Effect of resistance training on resting blood pressure: a meta-analysis of randomized controlled trials

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Objective To assess the influence of resistance training on resting blood pressure in healthy sedentary adults.

Methods A comprehensive literature search with the MEDLINE computerized database was conducted and reference lists of published articles and reviews on the topic were checked. Inclusion criteria were as follows: the study involved a randomized, controlled trial; resistance training was the sole intervention; participants were sedentary normotensive and/or hypertensive adults with no other concomitant disease; the article was published in a peer-reviewed journal up to December 2003. We identified nine randomized controlled trials, involving 12 study groups and 341 participants. A standard protocol was used to extract information on sample size, participant characteristics, study design, training method and duration, and study outcomes. Pooled blood pressure estimates were obtained, weighted by either the number of participants in the training group or the inverse of the variance for blood pressure change.

Results The weighted net changes of blood pressure, after adjustment for control observations, averaged −3.2 [95% confidence limits (CL) −7.1 to +0.7]/−3.5 (95% CL −6.1 to −0.9) mmHg when weighted for the number of trained participants, and −6.0 (95% CL −10.4 to −1.6)/ −4.7 (95% CL −8.1 to −1.4) mmHg, when weighted by the reciprocal of the variance for the blood pressure change.

Conclusions Our results suggest that moderate intensity resistance training is not contraindicated and could become part of the non-pharmacological intervention strategy to prevent and combat high blood pressure. However, additional studies are needed, especially in the hypertensive population. _J Hypertens_ 23:251–259 © 2005 Lippincott Williams & Wilkins.

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Introduction

Elevated blood pressure (BP) has become the number one attributable risk for death throughout the world [1]. Adopting a healthy lifestyle is critical for the prevention of high BP and is an indispensable part of the treatment of those with hypertension [2]. Higher levels of physical activity and greater fitness are associated with a reduced incidence of hypertension [3]. Further, there is a general agreement in the literature that aerobic endurance training elicits small but significant reductions in BP [4–6] and recent guidelines recommend that everybody who is able should engage in regular aerobic physical activity, such as brisk walking, for at least 30 min/day, most days of the week, as a means to lower BP [3,7,8]. With the rise in popularity of the fitness industry, with weight or resistance training machines, an additional approach for the management of BP is being proposed. Research showing the beneficial effects of resistance training for the musculoskeletal system has led to recommendations that it be included in an overall fitness programme for all adults, and especially recommended for older adults. Still, resistance training, also known as static, strength or weight training, has not yet been recommended as a sole intervention to reduce the risk of hypertension and to decrease BP in mildly hypertensive subjects. Although resistance training does not seem to be associated with chronic elevations of BP [9,10], evidence for a blood pressure-lowering effect is much less compelling for this type of training than for aerobic endurance training. Recently, the American College of Sports Medicine (ACSM) [3] recommended resistance training to be an adjunct to an aerobic-based exercise programme in the prevention, treatment and control of hypertension. Because more precise knowledge regarding the possible benefits of resistance training on BP is warranted, we conducted a meta-analysis of randomized controlled trials examining the effects of static, strength, weight or resistance training on BP.

Methods

Selection of studies

We conducted a comprehensive literature search with the MEDLINE computerized database (from 1966 to December 2003), using the medical subject headings

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'isometric', 'static', 'resistance', 'strength training', 'weight training' and 'blood pressure' and checked the reference lists of published articles and reviews on the topic. In this meta-analysis we will use the term 'resistance training' to indicate all training programmes that involve strength, weight, static and/or isometric training, and that are designed specifically to increase muscular strength, power and/or endurance [11]. To be included in this meta-analysis, a study had to meet the following criteria: the study was conducted in normotensive or hypertensive humans, or both, in whom other concomitant diseases were reasonably well excluded; participants were at least 18 years of age; there was random allocation of study participants to training and control groups, or to control phases in the case of cross-over design; exercise training was the sole intervention difference with the control group; training included only 'resistance exercises' and no aerobic endurance exercises, designed to improve the function of the cardiovascular system and to increase endurance performance [11]; the intervention duration was at least 4 weeks, and systolic BP (SBP) and/or diastolic BP (DBP) was an outcome in the study and had to be reported for the control and intervention groups; finally, full publication in a peer-reviewed journal. When the effects of different training programmes were compared within studies, random allocation to the intervention groups or phases was required. We identified nine randomized controlled trials [12–20], which met these criteria. One trial involved a hypertensive and a normotensive group of subjects [13] and two trials applied different training regimens [18,20], so that a total of 12 study groups were available for the meta-analysis.

Data extraction

We used a standard protocol to extract information on sample size, participant characteristics, study design, intervention method and duration, and study outcomes. Hypertension was defined as SBP $\geq$ 140 mmHg and/or DBP $\geq$ 90 mmHg [7,8]. According to the type of muscle contraction, resistance training was divided into two major subgroups: 'dynamic' versus 'static' resistance training. Dynamic resistance training involves concentric and/or eccentric contractions of muscles while both the length and 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 or joint. Furthermore, the predominantly dynamic training programmes were divided into a 'circuit programme' or a 'conventional programme of isolated exercises'. A conventional protocol generally consists of lifting two or more sets of heavier weights in an isolated exercise with longer rest periods before going to the next exercise; while a circuit programme consists of lifting one set of lighter weights with shorter rest periods between exercises and this circuit may be repeated after one complete tour. Exercise intensity was expressed in percent of one repetition maximum (% of 1 RM), which is the maximum weight that can be lifted in one repetition. If intensity was not reported, it was calculated using Epley's formula: % of 1 RM = $1/(1 + 0.033 \times$ number of performed repetitions).

Statistical analysis

All analyses were performed with SAS version 8.0 (SAS Institute, Inc., Cary, North Carolina, USA). Mean age, BP, heart rate (HR), weight, maximal oxygen uptake (VO_2max) and percent body fat at baseline, for all participants in each study group, were calculated by combining mean values from the training and control groups, weighted by the total number of participants in each group. These means were not used for the calculation of the net changes. Given that all studies included in this meta-analysis involved parallel trials, net changes in BP were calculated as: (BP at the end of follow-up in the training group – BP at baseline in the training group) – (BP at the end of follow-up in the control group – BP at baseline in the control group). To calculate the overall effect size of training on BP, each trial was weighted by the inverse of its total variance for BP change. Since none of these parallel trials reported the variance for paired differences, this was calculated for each trial by using variances at baseline and at the end of the trial. We used the method of Follmann and colleagues, in which a correlation coefficient of 0.5 between the initial and final values was assumed [21]. The pooled variance of the difference for each comparison within each trial was computed using the formula $\sigma^2 = (n_1\sigma_1{}^2 + n_2\sigma_2{}^2)/(n_1 + n_2 - 2)$ in which $\sigma_1{}^2$ and $\sigma_2{}^2$ were the variances of the training group and control group, respectively, and n_1 and n_2 the number of participants in each group. This method was also used to calculate 95% confidence limits of net changes in BP for individual study groups. The reciprocal of the variance can be considered to provide a better weighting factor since it takes into account both variance and sample size. However, since the variance of the net change in blood pressure for the diverse study groups had to be calculated based on several assumptions, the overall effect size of training on BP was also calculated by weighting for the number of analysable subjects allocated to each training group, which is more traditional. Secondary outcomes were only calculated by weighting for the number of trained participants.

Q statistic was used to test the heterogeneity of net changes in resting SBP and DBP among trials [22]. Since heterogeneity of net changes in both resting SBP and DBP was not significant, a fixed effects model was used to calculate the overall effect size. To examine the influence of each study on the overall results, analyses were also performed with each study deleted from the model.

The influence of covariates on the net change of BP was investigated by performing a series of subgroup analyses.

Therefore study subjects were divided into categorical subgroups according to their hypertensive status (normotensive or hypertensive), the duration of the study (<15 weeks versus >15 weeks), the type of training programme, the intensity of the programme (<55% of 1 RM versus >55% of 1 RM) and the sample size (<20 subjects, 20–30 subjects, >30 subjects). Finally, pooled effects were calculated for each subgroup using the fixed effects model, weighted by the reciprocal of the total variance for change in BP, and statistical significance was tested by ANOVA.

The possibility of publication bias was explored by: (1) plotting net changes in BP against sample size for each trial; (2) calculating Kendall's Tau correlation coefficients between sample size and standardized SBP and DBP reduction and testing it for statistical significance [23].

Two-tailed statistical tests were used. A P-value < 0.05 was considered statistically significant.

Results

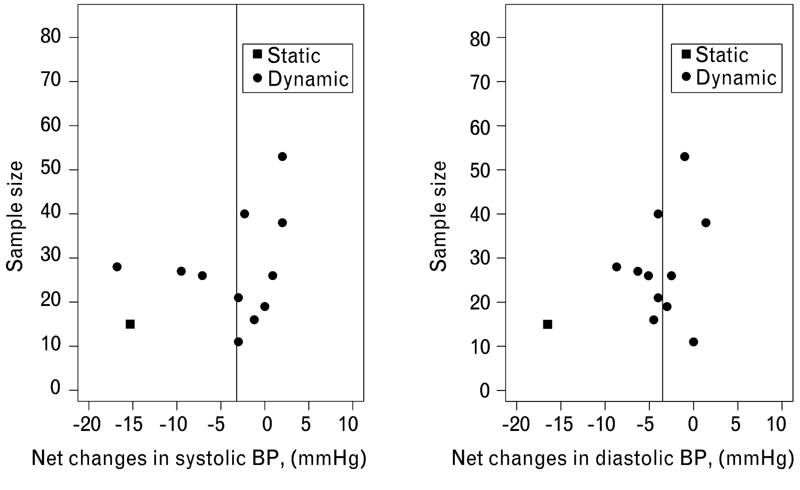
Testing for publication bias

Kendall's Tau correlation coefficients between sample size and standardized SBP and DBP reduction were 0.25 ($P = 0.27$) and 0.08 ($P = 0.73$), respectively. As shown in Figure 1, the funnel plot revealed a slightly negatively skewed distribution for the net changes in both SBP and DBP. Net changes in BP tended to be smaller for larger studies. When only the dynamic resistance training groups were included in the analysis, with the exclusion of the static training group [16] the funnel plots showed less asymmetry.

Baseline participant characteristics and study design

Participant and selected study design characteristics of the 12 study groups are presented in Table 1. The studies were published between 1987 and December 2003. The average number of subjects at the start in each study ranged from 7 to 35 in the exercisers and from 5 to 23 in the controls; 61% of the 341 participants were male. Two trials included only male [12,17], one only female [15] and the others comprised both sexes (or sex unknown in one [16]). The mean drop out percentage was 15% (range: 0–37%) so that a total of 290 participants could be evaluated. All trials were conducted in adults; the average age of the various study groups ranged from 20 to 72 years (median: 69 years). Based on the average pre-training BP, three trials were conducted in hypertensive patients [12–14] and nine in normotensive subjects [15–20]. Among the normotensives, two studies reported that none of the subjects was taking any antihypertensive medications before or during the study [17,18], another one reported that some subjects were taking antihypertensive medications throughout the study [13] and four did not report on treatment [15,16,19,20]. Among the hypertensive study groups, one reported that subjects were taken off antihypertensive medication 4 weeks before baseline screening [14], and another one reported that some subjects were on antihypertensive treatment [13]. All studies used a parallel design and varied in duration from 6 to 26 weeks (mean ± SD; 16.4 ± 7.5 weeks). Average training frequency was three times a week, except in two trials [14,17] in which participants trained twice a week on average. Intensity ranged from 30 to 90% of 1 RM (mean ± SD; 61 ± 20% of 1 RM). The number of different exercises performed ranged from 1 to 14 (mean ± SD; 9.9 ± 3.8) while the number of sets for

Fig. 1



Funnel plots of net changes in systolic blood pressure (left) and diastolic blood pressure (right) versus sample size in 12 study groups. Mean blood pressure change (vertical line) was weighted for the number of participants in the training group.

Table 1 **Characteristics of the 12 study groups at baseline and characteristics of the training programmes**

						Training programme characteristics						
Author	Group	Subj. Start (*n*)	Subj. End (*n*)	Sex (%male)	Age (years)	Method	Duration (weeks)	Frequency (*n*/week)	Intensity (% of 1 RM)	*N* of exercises	*N* of sets	*N* of repetitions/set
I. Normotension												
Coconie *et al.* (1) [13]	Ex	15	14	45	72	Dynamic	26	3	72–79*	10	1	8–12
	Con	7	7		72							
Katz and Wilson [15]	Ex	13	13	0	22	Dynamic: circuit	6	3	30	14	1	LB:14–15 UB:11–12
	Con	13	13		18							
Wiley *et al.* [16]	Ex	10	8	?	28	Static	8	3	30	1	4	1
	Con	10	7		28							
Vanhoof *et al.* [17]	Ex	15	8	100	38	Dynamic	22	2	70 + 90	6	3	12 + 4
	Con	15	11		38							
Tsutsumi *et al.* (1) [18]	Ex	14	14	79	69	Dynamic	12	3	55–65	12	2	12–16
	Ex	14	13		68	Dynamic	12	3	75–85	12	2	8–12
Tsutsumi *et al.* (2)	Con	14	14		70							
Wood *et al.* [19]	Ex	13	10	50	70	Dynamic	12	3	72–79*	8	2	8–12
	Con	7	6		68							
Vincent *et al.* (1) [20]	Ex	34	22	54	68	Dynamic	24	3	50	13	1	13
	Ex	30	24		67	Dynamic	24	3	80	13	1	8
Vincent *et al.* (2)	Con	20	16		71							
II. Hypertension												
Harris and Holly [12]	Ex	10	10	100	33	Dynamic: circuit	9	3	40	10	3	20–25
	Con	16	16		31							
Coconie *et al.* (2) [13]	Ex	7	6	46	72	Dynamic	26	3	72–79*	10	1	10–12
	Con	5	5		72							
Blumenthal *et al.* [14]	Ex	35	31	62	46	Dynamic: circuit	16	2	?	?	?	?
	Con	23	22		46							

Subj, subjects; *N*, number; *n*/week, number of sessions per week; 1 RM, one repetition maximum; Ex, exercise group; Con, control group; LB, lower body; UB, upper body. *, % of 1 RM calculated with Epley's formula: % of 1 RM = 1/(1 + 0.033 × number of reps/set); ?, unknown data.

Table 2 **Blood pressure values before and after training, and the net changes in the 12 study groups**

		Systolic blood pressure (mmHg)			Diastolic blood pressure (mmHg)		
Author	Group	Pre-training	Post-training	Net change in SBP mean (95% CL)	Pre-training	Post-training	Net change in DBP mean (95% CL)
I. Normotension							
Coconie *et al.* [13]	Ex	122 ± 8	122 ± 11	−3.0 (−11.9 to 5.9)	76 ± 9	75 ± 10	−4.0 (−12.5 to 4.5)
	Con	126 ± 7	129 ± 7		94 ± 5	97 ± 5	
Katz and Wilson [15]	Ex	107.5 ± 11.6	99.1 ± 13.6	−7.1 (−15.7 to 1.5)	65.3 ± 6.8	61.2 ± 7.8	−5.1 (−10.9 to 0.7)
	Con	113.8 ± 8.3	112.5 ± 5.8		67.2 ± 6.0	68.2 ± 6.7	
Wiley *et al.* [16]	Ex	134.1 ± 0.95	121.4 ± 1.3	−15.3 (−22.5 to −8.1)	86.5 ± 2.01	71.6 ± 3.5	−16.5 (−24.6 to −8.4)
	Con	134 ± 3.3	136.6 ± 2.8		83.4 ± 1.7	85 ± 2.4	
Vanhoof *et al.* [17]	Ex	129 ± 8	125 ± 6	0.0 (−10.6 to 10.6)	81 ± 10	76 ± 5	−3.0 (−14.1 to 8.1)
	Con	124 ± 15	120 ± 9		78 ± 14	76 ± 11	
Tsutsumi *et al.* (1) [18]	Ex	124.2 ± 16.4	110.8 ± 15	−16.8 (−28.4 to −5.2)	72.6 ± 9.5	67.5 ± 9.1	−8.7 (−16.1 to −1.3)
	Ex	109.8 ± 18.8	103.7 ± 17.4	−9.5 (−22.4 to 3.4)	65 ± 9.9	62.3 ± 9.9	−6.3 (−14.1 to 1.5)
Tsutsumi *et al.* (2)	Con	122 ± 11.8	125.4 ± 14.1		72.4 ± 8.1	76 ± 9.8	
Wood *et al.* [19]	Ex	129.1 ± 22.5	124.1±16.3	−1.2 (−24.2 to 21.8)	75.1 ± 10.3	72.6 ± 10.6	−4.5 (−15.8 to 6.8)
	Con	133.5 ± 22.4	129.7 ± 16.5		78.3 ± 6.9	80.3 ± 8.8	
Vincent *et al.* (1) [20]	Ex	137.8 ± 17	138.9 ± 15	+2.0 (−9.3 to 13.3)	80.7 ± 9	83.4 ± 6	+1.4 (−4.8 to 7.6)
Vincent *et al.* (2)	Ex	132.9 ± 10	129.7 ± 9	−2.3 (−11.2 to 6.6)	83.8 ± 8	81.1 ± 10.1	−4.0 (−10.6 to 2.6)
	Con	130.2 ± 16	129.3 ± 19		78.2 ± 10	79.5 ± 12	
II. Hypertension							
Harris and Holly [12]	Ex	141.7 ± 7.9	142.3 ± 7.5	+0.9 (−8.7 to 10.5)	95.8 ± 6.4	91.3 ± 8.0	−2.5 (−10.0 to 5.0)
	Con	146.1 ± 8.2	145.8 ± 6.9		94.6 ± 3.8	92.6 ± 3.3	
Coconie *et al.* [13]	Ex	151 ± 7	151 ± 11	−3.0 (−16.2 to 10.2)	82 ± 9	82 ± 14	0.0 (−14.7 to 14.7)
	Con	153 ± 7	156 ± 10		85 ± 8	85 ± 6	
Blumenthal *et al.* [14]	Ex	143 ± 10.3	136 ± 11.6	+2.0 (−4.1 to 8.1)	95 ± 5.4	89 ± 6.4	−1.0 (−4.4 to 2.4)
	Con	142 ± 12	133 ± 8.6		95 ± 6.2	90 ± 6.2	

SBP, systolic blood pressure; DBP, diastolic blood pressure; Ex, exercise group; Con, control group; Values are given as mean ± SD for baseline and post-training blood pressures. Values are means and 95% confidence limits (CL) for net changes in blood pressure.

each type of exercise ranged from 1 to 4 (mean ± SD; 1.8 ± 1.1). The number of repetitions per set ranged from 1 to 25, but since most studies reported the range for the total number of repetitions performed, we were unable to calculate an overall mean and SD. Exercises involved use of arms, trunk and legs in 10 of the study groups [12,13,15,17–20], only arms in one [16] and with no information in another [14]. Three trials reported using a circuit training protocol [12,14,15], and one trial involved only static exercise [16]. In all but one trial [18] participants in the control group were instructed not to modify their usual lifestyle, including physical activity. In two trials [15,16], participants in the control group had their BP measured three times a week, in two other trials [14,19] controls received monthly phone calls to check on lifestyle, and one trial had control subjects fill in a questionnaire halfway through the study period [17].

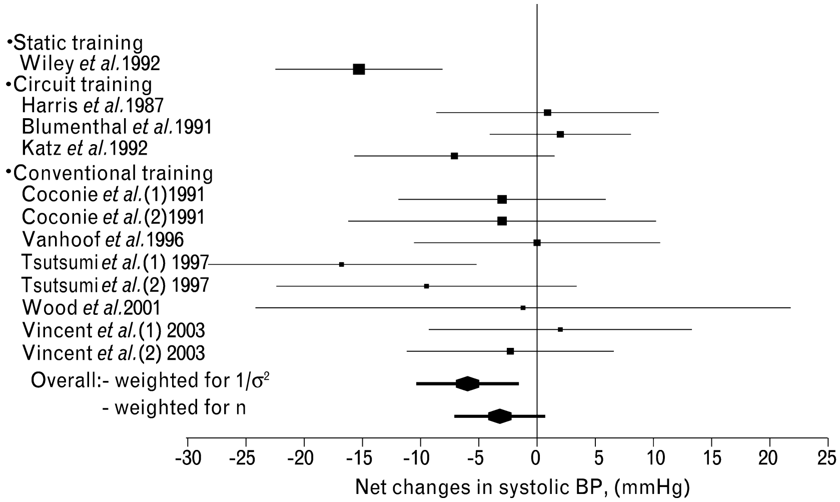
Average pre-training BP for the various trials ranged from 109.9 to 151.9 mmHg for SBP (median: 131.3 mmHg) and from 66.0 to 95.1 mmHg (median: 78.8 mmHg) for DBP. At baseline mean VO_2max varied from 18.8 to 41.4 ml/kg per min (median: 22.0 ml/kg per min) and mean HR varied from 63.3 to 77.5 beats/min (median: 69.8 beats/min) in the six [12–14,17,18,20] or seven [12–14,17–20], respectively, of the nine trials in which it was measured. Mean body weight was available in seven trials [12–14,17–20] and ranged from 70.9 to 85.8 kg (median: 75.6 kg) while mean percent fat, available in four trials [12,14,18,20], ranged from 25.2 to 33.0% (median: 31.0%).

Net changes in BP and secondary outcomes in response to training

Baseline and final BP results in the training and control groups, as well as the net changes for each of the training groups, are shown in Table 2. The training groups showed average net changes in BP of +2 to −16.8 mmHg and of +1.4 to −16.5 mmHg for DBP. Six of the 12 study groups demonstrated an intervention-related trend toward a reduction of SBP and two showed a significant reduction of SBP (Fig. 2). DBP decreased in 10 of the 12 study groups after training, but the reduction was statistically significant in only two (Fig. 3).

Table 3 summarizes the overall results in response to training. Because there was no statistically significant heterogeneity for both SBP ($Q = 4.39$, $P = 0.95$) and DBP ($Q = 4.08$, $P = 0.95$), the reported results are based on a fixed effects model. The overall pooled net effect of training on SBP and DBP was −3.2 mmHg ($P = 0.10$) and −3.5 mmHg ($P < 0.01$), respectively, when weighted by the number of participants in the training group. These changes amounted to −6.0 mmHg ($P < 0.01$) for SBP and to −4.7 mmHg ($P < 0.01$) for DBP when weighted by the inverse of the variance of BP change. With consecutive deletion of each study group from the model, changes ranged from −6.7 to −3.0 mmHg for SBP and from −5.5 to −3.1 mmHg for DBP when

Fig. 2

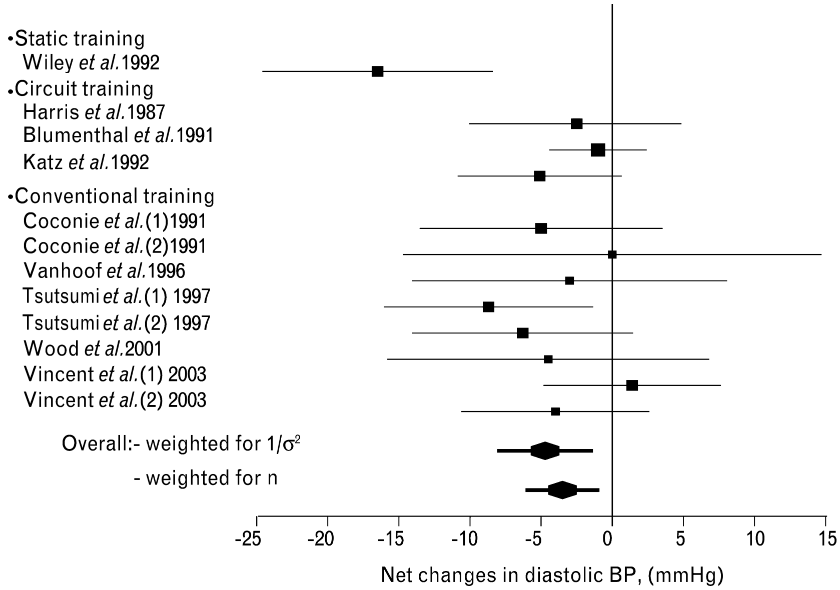


Average net changes in systolic blood pressure and corresponding 95% confidence limits in nine randomized controlled trials involving 12 study groups. The overall effect represents a pooled estimate obtained by summing the average net change for each trial, weighted by either the inverse of its variance or the number of participants in the training group. Size of the squares corresponds to the value of the weighting factor (inverse of the variance): < 0.005; 0.005–0.0099; 0.01–0.02; > 0.02.

weighted for the inverse of the variance of the BP change. When weighted for the number of participants in the training group, the changes were between −4.4 and −2.1 mmHg for SBP and between −4.2 and −3.0 mmHg for DBP.

The overall net changes for the secondary outcomes are reported after weighting for the number of trained participants (Table 3). VO_2max increased significantly by 10.5% [95% confidence limits (CL) 1.2–19.4%] after training. There was no significant change in HR. The

Fig. 3



Average net changes in diastolic blood pressure and corresponding 95% confidence limits in nine randomized controlled trials involving 12 study groups. The overall effect represents a pooled estimate obtained by summing the average net change for each trial, weighted by either the inverse of its variance or the number of participants in the training group. Size of the squares corresponds to the value of the weighting factor (inverse of the variance): 0.005–0.0099; 0.01–0.02; >0.02.

Table 3 Baseline data for the training group and net changes in response to resistance training

	Baseline		Net change		
Variable	*N*	Mean (95% CL)	*N*	Mean (95% CL)	*P* value
Blood pressure (mmHg)					
weighted for $1/\sigma^2$					
Systolic	12	131.6 (123.5–139.6)	12	−6.0 (−10.4 to −1.6)	< 0.01
Diastolic	12	80.9 (73.9–87.8)	12	−4.7 (−8.1 to −1.4)	< 0.01
weighted for *n*					
Systolic	12	131.0 (123.0–138.8)	12	−3.2 (−7.1 to +0.7)	= 0.10
Diastolic	12	81.1 (74.5–87.7)	12	−3.5 (−6.1 to −0.9)	< 0.01
VO_2max (ml/min per kg)	9	24.7 (19.2–30.2)	6	+2.6 (+0.3 to +4.8)	< 0.05
Heart rate (beats/min)	10	70.7 (66.9–74.4)	8	+1.0 (−1.7 to +3.7)	NS
Percent body fat (%)	6	30.1 (27.7–32.5)	4	−0.94 (−1.6 to −0.25)	< 0.01
Weight (kg)	8	76.4 (69.4–83.4)	4	+0.33 (−2.7 to +3.4)	NS

N, number of trials; *n*, number of trained participants; VO_2, oxygen uptake. Values are given as weighted mean and 95% confidence limits (CL).

four studies that reported on changes in percent body fat demonstrated a small but statistically significant decrease, whereas body weight remained unchanged.

Subgroup analysis

When subjects were divided into subgroups according to hypertensive status, hypertensive patients tended to have a smaller reduction in both SBP and DBP compared to their normotensive counterparts, but this trend was not significant ($P = 0.09$ for SBP and $P = 0.13$ for DBP). Trials with the longest follow-up (>15 weeks) had a smaller effect size than trials with short follow-up, for both SBP ($P < 0.01$) and DBP ($P < 0.05$). The degree of BP reduction did not differ among study groups with different sample size, although the effect size tended to be reduced with increasing number of participants ($P = 0.26$ for SBP and $P = 0.24$ for DBP). Reduction in BP did not differ among trials with different intensities. When the one trial that involved static training was excluded, the mean net change in BP decreased to −3.0 mmHg (95% CL −6.3 to 0.3; $P = 0.07$) for SBP and to −3.1 mmHg (95% CL −5.1 to −1.2; $P < 0.005$) for DBP. The conventional and circuit training protocols did not differ from each other, neither for SBP ($P = 0.53$) nor for DBP reduction ($P = 0.70$).

Discussion

It was once thought that resistance training could cause a chronic elevation of resting BP by inducing vascular hypertrophy and increasing vascular resistance, due to large acute increases in BP elicited by the exercise. Our meta-analysis does not support this contention. We even found a significant net decrease of DBP of 3.5 mmHg and a borderline non-significant decrease of SBP of 3.2 mmHg when weighted by the number of participants in the trained group; and a decrease of 6.0 mmHg for SBP and of 4.7 mmHg for DBP when weighted for the inverse of the variance for the BP change. These results confirm previous narrative reviews [24–26] and one meta-analysis [10] which suggested that resistance training does not increase BP and might even have potential benefits on resting SBP and DBP; the findings are also compatible with the lack of hypertension observed among isometric and power athletes [27,28]. It is well-known that such small reductions in the population-average BP decrease the incidence of coronary heart disease and stroke [2,29,30]. Consequently, the reported reductions of BP in the present meta-analysis could have an important impact on these cardiovascular complications. Control of BP is even more important in hypertensive patients. With regard to dynamic aerobic endurance training, there is general agreement in the literature that training lowers resting BP to a greater extent in patients with moderate-to-severe hypertension than in normotensives [4–6]. By contrast, our subgroup analysis indicated that resistance training tended to induce smaller reductions in BP in the hypertensive as compared to the normotensive groups. However, caution is warranted when interpreting these results. Only three of the 12 study groups were carried out in subjects with a mean initial resting SBP ≥ 140 mmHg and/or a DBP ≥ 90 mmHg. More studies are definitively needed in patients with hypertension.

Whereas the results of this meta-analysis provide some valuable information, there are a number of limitations. One significant limitation is the paucity of available studies and the relatively small number of subjects in each study. This makes subgroup analysis nearly impossible. Next, the interpretation of the effect of resistance training on BP is difficult due to the variability of the training programmes and often incomplete reporting of the protocols. For example, the duration of a complete training session is only known in five of the 12 study groups [13–15,19]. No more than three trials [16–18] mentioned the duration of one contraction, which is, however, required to make the difference between predominantly static or predominantly dynamic training. The amount of time that subjects rested between exercises was only reported in five trials [12,13,16–18]. Finally just one trial gave information about the duration of a complete set of each exercise [12]. Such information, however, would allow a more accurate quantification of the training stimulus. In the current meta-analysis, all randomized controlled trials examining the influence of some kind of resistance training on BP were included. However, as already mentioned above, resistance training can be divided into two subgroups according to the type of muscle contraction: dynamic resistance training versus static resistance training. Since only one randomized controlled trial has examined the effects of static training on BP, it was not possible to compare both types of training. Therefore, given the small number of studies available, additional randomized controlled trials are needed to examine the effects of purely static training on resting BP, and to compare them with the effects of dynamic resistance training. Subsequently, the dynamic training programmes were divided into a circuit programme or a conventional programme of isolated exercises. No differences were found for changes in resting BP between trials that used a conventional compared to a circuit protocol. It is worth mentioning that the VO_2max increased by 10.5% in the six trials in which it was measured, which is only slightly less than what is observed after aerobic endurance training. Conley *et al.* [31] already pointed out that muscle volume is an important determinant in the response of VO_2max to training. Therefore by increasing the amount of the muscle mass used in the various exercises, independently of the mode of (resistance) training, the haemodynamic responses become more dynamic (aerobic) in nature. This was confirmed by Longhurst [27] who attributed the slight increase of VO_2max in weight lifters to the dynamic components in the exercises. This suggests that the kind of resistance training used in most protocols comprises an aerobic component to some extent.

Previous meta-analyses investigating the influence of dynamic aerobic training on BP reduction suggested that the effect is smaller in long-term intervention trials than in short-term trials [4–6]. This is confirmed by the current meta-analysis: both SBP and DBP decreased significantly in the shorter trials (<15 weeks), whereas the reduction was no longer significant in the longer trials (>15 weeks). Consistent with the aerobic training trials, the intensity of training did not significantly influence the BP-lowering effect of resistance training.

The underlying mechanisms responsible for the training-induced reduction in BP remain unclear. Despite the fact that the decline in BP is likely to be multifactorial, the most commonly suggested mechanism is a reduced sympathetic tone after training. Aerobic endurance training has been shown to decrease resting plasma norepinephrine levels as well as muscle sympathetic nerve activity [3]. By contrast, Vanhoof *et al.* [17] could not observe any change in sympathetic tone, assessed by heart rate variability in response to resistance training, and also Coconie [13] found no change in plasma epinephrine and norepinephrine levels at rest after training. The lack of a change in HR in our meta-analysis, compatible with the fact that HR is not different from controls in strength-trained athletes [32], could support the absence of a change in sympathetic activity.

In summary, although the number of studies on the effects of resistance training on blood pressure is small, our results suggest that moderate resistance exercise may become part of the non-pharmacological intervention strategy to prevent and combat high BP, preferably in combination with aerobic endurance training, and provided that appropriate precautions are taken. It may not only increase whole-body muscular strength, but also decrease BP and probably the risk for future development of cardiovascular disease.

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