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# Impact of Resistance Training on Blood Pressure and Other Cardiovascular Risk Factors

## A Meta-Analysis of Randomized, Controlled Trials

Véronique A. Cornelissen, Robert H. Fagard, Ellen Coeckelberghs, Luc Vanhees

*Abstract*—We reviewed the effect of resistance training on blood pressure and other cardiovascular risk factors in adults. Randomized, controlled trials lasting $\geq 4$ weeks investigating the effects of resistance training on blood pressure in healthy adults (age $\geq 18$ years) and published in a peer-reviewed journal up to June 2010 were included. Random- and fixed-effects models were used for analyses, with data reported as weighted means and 95% confidence limits. We included 28 randomized, controlled trials, involving 33 study groups and 1012 participants. Overall, resistance training induced a significant blood pressure reduction in 28 normotensive or prehypertensive study groups [$-3.9$ ($-6.4$; $-1.2$)/$-3.9$ ($-5.6$; $-2.2$) mm Hg], whereas the reduction [$-4.1$ ($-0.63$; $+1.4$)/$-1.5$ ($-3.4$; $+0.40$) mm Hg] was not significant for the 5 hypertensive study groups. When study groups were divided according to the mode of training, isometric handgrip training in 3 groups resulted in a larger decrease in blood pressure [$-13.5$ ($-16.5$; $-10.5$)/$-6.1$($-8.3$; $-3.9$) mm Hg] than dynamic resistance training in 30 groups [$-2.8$ ($-4.3$; $-1.3$)/$-2.7$ ($-3.8$; $-1.7$) mm Hg]. After dynamic resistance training, $V_{O_2}$ peak increased by 10.6% ($P=0.01$), whereas body fat and plasma triglycerides decreased by 0.6% ($P<0.01$) and 0.11 mmol/L ($P<0.05$), respectively. No significant effect could be observed on other blood lipids and fasting blood glucose. This meta-analysis supports the blood pressure–lowering potential of dynamic resistance training and isometric handgrip training. In addition, dynamic resistance training also favorably affects some other cardiovascular risk factors. Our results further suggest that isometric handgrip training may be more effective for reducing blood pressure than dynamic resistance training. However, given the small amount of isometric studies available, additional studies are warranted to confirm this finding. (*Hypertension*. 2011;58:950-958.) ● Online Data Supplement

**Key Words:** resistance ■ exercise ■ blood pressure ■ risk factors ■ lipids

H igh blood pressure (BP) is 1 of the 9 leading risk factors influencing the global burden of cardiovascular disease[1] and is estimated to lead to >7 million deaths each year, that is, about 13% of the total deaths worldwide.[2] Data from observational studies in healthy individuals show a direct, strong, independent, and continuous relation between BP and cardiovascular morbidity and mortality without any evidence of a threshold down to at least 115/75 mm Hg.[3] Therefore, adequate control of BP is important for public health. Lowering of BP and prevention of hypertension is in first instance preferable by lifestyle changes. These include weight loss, moderation of alcohol intake, a diet with increased fresh fruit and vegetables, reduced saturated fat, reduced salt intake, and, finally, increased physical activity.[2,4] With regard to the latter, former guidelines predominantly recommended aerobic exercises such as walking, jogging, and cycling for lowering BP. Nowadays, aside from the well-documented effects of resistance training (RT) for the maintenance of

functional capacity and prevention of sarcopenia and osteoporosis, a body of research is emerging that shows that RT may also beneficially affect metabolic health.[5] This information may be important because it effectively highlights an underappreciated aspect of RT. Therefore, both the American Heart Association and the American College of Sports Medicine have endorsed the inclusion of RT as an integral part of an exercise program for promoting health and preventing cardiovascular disease.[5,6] However, contrary to endurance training, evidence for a BP-lowering effect of RT remains scarce and much less compelling. Whereas the most recent meta-analysis on the effect of RT, published in 2005, already suggested that moderate RT could become part of the nonpharmacological intervention strategy to prevent and decrease high BP, this conclusion was based on only 9 randomized, controlled trials, involving 12 study groups.[7] Further, these trials have generally been small and often of questionable methodological quality. Since then, the number

of eligible trials has substantially increased, which should allow a more precise estimate of the overall effect of RT.

To date, the importance of the role of each of the different RT characteristics has not yet been determined. This is, however, of clinical importance if we aim to adequately prescribe RT for the control of BP.

Finally, previous meta-analyses have not reported outcomes for other cardiovascular risk factors. However, BP control should be integrated in the management of total cardiovascular risk.[4] This concept is based on the fact that only a small fraction of the hypertensive population has an elevation of BP alone, with the great majority exhibiting additional risk factors,[8,9] with a relationship between the severity of the BP elevation and that of alterations in glucose and lipid metabolism.[10] Therefore, it is of interest to assess to what extent one potential BP lowering tool, such as RT, may also concomitantly influence other major cardiovascular risk factors.

Thus, the aims of this study were (1) to update the meta-analysis of the effect of RT on BP; (2) to assess a potential relation between different RT characteristics and the BP response; and (3) to examine the simultaneous effect of RT on other cardiovascular risk factors.

## Methods

### Data Sources and Study Selection

We updated our database of randomized, controlled trials on the effect of RT on BP, which was started in 2004.[7] Computerized literature searches of MEDLINE, PubMed, SPORTDiscus, and EMBASE databases, from their inception to June 2010, were undertaken. Search terms used were "blood pressure," "isometric," "resistance," "resistive," "eccentric," "strength," "weight," "training," and "exercise." These terms were used in different combinations with each other. In addition, we reviewed the reference lists of the original articles and reviews on the topic to identify other possible eligible trials. The inclusion criteria for this meta-analysis were as follows: (1) randomized, controlled trials involving RT of at least 4 weeks' duration as the sole intervention; (2) participants were normotensive and/or hypertensive adults (age ≥18 years) with no other concomitant disease; (3) resting systolic and/or diastolic BP were available; and finally, (4) the article was published in a peer-reviewed journal up to June 2010.

### Data Extraction and Assessment of Study Quality

Data on study source, study design, study quality, sample size, characteristics of participants and exercise programs, details on BP measurement, and the outcomes of the interventions were extracted by 1 reviewer using a specific developed data extraction sheet and checked by an independent reviewer; disagreements were resolved by discussion. The primary outcome was resting BP; secondary outcomes included anthropometrics, data on exercise tolerance, data on blood lipids, and glucose.

Study quality was assessed using a 3-item questionnaire designed to collect data on random assignment, blinding, and withdrawals/dropouts.[11] All questions were bipolar (yes, 1; or no response, 0). The minimum number of points possible was 0 and the maximum was 5, with a higher number reflecting a greater study quality. However, we customized these criteria regarding blinding requirements; that is, we regarded blinding of participants as not applicable to exercise interventions and used blinding of outcome assessment as a quality criterion instead. BP measurements using an automated, semiautomated or random-zero device were also considered as blinded measurements. Study quality was independently assessed by 2 reviewers. Because there was complete agreement between both

reviewers regarding quality assessment, a κ-statistic was not calculated.

### Statistical Analyses

Statistical analyses were performed using SAS version 9.1 (SAS Institute, Inc) and Review Manager Software (RevMan 5.0; Cochrane Collaboration, Oxford, United Kingdom). Descriptive data of treatment groups and participants are reported as the mean±standard deviation (SD) or median and range. Treatment effects were calculated by subtracting the preexercise value from the postexercise value (post-pre) for both the exercise (Δ1) and control groups (Δ2). The net treatment effect was then obtained as Δ1 minus Δ2. Review Manager Software calculated the variances from the inserted pooled standard deviations of change scores in the exercise and control groups. However, the majority of studies included in this meta-analysis reported only the SDs for the baseline and postintervention, or the standard errors of the mean. Therefore, change scores SDs that were missing in these studies were calculated from pre- and post-SD values, using the following formula: $SDchange = \sqrt{[(SDpre)^2 + (SDpost)^2 - 2 \times corr(pre, post) \times SDpre \times SDpost]}$, for which we assumed a correlation coefficient of 0.5 between the initial and final values.[12] The results were combined using fixed-effect models and presented with 95% confidence limits (CL). When there was evidence of heterogeneity, a random-effects model was applied. Because the variance of the net changes in BP for the diverse study groups had to be calculated on the basis of several assumptions, the overall effect size of training on BP was also calculated by weighting for the number of analyzable subjects allocated to each training group, which is more traditional. Secondary outcomes were only assessed by weighting for the number of trained participants. Two-sided tests for overall effects were considered significant at $P \leq 0.05$. Statistical heterogeneity among the studies was assessed using the Cochran Q statistic. Probability values were obtained by comparing the Q statistic with a $\chi^2$ distribution and $k-1$ degrees of freedom. A probability value $\leq 0.05$ indicated significant heterogeneity. However, because heterogeneity is to a certain extent inevitable in meta-analytic research, and even more so with regard to exercise trials, there is ample debate regarding the utility of assigning statistical significance to this computation. Thus we also reported the $I^2$ statistic,[13] which assesses consistency of treatment effects across trials; $I^2 > 50\%$ was used as the cutoff for significant heterogeneity.

Using stratified meta-analyses, we tested 5 a priori hypotheses that there may be differences in the effect of dynamic RT on BP across particular subgroups: BP group (optimal BP, prehypertension, hypertension), trial quality (≤2 versus >2), year of publication (2003 or earlier versus later than 2003), age of participants at baseline (≤50 years versus >50 years), and duration of intervention (<16 versus ≥16 weeks). In addition, single-weighted metaregression analyses were performed to assess whether variations in the response of BP may be related to variations in different training program characteristics.

Finally, funnel plots were used to assess the potential of small publication bias.

## Results

### Characteristics of the Participants and Study Designs

We identified 28 trials that fulfilled the inclusion criteria.[14–41] Some of these trials involved several groups of individuals[16] or applied different training regimens,[19,21,26,36] so that a total of 33 study groups were available for analysis. A general description of each trial is shown in online Supplement Table S1 (please see http://hyper.ahajournals.org). The trials were conducted between 1987 and June 2010 and were all of parallel design with a nontraining control group. Trial quality was poorly reported. Only 4 trials[21,23,27,33] (14%) provided details on random assignment, with only 1[27] of them reporting

**Figure 1.** Average net changes in systolic blood pressure and corresponding 95% confidence limits in 28 randomized, controlled trials involving 33 study groups. The overall effect represents a pooled estimate obtained by summing the average net change for each trial, weighted by the inverse of its variance. Open squares represent optimal blood pressure study groups; half-closed squares represent prehypertensive study groups; closed squares represent hypertensive study groups.

some details of concealment. Blinding of outcome assessment was performed in 19 trials (68%), but no more than 3 trials[24,28,36] (10%) specifically reported that the observers were blinded to treatment allocation. The median Jadad score was 2 (range, 1–4). Sample size of the trials at baseline ranged from 15 to 143 participants (median, 30), totaling 1124 participants. Median dropout percentage was 3.3% (range, 0–37), so that a total of 1012 participants were available for final analysis. Mean age ranged from 19 to 84 years (median, 53.6) and the percentage of men from 0% to 100% (median, 35). Average baseline resting BP ranged from 103.2 to 154.1 mm Hg (mean, 126.0) for systolic BP (SBP) and from 59.3 to 95.1 mm Hg (mean, 74.5) for diastolic BP (DBP). Based on the average baseline BP, 13 study groups included individuals with optimal BP (SBP <120 mm Hg and

DBP <80 mm Hg), 15 study groups involved prehypertensive participants (120 mm Hg ≤SBP ≤139 mm Hg and/or 80 ≤DBP ≤89 mm Hg), and 5 training interventions were performed in hypertensive patients (SBP ≥140 mm Hg and/or DBP ≥90 mm Hg) (see online Data Supplement Table S1). None of the participants with optimal BP was on antihypertensive treatment, whereas a total of 8 prehypertensive participants used antihypertensive treatment.[34,35] However, the use of antihypertensive treatment was not reported in 3 trials,[15,26,36] 4 trials,[21,28,38,39] and 1[14] trial of patients with optimal BP, prehypertension, or hypertension, respectively.

According to the type of muscle contraction, RT could be divided into 2 major subgroups: "dynamic" versus "static or isometric" RT. Dynamic RT involves concentric and/or eccentric contractions of muscles while both the length and
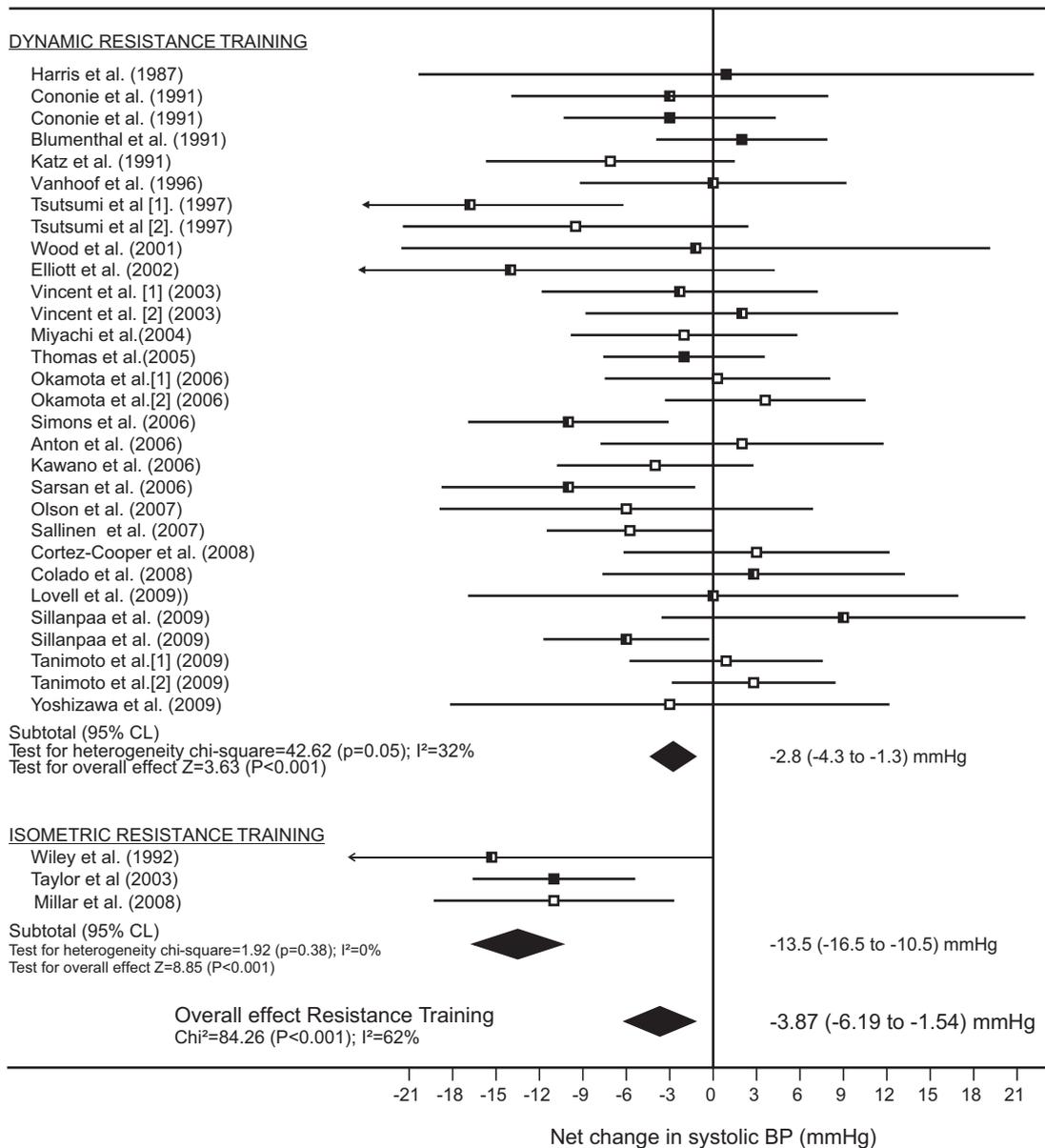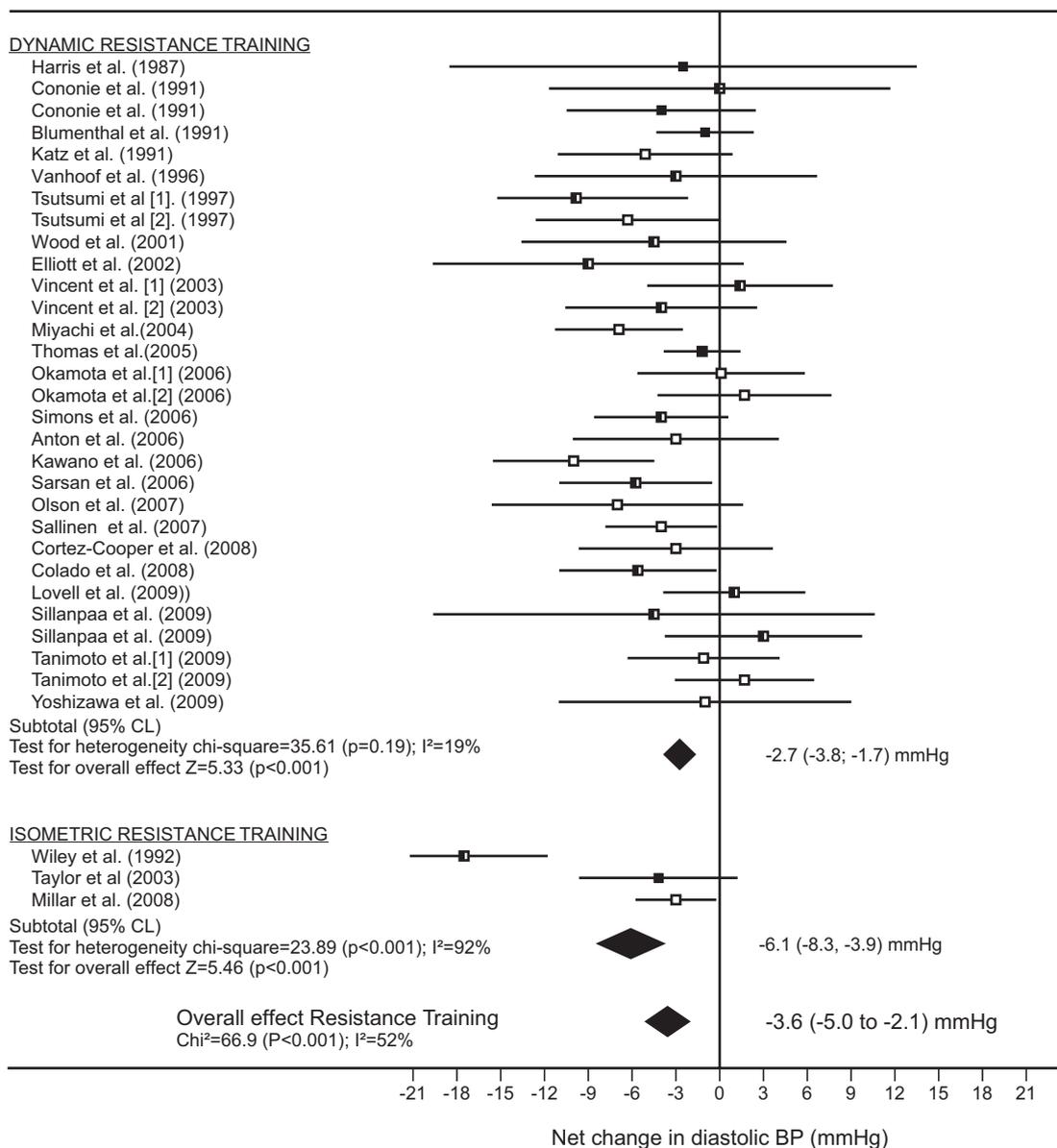
**Figure 2.** Average net changes in diastolic blood pressure and corresponding 95% confidence limits in 28 randomized controlled trials involving 33 study groups. The overall effect represents a pooled estimate obtained by summing the average net change for each trial, weighted by the inverse of its variance. Open squares represent optimal blood pressure study groups; half-closed squares represent prehypertensive study groups; closed squares represent hypertensive study groups.

the tension of the muscles change. Static exertion involves sustained contraction against an immovable load or resistance with no change in length of the involved muscle group. Twenty-five trials evaluated the effect of dynamic RT on BP, whereas the remaining 3[39–41] examined the effect of isometric RT. The duration of the interventions ranged from 6 to 52 weeks (median, 16) in the dynamic RT groups and varied between 8 and 10 weeks (median, 8) for the 3 isometric groups. Irrespective of training mode, the median frequency of exercise was 3 sessions per week, with a range from 2 to 3 sessions weekly. Average training intensity was between 30% and 100% of 1 repetition maximum (1RM) (median, 76) and between 30% to 40% of 1 maximal volitional contraction (median, 30), for dynamic resistance and isometric RT, respectively.

Among the dynamic RT groups, 27 reported using weight or RT machines to train the muscles of upper and/or lower body, 2 reported the use of dynabands,[23,32] whereas 1 did not provide information on the mode of dynamic RT.[16] At the end of the intervention program, the maximal number of sets per exercise session for each individual muscle ranged from 1 to 6 (median, 3), whereas the number of exercises performed ranged from 1 to 14 (median, 8). Finally, the number of repetitions performed for each set ranged from 6 to 30, but because most studies reported the range for the total number of repetitions performed, we were unable to calculate a median value.

Isometric handgrip training (IHGT) was the only mode of training among the isometric training groups and involved 4×2-minute bilateral[40,41] or unilateral contractions,[39] with a rest period of 3, respectively, 1 minute between contractions.

For the studies that reported data, exercise was performed exclusively in a supervised setting in 22 trials and comprised

**Table 1.  Baseline Data for the Training Groups and Weighted Net Changes in Response to Resistance Training**

| Variable | n | Baseline Mean (95% CL) | Net Change Mean (95% CL) | P Value |
|---|---|---|---|---|
| VO$_2$ peak, mL/kg per min | 8 | 27.4 (22.1; 32.7) | +2.7 (+0.81; +4.6) | <0.05 |
| Resting heart rate, bpm | 18 | 67 (64; 71) | +0.019 (−1.5; +1.6) | NS |
| Body fat, % | 12 | 30.2 (25.7; 34.7) | −0.55 (−0.91; −0.19) | <0.01 |
| Body mass index, kg/m$^2$ | 16 | 26.1 (24.5; 27.7) | −0.046 (−0.37; +0.28) | NS |
| Weight, kg | 17 | 70.7 (65.3; 76.1) | −0.053 (−0.96; +0.85) | NS |
| SBP, mm Hg | | | | |
|   All study groups | 33 | 125.6 (120.9; 130.3) | −3.5 (−5.6; −1.3) | <0.01 |
|   Dynamic resistance | 30 | 124.4 (119.7; 129.2) | −2.6 (−4.7; −0.53) | 0.015 |
|   Isometric handgrip | 3 | 131.6 (90.4; 172.8) | −11.8 (−17.0; −6.7) | 0.01 |
| DBP, mm Hg | | | | |
|   All study groups | 33 | 74.7 (71.4; 78.1) | −3.2 (−4.4; −1.9) | <0.001 |
|   Dynamic resistance | 30 | 74.3 (70.7; 77.8) | −3.1 (−4.4; −1.9) | <0.001 |
|   Isometric hangrip | 3 | 75.7 (54.0; 97.5) | −5.8 (−21.6; +10.0) | NS |
| Total cholesterol, mmol/L | 11 | 5.2 (4.9; 5.6) | −0.075 (−0.21; +0.061) | NS |
| HDL, mmol/L | 11 | 1.5 (1.3; 1.7) | +0.0062 (−0.053; +0.065) | NS |
| LDL, mmol/L | 11 | 3.2 (2.9; 3.6) | −0.082 (−2.3; +0.084) | NS |
| Triglycerides, mmol/L | 10 | 1.1 (0.94; 1.3) | −0.15 (−0.22; −0.065) | <0.01 |
| Glucose, mmol/L | 8 | 5.0 (4.7; 5.4) | −0.001 (−0.14; +0.14) | NS |

CL indicates confidence limit; VO$_2$ peak, peak oxygen consumption; SBP, systolic blood pressure; DBP, diastolic blood pressure; HDL, high-density lipoprotein cholesterol; LDL, low-density lipoprotein cholesterol; NS, not significant; n=number of study groups.

All values are reported as weighted mean (95% CLs), weighted for the number of trained participants.

supervised and home-based exercise in another trial[41]; there was no information on supervision in 5 trials.[20,21,36,39,40] Further, Olson[29] reported that supervised sessions were provided during the first 16 weeks only.

In the majority of the trials, participants in the control group were only instructed not to modify their usual lifestyle, including nutrition and physical activity. However, 5 trials reported that they tried to control for placebo effect by having control participants engage in weekly one-on-one 10-minute discussion sessions related to hypertension,[41] organizing stretching exercise sessions 3 times per week[24,31] or performing BP measurements in the participants thrice weekly.[17,39] In addition, in 2 other trials,[15,20] control subjects received monthly phone calls to check on lifestyle, 1 trial organized 6 1-hour health lectures every 3 weeks for the control participants,[28] and 1 trial had control subjects fill in a questionnaire halfway through the study period.[18]

### Assessment of Resting BP
BP measurements in the sitting and supine position were used in, respectively, 15 and 11 trials, whereas 2 trials did not report the position. Measurements were performed using a conventional sphygmomanometer (n=9); a random-zero device (n=2); a semiautomated (n=3) or an automated device (n=11); and was not reported in 3 studies. Only 2 trials measured 24-hour ambulatory BP.[15,18] The time between the last training session and the BP measurement was reported for 9 trials and amounted to between 20 to 24 hours in 2 trials,[22,25] at least 24 hours in 3 trials,[16,21,24] a minimum of 2

days in 3 trials,[29,37,38] and between 4 and 5 days in another trial.[36]

### Changes in BP
Figures 1 and 2 provide forest plots of the main effects for SBP and DBP, as well as CL for all 33 study groups. Overall, RT induced a significant decrease of BP ($P<0.01$), with a mean reduction of 3.9 (95% CL, −6.2; −1.5)/3.6 (95% CL, −5.0; −2.1) mm Hg. A random-effect model was chosen owing to the significant heterogeneity between the studies ($P<0.001$ for both, $I^2=62\%$ for SBP and $I^2=52\%$ for DBP). By excluding the 3 isometric studies, the 30 dynamic RT groups showed homogeneity, with a heterogeneity probability value ≥0.05 and $I^2<35\%$. The effect sizes became smaller at −2.7 (−4.6; −0.78)/−2.9(−4.1; −1.7) mm Hg using a random-effect model and −2.8 (−4.3; −1.3)/−2.7 (−3.8; −1.7) using a fixed-effect model. By contrast, IHGT resulted in a larger BP reduction of 13.5 (−16.5; −10.5)/7.8 (−16.3; +0.62) mm Hg using a random-effect model and a reduction of 13.5 (−16.5; −10.5)/6.1 (−8.3; −3.9) using a fixed-effect model. When we weighted for the number of analyzable individuals allocated to each training group, results were similar (Table 1).

### Changes in Secondary Outcomes
Table 1 shows the overall net changes for secondary outcomes in response to dynamic RT, after weighting for the number of trained participants. Peak oxygen uptake increased by 10.6% (+2.6; +18.6) in the 8 trials in which it was

**Table 2.  Subgroup Analyses for the Effect of Dynamic Resistance Training on Resting BP**

| Characteristic | Systolic BP, mm Hg | | Diastolic BP, mm Hg | |
|---|---|---|---|---|
| | n | Effect Size (95% CL) | n | Effect Size (95% CL) |
| Hypertensive status | | | | |
| Optimal BP | 12 | −1.2 (−3.5; +1.0) | 12 | −3.2 (−5.4; −0.92) |
| Prehypertension | 14 | −4.7 (−7.8; −1.6) | 14 | −3.2 (−5.0; −1.4) |
| Hypertension | 4 | −1.7 (−5.5; +2.0) | 4 | −1.1 (−3.1; +0.91) |
| Age at baseline | | | | |
| ≤50 y | 18 | −4.2 (−6.3; −2.1) | 18 | −2.8 (−4.4; −1.2) |
| >50 y | 12 | −1.2 (−3.4; +0.9) | 12 | −2.7 (−4.0; −1.4) |
| Duration of intervention | | | | |
| <16 wk | 14 | −2.1 (−4.5; +0.23) | 14 | −2.2 (−4.1; −0.22) |
| ≥16 wk | 16 | −3.2 (−5.1; −1.3) | 16 | −3.2 (−4.7; −1.7) |
| Study quality | | | | |
| ≤2 | 14 | −2.1 (−4.2; +0.09) | 14 | −3.9 (−5.5; −2.3) |
| >2 | 16 | −3.5 (−5.6; −1.4) | 16 | −2.6 (−3.7; −1.5) |
| Year of publication | | | | |
| 2003 or earlier | 12 | −3.1 (−6.0; −0.28) | 18 | −3.3 (−5.2; −1.4) |
| Later than 2003 | 18 | −2.6 (−4.4; −0.87) | 11 | −2.6 (−3.7; −1.4) |

BP indicates blood pressure; CL, confidence limit; n=number of study groups.

Overall effect sizes, pooled using fixed effect models, and 95% CLs for the effect of dynamic resistance training on systolic BP and diastolic BP in different subgroups.

measured, whereas resting heart rate remained unaltered ($P>0.05$). Changes in weight, body mass index, and percentage of body fat were reported in 17, 15, and 12 study groups, respectively. Whereas weight and body mass index remained unchanged after dynamic RT ($P>0.05$ for both), percentage of body fat decreased ($P<0.01$). In addition, dynamic RT significantly decreased plasma triglycerides ($P<0.05$), whereas total cholesterol, LDL cholesterol, HDL cholesterol, and fasting blood glucose remained unchanged.

## Subgroup Analyses and Metaregression

Stratified meta-analyses showed that the effect of dynamic RT on BP may vary between the different subgroups (Table 2). The overlap in 95% confidence intervals of each within-stratum comparison suggests, however, that none of these subgroup differences were statistically significant. In addition, weighted single metaregression analysis did not show any significant relationship for net changes in SBP ($r=0.048$; $P=0.82$) or DBP ($r=0.12$; $P=0.57$) and training intensity. Further, changes in BP were also not significantly related tot the weekly training frequency, number of sets, number of repetitions, duration of the intervention, the number of exercises per session, or the total volume of exercise (frequency×sets×repetitions×number of exercises) ($P>0.10$ for all).

## Publication Bias

As shown in Figure 3, the funnel plots with respect to the effect size changes in SBP and DBP in response to RT in general, and isometric and dynamic RT in particular appeared to be reasonably symmetrical and do not seem to suggest the presence of study bias, except for the changes in DBP in response to IHGT.

## Discussion

The findings of this meta-analysis suggest that both moderate-intensity dynamic RT and low-intensity isometric RT may cause a reduction in SBP and DBP. Variances in training characteristics did not explain the divergent BP response among dynamic RT studies. Dynamic RT also



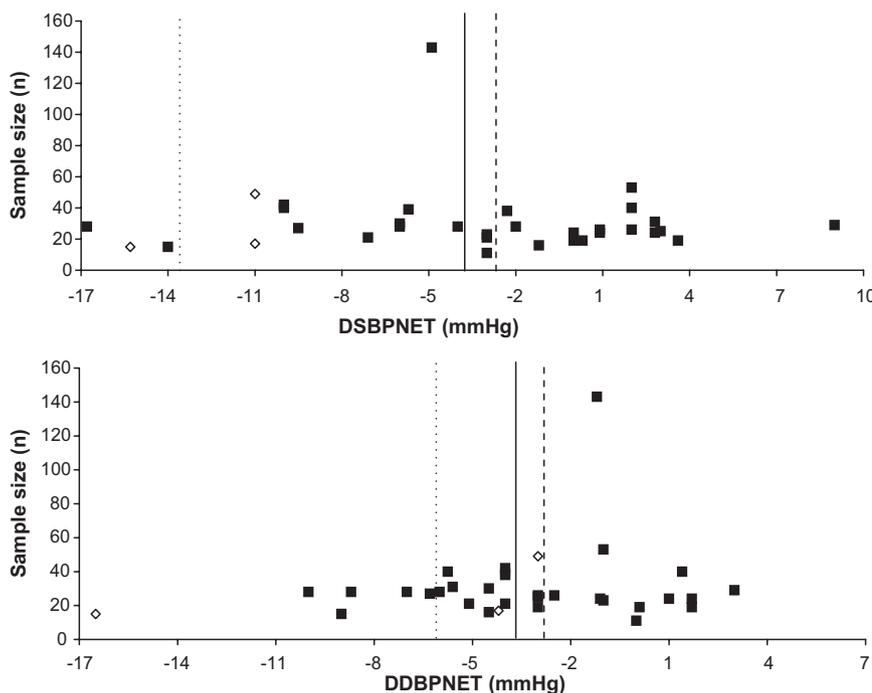**Figure 3.** Funnel plots of net changes and 95% confidence limits in systolic blood pressure (top) and diastolic blood pressure (bottom) versus sample size in 33 study groups. Mean blood pressure change (vertical line) was weighted for the inverse of the variance. Dotted line: Mean net change for isometric RT; dashed line: mean net change for dynamic RT; full line: mean net change for all RT groups.

favorably affects some other cardiovascular risk factors such as an increase in peak $V_{O_2}$ and a reduction in body fat and plasma triglycerides.

In line with previous meta-analyses, our results confirm that both dynamic RT[7,42] and static RT[43,44] have a beneficial effect on BP in subjects with optimal pressure and/or prehypertension. The clinical importance of these BP reductions can be estimated from large, prospective intervention studies investigating morbidity and mortality outcomes that suggest that small reductions in resting SBP and DBP of 3 mm Hg can reduce coronary heart disease risk by 5%, stroke by 8%, and all-cause mortality by 4%.[3,45,46] Moreover, given that the association between BP and cardiovascular risk has no lower threshold, reductions of this magnitude in individuals with even optimal BP at baseline still seem to have clinical significance.[2] This underlines the potential of RT as adjuvant therapy for the prevention and treatment of high BP. It is, however, noteworthy that although not significantly different from the results in normotensive individuals, the reductions in BP were not statistically significant in hypertensive participants. This contrasts with the significantly larger BP reduction that has been observed after endurance training in hypertensive subjects compared with normotensive individuals.[47] However, only 4[14–16,23] of the 30 dynamic resistance study groups involved hypertensive patients; therefore, more research on the effect of RT is definitively needed in hypertensive populations. Until then, some caution is warranted when prescribing RT for hypertensive individuals. Indeed, whereas none of the studies reported a serious adverse event in hypertensive participants as a result of the training intervention, acute intervention studies have shown that a single bout of resistance exercise may produce a pronounced rise in SBP,[48] which may represent a risk for hypertensive patients who are more prone to hemorrhage from cerebral aneurysms than are normotensive individuals.[48,49]

To prescribe RT as a potential tool in the control of BP, one should know how different training characteristics influence the BP response. With regard to the type of resistance exercise, reductions in resting SBP were somewhat more pronounced after IHGT compared with dynamic RT programs. The fact that there was no between trial heterogeneity among the 3 isometric training groups, at least for SBP, and the lack of publication bias suggest that the findings are more or less robust. Nevertheless, as previously suggested, the generalizability of these results is limited because only 3 isometric trials are available.[43,44] Randomized, controlled trials comparing the effect of dynamic and isometric RT programs are needed for confirmation. Improvements in BP were achieved over a broad range of exercise intensities, that is, 30% to 100% of 1RM. Individual studies comparing different training intensities within the same trial were inconclusive with regard to the effect of training intensity.[19,21,36] Therefore, we performed meta-regression analysis and found no relation between BP response and training intensity. This might partly be explained (1) by the fact that most study groups exercised at moderate intensity (60% to 80% of 1RM) and that only 6 exercise programs were performed at an intensity below 60% of 1RM or above 80% of 1RM, and (2)

by the variance in other training characteristics. Further, weekly training frequency, number of exercises, and sets and volume of exercise were also not significantly related to the reduction in SBP or DBP.

Previous meta-analyses that investigated the effect of RT have restricted their analyses to changes in BP. Whereas we included only those studies that reported on the effect of RT on BP, we also extracted data on other major cardiovascular risk factors. In addition to a decrease in BP, we observed a significant increase in peakVO$_2$ and significant decreases in body fat and plasma triglycerides after dynamic RT. Based on data of 33 studies, including 102 980 participants, Kodama et al recently concluded that a better physical fitness was associated with a lower risk of all-cause mortality and cardiovascular events and was independently associated with longevity.[50] According to their subsequent dose-response analyses, a 1-MET higher level of maximal aerobic capacity (ie, 3.5 mL O$_2$/kg per minute) was associated with 13% and 15% reductions, respectively, in risk of all-cause mortality and coronary heart disease/cardiovascular heart disease events.[50] In addition, although abdominal circumference was not measured, the decrease in fat mass by 0.6% suggests that dynamic RT improves 1 of the major risk factors for the metabolic syndrome.[51] The associated lack of a decrease in body weight probably reflects an increase in muscle mass, which is heavier than adipose tissue. There was also a significant lowering of plasma triglycerides but no effect on other blood lipids or fasting glucose. In an earlier meta-analysis, Kelley and Kelley showed that RT also reduces total cholesterol, LDL-cholesterol and triglycerides in adults.[52] However, given the normal baseline lipoprotein-lipid profiles, it might be that the training stimulus of the included RT studies in our meta-analysis was not high enough. That is, individuals with normal lipoprotein levels may require greater exercise stimulus and energy expenditure to further improve lipid profiles.[6]

The present results have to be interpreted within the context of their limitations. First of all, the poor methodological quality of many trials should be acknowledged. Although all the included studies were randomized, controlled trials, only a few provided details of the process of random assignment, allocation concealment, or blinding of outcome assessment. Moreover, the quality of trials did not appear to have improved over the last decade. Further, only 4 of the included studies were conducted in hypertensive individuals. There is an urgent need for randomized, controlled trials on the effect of RT in hypertensives, for whom it is of greater interest. Although there was no real evidence of publication bias, the inability to identify unpublished studies may have led to overestimation of effect of isometric exercise training on BP, and so caution is warranted with regard to the interpretation of these results. Again, future trials comparing the effect of isometric RT with dynamic RT and/or aerobic endurance training are warranted. The majority of the studies included in the current analysis inferred subject drop out from initial recruitment to postintervention testing. Analysis based on those who successfully completed the training intervention rather than an intention to treat approach can be considered a weakness in the exercise literature in general and RT in

particular. Therefore, it would seem plausible to suggest that future studies report the 2 types of analyses to examine both the efficacy and effectiveness of the training programs.

## Perspectives

Despite some limitations, this meta-analysis provides evidence for the potential of dynamic resistance exercise training to significantly decrease BP, increase peak $V_{O_2}$, and decrease body fat and plasma triglycerides. It further supports the efficacy of IHGT in the management of high BP. However, it also underlines the scarcity of data with regard to the effect of dynamic RT in hypertensives and the effect of isometric RT in general and stresses the need for large, randomized, controlled trials investigating the effect of dynamic and isometric RT on BP and other cardiovascular risk factors and BP-regulating mechanisms that can help us to understand their BP-lowering effect.

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## Disclosure

None.

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# THE IMPACT OF RESISTANCE TRAINING ON BLOOD PRESSURE AND OTHER CARDIOVASCULAR RISK FACTORS: A META-ANALYSIS OF RANDOMIZED CONTROLLED TRIALS

**Short Title: Resistance training and blood pressure**

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**TABLE S1** General Characteristics of included resistance training trials.

| First Author (year) | Origin | Quality | Participants included in analysis | Exercise intervention |
|---|---|---|---|---|
| **DYNAMIC RESISTANCE TRAINING** | | | | |
| Harris et al.[1] (1987) | USA | 2 | 26 hypertensive men randomized to exercise (n=10, age=32.7±5.2 yrs) or control (n=16; age= 31.4±6.2 yrs) | 9 weeks of supervised circuit weight training, 3 sessions per week, 40% of 1RM, 10 exercises, 3 sets/exercise, 20-25 reps/set |
| Blumenthal et al[2] (1991) | USA | 3 | 33 hypertensive men and 20 hypertensive women randomized to exercise (n=31, age=46±7 yrs) and control (n=22, age 45.7±7.8 yrs) | 16 weeks of circuit weight training, 2-3 sessions per week, 30 minutes/session |
| Cononie et al[3] (1991) | USA | 2 | 15 men and 17 women (age 72+2.6 yrs) randomized to an exercise (n=14 prehypertensives and 6 hypertensives) and control group (n=7 prehypertensives and 5 hypertensives) | 6 months of supervised resistance training on Nautilus machines, 10 exercises, 3 sessions/week, 8-12 RM, 1 set/exercise, 12 reps/set |
| Katz et al[4] (1992) | USA | 1 | 26 women with optimal BP randomized to an exercise (n=13, age 22) and control (n=13, age 18.8 yrs) group | 6 weeks of resistance training on Nautilus exercise machines, 3 sessions per week, 30% of 1RM, 13 exercise, 1 set/exercise, 14-15 reps/set for LB, 11-12 reps/set for UB |
| Vanhoof et al[5] (1996) | Belgium | 3 | 19 prehypertensive men randomized to an exercise (n=8, age 38) and control (n=11, age=38 yrs) group | 16 weeks of supervised strength training on multigym, 3 sessions/week, 70-90% of 1RM, 6 exercises, 3 sets/exercise, 10 reps/set |
| Tsutsumi et al[6] (1997) | USA | 2 | 33 men and 8 women with optimal BP or prehypertension randomized to EXH (n=13, age 67.8+4.9), EXL(n=14, age 68.9±7.5yrs) or control group (n=14, age (69.8±4.6yrs) | 12 weeks of supervised strength training by using dynamic variable resistance weight machines involving 11 exercises, 3 sessions/week, 2 sets/exercise, 75-85% of 1RM (EXH), 8-12 reps/set (EXH), 55-65% of 1RM (EXL), 12-16 reps/set (EXL), 2 sets/exercise |
| Wood et al[7] (2001) | USA | 2 | 8 prehypertensive men and 8 prehypertensive women randomized to exercise (n=10; 69.8±6yrs)and control (n=9; age 68±5.4yrs) group | 12 weeks of resistance training using Med-X brand devices, 3 sessions/week, 8 exercises, 8-12 RM, 2 sets/exercise |

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| Elliott et al[8] (2002) | UK | 3 | 15 postmenopausal women randomized to exercise (n=8) or control group (n=7) | 8 weeks of supervised resistance training using 5 weight machines, 3 sessions/week, 3 sets/exercise, 8 reps/set, 80% of 10RM, 2 min rest between sets |
| Vincent et al[9] (2003) | USA | 3 | 28 prehypertensive men and 34 prehypertensive women randomized to EXL (n=24, age 67.6±6yrs) or EXH (n=22, age 66.6±7yrs) or control (n=16, age71±5yrs) | 6 months of resistance training using MedX resistance machines involving 13 exercises, 3 sessions/week, 1 set/exercise, 8 reps/ex (HEX), 13 reps/ex (LEX), 50% of 1RM LEX, 80% of 1RM (HEX) |
| Miyachi et al[10] (2004) | JAPAN | 2 | 28 men with optimal BP randomized to exercise (n=14, age 22±1yrs) and control (n=14, age 22±1yrs) | 16 weeks of supervised resistance training, 3 sessions/week, 8-12 exercises, 3 sets/exercise, 80% of 1RM, 12 reps/set for set 1 and 2, as many reps/set in set 3 |
| Thomas et al[11] (2005) | CHINA | 3 | 79 hypertensive men and 31 hypertensive women randomized to exercise (n=54; 69±3.2 yrs) and control (n=54, age 69±3yrs) | 52 weeks of resistance training using Theraband, 3 sessions/week, 7 exercises, 1 set/exercise, 30 repetitions/set |
| Anton et al[12] (2006) | USA | 2 | 7 men and 19 women with optimal BP randomized to exercise (n=13; 52±2 yrs) or control (n=13; 53±2 yrs) | 13 weeks of supervised resistance training involving 9 exercises, 75% of 1RM, 1 set, 12 reps/set. |
| Kawano et al[13] (2006) | JAPAN | 2 | 28 men with optimal BP randomized to exercise (n=12, age 20±1yrs) and control group (n=16, age 22±1yrs) | 4 months of supervised resistance training involving 14-16 exercises, 50% of 1RM, 3 sessions/week, 45 minutes/session, 3 sets/exercise, |
| Okamoto et al[14] (2006) | JAPAN | 3 | 29 women with optimal BP randomized to CRT (n=10, age 19.1+0.3), ERTn=10, age18.9+0.3) or control group (n=9; age 19.9+1.2) | 8 weeks of supervised ERT or CRT using arm curl, 3 sessions/week, 100% of 1RM (ERT), 80% of 1RM (CRT), 5 sets/exercise, 10 reps/set |
| Sarsan et al[15] (2006) | Turkey | 3 | 40 prehypertensive women randomized to exercise (n=20; 42.5±10.07)) and control (n=20, age = 43.6±6.46) | 12 weeks of supervised resistance training using a stationary exercise unit, 75-80% of 1RM, 3 sessions/week; 6 exercises, 3 sets/exercise, 10 reps/set |
| Simons et al[16] (2006) | USA | 3 | 9 prehypertensive men and 33 prehypertensive women randomized to exercise (n=21, age 84.6±4.5yrs) and control (n=21, age 84±3.3yrs) group | 16 weeks of supervised resistance training on Keiser machines, 2 sessions/week, 75% of 1RM, 6 exercises, one set/exercise, 10 reps/set |

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| Olson et al[17] (2007) | USA | 3 | 28 women with optimal BP randomized to exercise (n=16; age 39±5yrs) or control (n=12, age 38±6yrs) group | 52 weeks of resistance training on isotonic variable resistance machines and free weights (first 16 weeks: supervised, thereafter meeting twice every 12 weeks), 2 sessions/week, 3 sets, 8-10 reps/set |
| Sallinen et al[18] (2007 | FINLAND | 3 | 39 prehypertensive men randomized to exercise (n=20, age 57.9+6.1) or control (n=19, age 58.2+6.1) | 21 weeks of supervised whole body resistance training using 14 dynamic strength machines (David and Frapp), 2 sessions/week, 6 sets per exercise, 5-8 reps/set, 80% of 1RM |
| Cortez-Cooper et al[19] (2008) | USA | 2 | 25 men and women with optimal BP randomized to exercise (n=13, age52) or control (n=12, age 5) | 13 weeks of supervised whole body resistance training using 10 devices, 3 sessions/week, 1 set per exercise, 8-12 reps/set, 70% of 1RM |
| Colado et al[20] (2009) | SPAIN | 2 | 31 prehypertensive women randomized to exercise (n=21; age 54+2.8) and control (n=10, age 52.1+1.9) group | 24 weeks of supervised circuit resistance exercise using therabands, 3 sessions/week,8-16 exercise, 2 sets, 15-30 reps/set |
| Lovell et al[21] (2009) | Australia | 4 | 24 prehypertensive men randomized to exercise (n=12, age 74.1±2.7yrs) and control (n=12; age: 73.5±3.3yrs) | 16 weeks of supervised resistance exercise on incline squat machine, 70-90% of 1RM, 3 sessions/week, 1 exercise, 3 sets, 6-10 reps/set |
| Sillanpää et al[22] (2009) | FINLAND | 2 | 29 women with optimal BP randomized to exercise (n=17, age 50.8±7.9yrs) or control (n=12, age51.4±7.8yrs) | 21 weeks of supervised strength training, 2 sessions/week, 7-8 exercises ,70-90% of 1RM, 6-8 reps/set, 3-4 sets/exercise |
| Sillanpää et al[23] (2009) | FINLAND | 2 | 30 men with optimal BP randomized to exercise (n=15, 54.1±6 yrs) or control (n=15; 53.8±7.7yrs) | 21 weeks of supervised strength training, 2 sessions/week, 7-8 exercises ,70-90% of 1RM, 6-8 reps/set, 3-4 sets/exercise |
| Yoshizawa et al[24] (2009) | JAPAN | 3 | 23 women with optimal BP randomized to exercise (n=11; age 47+2) and control (n=12, age 49+3) | 12 weeks of resistance training using resistance devices, 60% of 1RM 2 sessions/week, 6 exercise, 3 sets/exercise, 10 reps/set |

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| Tanimoto et al[25] (2009) | JAPAN | 2 | 36 men with optimal BP randomized to LEX (n=12, age 19+0.2), HEX (n=12, age 19.5+0.1) or control group (n=12, age 19.8+0.2) | 13 weeks of resistance training consisting of 5 exercises, 8RM, 55-60% of 1RM with slow movement and tonic force generation and no relaxation phase(LEX), 89-90% of 1RM with normal speed (HEX), 3 sets/ex, 2 sessions/week |

**ISOMETRIC RESISTANCE TRAINING**

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| Wiley et al[26] (1992) | USA | 2 | 15 prehypertensive participants (20-35 yrs) randomized to exercise (n=8) or control group (n=7) | 8 weeks of isometric handgrip training, 4x2 min isometric contractions at 30% MVC using dominant arm and 3 min rest period between contractions, 3 sessions/week |
| Taylor et al[27] (2003) | CANADA | 1 | 17 hypertensive men and women randomized to exercise (n=9; age 69.3±6yrs ) or control group (n=8, age 64.2+5.5yrs) | 10 weeks of isometric handgrip training, 4x2min bilateral isometric contractions at 30% MVC, 1-min rest period between contractions, 3 sessions/week |
| Millar et al[28] (2008) | CANADA | 3 | 21 men and 28 women with optimal BP randomized to exercise (n=25, age 66±1yrs) and control group (n=24, age 67±2yrs) | 8 weeks of isometric handgrip training, 4x2 min bilateral isometric  contractions at 30-40% MVC,1-min rest period between contractions, 3 sessions/week |

Abbreviations: N, number of participants allocated to exercise or control group; LEX, low intensity exercise group; HEX, high intensity exercise group; BP, blood pressure; MVC, maximal voluntary contraction; RM, repetition maximum; reps, repetitions.