

Effect of Aerobic Exercise on Blood Pressure: A Meta-Analysis of Randomized, Controlled Trials

Seamus P. Whelton; Ashley Chin, MPH, MA; Xue Xin, MD, MS; and Jiang He, MD, PhD

Purpose: Physical activity has been associated with reduced blood pressure in observational epidemiologic studies and individual clinical trials. This meta-analysis of randomized, controlled trials was conducted to determine the effect of aerobic exercise on blood pressure.

Data Sources: English-language articles published before September 2001.

Study Selection: 54 randomized, controlled trials (2419 participants) whose intervention and control groups differed only in aerobic exercise.

Data Extraction: Using a standardized protocol and data extraction form, three of the investigators independently abstracted data on study design, sample size, participant characteristics, type of intervention, follow-up duration, and treatment outcomes.

Data Synthesis: In a random-effects model, data from each trial were pooled and weighted by the inverse of the total variance. Aerobic exercise was associated with a significant reduction in mean systolic and diastolic blood pressure (-3.84 mm Hg [95% CI, -4.97 to -2.72 mm Hg] and -2.58 mm Hg [CI, -3.35 to -1.81 mm Hg], respectively). A reduction in blood pressure was associated with aerobic exercise in hypertensive participants and normotensive participants and in overweight participants and normal-weight participants.

Conclusions: Aerobic exercise reduces blood pressure in both hypertensive and normotensive persons. An increase in aerobic physical activity should be considered an important component of lifestyle modification for prevention and treatment of high blood pressure.

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For author affiliations, current addresses, and contributions, see end of text.

High blood pressure, which affects nearly 50 million Americans, is a serious public health challenge for the United States (1). Cardiovascular disease has been the leading cause of death in the United States for more than 80 years. It is estimated that more than \$320 billion is spent annually on the approximately 60 million Americans with cardiovascular disease, for which high blood pressure is an important modifiable risk factor (2). Epidemiologic studies indicate that uncontrolled elevated blood pressure leads to stroke, coronary heart disease, congestive heart failure, and end-stage renal disease (3). Clinical trials have demonstrated that lowering blood pressure reduces incidence of and death from cardiovascular disease (3, 4). These studies also indicate that a decrease of as little as 2 mm Hg in mean diastolic blood pressure in the general population could substantially reduce the risk for disease associated with elevated blood pressure (5).

Physical inactivity is a major risk factor for cardiovascular disease, and persons who are less active and less fit have a 30% to 50% greater risk for high blood pressure (2). Several recent clinical trials have demonstrated that physical activity reduces blood pressure in hypertensive and normotensive persons, independent of weight loss (6–9). However, evidence regarding the

magnitude of exercise-related reductions in blood pressure is inconsistent, both in general and among subgroups of the population. Pooling results from individual clinical trials provides more precise and accurate information on the effect of aerobic exercise on blood pressure and allows exploration of variation in intervention effect among subgroups of interest.

METHODS

Study Selection

We conducted a comprehensive literature search of MEDLINE (1966 to September 2001) using the Medical Subject Headings *exercise*, *physical fitness*, *hypertension*, and *blood pressure* and the keywords *physical activity* and *aerobic exercise*. We also searched the SPORTDiscus database using the same strategy. In addition, we conducted a manual search by examining reference lists from original research papers and review articles. Initially, three of the authors used predetermined selection criteria to identify and independently review 104 original research reports that included 121 trials. Disagreements were resolved by discussion and, when necessary, by deliberation with a fourth investigator. We included studies that were published in English-language jour-

Context

Exercise can lower blood pressure, but by how much and in whom?

Contribution

This meta-analysis of 54 trials showed that previously sedentary adults could decrease systolic blood pressure by 3.8 mm Hg (95% CI, 2.7 to 5.0 mm Hg) and diastolic blood pressure by 2.6 mm Hg (CI, 1.8 to 3.4 mm Hg) with regular aerobic exercise.

Exercise lowered blood pressure in people who were normotensive or hypertensive; overweight or of normal weight; and black, white, or Asian.

All frequencies, intensities, and types of aerobic exercise lowered blood pressure.

Cautions

Trials lasting longer than 6 months showed smaller reductions in blood pressure, perhaps because of difficulties in sustaining regular exercise.

—The Editors

nals; were conducted in persons at least 18 years of age; randomly assigned patients to intervention and concurrent control groups; limited differences between treatment and control groups to aerobic physical activity; lasted for at least 2 weeks; and reported changes in blood pressure (systolic, diastolic, or both) from baseline to follow-up, as well as variances or data to estimate them. Adherence to the program of physical activity and sample size were not defined as inclusion criteria, but their influence on blood pressure reduction was identified as an issue to be investigated. Fifty-four trials (from 38 reports) met the eligibility criteria and were included in the meta-analysis (10–47).

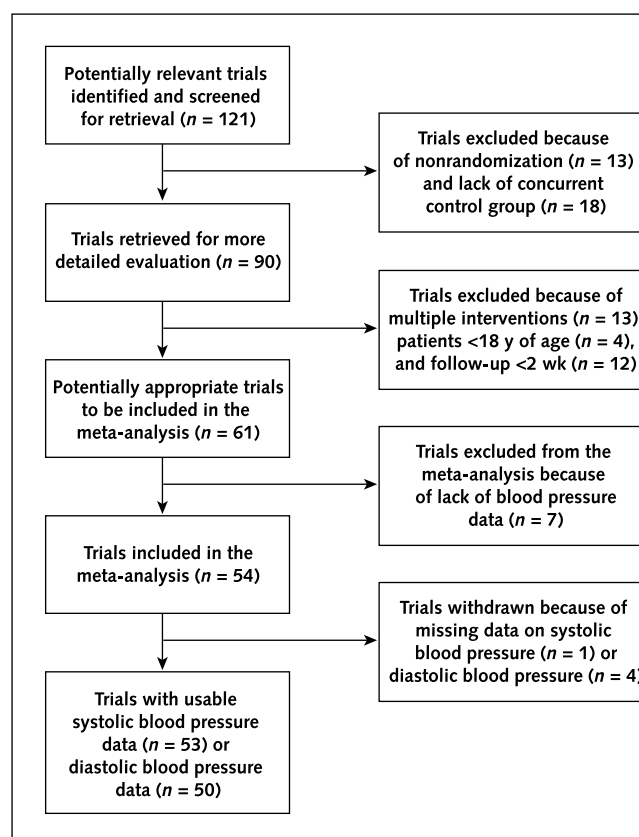
Sixty-seven trials did not meet the eligibility criteria for the meta-analysis (Figure 1). The main reasons for exclusion were nonrandomized assignment of the trial participants (13 trials), lack of an appropriate concurrent control group (18 trials), a difference other than aerobic exercise between the active treatment and control groups (13 trials), inclusion of participants younger than 18 years of age (4 trials), a follow-up period of less than 2 weeks (12 trials), and lack of data on blood pressure outcome (7 trials). Results from these trials were not included in the current meta-analysis; a list of

excluded clinical trials can be requested from the corresponding author. In addition, 1 trial was missing data on systolic blood pressure and 4 trials were missing data on diastolic blood pressure. These trials, however, were included in analyses of diastolic blood pressure and systolic blood pressure, respectively.

Data Abstraction

Three of the authors used a standardized protocol and reporting form to independently abstract data on characteristics of trial participants and study design, intervention method and duration, and study outcomes. Where unstated, ethnicity was assumed to be white if the study was conducted in Europe, Australia, or New Zealand; Asian if the study was conducted in Asia; and black if the study was conducted in Africa. Differences in duplicate data extraction among the primary reviewers were resolved by discussion and, where necessary, by obtaining additional input from a fourth author.

Figure 1. Study selection.



Statistical Analysis

The mean baseline body weight and blood pressure for each trial were calculated by combining mean values from the intervention and control groups, weighted by the number of participants. This mean was not used for calculations of net changes in weight or blood pressure. For parallel and factorial trials, net changes in blood pressure (BP) were calculated as (BP at the end of follow-up in the intervention group – BP at baseline in the intervention group) – (BP at the end of follow-up in the control group – BP at baseline in the control group). For crossover and Latin-square trials, net changes in blood pressure were calculated as BP at the end of the intervention period – BP at the end of the control period.

To pool the overall effect size, we weighted each study by the reciprocal of the total variance for blood pressure change (separate values for systolic and diastolic blood pressure). Variances for net changes in blood pressure were calculated by using confidence intervals, *P* values, *t*-statistics, or individual variances for intervention and control groups (parallel and factorial design) or intervention or control periods (crossover and Latin-square design). For parallel trials that reported variance for paired differences separately for each group, we used standard methods to calculate the pooled variance for net change (48). If the variance for paired differences was not reported, it was calculated by using variances at baseline and at the end of the trial. We used the method of Follmann and colleagues (49), in which a correlation coefficient of 0.5 between initial and final values is assumed. Within each trial, equal variance was assumed between the control and intervention groups, as well as between the beginning and end of the trial.

Fixed-effects and DerSimonian and Laird random-effects models (50) were used to calculate the estimated mean effect of aerobic exercise on blood pressure and associated 95% CIs. Although both models yielded similar results, we chose the random-effects model to present the results because the trials had significant heterogeneity in effect size (50) and were conducted among participants of different ethnic backgrounds, sexes, and hypertensive status, as well as other important covariables.

We performed a series of prestated subgroup analyses to examine the influence of covariables. The subgroups were chosen on the basis of biological plausibility and knowledge of previous studies on the relationship

between exercise and blood pressure. For each subgroup, pooled effects were calculated by using the random-effects model and statistical significance was tested by using one-way analysis of variance, weighted by the reciprocal of the total variance for change in blood pressure. Multivariate meta-regression analysis was not performed because many trials did not report important covariables, such as hypertensive status and ethnicity.

We examined the potential for publication bias by using a funnel plot, in which sample size was plotted against net change in blood pressure (51). In addition, a nonparametric “trim and fill” method was used to test and adjust for potential publication bias (52, 53). This method may be used to estimate the number of missing studies that might exist in a meta-analysis and the influence that the missing studies might have had on the estimates of overall effect size.

We used Stata, version 8.0 (Stata Corp., College Station, Texas), for the “trim and fill” method and SAS, version 8 (SAS Institute, Inc., Cary, North Carolina), for all other analyses.

Role of the Funding Source

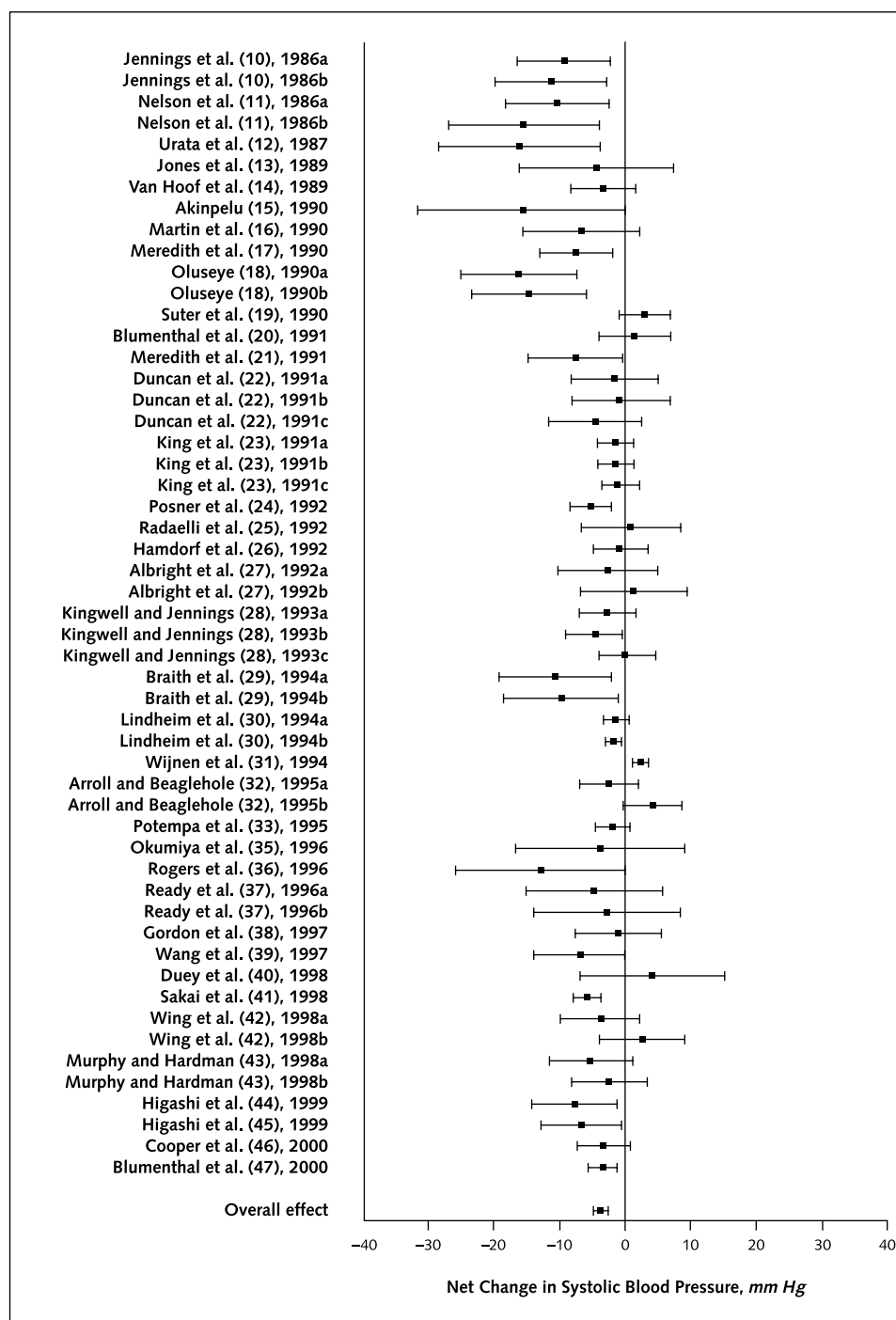
The funding source had no role in the collection, analysis, or interpretation of the data or in the decision to submit the manuscript for publication.

RESULTS

Characteristics of the Participants and Study Designs

Characteristics of the 54 trials and their participants are shown in **Appendix Table 1** (available at www.annals.org). The trials were conducted between 1986 and 2000 and varied in size from 8 to 247 participants (median, 28 participants). Overall, 2419 participants were evaluated, but 39 were included twice or three times in separate protocols (10, 11, 28). All trials were conducted in adults (mean age, 21 to 79 years). Of the 51 trials that reported sex distribution, 10 included predominantly ($\geq 80\%$) men and 17 included predominantly women. Among the 37 trials that reported distribution of ethnicity, all or most of the participants ($\geq 80\%$) were white in 23 trials, Asian in 6 trials, and black in 4 trials. Fifteen of the 47 trials that reported hypertension status were conducted in hypertensive patients, and 28 were conducted in normotensive participants. Antihypertensive medication was administered in 4 trials in

Figure 2. Average net change in systolic blood pressure and corresponding 95% CIs related to aerobic exercise intervention in 53 randomized, controlled trials.



Data on systolic blood pressure were not available in 1 trial (34). Net change was calculated as the difference between the follow-up and baseline blood pressure levels for the intervention and control groups (parallel and factorial trials) or the difference in blood pressure levels at the end of the intervention and control treatment periods (crossover and Latin-square trials). The overall effect represents a pooled estimate obtained by summing the average net change for each trial, weighted by the inverse of its variance.

which all or some of the participants were hypertensive. All 51 trials that reported baseline physical activity were conducted among participants with sedentary lifestyles. The trials varied in length from 3 weeks to 2 years (median duration, 12 weeks). A parallel design was used in 39 trials, a crossover design in 5 trials, a factorial design in 2 trials, and a Latin-square design in 8 trials. All of the trials were open, with the exception of one trial that used a single-blind design (16). In most of the trials, participants in the control groups were instructed not to modify their usual lifestyle, including physical activity. However, in 5 of the trials, participants in the control groups were encouraged to participate in monitored reading, discussion, stretching routines, or a walking program (16, 21, 24, 33, 37).

Average pretreatment blood pressure varied from 101 to 168 mm Hg for systolic blood pressure (median, 126.5 mm Hg) and 61 to 104 mm Hg for diastolic blood pressure (median, 77.0 mm Hg). At baseline, mean body weight varied from 53.4 kg to 99.1 kg (median, 69.3 kg). Mean body mass index at baseline varied from 20.7 kg/m² to 36.0 kg/m² (median, 25.4 kg/m²). Net mean change in body weight was available for 38 trials and ranged from −4.1 kg to 1.5 kg (median, −0.3 kg). The net change in mean body weight weighted by sample size (−0.42 kg) did not differ statistically from 0 ($t = -1.76$; $P = 0.09$).

Net Change in Blood Pressure

Fifty-three trials provided information on systolic blood pressure, and 50 trials provided information on diastolic blood pressure. Net change in these variables

varied from −16.7 to 3.9 mm Hg and from −11 to 11.3 mm Hg, respectively (Appendix Table 2, available at www.annals.org). Systolic blood pressure decreased in 44 of the 53 trials, but the reduction was statistically significant in only 20 (Figure 2). Diastolic blood pressure decreased in 42 of the 50 trials, but the reduction was statistically significant in only 16 (Figure 3).

The overall pooled net effect of aerobic exercise on systolic and diastolic blood pressure was −3.84 mm Hg (95% CI, −4.97 to −2.72 mm Hg; $P < 0.001$) and −2.58 mm Hg (CI, −3.35 to −1.81 mm Hg; $P < 0.001$), respectively (Table 1). When trials that did not require supervision of the exercise intervention were excluded (19, 25, 27, 31, 44–46), the mean net change in blood pressure increased to −4.13 mm Hg (CI, −5.21 to −3.05 mm Hg; $P < 0.001$) for systolic blood pressure and −2.68 mm Hg (CI, −3.55 to −1.81; $P < 0.001$) for diastolic blood pressure (Table 1). After we excluded trials in which antihypertensive medication was administered (25, 32, 33), the mean net change in blood pressure increased to −4.23 mm Hg (CI, −5.42 to −3.05 mm Hg; $P < 0.001$) for systolic blood pressure and −2.91 mm Hg (CI, −3.69 to −2.13 mm Hg; $P < 0.001$) for diastolic blood pressure. After we excluded trials with multiple interventions (25, 30, 32, 38, 42), the net change in blood pressure increased to −4.39 mm Hg (CI, −5.68 to −3.10 mm Hg; $P < 0.001$) for systolic blood pressure and −2.97 mm Hg (CI, −3.82 to −2.12 mm Hg; $P < 0.001$) for diastolic blood pressure. When trials in which blood pressure was not the primary end point were excluded (22–24, 26, 30, 35, 37, 39, 43, 45), the net change in blood pressure

Table 1. Mean Net Changes in Systolic and Diastolic Blood Pressure according to Different Exclusion Criteria

Variable	Systolic Blood Pressure			Diastolic Blood Pressure		
	Trials Examined	Net Change (95% CI)	P Value	Trials Examined	Net Change (95% CI)	P Value
	<i>n</i>	<i>mm Hg</i>		<i>n</i>	<i>mm Hg</i>	
All trials	53	−3.84 (−4.97 to −2.72)	<0.001	50	−2.58 (−3.35 to −1.81)	<0.001
Exercise supervised*	45	−4.13 (−5.21 to −3.05)	<0.001	42	−2.68 (−3.55 to −1.81)	<0.001
Antihypertensive medication not administered†	49	−4.23 (−5.42 to −3.05)	<0.001	46	−2.91 (−3.69 to −2.13)	<0.001
Single intervention between groups‡	47	−4.39 (−5.68 to −3.10)	<0.001	44	−2.97 (−3.82 to −2.12)	<0.001
Blood pressure as primary outcome§	37	−4.39 (−5.93 to −2.86)	<0.001	36	−2.87 (−3.91 to −1.84)	<0.001

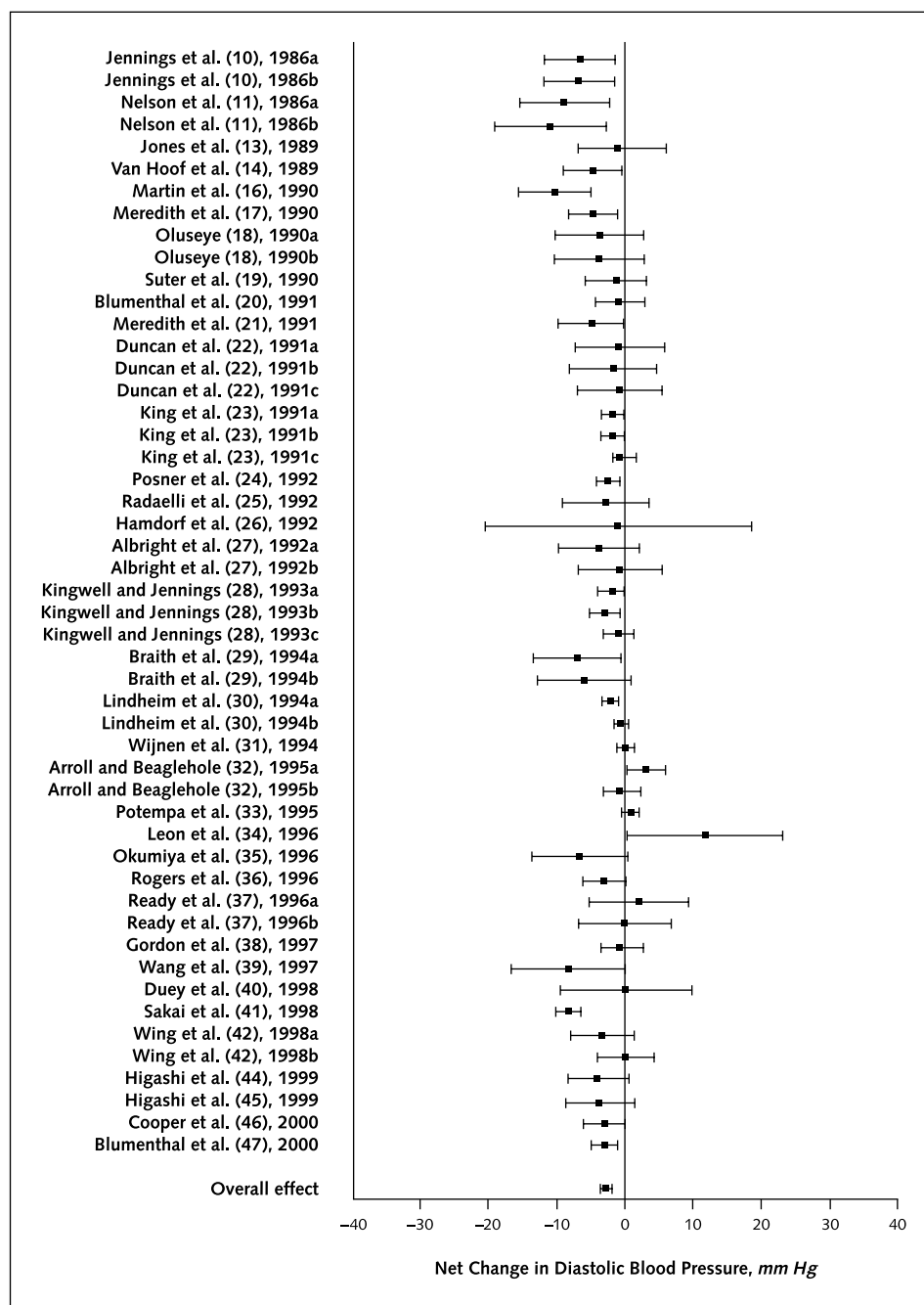
* Trials that did not require supervised exercise intervention were excluded (19, 25, 27, 31, 44–46).

† Trials in which antihypertensive medications were administered were excluded (25, 32, 33).

‡ Trials that conducted multiple interventions were excluded (25, 30, 32, 38, 42).

§ Trials in which blood pressure was not the primary outcome were excluded (22–24, 26, 30, 35, 37, 39, 43, 45).

Figure 3. Average net change in diastolic blood pressure and corresponding 95% CIs related to aerobic exercise intervention in 50 randomized, controlled trials.



Data on diastolic blood pressure were not available in 4 trials (12, 15, 43). Net change was calculated as the difference between the follow-up and baseline blood pressure levels for the intervention and control groups (parallel and factorial trials) or the difference in blood pressure levels at the end of the intervention and control treatment periods (crossover and Latin-square trials). The overall effect represents a pooled estimate obtained by summing the average net change for each trial, weighted by the inverse of its variance.

increased to -4.39 mm Hg (CI, -5.93 to -2.86 mm Hg; $P < 0.001$) for systolic blood pressure and -2.87 mm Hg (CI, -3.91 to -1.84 mm Hg; $P < 0.001$) for diastolic blood pressure.

Subgroup Analysis

Table 2 summarizes pooled estimates for treatment effect in subgroups of trials defined according to characteristics of participants and study design. Overall, reduced blood pressure was observed in all subgroups. Among the three ethnic groups, black participants had

significantly greater reductions in systolic blood pressure and Asian participants had significantly greater reductions in diastolic blood pressure compared with white participants. Trials with the longest follow-up (>24 weeks) had a smaller effect size than trials with short (<10 weeks) or medium (10 to 24 weeks) follow-up. This difference was noted for both systolic and diastolic blood pressure but achieved statistical significance only for the latter. Larger trials (>39 participants) had a statistically significant smaller reduction in blood pressure than smaller trials (22 to 39 or <22 participants). Re-

Table 2. Mean Net Changes in Systolic and Diastolic Blood Pressure in Subgroups of Trials Defined by Characteristics of Participants and of Study Design*

Characteristic	Systolic Blood Pressure			Diastolic Blood Pressure		
	Studies	Effect Size (95% CI)	P Value	Studies	Effect Size (95% CI)	P Value
	<i>n</i>	<i>mm Hg</i>		<i>n</i>	<i>mm Hg</i>	
Hypertensive status			>0.2			>0.2
Hypertensive	15	-4.94 (-7.17 to -2.70)		13	-3.73 (-5.69 to -1.77)	
Normotensive	27	-4.04 (-5.32 to -2.75)		26	-2.33 (-3.14 to -1.51)	
Ethnicity			0.03			0.11
White	23	-3.44 (-5.28 to -1.60)		22	-2.61 (-3.82 to -1.40)	
Asian	6	-6.22 (-7.36 to -5.08)		5	-6.58 (-8.44 to -4.72)	
Black	4	-10.96 (-21.02 to -0.89)		2	-3.25 (-7.11 to 0.60)	
Study duration			0.16			0.05
<10 wk	20	-5.15 (-7.44 to -2.85)		17	-4.31 (-6.09 to -2.53)	
10–24 wk	19	-4.62 (-6.90 to -2.34)		19	-2.54 (-3.07 to -2.02)	
>24 wk	14	-2.00 (-3.13 to -0.87)		14	-1.44 (-2.33 to -0.55)	
Sample size			0.004			0.03
<22 participants	17	-6.51 (-9.51 to -3.50)		14	-3.61 (-5.20 to -2.03)	
22–39 participants	17	-5.95 (-7.91 to -3.98)		17	-3.61 (-5.48 to -1.73)	
>39 participants	19	-1.81 (-2.69 to -0.93)		19	-1.31 (-2.06 to -0.56)	
Study design			>0.2			0.18
Parallel or factorial	41	-3.33 (-4.41 to -2.24)		37	-2.23 (-3.10 to -1.35)	
Crossover or Latin square	12	-5.48 (-8.77 to -2.19)		13	-3.68 (-5.42 to -1.94)	
Baseline BMI			>0.2			0.12
<24.5 kg/m ²	11	-3.90 (-6.82 to -0.97)		11	-2.38 (-3.69 to -1.06)	
24.5–26.4 kg/m ²	12	-4.54 (-7.19 to -1.89)		9	-3.62 (-6.45 to -0.79)	
>26.4 kg/m ²	12	-2.17 (-3.30 to -1.03)		12	-1.75 (-2.31 to -1.18)	
Net weight change			>0.2			>0.2
<-1.5 kg	13	-4.76 (-6.19 to -3.33)		10	-3.28 (-5.80 to -0.76)	
-1.5 to 0.2 kg	12	-4.95 (-7.22 to -2.68)		13	-2.91 (-4.86 to -0.97)	
>0.2 kg	12	-2.74 (-4.37 to -1.10)		11	-1.61 (-2.56 to -0.67)	
Exercise type			>0.2			0.16
Bike	17	-5.58 (-8.25 to -2.92)		16	-3.97 (-5.78 to -2.17)	
Walk or jog	23	-2.59 (-3.89 to -1.29)		21	-1.68 (-2.43 to -0.92)	
Mixed or other	13	-3.63 (-6.64 to -1.61)		13	-2.34 (-3.73 to -0.95)	
Exercise frequency			>0.2			>0.2
<120 min/wk	21	-2.82 (-4.22 to -1.43)		21	-2.19 (-3.24 to -1.14)	
120–150 min/wk	15	-4.67 (-7.19 to -2.16)		12	-2.11 (-3.10 to -1.12)	
>150 min/wk	13	-5.13 (-7.64 to -2.61)		13	-2.78 (-3.08 to -1.01)	
Exercise intensity			>0.2			0.18
Low	7	-4.13 (-6.19 to -2.08)		7	-2.71 (-4.05 to -1.36)	
Moderate	28	-4.34 (-5.76 to -2.93)		24	-3.55 (-4.76 to -2.35)	
High	10	-4.00 (-7.06 to -0.94)		11	-1.52 (-2.82 to -0.22)	

* P values were obtained by using analysis of variance. BMI = body mass index.

duction in blood pressure was not statistically significantly different among trials in which participants were overweight or of normal weight and lost weight or did not lose weight during the intervention. Reduction in blood pressure was also not statistically significantly different among trials with various types, frequencies, and intensities of exercise intervention.

Publication Bias

A plot of sample size versus effect size for systolic and diastolic blood pressure showed that several large trials reported a moderate reduction in blood pressure (23, 24). However, in a sensitivity analysis using a non-parametric “trim and fill” method, no study was removed and overall effect size remained unchanged.

DISCUSSION

High blood pressure is a major risk factor for stroke, coronary heart disease, congestive heart failure, and end-stage renal disease (2–4). While antihypertensive treatment trials have shown that pharmacologic intervention reduces the risk for cardiovascular and renal disease, concerns have also been raised about the potential for deleterious side effects of antihypertensive drugs (54, 55). As a result, interest in lifestyle modification, including aerobic exercise for the treatment and prevention of hypertension, has increased. Several narrative reviews and meta-analyses have examined the relationship between exercise and blood pressure (6–9). However, previous publications have not systematically reviewed the totality of available evidence and have not explored the influence of important covariables (such as characteristics of study participants, study design, and intervention programs) on change in systolic and diastolic blood pressure.

This meta-analysis is a comprehensive examination of the effect of aerobic exercise on blood pressure and is based on randomized, controlled clinical trials. Our meta-analysis included 54 clinical trials that involved 2419 participants and were conducted in a wide range of geographic regions and ethnic populations. Our study showed that aerobic exercise has an impressive blood pressure-lowering effect: 3.84 mm Hg for systolic blood pressure and 2.58 mm Hg for diastolic blood pressure. Furthermore, the blood pressure reduction associated with aerobic exercise was consistent in sensitivity analy-

ses that included or excluded subgroups of the clinical trials on the basis of study design.

It is important to distinguish between the individual and public health implications of our findings. The blood pressure reduction that we observed may be of moderate interest to practitioners treating individual patients. However, a small decrease in the population's average blood pressure level should dramatically reduce incidence of and death from cardiovascular disease in communities (5).

Our analysis indicates that aerobic exercise lowers blood pressure even in participants whose mean body mass indexes are in the normal range. Indeed, in our meta-analysis, the average overall intervention-related weight change (−0.42 kg) was not statistically significant or biologically important. In addition, our study indicated that mean blood pressure reduction was not significantly associated with mean change in body weight. Instead, blood pressure was significantly reduced even in trials whose participants did not lose weight overall. These findings suggest that the effects of aerobic exercise on blood pressure may be independent of change in body weight.

The blood pressure reduction was not as marked in trials with longer follow-up periods, most likely because participant adherence to the intervention program decreased over time. Study participants were required to participate in exercise sessions supervised by study personnel in all of the short-term trials, while study participants were allowed to exercise independently in longer-term trials. This effect was also noted in individual trials. For example, Wing and coworkers (42) reported a much larger reduction in blood pressure at 6 months than at 2 years. Poor adherence to the intervention program after 6 months, when supervised training was not required, was the most likely explanation (42). Adherence to the intervention program is an essential element for success in achieving and maintaining the maximum benefit of exercise on blood pressure. Our meta-analysis also indicated that blood pressure reduction was smaller in trials with a larger sample size. This may reflect the fact that all of the trials with a large sample size were also longer in duration. In addition, blood pressure was not the primary end point for several of the larger clinical trials (23, 24).

The degree of blood pressure reduction did not differ significantly among trials with different forms of in-

tervention. The blood pressure reduction related to aerobic exercise also did not significantly differ by subgroup according to frequency or intensity of aerobic exercise. Our results, however, indicate that all forms of exercise seem to be effective in reducing blood pressure. Our meta-analysis also suggests that clinical trials that use a crossover or Latin-square design yield a greater reduction in blood pressure than those that use a parallel or factorial design. The elimination of intra-individual variation in trials using crossover or Latin-square design can increase the efficiency of the trial, assuming no carryover effect of exercise on blood pressure. Most crossover or Latin-square trials in our meta-analysis had short interventions and small sample sizes.

Our study has limitations. We could not perform a multivariate meta-regression analysis because data were missing for important covariables, such as ethnicity (17 trials) and hypertensive status (7 trials). We did, however, conduct subgroup analyses based on these important covariables. Aerobic exercise had a slightly greater effect on blood pressure in hypertensive participants than in normotensive participants. The reduction was greater for systolic blood pressure in black persons and for diastolic blood pressure in Asian persons, but only a relatively small number of trials were conducted in persons of these ethnic backgrounds. In addition, all but one trial included in our meta-analysis used an open design. However, many trials masked observers who obtained blood pressure measures. We identified a potential publication bias by funnel-plot method. Several large trials reported a moderate reduction in blood pressure. However, blood pressure was not the primary outcome of interest in most of these trials (23, 26, 30). Furthermore, in a formal test using the "trim and fill" method, reductions in systolic and diastolic blood pressure remained unchanged.

The underlying mechanism or mechanisms responsible for an exercise-induced reduction in blood pressure remain unclear. Recent evidence shows that insulin resistance and hyperinsulinemia may contribute to the pathogenesis of hypertension (56, 57). Clinical trials have shown that aerobic exercise reduces insulin resistance and insulin levels in hypertensive patients (58, 59). Brett and associates (60) have reported that change in blood pressure during exercise is strongly associated with reduction in serum concentrations of total cholesterol and insulin resistance.

In summary, our results suggest that aerobic exercise is an important strategy for prevention and treatment of high blood pressure. We recognize the difficulty of comparing results from meta-analyses conducted on different clinical trials. However, the blood pressure reduction associated with aerobic exercise in our study exceeded that in meta-analyses that explored the corresponding effects of sodium reduction, potassium supplementation, and alcohol reduction on systolic and diastolic blood pressure (61–63). Additional studies are needed to identify ways to improve adherence to exercise. Likewise, the effect of physical activity in ethnic subgroups, especially African-American women, needs further attention.

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Requests for Single Reprints: Jiang He, MD, PhD, Department of Epidemiology, Tulane University School of Public Health and Tropical Medicine, 1430 Tulane Avenue SL18, New Orleans, LA 70112; e-mail, jhe@tulane.edu.

Current Author Addresses: Mr. Whelton: Princeton University, Mailbox 2162, Princeton, NJ 08544.

Ms. Chin and Dr. He: Department of Epidemiology, Tulane University School of Public Health and Tropical Medicine, 1430 Tulane Avenue SL18, New Orleans, LA 70112.

Dr. Xin: Department of Biostatistics, Tulane University School of Public Health and Tropical Medicine, 1430 Tulane Avenue SL18, New Orleans, LA 70112.

Author Contributions: Conception and design: S.P. Whelton, A. Chin, J. He.

Analysis and interpretation of the data: S.P. Whelton, A. Chin, X. Xin, J. He.

Drafting of the article: S.P. Whelton, J. He.

Critical revision of the article for important intellectual content: S.P. Whelton, A. Chin, X. Xin, J. He.

Final approval of the article: S.P. Whelton, A. Chin, X. Xin, J. He.

Provision of study materials or patients: S.P. Whelton, X. Xin.

Statistical expertise: X. Xin, J. He.

Obtaining of funding: J. He.

Collection and assembly of data: S.P. Whelton, A. Chin, X. Xin, J. He.

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