

Effects of exercise training on home blood pressure values in older adults: a randomized controlled trial

Takayoshi Ohkubo^a, Atsushi Hozawa^a, Ryoichi Nagatomi^b, Kazuki Fujita^{a,b}, Catherine Sauvaget^{a,e}, Yoko Watanabe^a, Yukiko Anzai^d, Akira Tamagawa^b, Ichiro Tsuji^a, Yutaka Imai^c, Hiroaki Ohmori^b and Shigeru Hisamichi^a

Objective To determine the effects of exercise training on the blood pressure (BP) values of older adults, using home blood pressure measurement.

Design Randomized controlled trial.

Participants A total of thirty-nine free-living older adults (including 19 men) aged from 60–81 years with home systolic blood pressure > 120 mmHg and without significant cardiopulmonary-musculoskeletal disease, were randomly allocated to either 25 weeks of exercise training (exercise group) or to a control program (control group).

Main outcome measurements Change in the 2-week averages of home systolic and diastolic blood pressure values measured with a validated automatic device before, during and after the intervention period.

Results Compared with the control group, the exercise group showed a significant decrease in values for home systolic blood pressure (maximum between-group difference = 7.7 mmHg, $P = 0.003$) and home diastolic blood pressure (4.2 mmHg, $P = 0.001$). These changes

were observed for both genders.

Conclusions Exercise training was effective for older adults in lowering home blood pressure values. This is the first trial to demonstrate the usefulness of home blood pressure measurement in examining the effect of exercise training on blood pressure values. *J Hypertens* 19:1045–1052 © 2001 Lippincott Williams & Wilkins.

Journal of Hypertension 2001, 19:1045–1052

Keywords: elderly subjects, exercise, home blood pressure, randomized controlled trial

Departments of ^aPublic Health, ^bMedicine and Science in Sports and Exercise, ^cClinical Pharmacology and Therapeutics, Tohoku University Graduate School of Medicine and Pharmaceutical Science, Sendai, ^dResearch Unit of Public Health Nursing, Miyagi University School of Nursing, Miyagi, and ^eDepartment of Epidemiology, Radiation Effects Research Foundation, Hiroshima, Japan.

Sponsorship: This work was supported by research grants from Ministry of Education and Culture (09557034 and 01180) and Ministry of Health and Welfare (Research on Health Services: H10-025), Japan.

Correspondence and requests for reprints to Ichiro Tsuji, MD, Department of Public Health, Tohoku University Graduate School of Medicine, Sendai, 980–8575, Japan.
Tel: +022 717 8121; fax: +022 717 8125; e-mail: tsuji1@mail.cc.tohoku.ac.jp

Received 25 August 2000 **Revised** 5 February 2001
Accepted 13 February 2001

Introduction

Regular physical activity is associated with multiple health benefits, including a reduced incidence of coronary heart disease [1] and stroke [2]. Although it is generally accepted that regular physical activity also reduces blood pressure (BP) and prevents hypertension [3], there is still inconsistency among existing studies documenting these effects in older subjects. Cross-sectional studies have shown that physically active individuals tend to have lower BP than their sedentary counterparts [4], but this association is not always observed for coronary risk factors [5]. Population-based cohort studies suggest that being physically active is associated with a reduced incidence of hypertension [6]. Likewise, intervention trials tend to demonstrate that exercise has a significant BP-lowering effect. However, several meta-analyses have shown that many of these trials had major design limitations such as lack or an inadequacy of a control group, or a small sample size

[7,8]. Furthermore, trials with a smaller number of subjects or with an inadequate control group tended to report a greater reduction in BP than did studies with a larger sample size or adequate control groups [7,8].

Older people have an increased incidence of short-term variations in BP [9] and show a large white-coat effect [10,11]. Therefore, it is difficult to determine the true effect of exercise training on BP using the conventional type of casual BP measurement, which is known to be influenced by several biases, such as observer bias, regression dilution bias and the white-coat effect [9–11]. To avoid these biases, several studies have used ambulatory BP as a tool to determine the true effect of exercise training on BP [12–18]. However, their results have also been inconsistent. Ambulatory BP values are reported to be influenced by daily physical and mental activity, leading to poor reproducibility [19]. Two studies of older populations have reported that exercise

training was not effective in lowering the ambulatory BP [17,18].

Conversely, BP measured by the subject at home (home BP), which makes it possible to obtain multiple measurements over a long intervention period under well-controlled conditions, has been reported to be more reliable because it avoids the biases that are associated with conventional casual BP measurement [20]. Furthermore, its reproducibility is at least as good or even better than that of ambulatory BP [20,21]. Despite these advantages, no study has ever investigated the BP-lowering effect of exercise training using home BP measurements.

Sendai City Silver Center, a health and welfare facility for older people, developed an exercise training program for minimizing cardiovascular risk factors and improving physical function in older people, and evaluated its efficacy using a randomized controlled trial (Sendai Silver Center Trial: SSCT) [22]. We have previously reported the findings of that trial, i.e. that exercise training significantly improved the maximum oxygen consumption [22]. The objective of our present analysis was to examine the effect of 6 months of exercise training on the BP of elderly participants who attended SSCT, using home BP measurement.

Methods

Design

This further study of the above-mentioned SSCT exercise training program was also a randomized controlled trial utilizing the same criteria as those reported for our previous study [22]. The study protocol was approved by the Executive Board of the Sendai Health and Welfare Foundation. All subjects gave written informed consent.

Study participants

Details of selection of the study subjects, and the inclusion and exclusion criteria, have been reported previously [22]. In brief, using advertisements, we recruited free-living men and women aged 60 years or older resident in Sendai City. A total of two hundred and nine possible participants applied and attended the screening session. Of these, 121 were excluded in accordance with the exclusion criteria, such as the use of antihypertensive agents, BP at the screening session > 160 mmHg for systolic and/or > 90 mmHg for diastolic, a history of cerebro-cardiovascular disease or any other significant cardiopulmonary-musculoskeletal disease which might have interfered with participation and safety in the exercise training. Of the 88 remaining subjects, 78 attended the baseline measurement examination. Of those, 12 subjects were excluded, mainly because of abnormal electrocardiograms during exercise. The remaining 65 eligible participants, stratified

for age and sex, were randomly allocated into either an exercise group ($n = 32$) or a control group ($n = 33$) by epidemiologists, who were masked from the measurement results using a random numbers table.

These participants were then given a home BP measuring device, and asked to measure their BP. Of these 65 participants, a further 26 subjects who had low baseline home systolic BP values < 119 mmHg (in accordance with our previously reported criteria [23]) were excluded from this study, which aimed to analyze the BP-lowering effect of exercise training. Therefore, the study subjects comprised 39 individuals (22 subjects in the exercise group and 17 in the control group).

Exercise group

We gave three 2 h classes per week for 25 weeks. The subjects in the exercise group were asked to attend the classes at the Center at least twice a week. The main session consisted of an endurance training session and a resistance exercise training session. Details of the exercise training have been reported previously [22].

Endurance training

Subjects cycled at 50–60 rpm on a bicycle ergometer at an individually prescribed workload for 10–25 min (Table 1). The intensity of exercise was determined according to the American College of Sports Medicine (ACSM) guidelines for exercise prescription [24]. The intensity of exercise was calculated as a percentage of heart rate (HR) reserve using the following formula, based on the subject's predicted age-adjusted maximum HR ($220 - \text{age}$), and his or her seated resting HR: $\%HR \text{ reserve} = (\text{target HR} - \text{resting HR}) / (\text{maximum HR} - \text{resting HR}) \times 100$.

Resistance exercise training

Five exercises using rubber film manufactured for resistance exercise (Thera-Band Resistive Exerciser;

Table 1 Exercise prescription for endurance training

Week	Phase	Target intensity of exercise (%HR reserve)	Duration of exercise (min)
1	Educational 1	< 25*	10
2–4	Educational 2	50	10
5–9	Build-up 1	50	15
10	Evaluation	**	**
11–12	Build-up 2a	50	20
13–15	Build-up 2b	60	20
16	Recovery 1	40	20
17–19	Build-up 3	60	20
20	Recovery 2	40	20
21–25	Build-up 4	60	25

*Workload was fixed for educational purposes. **Subjects' HR response to exercise was evaluated by the same protocol as in the baseline measurement. HR, heart rate.

Hygienic Corp. Akron, Ohio, USA) were performed in a five-stage incremental program under the supervision of an expert exercise trainer [25]. Each stage lasted 2–6 weeks, with 1 week recovery periods at the 15th, 19th, and 22nd weeks, in which the number of exercises was limited to two and the working strength of each exercise was reduced. Each exercise was repeated 20 times, side-raise for supraspinatus and deltoid muscles, elbow flexion for biceps muscles, knee extension for quadriceps muscles, hip abduction, and hip adduction.

Safety considerations

For safety, a research nurse and a physician checked the health status and vital signs of the participants before and after each class, and attended during the classes [22].

Control group

We provided two 2 h classes a month. The subjects were asked to attend classes at least once a month. The classes consisted of a 1 h lecture, the topic of which was not related to physical exercise, and 1 h of seated recreational activity, such as playing games. Otherwise, they were asked to continue their usual way of life.

Blood pressure measurements

Blood pressure measuring device

Both home BP and casual BP were measured with the HEM 705CP (Omron Life Science Kyoto, Japan), a fully automatic device, based on the cuff-oscillometric method [26] that generates a digital display of systolic BP, diastolic BP and HR. This device has been validated previously [26] and meets the criteria of the Association for the Advancement of Medical Instrumentation [27] and the British Hypertension Society [28]. The circumference of the arm was less than 34 cm in all participants, so we used a standard arm cuff for both BP measurements.

Home blood pressure

Two weeks before the start of the intervention period, physicians and/or public health nurses instructed the subjects on how to perform home BP measurements. Subjects were asked to measure and record their BP every morning within 1 h of waking, in the sitting position after more than 2 min of rest, and to report the values every other week to the Center, before, during and after the intervention period. These methods were based on those of our cohort study that reported the prognostic significance of home BP [23,29].

The ‘baseline home BP’ was defined as the 2 week average value before intervention. Home BP during intervention was defined as the average of the 2 week home BP averages. The home BP during the periods showing the largest between-group difference was defined as ‘max-difference home BP’. The post-inter-

vention home BP was defined in two parts: 2 week average home BP for weeks 1–2 after intervention (‘post1 home BP’) and 2 week average home BP for weeks 3–4 after intervention (‘post2 home BP’).

Casual blood pressure

BP and HR in a sitting position after 2 min of rest were measured twice by public health nurses, on two separate screening occasions. The baseline and post-intervention casual BP values were defined as the average of the four readings on two separate screening occasions during the 2 weeks before and after the intervention period, respectively.

Measurement of other variables

We measured several variables within the 2 weeks before and after the intervention period. Habitual physical activities were assessed by a physical activity diary in which the subjects were asked to record their activities every 15 min during waking hours, for three workdays. The energy consumption of each physical activity recorded in the diary was estimated by multiplying the duration of the activity by its rate of energy [30,31]. Daily total energy consumption was then calculated by summing the energy consumption of each physical activity [30,31]. Body height, while standing and body weight, without shoes and while wearing only underwear, were measured. Daily sodium intake was calculated according to a previously validated food frequency questionnaire consisting of 133 items [32]. An incremental submaximal exercise test was done on an electrically braked upright cycle ergometer (Aerobike 800; COMBI Corp, Tokyo, Japan) to estimate the maximal oxygen consumption of the subjects.

Data analysis

The study was a standard comparative trial testing the effects on BP of the two interventions. According to a previous analysis, the sample size of 30 participants was adequate to detect a mean difference of 10 mmHg in home systolic BP with a significance level of 0.05 at a power of 80%, which allows a smaller sample size than is required if casual BP measurement is used [33].

Mean between-group difference in home systolic BP, calculated as the BP change within the exercise group minus the BP change within the control group, was the primary outcome variable; mean between-group difference in home diastolic BP and casual BP, home and casual HR, and white-coat effect were secondary outcomes. White-coat effect was calculated as casual BP minus home BP for systolic and diastolic BP, respectively.

All analyses were performed on an intention-to-treat basis. The inspectors were not masked to group allocation at the post-intervention measurement, but the

investigators who were in charge of the measurement of blood parameters and statistical analysis were masked to group allocation. The χ^2 -test, *t*-test, or analysis of covariance (ANCOVA) was used as appropriate. Differences at $P < 0.05$ were accepted as statistically significant. SAS software, Version 6.12 (SAS Institute Inc, Cary, North Carolina, USA) was used for all statistical calculations.

Results

Baseline characteristics

The subjects ranged from 60–81 years. Baseline age, maximum oxygen consumption, body mass index (BMI), salt intake, and proportions of females, those who had never smoked and those who had never drunk alcohol did not differ significantly between the exercise and control groups: (age: 67.5 and 66.8 years; maximal oxygen consumption: 24.1 and 25.0 ml/kg per min; BMI: 23.6 and 23.3 kg/m²; salt intake: 9.5 and 8.7 g/day; proportion of female: 50 and 53%; never smoked: 64 and 53%; never drunk alcohol: 41 and 53%, in the exercise and control groups, respectively). All participants were independent in the instrumental activities of daily living.

Subject compliance

Throughout the 25 weeks of intervention, there were no drop-outs from either group. The mean attendance rate for each class was 80% in the exercise group and 87% in the control group. In the exercise group, 20 subjects (91%) attended at least twice a week throughout the course. Of the 17 subjects in the control group, 16 (94%) attended at least once a month throughout the course. No-one was injured in a fall or experienced a cardiovascular event. Two subjects in the exercise group reported that they started taking an antihypertensive agent after the training had started.

The average number of home BP measurements every 2 weeks during the intervention period was 13.2 times (range: 11.4–13.9) in the exercise group and 13.2 times (range: 12.1–13.9) in the control group, indicating that both groups were sufficiently compliant in measuring home BP.

All subjects in the exercise group and control group participated in the post-intervention measurement.

Home blood pressure change

Baseline home BP did not differ significantly between the exercise and control groups (Table 2). Figure 1 displays trends in home systolic and diastolic BP changes with the change in outside temperature across the intervention period. For the exercise group, home systolic and diastolic BP gradually decreased, became lowest in weeks 18–19, remained almost constant up to the end of the intervention period, then increased after the intervention. For the control group, the home BP gradually changed as the outside temperature changed (Fig. 1).

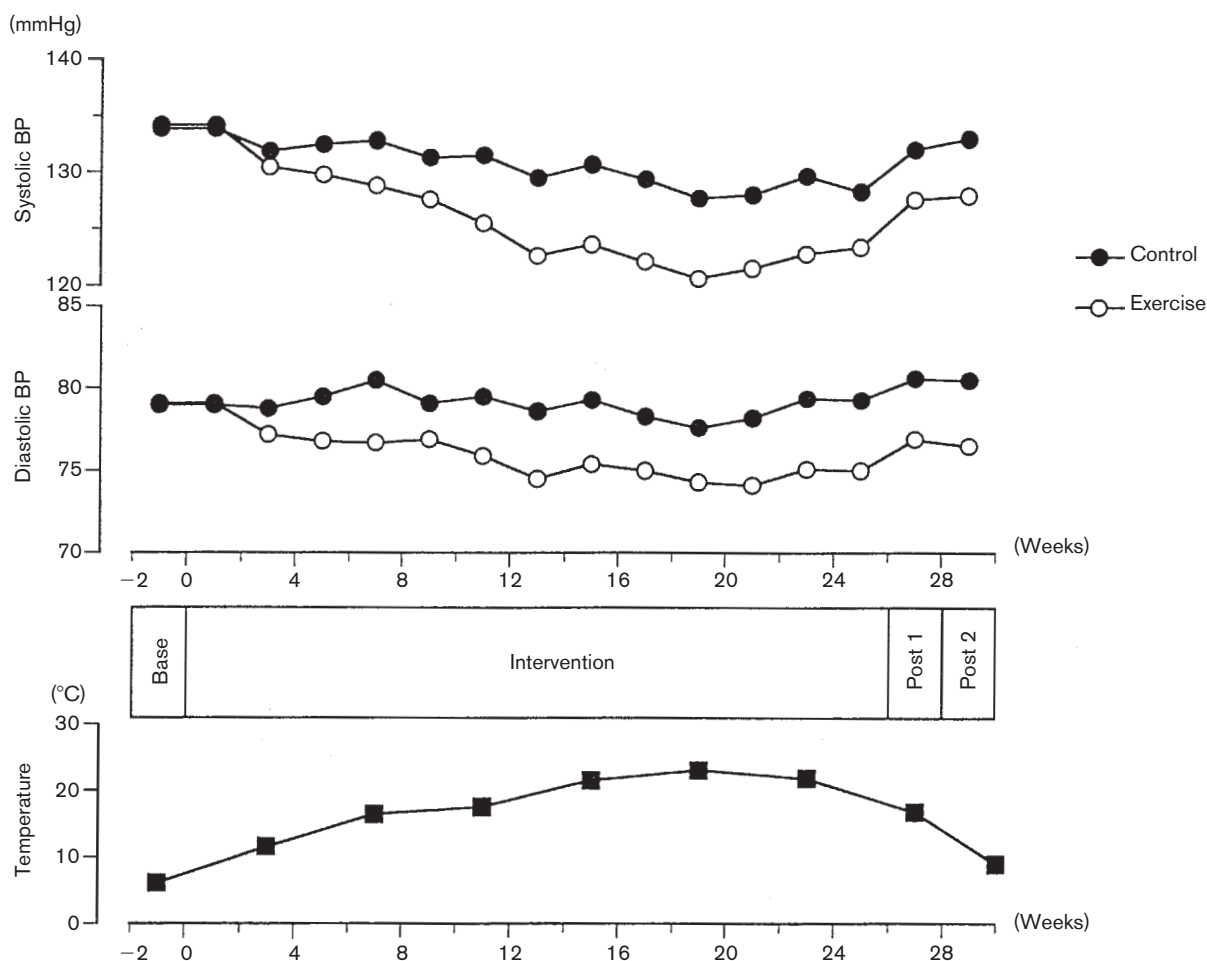
The maximum between-group difference was observed at weeks 14–15 of intervention for systolic BP (7.6 mmHg, $P = 0.003$) (Table 2), which corresponded to the interval at an exercise intensity of 60%. For diastolic BP, the maximum between-group difference was observed at weeks 12–13 of intervention (4.2 mmHg, $P = 0.001$) (Table 2), which corresponded to the interval at an exercise intensity of 50–60%. The between-group difference became smaller and nearly significant during the post1 period for systolic BP (4.7 mmHg, $P = 0.081$), although the difference did not change during the post2 period (5.4 mmHg, $P = 0.087$). For diastolic BP, the between-group difference was similar and remained significant throughout the post-intervention period (post1 period: 3.8 mmHg,

Table 2 Change in home blood pressure (BP; mmHg)

	Home BP values (SE)				Within group differences (95% confidence interval)			Between group differences (95% confidence interval)		
	Base	Max	Post1	Post2	Base-Max	Base-Post 1	Base-Post 2	Base-Max	Base-Post1	Base-Post2
Systolic										
Exercise	134.2 (2.4)	122.1 (2.2)	127.6 (2.3)	128.0 (2.3)	12.1** (8.8–15.4)	6.6** (2.9–10.3)	6.2** (1.9–10.5)	7.6** (2.9–12.3)	4.7 (–0.4 to 9.8)	5.4 (–0.5 to 11.3)
Control	133.9 (2.2)	129.4 (2.1)	132.0 (2.7)	133.1 (2.6)	4.5* (1.2–7.8)	1.9 (–1.6 to 5.4)	0.8 (–3.3 to 4.9)			
Diastolic										
Exercise	79.1 (1.3)	74.5 (1.4)	76.9 (1.3)	76.3 (1.4)	4.6** (3.0–6.2)	2.2* (0.4–4.0)	2.8* (0.8–4.8)	4.2** (1.8–6.6)	3.8** (1.3–6.3)	4.3** (1.4–7.2)
Control	79.0 (1.1)	78.6 (1.4)	80.6 (1.5)	80.5 (1.3)	0.4 (–2.2 to 1.4)	–1.6 (–3.6 to 0.4)	–1.5 (–3.7 to 0.7)			

Within group differences and between group differences were calculated by paired *t*-test and repeated analysis of covariance (ANCOVA), respectively. * $P < 0.05$, ** $P < 0.01$. Base: 'Baseline home BP' defined as the 2 week average home blood pressure (BP) before intervention. Max: 'Max-difference home BP' defined as the home BP at the periods showing the largest between group difference, corresponding to the 14th–15th weeks and 12th–13th weeks for systolic and diastolic BP, respectively. Post1: 'Post1 home BP' defined as the 2 week average home BP of the 1st–2nd weeks after intervention. Post2: 'Post2 home BP' defined as the 2 week average home BP of the 3rd–4th weeks after intervention. Numbers in brackets (SE) standard errors.

Fig. 1



Change in home systolic, diastolic blood pressure (BP) averaged every 2 weeks in the exercise and control groups, and outside temperature during the study period, respectively. Base: 2 week average before intervention period; Post1: 1st–2nd week average after intervention period; Post2: 3rd–4th week average after intervention period.

$P = 0.009$; post2 period: 4.3 mmHg, $P = 0.009$) (Table 2).

These group differences were observed for both genders (male: maximum between-group difference for systolic BP/diastolic BP = 10.0/6.6 mmHg, $P = 0.029/0.001$; female: maximum between-group difference for systolic BP/diastolic BP = 5.4/3.6 mmHg, $P = 0.048/0.045$).

There were no significant between-group differences in BMI and salt intake change, and further adjustment for the baseline values for age, BP, change in BMI and salt intake did not affect the between-group differences in the change in home BP (data not shown).

None of the above parameters changed even after we excluded the two subjects in the exercise group who

started taking an antihypertensive agent after the training had started (data not shown).

Change in casual blood pressure, home and casual heart rate, and white-coat effect

Casual systolic BP decreased significantly within both the exercise and the control groups, although there was no significant between-group difference (Table 3). Casual diastolic BP did not change significantly (Table 3). There were no significant between-group differences in the change in white-coat effect or the change in home and casual HR (Table 3).

Physical activity change

Physical activity, calculated as the total energy consumption, increased significantly within the exercise group (baseline: 40.4 kcal/kg per day; post-intervention: 43.2 kcal/kg per day; within-group difference: 2.8 kcal/

Table 3 Change in casual blood pressure, white coat effect and heart rate

			Value (SE)		Within group difference (95% confidence interval)	Between group difference (95% confidence interval)	
			Base	Post			
Casual BP (mmHg)	Systolic	Exercise	143.0 (2.1)	129.6 (2.2)	13.4** (8.1–18.7)	6.8 (–1.4 to 15.0)	
		Control	144.1 (2.5)	137.5 (2.7)	6.6* (0.3–12.9)		
	Diastolic	Exercise	78.7 (2.4)	74.9 (1.6)	3.8 (–0.5 to 8.1)		2.0 (–3.9 to 7.9)
		Control	81.4 (2.1)	79.6 (1.9)	1.8 (–2.1 to 5.7)		
White coat effect (mmHg)	Systolic	Exercise	8.8 (3.0)	2.0 (2.4)	6.8* (0.5–13.1)	2.1 (–8.1 to 12.3)	
		Control	10.2 (2.7)	5.5 (4.0)	4.7 (–3.3 to 12.7)		
	Diastolic	Exercise	–0.4 (2.4)	–2.0 (1.6)	1.6 (–2.5 to 5.7)		–1.8 (–7.3 to 3.7)
		Control	2.4 (1.8)	–1.0 (1.8)	3.4 (–0.3 to 7.1)		
Heart rate (bpm)	Home	Exercise	62.6 (1.3)	60.2 (1.6)	2.4** (1.2–3.6)	0.2 (–2.3 to 2.7)	
		Control	66.2 (2.1)	64.0 (1.9)	2.2 (–0.2 to 4.6)		
	Casual	Exercise	75.4 (2.4)	70.4 (1.9)	5.0* (1.3–8.7)		1.9 (–4.8 to 8.6)
		Control	79.4 (2.3)	76.4 (2.2)	3.1 (–2.4 to 8.6)		

Within group difference and between group difference were calculated by paired t-test and repeated analysis of covariance, respectively. * $P < 0.05$, ** $P < 0.01$. White coat effect was defined as (casual BP – home BP) value. BP, blood pressure; SE, standard error; bpm, beats-per-minute.

kg per day, 95% confidence interval 0.1–5.5), while no significant change was observed within the control group (–0.8 kcal/kg per day, 95% confidence interval –1.8 to 0.2), showing a significant between-group difference (3.6 kcal/kg per day, 95% confidence interval 0.2–7.0).

Discussion

Our results are based on a randomized controlled trial of a 6 month exercise training program in healthy elderly men and women. We found that exercise training decreased home BP to a maximum of approximately 8 mmHg for systolic BP and 4 mmHg for diastolic BP. This decrease was independent of gender, baseline age, or changes in BMI and salt intake, demonstrating that exercise training is beneficial for reducing BP in older people.

Two studies used ambulatory BP as a tool to determine the true effect of exercise on BP among older people [17,18], although the results of these studies were not consistent with ours. Seals and Reiling [17] investigated 19 men and seven women, aged 50–74 years with mild diastolic hypertension, and reported that 6 months of exercise training for 3–4 days per week at an intensity of 40–50% HR reserve did not produce a significant reduction in ambulatory BP. The same authors also reported that 12 weeks of moderate intensity exercise training did not reduce ambulatory BP among 10 postmenopausal women [20].

Conversely, we have demonstrated that exercise training significantly decreased home BP using a randomized controlled design with a control group having similar characteristics to the exercise group. We attribute the difference between our study and these previously reported ambulatory BP trials to difference in study design, such as appropriate selection of the

control group and the methods used for BP measurement. Reproducibility of home BP has been reported to be better than that of ambulatory BP, since ambulatory BP values were strongly influenced by physical and mental activity on any given day [19–21]. Fixed conditions for home BP measurements (e.g. fixed time of measurements, resting condition, constant position, etc.) would improve the reproducibility of home BP. Such characteristics of home BP are advantageous for assessing the response to exercise training.

Furthermore, in these previous ambulatory BP trials [17,18], the timing of ambulatory BP recording was not considered and the change in ambulatory BP during exercise intervention was not investigated. In our study, the effect of exercise training on BP was reduced with time after the training period, so it is possible that the effect of exercise training was not reflected in the ambulatory BP values in these previous studies if ambulatory BP was measured a few weeks after cessation of training. Home BP also has the advantage of enabling the assessment of detailed changes in BP with time throughout the exercise intervention.

In the control group, home BP decreased by approximately 5 mmHg at the time of the highest outside temperature, suggesting the influence of seasonal variation, which was consistent with our previous observation in the same Sendai area [34]. The baseline and the post-intervention home BP values in the control group showed similar values at the same outside temperature, indicating that the reproducibility of home BP measurement was better than that of casual BP, since casual BP values were decreased in the control group. However, it must be stressed that seasonal temperature variations are well reflected in home BP measurement. Therefore, a long-term intervention trial of home BP without a control group might possibly overestimate or

underestimate the blood pressure-lowering effect of the intervention, if a difference exists between the outside temperature during the baseline and post-intervention periods.

In our present study, the white-coat effect and HR decreased significantly within the exercise group, while they did not decrease significantly within the control group, although this might have been due to the limited number of subjects and the variability of these parameters. However, these results also suggest that the decrease in casual BP due to exercise training was partly attributable to the decrease in the white-coat effect caused by habituation to the medical situation at the time of training in the exercise group, since the frequency of contact with the training staff was higher in the exercise group than in the control group. To exclude these systematic biases, home BP measurement is suggested to be a better method because the measurement frequency and the environment in which the measurements are taken are the same for each subject in both the exercise group and the control group.

The net difference between groups became smaller after 2 weeks of training but remained constant thereafter. Daily physical activity in the exercise group increased significantly after training. Increased daily physical activity is reported to decrease BP [35]. Therefore it is possible that the maintenance of lower home BP levels in the exercise group after training was partly attributable to increased physical activity. We are currently following up these possibilities to clarify the association between maintenance of daily physical activity and home BP.

We selected our study subjects according to exclusion criteria. The participants were asymptomatic at the time of submaximal exercise tests, and tolerated the 25-week exercise training well. Therefore, they were apparently active and healthy, and their health and functional status was better than that of the general population at this age [22]. Our trial confirmed the efficacy of exercise training for reducing BP in active and healthy older subjects with normal or mildly increased BP. There is no evidence that the present findings can be generalized to other types of older people. Any beneficial effect of training for sedentary, less fit, frail older people, or those with severe hypertension, needs to be tested by another randomized trial.

In conclusion, the present study has demonstrated that (1) regular exercise training at an intensity of 50–60% over a 15 week period decreased home systolic BP by 8 mmHg and diastolic BP by 5 mmHg, and that (2) home BP measurement was useful for measuring small changes in BP throughout the exercise training. In view

of these results, we recommend that home BP measurements should be used more effectively in non-pharmacological intervention trials to clarify the true change in BP throughout those trials.

Acknowledgement

The authors are grateful to all the participants of SSCT, Yuka Atsumi, Mariko Ishikawa, Yoshiko Kamigawa, Yumiko Kon, Akiko Ohtomo, and Kumiko Takashima for training the participants at the Sendai Silver Center, Naoko Suzuki, Yoshiko Nakata, Shuko Sato, and Reiko Taneichi for secretarial assistance.

References

- Rodriguez BL, Curb JD, Burchfiel CM, Abbott RD, Petrovitch H, Masaki K, *et al.* Physical activity and 23-year incidence of coronary heart disease morbidity and mortality among middle-aged men. The Honolulu Heart Program. *Circulation* 1994; **89**:2540–2544.
- Wannamethee G, Shaper AG. Physical activity and stroke in British middle-aged men. *BMJ* 1992; **304**:597–601.
- Paffenbarger RS Jr, Jung DL, Leung RW, Hyde RT. Physical activity and hypertension: an epidemiological view. *Ann Med* 1991; **23**:319–327.
- Caspersen CJ, Bloemberg BP, Saris WH, Merritt RK, Kromhout D. The prevalence of selected physical activities and their relation with coronary heart disease risk factors in elderly men: the Zutphen Study, 1985. *Am J Epidemiol* 1991; **133**:1078–1092.
- Folsom AR, Caspersen CJ, Taylor HL, Jacobs DR Jr, Luepker RV, Gomez-Marin O, *et al.* Leisure time physical activity and its relationship to coronary risk factors in a population-based sample. The Minnesota Heart Survey. *Am J Epidemiol* 1985; **121**:570–579.
- Blair SN, Goodyear NN, Gibbons LW, Cooper KH. Physical fitness and incidence of hypertension in healthy normotensive men and women. *JAMA* 1984; **252**:487–490.
- Kelley G, McClellan P. Antihypertensive effects of aerobic exercise. A brief meta-analytic review of randomized controlled trials. *Am J Hypertens* 1994; **7**:115–119.
- Halbert JA, Silagy CA, Finucane P, Withers RT, Hamdorf PA, Andrews GR. The effectiveness of exercise training in lowering blood pressure: a meta-analysis of randomised controlled trials of 4 weeks or longer. *J Hum Hypertens* 1997; **11**:641–649.
- Imai Y, Aihara A, Ohkubo T, Nagai K, Tsuji I, Minami N, *et al.* Factors that affect blood pressure variability. A community-based study in Ohasama, Japan. *Am J Hypertens* 1997; **10**:1281–1289.
- Mansoor GA, McCabe EJ, White WB. Determinants of the white coat effect in hypertensive subjects. *J Hum Hypertens* 1996; **10**:87–92.
- Aihara A, Imai Y, Sekino M, Kato J, Ito S, Ohkubo T, *et al.* Discrepancy between screening blood pressure and ambulatory blood pressure: a community-based study in Ohasama. *Hypertens Res* 1998; **21**:127–136.
- Van Hoof R, Hespel P, Fagard R, Lijnen P, Staessen J, Amery A. Effect of endurance training on blood pressure at rest, during exercise and during 24 hours in sedentary men. *Am J Cardiol* 1989; **63**:945–949.
- Blumenthal JA, Siegel WC, Appelbaum M. Failure of exercise to reduce blood pressure in patients with mild hypertension. Results of a randomized controlled trial. *JAMA* 1991; **266**:2098–2104.
- Somers VK, Conway J, Johnston J, Sleight P. Effects of endurance training on baroreflex sensitivity and blood pressure in borderline hypertension. *Lancet* 1991; **337**:1363–1368.
- Marceau M, Kouame N, Lacourciere Y, Cleroux J. Effects of different training intensities on 24-hour blood pressure in hypertensive subjects. *Circulation* 1993; **88**:2803–2811.
- Cox KL, Puddey IB, Morton AR, Burke V, Beilin LJ, McAleer M. Exercise and weight control in sedentary overweight men: effects on clinic and ambulatory blood pressure. *J Hypertens* 1996; **14**:779–790.
- Seals DR, Reiling MJ. Effect of regular exercise on 24-hour arterial pressure in older hypertensive humans. *Hypertension* 1991; **18**:583–592.
- Seals DR, Silverman HG, Reiling MJ, Davy KP. Effect of regular aerobic exercise on elevated blood pressure in postmenopausal women. *Am J Cardiol* 1997; **80**:49–55.
- Musso NR, Vergassola C, Barone C, Lotti G. Ambulatory blood pressure monitoring: how reproducible is it? *Am J Hypertens* 1997; **10**:936–939.
- Asmar R and Zanchetti A, on behalf of the Organizing Committee and

- participants. Guidelines for the use of self-blood pressure monitoring: a summary report of the first international consensus conference. *J Hypertens* 2000; **18**:493–508.
- 21 James GD, Pickering TG, Yeates LS, Harshfield GA, Riva S, Laragh JH. The reproducibility of average ambulatory, home and clinic pressures. *Hypertension* 1988; **11**:545–549.
 - 22 Tsuji I, Tamagawa A, Nagatomi R, Irie N, Ohkubo T, Saito M, *et al.* Randomized controlled trial of exercise training for older people (Sendai Silver Center Trial; SSCT): study design and primary outcome. *J Epidemiol* 2000; **10**:55–64.
 - 23 Tsuji I, Imai Y, Nagai K, Ohkubo T, Watanabe N, Minami N, *et al.* Proposal of reference values for home pressure measurement. Prognostic criteria based on a prospective observation of the general population in Ohasama, Japan. *Am J Hypertens* 1997; **10**:409–418.
 - 24 American College of Sports Medicine. *Guidelines for exercise testing and prescription*, 4th edn. Philadelphia, PA: Lea and Febiger; 1991.
 - 25 The Hygenic Corporation. *Instruction manual for theraband resistive exercise*, 3rd edn. Akron: The Hygenic Corporation; 1996.
 - 26 O'Brien E, Mee F, Atkins N, Thomas M. Evaluation of three devices for self-measurement of blood pressure according to the revised British Hypertension Society Protocol: the Omron HEM-705CP, Philips HP5332, and Nissei DS-175. *Blood Press Mon* 1996; **1**:55–61.
 - 27 American National Standard. *Electronic device or automated sphygmomanometers*. Association for the Advancement of Medical Instrumentation. Arlington, VA: ANS; 1993.
 - 28 O'Brien E, Petrie J, Littler W, de Swiet M, Padfield PL, Altman D, *et al.* The British Hypertension Society protocol for the evaluation of blood pressure measuring devices. *J Hypertens* 1993; **11**:S43–S63.
 - 29 Ohkubo T, Imai Y, Tsuji I, Nagai K, Kato J, Kikuchi N, *et al.* Home BP measurement has a stronger predictive power for mortality than does screening BP measurement: a population-based observation in Ohasama, Japan. *J Hypertens* 1998; **16**:971–975.
 - 30 Boucharde C, Tremblay A, Leblanc C, Lortie G, Savard R, Theriault G. A method to assess energy expenditure in children and adults. *Am J Clin Nutr* 1983; **37**:461–467.
 - 31 Ainsworth BE, Haskell WL, Leon AS, Jacobs DR Jr, Montoye HJ, Sallis JF, *et al.* Compendium of physical activities: classification of energy costs of human physical activities. *Med Sci Sports Exerc* 1993; **25**:71–80.
 - 32 Ogawa K, Tsubono Y, Nishino Y, Watanabe Y, Ohkubo T, Watanabe T, *et al.* Inter- and intra-individual variation of food and nutrient consumption in a rural Japanese population. *Eur J Clin Nutr* 1999; **53**:781–785.
 - 33 Mengden T, Battig B, Vetter W. Self-measurement of blood pressure improves the accuracy and reduces the number of subjects in clinical trials. *J Hypertens* 1991; **9** (suppl):S336–S337.
 - 34 Imai Y, Munakata M, Tsuji I, Ohkubo T, Satoh H, Yoshino H, *et al.* Seasonal variation in blood pressure in normotensive women studied by home measurements. *Clin Sci* 1996; **90**:55–60.
 - 35 Young DR, Appel LJ, Jee S, Miller ER 3rd. The effects of aerobic exercise and Tai Chi on blood pressure in older people: results of a randomized trial. *J Am Geriatr Soc* 1999; **47**:277–284.

Appendix

List of SSCT Investigators and committees

Principal Investigator: Ichiro Tsuji^a.

Advisory Committee: Shigeru Hisamichi^a, Hiroaki Ohmori^b, Hideo Hashimoto^c, Noboru Kokubo^c, Shin-ichi Shoji^c, Kei Kudo^d.

Project Office: Tomohiko Konno^c, Noriko Irie^c, Masahiro Saito^c.

Randomized Allocation Committee: Yoshikazu Nishino^a, Keiko Ogawa^a.

Eligibility Committee: Catherine Sauvage^h, Seiki Kanemura^a, Aya Kuwahara^a, Chikako Nakagawa^a, Peng Hua Qiang^a.

Measurement Committee: Akira Tamagawa^b, Takayoshi Ohkubo^a, Keiko Ogawa^b, Yoshitaka Tsubono^a, Tasuku Sato^c, Masafumi Ohsako^f, Tetsuro Suzuki^f, Yoko Watanabe^a, Yuko Yoshida^{bj}, Mitsuharu Okutsu^b, Zhang Xiu Ming^b, Osamu Kanemi^b, Koya Sato^b, Hirotohi Sasaki^b, Akira Sato^b, Yutaka Imai^g.

Training Committee: Ryoichi Nagatomi^b, Kazuki Fujita^b, Mie Izumi^c, Eiko Kitame^c, Reiko Konishi^c, Midori Neda^c, Megumi Watanabe^c.

Safety and Monitoring Committee: Atsushi Hozawa^a, Yuki-ko Anzai^d, Setsuko Goto^c, Junko Tanaka^c.

^aDepartment of Public Health, Tohoku University Graduate School of Medicine

^bDepartment of Medicine & Science in Sports & Exercise, Tohoku University Graduate School of Medicine

^cSendai City Silver Center, Sendai City Health and Welfare Foundation

^dResearch Unit of Public Health Nursing, Miyagi University School of Nursing

^eDepartment of Sports Science, Faculty of Physical Education, Sendai College

^fDepartment of Sports and Health Science, Course of Liberal Arts, Toyo University

^gDepartment of Clinical Pharmacology and Therapeutics, Tohoku University Graduate School of Medicine and Pharmaceutical Science

^hDepartment of Epidemiology, Radiation Effects Research Foundation

^jDepartment of Community Health, Tokyo Metropolitan Institute of Gerontology.