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Hypertension

Exercise BP Response in Subjects With High-Normal BP

Exaggerated Blood Pressure Response to Exercise and Risk of Future Hypertension in Subjects With High-Normal Blood Pressure

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OBJECTIVES This study was designed to assess the clinical usefulness of an exaggerated blood pressure (BP) response to exercise (EBPR) in predicting the development of hypertension from a high-normal state.

BACKGROUND Exaggerated BP response during both dynamic and isometric exercises are associated with increased risk of future hypertension, while the significance of these responses concerning the identification of individuals with high-normal BP who are prone to develop hypertension is unknown.

METHODS The study population comprised a sample of 239 men with high-normal BP (aged 42.3 ± 5.9 years) who underwent a symptom-limited bicycle ergometer exercise testing at baseline and then were followed for 5.1 years.

RESULTS The Kaplan-Meier survival analysis showed that the subjects in the upper quartile of BP response to exercise had a significantly higher cumulative incidence of hypertension on follow-up than those in the middle two and lower quartiles (log-rank test, $p < 0.05$). Multivariate analysis using the Cox proportional hazards survival model showed that the EBPR was significantly and independently associated with the risk of developing hypertension after adjustment for some traditional risk factors for hypertension (RR = 2.31, 95% confidence interval = 1.45 to 6.25).

CONCLUSIONS These findings suggest that an EBPR is an important risk factor for new-onset hypertension from a high-normal state and, thus, exercise testing can provide valid information that may help identify individuals with high-normal BP at a greater risk of future hypertension. (J Am Coll Cardiol 2000;36:1626–31) © 2000 by the American College of Cardiology

The Fifth Report of the Joint National Committee on the Detection, Evaluation and Treatment of High Blood Pressure (JNC-V) introduced the concept regarding high-normal blood pressure (BP) at the levels previously considered to be a normal BP (1). The longitudinal investigations in the Framingham Heart study provided the specific epidemiological findings that the probability of developing established hypertension in individuals with high-normal BP was twofold to threefold higher than in those with normal BP (2). Results of the trials of Hypertension Prevention suggested that the individuals with high-normal BP should be followed-up with frequent BP testing and advised to modify the lifestyle risk factors for hypertension (3). However, the great majority of individuals with high-normal BP will neither develop hypertension nor advance to future cardiovascular complications. From a preventive point of view, if we were able to identify persons who are prone to develop established hypertension, it would have the obvious benefit of providing more time for applying measures to prevent or delay the onset of hypertension.

Environmental and behavioral challenges such as a mental arithmetic task, cold water immersion and both isometric and dynamic exercise tests have been found to be a potential procedure for early prediction of future hypertension (4–6). One of the most useful tests may be exercise testing because it is widely used as a noninvasive assessment of coronary artery diseases or as fitness testing in a health promotion program, and the BP responses during graded ergometer or treadmill exercise have been thoroughly described (7). Several studies indicated that normotensive individuals with an exaggerated BP response to exercise (EBPR) are at increased risk of developing established hypertension in later years when compared with those with a normal BP response (6,8–14). However, there has been few data available on the significance of an EBPR among individuals with high-normal BP in relation to the risk of future hypertension (14). To assess the clinical usefulness of an EBPR in predicting the new onset of hypertension from a high-normal state, middle-aged men with high-normal BP who

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Abbreviations and Acronyms

BMI = body mass index
BP = blood pressure
DBP = diastolic blood pressure
EBPR = exaggerated blood pressure response
HR = heart rate
RR = relative risk
SBP = systolic blood pressure

exhibited an EBPR during exercise testing were followed prospectively over six years.

METHODS

Study population. The study population consisted of 1,054 men who participated in the biannual medical examination by our laboratory from 1992 to 1998. Of these, a total of 317 subjects with baseline resting systolic (SBP) and diastolic (DBP) BPs designated to be high-normal in the classification of hypertension (SBP: 130 to 139 mm Hg, DBP: 85 to 89 mm Hg) were screened as a sample cohort. For this analysis subjects were excluded if they had a history of cardiovascular diseases, stroke or diabetes (n = 18), were taking any medication that was known to affect BP (n = 14), did not perform an ergometer exercise test (n = 37) or had missing data on the covariates at baseline (n = 9). Thus, the complete data on exercise testing and covariates at baseline and hypertensive status at follow-up were obtained for 239 subjects. Written informed consent was obtained after they received a detailed explanation of the aim and procedures as well as clearance for their examination data to be used for follow-up study. Average length of follow-up period was 5.1 years (range 3.1 to 6.2 years). Baseline characteristics of the study subjects are presented in Table 1. The 46 men with high-normal BP who did not complete the data on the exercise testing or the covariates at baseline had resting BP and anthropometric characteristics similar to the study subjects.

Baseline and follow-up examinations. The subjects received a standardized medical examination that consisted of anthropometric, physiological and biochemical measures at both baseline and follow-up periods. A graded ergometer exercise test was administered at the baseline examination. They also completed a questionnaire about personal and parental medical histories and medication used and the habits of daily living, including cigarette smoking, alcohol consumption and physical activity.

Table 1. Baseline Characteristics of Study Population

Variables	
Number	239
Age (yrs)	42.3 ± 5.9
Body mass index (kg/m^2)	23.2 ± 2.4
Systolic BP (mm Hg)	135.3 ± 9.8
Diastolic BP (mm Hg)	86.4 ± 6.5
Heart rate (beats/min)	75.6 ± 7.3
Alcohol consumption (ml/week)	215.0 ± 105.6
Total cholesterol (mg/dl)	179.3 ± 37.6
Triglyceride (mg/dl)	126.0 ± 76.5
Current smoker (%)	118 (49.7)
Parental hypertension (%)	86 (36.0)

Values are shown as mean ± SD or numbers (%). BP = blood pressure; parental hypertension = parental history of hypertension.

Resting BP measurement. Resting BP was taken in a seated position by well-trained physicians after the subjects had been resting for at least 5 min. The measurement was performed 3 times per each visit, and the average of three readings was considered to be a representative value. The screening BP to separate normotensive from hypertensive patients at baseline and follow-up periods was based on the average of BPs taken on three separate medical visits.

Exercise testing and assessment of BP response. A graded uninterrupted symptom-limited maximum exercise test was performed on an electrically braked bicycle ergometer (Fukuda Denshi, BE-14, Japan). After 2 min of unloaded pedaling, the workload was progressively increased using a linear-slope method at a rate of 12.5 W $\times$ min^{-1} until the subjects complained of exhaustion. At rest in the seated position on the bicycle ergometer during exercise and recovery phase, a 3-lead electrocardiogram and heart rate (HR) were continuously monitored, and BP was measured at 1-min intervals by an automated BP monitor (Nippon Colin, STBP-780B, Japan).

After the exercise testing an individual target HR was calculated by taking 50% of relative HR using the equation described by Karvonen and Freund (15); (age-predicted maximal HR − resting HR) × 0.5 + resting HR. Subsequently, SBP readings corresponding to the target HR were interpolated from the individual regression line contrasting SBP with HR during graded exercise. Then a change in score (ΔSBP) was calculated as the difference between the SBP at target level of HR and resting SBP. We preliminarily evaluated the test-retest correlation for this method across the intervals of time from one to two weeks by using 25 normotensive middle-aged men. The test-retest correlation coefficient was 0.84 for the ΔSBP changes ($p < 0.01$).

Follow-up and hypertension status. Hypertensive status at follow-up was ascertained by questionnaire and BP measurements at the biannual medical examinations. A subject was considered to be hypertensive if: 1) his resting SBP was greater than or equal to 140 mm Hg or his resting DBP was greater than or equal to 90 mm Hg, and the subsequent BP readings during the follow-up period did not decrease to below these levels or 2) antihypertensive medications started to be administered to him.

Statistical analysis. The comparisons of continuous valuables were analyzed using Student unpaired *t* test, and the differences of categorical variables were assessed by the chi-square test. The relation between BP response to exercise and the incidence of hypertension over the follow-up period was evaluated by Kaplan-Meier survival curves. For this analysis, the BP response values were arbitrarily divided into three categories. The categories were

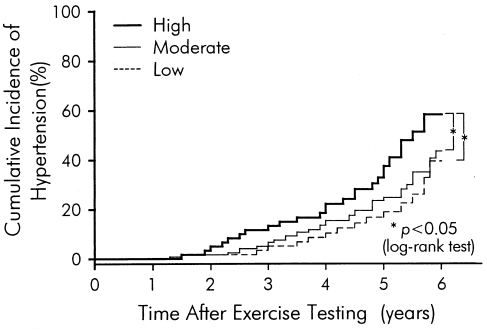

Figure 1. Cumulative incidence of hypertension in subjects with high-normal blood pressure as a function of three categories of systolic blood pressure change during ergometric exercise at baseline. Three categories are upper (high, n = 60), middle two (moderate, n = 120) and lower quartiles (low, n = 59). The subjects in the high category showed significantly higher incidence of hypertension compared with those in moderate and low categories over six years of follow-up.

created on the basis of quartiles in the study population distribution of ΔSBP: the upper 25% (high), the middle 50% (moderate) and the lower 25% (low). A comparison of characteristics among subjects in the three categories revealed no significant differences in resting BP, body mass index (BMI, kg/m^2), serum lipid, cigarette smoking and alcohol consumption. The log-rank test was used to assess the statistical significance of the difference among the incidence curves. The BP response to exercise was treated as both categorical and continuous variables and was entered into the Cox proportional hazards survival model to analyze multivariate association with the development of hypertension. Relative risks (RR) with corresponding 95% confidence intervals were estimated with the Cox model. The following traditional risk factors for hypertension were included as variables in the model: entry age, BMI, resting SBP and DBP, total cholesterol, triglyceride, cigarette smoking, alcohol consumption, physical activity, parental history of hypertension and weight gain from baseline to the end of the follow-up period. The null hypothesis was rejected at a $p < 0.05$ level of significance. Data analysis were performed by using SPSS statistical package 7.5 for Windows.

RESULTS

BP response during exercise test. The distribution of the ΔSBP exhibited an approximately normal curve with a mild skew toward higher values. The values of quartile range in the distribution were 19 to 27 mm Hg, 28 to 32 mm Hg and 33 to 59 mm Hg for lower, middle two and upper quartiles, respectively. The ΔSBP was positively associated with entry age ($r = 0.54$, $p < 0.05$).

Follow-up and survival analysis. Over the 1,117 person-years of follow-up, a total of 73 subjects developed hypertension among 239 study subjects (30.5%). The cumulative incidence of hypertension as a function of three categories of ΔSBP (high, moderate and low) is illustrated in Figure 1. The curves demonstrated that the subjects in the high category had the significantly higher incidence of hypertension compared with those in the moderate and low categories (log-rank test, both $p < 0.05$).

Table 2. Progression to Hypertension Over Six Years of Follow-up and Relative Risks as a Function of Three Categories of BP Response to Exercise

Categories of BP Response	Subjects at Risk (n)	Events of HT (n)	Relative Risk (95% CI)
Low	59	14	1.00 (reference)
Moderate	120	34	1.26 (1.01–2.74)
High	60	25	2.87 (1.69–5.32)
Total	239	73	—

Relative risk estimated from Cox proportional hazards survival model with adjustment for entry age, body mass index, resting systolic and diastolic blood pressure, total cholesterol, triglyceride, cigarette smoking, alcohol consumption, physical activity and parental hypertension.
BP = blood pressure; CI = confidence interval; HT = hypertension.

Multivariate Cox analysis. Progression to hypertension of subjects in the three categories over six years and corresponding RR for the incidence of hypertension assessed by the Cox proportional hazard survival model are shown in Table 2. The Cox model revealed a graded association, with the high category group at 2.87 times at risk for developing hypertension on follow-up relative to the low category group after adjustment for entry age, BMI, resting SBP and DBP, total cholesterol, triglyceride, cigarette smoking, alcohol consumption, physical activity, parental history of hypertension. The stepwise Cox multivariate analysis of risk factors for incidence of hypertension was shown in Table 3. The BP response to exercise was also significantly associated with the risk of developing hypertension when it was treated as a continuous variable. The RR of hypertension for the ΔSBP increase of 20 mm Hg was 2.31. Additionally, the following variables were also significantly associated with the development of hypertension: weight gain of more than 5 kg from baseline to the end of the follow-up period compared with no weight gain and positive parental history of hypertension compared with negative history of hypertension.

DISCUSSION

The primary finding of this study was that an EBPR was independently and significantly associated with the risk of developing established hypertension from a high-normal

Table 3. Stepwise Proportional Hazards Analysis of Risk Factors for Incidence of Hypertension Over Six Years of Follow-up in Subjects With High-Normal BP

Risk Factors	Relative Risk	95% CI	p Value
BP response to exercise	2.31	1.45–6.25	0.016
Parental hypertension	1.86	1.25–4.13	0.022
Weight gain	1.43	1.17–3.28	0.038

Variables into the models are: entry age, body mass index, resting systolic and diastolic blood pressure, BP response to exercise, total cholesterol, triglyceride, cigarette smoking, alcohol drinking, physical activity, parental history of hypertension and weight gain from baseline to the end of follow-up.
BP = blood pressure; CI = confidence interval.

state after adjustment for traditional risk factors for hypertension. Thus, an exercise test provides valid additional information that may help identify individuals with high-normal BP at a greater risk of future hypertension.

Resting BP and hypertension. The preeminence of baseline BPs is widely accepted to be predictive of future hypertension. The Framingham Heart study reported that the individuals with high-normal BP progress to hypertension with twofold to threefold more frequency than subjects with normal BP on 26-year follow-up (2). Although the definition of hypertension was somewhat different, we also detected a high probability of developing hypertension among middle-aged men with high-normal BP over six years. These results would confirm claims in previous studies that the initial level of resting BP is strongly correlated with the risk of subsequent hypertension, but we have been more precise in identifying the risk in the specific group of individuals with high-normal BP.

BP response during exercise and hypertension. Cardiovascular reactivity to both isometric and dynamic exercise has been shown to be one of the most important markers for predicting hypertension. Several studies have indicated that subjects with normal BP at rest but an EBPR during exercise are at a greater risk of developing hypertension (6,8–14). However, the EBPR as a risk factor for new-onset hypertension is still a controversial issue. Some researchers observed a stronger association between an EBPR and risk of developing hypertension (6,8,10,13), while others have suggested that resting BP is a better predictor of future hypertension (14,16,17). This discrepancy probably arises partially from differences in characteristics of the study population tested. An exercise testing may not be a valid and reliable procedure in determining hypertension risks for all normotensive individuals having a wide range of resting BP. In this study the analysis of individuals with high-normal BP enables us to eliminate the confounding effect of resting BP on hypertension risks, and we did find a graded association between the levels of BP change during ergometer exercise test and probability of hypertension. These results confirm the additional and incremental contribution of BP response to exercise above resting BP in predicting future hypertension. The results of secondary stepwise multivariate analysis of risk factors for developing hypertension revealed that positive parental history of hypertension and weight gain of more than 5 kg were also independent risk factors for hypertension from a high-normal state. The subgroup of subjects with a combination of these risk factors was estimated to be 3.3-fold more likely to develop hypertension compared with those with a negative history of hypertension and no weight gain. Among this subgroup, the estimated risk in those who also exhibited an EBPR was further increased to 5.2 when the EBPR was defined as above the 75th percentile value of BP change score, namely the "high response category." Therefore, additional value of the BP response to exercise on their estimated risk of hypertension is calculated at nearly 55%.

Assessment of BP response. The inconsistent results obtained in the previous reports may also depend on nonstandardized protocol and procedures in the assessment of exercise-induced hyper-reactivity. Most previous studies defined an EBPR on the basis of a designated exercise SBP at maximal exertion or at a given workload without adjustment of resting SBP (9,18). Several studies indicated that the individuals with increased levels of SBP during maximal exercise are also likely to have higher levels of resting SBP and that the BP response should be evaluated by taking resting BP into account by expressing the data as a changed score (6,19–22). By calculating an acute change in SBP from rest to exercise, we can remove the potential of a confounding effect of resting BP on hypertension risk. Additionally, the cut off point separating a normal from an abnormal response should be defined according to gender, age and physical fitness, which are all shown to affect the BP response to exercise independently and significantly. Nevertheless, none of the previous studies took into consideration these impacts in the assessment of BP response to exercise. The relative HR, which is expressed as a percentage of the difference in HR from rest to maximal can compensate for the interindividual differences by age, sex and physical fitness and is considered to be a reliable assessment of exercise intensity (23). Applying the relative HR, we could more accurately quantify the EBPR that is associated with a greater risk of developing hypertension.

Mechanisms of exaggerated BP response. Although the mechanism responsible for the EBPR has not been revealed, there are some plausible mechanisms linking with underlying structural abnormalities in the cardiovascular system. Wilson et al. (24) found that the total peripheral resistance in those with EBPR did not fall adequately to compensate for the rise in cardiac output during exercise. Accordingly, the EBPR can partially be explained by increased peripheral vascular resistance and impaired capacity for exercise-induced vasodilatation. These responses of peripheral vascular function can be explained by a hyper-reactivity of sympathetic nerves and an increased vascular response to adrenergic stimulation or by a thickening of the arteriolar wall that alters its ability to respond to vasoconstrictor stimuli (25). Among those patients with these characteristics, higher cardiac output not only raises the SBP but also causes marked DBP elevations like those occurring in established hypertension. Moreover, several studies have found that normotensive individuals with EBPR present changes in the heart structure and function that are usually observed in the early course of the hypertension disease (26–28).

Clinical implications and study limitations. The findings that an individual's risk of developing hypertension in those with high-normal BP was greatly increased if they exhibit an EBPR confirms an incremental contribution of exercise BP response above resting BP in predicting future hypertension. Therefore, exercise testing in populations at high risk for hypertension could provide important additional

information concerning hypertension risk. We have some opportunity for obtaining exercise test data since exercise testing is now a widely used screening method for coronary artery disease, or fitness testing in health promotion programs could also be used. Although we do not recommend exercise testing for mass screening of hypertension risk, if exercise BP information is available, the data should be taken into account in clinical evaluation of normotensive subjects with a high risk of hypertension. In addition, closer follow-up and preventive measure should be required in the specific group having the combination of these high-risk profiles. Our data on the positive relationship between the EBPR and the risk of future hypertension suggested that the normalization of abnormal hyper-reactivity would be effective on the reduction of risks. Franz et al. (7) examined an antihypertensive effect of endurance training on patients with essential hypertension and clearly showed not only a significant fall of resting BP but also a marked reduction of the BP and HR and, thus, of myocardial oxygen consumption during exercise after an endurance training program. Accordingly, it is suggested that endurance training would have the beneficial effect on modification of risk factors, especially when linking the exercise-induced EBPR. Further research should be required to clarify which nonpharmacologic interventions have the potential ability to prevent the development of hypertension in those with high-risk profiles.

There are several potential limitations in this study. First, the population in this study sample consisted of middle-aged Japanese men. Therefore, it is possible that our results may not be fully generalizable to younger populations, women and other racial groups. Second, in previous studies examining the relation between an EBPR and subsequent hypertension risk, there was no standardization of the protocols and procedures of the exercise testing. Additionally, there is still need for methodological development and confirmation in the assessment of BP response during exercise testing. In this study we attempted to establish the technique to remove the potential confounding effect of variables such as sex, age, resting BP and physical fitness on BP response to exercise. However, the reproducibility of this technique was confirmed only for healthy subjects but not for the subgroup who had some risks of hypertension, like this study sample. If the reliability will be confirmed by further research, this technique can provide more precise identification of exercise-induced abnormal hyper-reactivity. Third, several cross-sectional studies observed that an EBPR positively correlated to an echocardiographically determined left ventricular hypertrophy that was associated with subsequent cardiovascular risks (28,29). Our efforts were focused on estimating the risk of developing hypertension in the subjects with high-normal BP and EBPR. Further research with controlled longitudinal design will be required to clarify whether the apparently healthy normotensive subjects with EBPR are not only more likely to develop hypertension but also whether they will progress to subsequent cardiovascular complications or not.

Conclusions. We observed that an EBPR was a significant and independent risk marker in determining the onset of hypertension from a high-normal state. Exercise testing may, thus, provide valid information that helps identify the subgroup of individuals more likely to develop subsequent hypertension and in whom preventive interventions should be particularly warranted.

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