Isometric Exercise Training for Blood Pressure Management: A Systematic Review and Meta-analysis

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ORIGINAL ARTICLE

Isometric Exercise Training for Blood Pressure Management: A Systematic Review and Meta-analysis

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Abstract

Objective: To conduct a systematic review and meta-analysis quantifying the effects of isometric resistance training on the change in systolic blood pressure(SBP), diastolic blood pressure (DBP), and mean arterial pressure in subclinical populations and to examine whether the magnitude of change in SBP and DBP was different with respect to blood pressure classification.

Patients and Methods: We conducted a systematic review and meta-analysis of randomized controlled trials lasting 4 or more weeks that investigated the effects of isometric exercise on blood pressure in healthy adults (aged ≥18 years) and were published in a peer-reviewed journal. PubMed, CINAHL, and the Cochrane Central Register of Controlled Trials were searched for trials reported between January 1, 1966, and July 31, 2013. We included 9 randomized trials, 6 of which studied normotensive participants and 3 that studied hypertensive patients, that included a total of 223 participants (127 who underwent exercise training and 96 controls).

Results: The following reductions were observed after isometric exercise training: SBP—mean difference (MD), −6.77 mm Hg (95% CI, −7.93 to −5.62 mm Hg; $P<.001$); DBP—MD, −3.96 mm Hg (95% CI, −4.80 to −3.12 mm Hg; $P<.001$); and mean arterial pressure—MD, −3.94 mm Hg (95% CI, −4.73 to −3.16 mm Hg; $P<.001$). A slight reduction in resting heart rate was also observed (MD, −0.79 beats/min; 95% CI, −1.23 to −0.36 beats/min; $P=.003$).

Conclusion: Isometric resistance training lowers SBP, DBP, and mean arterial pressure. The magnitude of effect is larger than that previously reported in dynamic aerobic or resistance training. Our data suggest that this form of training has the potential to produce significant and clinically meaningful blood pressure reductions and could serve as an adjunctive exercise modality.

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Current National Health and Nutrition Examination Survey data suggest that the prevalence of hypertension varies with ethnicity and sex but is between 25% and 43% in the US population, with an upward trend noted over the past 3 surveys.[1] Hypertension, or the long-term elevation of resting arterial blood pressure (BP) above 140 mm Hg systolic (SBP) and/or 90 mm Hg diastolic (DBP) remains one of the most significant modifiable risk factors for cardiovascular disease (eg, coronary artery disease, stroke, heart failure).[2] In light of the prevalence of hypertension,[3] the associated economic health care costs are considerable. Additionally, although antihypertensive medications generally have minimal adverse effects, they are efficacious in perhaps 50% of those who are prescribed treatment.[4] Both national and international treatment guidelines for primary and secondary prevention of hypertension recommend nonpharmacological lifestyle modifications as the first line of therapy, including increasing levels of physical activity.[5] There is class I, level B evidence that 150 minutes of physical activity weekly offers an alternative that may be used to complement antihypertensive medication,[6] although the optimal exercise training prescription remains unclear.

One important factor that may impact the effectiveness to lower BP is the type of exercise performed. Recent analyses suggest that isometric exercise may elicit BP reductions greater than those seen with dynamic aerobic and resistance exercise.[7,8] Currently, dynamic aerobic endurance activity is the preferred exercise modality for BP management. Aerobic exercise often

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requires access to a gymnasium or suitable equipment; moreover, considerable energy expenditure is required to elicit BP reductions, which is also time-consuming. For these reasons, adherence to aerobic exercise is often suboptimal. Isometric exercise involves sustained contraction against an immovable load or resistance with no or minimal change in length of the involved muscle group. Low- to moderate-intensity isometric activity can be performed anywhere, requires relatively inexpensive equipment, and does not elicit the same level of cardiovascular stress (eg, rate-pressure product) as aerobic activity. Isometric activity has previously been associated with exaggerated hypertensive responses, but recent work has suggested that isometric handgrip activity may become a new tool in the nonpharmacological treatment of high BP.[9,10] Relative to aerobic activity, isometric exercise has the potential for superior adherence due to simplicity, lower cost, and perhaps less exercise time. Previous meta-analyses have examined the effects of endurance training,[11] dynamic resistance training,[12,13] and isometric resistance training[10] on BP. The findings revealed that isometric resistance exercise does lower BP; however, the sample sizes of the trials to date are generally small. Recently, several isometric exercise training trials have been reported that necessitate an updated analysis of data from randomized, controlled, and crossover trials.

The aims of this study were (1) to conduct a systematic review and meta-analysis quantifying the effects of isometric resistance training on the change in SBP, DBP, and mean arterial pressure (MAP) in subclinical populations and (2) to examine whether the magnitude of change in SBP and DBP was different with respect to BP classification.

PATIENTS AND METHODS

Search Strategy

Potential studies were identified by conducting a systematic search using PubMed for randomized controlled trials lasting 4 or more weeks that investigated the effects of isometric exercise on blood pressure in healthy adults (aged ≥18 years) and were published in a peer-reviewed journal between January 1. 1966, and July 31, 2013. The PubMed search strategy is presented in Supplemental Figure 1 (available online at http://www.mayoclinicproceedings.org). CINAHL and the Cochrane Central Register of Controlled Trials were also searched for the same period. The search strategy included the terms *hypertension*, *blood pressure*, *isometric exercise*, *isometric resistance training*, *physical training*, and *exercise training*. These terms were combined with a sensitive search strategy to identify randomized controlled and crossover trials. Reference lists of selected articles were scrutinized for new references. All identified articles were assessed independently by 2 reviewers (G.D. and D.J.C.), and a third reviewer (N.A.S.) was consulted to resolve disputes. The latest editions of relevant journals (through July 31, 2013) were also examined.

Study Selection

Randomized controlled trials and crossover studies of isometric exercise training in adults were included. There were no language restrictions. Animal studies, review articles, short-term exercise studies, and nonrandomized controlled trials were excluded. Studies that did not have any of the desired outcome measures or a sedentary control group were excluded. Several authors were contacted to provide missing data or to clarify whether data were duplicated in multiple publications. Incomplete data, or data from an already included study, were excluded. Studies using interventions other than pure isometric exercise (eg, aerobic or dynamic resistance exercise) were excluded.

Our initial search identified 1288 articles, and examination of the latest editions of relevant journals yielded 1 more article. Of the 1289 studies, 368 were excluded at first inspection as duplicates, 152 were removed after reading titles or abstracts, and 598 studies were not trials of isometric exercise therapy in adults, leaving 171 studies; 159 of the 171 studies were not randomized controlled trials with a duration of 4 weeks or longer, and 3 others were excluded because of data duplication, leaving 9 studies for analysis (Figure 1) that included 223 participants (127 who underwent exercise training and 96 controls).

Data Synthesis

Information on outcome measures was archived in a database. The outcome measures were SBP, DBP, MAP (which was calculated by adding DBP plus one-third pulse pressure), and resting heart rate (RHR).

Statistical Analyses

Meta-analyses were completed for continuous data by using the change in the mean and SD of outcome measures. It is an accepted practice to use only postintervention data for meta-analysis, but this method assumes that random allocation of participants always creates intervention groups matched at baseline for characteristics such as age and disease severity. Change in postintervention mean was calculated by subtracting baseline from postintervention values. Change in the SD of postintervention outcomes was calculated using the Review Manager (RevMan) computer program, version 5.0 (Nordic Cochrane Centre). Data required were: (1) 95% CI data for baseline-postintervention change for each group; (2) if 95% CI data were unavailable, we used actual *P* values for baseline-postintervention change for each group; and (3) if only the level of statistical significance was available, we tried to obtain precise *P* values (eg, $P=.034$) or 95% CIs from authors. We attempted when possible to obtain these precise data, but if these data were not forthcoming, we used default *P* values, eg, $P<.05$ becomes $P=.049$ and *P*=NS (not significant) becomes $P=.05$. A random effects inverse variance was used with the effects measure of MD. Heterogeneity was quantified using the Cochrane Q test.[14] Egger plots were provided to assess the risk of publication bias. Study quality was assessed using a modified Physiotherapy Evidence Database (PEDro) scale[15]

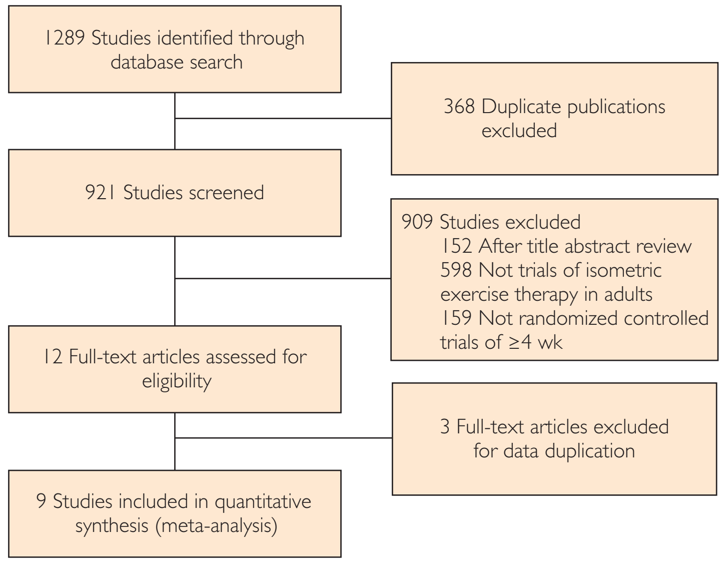

FIGURE 1. Flowchart of study selection.

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Study or subgroup	Isometric Mean	Isometric SD	Isometric Total	Control Mean	Control SD	Control Total	Weight (%)	Mean difference IV, fixed (95% CI)
Badrov et al,[16] 2013 Fem 3	−6	5.0308	12	2	1.6107	5	13.2	−8.00 (−11.18 to −4.82)
Badrov et al,[16] 2013 Fem 5	−6	6.2595	11	2	1.2569	4	8.7	−8.00 (−11.90 to −4.10)
Badrov et al,[17] 2013 Mixed	−8	4.973	12	1	12.4515	12	2.3	−9.00 (−16.59 to −1.41)
Baross et al,[18] 2013	−11	9.3945	10	−0.1	0.1398	10	3.9	−10.90 (−16.72 to −5.08)
Devereaux et al,[19] 2011	−4.9	3.4968	7	−0.1	2.3194	6	13.1	−4.80 (−7.99 to −1.61)
Millar et al,[20] 2008	−10	8.9835	25	−1	2.3682	24	10.0	−9.00 (−12.65 to −5.35)
Stiller-Moldovan et al,[21] 2012	−0.9	1.3397	11	2.5	3.2524	9	25.8	−3.40 (−5.67 to −1.13)
Taylor et al,[22] 2003	−19	11.2885	9	−8	5.5935	8	1.9	−11.00 (−19.33 to −2.67)
Wiles et al,[23] 2010 High c	−5.2	6.2402	11	2.9	2.7634	6	7.2	−8.10 (−12.40 to −3.80)
Wiles et al,[23] 2010 Low c	−3.7	4.8552	11	2.9	2.3356	5	10.7	−6.60 (−10.12 to −3.08)
Wiley et al,[24] 1992	−12.7	8.8797	8	2.6	2.8113	7	3.1	−15.30 (−21.80 to −8.80)
Total (95% CI)			**127**			**96**	**100.0**	**−6.77 (−7.93 to −5.62)**

Heterogeneity: $\chi^2=22.60$, $df=10$ ($P=.01$); $I^2=56\%$
Test for overall effect: $Z=11.52$ ($P<.001$)

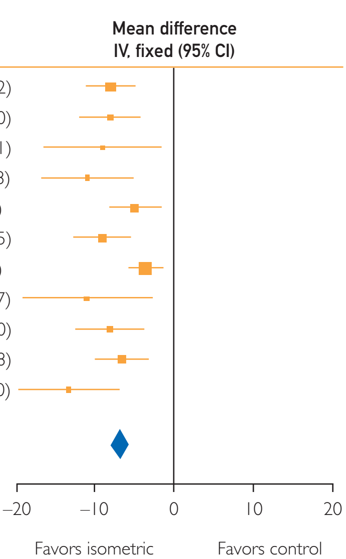

FIGURE 2. Change in systolic blood pressure (mm Hg) with isometric exercise. Percentages do not total 100 as a result of rounding. Fem 3 = group of females who exercised 3 times weekly; Fem 5 = group of females who exercised 5 times weekly; High c = high-intensity exercise; IV = inverse variance; Low c = low-intensity exercise; Mixed = mixed male/female study; Total = number of participants.

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Study or subgroup	Isometric Mean	Isometric SD	Isometric Total	Control Mean	Control SD	Control Total	Weight (%)	Mean difference IV, fixed (95% CI)
Badrov et al,[16] 2013 Fem 3	−3	4.7217	12	0.01	0.013	5	9.9	−3.01 (−5.68 to −0.34)
Badrov et al,[16] 2013 Fem 5	0.5	2.3697	11	0.5	1.3074	4	0.0	0.00 (−1.90 to 1.90)
Badrov et al,[17] 2013 Mixed	−5	5.5768	12	1	1.5739	12	6.5	−6.00 (−9.28 to −2.72)
Baross et al,[18] 2013	−2	2.7958	10	−0.1	0.1398	10	23.4	−1.90 (−3.63 to −0.17)
Devereaux et al,[19] 2011	−2.8	1.9982	7	1.3	1.7589	6	16.9	−4.10 (−6.14 to −2.06)
Millar et al,[20] 2008	−3	5.363	25	0.01	0.0237	24	15.9	−3.01 (−5.11 to −0.91)
Stiller-Moldovan et al,[21] 2012	−5	7.4426	11	0.1	0.1301	9	3.6	−5.10 (−9.50 to −0.70)
Taylor et al,[22] 2003	−7.3	9.4969	9	−3.1	3.708	8	1.6	−4.20 (−10.92 to 2.52)
Wiles et al,[23] 2010 High c	−2.6	3.1201	11	3.1	2.954	6	7.8	−5.70 (−8.70 to −2.70)
Wiles et al,[23] 2010 Low c	−2.5	3.2806	11	3.1	2.4966	5	8.2	−5.60 (−8.52 to −2.68)
Wiley et al,[24] 1992	−6.4	4.4748	8	1.6	1.73	7	6.2	−8.00 (−11.36 to −4.64)
Total (95% CI)			**116**			**92**	**100.0**	**−3.96 (−4.80 to −3.12)**

Heterogeneity: χ^2=16.53, *df*=9 (*P*=.06); I^2=46%
Test for overall effect: *Z*=9.26 (*P*<.001)

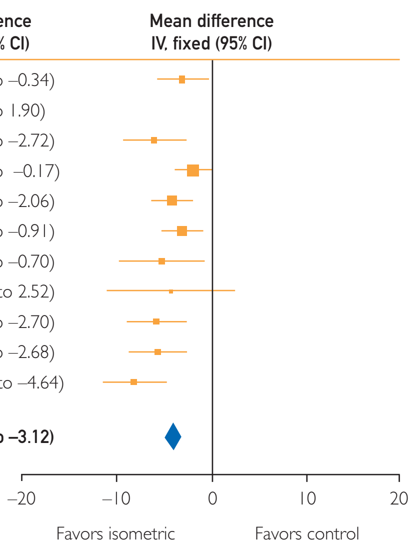

FIGURE 3. Change in diastolic blood pressure (mm Hg) with isometric exercise. Percentages do not total 100 as a result of rounding. Fem 3 = group of females who exercised 3 times weekly; Fem 5 = group of females who exercised 5 times weekly; High c = high-intensity exercise; IV = inverse variance; Low c = low-intensity exercise; Mixed = mixed male/female study; Total = number of participants.

score (0-9) because blinding is difficult in exercise training studies. Significance was considered at *P*<.05 with 95% CIs; figures were produced using RevMan 5.

RESULTS

Nine studies were included in our analysis,[16-24] with a total of 223 patients (Supplemental Table 1, available online at http://www.mayoclinicproceedings.org). Six studies used handgrip, and 3 studies used leg exercise. None of the studies reported any adverse events from isometric exercise. Four studies used automated BP measurements, 2 others collected waveform analyses, and 3 used auscultation, but methods were not otherwise standardized. Systolic blood pressure was significantly reduced in all participants, with an MD of −6.77 mm Hg (95% CI, −7.93 to −5.62 mm Hg; *P*<.001) (Figure 2). Hypertensive participants, who were all on medication, had a smaller reduction in SBP (MD, −4.31 mm Hg; 95% CI, −6.42 to −2.21 mm Hg; *P*<.001) than normotensive participants (MD, −7.83 mm Hg; 95% CI, −9.21 to −6.45 mm Hg; *P*<.001) (Supplemental Figures 2a and 2b, respectively; available online at http://www.mayoclinicproceedings.org).

Diastolic blood pressure was significantly reduced, with an MD of −3.96 mm Hg (95% CI, −4.80 to −3.12 mm Hg; *P*<.001) (Figure 3). Hypertensive participants had a larger reduction in DBP, with an MD of −5.48 mm Hg (95% CI, −7.93 to −3.03 mm Hg; *P*<.001) than normotensive participants (MD, −3.08 mm Hg; 95% CI, −3.88 to −2.27 mm Hg; *P*<.001) (Supplemental Figures 3a and 3b, respectively; available online at http://www.mayoclinicproceedings.org).

MAP was reduced, with an MD of −3.94 mm Hg (95% CI, −4.73 to −3.16 mm Hg; *P*<.001) (Figure 4). Medicated hypertensive participants had a larger reduction in MAP, with an MD of −6.01 mm Hg (95% CI, −8.04 to −3.97 mm Hg; *P*<.001) than normotensive participants (MD, −3.58 mm Hg; 95% CI, −4.43 to −2.73 mm Hg; *P*<.001) (Supplemental Figures 4a and 4b, respectively; available online at http://www.mayoclinicproceedings.org).

A slight reduction in RHR was noted, with an MD of −0.79 beats/min (95% CI, −1.23 to −0.36 beats/min; *P*=.003) (Figure 5).

Study Quality Assessment

The median modified PEDro score was 6 on a scale of 0 to 9. Five studies scored 6, 2 scored 5, and 2 scored 4 (Supplemental Table 2, available

Study or subgroup	Isometric Mean	Isometric SD	Isometric Total	Control Mean	Control SD	Control Total	Weight (%)	Mean difference IV, fixed (95% CI)
Badrov et al,[16] 2013 Fem 3	−4	6.2955	12	0.01	0.0081	5	4.9	−4.01 (−7.57 to −0.45)
Badrov et al,[16] 2013 Fem 5	−2	2.977	11	0.01	0.0063	4	19.9	−2.01 (−3.77 to −0.25)
Badrov et al,[17] 2013 Mixed	−6	3.7324	12	0.01	0.0157	12	13.8	−6.01 (−8.12 to −3.90)
Baross et al,[18] 2013	−5	4.8559	10	0.7	0.9785	10	6.5	−5.70 (−8.77 to −2.63)
Devereaux et al,[19] 2011	−2.6	1.1544	7	0.4	1.7031	6	23.8	−3.00 (−4.61 to −1.39)
Taylor et al,[22] 2003	−11	9.7952	9	−5	5.9807	8	1.1	−6.00 (−13.62 to 1.62)
Wiles et al,[23] 2010 High c	−2.5	2.3073	11	2	1.9058	6	14.7	−4.50 (−6.55 to −2.45)
Wiles et al,[23] 2010 Low c	−2.6	2.3996	11	2	1.6107	5	15.4	−4.60 (−6.60 to −2.60)
Total (95% CI)			**83**			**56**	**100.0**	**−3.94 (−4.73 to −3.16)**

Heterogeneity: χ^2=11.88, *df*=7 (*P*=.10); I^2=41%
Test for overall effect: *Z*=9.85 (*P*<.001)

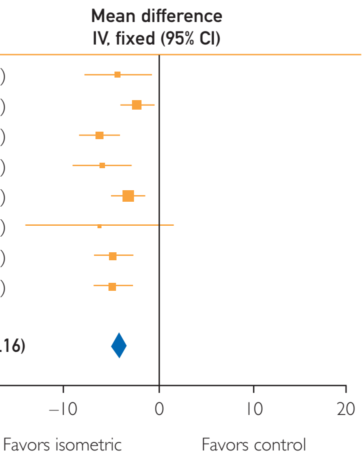

FIGURE 4. Change in mean arterial blood pressure (mm Hg) with isometric exercise. Percentages do not total 100 as a result of rounding. Fem 3 = group of females who exercised 3 times weekly; Fem 5 = group of females who exercised 5 times weekly; High c = high-intensity exercise; IV = inverse variance; Low c = low-intensity exercise; Mixed = mixed male/female study; Total = number of participants.

online at http://www.mayoclinicproceedings.org).

Publication Bias

Egger plots illustrated minimal evidence of publication bias (Supplemental Figures 5-7).

DISCUSSION

Our updated systematic review and subsequent meta-analysis confirms previous findings that isometric resistance training reduces BP. The magnitude of reduction is similar, perhaps even greater, than benefits reported from other exercise modalities. The BP reductions were observed in SBP, DBP, and MAP and were consistent across included trials. Blood pressure reductions were seen in both medicated hypertensive and normotensive participants from secondary analyses, with medicated hypertensive participants experiencing a greater reduction in DBP and MAP. To date, the impact of antihypertensive medication class on the capacity of isometric exercise to reduce BP has not been examined. The magnitude of BP-lowering effects is likely to translate into a reduction in clinical events.

We found that SBP was lowered by almost 7 mm Hg in response to isometric training, an effect size similar to the 10-mm Hg SBP decrease in our previous meta-analysis.[8] Although the inclusion of the recently published trials increases the statistical power of the current analysis, there is a small decrease in absolute effect size compared with our earlier work.[8] Nevertheless, the effect size remains highly significant with a relatively small CI and substantiates the recent inclusion by the American Heart Association of isometric exercise as a potential nonpharmacological therapy to lower BP.[25] Furthermore, the effect size lends weight to the notion that isometric exercise training is comparable or superior to dynamic exercise training (aerobic or resistance) or combined dynamic exercise for reducing SBP. Although the reductions in DBP and MAP are smaller than those seen in SBP, the effect sizes are comparable to changes observed with other exercise modalities.[7] A novel finding of the current analysis is a slight statistical reduction in RHR, although the small effect size suggests it is unlikely a factor in mediating the changes in BP.

The mechanisms responsible for these BP effects remain equivocal. Similar to dynamic aerobic exercise training,[26] the BP-lowering effects of isometric exercise training are most likely mediated through changes in systemic vascular resistance. Limited evidence suggests that isometric exercise training may be associated with reduced vascular sympathetic modulation,[22] while a larger body of research has investigated potential beneficial adaptations in vascular function. Specifically, isometric exercise training has been reported to increase endothelial-dependent (eg, nitric oxide—mediated) vasodilation in response to reactive hyperemia in

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Study or subgroup	Isometric Mean	Isometric SD	Isometric Total	Control Mean	Control SD	Control Total	Weight (%)	Mean difference IV, fixed (95% CI)
Badrov et al,[16] 2013 Fem 3	−1	1.5739	12	−1	0.8054	5	14.5	0.00 (−1.14 to 1.14)
Badrov et al,[16] 2013 Fem 5	0.01	0.0149	11	1	0.6284	4	49.3	−0.99 (−1.61 to −0.37)
Badrov et al,[17] 2013 Mixed	0.01	0.0157	12	1	1.301	9	25.9	−0.99 (−1.84 to −0.14)
Baross et al,[18] 2013	−5	6.9515	10	−0.8	1.1183	10	1.0	−4.20 (−8.56 to 0.16)
Stiller-Moldovan et al,[21] 2012	−0.3	0.4466	11	−1.8	2.3417	9	7.8	1.50 (−0.05 to 3.05)
Taylor et al,[22] 2003	−2	2.6019	9	6	7.1354	8	0.7	−8.00 (−13.23 to −2.77)
Wiley et al,[24] 1992	−2	2.3923	8	5	5.4063	7	1.0	−7.00 (−11.33 to −2.67)
Total (95% CI)			**73**			**52**	**100.0**	**−0.79 (−1.23 to − 0.36)**

Heterogeneity: χ^2=28.37, *df*=6 (*P*<.0001); I^2=79%
Test for overall effect: *Z*=3.60 (*P*=.003)

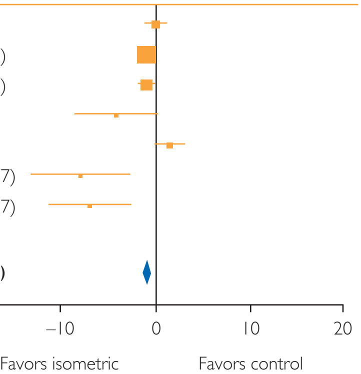

FIGURE 5. Change in resting heart rate (beats/min) with isometric exercise. Percentages do not total 100 as a result of rounding. Fem 3 = group of females who exercised 3 times weekly; Fem 5 = group of females who exercised 5 times weekly; IV = inverse variance; Mixed = mixed male/female study; Total = number of participants.

medicated hypertensive patients[27]; however, this effect was only noted in the trained limb (not the untrained limb) and was not found in normotensive individuals, even though BP was reduced.[28] More recently, isometric exercise training has been found to increase resistance vessel endothelial function[16] and increase training limb artery diameter, blood velocity, and blood flow in concert with reduced vascular conductance.[29] These findings are important because BP is primarily regulated at the level of the resistance vessels, and increased blood flow/velocity may increase the shear stress—mediated basal production of endothelial-dependent vasodilators such as nitric oxide. Isometric exercise training has also been reported to increase antioxidant concentrations.[30] Unfortunately, most mechanistic studies appear powered only to assess the primary variable of BP and not possible mechanistic pathways. Future robust trials are required to elucidate the role of isometric exercise training on neurohormonal (eg, sympathetic activity), inflammatory (eg, reactive oxygen species), and vascular (eg, endothelial function, arterial compliance) pathways as potential mechanisms for the reductions in BP.

Nevertheless, in the absence of a mechanistic explanation, health practitioners and individuals with hypertension can perhaps benefit from the simplicity and relatively low cost of isometric resistance exercise. The most common protocols have utilized a handheld dynamometer and four 2-minute isometric efforts at low to moderate intensity (30%-50% of maximal voluntary contraction), interspersed with 1 to 3 minutes of rest. The relatively short training session duration and flexibility of venue are obvious advantages of isometric exercise and may produce superior exercise adherence compared with aerobic or resistance training programs. It is possible that improved adherence may partially explain the relatively larger effect sizes that have been achieved almost without exception in isometric trials compared with other exercise modalities. In many cases, health care professionals turn immediately to pharmacological treatment of hypertension because exercise adherence is poor. In light of the effect sizes reported in our analysis and the removal of many common exercise barriers that may prevent good adherence, isometric resistance exercise has enormous potential for people with prehypertension and stage 1 hypertension. Moreover, as the only appreciable cost is a simple hand dynamometer, isometric training may be more cost-effective than antihypertensive medication.

It is important to remember that isometric exercise (as with dynamic aerobic exercise) immediately increases BP. However, as with dynamic resistance exercise, it is known that low- to moderate-intensity resistance exercise produces safe and minimal hemodynamic responses.[31] Thus, given the low intensity employed in current isometric exercise training studies, it is not surprising that the reported immediate mean ±

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SD increases in SBP (16±10 mm Hg), DBP (7±6 mm Hg), and heart rate (3±4 beats/min) are modest.[32] As a result, it is generally recommended that at low intensities (<40% of maximum), patients in whom dynamic aerobic exercise is considered appropriate should be permitted to complete equivalent-intensity isometric exercise.[33] Additionally, given the high prevalence of ischemic heart disease in patients with hypertension, the immediate hemodynamic differences between dynamic aerobic and isometric exercise warrant further clarification. Physiologically, isometric exercise may be associated with reduced myocardial oxygen demand due to an attenuated increase in heart rate and increased DBP (ie, coronary perfusion pressure).[30] In support, the addition of isometric exercise to dynamic aerobic exercise has been shown to attenuate the ST-segment depression observed with dynamic aerobic exercise alone,[34] while other studies have reported that dynamic lifting elicited higher heart rate, BP, and rate-pressure product responses than sustained handgrip contraction and that ischemic ST-segment depression and clinically important ventricular arrhythmias were infrequent with static effort.[35] In general, it would be helpful if studies continuously recorded BP during the performance of isometric activity to establish normal responses and categorize potential risk of adverse events in various populations.

Our analyses exhibit moderate to high evidence of between-study heterogeneity. Although most comparisons of exercise training studies reveal variations in study duration and exercise modality, the commonality of protocols renders differences negligible in this analysis. While the investigators performing assessment measures were aware of group assignment, this was not necessarily a limitation since we chose to modify the PEDro scale to assess study quality because all studies would have found it difficult to blind participants and investigators to the allocation of isometric exercise training or sedentary control. The median PEDro score was 6, suggesting a moderate study design and reporting. Future studies should employ sham isometric training (such as suboptimal intensity) to permit studies to use a stronger double-blind design. The Egger plots showed minimal evidence of publication bias, which is understandable because studies demonstrate consistent improvements and authors are apt to emphasize the antihypertensive benefits. It is therefore unlikely that unpublished negative or neutral data sets exist for most of our outcome measures, and the level of significance suggests that unpublished data would not change our findings.The major limitation of this field of study is that several desired measures such as continuous BP monitoring, neurohormonal and blood vessel compliance, and flow are unavailable, making it difficult to unravel the mechanistic interpretation of these antihypertensive findings.

CONCLUSION

Our findings document that isometric resistance training has the ability to significantly reduce resting BP. Interestingly, these antihypertensive responses are similar (if not larger) than those previously reported with aerobic or resistance exercise alone, even though they require a markedly smaller time commitment. Moreover, the relatively low cost and simplicity of delivery are likely to enhance exercise adherence. Our data suggest that this form of training has the potential to elicit significant and clinically meaningful BP reductions and may serve as an important adjunct to current exercise recommendations of dynamic exercise training.

SUPPLEMENTAL ONLINE MATERIAL

Supplemental material can be found online at http://www.mayoclinicproceedings.org.

Abbreviations and Acronyms: **BP** = blood pressure; **DBP** = diastolic BP; **MAP** = mean arterial pressure; **MD** = mean difference; **PEDro** = Physiotherapy Evidence Database; **RHR** = resting heart rate; **SBP** = systolic BP

Potential Competing Interests: Dr Millar has received (2010-2012) speaking and travel honoraria from Zona Health.

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