Original Article

Walking 10,000 Steps/Day or More Reduces Blood Pressure and Sympathetic Nerve Activity in Mild Essential Hypertension

Masataka IWANE, Mikio ARITA, Shigehiro TOMIMOTO, Osamu SATANI, Masanobu MATSUMOTO*, Kazuhisa MIYASHITA*, and Ichiro NISHIO

We investigated the effects of walking 10,000 steps/day or more on blood pressure and cardiac autonomic nerve activity in mild essential hypertensive patients. All subjects were males aged 47.0 ± 1.0 (mean $\pm$ SEM) years old. The original cohort consisted of 730 people in a manufacturing industry who measured the number of steps they walked each day using a pedometer. Eighty-three of these subjects walked 10,000 steps/day or more for 12 weeks. Thirty-two of these were hypertensives with systolic blood pressure (SBP) greater than 140 mmHg and/or diastolic blood pressure (DBP) greater than 90 mmHg. Thirty of these hypertensive subjects (HT) were examined twice, once during the pre- and once during the post-study period, for body mass index (BMI), maximal oxygen intake ($\dot{V}O_{2\max}$), blood pressure, heart rate (HR), and autonomic nerve activity by power spectral analysis of SBP and HR variability. In the HT group, walking $13,510 \pm 837$ steps/day for 12 weeks lowered blood pressure (from $149.3 \pm 2.7/98.5 \pm 1.4$ to $139.1 \pm 2.9/90.1 \pm 1.9$ mmHg; $p < 0.01$, respectively). In both the 34 normotensive controls and 17 hypertensive sedentary controls, blood pressure did not change. Walking also significantly lowered low-frequency fluctuations in SBP as an index of sympathetic nerve activity, from 1.324 ± 0.192 to 0.738 ± 0.154 mmHg²/Hz ($p < 0.05$). $\dot{V}O_{2\max}$ rose significantly from 26.1 ± 2.4 to 29.5 ± 2.5 ml/kg/min ($p < 0.05$). There were no changes in parasympathetic nerve activity, baroreceptor reflex sensitivity, or BMI. Our results indicate that walking 10,000 steps/days or more, irrespective of exercise intensity or duration, is effective in lowering blood pressure, increasing exercise capacity, and reducing sympathetic nerve activity in hypertensive patients. (*Hypertens Res* 2000; 23: 573-580)

Key Words: walking, pedometer, hypertension, autonomic nerve system, power spectral analysis

Introduction

Chronically elevated blood pressure is associated closely with increased risks of coronary heart disease, stroke and heart failure. Cardiovascular mortality and morbidity rates increase with elevations in blood pressure. Therefore, the goal of treating hypertension is to reduce the morbidity and mortality and to lower the blood pressure. Physical activity has been shown to be one of the most effective nonpharmacological treatments for hypertensive

patients. Several investigators have found significant reductions in resting blood pressures of hypertensive patients after physical activities. Most studies have employed walking, running or cycling as activity modes. On the other hand, the scientific evidence on the efficacy of many specific lifestyle interventions is incomplete. People have been advised to walk more than 10,000 steps a day for the purpose of promoting health. Walking 10,000 steps/day consumes about 2,000 kcal energy per week, and thus this daily activity is suitable for preventing obesity and diabetes mellitus. And in fact, Ralph *et al.* re-

Fig. 1. Subjects entry for this study. All subjects were recruited in a manufacturing industry. HT, Hypertensive group; NT, normotensive group; HT control, hypertensive control group.

ported that the relative risk of death from all causes was one-quarter to one third-lower among subjects expending 2,000 or more kcal per week than among less active subjects (1). Exercise therapy has been shown to lower blood pressure in patients with mild essential hypertension. Almost all of these studies, however, were performed under controlled conditions, and patients generally discontinue their exercise regimens after such training periods. There is thus need of a method of exercise training that can be easily extended to private use in the post-study period by a wide range of subjects. For this reason, we here investigated walking using a controlled number of steps per day. Although the antihypertensive effects of aerobic exercise walking have previously been investigated (2), there has been no study on whether walking 10,000 steps/day or more, as measured by a pedometer and irrespective of exercise intensity and duration, is effective at reducing blood pressure. In this study, we investigated the effects of walking 10,000 steps/day or more on blood pressure and on cardiac autonomic nerve activity in hypertensives in a manufacturing industry.

Methods

Subjects

All subjects were invited among workers in a manufacturing industry. Seven hundred and thirty industrial workers volunteered for participation in this study, among a total of 2,474 workers queried (Fig. 1). All participants were

asked to walk more than 10,000 steps a day as measured by a pedometer, irrespective of exercise intensity or duration. Three hundred and six people had performed 10,000 or more steps/day for 4 weeks, and 83 people had done for 12 weeks. Among the 83 subjects who had walked 10,000 or more steps/day for 12 weeks, 32 were hypertensives with systolic blood pressure (SBP) greater than 140 mmHg and/or diastolic blood pressure (DBP) greater than 90 mmHg, and the remaining 51 were normotensives. About 30 subjects among 32 hypertensives, measurements were available both pre- and post-study periods (HT group). None of them had been administered any anti hypertensive medication. We also selected 34 normotensive controls (NT group) from 51 normotensives, and 17 hypertensive sedentary control (HT control group) from a non-participant group who did not change their lifestyles during the training period. All of the HT patients gave their informed consent. None of the HT and HT control subjects had secondary hypertension, as determined by past history, subjective and objective symptoms, urinalysis, and blood examinations. These patients also showed no electrocardiographic signs of left ventricular hypertrophy, no abnormal findings in urinary protein or plasma creatinine level, and no past history of any cardiovascular disease.

Measurements

Each of the following was measured throughout the pre- and post-training periods: number of walking steps/day,

Table 1. Subjects Profile

	Hypertensives ≥10,000 steps/day for 12 weeks	Normotensives ≥10,000 steps/day for 12 weeks	Hypertensive control (Sedentary)
<i>n</i>	30	34	17
Age (y.o.)	48.5±1.5	44.7±1.6	48.7±1.9
Number of steps/day	13,510±837	14,500±809	5,790±458
BMI (kg/m ²)	24.6±0.7	23.0±0.4	25.2±0.9
SBP (mmHg)	149.3±2.7	120.5±1.9	153.2±3.0
DBP (mmHg)	98.5±1.4	76.7±1.4	99.1±1.8

All subjects were male. BMI, Body Mass Index; SBP, Systolic Blood Pressure; DBP, Diastolic Blood Pressure. (means ± SEM)

body mass index (BMI), maximal oxygen intake ($\dot{V}_{O_2\max}$), blood pressure, heart rate (HR), serum lipids, HbA1c, and autonomic nerve activity. Number of walking steps/day was measured by a pedometer (Hello Walk; Tanita, Tokyo, Japan). Office blood pressure and heart rate were measured in the sitting position by standard cuff methods 3 times on 3 different days before the study periods, and one time after the study period. $\dot{V}_{O_2\max}$ was measured by a bicycle ergometer (ergometer 232C; Minato, Tokyo, Japan) with gas analysis (Medical Gas Analyzer MG360; Minato Medical Science Co., Ltd., Tokyo, Japan) in the HT group. BMI, serum lipids, and HbA1c were also measured before and after study periods in the HT group.

Autonomic Nervous System

A continuous noninvasive blood pressure monitoring system based on arterial tonometry (CBM2000; Nihon Colin, Komaki, Japan) was used on the right radial artery to obtain arterial blood pressure waveform and ECG. After a 30-min rest, ECG and blood pressure waveforms were simultaneously recorded while subjects were resting quietly in the supine position with eyes closed. Successive 256 P-P intervals of ECG and SBPs without artifacts due to movement, premature ventricular contraction, and so forth, were directly conveyed to a personal computer (NEC PC9821), and computed using ANSP-200 software (Nihon Colin).

The power spectrum of variability in the P-P intervals on ECG and SBP was computed by Fast Fourier Transform in hypertensives to evaluate the autonomic nervous system. Fluctuations of HR and SBP were quantified by determining the spectral area in two frequency bands. The low-frequency fluctuations (LF) area was from 0.08 to 0.15 Hz, and the high-frequency fluctuations (HF) area was from 0.15 to 0.40 Hz. LF in SBP, HF in P-P interval, and a root of LF in P-P interval per LF in SBP were respectively the index of sympathetic activity, parasympathetic activity, and baroreceptor reflex sensitivity (3-8).

Statistical Analysis

All data were expressed as the mean ± SEM. Differences between pre- and post-study data were evaluated by Wilcoxon's signed rank test. The Mann-Whitney test was used for comparison of the mean values in the HT, NT, and HT control groups. Analyses were performed using Stat View software (Abacus Concepts Inc., Berkeley, CA). *P* values less than 0.05 were considered to indicate statistical significance.

Results

The subject profiles are given in Table 1. All subjects were male. The HT group included 30 men with a mean age of 48.5±1.5 years. Subjects in the HT group performed 13,510±837 steps/day walking for 12 weeks. Their BMI was 24.6±0.7 kg/m². Their blood pressure was 149.3±2.7/98.5±1.4 mmHg. The NT group included 34 men with a mean age of 44.7±1.6 years. Subjects in this group walked 14,500±809 steps/day and had a mean BMI of 23.0±0.4 kg/m² and mean BP of 120.5±1.9/76.7±1.4 mmHg. The HT control group included 17 men with a mean age of 48.7±7.6 years; these subjects walked 5,790±458 steps/day and had a mean BMI of 25.2±0.9 kg/m² and mean BP of 153.2±3.0/99.1±1.8 mmHg. There were no significant differences among the 3 groups in either age or BMI. The number of steps did not differ between the HT and NT groups, and BP did not differ between the HT and HT control groups.

Figure 2 shows time-related changes in the effects of walking on BP in the HT, NT, and HT control groups. There was no significant change in systolic or diastolic blood pressure in the NT group (from 120.5±1.9/76.7±1.4 mmHg to 116.2±2.0/75.1±1.4 mmHg). In the HT group, 12 weeks of walking lowered both systolic and diastolic blood pressure (from 149.3±2.7/98.5±1.4 mmHg to 139.1±2.9/90.1±1.9 mmHg, *p*<0.01), but 4 weeks was not enough time to do so (to 142.3±3.0/93.1±1.7 mmHg). Walking for 4 weeks or longer resulted in signif-

Fig. 2. Effects of walking 10,000 steps/day or more on blood pressure and heart rate. HT, Hypertensive group; NT, normotensive group; HT control, hypertensive control group. $^{\dagger}p < 0.05$, $^{\ddagger}p < 0.01$. $^{**}p < 0.01$ vs. pre-value in HT group.

icant differences in systolic blood pressure (148.9 ± 6.8 vs. 139.8 ± 3.2 mmHg, $p < 0.05$), and in significant differences in diastolic blood pressure (103.3 ± 1.8 vs. 93.1 ± 1.7 mmHg, $p < 0.001$) between the HT and HT control groups, respectively. There was no significant difference in heart rate between the HT and HT control groups (77.5 ± 2.6 vs. 75.8 ± 2.1 bpm, respectively).

Figure 3 shows the effects of walking exercise on autonomic nerve activity in hypertensives. Walking 10,000 steps/day or more significantly lowered sympathetic nerve activity (measured as LF in SBP) from 1.324 ± 0.192 to 0.738 ± 0.154 mmHg²/Hz ($p < 0.05$). Parasympathetic

Table 2. Effects of Walking $\geq 10,000$ Steps/Day on Serum Lipids and HbA1c in Hypertensive Patients

	Pre-training	Post-training
Body mass index (kg/m ²)	24.6 $\pm$ 0.7	24.7 $\pm$ 0.6
Total cholesterol (mg/dl)	189 $\pm$ 4.9	195 $\pm$ 4.1
HDL-cholesterol (mg/dl)	57 $\pm$ 2.0	57 $\pm$ 2.2
Triglyceride (mg/dl)	110 $\pm$ 11.7	117 $\pm$ 11.3
HbA1c (%)	5.25 $\pm$ 0.09	5.33 $\pm$ 0.08

$n = 30$ (mean $\pm$ SEM)

nerve activity (measured as HF in the P-P interval of ECG) did not change (from 100.3 ± 18.7 to 340.7 ± 136.3 ms²/Hz), and baroreceptor reflex sensitivity (measured as the root of LF in the P-P interval/LF in SBP) also remained constant throughout the training periods (from 8.40 ± 1.27 to 13.68 ± 2.84 ms/mmHg).

Maximal oxygen intake rose significantly after 12 weeks, from 26.1 ± 2.4 to 29.5 ± 2.5 ml/kg/min ($p < 0.05$). This results indicates that walking for 10,000 steps/day or more resulted in an improvement of exercise capacity.

Table 2 shows the effect of walking on BMI (from 24.6 ± 0.7 to 24.7 ± 0.6 kg/m²), serum lipids (total cholesterol, 189 ± 4.9 to 195 ± 4.1 mg/dl; HDL cholesterol, 57 ± 2.0 to 56 ± 2.2 mg/dl; triglycerides, 110 ± 11.7 to 117 ± 11.3 mg/dl) and HbA1c (from 5.25 ± 0.09 to $5.33 \pm 0.08\%$). There were no significant changes in any of these parameters.

In sum of the HT and the HT control groups ($n = 47$), the degrees of lowered blood pressure were correlated with the number of daily walking steps in neither SBP nor DBP (Fig. 4). But, significant correlation between the degrees of lowered DBP and the number of walking steps

Fig. 3. Power spectral analysis in hypertensives. (a) LF in SBP, low frequency fluctuations in systolic blood pressure as an index of sympathetic nerve activities; (b) HF in P-P interval, high frequency fluctuations in P-P intervals of ECG as an index of parasympathetic nerve activities; (c) root square of LF in P-P interval per LF in SBP as an index of baroreceptor sensitivity.

Fig. 4. Relationships between number of walking steps/day and degrees of lowered blood pressure in sum of HT and HT control groups. A and B, all subjects in the two groups, $n=47$; C and D, 40 subjects who walked less than 15,000 steps/day. Δ SBP, degrees of lowered systolic blood pressure; Δ DBP, degrees of lowered diastolic blood pressure. D: $r=0.33$, $p<0.05$. A, B, and C: NS.

was found in the restricted subjects who walked less than 15,000 steps per day ($n=40$, $r=0.33$, $p<0.05$). Changes of LF of SBP did not correlate with the number of walking steps per day.

Discussion

In this study, we investigated the effects of walking on blood pressure, autonomic nerve activity (as measured using power spectral analysis of heart rate and systolic blood pressure), body composition and biological indices of coronary risk factors in middle-aged subjects with essential hypertension. Walking 10,000 steps/day or more for 12 weeks was effective at lowering elevated blood pressure, sympathetic nerve activity, and maximal oxygen intake, but ineffective on parasympathetic nerve activity, baroreceptor reflex sensitivity, BMI, lipids, and glucose tolerance.

Subjects were advised to walk 10,000 steps/day or more, but were not advised on walking speed, exercise intensity, or duration. Walking 10,000 steps/day or more resulted in an improved exercise capacity and lowered elevated blood pressure and sympathetic nerve activity, but did not change BMI or the metabolism of lipids or glu-

cose in hypertensive patients.

Many studies have already shown the BP-lowering effects of exercise training in patients with mild essential hypertension. The World Hypertension League has reviewed that most such studies rely on endurance training, *i.e.*, prolonged dynamic, predominantly isotonic exercise of large muscle groups — for example, bicycling, walking, jogging, running, or calisthenics. The duration of training ranged from 4 to 32 weeks, generally with a frequency of 3 days a week and 30–120 min a day. Intensity of training was from 50% to 90% of maximal exercise capacity. These training programs resulted in an increase in exercise capacity of 6–38% (9). In the present study, $\dot{V}_{O_2\max}$ increased 13.0%. Accordingly, the subjects who maintained their full walking schedules evidenced a significant increase in this exercise capacities. Steven *et al.* reported a prospective study in which a higher level of physical fitness appeared to delay all-cause mortality primarily due to lowered rates of cardiovascular disease and cancer (10). Thus, the importance of walking was confirmed. The review of World Hypertension League showed that training produced an average change of $-11/-6$ mmHg in hypertensive patients. Our study obtained similar results of blood pressure reduction in HT of $-10.2/-8.4$

mmHg.

In the present study, neither the reduction in SBP nor that in DBP was significantly correlated with the number of steps. There was, however, a significant correlation between DBP reduction and the number of walking steps less than 15,000 steps per day. These findings indicate that walking more than 15,000 steps per day leads to no additional reduction in BP. Analysis of BP variability has been limited in its use as a routine clinical measure because the continuous recording of arterial BP generally requires the use of an invasive method, *e.g.*, intra-arterial cannulation. Recently, an improved tonometric device for measuring arterial BP has enabled us to noninvasively and continuously record the beat-to-beat arterial BP (11, 12). In addition to using methods that analyze fluctuations in cardiovascular parameters, several investigators have tried to delineate the relationship between HR and BP using power spectral analysis.

Power spectral analysis of the beat-to-beat variability of heart rate and blood pressure is now widely recognized as one of the indices reflecting cardiac autonomic nerve activity. Earlier studies using autonomic blocking agents, postural changes, and cross-spectral analysis suggest that HF in the heart rate variability reflects only parasympathetic nerve activity. LF in blood pressure variability is a marker of sympathetic activity, because it is increased during tilt and exercise, and disappears in traumatic quadriplegic humans. LF in heart rate variability reflects the Mayer waves through the baroreceptor reflex and is mediated by both parasympathetic and sympathetic activities. Therefore, the ratio of LF in heart rate variability to LF in blood pressure variability or the root of this ratio is thought as baroreceptor reflex sensitivity (3-8).

Guzzetti *et al.* reported on autonomic nerve activity in hypertensive patients using power spectral analysis of heart rate variability. They found that LF was greater and HF was smaller in hypertensive patients compared with normotensives. They also showed that the β -adrenergic blockade reduced LF and enhanced HF (13). A few studies were reported about the changes of autonomic nervous activity related with exercise training in patients with chronic heart failure (CHF). Coats *et al.* Reported that the LF of the R-R variability of ECG decreased and the HF increased in-patients with CHF. Their measurements showed a significant shift away from sympathetic toward enhanced vagal activity after training (14, 15). It is not known, however, how exercise therapy effects LF and HF in hypertensive patients. In the present study, LF in SBP was reduced from 1.324 ± 0.192 to 0.738 ± 0.154 mmHg²/Hz ($p < 0.05$). The HF in the P-P interval of ECG and the root of LF in the P-P interval/LF in SBP did not change among training periods. Our results indicate that walking reduced sympathetic nerve activity, but that parasympathetic nerve activity and baroreceptor reflex activity did not change. Dang *et al.* reported that the sympathetic

nervous system contributed to the pathogenesis of hypertension at the early phase (16). Therefore, walking is useful for not only lowering elevated blood pressure but also developing hypertension.

Changes in blood volume and in volume-regulating hormones have been suggested as potential mechanisms responsible for the antihypertensive effects of exercise training. Arakawa *et al.* investigated the mechanism by which exercise training reduces blood pressure (17-19). First, plasma norepinephrine concentration is reduced as the result of an increase of prostaglandin E and taurin. This is not affected by an exercise intensity of from 40% to 70% of $\dot{V}_{O_2\max}$. Duncan *et al.* and Hagberg *et al.* also showed that blood pressure reduction was mediated by plasma catecholamine level (20, 21).

Dixon *et al.* conducted a cross-sectional study comparing autonomic nerve activity between athletes and sedentary controls (22). Sympathetic nerve activity did not differ between the two groups. Sympathetic nerve activity may change only in one of the morbidity states as CHF or hypertension by exercise training. In the same study, parasympathetic nerve activity was found to be greater in athletes than sedentary controls. Coats *et al.* also reported that endurance training increased parasympathetic nerve activity in CHF. Our present results, however, showed no significant change in the LF of heart rate variability between before and after the study period. There were also no significant changes in heart rate between before and after the study period. Heart rate is affected dominantly by parasympathetic nerve activity, and exercise intensity may be related to parasympathetic nerve activity.

Baroreceptor sensitivity is thought to be lower in athletes than nonathletes (23, 24). On the other hand, in a study using methods similar to those used here, Shin *et al.* reported that baroreceptor sensitivity was unchanged during a training period (25, 26). And Shephard found that baroreceptor sensitivity was not lowered in a cohort of hypertensive patients (27). Further study will be needed on the effects of walking training on autonomic activity in hypertensive patients.

BMI, Serum lipids and HbA1c did not change after exercise in this study. Possible explanations for these results are that the subjects in this study were not obese, and thus their serum lipid levels were not particularly high at baseline. Agata *et al.* reported that insulin-resistant patients with essential hypertension might have more risk factors for arteriosclerotic complications than non-insulin resistant patients with hypertension (28). Various effects of walking have already been demonstrated. It is important that the efficacy appears on the improvement of insulin resistance (29, 30).

Although we verified the efficacy of walking 10,000 steps/day or more in this study, as the project progressed, we were confronted with a problem: although we began our exercise program with 730 subjects, by the end of the

study, we had only 83 participants who had completed the full 12-week walking schedule. This unfortunate results confirms the difficulty of continuing an exercise training program on a steady basis. It also indicates that some methods are needed to encourage people to continue exercising on a regular schedule, such as walking together with friends, spouses or coworkers.

In conclusion, our results indicate that walking 10,000 steps/day or more for 12 weeks, irrespective of exercise intensity or duration, is effective in lowering blood pressure, increasing exercise capacity, and reducing sympathetic nerve activity in hypertensive patients.

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