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The effectiveness of yoga in modifying risk factors for cardiovascular disease and metabolic syndrome: A systematic review and meta-analysis of randomized controlled trials

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Abstract

Background: Yoga, a popular mind-body practice, may produce changes in cardiovascular disease (CVD) and metabolic syndrome risk factors.

Design: This was a systematic review and random-effects meta-analysis of randomized controlled trials (RCTs).

Methods: Electronic searches of MEDLINE, EMBASE, CINAHL, PsycINFO, and The Cochrane Central Register of Controlled Trials were performed for systematic reviews and RCTs through December 2013. Studies were included if they were English, peer-reviewed, focused on asana-based yoga in adults, and reported relevant outcomes. Two reviewers independently selected articles and assessed quality using Cochrane's Risk of Bias tool.

Results: Out of 1404 records, 37 RCTs were included in the systematic review and 32 in the meta-analysis. Compared to non-exercise controls, yoga showed significant improvement for body mass index (−0.77 kg/m^2 (95% confidence interval −1.09 to −0.44)), systolic blood pressure (−5.21 mmHg (−8.01 to −2.42)), low-density lipoprotein cholesterol (−12.14 mg/dl (−21.80 to −2.48)), and high-density lipoprotein cholesterol (3.20 mg/dl (1.86 to 4.54)). Significant changes were seen in body weight (−2.32 kg (−4.33 to −0.37)), diastolic blood pressure (−4.98 mmHg (−7.17 to −2.80)), total cholesterol (−18.48 mg/dl (−29.16 to −7.80)), triglycerides (−25.89 mg/dl (−36.19 to −15.60), and heart rate (−5.27 beats/min (−9.55 to −1.00)), but not fasting blood glucose (−5.91 mg/dl (−16.32 to 4.50)) nor glycosylated hemoglobin (−0.06% Hb (−0.24 to 0.11)). No significant difference was found between yoga and exercise. One study found an impact on smoking abstinence.

Conclusions: There is promising evidence of yoga on improving cardio-metabolic health. Findings are limited by small trial sample sizes, heterogeneity, and moderate quality of RCTs.

Keywords

Yoga, cardiovascular disease, metabolic syndrome, systematic review, meta-analysis

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Introduction

Background

Cardiovascular disease (CVD) and metabolic syndrome are major public health problems in the USA and worldwide.[1,2] Metabolic syndrome is defined as having at least three metabolic risk factors – increased blood pressure, high blood sugar level, excess body fat, and abnormal cholesterol levels – and greatly increases the chance of future cardiovascular problems.[3] Lifetime risk of CVD is substantial as estimated through risk functions like those from the Framingham Heart Study,[4] underlining the need for prevention and control of risk factors.

CVD and metabolic syndrome share many of the same modifiable risk factors. Several guidelines name physical inactivity, the fourth leading risk factor of global mortality,[5] as an important modifiable risk factor for CVD and metabolic syndrome.[6–8] They state that regular and adequate levels of physical activity in adults can reduce the risk of hypertension, coronary heart disease, stroke, diabetes, and can help maintain a healthy weight. Yoga, an ancient practice from India that incorporates physical, mental, and spiritual elements, may be an effective form of physical activity.

Yoga therapy

In recent years, clinical literature has reported cardiovascular health benefits from mind-body therapies.[9–11] Yoga, one type of mind-body therapy, has been increasing in popularity in the USA and in many parts of the world. Yoga, meaning ''union'' in Sanskrit, incorporates physical, mental, and spiritual elements. In the West, Hatha yoga, one style of yoga, has been most commonly practiced. Hatha yoga consists of a series of physical exercises that focus on stretching and stimulating the spine and muscles in coordination with breath control, thought to stabilize the hypothalamic-pituitary-adrenal axis and sympathoadrenal activity.[12–14] According to the 2007 National Health Interview Survey, about 20% of the US population used some form of mind-body practice.[15] Another study estimates that about 15 million adults in America report having practiced yoga at least once in their life,[16] seeking wellness or treatment for specific health conditions.

Rationale

A 2005 Cochrane study reviewed the evidence of yoga for secondary prevention of coronary heart disease on mortality, cardiovascular events, hospital admissions, and quality of life and found no randomized controlled trials (RCTs) meeting its inclusion criteria.[17] Another review done in 2005 examined CVD clinical endpoints and insulin resistance with observational studies, uncontrolled trials, and nonrandomized controlled trials and found improvements in insulin resistance syndrome with yoga.[13] Other reviews have shown yoga to be beneficial in treatment of coronary heart disease, post-myocardial infarction rehabilitation, and hypertension.[11,13,18–22] Since this time, several new RCTs have been published. We sought to comprehensively review recent RCT evidence of the effectiveness of yoga on these risk factors and provide a pooled quantitative measure.

Objectives

Our objectives were (a) to identify and systematically evaluate the evidence on the effectiveness of yoga for modifying risk factors for CVD and metabolic syndrome in adult populations using published systematic reviews, (b) to update the evidence by conducting a systematic review of recent RCTs and (c) to estimate a summary measure of effectiveness by conducting a meta-analysis of the evidence of yoga's effectiveness versus no-exercise and exercise controls.

Methods

Data sources and search terms

The protocol for this review has been published on the PROSPERO website (http://www.crd.york.ac.uk/PROSPERO) with the registration number CRD42013006375. An amendment was added to the protocol including an exercise control group and published in an online revision note. Articles in this review were identified by accessing the following biomedical electronic databases with the assistance of a medical librarian: MEDLINE, CINAHL, Cochrane Central Register of Controlled Trials (CENTRAL), Cochrane Database of Systematic Reviews, EMBASE, and PsycINFO. Using existing published systematic reviews (SRs) as a starting point for gathering evidence, SRs and/or meta-analyses were searched through December 2013. To collect any recent data that may have been missed, we supplemented the search by searching for RCTs published in the last three years through December 2013. Citations were also retrieved by manually searching reference lists of relevant articles. The databases were searched using the keywords ''yoga'' and ''systematic review'' for published SRs and ''yoga'' and ''randomized controlled trials'' for recent RCTs (see online Supplementary Table S1 for search strategies).

Study selection and inclusion process

Records were pooled from the various databases. Titles and abstracts of SRs that appeared to meet the inclusion criteria were retrieved for further evaluation. Systematic reviews were defined as articles that included an explicit and repeatable literature search method and had explicit and repeatable inclusion and exclusion criteria for studies. RCTs included in the SRs were then retrieved. The process was repeated for the supplementary search of RCTs.

For inclusion in our SR, the studies had to be published in English in a peer-reviewed journal, be conducted in adults (18+ years) who were either healthy, at risk, or with a history of CVD or metabolic syndrome and no other major comorbidities, test an asana- (or posture-) based intervention, and report relevant outcomes. We focused only on SRs that included at least one randomized controlled trial with yoga therapy as a trial arm. No restrictions were placed on style of yoga practiced, frequency, or duration. Articles were excluded if we were unable to isolate the effect of yoga (i.e. yoga was part of a multimodal intervention whose non-yoga components were given to the active intervention group but not to the control group), outcomes reported only psychosocial risk factors or psychological outcomes like stress and anxiety, and the population treated focused on other conditions or comorbidities (e.g. women with breast cancer, populations with renal disease). Two investigators (PC and RG) independently selected studies for inclusion; disagreements were resolved by discussion.

Outcomes

The outcomes of interest were changes in the levels of modifiable risk factors for CVD and metabolic syndrome. Particularly, we were interested in measures of body composition, blood pressure, lipid panel, glycemic control, heart rate, and smoking status. Primary outcomes include body mass index (BMI), systolic blood pressure (SBP), low-density lipoprotein cholesterol (LDL-C), and high-density lipoprotein cholesterol (HDL-C). Other outcomes – body weight, diastolic blood pressure (DBP), total cholesterol (TC), triglycerides (TG), fasting blood glucose (FBG), glycosylated hemoglobin (HbA1c), heart rate, and smoking status – were considered secondary outcomes. Outcomes were kept in their natural units.

Data extraction and quality assessment

From each eligible study we extracted the characteristics of the participants, intervention description (type, length of session, frequency), control group description, duration of follow-up, number of patients randomized at baseline and number at follow-up, and effect measures (pre- and post-mean and standard deviations in intervention and control arms, mean change scores and standard deviations if reported). Data from the longest follow-up was extracted. Data extraction was performed by one investigator (PC) and checked for accuracy and completeness by a second reviewer (RG). Any discrepancies were resolved by discussion.

RCTs were appraised using the Cochrane Collaboration's Risk of Bias (ROB) tool, a commonly used tool to assess risk of bias.[23] Trial quality was evaluated by using categories of high, low, or unclear risk in regards to randomization method, allocation concealment, blinding of study personnel and outcomes assessment, attrition, and reporting methods. Two reviewers (PC and RG) independently evaluated RCT quality and resolved any discrepancies by discussion.

Statistical analysis

Change scores, mean differences (MDs) between treatment arms, and sample sizes reported were on an intention-to-treat basis. MDs were calculated by subtracting the change score in the control group from the change score in the yoga group. Where MDs and standard deviations were not reported, standard deviations were calculated using a conservative correlation coefficient of 0.5 for within-patient correlation from baseline to follow-up. MDs between groups and 95% confidence intervals (CIs) were calculated for each outcome.

The magnitude of heterogeneity was evaluated using the I^2 statistic testing the null hypothesis that all studies are evaluating the same effect.[24] I^2 values of 25%, 50%, and 75% correspond to low, moderate, and high heterogeneity, respectively. Because meta-analysis pools studies that are clinically and methodologically diverse, data on MDs from trials were statistically pooled using a random effects model.[25] We also categorized patients into four subgroups based on patient conditions – healthy, with CVD risk factors, with diabetes or metabolic syndrome, and diagnosed with coronary artery disease (CAD) – to depict heterogeneity in the populations included and their response to treatment. Healthy patients are those free of clinical manifestations of any medical or psychiatric illness including clinically significant CVD and diabetes mellitus. Those with CVD risk factors included patients with hypertension, high cholesterol levels, obesity, and current smokers. Diabetes and metabolic syndrome were diagnosed through medical examination or history, and CAD was confirmed through angiography.

Controls were separated into aerobic exercise (physical training, aerobic exercise, cycling, running, brisk walking) and non-aerobic exercise groups. Yoga was compared to these two control groups separately to

obtain an estimate of its effectiveness versus active controls and versus non-active controls (details published in protocol amendment). Reference Manager (RevMan) Version 5.2 software from the Cochrane Collaboration was used for data analysis.[26]

Publication bias

Publication bias was assessed for each of the primary outcomes by visual inspection of funnel plots generated using RevMan software. The MDs were plotted on the *x*-axis and the standard errors, a measure of study size, on the *y*-axis. In the absence of bias, the scatterplot should be approximately symmetrical; the more asymmetry, the more bias is present.

Results

Literature search

We identified 643 studies from the SR search and 761 studies from the RCT search for a total of 1404 records (Figure 1). After removal of duplicates, a total of 880 titles and abstracts were screened. A total of 37 RCTs (24 RCTs from 18 SRs and 13 additional RCTs) met our criteria for inclusion in the review. Although 37 studies met criteria, five studies did not report exact numbers for our primary or secondary outcomes and could not be included in the meta-analysis,[27–31] leaving 32 studies for statistical analysis.

Study quality

Study quality and description of methodology varied amongst the included studies (see Table 1). Thirteen studies[32–43] provided details on the specific randomization method that was used in the RCT and four[31,35,37,38] described treatment assignment. Due to the nature of the intervention, all studies had high risk of bias for blinding of participants; however, three studies reported blinding of the personnel, indicating that technicians were blinded to treatment assignment of individuals.[34,44,45] Almost all studies except one[34] had unclear risk for blinding of outcome

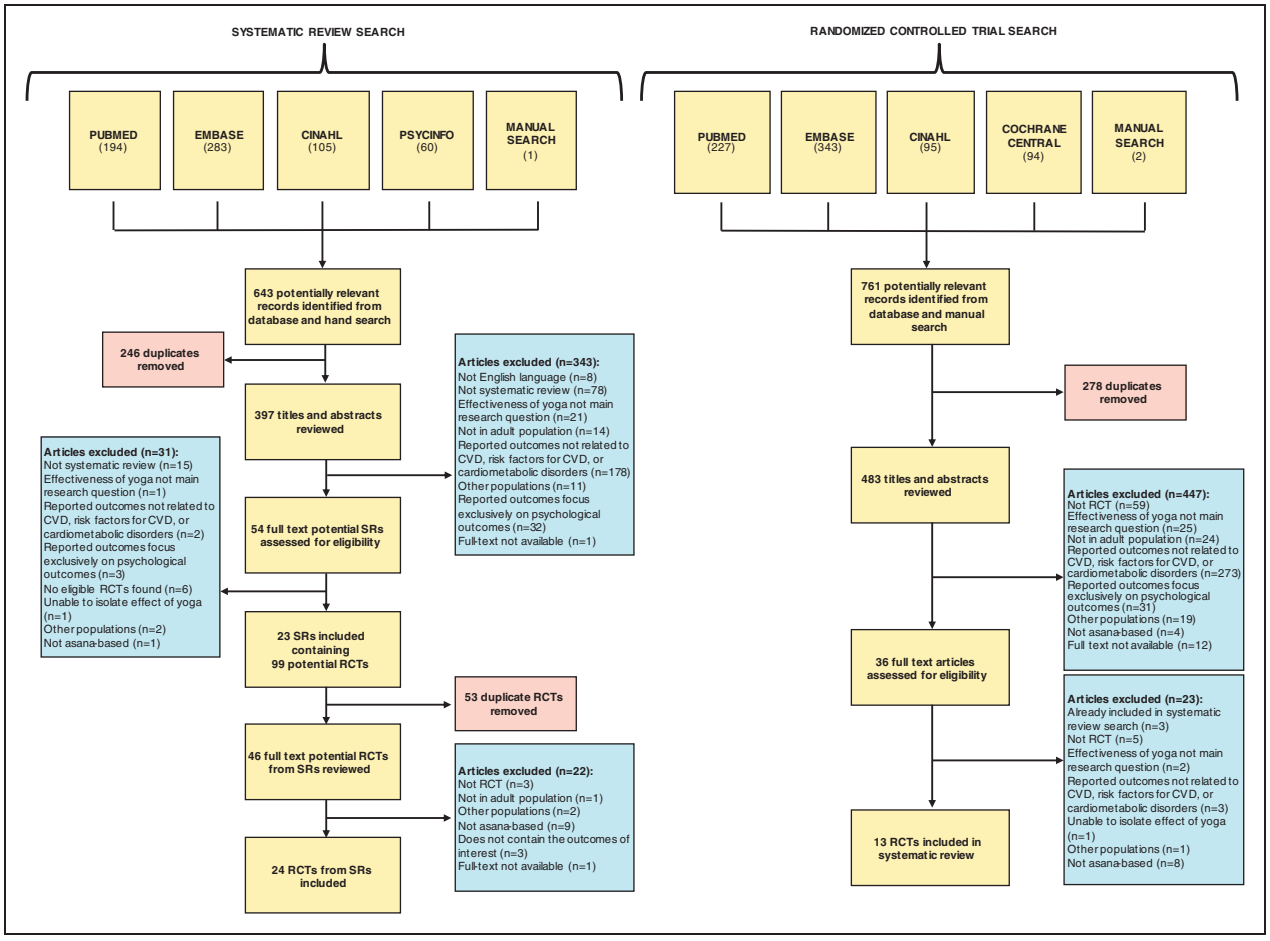


Figure 1. Flowchart depicting the search and screening process of systematic reviews and randomized controlled trials (RCTs). CVD: cardiovascular disease.

Table 1. Included randomized controlled trial study characteristics by population.

Study	From SR	Total no. randomized (yoga/control) Total no. at follow-up (yoga/control)	Treatment group	Mean age ± SD Age range	% female	Intervention Time per session	Control	Frequency Duration	Outcome measures	Study quality[a] No. of domains at low/unclear/high risk
Healthy adults										
Blumenthal et al. (1989)[27,b]	Patel et al. (2012),[60] Roland et al. (2011)[61]	101 (34/33/34) 97 (34/31/32)	Community dwelling elderly with no CAD	Yoga 67.8 ± 5.9, control 66.5 ± 4.3 (1), 66.8 ± 4.3 (2) Range: 60–83	50	Yoga and flexibility 60 min	1. Aerobic exercise (warm up, cycle, brisk walking/jogging, cool down) 60 min 2. Waiting list	2x/week 16 weeks	BW, SBP, DBP, TC, LDL-C, HDL-C	2/3/1
Cusumano et al. (1993)[12]	Innes et al. (2005)[13]	90 (45/45) 90 (45/45)	Female Japanese under-graduates	Range: 18–20	100	Hatha yoga 80 min	Jacobsen progressive muscle relaxation	1x/week 3 weeks	HR	2/3/1
Bowman et al. (1997)[46]	Innes et al. (2005),[13] Patel et al. (2012),[60] Roland et al. (2011),[61] Ross et al. (2010)[22]	40 (20/20) 26 (12/14)	Healthy sedentary elderly	68 Range: 62–81	38	Hatha yoga 90 min	Aerobic training (10 min warm up, 20 min stationary cycling, 10 min warm down) 40 min	2x/week 6 weeks	SBP, HR	0/3/3
Stachenfeld e al. (1998)[47]	Patel et al. (2012),[60] Yang (2007)[62]	17 (8/9) 15 (8/7)	Healthy older women	Yoga: 73 ± 3, control 71 ± 2 Range: >65	100	Yoga exercises 60 min	Aerobic training (treadmill 30 min or trampoline walking 40–50 min)	3–4x/week 12 weeks	BW, SBP, DBP, HR	1/3/2
Ray et al. (2001a)[41]	Jayasinghe (2004)[11]	40 (20/20) 28 (17/11)	Healthy men from Indian army	Yoga 21.9 ± 1.5, control 22.7 ± 2.0 Range: 19–23	0	Hatha yoga 60 min	Physical army training (slow running, body flexibility, pull-ups) 60 min	6x/week 24 weeks	BW, HR	2/2/2
Ray et al. (2001b)[56]	Innes et al. (2005)[13]	54 (28/26) 54 (28/26)	Healthy adults	Yoga 23.4 ± 4.0, control 22.2 ± 5.1 Range: 20–25	19	Hatha yoga 60 min	No intervention	3x/week 20 weeks	SBP, DBP, HR	2/3/1
Fields et al. (2002)[34]	Innes et al. (2005)[28]	15 (6/3/6) 15 (6/3/6)	Healthy seniors	Yoga 74 ± 6, control 76 ± 10 (1), control 77 ± 7 (2) Range: >65	NR	Mahrishi Vedic Medicine (meditation, herbal supplement, meetings, yoga asana, walking, diet) 60 min	1. Modern medicine (conventional dietary, exercise (walking, stretching), and multivitamin approaches); 2. Usual care	7x/week 52 weeks	SBP, DBP, TC, LDL-C, HDL-C TG, FBG, HbA1c	4/1/1
Harinath et al. (2004)[42]	Abel et al. (2012),[63] Innes et al. (2005)[13]	30 (15/15) 30 (15/15)	Healthy army soldiers	29.6 ± 4.9 Range: 25–35	0	Hatha yoga 60 min	Routine physical army training (slow running, body flexibility)	7x/week 12 weeks	SBP, DBP, HR	3/2/1
Chen et al. (2008)[28,a]	Patel et al. (2012),[60] Roland et al. (2011)[61]	204 (67/65/72) 176 (57/53/66)	Seniors in a community activity center	69 ± 6.3 Range: 60–75	73	1. Silver yoga (yoga, stretching, meditation) 70 min 2. Silver yoga (no meditation) 55 min	Waiting list	3x/week 24 weeks	BW, BMI, SBP	1/3/2

(continued)

Table 1. Continued.

Study	From SR	Total no. randomized (yoga/control) Total no. at follow-up (yoga/control)	Treatment group	Mean age ± SD Age range	% female	Intervention Time per session	Control	Frequency Duration	Outcome measures	Study quality[a] No. of domains at low/unclear/high risk
Vogler et al. (2011)[29,b]		40 (20/20) 38 (19/19)	Physically inactive older adults	Yoga 76, control 72 Range: 56–94	NR	Iyengar yoga 90 min Home practice 15–20 min	Usual daily routine	2x/week 3x/week (home practice) 8 weeks	SBP, DBP	2/3/1
Kanojia et al. (2013)[64]		50 (25/25) 50 (25/25)	Young healthy females	Yoga 18.6 ± 1.1, control 18.1 ± 0.8 Range: 18–20	100	Yoga 40 min	No intervention	6x/week	BW, SBP, DBP, HR	2/3/1
Kim et al. (2012)[65]		47 (27/20) 34 (16/18)	Normal premenopausal women	Yoga 45.7 ± 5.2, control 43.2 ± 4.5 Range: 35–50	100	Ashtanga yoga 60 min	Normal daily lifestyles	2x/week 32 weeks	SBP, DBP, HR	1/4/1
Wolever et al. (2012)[66]		239 (90/96/53) 205 (76/82/47)	Employees of a national insurance carrier	Yoga 41.6 ± 10.1, control 44.3 ± 9.4 (1), 42.7 ± 9.7 (2)	77	Viniyoga stress reduction program 60 min	1. Mindfulness at Work program 2. List of resources	1x/week 12 weeks	SBP, DBP	2/3/1
Tracy et al. (2013)[30,b]		32 (21/11) 21 (10/11)	Young healthy adults	Yoga 29 ± 6, control 26 ± 7 Range: 21–39	52	Bikram yoga 90 min	Normal lifestyle	3x/week 8 weeks	SBP, HR	0/3/3
Adults with CVD risk factors										
Van Montfrans et al. (1990)[67]	Innes et al. (2005),[13] Hagins et al. (2013)[19]	42 (23/19) 35 (18/17)	Adults with mild uncomplicated hypertension	Yoga 40, control 43 Range: 24–60	49	Hatha yoga + progressive muscle relaxation + stress management 60 min	Passive relaxation	1x/week; 2x/week (home practice) 52 weeks	BW, SBP, DBP, TC	2/3/1
Mahajan et al. (1999)[54]	Innes et al. (2005),[13] Jayasinghe (2004),[11] Yang (2007),[62] Patel et al. (2012)[60]	93 (52/41) 93 (52/41)	Angina patients and asymptomatic participants with CAD risk factors	Range: 56–59	0	4d yoga camp + diet; yoga practice + lifestyle advice 60 min	Conventional therapy (diet control, moderate aerobic exercise as prescribed) + lifestyle advice	4 days + 7x/week 14 weeks	BW, TC, LDL-C, HDL-C, TG	1/4/1
Murugesan et al. (2000)[53]	Innes et al. (2005),[13] Jayasinghe (2004),[11] Nicolson et al. (2004),[68] Innes et al. (2007),[14] Patel et al. (2012),[60] Hagins et al. (2013),[19] Wang et al. (2013)[69]	33 (11/11/11) 33 (11/11/11)	Hypertensive patients	Range: 35–65	NR	Yoga 60 min	1. Daily medical treatment with antihypertensives 2. No intervention	7x/week 11 weeks	BW, SBP, DBP	2/3/1
McCaffrey et al. (2005)[39]	Hagins et al. (2013),[19] Rioux et al. (2013),[70]	61 (32/29) 54 (27/27)	Adults with diagnosed hypertension not	Yoga 56.7, control 56.2	65	Yoga practice with instructional	General education about hypertension	3x/week 8 weeks	BMI, SBP, DBP, HR	2/2/2

(continued)

Table 1. Continued.

Study	From SR	Total no. randomized (yoga/control) Total no. at follow-up (yoga/control)	Treatment group	Mean age ± SD Age range	% female	Intervention Time per session	Control	Frequency Duration	Outcome measures	Study quality[a] No. of domains at low/unclear/ high risk
	Wang et al. (2013)[69]		currently taking medication			booklet and tape 63 min				
Cohen et al. (2011)[71]	Wang et al. (2013),[69] Hagins et al. (2013)[19]	78 (46/32) 57 (26/31)	Adults with untreated pre-hypertension or Stage 1 hypertension not taking anti-hypertensive medication	Yoga 48.2 ± 1.6, control 48.3 ± 2.4 Range: 22–69	50	Iyengar yoga 70 min (classes all weeks, 25 min home practice weeks 6–12)	Enhanced usual care with dietary education	2x/week first 6 weeks; 1x/week next 6 weeks 12 weeks	BW, SBP, DBP, HR	1/3/2
Subramanian et al. (2011)[48]	Hagins et al. (2013)[19]	100 (25/25/25/25) 94 (25/25/23/21)	Young adults with pre-hypertension and hypertension not taking anti-hypertensive medication	Yoga 23, control 23.3 (1), 23.7 (2), 23.7 (3)	33	Yoga 30–45 min	1. No intervention; 2. physical exercise (brisk walking) 50–60 min; 3. Salt intake reduction to at least half previous intake	5x/week 8 weeks	SBP, DBP	2/3/1
Bock et al. (2012)[32]	Carim-Todd et al. (2013)[72]	55 (32/23) 55 (32/23)	Middle age female smokers that intended to quit smoking	45.6 ± 8.3	100	Vinyasa yoga + CBT	Wellness sessions for health education + CBT	2x/week 8 weeks	7-day point-prevalence smoking abstinence	3/2/1
Lee et al. (2012)[73]		16 (8/8) 16 (8/8)	Obese postmenopausal women Yoga 54.5 ± 2.8, control 54.3 ± 2.9 100%			Yoga 60 min	No exercise	3x/week 16 weeks	BW, BMI, TC, LDL-C, HDL-C, TG, FBG	2/3/1
Adults with diabetes or metabolic syndrome										
Monro et al. (1992)[52]	Innes et al. (2005),[13] Aljasir et al. (2010),[74] Innes et al. (2007),[14] Pilkington et al. (2007)[75]	21 (11/10) 21 (11/10)	Patients with non-insulin-dependent DM controlled with medication or diet	Yoga 53, control 57	NR	Yoga + normal medication and diet 90 min	Usual care (continuation of medication, diet)	2–4x/week 12 weeks	FBG, HbA1c	1/3/2
Kerr et al. (2002)[31,b]	Innes et al. (2007),[14] Pilkington et al. (2007)[75]	37 (17/20) 33 (17/16)	Patients with poorly controlled type 1 and 2 DM	Yoga 60.3 ± 7.8, control 61.4 ± 10.7	NR	Hatha yoga + education + continued insulin 90 min	Education + simple exercises + continued insulin	2x/week 16 weeks	BW, BMI, TC, LDL-C, HDL-C, TG, HbA1c	1/2/3
Cohen et al. (2008)[33]	Anderson et al. (2011),[57] Sharma et al. (2012),[76] Hagins et al. (2013)[19]	26 (14/12) 24 (12/12)	Underactive, overweight adult men and women with metabolic syndrome not taking medication	Yoga 52 ± 9, control 52 ± 8 Range: 30–65	85	Yoga 90 min + 3 hr intro	Waiting list	2x/week for 5 weeks, then 1x/week for 5 weeks; 3x/week (home practice) 10 weeks	BW, BMI, SBP, DBP, TC, LDL-C, HDL-C, TG, FBG	3/2/1

(continued)

Table 1. Continued.

Study	From SR	Total no. randomized (yoga/control) Total no. at follow-up (yoga/control)	Treatment group	Mean age ± SD Age range	% female	Intervention Time per session	Control	Frequency Duration	Outcome measures	Study quality[a] No. of domains at low/unclear/high risk
Gordon et al. (2008)[45]	Patel et al. (2012),[60] Ross et al. (2010),[22] Sharma et al. (2012)[76]	231 (77/77/77) 231 (77/77/77)	Elderly patients with type 2 DM	Yoga 64, control 63.9 (1), 63.6 (2)	81	Hatha yoga + continued diet and medication 120 min	1. Conventional physical aerobic exercise (180 min) + continued diet and medication 2. No intervention/continued diet and medication	1x/week; 3–4x/week (home practice) 24 weeks	TC, LDL-C, HDL-C, TG, FBG	3/3/0
Saptharishi et al. (2009)[40]	Hagins et al. (2013)[19]	120 (30/30/30/30) 102 (21/29/27/25)	Young adults with hypertension and pre-hypertension not taking antihypertensive medication	Yoga: 22.5 ± 1.36, control 22.5 ± 1.4 (1), 22.4 ± 1.3 (2), 22.5 ± 1.47 (3)	33	Yoga 30–45 min	1. No intervention 2. Brisk walking 50–60 min 3. Salt intake reduction to at least half previous intake	5x/week 8 weeks	SBP, DBP	3/2/1
Skoro-Kondza et al. (2009)[37]	Sharma et al. (2012)[48]	59 (29/30) 59 (29/30)	Patients with type 2 DM not taking insulin	60 ± 10	61	Yoga + advice 90 min	Waiting list + advice	2x/week 12 weeks	HbA1c	2/2/2
Yang et al. (2011)[77]	Sharma et al. (2012),[74] Patel et al. (2012)[60]	25 (13/12) 23 (12/11)	Patients with metabolic syndrome not taking cholesterol, BP, or glucose-lowering medication	51.7 ± 4.9 Range: 45–65	91	Vinyasa style yoga 60 min	General health education materials every 2 weeks	2x/week 12 weeks	BW, SBP, DBP, TC, LDL-C, HDL-C, TG, FBG	2/3/1
Vaishali et al. (2012)[38]		60 (30/30) 57 (27/30)	Elderly subjects with type 2 DM more than 15 years on antidiabetic drugs	Yoga 65.8 ± 3.2, control 64.4 ± 3.8 Range: >60	37	Yoga + education + medication as in control 45–60 min	Education + conventional hypoglycemic medications	6x/week 12 weeks	TC, LDL-C, HDL-C, TG, FBG, HbA1c	4/1/1
Hegde et al. (2013)[78]		29 (14/15) 29 (14/15)	Prediabetic subjects	Yoga 46.5 ± 13.0, control 44.7 ± 9.6 Range: 30–75	52	Yoga 75–90 min	Waiting list	7x/week 12 weeks (one weekend break)	BMI, SBP, DBP, FBG, HbA1c	3/2/1
Shantakumari et al. (2013)[51]		100 (50/50) 100 (50/50)	Patients with type 2 DM and dyslipidemia, mean duration DM 5–10 years Yoga 45.5 ± 8, control 44.5 ± 11 48%			Yoga + drugs as in control 60 min	Oral hypoglycemic drugs	7x/week 12 weeks	BW, BMI, TC, LDL-C, HDL-C, TG	2/3/1
Adults with diagnosed CAD										
Manchanda et al. (2000)[49]	Innes et al. (2005),[13] Jayasinghe (2004),[11] Yang et al. (2007),[62] Patel et al. (2012)[60]	42 (21/21) 42 (21/21)	Male patients with CAD and chronic stable angina	Yoga 51 ± 9, control 52 ± 10 Range: 32–72	0	Yoga + medication for angina as in control 90 min	Conventional medical therapy (risk factor control and AHA step I diet) + medication for angina (no lipid-lowering drugs)	7x/week 4 days training + 1 year follow-up	BW, TC, LDL-C, HDL-C, TG	3/3/0

(continued)

Table 1. Continued.

Study	From SR	Total no. randomized (yoga/control) Total no. at follow-up (yoga/control)	Treatment group	Mean age ± SD Age range	% female	Intervention Time per session	Control	Frequency Duration	Outcome measures	Study quality[a] No. of domains at low/unclear/ high risk
Jatuporn et al. (2003)[55]	Innes et al. (2005)[13]	44 (22/22) 44 (22/22)	Adults with CAD without prior therapeutic intervention	Yoga 61.5 ± 4.7, control 56.8 ± 7.6	20	Intensive lifestyle modification without lipid-lowering drugs (yoga, support, dietary advice, relaxation) 60 min	Conventional treatment with lipid-lowering drugs	3x/week 16 weeks	BMI, TC, LDL-C, HDL-C, TG	2/3/1
Ades et al. (2005)[43]	Patel et al. (2012)[60]	51 (25/26) 42 (21/21)	Community-dwelling women with established CAD for at least 6 months	Yoga: 71.5 ± 4.8, control 72.9 ± 6.1 Range: >65	100	Light yoga + continued medication as in control 30–40 min	Resistance exercise training + continued medication (aspirin, β-adrenergic blockers, nitrates, calcium-blockers)	3x/week 24 weeks	BW, BMI	3/2/1
Pal et al. (2011)[35]		160 (85/85) 154 (80/74)	Patients diagnosed with CAD	Yoga 58.9 ± 9.4, control 58.6 ± 10.5	16	Yoga + medication as in control 35–40 min	Medication only (metoprolol/ atenolol, aspirin, clopidopril, atorvastatin/rosuvastatin, ramipril/losartan/ telmisartan)	5x/week 24 weeks	BMI, SBP, DBP, TC, LDL-C, HDL-C, TG, HR	4/1/1
Pal et al. (2013)[36]		258 (129/129) 208 (105/103)	Patients diagnosed with CAD	Yoga 59.1 ± 9.9, control 56.4 ± 10.9	20	Yoga + medication as in control 35–40 min	Medication only (metoprolol/ atenolol, aspirin, clopidopril, atorvastatin/rosuvastatin, ramipril/losartan/ telmisartan)	5x/week 72 weeks	BMI, SBP, DBP, HR	2/3/1

AHA: American Heart Association; BMI: body mass index; BW: body weight; CAD: coronary artery disease; CBT: cognitive behavioral therapy; DBP: diastolic blood pressure; DM: diabetes mellitus; FBG: fasting blood glucose; HbA1c: glycosylated hemoglobin; HDL-C: high-density lipoprotein cholesterol; LDL-C: low-density lipoprotein cholesterol; NR: not reported; SBP: systolic blood pressure; SD: standard deviation; SR: systematic review; TC: total cholesterol; TG: triglycerides; HR: heart rate.

[a]Based on the Cochrane Collaboration's risk of bias tool, numbers correspond to number rated low risk, unclear risk, and high risk on six domains.

[b]Findings only described in text, numbers not reported.

Unless otherwise noted, the yoga group also received usual care in addition to the listed interventions.

assessment. However, there was generally low risk of bias for incomplete reporting of outcomes and selective reporting of outcomes. A summary of study quality can be seen in online Supplementary Figure S1.

Study characteristics

Characteristics of the included studies are listed in Table 1. The included studies comprised a total of 2768 participants, with about an equal mix of men (47%) and women (53%). RCTs included adult participants of all ages with an average age of 50 years. Of these participants, 1287 (47%) were assigned to receive the yoga intervention and 1461 (53%) assigned to the control arm. Altogether 1094 (85%) of yoga participants completed the study while 1301 (89%) of control participants made it to follow-up. Duration of studies varied, with follow-up times ranging from 3 weeks to 52 weeks, with a median of 12 weeks. Dividing into subgroups, 38% (14/37) of studies were conducted in healthy populations, 22% (8/32) of studies in populations with CVD risk factors, 27% (10/32) in populations with diabetes or metabolic syndrome, and 13% (5/32) in populations with CAD.

Control arms included usual care or conventional medical therapy (23%), a form of relaxation (6%), education (11%), diet alone (4%), waiting list or no intervention (32%), cognitive-based therapy (2%), and exercise (21%). Five two-arm RCTs,[41–43,46,47] three three-arm RCTs,[27,40,45] and one four-arm RCT[48] used exercise as one of the comparator strategies. Exercise controls consisted of physical training, cycling, running, brisk walking, or resistance training.[43] One exercise trial[27] was excluded from the meta-analysis due to incomplete reporting of effect measures.

Risk factor outcomes

Yoga versus non-exercise controls. Yoga showed significant improvement of risk factors versus non-exercise controls for each of the primary outcomes: BMI ($-0.77\,kg/m^2$ (-1.09 to -0.44)), SBP (-5.21 mmHg (-8.01 to -2.42)), LDL–C (-12.14 mg/dl (-21.80 to -2.48)), and HDL-C (3.20 mg/dl (1.86 to 4.54)) (Figure 2). For the secondary outcomes, significant improvement was seen in all risk factors except FBG (-5.91 mg/dl (-16.32 to 4.50)) and HbA1c (-0.06% Hb (-0.43 to 0.31)) (online Supplementary Figure S2). Improvements reported in secondary outcomes include reductions of body weight (-2.35 kg (-4.33 to -0.37)), DBP (-4.98 mmHg (-7.17 to -2.80)), TC (-18.48 (-29.16 to -7.80), TG (-25.89 mg/dl (-36.19 to -15.60)), and heart rate (-5.27 beats/min (-9.55 to -1.00)) (online Supplementary Figure S2).

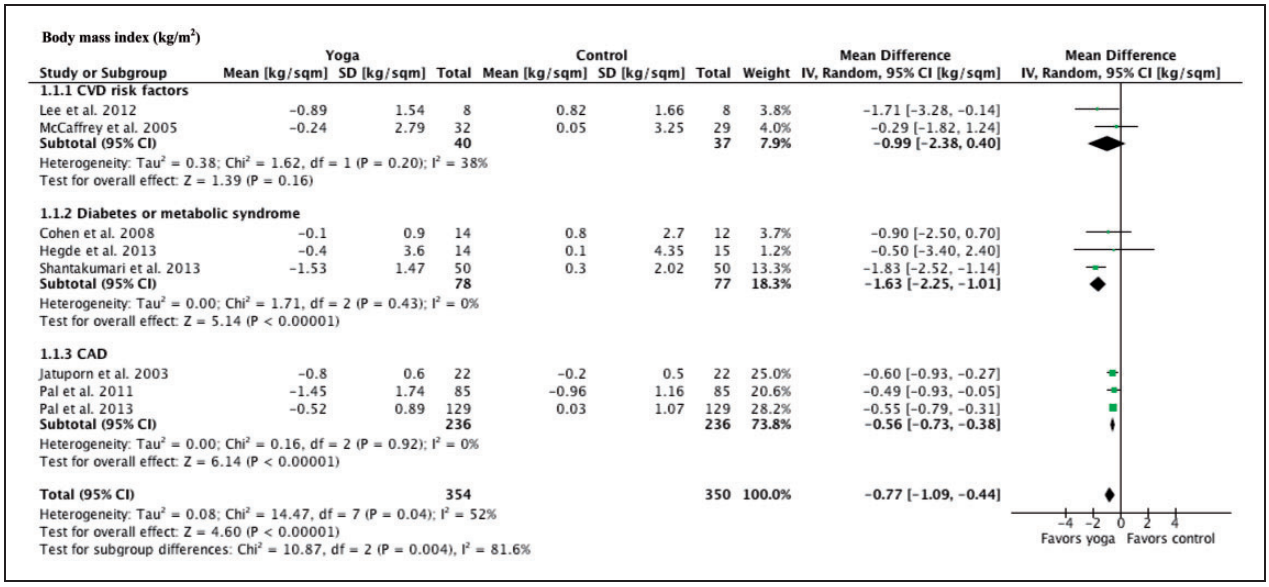
Only one trial was found which evaluated the impact of yoga on smoking status.[32] When twice-weekly Vinyasa-style yoga was given in addition to cognitive behavioral therapy (CBT) for smoking cessation, smokers in the intervention group had higher odds of seven-day and 24-hour abstinence compared to a control group receiving CBT and education at the end of the eight-week study period (seven-day quit odds ratio (OR) 4.56 (95% CI 1.12 to 18.57), 24-hour quit OR 4.19 (1.16 to 15.11). These results did not last, however, when abstinence was measured at six-month follow-up (seven-day quit OR 1.54 (0.34 to 6.92), 24-hour quit OR 1.87 (0.43 to 8.16)).

When yoga is used in addition to medication, significant improvement was found in body weight,[49] BMI,[35,36] blood pressure,[20,50] lipid levels,[35,38,49,51] FBG,[38,52] HbA1c,[38,52] and heart rate[36] in patients with type 2 diabetes or CAD. As a substitute for medical therapy, results are less definitive. Two RCTs found yoga more effective than drug therapy in controlling blood pressure[53] and body weight.[53,54] In a three-arm trial in which yoga was directly compared to a group that received antihypertensive treatment and a group receiving no treatment in patients at high risk for CVD, yoga reduced SBP almost three times more than the antihypertensive therapy (MD -29.17 mmHg (-37.75, -20.59) and -9.60 mmHg (-18.78, -0.42), respectively).[53] When yoga is included in addition to continued medication in CAD patients, an additional benefit, although smaller, is still observed.[35,36] Among CAD patients, yoga is less effective as a substitute for medication such as statins and lipid-lowering drugs in lowering LDL-C;[55] however, as an adjunct treatment to medication, yoga provides an additional statistically significant benefit.[35,49]

Yoga versus exercise. Five out of nine trials comparing yoga to exercise were conducted in healthy populations[27,41,42,46,47,56] and the remaining were conducted in young patient populations with hypertension,[40,48] an elderly female population with CAD,[43] and a population with type 2 diabetes mellitus.[45]

Among the outcomes that were reported by more than one study, there was no significant difference in the effectiveness of yoga versus aerobic exercise in modifying body weight (-0.61 kg (-2.70, 1.49)),[41,43,47] SBP (-0.64 mmHg (-6.71, 5.43)),[40,42,46–48] DBP (-0.14 mmHg (-5.73, 5.44)),[40,42,47,48] and heart rate (-1.42 beats/min (-6.11, 3.27))[41,42,46,47,56] (Figure 3). In addition, there was also no difference comparing the two strategies for BMI,[43] LDL-C,[45] HDL-C,[45] TC,[45] TG,[45] or FBG.[45]

When all studies were pooled together, all trends remained irrespective of controls. MDs in risk factor



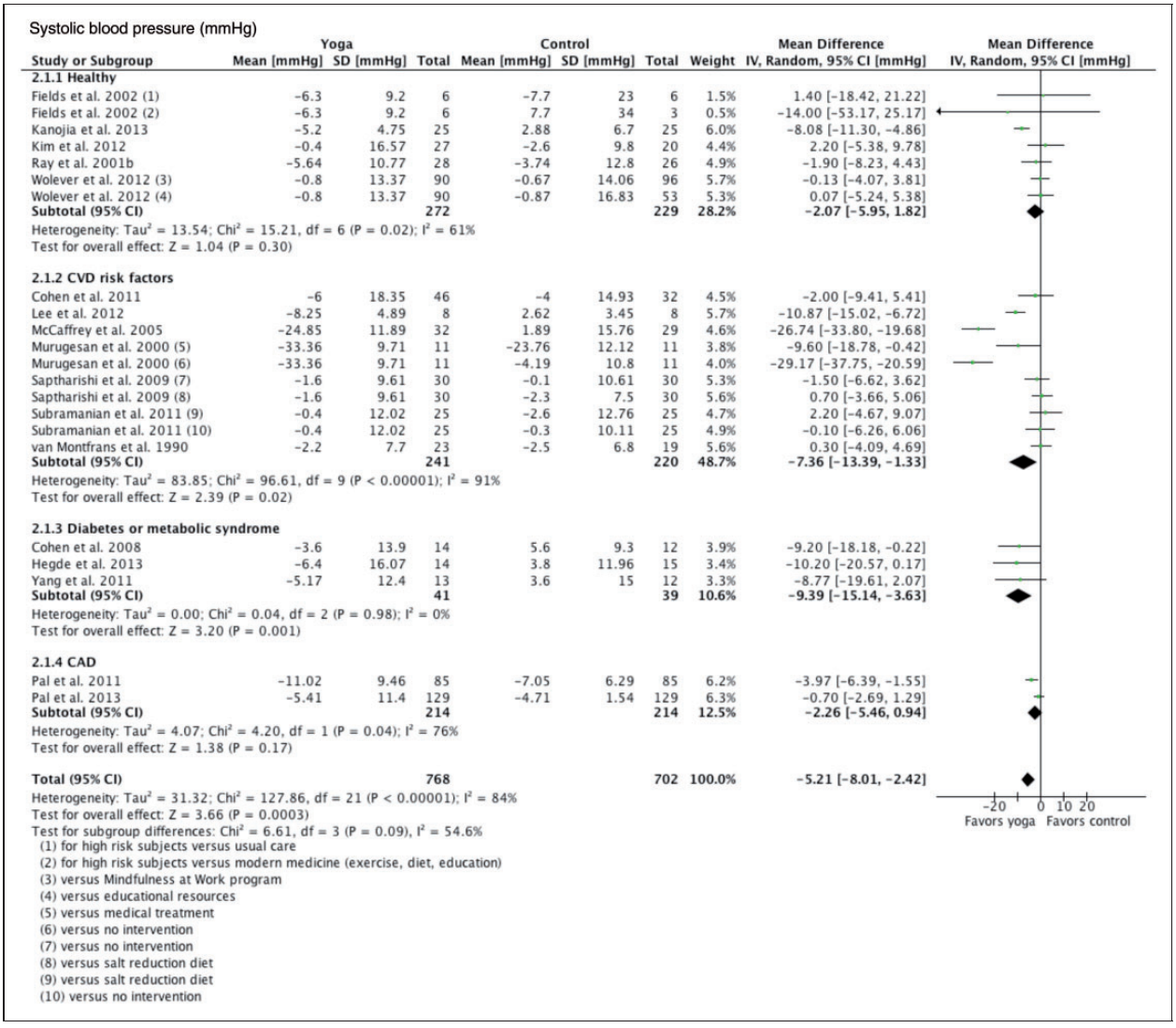
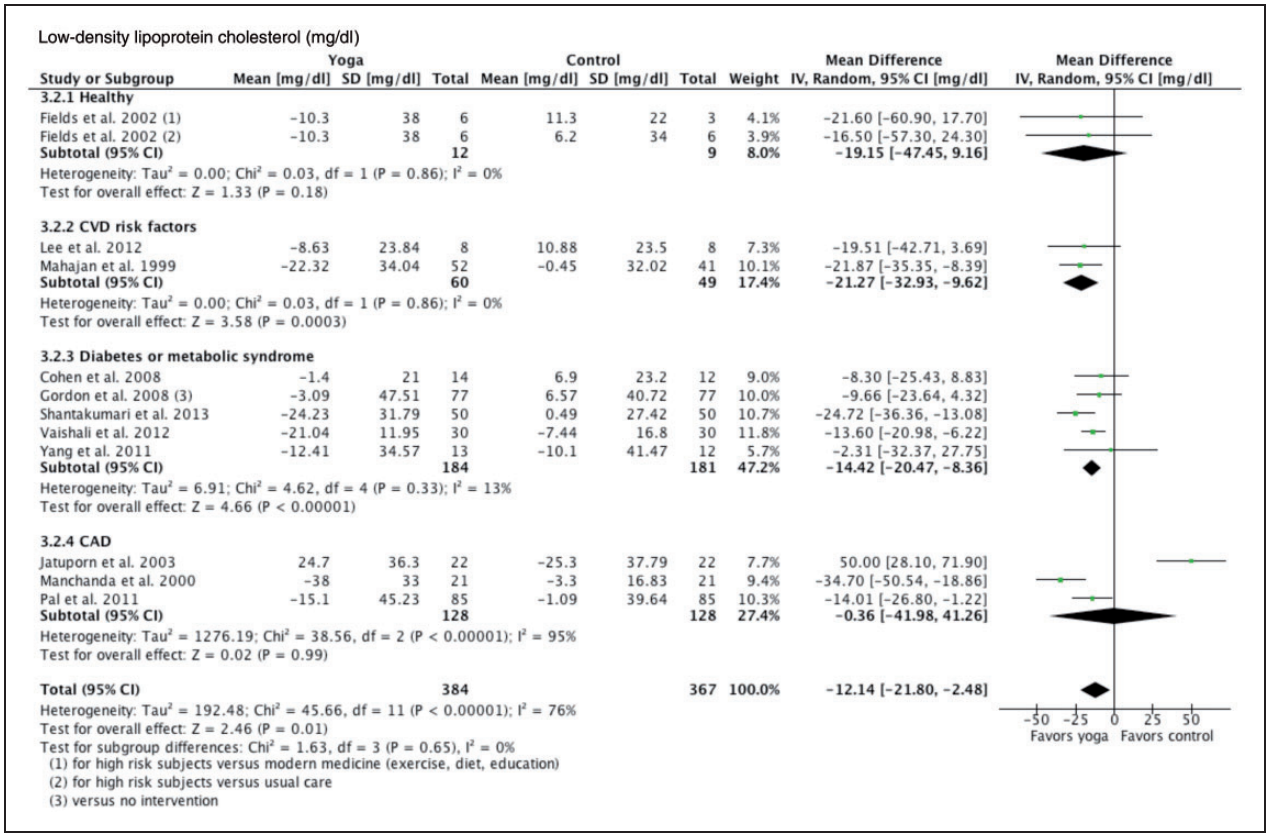


Figure 2. Forest plots of body mass index, systolic blood pressure, low-density lipoprotein, and high-density lipoprotein cholesterol results. Negative mean differences between groups favor the yoga intervention, positive mean differences favor control.
CAD: coronary artery disease; CI: confidence interval; CVD: cardiovascular disease; SD: standard deviation.



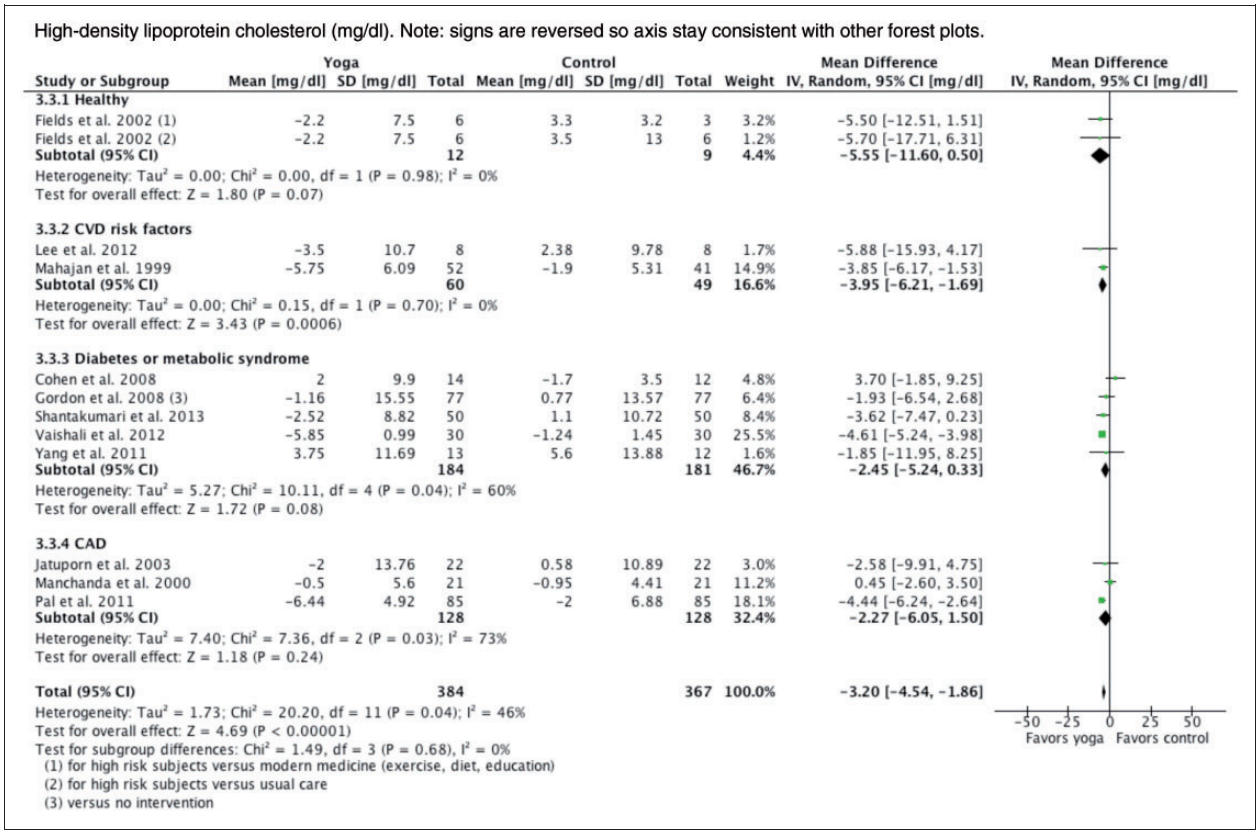


Figure 2. Continued.

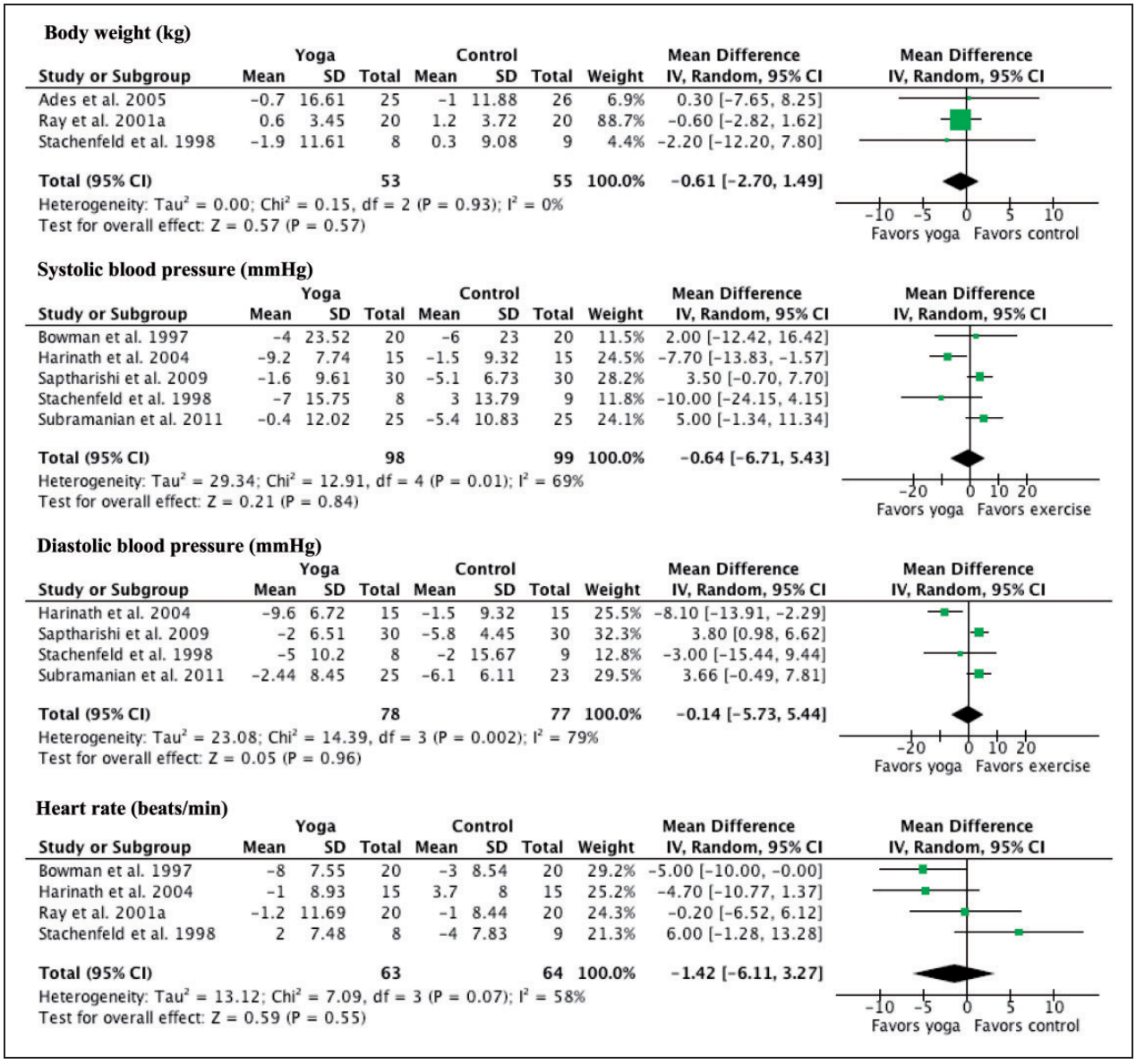


Figure 3. Forest plots of yoga versus physical exercise results for body weight, systolic blood pressure, diastolic blood pressure, and heart rate.
CI: confidence interval; SD: standard deviation.

reductions changed only slightly (online Supplementary Table S2).

Publication bias

Funnel plots assessing publication bias of the primary outcomes are shown in online Supplementary Figure S3. As the funnel plots are mostly symmetrical, we do not find evidence of strong publication bias.

Discussion

The review shows that the practice of yoga may be beneficial to managing and improving risk factors associated with CVD and metabolic syndrome. This finding, however, should be cautiously interpreted as the RCTs included were of limited sample size, heterogeneous, and had unclear or high risk of bias on several domains. When trials were pooled, all but two of the outcomes examined in this review showed improvement after a yoga intervention when compared to non-exercise controls.

Compared to traditional aerobic exercise controls, there was no significant difference in how exercise or yoga changed risk factors, suggesting similar effectiveness of the two forms of physical activity and possibly similar underlying mechanisms. The mechanism behind the therapeutic effect of yoga for CVD is still unclear; studies have suggested that yoga may modulate

autonomic function and beneficially alter markers of sympathetic and parasympathetic activity.[12–14] Through practicing yoga, the effects of stress can be reduced, leading to positive impacts on neuroendocrine status, metabolic and cardio-vagal function, and related inflammatory responses.[12–14] The similarity in effectiveness on risk factors between the two forms of exercise suggest that there could be comparable working mechanisms, with some possible physiological aerobic benefits occurring with yoga practice, and some stress-reducing, relaxation effect occurring with aerobic exercise.

This review helps strengthen the evidence base for yoga as a potentially effective therapy for cardiovascular and metabolic health. Our results support earlier reviews on the positive benefits of yoga on primary and secondary prevention of CVD and metabolic syndrome.[11,13,18–20,22,50,57] Two systematic reviews that were recently published find that there is some evidence for yoga having favorable effects on CVD risk factors.[58,59] One review, conducted by the Cochrane Collaboration, included 11 trials with its more restrictive inclusion criteria and found significant improvement in DBP, TG, and HDL.[59] The second review, with broad inclusion criteria and a wider list of outcomes, included 44 trials and found that yoga improves SBP, DBP, heart rate, respiratory rate, waist circumference, waist/hip ratio, TC, HDL, very low density lipoprotein, HbA1c, and insulin resistance.[58] All studies find that published RCTs on yoga are small, of short duration, and heterogeneous, precluding any strong conclusions on the effectiveness of yoga.

Yoga may provide the same benefits in risk factor reduction as traditional physical activity such as cycling or brisk walking, supporting a previous narrative review.[22] This finding is significant as individuals who cannot or prefer not to perform traditional aerobic exercise might still achieve similar benefits in CVD risk reduction. Evidence supports yoga's accessibility and acceptability to patients with lower physical tolerance like those with pre-existing cardiac conditions, the elderly, or those with musculoskeletal or joint pain.[28]

Lastly, in addition to CVD risk factor improvements, other benefits may result from practicing yoga. For example, yoga may provide health-related quality of life improvements such as reductions in stress and anxiety and better coping mechanisms distinct from other forms of exercise. Yoga may also be practiced in a variety of settings with no special equipment needed, potentially increasing the frequency and ease of practice. These benefits may produce greater willingness to engage in a form of physical activity and better adherence and sustainability, ultimately facilitating greater long-term individual- and population-level CVD and metabolic risk reductions.

Limitations

There are potential limitations of this review. First, we included only English language articles and articles published in peer-reviewed journals. Second, several outcomes are related to cardiovascular and metabolic health; we focused on the major risk factors and surrogate markers for these conditions, as they are predictive of CVD risk[4] and concrete outcomes such as cardiac death and myocardial infarction were not reported in the RCTs. As with all RCTs, findings are applicable to the patient population in which the study was conducted and wide generalizations should be avoided.

There was a great deal of heterogeneity across included studies. Because part of the appeal and feasibility of yoga is the customizability of the practice to individual practitioners, a wide variety of yoga interventions, frequencies and lengths of practice and follow-up were included. To deal with some of this variation, we used random effects in the meta-analysis and divided patient populations into subgroups. Although I^2 values did drop within subgroups compared to overall, heterogeneity was still present. As more studies are undertaken and published, further division by yoga tradition, duration of follow-up, and other factors can be performed.

Lastly, study quality and assessment could be improved. Many studies had small sample sizes and did not fully report all methods and outcomes, leading to high or unclear ratings in the risk of bias on several domains. On a related note, although the Cochrane Risk of Bias tool is widely used and applicable, the definitions and structure of the rating system can lead to inaccurate estimation of study quality. For example, blinding of participants is not possible in RCTs, automatically leading to a high bias rating in the 'performance bias' domain, which assesses blinding of participants and personnel. Study quality could thus be underestimated in many cases. Nevertheless, more complete reporting of methodology and outcomes by authors can help enhance the usefulness and rigor of the trials.

Future research directions

Despite the growing evidence on the health implications of yoga, the physiological mechanisms behind the observed clinical effects of yoga on cardiovascular risk remains unclear. Inquiries into the minimum effective dose of yoga and the dose-response relationship can help elucidate yoga's potential as a medical therapy. Research is also still lacking on the costs and economic implications; more research can be done comparing the relative costs and benefits of yoga versus traditional methods like exercise or medication. Yoga has the potential to be a cost-effective treatment and

prevention strategy given its low cost, lack of expensive equipment or technology, potential greater adherence, health-related quality of life improvements, and possible accessibility to larger segments of the population.

Conclusion

Our review finds emerging evidence to support a role for yoga in improving common modifiable risk factors of CVD and metabolic syndrome. Whereas previous reviews have looked at a single or a few risk factors, our review updates the existing literature and encompasses numerous CVD and metabolic risk factors that can be used to calculate overall CVD risk. We believe that these findings have important implications for the acceptance of yoga as an effective therapeutic intervention. Given the growing popularity of yoga in the US and around the world, there is a need for larger randomized controlled studies that meet explicit, high quality methodological standards to ascertain the effects of yoga. This review demonstrates the potential of yoga to have an impact on concrete, physiological outcomes that represent some of the greatest health burdens today.

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Conflict of interest

None declared.

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