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Progressive Resistance Exercise and Resting Blood Pressure
A Meta-Analysis of Randomized Controlled Trials

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Abstract—Hypertension is a major public health problem affecting an estimated 43 million civilian, noninstitutionalized adults in the United States (24% of this population). The purpose of this study was to use the meta-analytic approach to examine the effects of progressive resistance exercise on resting systolic and diastolic blood pressure in adult humans. Studies were retrieved via (1) computerized literature searches, (2) cross-referencing from original and review articles, and (3) review of the reference list by 2 experts on exercise and blood pressure. Inclusion criteria were as follows: (1) trials that included a randomized nonexercise control group; (2) progressive resistance exercise as the only intervention; (3) adult humans; (4) journal articles, dissertations, and masters theses published in the English-language literature; (5) studies published and indexed between January 1966 and December 1998; (6) resting systolic and/or diastolic blood pressure assessed; and (7) training studies lasting a minimum of 4 weeks. Across all designs and categories, fixed-effects modeling yielded decreases of ≈2% and 4% for resting systolic and diastolic blood pressure, respectively (mean±SD systolic, −3±3 mm Hg; 95% bootstrap CI, −4 to −1 mm Hg; mean±SD diastolic, −3±2 mm Hg; 95% bootstrap CI, −4 to −1 mm Hg). It was concluded that progressive resistance exercise is efficacious for reducing resting systolic and diastolic blood pressure in adults. However, a need exists for additional studies that limit enrollment to hypertensive subjects as well as analysis of data with an intention-to-treat approach before the effectiveness of progressive resistance exercise as a nonpharmacological intervention can be determined. (*Hypertension*. 2000;35:838-843.)

Key Words: exercise ■ blood pressure ■ meta-analysis

Hypertension, defined as resting systolic and/or diastolic blood pressure ≥140/90 mm Hg, is a major public health problem affecting an estimated 43 million civilian, noninstitutionalized adults in the United States (24% of this population).[1] Recently, the Sixth Report of the Joint National Committee on the Prevention, Detection, Evaluation, and Treatment of High Blood Pressure[2] recommended adherence to the physical activity guidelines outlined in the Surgeon General's Report[3] for lowering resting blood pressure. This includes moderately intense aerobic exercise at 40% to 60% of maximum oxygen consumption, such as 30 to 45 minutes of brisk walking on most days of the week.[3] It has been suggested that progressive resistance exercise may also lower resting blood pressure, possibly by reducing peripheral resistance at rest.[4] However, absent from the previous recommendations was the promotion of progressive resistance exercise for controlling resting blood pressure levels. This is not surprising given the lack of statistically significant and positive findings regarding the use of progressive resistance exercise as a nonpharmacological intervention for controlling resting blood pressure in adults.[5–15] For example, only 7% and 13% of the aforementioned studies reported statistically significant reductions in resting systolic and diastolic blood pressure, respectively. However, most of these studies suffer from small sample sizes, thus increasing the risk of incorrectly concluding that progressive resistance exercise has no positive effect on resting systolic and diastolic blood pressure in adults. Additionally, because some of the studies were not specifically testing the hypothesis of progressive resistance exercise on blood pressure, the standardized mechanisms for assessing blood pressure may not have been as rigorous as those studies specifically testing for such a hypothesis. Consequently, the lack of observed effect in these studies could be due to measurement bias. Furthermore, use of the vote-counting method (counting the number of studies yielding statistically significant versus nonsignificant results and declaring the one with the most votes the winner) has been criticized because (1) it does not incorporate sample size into the vote, (2) it does not allow one to determine the magnitude of the treatment effect, and (3) it has been shown to have very low power.[16] Meta-analysis is a quantitative approach in which individual studies addressing a common problem are statistically combined to arrive at conclusions about a body of research.[16] Meta-analysis allows one to (1) improve power for primary outcomes and subgroup analyses, (2) help resolve uncertainty when studies disagree, (3) improve estimates of treatment effectiveness, and (4) answer questions not posed at the start of individual trials.[17] A need exists to use a

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quantitative approach to examine the effects of progressive resistance exercise on resting systolic and diastolic blood pressure in adults. Thus, the purpose of this study was to use the meta-analytic approach to examine the effects of progressive resistance exercise as a nonpharmacological intervention for reducing resting systolic and diastolic blood pressure in adult humans.

Methods

Data Sources
Computerized literature searches of articles indexed between January 1966 and December 1998 were performed with the use of MEDLINE, Embase, Current Contents, Sport Discus, and Dissertation Abstracts International databases. However, since computer searches have been shown to yield less than two thirds of relevant articles,[18] the reference lists from both original and review articles retrieved were also reviewed to identify any studies that had not been previously identified and that appeared to contain information on the topic of interest. In addition, 2 experts on exercise and blood pressure (Dr James Hagberg and Dr Douglas Seals) reviewed our reference list for thoroughness and completeness.

Study Selection
Inclusion criteria for this study were as follows: (1) randomized trials that included a nonexercise control group; (2) progressive resistance exercise as the only intervention; (3) adult humans (aged 18 and older) as subjects; (4) journal articles, dissertations, and masters theses published in the English-language literature; (5) studies published and indexed between January 1966 and December 1998; (6) resting systolic and/or diastolic blood pressure assessed; and (7) training studies lasting a minimum of 4 weeks.

Data Extraction
Coding sheets that could hold 241 items were developed and used in this investigation. To avoid interobserver bias, all data were independently extracted by 2 authors. The authors then met and reviewed every item for accuracy and consistency. Disagreements were resolved by consensus. The major categories of variables coded included (1) study characteristics, (2) physical characteristics of subjects, (3) blood pressure assessment characteristics, and (4) exercise program characteristics.

Statistical Analysis

Primary and Secondary Outcomes
The primary outcomes in this study were changes in resting systolic and diastolic blood pressure, analyzed separately. Since all studies were parallel trials, net changes in blood pressure were calculated as the difference (exercise minus control) of the changes (initial minus final) in these mean values. Pooled effect sizes were calculated by assigning weights equal to the inverse of the total variance for net changes in blood pressure. Because of the small sample size in this study, bootstrap resampling (5000 iterations) was used to generate 95% bootstrap confidence intervals (BCI) around mean effect size changes for resting systolic and diastolic blood pressure.[19] The number of iterations chosen was based on previous research demonstrating that improvement of estimation accuracy was limited beyond 5000 iterations.[20] If the 95% CI included zero (0.00), it was concluded that there was no effect of progressive resistance exercise on blood pressure. Heterogeneity of net changes in resting systolic and diastolic blood pressure was examined with the Q statistic.[16] For all analyses, a fixed-effects model was used if results were homogeneous, while a random-effects model was used if heterogeneity was present.[21]

To examine the influence (sensitivity) of each study on the overall results, analyses were also performed with each study deleted from the model. Cumulative meta-analyses, ranked by year, were also performed for net changes in resting systolic and diastolic blood pressure to examine at what point in time, if any, the primary outcome measures stabilized.

Publication bias (the tendency for studies to be published that yield statistically significant and positive results) was examined with the Kendall τ rank correlation test (r_τ).[22] This consisted of correlating observed outcomes, ie, changes in resting systolic and diastolic pressure, with sample size. Study quality was assessed with a 3-item questionnaire designed to assess bias, specifically, randomization, blinding, and withdrawals/dropouts.[23] The minimum number of points possible was 0, and the maximum was 5. All questions were designed to elicit responses of yes (1 point) or no (0 points). Completion of the questionnaire required <10 minutes per study. The questionnaire has been shown to be both valid (face validity) and reliable (researcher interrater agreement, $r=0.77$; 95% CI, 0.60 to 0.86).[23] We chose this scale over numerous others[24] because it appears to be the most valid and reliable scale that currently exists and has been successfully used in the past.[25]

Secondary outcomes, ie, changes in body weight, body mass index, percent body fat, lean body mass, maximum oxygen consumption, and resting heart rate, were examined with the same methods as those for examining net changes in resting systolic and diastolic blood pressure.

Moderator Analysis
For categorical variables as well as study quality, subgroup analyses were performed with ANOVA-like procedures for meta-analysis.[16] Net changes in resting systolic and diastolic blood pressure were examined when data were partitioned according to source of publication (journal compared with other), country in which study was conducted (United States compared with other), study quality (<2 compared with ≥2), whether subjects were hypertensive or not (systolic, <140 mm Hg compared with ≥140 mm Hg; diastolic, <90 mm Hg compared with ≥90 mm Hg), type of blood pressure instrument used (electronic compared with manual), position of subject when blood pressure was assessed (sitting compared with supine), and type of progressive resistance training program (conventional compared with circuit). Because of the potential for a lack of rigor in the assessment of blood pressure and subsequent increase in measurement bias for those studies not specifically testing the hypothesis of progressive resistance exercise on blood pressure, we also performed subgroup analysis according to those studies that were specifically testing for such a hypothesis compared with those that were not. Randomization tests (5000 iterations) were used to determine the significance level for between group differences, while 95% BCI were generated from 5000 iterations.

To examine the influence of continuous variables on changes in resting systolic and diastolic blood pressure, least squares regression models, calculated with each effect size weighted by the reciprocal of its variance, were used.[16]

Unless otherwise noted, all data are reported as mean±SD. All CIs reported were based on 5000 bootstrap iterations, corrected for bias. The α level for a type I error was set at $P \leq 0.05$. The α level for between-group differences for subgroup analyses was derived from randomization tests (5000 iterations). Bonferroni adjustments were not made because of the increased risk of a type II error.

Results

Study Characteristics
A total of $\approx 11\,700$ studies were located, and the title and abstract were reviewed to determine whether they met the criteria for inclusion. Of these, 12 studies met the necessary criteria[5–15,26]; however, we were unable to include 1 study in the final analysis because of inability to obtain missing blood pressure data.[26] Thus, our percent loss that met our inclusion criteria was $\approx 8\%$. The per person time to code each study once ranged from 0.52 to 1.75 hours (mean±SD, 0.96±0.40 hours). Six of the studies were published in journals,[6,8,10–12,15] and 5 were doctoral dissertations.[5,7,9,13,14] Nine of the studies

TABLE 1.   Initial Characteristics of Subjects

Variable	No.	Exercise	No.	Control
Age, y	13	47.2±20.9	11	47.4±20.8
Height, cm	6	170.3±6.2	4	169.3±8.8
Weight, kg	11	75.2±11.4	9	74.3±12.6
BMI, kg/m^2	8	26.1±2.5	6	25.7±2.9
Fat, %	7	27.9±7.1	5	28.2±6.4
LBM, kg	7	50.9±7.8	5	50.0±9.9
$\dot{V}o_2$max, mL/kg^{-1}/min^{-1}	9	28.8±7.5	7	30.9±8.2
RHR, bpm	11	71.1±5.8	8	70.9±5.0

No. indicates number of groups reporting data; BMI, body mass index; LBM, lean body mass; $\dot{V}o_2$max, maximum oxygen consumption; and RHR, resting heart rate.

were conducted in the United States[5–9,11–14] and 1 each in Belgium[15] and Australia.[10] The 11 studies included in the final analysis represented initial and final blood pressure assessment in a total of 320 subjects (182 exercise, 138 control). There were a total of 14 exercise and 12 control groups, from which a total of 15 primary outcomes were generated (some studies had >1 group and/or assessed blood pressure in >1 position). The average number of subjects in each group ranged from 6 to 31 in the exercisers (mean±SD, 13±6) and 5 to 22 in the controls (mean±SD, 12±5). For those groups in which data were available, percent dropout, defined as the number of subjects who did not complete the study, ranged from 0% to 58% in the exercise groups (mean±SD, 18±20%) and 0% to 38% in the control groups (11±13%). All of the studies appeared to use an analysis-by-protocol approach in the analysis of their blood pressure data. Study quality ranged from 1 to 3 (mean±SD, 2±1).

Subject Characteristics
Initial subject characteristics for the exercise and control groups are shown in Table 1. For those groups that reported such data, the percentage of men ranged from 0% to 100% (mean±SD, 50±42%). Three studies reported that all of the subjects were male,[5,11,15] another 3 reported that all of the subjects were female,[7,9,12] and 4 reported that both men and women were included.[6,8,10,14] For the 4 studies that reported information on race, all reported that the majority of subjects were white.[5–7,14] Two studies reported that none of the subjects were taking any antihypertensive medications before or during the study,[14,15] another reported that subjects were taken off antihypertensive medications 4 weeks before being screened for the study,[6] and another reported that some subjects were taking antihypertensive medications both before and during the study.[8] One study that included hypertensive subjects did not report any information about antihypertensive therapy.[11] Three studies[10–12] reported that none of the subjects smoked cigarettes, while 1 reported that some of the subjects smoked.[5] None of the studies reported information on the consumption of alcohol. The 3 studies that provided information on diet reported that no significant changes in diet occurred throughout the study.[6,7,10] All of the studies reported that the subjects were previously inactive before the start of the investigation.[5–15]

Blood Pressure Assessment Characteristics
For those studies that reported information on the type of instrument used to assess resting blood pressure, 3 reported using a manual sphygmomanometer,[6,8,15] 3 used an electronic sphygmomanometer,[9,10,14] and 1 used a semielectronic sphygmomanometer.[7] Five studies assessed resting blood pressure with the subject in the seated position,[6,8,11–13] 3 in the supine position,[5,7,10] and 1 in both the sitting and supine positions.[15] For those studies that reported such data,[5,6,8–10,12,14,15] the number of measures taken to arrive at a mean blood pressure level ranged from 3 to 20. The rest period before assessment of resting blood pressure ranged from 5 to 15 minutes,[7,8,11–15] while the rest period between assessments ranged between 1 and 5 minutes.[5–8,15] Three studies used the fifth Korotkoff sound to assess resting diastolic blood pressure,[6,8,12] while 1 used the fourth Korotkoff sound.[15] Only 2 studies reported the time after the last exercise session before resting blood pressure was assessed, with 1 reporting assessment 24 hours after exercise[8] and the other 36 to 72 hours after exercise.[7] While none of the studies reported any specific information on blinding, 3 studies reported using a random-zero sphygmomanometer in the assessment of resting blood pressure.[6,8,15]

Training Program Characteristics
Length of training in the studies ranged from 6 to 30 weeks (mean±SD, 14±6 weeks), frequency from 2 to 5 times per week (mean±SD, 3±1 times per week), intensity from 30% to 90% of 1 repetition maximum (RM) (mean±SD, 35±7%), and duration from 20 to 60 minutes per session (mean±SD, 38±14 minutes). The number of sets per exercise session ranged from 1 to 4 (mean±SD, 2±1), while the number of exercises performed ranged from 6 to 14 (mean±SD, 10±3). Because most studies reported the range versus the mean for the number of repetitions performed as well as the rest period between exercises, we were unable to calculate an overall mean, SD, and between-group range of means for these data. However, the within-group number of repetitions performed for each set ranged between 4 and 50, while the rest period between sets ranged from 15 to 120 seconds. Compliance, defined as the percentage of exercise sessions attended, ranged from 89% to 93% (mean±SD, 91±2%). Five of the studies reported using a circuit training protocol.[5,6,10–12]

Primary and Secondary Outcomes
Initial and final blood pressure results for each study are shown in Table 2. Initial resting systolic blood pressure ranged from 104 to 151 mm Hg in the exercise groups (mean±SD, 125±14 mm Hg) and from 99 to 153 mm Hg in the control groups (mean±SD, 125±16 mm Hg). For resting diastolic blood pressure, initial values ranged from 63 to 96 mm Hg in the exercise groups (mean±SD, 76±10 mm Hg) and from 57 to 95 mm Hg in the control groups (mean±SD, 75±11 mm Hg). Across all designs and categories, decreases of ≈2% and 4% were found for resting systolic and diastolic blood pressure, respectively (mean±SD systolic, −3±3 mm Hg; 95% BCI, −4 to −1 mm Hg; mean±SD diastolic, −3±2 mm Hg; 95% BCI, −4 to −1 mm Hg). Primary outcome results were based on a fixed-effects model because of a lack of statistically significant

TABLE 2. Blood Pressure Results From Individual Studies

Author	Group	No. Assessed	Systolic, mm Hg		Diastolic, mm Hg	
			Initial	Final	Initial	Final
Belles[5]	Exercise	14	122.36±11.85	121.57±NA	82.57±9.56	79.14±NA
	Control	10	NA±NA	NA±NA	NA±NA	NA±NA
Blumenthal et al[6]	Exercise	31	143±10.3	136±11.6	95±5.4	89±6.4
	Control	22	142±12	133±8.6	95±6.2	90±6.2
Byrne[7]	Exercise	10	118.9±9.8	115.9±10.75	71.8±5.38	69.7±5.69
	Control	9	115±11.7	115.7±14.09	71.7±5.39	71.4±8.39
Cononie et al[8]	Exercise, normotensives	14	122±8	122±11	76±9	75±10
	Exercise, hypertensives	6	151±7	151±11	82±9	82±14
	Control, normotensives	7	126±7	129±7	78±6	81±5
	Control, hypertensives	5	153±7	156±10	85±8	85±6
Don[9]	Exercise, high intensity	12	104.1±5.6	104.8±6.3	62.9±4.1	62.7±4.4
	Exercise, moderate intensity	12	105.7±11.3	104.6±9.7	63.8±7.6	63.3±6.1
	Control	11	98.7±8.7	100.4±6.2	57.2±5	57.8±2.8
Dunstan et al[10]	Exercise	11	126±9.95	127±9.95	73±6.63	73±6.63
	Control	10	130±12.65	127±12.65	72±6.32	72±6.32
Harris and Holly[11]	Exercise	10	141.7±7.9	142.3±7.5	95.8±6.4	91.3±8
	Control	16	146.1±8.2	145.8±6.9	94.6±3.8	92.6±3.3
Katz and Wilson[12]	Exercise	13	113.3±11.6	99.1±13.6	70.9±6.8	62±7.8
	Control	8	115.2±8.3	112.5±5.8	70.4±6	68.5±6.7
Moul[13]	Exercise	14	136.57±12.2	131.42±12.53	81.14±9.43	77.85±9.99
	Control	15	133.25±12.94	132.12±13.13	77.38±10.81	77±9.99
Tsutsumi[14]	Exercise, high intensity	13	109.8±18.8	103.7±17.4	65±9.9	62.3±9.9
	Exercise, low intensity	14	124.2±16.4	110.8±15	72.6±9.5	67.5±9.1
	Control	14	122±11.8	125.4±14.1	72.4±8.1	76±9.8
Van Hoof et al[15]	Exercise, supine	8	126±9	124±5	71±8	67±11
	Exercise, sitting	8	129±8	125±6	81±10	76±5
	Control, supine	11	121±14	116±11	69±11	62±15
	Control, sitting	11	124±15	120±9	78±14	76±11

Data are listed as reported in studies (mean±SD). NA indicates not available.

heterogeneity for both resting systolic ($Q=15.89$, $P=0.32$) and diastolic ($Q=14.42$, $P=0.42$) blood pressure. When limited to study results that appeared in journals, no publication bias was found for changes in either resting systolic or diastolic blood pressure (systolic, $r_\tau=0.23$, $P=0.42$; diastolic, $r_\tau=-0.15$, $P=0.59$). With each study deleted from the model once, changes ranged from -2 to -3 mm Hg for resting systolic blood pressure and -2 to -4 mm Hg for resting diastolic blood pressure. Cumulative meta-analysis, ranked by year, showed that changes had remained constant over time (systolic range, -2 to -4 mm Hg; diastolic range, -3 to -4 mm Hg).

For secondary outcomes, small but statistically significant decreases were found for percent body fat (mean±SD, $-2\pm1\%$; 95% BCI, -3% to -2%), while statistically significant increases were found for lean body mass (mean±SD, 4 ± 1 kg; 95% BCI, 3 to 7 kg). No statistically significant changes were found for body weight, body mass index, maximum oxygen consumption, or resting heart rate. We were unable to compare changes in muscular strength between exercise and control groups because of missing data for the control groups. Thus, percent change in muscular strength

was reported for exercise groups only with increases ranging from 15% to 62% (mean±SD, $34\pm12\%$).

Moderator and Regression Analyses

No statistically significant differences or relationships were observed when changes in resting systolic and diastolic blood pressure were partitioned or regressed according to (1) study characteristics, (2) blood pressure assessment characteristics, (3) physical characteristics, and (4) training program characteristics.

Discussion

The overall results of this study suggest that progressive resistance exercise results in small reductions in resting systolic and diastolic blood pressure. While such small reductions may do little in reducing cardiovascular disease morbidity and mortality, it has been shown that small reductions similar to these have resulted in a decreased risk for stroke and coronary heart disease.[27] More importantly, it does not appear that progressive resistance exercise raises resting blood pressure. Although the results are

promising, additional definitive research on stage 2+ hypertensives is needed.

An interesting finding of this study was the paucity of outcomes for hypertensive subjects. Only 20% of the outcomes were based on a mean initial resting systolic blood pressure ≥140 mm Hg, while only 13% had a mean initial resting diastolic blood pressure ≥90 mm Hg. It may be that the addition of more studies in which enrollment was limited to hypertensive subjects would have resulted in greater decreases in resting blood pressure. Since hypertensive adults probably have the most to gain from lowering their resting blood pressure, future studies need to limit enrollment to subjects initially classified as hypertensive. Since persons with isolated systolic hypertension (systolic blood pressure >140 mm Hg and diastolic blood pressure <90 mm Hg[2]) routinely are not treated with pharmacological agents, the inclusion of these types of subjects in future studies would also seem warranted. In our investigation, decreases of 3 mm Hg were found for the only study in which the summary means resulted in the subjects being classified as having isolated systolic hypertension.[8] In addition, since antihypertensive medication use was reported in only 4 studies,[6,8,14,15] the inclusion of such information as well as its potential interaction should be taken into account in future study designs.

The fact that we included 1 study with some hypertensive subjects who continued to take antihypertensive medications during the study[8] as well as another study that did not provide information on antihypertensive therapy in its subjects[11] could be thought to affect our overall results. However, as previously described, sensitivity analysis with each of these studies deleted from the model did not have a significant effect on our overall results. Despite this, it would appear plausible to suggest that future studies interested in the independent effects of progressive resistance exercise on resting blood pressure withdraw all subjects from antihypertensive medications before participation in the study.

Another interesting finding of this study was the fact that no differences were found for changes in resting blood pressure between studies that used a conventional compared with a circuit protocol. A conventional protocol generally consists of lifting heavier weights with longer rest periods, while a circuit protocol consists of lifting lighter weights with shorter rest periods between exercises. However, while we are not aware of any cardiovascular problems in healthy or unhealthy subjects as a result of heavy progressive resistance exercise, the large increases in both systolic and diastolic blood pressure that have been demonstrated during heavy weightlifting may warrant caution, especially for those at risk for cardiovascular complications. For example, increases of 320 and 250 mm Hg have been shown to occur in peak systolic and diastolic blood pressure, respectively, during a 1-repetition maximum lift.[28]

The fact that it appeared that almost all of the studies used an analysis-by-protocol versus intention-to-treat approach limits our ability to judge the effectiveness of progressive resistance exercise for reducing resting blood pressure in adults. An analysis-by-protocol approach is used to judge whether a treatment is efficacious, that is, whether the treatment works or not. In this design, the results from subjects who drop out of the treatment group are not included in the final analysis. In contrast, an intention-to-treat approach, which is designed to judge whether a treatment is effective or not, includes dropouts in the final analysis.[29] Unfortunately, few clinical trials attempt to address the question of effectiveness. It is important that future clinical trials examining the effects of progressive resistance exercise on resting blood pressure in adults include an examination of the effectiveness of such an intervention. This may be especially true given the fact that only 16% of adults between the ages of 18 and 64 years in the United States reported that they participate in a regular program of progressive resistance exercise.[30]

In conclusion, meta-analysis of included studies supports the efficacy of progressive resistance exercise for reducing resting systolic and diastolic blood pressure in adults. However, a need exists for additional studies that limit enrollment to hypertensive subjects as well as analysis of data using an intention-to-treat approach so that the effectiveness of progressive resistance exercise as a nonpharmacological intervention can be determined.

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