Yoga as Antihypertensive Lifestyle Therapy: A Systematic Review and Meta-analysis

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Abstract

Objective: To investigate the efficacy of yoga as antihypertensive lifestyle therapy and identify moderators that account for variability in the blood pressure (BP) response to yoga.

Methods: We systematically searched 6 electronic databases from inception through June 4, 2018, for articles published in English language journals on trials of yoga interventions that involved adult participants, reported preintervention and postintervention BP, and had a nonexercise/nondiet control group. Our search yielded 49 qualifying controlled trials (56 interventions). We (1) evaluated the risk of bias and methodological study quality, (2) performed meta-regression analysis following random-effects assumptions, and (3) generated additive models that represented the largest possible clinically relevant BP reductions.

Results: On average, the 3517 trial participants were middle-aged (49.2±19.5 years), overweight (27.9±3.6 kg/m^2) adults with high BP (systolic BP, 129.3±13.3 mm Hg; diastolic BP, 80.7±8.4 mm Hg). Yoga was practiced 4.8±3.4 sessions per week for 59.2±25.0 minutes per session for 13.2±7.5 weeks. On average, yoga elicited moderate reductions in systolic BP (weighted mean effect size, −0.47; 95% CI, −0.62-0.32, −5.0 mm Hg) and diastolic BP (weighted mean effect size, −0.47; 95% CI, −0.61 to −0.32; −3.9 mm Hg) compared with controls ($P<.001$ for both systolic BP and diastolic BP). Controlling for publication bias and methodological study quality, when yoga was practiced 3 sessions per week among samples with hypertension, yoga interventions that included breathing techniques and meditation/mental relaxation elicited BP reductions of 11/6 mm Hg compared with those that did not (ie, 6/3 mm Hg).

Conclusion: Our results indicate that yoga is a viable antihypertensive lifestyle therapy that produces the greatest BP benefits when breathing techniques and meditation/mental relaxation are included.

 ■ Mayo Clin Proc. 2019;94(3):432-446

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Hypertension (systolic blood pressure [SBP] ≥140 mm Hg and/or diastolic blood pressure [DBP] ≥90 mm Hg according to the seventh report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure[1]) is the most prevalent cardiovascular disease (CVD) risk factor. In the United States, hypertension affects approximately 86 million (34.0%) adults (≥18 years)[2-4] and results in about 73,000 deaths each year.[3,4] The 2017 American College of Cardiology and American Heart Association (AHA) Guidelines redefined hypertension to a lower blood pressure (BP) threshold of 130 mm Hg for SBP or 80 mm Hg for DBP[1,5]; accordingly, 46% of US adults now present with hypertension.[5] The 2017 American College of Cardiology/AHA Guidelines also emphasize the importance of lifestyle interventions, such as regular exercise, for the treatment of hypertension.[5]

Traditional yoga is a holistic practice that aligns the body and mind[6]; its simplified modern form typically consists of 3 yoga elements in various combinations, which are physical postures (eg, warrior pose), breathing techniques (eg, alternate nostril breathing), and meditation/mental relaxation (eg, chakra meditation).[6] In recent years, yoga has attracted attention worldwide from the scientific community and general population

 Mayo Clin Proc. ■ March 2019;94(3):432-446 ■ https://doi.org/10.1016/j.mayocp.2018.09.023
www.mayoclinicproceedings.org

because of its numerous health benefits, including lower BP.[7] Yoga elicits changes in resting blood pressure ranging from -29.2 to +10.2 mm Hg. Reasons for this large variability in the BP response to yoga are not clear. The AHA and the 2018 Physical Activity Guidelines Advisory Committee both state that high-quality intervention trials with large sample sizes, and eventually meta-analysis, are needed to form the evidence-based recommendations regarding the BP benefits of yoga.[8,9]

To the best of our knowledge, 3 meta-analyses have been published with the primary aim of examining the antihypertensive effects of yoga among adults with prehypertension to established hypertension.[10-12] Results from these meta-analyses were encouraging, yet inconsistent: they revealed a considerable range of the BP response to yoga among adults with hypertension, with SBP reductions from 4 to 14 mm Hg and DBP reductions from 4 to 11 mm Hg.[10-12] In addition, 2 of these meta-analyses compared the BP reductions resulting from different combinations of physical postures, breathing techniques, and meditation/mental relaxation.[12] Cramer et al[12] reported that only yoga interventions that did not include physical postures elicited substantial BP reductions greater than control. In contrast, Hagins et al[11] found that only yoga interventions with all 3 yoga elements elicited notable BP reductions greater than control. The main factor that may have contributed to the inconsistent results is that all 3 previous meta-analyses only performed subgroup analysis because of small sample sizes (ie, 7-17 trials) that were further divided to perform subgroup analyses, which may have increased the chance for false-negative fndings.[10-12] Furthermore, because BP responses to yoga are simultaneously influenced by multiple factors in any intervention,[13] subgroup analysis may lack precision since it can only examine one potential moderator at a time, while the influences from other moderators are not being controlled.

The primary purpose of our meta-analysis was to provide more precise estimates of the antihypertensive effects of yoga by including the largest sample size to date, enabling us to perform meta-regression analyses to examine multiple moderators simultaneously.[14-16] In particular, we aimed to identify which combination of elements of yoga practice yielded the greatest BP-lowering effects.

METHODS

Selection Criteria

Trials were eligible if they met all 5 a priori inclusion criteria: (1) included any combination of physical postures, breathing techniques, and meditation/mental relaxation, while explicitly stating that the intervention was yoga,[6] (2) reported BP before and after intervention for the yoga and control groups, (3) enrolled adult participants (≥18 years) of any BP status, (4) included a nonexercise/nondiet control group, and (5) were published in peer-reviewed English language journals. We included only trials with a nonexercise/nondiet control group because a major purpose of our meta-analysis was to precisely estimate the antihypertensive effects of yoga, which would not be possible with an active content control group. An active control group would constitute an intervention in and of itself and thus would underestimate the antihypertensive effects of yoga.[17] Trials were excluded if they (1) prescribed drugs/supplements, dietary change, or another type of exercise in addition to yoga or (2) involved a single yoga session (ie, a short-term intervention).

Search Strategy

Aided by a medical librarian (J.L.), we systematically searched 6 electronic databases from inception until June 4, 2018 (see Supplemental Material, Data S1, available online at http://www.mayoclinicproceedings.org). Potential relevant reports were screened in duplicate (Y.W., H.K.L., S.C.) first by title and abstract and then by full text. Reference lists of included trials, relevant meta-analyses, and reviews were manually searched for additional reports.

Data Extraction and Coded Variables

Data were extracted using our standardized coding form and coder manual,[18,19] which was adapted for yoga by an expert author of yoga practice and research (C.L.P.). Three trained coders (Y.W., R.L.A., S.C.) independently extracted and entered study information with high reliability (mean Cohen κ, 0.88; Pearson *r*, 0.90) with all disagreements resolved through discussion.

We coded characteristics related to the study design and sample (eg, location [country], body mass index). For features of the yoga intervention, we coded whether each of the 3 yoga elements was included (for coding criteria, see Supplemental Material, Data S2, available online at http://www.mayoclinicproceedings.org), with the practice time of each element in a single session when reported. In addition, we coded the frequency, intensity, and time of the yoga intervention, level of supervision, and number and credentials of the personnel who supervised yoga practice. Methodological study quality was assessed using an augmented version of the Downs and Black[20] checklist (27 items) that was scored as the percentage of items satisfied out of a possible 31-point total. Overall methodological study quality scores were grouped into low (≤15 points, <50%), moderate (>15 to 24 points, 50%-79%), or high (≥25 points, ≥80%).[21,22] Risk of bias was assessed using the Cochrane risk of bias tool.[23] Under the category of "other bias," we coded the time between the last session of yoga practice and the postintervention BP measurements. It is important for authors to disclose this information because if the postintervention BP measurement was taken within 24 hours after the last yoga session, the long-term BP response to yoga training or the long-term effects maybe confounded by the short-term BP effects of the last yoga session (ie, postexercise hypotension).[13,24] In addition, if the postintervention BP measurement was taken 48 hours or more after the last yoga session, detraining effects may have occurred, which also confounds the results.[25]

Effect-Size Calculation

The standardized mean difference effect size (*d*) quantified the effectiveness of yoga as an antihypertensive therapy and was calculated as the mean difference in resting SBP or DBP between the yoga and control groups after vs before intervention divided by the pooled standard deviation, correcting for small sample size bias and baseline differences between groups.[26,27] Of note, we observed considerable variability of the BP measurements (eg, BP assessment instrument, body position) across studies and the distribution of SBP (SD ranged from 1.6 to 31.0) and DBP (SD ranged from 1.9 to 13.8) among included trials.[28,29] Therefore, even though all BP values were reported in mm Hg, we chose to use standardized effect sizes, which are more robust with less bias and better efficiency compared with unstandardized effect sizes under many statistical circumstances.[30] When trials measured resting BP at multiple time points, we treated the measurement before and closest to the onset of the yoga intervention as the preintervention value and the time point after and closest to the end of the yoga intervention as the postintervention value. When trials had multiple yoga interventions, we disaggregated comparisons[18,19] and then calculated and analyzed *d*s for each comparison (*k*) as separate trials.[31] Negative *d* values indicate that yoga reduced BP more after vs before intervention compared with the control group. When reaching statistical significance ($P<.05$), *d*s were interpreted as insufficient (0 to −0.19), small (−0.20 to −0.49), medium (−0.50 to −0.79), and large (−0.80 or greater) BP reductions.[32] We also calculated the unstandardized mean effect size in mm Hg.[19]

Inconsistencies in *d* values were assessed with the *Q* statistic, which we transformed into the I^2 statistic and its confidence intervals (95% CIs).[33,34] I^2 values range from low (0%) to high (100%) heterogeneity.

Sensitivity Analyses

We used the trim and fill technique[35] as a first sensitivity analysis, which examined the asymmetry of the funnel plots, and no corrections were suggested by the test. Of note, in order to include the sample size large enough to perform meta-regression analysis, we did not restrict our sample to randomized controlled trials

(RCTs); therefore, we performed sensitivity analyses to compare the *d*s from RCTs and non-RCTs.[36] Supporting the decision to combine RCTs and non-RCTs for analyses, (1) the mean effect sizes of RCTs and non-RCTs were similar for SBP (−0.41 vs −0.42; P=.83) and DBP (−0.45 vs −0.42; P=.76), (2) the methodological study quality and risk of bias were similar between RCTs and non-RCTs (Table 1), and (3) randomization was not a significant moderator in the multiple moderator models of SBP (P=.99) or DBP (P=.96). In addition, there was no significant difference between RCTs and non-RCTs for all significant moderators of the BP responses to yoga, specifically, (1) the inclusion of yoga breathing techniques (P=.88) and yoga meditation/mental relaxation (P=.37), (2) the baseline SBP (P=.56) and DBP (P=.88), (3) the standard error of the SBP response to yoga (P=.78), and (4) the frequency of yoga practice (P=.42).

Publication Bias

We evaluated the potential for publication or other reporting biases in both SBP and DBP *d*s by (1) visually examining the distribution and asymmetry of funnel plots[37] and (2) using the tests introduced by Begg and Mazumdar[38] and Egger et al.[39] In addition, we also performed precision effect test and precision effect estimate with standard error analyses to decide if potential publication bias needed to be controlled, by including the standard error of the BP response to yoga in the multiple moderator models for SBP and DBP.[40]

Moderator Analyses

In addition to examining the different combinations of yoga elements as a moderator, we explored other characteristics related to the study design, sample, and yoga interventions. Weighted regression models with maximum likelihood estimation of the random-effects weights (ie, the inverse of the variance for each *d*) were used to explain variability in *d*s for SBP and DBP. In multiple moderator models, we examined significant or trending moderators ($P \leq .10$) from bivariate meta-regression analyses[31] in conjunction with the model coefficients and R^2 values (ie, between-study variance explained by a covariate) to determine the influence of individual moderators on the BP response to yoga.[41]

The moving constant technique[42] estimated the magnitude of the weighted mean effect size (d_+) and its 95% CI at different levels of interest for individual moderators while statistically controlling for the presence of other moderators held constant at their mean levels and arrived at an estimate, or predicted d_+, denoted as $\widehat{d}_+$.[42]

For SBP and DBP, additive models were generated from the final multiple moderator models that represented the greatest potential antihypertensive benefit from yoga. Individual moderators were assessed within the same model at the level that yielded the greatest BP reduction (ie, $\widehat{d}_+$ and 95% CI). To facilitate clinical interpretation, for each moderator dimension and level of interest, we back-converted the standardized estimate (ie, $\widehat{d}_+$) into mm Hg of BP change.[30]

Statistical Analyses

Analyses were performed using Stata statistical software, version 13.1 (StataCorp) with macros for meta-analysis[31,43] and incorporated random-effects assumptions. Stata

TABLE 1. Comparison of Methodological Study Quality and Risk of Bias Between RCTs and non-RCTs[a,b]

Variable	RCTs (k=41)	Non-RCTs (k=15)	P value
Methodological study quality (%)	60.5±16.2	56.6±12.2	.40
Risk of bias			
Selection bias			
Random sequence generation	41 (100.0)	0 (0.0)	NA
Allocation concealment	34 (82.9)	NA	NA
Performance bias	41 (100.0)	15 (100.0)	NA
Detection bias	38 (92.7)	15 (100.0)	.28
Attrition bias	16 (39.0)	9 (60.0)	.16
Reporting bias	4 (9.8)	2 (13.3)	.70
Other bias			
Posintervention BP measurement	38 (92.7)	15 (100.0)	.28

[a]BP = blood pressure; NA = not applicable; RCT = randomized controlled trial.
[b]Summary statistics are based on 56 yoga interventions (k) and are presented as mean ± SD for continuous variables and No. (percentage) of observations for categorical variables.

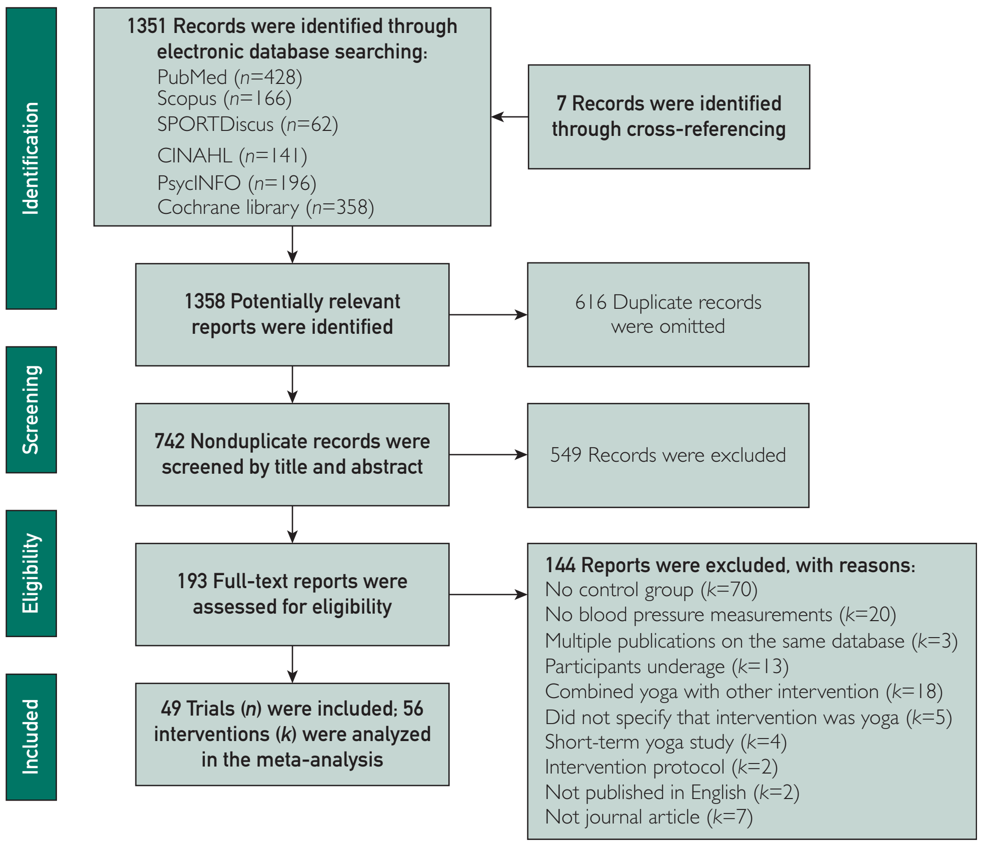

FIGURE. Flowchart detailing the systematic search of potential reports and selection process of included yoga trials (*n*) and interventions (*k*).

commands are listed in Supplemental Material, Data S3 (available online at http://www.mayoclinicproceedings.org). Descriptive statistics are reported as mean ± SD unless stated otherwise. The 2-sided significance level was $P<.05$.

RESULTS

We identified 49 controlled yoga trials that satisfied the inclusion criteria (Figure).[28,29,44-90] Seven trials involved 2 yoga groups, yielding 56 total interventions.

Study Characteristics

The articles reporting the 56 yoga interventions were published between October 1, 1983, and March 1, 2018 (mean ± SD, 2010±8 years). They included 10 to 238 participants (62±50) and were conducted in India (42.9%, k=24), non-Indian Asian countries (eg, South Korea, 16.1%, k=9), or non-Asian countries (eg, United States, 41.1%, k=23). Most were RCTs (73.2%, k=41) and examined BP as a primary outcome (73.2%, k=41). On average, the yoga interventions achieved "moderate" methodological study quality on the augmented Downs and Black[20] checklist (59.5%±15.2%) despite widely varying scores (30.6%-93.5%). The interventions also exhibited high levels of risk of bias based on the Cochrane risk of bias tool.[23] In particular, most of the interventions did not report any methods (1) to conceal group allocation after randomization (82.9%), (2) to blind investigators to the group allocation (94.6%), and (3) to differentiate the BP response to the last yoga session or short-term effects from the long-term BP response to yoga training or long-term effects

Mayo Clin Proc. ■ March 2019;94(3):432-446 ■ https://doi.org/10.1016/j.mayocp.2018.09.023
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(94.6%). Supporting our decision to include RCTs and non-RCTs, the methodological study quality and the risk of bias were similar between RCTs and non-RCTs (Table 1).

Sample Characteristics

Baseline sample characteristics were similar between the yoga (n=1780) and control (n=1737) groups (P>.05) (Supplemental Material, Data S4, available online at http://www.mayoclinicproceedings.org). On average, participants (N=3517) were middle-aged (49.2±19.5 years), overweight (27.9±3.6 kg/m^2) adults with prehypertension to established hypertension by the seventh Joint National Committee BP scheme[1] (SBP, 129.3±13.3 mm Hg; DBP, 80.7±8.4 mm Hg). Among our sample, based on baseline BP values and use of BP medications,[1] 16 of the 56 interventions (28.6%) involved participants with normal BP (n=730) (mean ± SD SBP/DBP, 115±5/74±4 mm Hg), 25 (44.6%) involved participants with prehypertension (n=1742) (mean ± SD SBP/DBP, 129±6/80±4 mm Hg), and 15 (26.8%) involved participants with hypertension (n=993) (mean ± SD SBP/DBP, 147±6/90±8 mm Hg). When reported, interventions involved healthy adults (k=14, 25.0%) with no reported diseases or health conditions, adults with CVD or CVD risk factors (k=28, 50.0%), or non−CVD-related conditions or diseases (k=4, 7.1%) (Supplemental Material, Data S4). Few interventions (k=16, 28.6%) reported BP medication use; of these, participants were not taking medication (k=8, 14.3%), the majority of the participants (85.0%-96.7%) were taking on average 1 to 2 types of BP medication (k=4, 7.1%), or various portions (1.2%-100.0%) of participants were taking medications for purposes such as lowering glucose levels or managing anxiety/depression (k=4, 7.1%).

Yoga Intervention Features

On average, yoga was practiced 4.8±3.4 sessions per week for 59.2±25.01 minutes per session for 13.2±7.5 weeks (Table 2). Most of the interventions (91.1%, k=51) included supervised yoga training or combined it with unsupervised yoga training. Among the remaining 5 interventions that included only unsupervised yoga practice, 3 had personnel who taught participants the yoga practice at the beginning of the intervention, then proceeded with unsupervised practice at home and 2 gave participants audio recordings to use during unsupervised practice. Among the 51 interventions that had supervised yoga practice, the majority (72.5%, k=37) reported yoga-related credentials for the personnel who supervised yoga practice (eg, certified yoga instructor), while others did not disclose any yoga-related credentials (eg, study physician). Most interventions (83.9%, k=47) involved more than 1 of the 3 yoga elements, with 64.3% (k=36) having 3 and 19.6% (k=11) having 2. Yet, only 53.6% (k=30) of the interventions reported the practicing time for the yoga elements. On average, when reported, participants performed physical postures for 31.9±21.7 minutes, breathing techniques for 16.2±12.7 minutes, and meditation/mental relaxation for 17.1±15.2 minutes in each yoga training session.

Resting BP Assessment

Most interventions (71.4%, k=40) reported the BP assessment instrument, including automated/digital units (33.9%, k=19) or manual sphygmomanometers (37.5%, k=21). More than half of the interventions (60.7%, k=34) reported the body position during the BP assessment, including seated (39.3%, k=22) or supine (21.4%, k=12). Only a few trials (5.4%, k=3) reported the time between the postintervention BP measurement and the last session of yoga practice. In addition, 8 interventions (14.3%) did not report any details of the resting BP assessment procedures.

Yoga as Stand-Alone Antihypertensive Therapy

Overall, yoga elicited moderate reductions in SBP (d_+, 0.47; 95% CI, 0.62-0.32; 5.0 mm Hg) and DBP (d_+, 0.47; 95% CI, 0.61-0.32; 3.9 mm Hg) than control (P<.001) (Supplemental Material, Data S5, available

TABLE 2. Features of Included Yoga Interventions (k=56)[a,b]

Program characteristics	k	Value	Range
Supervision			
Supervised only	40	71.4%	NA
Supervised and unsupervised	11	19.6%	NA
Unsupervised only	5	8.9%	NA
FIT of yoga interventions			
Frequency (sessions/wk)			
Supervised only	39	4.2±3.0	1.0-14.0
Supervised and unsupervised	11	5.4±3.2	3.0-14.0
Unsupervised only	4	9.6±5.1	5.0-14.0
Time (min/session)			
Supervised	38	59.9±22.7	20.0-90.0
Supervised and unsupervised	10	70.0±26.1	17.5-120.0
Unsupervised only	4	23.1±10.7	15.0-37.5
Length of intervention (wk)	56	13.2±7.5	4.0-52.0
Personnel who supervised yoga practice			
No. of personnel supervising practice	33	1.4±0.69	1.0-3.0
Description of personnel supervising practice			
Reported clear yoga-related credentials	37	66.1%	NA
Did not report any yoga-related credentials or no personnel supervised practice	14	25.0%	NA
Yoga elements			
Physical posture included	49	NA	NA
Time of physical posture (min/session)	28	31.9±21.7	4.0-75.0
Breathing techniques included	39	NA	NA
Time of breathing techniques (min/session)	29	16.2±12.7	3.0-50.0
Meditation/mental relaxation included	38	NA	NA
Time of meditation/mental relaxation (min/session)	28	17.1±15.2	5.0-60.0

[a]FIT = frequency, intensity, time; NA = not applicable.
[b]Summary statistics are based on 56 yoga interventions (k) and are presented as mean ± SD unless otherwise stated. Range represents the minimum and maximum values reported for the item.

online at http://www.mayoclinicproceedings.org), and the effect sizes for SBP (I^2, 77.2%; 95% CI, 70.7%-82.3%) and DBP (I^2, 71.5%; 95% CI, 62.4%-78.4%) lacked homogeneity.

Publication Bias

Both the funnel plot and the Begg test suggested that there was significant publication bias for the SBP response to yoga (Begg test z score, −2.25; P=.03) but not the DBP response to yoga (Begg test z score, −1.91; P=.06).[37,38] Meanwhile, no publication bias was identified by the Egger test for the SBP (t, −1.54; P=.13) or the DBP (t, −0.88; P=.38) response to yoga.[39] Following the precision effect test and precision effect estimate with standard error[40] analysis, potential publication bias was apparent (P=.04) only for the SBP response to yoga; thus, it was controlled in the multiple moderator model.

Moderator Analyses: Multiple Moderator Models

When controlling for publication bias, SBP reductions were greater among yoga interventions that included breathing techniques (7.9 mm Hg) than interventions that did not (2.7 mm Hg; P=.02) (Table 3). In addition, SBP was reduced more in samples with the highest baseline SBP (P=.006): 8.7 mm Hg for samples with hypertension, 5.2 mm Hg for samples with prehypertension, and 2.6 mm Hg for samples with normal BP. Finally, SBP reductions were largest among interventions with lower methodological study quality, as evaluated by the Downs and Black[20] checklist (P=.004):

TABLE 3. Multiple Moderator and Additive Models: SBP Response to Yoga (k=56)[a,b]

Moderator dimension/level	$\widehat{d}_+$ (95% CI)	β	P value	SBP Δ (mm Hg)
Included yoga breathing techniques		−0.260	.02	
Yes (k=44)	−0.61 (−0.76 to −0.45)			−7.9 (−9.9 to −5.9)
No (k=12)	−0.21 (−0.50 to 0.08)			−2.7 (−6.5 to 1.0)
Baseline SBP of sample (mm Hg)		−0.294	.006	
Normal, 115±5 (k=16)	−0.20 (−0.43, 0.03)			−2.6 (−5.6 to 0.4)
Prehypertension, 129±6 (k=25)	−0.40 (−0.57 to −0.24)			−5.2 (−7.4 to −3.1)
Hypertension, 147±6 (k=15)	−0.67 (−0.91 to −0.42)			−8.7 (−11.8 to −5.5)
Methodological study quality (% satisfied)		0.325	.004	
Lowest tier, 42±7 (k=16)	−0.65 (−0.88 to −0.42)			−8.5 (−11.4 to −5.5)
Middle tier, 57±5 (k=20)	−0.44 (−0.61 to −0.28)			−5.7 (−7.9 to −3.6)
Highest tier, 76±7 (k=20)	−0.18 (−0.41 to 0.05)			−2.3 (−5.3 to 0.7)
Publication bias		−0.245	.04	
Additive model: (1) among samples with hypertension; (2) among trials with average methodological study quality; and (3) controlling for publication bias:				
Yoga breathing techniques were included	−0.87 (−1.12 to −0.62)			−11.3 (−14.6 to −8.1)
Yoga breathing techniques were not included	−0.47 (−0.80 to −0.14)			−6.1 (−10.4 to −1.8)

[a]β = standardized coefficient represents unique variance explained by moderator; Δ = change; k = No. of observations; SBP = systolic blood pressure.
[b]Effect sizes (ds) are regressed simultaneously on the 4 moderators; the predicted weighted mean effect size ($\widehat{d}_+$) is estimated holding the other moderators constant at their means. Resting SBP and methodological study quality are presented as mean ± SD. Multiple R^2 (variance explained by model, adjusted for number of moderators), 34.1%.

8.5 mm Hg among interventions ranked in the lowest tier (ie, the lowest 28.6%) among our sample, 5.7 mm Hg among interventions ranked in the middle tier (ie, the middle 35.7%), and 2.3 mm Hg among interventions ranked in the highest tier (ie, the highest 35.7%). Collectively, these moderators accounted for 34.1% of the variance in the SBP response to yoga. The additive statistical model (Table 3) revealed that after controlling for methodological study quality and publication bias, yoga interventions that included breathing techniques can elicit SBP reductions as large as 11.3 mm Hg among samples with hypertension.

Diastolic BP reductions were greater among yoga interventions that included yoga meditation/mental relaxation (4.3 mm Hg) than interventions that did not (1.6 mm Hg; P=.03) and among interventions that practiced yoga more than 3 sessions per week (3.6 mm Hg) than yoga interventions that practiced yoga 1 to 3 sessions per week (2.4 mm Hg; P=.04) (Table 4). In addition, DBP was reduced more in samples with the highest baseline DBP (P=.003): 4.8 mm Hg for samples with hypertension, 2.8 mm Hg for samples with prehypertension, and 1.6 mm Hg for samples with normal BP. Finally, DBP reductions were largest among interventions with lower methodological study quality evaluated by the Downs and Black[20] checklist (P=.005): 4.6 mm Hg among interventions ranked in the lowest tier (ie, the lowest 31.4%); 3.2 mm Hg among interventions ranked in the middle tier (ie, the middle 37.2%); and 1.4 mm Hg among interventions ranked in the highest tier (ie, the highest 31.4%). Collectively, these moderators accounted for 34.5% of the variance in the DBP response to yoga. The additive statistical models (Table 4) revealed that after controlling for methodological study quality and when yoga was practiced at 3 sessions per week, yoga interventions that included meditation/mental relaxation can elicit DBP reductions as large as 5.5 mm Hg among samples with hypertension.

DISCUSSION

Our meta-analysis aimed to provide precise estimates of the antihypertensive effects of yoga by performing meta-regression analysis examining multiple moderators simultaneously. In particular, we aimed to identify which combination of yoga elements yields the greatest BP-lowering effects. On average,

TABLE 4. Multiple Moderator and Additive Models: DBP Response to Yoga (k=51)[a,b]

Moderator dimension/level	$\widehat{d}_+$ (95% CI)	β	P value	DBP Δ (mm Hg)
Included yoga meditation/mental relaxation		−0.251	.03	
Yes (k=40)	−0.54 (−0.68 to −0.39)			−4.3 (−5.4 to −3.1)
No (k=11)	−0.20 (−0.46 to 0.07)			−1.6 (−3.7 to 0.6)
Frequency of yoga practice (sessions/wk)		−0.247	.04	
1-3 (k=27)	−0.30 (−0.47 to −0.13)			−2.4 (−3.8 to −1.0)
≥4 (k=24)	−0.45 (−0.62 to −0.29)			−3.6 (−5.0 to −2.3)
Baseline DBP of sample (mm Hg)		−0.340	.003	
Normal, 74±4 (k=16)	−0.20 (−0.39 to −0.02)			−1.6 (−3.1 to −0.2)
Prehypertension, 80±4 (k=21)	−0.35 (−0.50 to −0.20)			−2.8 (−4.0 to −1.6)
Hypertension, 90±8 (k=14)	−0.60 (−0.81 to −0.39)			−4.8 (−6.5 to −3.1)
Methodological study quality (% satisfied)		0.313	.005	
Lowest tier, 42±7 (k=16)	−0.58 (−0.80 to −0.36)			−4.6 (−6.4 to −2.9)
Middle tier, 57±5 (k=19)	−0.40 (−0.55 to −0.24)			−3.2 (−4.4 to −1.9)
Highest tier, 76±7 (k=16)	−0.17 (−0.36 to 0.03)			−1.4 (−2.9 to 0.2)
Additive Models: (1) among samples with hypertension; (2) among interventions with average methodological study quality; and (3) when yoga was practiced at 3 sessions/wk:				
Yoga meditation/mental relaxation was included	−0.69 (−0.92 to −0.47)			−5.5 (−7.4 to −3.8)
Yoga meditation/mental relaxation was not included	−0.36 (−0.68 to −0.03)			−2.9 (−5.4 to −0.2)

[a]β = standardized coefficient represents unique variance explained by moderator; DBP = diastolic blood pressure; Δ = change; k = No. of observations.
[b]Effect sizes (ds) are regressed simultaneously on the 4 moderators; the predicted weighted mean effect size ($\widehat{d}_+$) is estimated holding the other moderators constant at their means. Resting DBP and methodological study quality are presented as mean ± SD. Multiple R^2 (variance explained by model, adjusted for No. of moderators), 34.5%.

we found that yoga interventions that were practiced approximately 5 sessions per week for about 60 minutes per session for approximately 13 weeks produced BP reductions of about 4 to 5 mm Hg. However, after controlling for publication bias and methodological study quality, our novel and most clinically relevant findings were that when yoga was practiced 3 sessions per week among samples with hypertension, yoga interventions that included breathing techniques and meditation/mental relaxation elicited SBP/DBP reductions of −11/−6 mm Hg compared with those that did not (ie, −6/−3 mm Hg). Our findings support the use of yoga, when both breathing techniques and meditation/mental relaxation are included, as a viable alternative lifestyle option to treat hypertension because the magnitude of these BP reductions rival those of antihypertensive medications and can reduce the risk of CVD by nearly 50%.[91]

Currently, aerobic exercise is the primary form of exercise recommended by professional organizations throughout the world to treat hypertension.[92] However, only 28% of adults with high BP adhere to the current exercise recommendations for hypertension.[93] Therefore, our findings are encouraging for 2 main reasons. First, the potential BP reductions as large as approximately 11/6 mm Hg from practicing yoga at 3 sessions per week equal or exceed the magnitude of those reported for aerobic exercise training.[92,94] Second, individuals with hypertension may have better adherence to yoga because it is low impact, is enjoyable, and promotes social interaction.[95-99] Indeed, the number of yoga practitioners continues to increase because of the appeal of yoga as an alternative form of physical activity for people who are resistant to or unable to engage in aerobic exercise training.[100] In addition, yoga provides various physiologic (eg, reduced back pain, improved flexibility) and psychological (eg, stress reduction) health benefits, some of which are distinct from more traditional forms of exercise (eg, spirituality).[95,101-103] Nonetheless, whether yoga antihypertensive lifestyle therapy is superior to more traditional types of exercise (ie, aerobic, dynamic resistance exercise) is still open to debate until our findings are validated in future RCTs.

Our meta-analysis also identified several moderators of the BP responses to yoga that deserve further comments. The first novel findings were that (1) SBP reductions were larger among interventions that included breathing techniques (about 8 mm Hg) than interventions that did not (approximately 3 mm Hg) and (2) DBP reductions were larger among interventions that included meditation/mental relaxation (about 4 mm Hg) than interventions that did not (approximately 2 mm Hg). We found that the inclusion of physical postures was not a significant moderator, likely because there were so few (k = 7; 12.5%) that did not include physical postures, limiting the statistical power to detect a difference. Two previous meta-analyses also investigated the influence of yoga elements on BP responses. Cramer et al[12] found that only yoga interventions that did not include physical postures elicited significant BP reductions (about 3-7 mm Hg) vs control, while Hagins et al[11] concluded that only yoga interventions with all 3 yoga elements elicited significant BP reductions (approximately 6-8 mm Hg) vs control. The exact reasons for the differences in results reported by Cramer et al[12] and Haggins et al[11] and our findings are unknown. Yet, only our results demonstrated that adding yoga breathing techniques and meditation/mental relaxation can independently increase the SBP and DBP reductions by about 5 mm Hg and 2 mm Hg, even after parsing out the influence from baseline BP, frequency of yoga practice, methodological study quality, and publication bias. Meanwhile, in previous meta-analyses, the differences of BP reductions between subgroups, created on the basis of the inclusion of different yoga elements, likely resulted from the inclusion of different yoga elements combined with other moderators of the BP response to yoga.[14-16,41]

Our second finding was that BP reductions were the largest among interventions that involved samples with hypertension (SBP/DBP, approximately 9/5 mm Hg), followed by prehypertension (about 5/3 mm Hg) and samples with normal BP (approximately 3/2 mm Hg).[1] This finding is consistent with the law of initial values,[24] that the magnitude of the response is directly related to the initial level of the health outcome being measured. Similar to our findings, Cramer et al[12] found that only interventions involving samples with hypertension elicited significant and large BP reductions (SBP/DBP, 14/11 mm Hg), while interventions involving mixed samples with both prehypertension and hypertension elicited insignificant and small BP reduction (SBP/DBP, 0.9/0.1 mm Hg). However, it should be noted that our results, although more conservative than those of Cramer et al,[12] may be a more precise representation of the influence of baseline BP over the BP responses to yoga. Our meta-analysis included samples with various BP statuses (28.6% with normal BP, 44.6% with prehypertension, and 26.8% with hypertension) and examined actual baseline BP values as a continuous variable with other moderators in a single meta-regression model.[14-16] As a result, our meta-analysis is the first to demonstrate conclusively a dose-response effect for the BP response to yoga, supporting that its antihypertensive effects, as with other more traditional forms of exercise, are greater for individuals with higher BP.[92,104]

Our third new finding was that DBP reductions were larger among interventions that prescribed yoga practice more than 3 sessions per week (about 4 mm Hg) than interventions that practiced yoga 1 to 3 sessions per week (approximately 2 mm Hg). Our results are in line with the current exercise recommendations for hypertension[92,104] that higher frequency of exercise is recommended for individuals with hypertension. Of note, in the DBP additive model (Table 4), when estimating the effects of yoga practice frequency at 3 sessions per week, a more conservative BP reduction resulted compared with those of a higher frequency. Nonetheless, our results remained generalizable to the general population because 3 sessions per week is the most common frequency of yoga practice (30.4%, k=17) among our sample.

In addition, Ross et al[105] investigated the frequency of yoga practice in the United States and found that 3 sessions per week is achievable by average yoga practitioners (ie, individuals who practice yoga <5 sessions per week).

Finally, we also found that BP reductions were largest among interventions that ranked in the lowest tier on methodological study quality, evaluated by the Downs and Black[20] checklist, among our sample (SBP/DBP, about 9/5 mm Hg), followed by the interventions that ranked in the middle tier (6/3 mm Hg) and interventions that ranked in the highest tier (2/1 mm Hg). The exact reasons for this finding are not clear; however, we observed that interventions with lower methodological study quality were more likely to have smaller sample size (r, −0.34; P=.01), have been more often conducted in India (r, 0.39; P<.001), and had not included physical postures (r, 0.28; P=.04).

It should be noted that, overall, the included yoga interventions were of moderate methodological study quality (eg, 59.5% of items satisfied on the Downs and Black[20] inventory). Following the Grading of Recommendations Assessment, Development and Evaluation approach,[106,107] we recommend that readers place moderate certainty in the results because included yoga trials exhibited (1) a high risk of bias (see Table 1), (2) high levels of heterogeneity (ie, I^2 ranged from 71.5% to 77.2%), and (3) some evidence of publication bias, especially in relation to SBP. Although our multiple moderator models explained a clinically meaningful portion of the variance of the SBP (34.1%) and DBP (34.5%) responses to yoga, it was not surprising to see that these models left a large amount of variance in effects unexplained. We also evaluated 16 other potential sources of influence (Supplemental Material, Data S6, available online at http://www.mayoclinicproceedings.org) and found that these factors were unrelated to the BP responses to yoga. Nonetheless, it is possible that some investigators from the included yoga trials may have inadvertently omitted details of their studies (ie, what yoga elements were included) because of space limitations or for other unknown reasons, which limited our ability to extract such information and perform analyses. We also acknowledge that additional unidentified moderators may exist in this literature. For example, several potentially important moderators could not be investigated because they were not adequately disclosed, such as the intensity (3.6%, k=2) and pace (19.6%, k=11) of yoga practice when physical postures were included and medication use (28.6%, k=16). Another limitation of our study was that we included only studies published in the English language. However, our study included interventions from 11 different countries (a proxy of publishing language); meanwhile, study location (ie, India vs non-Indian Asian countries vs non-Asian countries) was not a significant moderator in the SBP (P=.07) or DBP (P=.16) multiple moderator models. Nonetheless, we acknowledge that by including interventions published in non-English languages, we may have had more statistical power to precisely estimate the antihypertensive effect of yoga.

Our meta-analyses also had several strengths. First, instead of subgroup analysis, we performed meta-regression analysis (ie, examining multiple moderators of the BP responses to yoga simultaneously).[14-16] Therefore, compared with previous meta-analyses, our results (1) fit better with the nature of the BP response to exercise, which is influenced by multiple factors simultaneously,[13] and (2) identified the unique variance in the BP response to yoga explained by each moderator (eg, inclusion of yoga elements).[15,16,36,41] Second, the use of contemporary statistical strategies, in particular the moving constant technique,[42] allowed us to estimate the magnitude of BP reduction at different clinically significant levels of the individual moderators.

CONCLUSION

Our meta-analysis supports the use of yoga as a viable, stand-alone lifestyle therapeutic option to treat hypertension. We found that when practiced 3 sessions per week

Mayo Clin Proc. ■ March 2019;94(3):432-446 ■ https://doi.org/10.1016/j.mayocp.2018.09.023
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and including both yoga breathing techniques and meditation/mental relaxation, yoga can elicit SBP/DBP reductions as large as 11/6 mm Hg among individuals with hypertension, which doubles the BP reductions resulting from interventions that do not (ie, 6/3 mm Hg). Blood pressure reductions of this magnitude rival or exceed those reported to result from aerobic exercise, the primary type of exercise currently recommended for adults with hypertension, and suggest that current exercise recommendations should be expanded to include yoga. Despite these encouraging findings, additional RCTs are needed that directly compare yoga to the current recommended forms of exercise for hypertension to better inform the evidence-based recommendations that can be made regarding the use of yoga as antihypertensive lifestyle therapy.

SUPPLEMENTAL ONLINE MATERIAL

Supplemental material can be found online at http://www.mayoclinicproceedings.org. Supplemental material attached to journal articles has not been edited, and the authors take responsibility for the accuracy of all data.

Abbreviations and Acronyms: **AHA** = American Heart Association; **BP** = blood pressure; **CVD** = cardiovascular disease; ***d*** = standardized mean difference effect size; $\boldsymbol{d_+}$ = weighted mean effect size; $\hat{d}_+$ = estimated d_+; **DBP** = diastolic BP; **RCT** = randomized controlled trial; **SBP** = systolic blood pressure

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Grant Support: This work was supported in part by the National Institutes of Health Science of Behavior Change Common Fund Program through an award administered by the National Institute on Ageing (5U24AG052175) and the University of Connecticut Center for Excellence in Teaching and Learning.

Potential Competing Interests: The authors report no competing interests.

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