4.9; $P = 0.46$). Mean arterial BP also demonstrated similar reductions in both groups after the intervention (IMST: $P = 0.04$, AE: $P = 0.01$), with comparable changes between IMST and AE ($P = 0.79$). For brachial DBP, the IMST group did not show a significant decrease at follow-up (−3.3 ± 6.8 mmHg, $P = 0.09$). In contrast, the AE group demonstrated a significant decrease at follow-up (−3.9 ± 5.7 mmHg, $P = 0.03$), with no significant difference between groups (0.6 mmHg; 95% CI, −4.3 to 5.4; $P = 0.81$).

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Table 1. Baseline characteristics of trial participants

Variables	All (*N* = 28)	IMST (*n* = 14)	AE (*n* = 14)	*P*-value
Sex, male/female	9/19	4/10	5/9	0.686
Age (yr)	60.7 ± 6.9	59.9 ± 7.4	61.5 ± 6.4	0.536
Weight (kg)	68.2 ± 15.8	67.9 ± 18.6	68.6 ± 13.1	0.910
BMI (kg/m^2)	26.4 ± 4.6	26.3 ± 4.8	26.5 ± 4.5	0.888
Percent body fat (%)	31.5 ± 8.0	29.9 ± 8.2	33.1 ± 7.8	0.295
Skeletal muscle mass (kg)	25.4 ± 5.9	25.8 ± 6.8	25.0 ± 4.9	0.714
Brachial SBP (mmHg)	127.1 ± 15.4	124.4 ± 18.6	129.9 ± 11.5	0.361
Brachial DBP (mmHg)	85.4 ± 11.1	82.4 ± 13.9	88.5 ± 6.4	0.146
Resting HR (beats/min)	67.3 ± 12.8	66.4 ± 11.2	68.2 ± 14.6	0.720
Antihypertensive				
ARB	15	8	7	
CCB	9	5	3	
Diuretic	2	0	2	
β-blocker	1	0	1	
None	5	3	2	
Duration of medication (yr)	7.4 ± 6.7	6.9 ± 5.8	7.9 ± 7.7	0.747
Other conditions				
Dyslipidemia	16	7	9	
Diabetes	3	1	2	
Others	6	2	4	

IMST, inspiratory muscle strength training group; AE, aerobic exercise training group; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; HR, heart rate; ARB, angiotensin receptor blocker; CCB, calcium channel blocker.

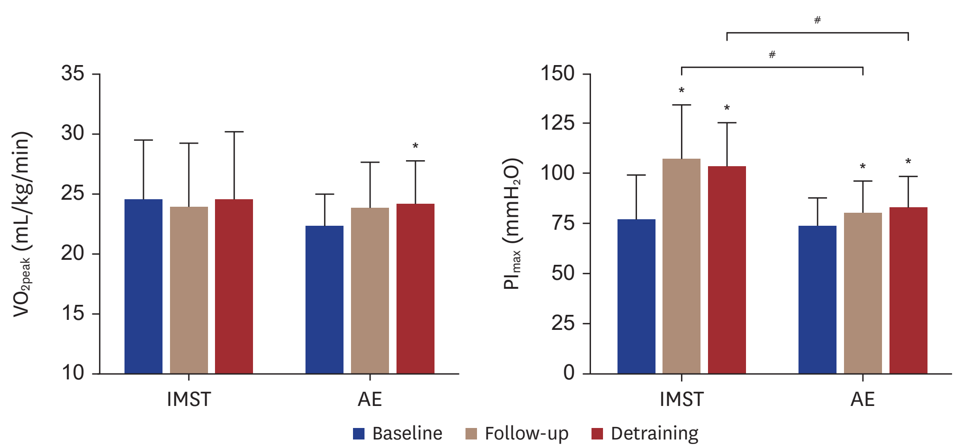

Fig. 2. Changes in cardiorespiratory fitness and maximal inspiratory pressure at baseline, follow-up, and detraining between IMST group and AE group.
IMST, inspiratory muscle strength training group; AE, aerobic exercise training group; VO_{2peak}, peak oxygen consumption; PI_{max}, maximal inspiratory pressure.
**P* < 0.05 vs. baseline; #*P* < 0.05 mean between-group difference in change.

The mean (± SD) change in central SBP significantly decreased by −9.0 (11.9) mmHg ($P = 0.01$) in the IMST group and by −5.7 (6.2) mmHg in the AE group at follow-up ($P = 0.01$), with no significant difference between groups (−3.3 mmHg; 95% CI, −10.6 to 4.1; $P = 0.37$). Mean central arterial BP also demonstrated similar reductions in both groups after the intervention (IMST: $P = 0.04$, AE: $P = 0.01$), with comparable changes between IMST and AE (−0.6 mmHg; 95% CI, −6.1 to 4.8; $P = 0.81$). Central DBP did not show significant reductions in the IMST group at follow-up [−3.4 (7.0) mmHg, $P = 0.10$], whereas the AE group demonstrated a significant decrease at follow-up [−4.6 (5.7) mmHg, $P = 0.03$]. There were no significant difference in changes in central DBP between groups (−0.6 mmHg; 95% CI, −6.1 to 4.8; $P = 0.81$).

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Table 2. Comparison of brachial and central blood pressure at baseline, follow-up, and detraining between IMST group and AE group

Variables	Study group		Mean between-group difference in change[a] (95% CI)	*P*-value
	IMST (*n* = 14)	AE (*n* = 14)		
Brachial SBP at baseline (mmHg)	124.4 ± 18.6	129.9 ± 11.5	NA	0.361
Mean change in brachial SBP from baseline (mmHg)				
Follow-up	−9.1 ± 12.1[b]	−6.2 ± 7.2[b]	−2.9 (−10.6 to 4.9)	0.455
Detraining	−4.4 ± 10.4	−6.0 ± 6.8[b]	1.6 (−5.2 to 8.5)	0.625
Brachial DBP at baseline (mmHg)	82.4 ± 13.9	88.5 ± 6.4	NA	0.151
Mean change in brachial DBP from baseline (mmHg)				
Follow-up	−3.3 ± 6.8	−3.9 ± 5.7[b]	0.6 (−4.3 to 5.4)	0.811
Detraining	−0.4 ± 7.6	−2.9 ± 5.4	2.6 (−2.5 to 7.7)	0.311
Brachial MAP at baseline, mmHg	96.4 ± 15.2	102.3 ± 7.4	NA	0.208
Mean change in brachial MAP from baseline (mmHg)				
Follow-up	−5.3 ± 8.3[b]	−4.6 ± 5.6[b]	−0.7 (−6.2 to 4.8)	0.792
Detraining	−1.7 ± 8.3	−3.9 ± 5.7[b]	2.2 (−3.3 to 7.8)	0.419
Central SBP at baseline (mmHg)	118.6 ± 20.0	124.4 ± 9.9	NA	0.344
Mean change in central SBP from baseline (mmHg)				
Follow-up	−9.0 ± 11.9[b]	−5.7 ± 6.2[b]	−3.3 (−10.6 to 4.1)	0.367
Detraining	−4.6 ± 9.8	−5.2 ± 6.1[b]	0.6 (−5.7 to 7.0)	0.836
Central DBP at baseline (mmHg)	83.4 ± 13.8	89.9 ± 6.2	NA	0.126
Mean change in central DBP from baseline (mmHg)				
Follow-up	−3.4 ± 7.0	−4.1 ± 6.0[b]	0.7 (−4.4 to 5.8)	0.774
Detraining	−0.4 ± 7.5	−3.4 ± 5.3[b]	3.0 (−2.0 to 8.0)	0.233
Central MAP at baseline (mmHg)	95.1 ± 15.6	101.4 ± 6.9	NA	0.184
Mean change in central MAP from baseline (mmHg)				
Follow-up	−5.3 ± 8.2[b]	−4.6 ± 5.7[b]	−0.6 (−6.1 to 4.8)	0.811
Detraining	−1.8 ± 8.1	−4.0 ± 5.3[b]	2.2 (−3.1 to 7.5)	0.400

IMST, inspiratory muscle strength training group; AE, aerobic exercise training group; CI, confidence interval; NA, not applicable; SBP, systolic blood pressure; DBP, diastolic blood pressure; MAP, mean arterial pressure.
[a]Mean difference in change compared to AE group (IMST - AE); [b]*P* < 0.05 vs. baseline.

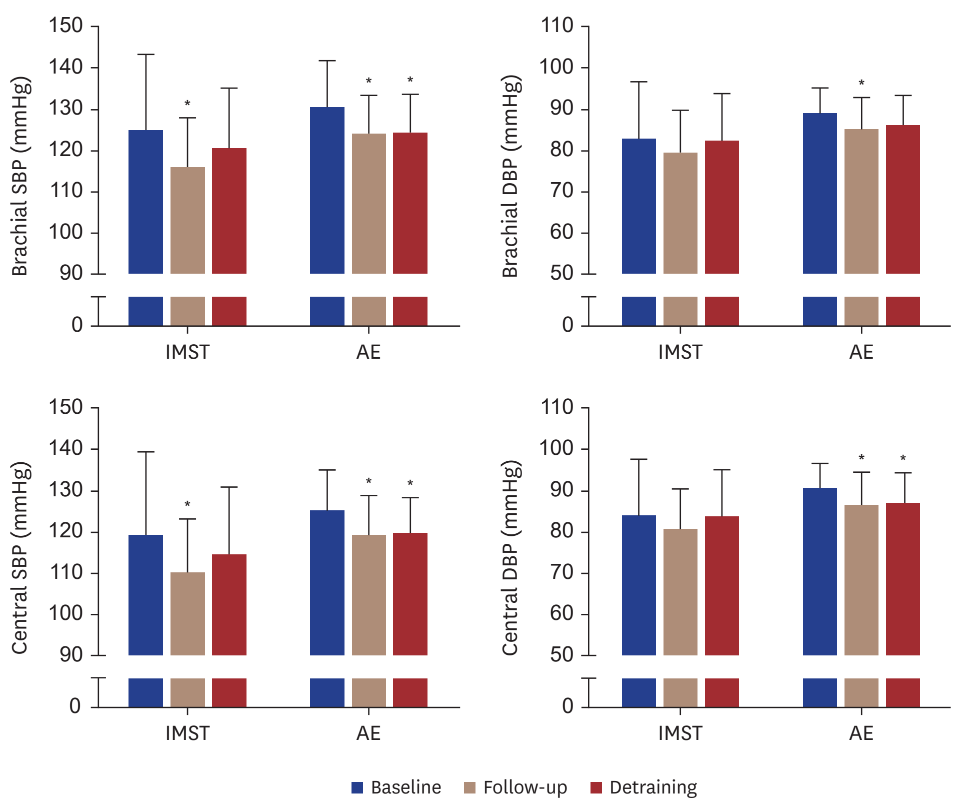

Fig. 3. Changes in brachial and central blood pressure at baseline, follow-up, and detraining between IMST group and AE group.
IMST, inspiratory muscle strength training group; AE, aerobic exercise training group; SBP, systolic blood pressure; DBP, diastolic blood pressure.
*$P < 0.05$ vs. baseline.

Effects of detraining

After the 4-week detraining period, the IMST group did not show significant differences in any BP variables compared to baseline. In contrast, the AE group maintained significantly lower SBP levels, with brachial SBP (−6.0 ± 6.8 mmHg, $P = 0.01$) and central SBP (−5.2 ± 6.1 mmHg, $P = 0.01$) compared to baseline.

DISCUSSION

This randomized clinical trial demonstrated that both IMST and AE effectively reduced brachial and central BP after 8 weeks, suggesting that IMST may serve as a time-efficient option, particularly for individuals with limited ability to engage in AE. However, BP reductions were maintained only in the AE group during the 4-week detraining period, indicating a more sustained long-term effect with AE.

IMST has recently emerged as an effective intervention for hypertension, primarily studied for its impact on resting office BP. Craighead et al. [8,9] reported an SBP reduction of approximately 9 mmHg after 6 weeks of IMST at 55–75% of PI_{max} in middle-aged and older adults with elevated BP. Similarly, our study found an SBP decrease of 9.1 mmHg after 8 weeks, reinforcing its effectiveness in hypertensive patients. Additionally, our study extends prior findings by demonstrating IMST's efficacy in an East Asian hypertensive population, supporting its broader applicability.

A recent meta-analysis by Zheng et al. [7] reported that IMST reduced SBP by 12.5 mmHg and SBP by 4.8 mmHg, regardless of protocol variations, participant characteristics, or study durations. This reduction is comparable to that reported in AE studies [2,17], including other lifestyle modification strategies [1,18]. In our study, while the BP reduction difference between IMST and AE was not statistically significant, IMST (10 minutes/day) showed a trend toward a similar or greater SBP decrease (9.1 mmHg) compared to AE (6.2 mmHg, 30 minutes/day). Notably, IMST achieved these results with a significantly lower time commitment, highlighting its potential practicality. However, additional studies are needed to confirm whether IMST provides comparable or superior BP reduction to AE across diverse populations and protocols.

In our study, IMST also reduced central SBP by approximately 9 mmHg, comparable to the 6 mmHg reduction with AE in hypertensive patients. While evidence regarding the effects of IMST on central BP is limited, Kahraman et al. [12] reported a 4.7 mmHg decrease after 8 weeks of IMST in patients with pulmonary hypertension. These findings add growing evidence supporting the potential benefits of IMST, particularly its impact on central BP. Given the association between central BP and cardiovascular risk [13], IMST may serve as a promising non-pharmacological intervention for BP reduction. However, Further research is required to confirm these results, investigate the underlying mechanisms, and assess the long-term effects of IMST on central BP.

The differences in the mechanisms by which AE and IMST lower BP are not yet fully understood, but existing research suggests several potential pathways. Both AE and IMST have been shown to enhance oxidative stress markers, inflammatory indices, and nitric oxide bioavailability [8,19], which may contribute to BP reduction [20,21]. However, their underlying mechanisms may differ due to potential differences in hemodynamic and autonomic responses. AE increases cardiac output and systemic blood flow, leading to sustained anterograde shear stress, which enhances endothelial function via nitric oxide production and vascular remodeling, ultimately contributing to BP reduction [19]. In contrast, IMST generates intrathoracic pressure fluctuations [22,23], increasing retrograde shear stress during inspiration [24]. Although direct evidence remains limited, we speculate that IMST-induced fluctuations in intrathoracic pressure may contribute to transient post-exercise blood flow redistribution, potentially increasing anterograde shear stress in peripheral arteries and leading to BP reduction. However, further studies are needed to validate this hypothesis. Additionally, AE and IMST differ in their influence on autonomic regulation. AE gradually enhances baroreflex sensitivity and reduces sympathetic nervous system activity through systemic circulatory improvements [25,26]. IMST, by contrast, directly stimulates arterial baroreceptors via intrathoracic pressure shifts, potentially leading to an immediate reduction in sympathetic activity and systemic vascular resistance [16,27,28], though the duration of this effect remains unclear. Further research is warranted to clarify the specific physiological pathways underlying AE and IMST's antihypertensive effects, particularly the unique role of intrathoracic pressure modulation and pulsatile shear stress in IMST.

While IMST effectively lowers BP, its long-term effectiveness remains unclear. Craighead et al. [8] reported that a 9 mmHg BP reduction with IMST was largely maintained for 6-week post-training, BP remained lower than baseline for 8 weeks after the cessation of isometric resistance training in young normotensive individuals [29]. However, in our study, IMST did not sustain BP reductions after the detraining period. This disparity may stem from differences in study design, intervention duration, and participant characteristics. Our study involved an 8-week intervention with a 4-week detraining period, whereas prior studies examined a 6-week intervention with a 6-week detraining period [8]. Additionally, IMST requires specialized equipment, which may have limited participant's ability to maintain training effects post-intervention. Given the limited studies on IMST's detraining effects [8,11], further study is needed to determine factors influencing its long-term efficacy and strategies for sustaining its benefits.

In contrast, BP reductions in the AE group persisted during the 4-week detraining follow-up, suggesting that AE provides a more sustained long-term BP reduction. This finding is consistent with previous findings that BP improvements from AE can persist post-training [30]. However, some studies indicate that SBP may gradually return toward baseline after AE cessation, highlighting variability in its long-term effects [31,32].

The comparable effectiveness of IMST and AE, a well-established non-pharmacological intervention for BP reduction, is both clinically and practically significant. While AE is widely recommended for its cardiovascular benefits [33], adherence remains a challenge due to time constraints, limited access to facilities, and physical limitations [5,6]. IMST, requiring only about 10 minutes per day, may serve as a feasible option for individuals who struggle to engage in regular AE. However, further research is needed to fully establish its long-term benefits and broader applicability.

This study has several limitations. First, the participants were Asian, which may limit the generalizability of the findings to other racial or ethnic groups. Future research is needed to validate these results across diverse populations and to explore potential gender-specific variations. Second, the small sample size and relatively short intervention and detraining periods restrict our ability to assess the long-term durability of the observed effects. Furthermore, BP was measured at single-time points, potentially introducing variability. Further studies using 24-hour ambulatory BP monitoring are needed to more comprehensive BP assessment. Given these limitations, the findings should be interpreted with caution and considered hypothesis-generating, warranting further investigation in larger, well-designed trials.

Despite the limitations, this study has notable strengths. It is the first randomized controlled trial to compare the antihypertensive effects of IMST and AE, examining both brachial and central BP as well as detraining effect in Asian hypertensive patients. By targeting an Asian population, this study provides valuable insights into the efficacy of these exercise modalities within this demographic, addressing a significant gap in the literature.

CONCLUSIONS

Both IMST and AE effectively reduced brachial and central BP after 8 weeks of intervention. While IMST offers a time-efficient adjunctive option, its long-term effectiveness remains uncertain, as BP reduction were not sustained during detraining, unlike AE. Further research is needed to determine IMST's role in long-term hypertensive management and strategies to enhance its sustainability.

SUPPLEMENTARY MATERIAL

Supplementary Fig. 1

Overview of IMST protocol.

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