Special Article

Effect of tea on blood pressure for secondary prevention of cardiovascular disease: a systematic review and meta-analysis of randomized controlled trials

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Context: *Tea has been proposed as an antihypertensive agent for individuals with elevated blood pressure, yet the evidence for this has not been systematically reviewed to date.*

Objective: *The aim of this review was to evaluate the effects of tea on blood pressure in individuals within the prehypertensive and hypertensive blood pressure ranges.*

Data Sources: *The CENTRAL, PubMed, Embase, and Web of Science databases were searched for all relevant studies published from 1946 to September 27, 2013.*

Study Selection: *The selection criteria included randomized controlled trials of adults whose blood pressure was within hypertensive or prehypertensive ranges and in which the applied intervention was green or black tea; controls consisting of placebo, minimal tea intervention, or no intervention; and a follow-up period of at least 2 months.*

Data Extraction: *Two reviewers independently extracted data on participants, interventions, comparators, outcomes, and study design. Mean differences (MDs) and 95% confidence intervals (95%CIs) were pooled to generate summary effect estimates.*

Results: *Meta-analyses of 10 trials (834 participants) showed statistically significant reductions in systolic blood pressure (MD −2.36 mmHg, 95%CI −4.20 to −0.52) and diastolic blood pressure (MD −1.77 mmHg, 95%CI −3.03 to −0.52) with tea consumption.*

Conclusions: *Consumption of green or black tea can reduce blood pressure in individuals within prehypertensive and hypertensive ranges, although further investigation with studies of longer duration and stronger methodological quality is warranted to confirm these findings.*

INTRODUCTION

Cardiovascular diseases (CVDs) are a group of disorders of the heart and blood vessels and include coronary heart disease, cerebrovascular disease, peripheral arterial disease, rheumatic heart disease, congenital heart disease, and deep vein thrombosis.[1] Globally, more people die every year from CVDs than from any other cause.[1] Most CVDs, however, can be prevented by addressing modifiable risk factors such as tobacco use, poor diet, physical inactivity, high blood pressure, diabetes, and elevated lipids.[1] Of these risk factors, high blood pressure is

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responsible for approximately 9.4 million deaths each year, including 51% of deaths due to stroke and 45% of deaths due to coronary disease.[1,2]

High blood pressure, or hypertension, is diagnosed when an individual has a systolic blood pressure (SBP) of ≥140 mmHg and/or a diastolic blood pressure (DBP) of ≥90 mmHg. Aging, dietary factors (e.g., alcohol consumption, excessive salt intake, insufficient fruit and vegetable consumption), lifestyle factors (e.g., smoking, physical inactivity), and genetic predisposition have all been identified as risk factors for this condition.[3]

The Global Burden of Disease Study recently ranked hypertension as the leading risk factor for disease globally.[4] This debilitating condition affects 1 billion people and is responsible for 9 million deaths per year globally. The toll is expected to increase as the incidence of hypertension continues to rise in low- and middle-income countries, where the social and economic costs associated with the condition are expected to place an especially heavy burden on socioeconomic development.[5]

Tea is a beverage prepared by pouring hot or boiling water over the cured leaves or leaf buds of the plant *Camellia sinensis*. It is the second most commonly consumed beverage globally, after water, and has been touted historically for having a variety of presumed health benefits.[6] More recently, intake of both green and black teas has been linked to a reduced risk of CVD and some forms of cancer, improved oral health, weight control benefits, improved antibacterial and antiviral activity, increased bone mineral density, and improved cognition in the elderly.[7,8]

The various health benefits linked to this beverage are often attributed to tea being rich in a class of polyphenolic compounds called flavonoids.[9] Green and black teas are roughly similar in total flavonoid content but have different chemical structures. In green tea, flavonoids are normally found in the form of catechins, while in black tea, flavonoids are typically found as theaflavins.

Experimental studies in animals have provided support for an effect of green and black tea extracts to reduce blood pressure among both normotensive and spontaneously hypertensive rats,[10–13] while observational studies have been largely inconsistent.[14–17]

A recent systematic review and meta-analysis identified 4 randomized controlled trials (RCTs) that assessed the effect of green or black tea on blood pressure levels for a minimum of 3 months in the context of primary prevention of CVD. The review found evidence for statistically significant reductions of both SBP and DBP among those not at immediate risk of CVD.[18]

Considering that tea is widely consumed around the world, there is strong potential for a large public health impact on those with elevated blood pressure. It is, thus, important to determine whether the hypotensive effect of green and black teas observed within the context of primary prevention extends to individuals whose blood pressure lies within an elevated range and, if so, whether it can act as secondary prevention against CVD. The objective of this review is to synthesize the available evidence from RCTs to determine the effect of black and green teas on SBP and DBP in individuals within prehypertensive and hypertensive ranges.

METHODS

Literature search

The systematic review was conducted in accordance with the *Cochrane Handbook for Systematic Reviews of Interventions*.[19] The following bibliographic databases were searched: Cochrane Central Register of Controlled Trials (CENTRAL) (*The Cochrane Library* 2013, issue 7), Embase (OVID, 1980 to 2013 [week 34]), PubMed (1946 to July 2013 [week 2]), and Web of Science (Thomson Reuters, 1970 to July 3, 2013). Additionally, ClinicalTrials.gov and the grey literature (Open Grey, Grey Literature Report [New York Academy of Medicine]) were searched. Medical subject headings (or equivalent) and text word terms were used. Searches were individualized to specific databases. The complete PubMed search strategy is presented in Table S1, available in the Supporting Information for this article online.

Inclusion and exclusion criteria

The PICOS (patients, intervention, comparator, outcome, study design) criteria used to establish study eligibility are provided in Table 1. Included studies had to fulfill all of the following criteria: 1) RCT (parallel or crossover design); 2) adult population (≥16 years of age) with a mean or median SBP and/or DBP at baseline within, at minimum, the established prehypertensive range (SBP >120 mmHg and/or DBP >80 mmHg); 3) subjects who were randomly assigned to receive green or black tea (beverage or tea extract) or placebo, minimal tea intervention (<100 mg tea or extract), or no intervention; and 4) a minimum follow-up period of 8 weeks.

Studies were excluded if the trial had multiple intervention arms without pooled analyses between arms, if the design was multifactorial, or if a tea intervention was combined with another intervention. No limits were placed on the dosage of tea assigned, the frequency of tea consumption, or the consumption of tea with additives (e.g., milk, sugar, lemon). Furthermore, no limits were placed on the comorbidities of participants. Lastly, only studies published in English were considered eligible for this review.

Table 1 **PICOS criteria for inclusion and exclusion of studies**

Parameter	Inclusion criteria	Exclusion criteria
Population	Participants ≥16 y of age at baseline with mean or median SBP and/or DBP at baseline within, at minimum, the established pre-hypertensive range (SBP >120 mmHg and/or DBP >80 mmHg). Participants with or without comorbidities potentially related to prehypertension or hypertension	Participants <16 y of age at baseline
Intervention	Green or black tea intake (beverage or tea extract)	
Comparators	Placebo, minimal tea intervention (<100 mg of tea or extract), or no intervention	
Outcomes	Comparison, between groups, of change in blood pressure from baseline	
Study design	RCT (parallel or crossover design)	Observational study designs were excluded.RCTs were excluded if trial had 1) multiple intervention arms without pooled analysis between arms, 2) a multifactorial design, or 3) a combination of a tea intervention with another intervention

Abbreviations: DBP, diastolic blood pressure; SBP, systolic blood pressure; RCT, randomized controlled trial.

Data extraction and quality assessment

Data was extracted by 2 independent reviewers (J.Y. and G.G.). Any discrepancies between reviewers were reconciled. Principal investigators or coinvestigators of selected studies were contacted for additional information, if necessary. Details on study design, participants, intervention, length of follow-up, outcome data (including data on outcome assessment and adverse effects), and methodological quality (randomization, allocation concealment, blinding, attrition) were extracted from each study. The primary author and coauthor of Auvichayapat et al.[20] were contacted for additional data and responded with requested data. The corresponding author and a coauthor of Mukamal et al.[21] were contacted for additional data but did not respond with requested data. Required data from Mukamal et al. were extracted from the Hartley et al.[18] review.

Risk of bias in all included studies was independently assessed by 2 reviewers (J.Y. and G.G.) by examining random sequence generation, allocation concealment, blinding (participants, personnel, outcome assessors), description of exclusions and withdrawals by study arm, selective outcome reporting, and any other biases arising from the nature of the study design. Risk of bias in each of these domains was coded as "high risk," "low risk," or "unclear."

Meta-analysis and statistical analyses

For the 2 outcomes analyzed – difference in mean SBP and difference in mean DBP – and the subgroup analyses, the magnitude of interstudy heterogeneity was assessed by the I^2 statistic. When heterogeneity was considered low (I^2<30%), a fixed-effects model was first fitted. When heterogeneity was considered moderate (I^2 30–60%), with a plausible explanation to account for it, a random-effects model was fitted. If no plausible explanation could be provided to explain heterogeneity, trials were not aggregated.

Analysis of effect was stratified by average daily dosage of flavonoid (active ingredient) (<500 mg or ≥500 mg) and caffeine content (present or absent). A meta-regression was also run to assess a dose–response relationship between daily dosage of flavonoid and effect size by trial. It was furthermore the intention of this review to stratify trials by type of tea (green or black) and duration of the intervention.

For the 2 outcomes, net changes were compared (i.e., comparison of the arithmetic mean before and after intervention or placebo) and a mean difference (MD) and 95% confidence interval (95%CI) calculated for each trial. The *Cochrane Handbook for Systematic Reviews of Interventions* was consulted for 4 trials that did not report data for standard deviation of change.[19] *Cochrane* recommended imputation of a reported standard deviation of change from another trial in the meta-analysis to all trials for which this data was not reported. To test the potential differential effect of imputing different reported standard deviations of change on the pooled analysis, a sensitivity analysis was conducted by imputing each reported standard deviation of change to all trials for which this value was missing and then comparing the pooled analyses generated. All 95%CIs for pooled analyses overlapped for both SBP and DBP.

In order to establish a conservative estimate of the magnitude of the net effect, standard deviation of change values from Auvichayapat et al.[20] were imputed into the 4 trials for which data were missing, as this generated the widest confidence interval around the net effect size among all imputations performed. If data were presented at more than one time point, blood pressure outcomes were taken from the final time point measured. Additionally, standard deviations of change

for blood pressure by study group were calculated from raw baseline and final blood pressure data obtained from the investigators of 1 study.[20] Lastly, in the single crossover trial included, there was risk of carryover effect because no washout period between the early intervention and the later intervention periods was utilized.[22] This issue was approached, as *Cochrane* advised, by analysis of first-period data only.

Sensitivity analyses were carried out, excluding trials with unclear or high risk of selection bias due to methods of allocation concealment. The presence of publication bias in the meta-analysis was assessed using funnel plots and tests of asymmetry.[23] Statistical analyses were performed using Cochrane Review Manager 5.2 (Cochrane Library Software, Oxford, UK) and STATA 12 (StataCorp, College Station, Texas, USA).

RESULTS

Electronic searches yielded 784 records, of which 593 remained after removal of duplicates. Screening of titles and abstracts (if available) identified 13 papers for formal inclusion or exclusion. After full-text retrieval of articles, 3 further trials were excluded[24–26]; the remaining 10 randomized trials that met all inclusion criteria were included in this review. Details of the literature search and selection process are provided in Figure 1.

Included studies

A summary of the characteristics of included trials is presented in Table 2. Nine trials examined the effect of green tea on blood pressure,[20,22,27–33] and 1 trial examined the effect of black tea.[21] Nine trials were parallel RCTs, and 1 trial utilized a crossover design.[22] In 4 trials, all of the participants were either obese[20,27,30] or had a body mass index between 28 kg/m^2 and 38 kg/m^2 [28]; in 1 trial, all participants had visceral-fat type obesity[32]; in 2 trials, all had glucose abnormalities[22,29]; in 1 trial, all had either diabetes or 2 other cardiovascular risk factors[21]; in 1 trial, all were healthy adults[33]; and in 1 trial, all participants were active older adults.[31] The majority of trials recruited and assessed both sexes, while the trial of Hsu et al.[30] recruited females exclusively and the trial of Brown et al.[28] recruited males exclusively. One trial had an intervention duration of 6 months,[21] 1 had a duration of 14 weeks,[31] 5 had a duration of 12 weeks,[20,27,30,32,33] and 3 had a duration of 2 months.[22,28,29] Intervention was in the form of a test beverage,[27,31,32] a tea extract,[20,30,33] a catechin extract,[28]

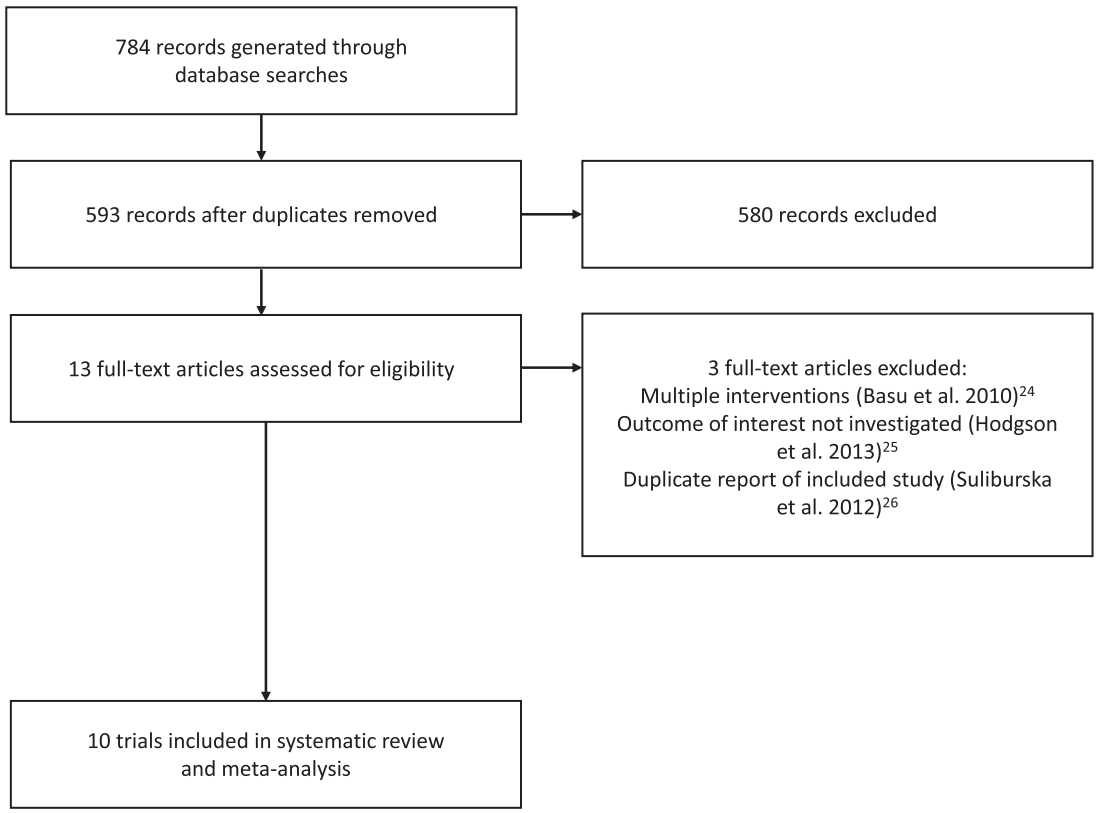

Figure 1 **Flow diagram for selection of trials included in the systematic review.**

Table 2 **Characteristics of included trials examining the effect of green or black tea consumption on blood pressure**

Reference	Study design and duration	Location	Participants	Intervention	Control
Auvichayapat et al. (2008)[20]	RCT of parallel-group design; 12 wk	Thailand	60 obese adults of both sexes. Inclusion criteria: males between 40 y and 60 y of age, females postmenopausal >1 y, and BMI >25 kg/m^2	250-mg green tea capsule 3× daily	Cellulose capsules, which were indistinguishable from the green tea capsules
Bogdanski et al. (2012)[27]	RCT of parallel-group design; 3 mo	Poland	56 obese, hypertensive participants of both sexes. Inclusion criteria: age 30–60 y, BMI ≥30 kg/m^2, stable body weight (<3 kg self-reported change during the previous 3 mo), and well-controlled arterial hypertension, defined as SBP <160 mmHg and/or DBP <100 mmHg, with stable treatment for at least 6 mo	379-mg green tea extract capsule 1× daily	Placebo (pure microcrystalline cellulose) 1× daily
Brown et al. (2009)[28]	RCT of parallel-group design; 8 wk	England	88 male nonsmokers aged 40–65 y, with BMI >28 and <38 kg/m^2, fasting plasma glucose values <7.0 mmol/L, no significant history of disease, current disease, or current use of medication	400-mg capsule (EGCG) 2× daily	400-mg capsule (lactose) 2× daily
Fukino et al. (2005)[29]	RCT of parallel-group design; 2 mo	Japan	66 adults aged 32–73 y (53 males and 13 females) with a fasting blood glucose level of ≥110 mg/dL or a nonfasting blood glucose level of ≥140 mg/dL in a recent health check-up	544-mg tea packet (mixture of green tea extract and green tea powder) per day. Participants asked to dissolve 1/4–1/3 of the packet in hot water to drink after every meal or snack	Followed
Fukino et al. (2008)[22]	RCT of crossover design; 2 mo	Japan	60 adults of both sexes, aged 32–73 y. Inclusion criteria: fasting blood glucose level of >6.1 mmol/L or a nonfasting blood glucose level of >7.8 mmol/L in a recent health check-up	544-mg tea packet (mixture of green tea extract and green tea powder) per day. Participants asked to dissolve 1/4–1/3 of the packet in hot water to drink after every meal or snack	Followed
Hsu et al. (2008)[30]	RCT of parallel-group design; 12 wk	Taiwan	78 women aged 16–60 y, with BMI >27 kg/m^2, who had not received any other weight-control maneuvers within the 3 mo prior to the study were enrolled	400-mg green tea extract capsule 3× daily	Cellulose capsule 3× daily
Miyazaki et al. (2013)[31]	RCT of parallel-group design; 14 wk	Japan	50 older adults of both sexes, with a mean age of 69.1 y	GTC beverage (630.9 mg GTC per 350 mL) 1× daily	88.7 mg of GTC beverage 1× daily
Mukamal et al. (2007)[21]	RCT of parallel-group design; 6 mo	United States	28 adults (10 males, 18 females), aged 55 y and older, with diabetes or 2 other cardiovascular risk factors but no established clinical CVD were enrolled	Dehydrated black tea powder (106 mg of catechin equivalent) 3× daily	Glass of water 3× daily

(continued)

Table 2. **Continued**

Reference	Study design and duration	Location	Participants	Intervention	Control
Nagao et al. (2007)[32]	RCT of parallel-group design; 12 wk	Japan	240 adults (140 men, 100 women) with visceral-fat type obesity, aged 25–55 y. Inclusion criteria: BMI of 24–30 kg/m^2 and/or a waist circumference of 80–94 cm who were considered to be visceral-fat-type obese but had not been treated at an outpatient department and had no serious liver or renal disease	583 mg of GTCs as beverage 1× daily	96 mg of GTCs
Nantz et al. (2009)[33]	RCT of parallel-group design; 12 wk	United States	111 healthy adults of either sex, aged 21–70 y	*Camellia sinensis* compound capsule (100 mg L-theanine, 200 mg of decaffeinated catechin green tea extract) 2× daily	Placebo capsule 2× daily

Abbreviations: BMI, body mass index; CVD, cardiovascular disease; DBP, diastolic blood pressure; EGCG, epigallocatechin-3-gallate; GTC, green tea catechin; RCT, randomized controlled trial; SBP, systolic blood pressure.

or a packet dissolved in water.[21,22,29] The dosage of daily flavonoid consumption varied among studies, ranging from 800 mg of daily catechin intake in the trial of Brown et al.[28] to 142 mg of catechins per day in the trial of Auvichayapat et al.[20] Flavonoid values for all other trials, within the range defined by Brown et al.[28] and Auvichayapat et al.,[20] included 208 mg of catechins,[27] 318 mg of catechins,[21] 400 mg of catechins from a green tea extract,[33] 456 mg total catechin concentration,[22,29] 487 mg of green tea catechins,[32] 614 mg of catechins from a green tea extract,[30] and 630.8 mg of catechins.[31]

Risk of bias in included studies

The Cochrane Collaboration's "risk of bias" assessment tool was used to characterize the risk of bias in included studies.[19] Four trials provided adequate information on the method of random sequence generation and 6 trials did not provide information on random sequence generation. Four trials provided information on a suitable method of allocation concealment and were at low risk of selection bias, while 6 trials were at unclear risk because of the lack of information provided. Performance bias due to blinding of participants and personnel was considered low in 6 trials, unclear in 1 trial, and high in 3 trials. Detection bias was low in 1 trial, unclear in 8 trials, and high in 1 trial. The risk of attrition bias was deemed to be low in 5 trials, unclear in 2 trials, and high in 3 trials, while the risk of detection bias was considered to be low in 8 trials, unclear in 1 trial, and high in 1 trial. Lastly, the risk of other bias was unclear because of insufficient information in all but 1 trial. Full details on the risk of bias, organized by included study, are provided in Table 3. A summary of the risk of bias for all trials is shown in Figure 2.

Effects on systolic and diastolic blood pressure

Ten trials (834 participants randomized) measured the effect of green or black tea on blood pressure. A meta-analysis of these studies showed statistically significant reductions in SBP (MD −2.36 mmHg, 95%CI −4.20 to −0.52) and DBP (MD −1.77 mmHg, 95%CI −3.03 to −0.52). There was low heterogeneity among the studies evaluating SBP (I^2=0%) and DBP (I^2=0%), so a fixed-effects model was fitted for each anlaysis. Sensitivity analysis, after the exclusion of 6 trials at unclear or high risk of bias, remained statistically significant for both SBP (MD −2.93 mmHg, 95%CI −5.69 to −0.17) and DBP (MD −2.40 mmHg, 95%CI −4.22 to −0.57). Thus, since the findings of the sensitivity analysis were stable, all trials were analyzed. Individual and pooled estimates for effect size are shown in Figures 3 and 4.

Table 3 **Risk-of-bias assessment by bias category and included trial**

Reference	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants or personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Auvichayapat et al. (2008)[20]	Unclear	Unclear	Unclear	Unclear	Low	High	Unclear
Bogdanski et al. (2012)[27]	Unclear	Low	Low	Unclear	Low	Low	Unclear
Brown et al. (2009)[28]	Low	Low	Low	Unclear	Low	Low	Unclear
Fukino et al. (2005)[29]	Unclear	Unclear	High	Unclear	Unclear	Low	Unclear
Fukino et al. (2008)[22]	Unclear	Unclear	High	High	Unclear	Low	High
Hsu et al. (2008)[30]	Low	Unclear	Low	Unclear	High	Low	Unclear
Miyazaki et al. (2013)[31]	Unclear	Low	Low	Unclear	Low	Low	Unclear
Mukamal et al. (2007)[21]	Low	Low	High	Unclear	Low	Unclear	Unclear
Nagao et al. (2007)[32]	Unclear	Unclear	Low	Unclear	High	Low	Unclear
Nantz et al. (2009)[33]	Low	Unclear	Low	Low	High	Low	Unclear

Subgroup analyses

A comparison of trials with interventions using <500 mg of flavonoid intake (7 trials) and ≥500 mg (3 trials) reported reductions, though not statistically significant, in SBP; these reductions were found for trials using <500 mg of flavonoid intake (MD −2.14 mmHg, 95%CI −4.36 to 0.08) as well as for trials with ≥500 mg of flavonoid intake (MD −2.32 mmHg, 95%CI −4.94 to 0.30). Low interstudy heterogeneity (I^2=0% for both) was found, so a fixed-effects model was fitted. For DBP, a reduction that was not statistically significant was found for trials using <500 mg of flavonoid intake (MD −1.58 mmHg, 95%CI −3.34 to 0.17), and a statistically significant reduction was found for trials using ≥500 mg of flavonoid intake (MD −1.97 mmHg, 95%CI −3.76 to −0.18). Low interstudy heterogeneity (I^2=0% for <500 mg and I^2=5% for ≥500 mg) was found, so a fixed-effects model was fitted (the net effect in the ≥500 mg flavonoid intake group, however, was attenuated toward nonsignificance if a random-effects model was fitted [MD −1.89 mmHg, 95%CI −3.82 to 0.05]). The sensitivity analysis did not produce significantly different results. Individual and pooled estimates for effect size by flavonoid dosage are shown in Figures S1 and S2, available in the Supporting Information online. A meta-regression was performed to assess a possible dose–response relationship between flavonoid content and effect size by fitting a regression between these variables. It failed to find a statistically significant association for DBP or SBP (P>0.48 for both).

For SBP, a comparison of trials investigating caffeinated-tea (4 trials) and decaffeinated-tea (3 trials) showed evidence of a statistically significant reduction in the decaffeinated-tea group (MD −2.67 mmHg, 95%CI −4.79 to −0.54) but not the caffeinated-tea group (MD −1.11 mmHg, 95%CI −5.47 to 3.26). Low interstudy heterogeneity (I^2=0 for both) was found, so a fixed-effects model was fitted. Likewise for DBP, a comparison of pooled caffeinated-tea trials and decaffeinated-tea trials showed a statistically significant reduction in the decaffeinated-tea group (MD −1.68 mmHg, 95%CI −3.13 to −0.22) but not in the caffeinated-tea group (MD −1.69 mmHg, 95%CI −4.72 to 1.33). Low interstudy heterogeneity (I^2=13% for caffeinated-tea and I^2=20% for decaffeinated tea) was again found, so a fixed-effects model was fitted (the net effect in the decaffeinated group, however, was attenuated towards nonsignificance if a random-effects model was fitted [MD −1.68 mmHg, 95%CI −3.39 to 0.03]). For all caffeinated-tea trials and 2 decaffeinated-tea trials, the risk of bias due to allocation concealment was unclear, so these trials were removed from the pooled analysis in sensitivity analyses. Individual and pooled estimates for effect size by presence of caffeine are presented in Figures S3 and S4 in the Supporting Information online.

Both the funnel plot and the Egger's regression test failed to find evidence of publication bias. Funnel plots of the 10 trials that evaluated the effect of tea on blood pressure are shown in Figures 5 and 6.

DISCUSSION

Tentative evidence of a favorable effect of green and black tea on both SBP (MD −2.36 mmHg, 95%CI −4.20 to −0.52) and DBP (MD −1.77 mmHg, 95%CI −3.03 to −0.52) for a median duration of 3 months was found among individuals whose blood pressure was within hypertensive and prehypertensive ranges. While the dosage of flavonoid (active ingredient) varied among trials, the median dosage of 456 mg of flavonoids per day from the 10 included trials is consistent with consumption of approximately 2 cups (200 mL each) of black or green tea per day.[34] Some important limitations of this review and meta-analysis deserve mention. First, only a moderate number of trials contributed to these analyses (especially subgroup analyses), and half

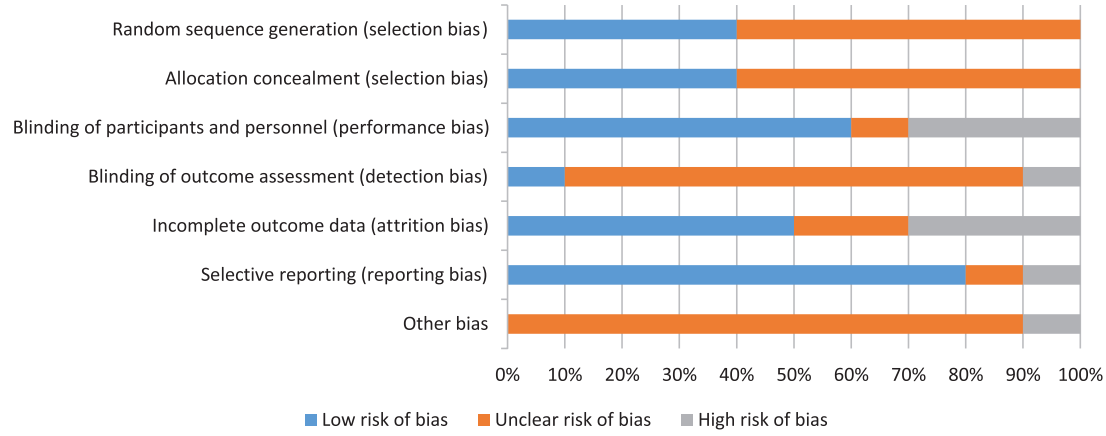

Figure 2 **Risk of bias with each risk of bias presented as a percentage across all included studies.**

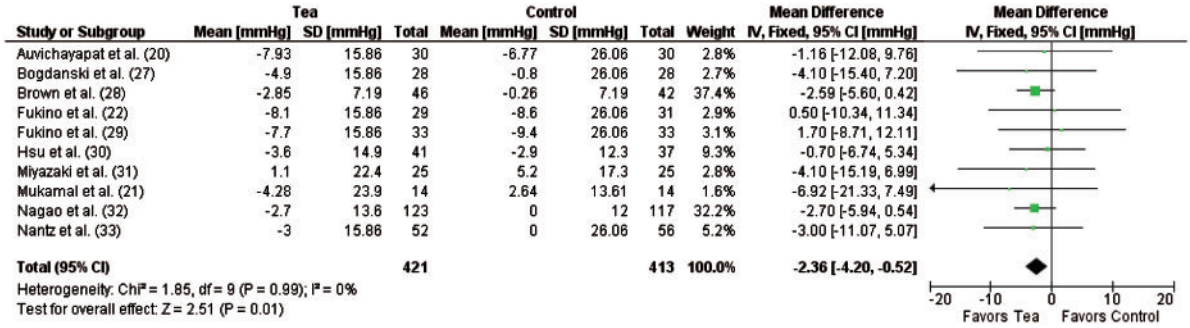

Figure 3 **Mean differences and 95%CIs (individual and pooled) for fixed-effects models examining the effect of green or black tea consumption on systolic blood pressure.** Standard deviation was imputed from Auvichayapat et al. (2008)[20] for the following studies: Fukino et al. (2008),[22] Bogdanski et al. (2012),[27] Fukino et al. (2005),[29] and Nantz et al. (2009).[33] Total refers to the total number of participants. *Abbreviations*: IV, inverse variance.

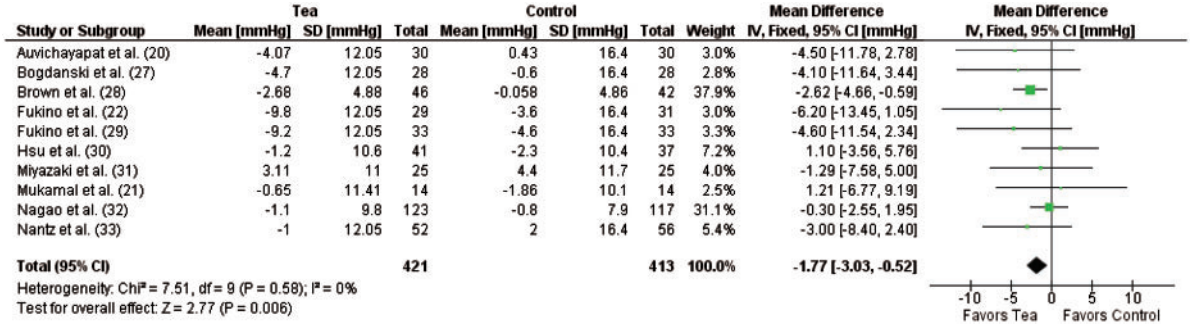

Figure 4 **Mean differences and 95%CIs (individual and pooled) for fixed-effects models examining the effect of green or black tea consumption on diastolic blood pressure.** Standard deviation was imputed from Auvichayapat et al. (2008)[20] for the following studies: Fukino et al. (2008),[22] Bogdanski et al. (2012),[27] Fukino et al. (2005),[29] and Nantz et al. (2009).[33] Total refers to the total number of participants. *Abbreviations*: IV, inverse variance.

of the trials were small (n ≤60 participants). Subgroup analyses by caffeine content of tea showed a statistically significant reduction in SBP and DBP for decaffeinated-tea trials, but not for caffeinated-tea trials. However, only a small number of trials contributed to these analyses, and pooled caffeinated-tea trials had less than half the number of participants as decaffeinated-tea trials and may, thus, have lacked statistical power to detect an effect. The protective effect of decaffeinated tea for DBP was attenuated toward nonsignificance when a random-effects model was used. Moreover, sensitivity analyses performed by removing trials at unclear or high

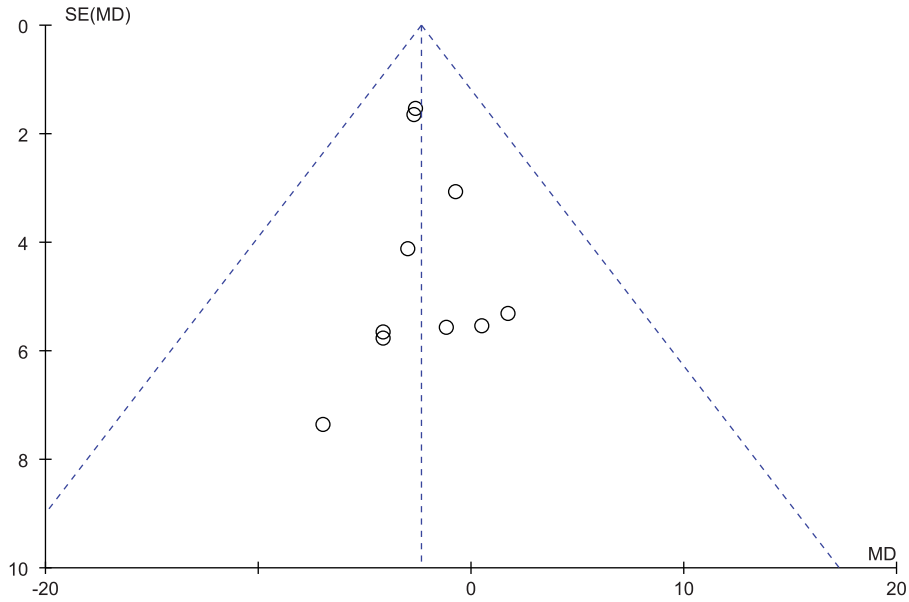

Figure 5 **Funnel plot of trials examining the effect of green or black tea consumption on systolic blood pressure.** Dotted lines are pseudo 95%CIs. Large trials at the top and smaller trials at the bottom of the plot were both roughly symmetrical, suggesting low evidence of publication bias.

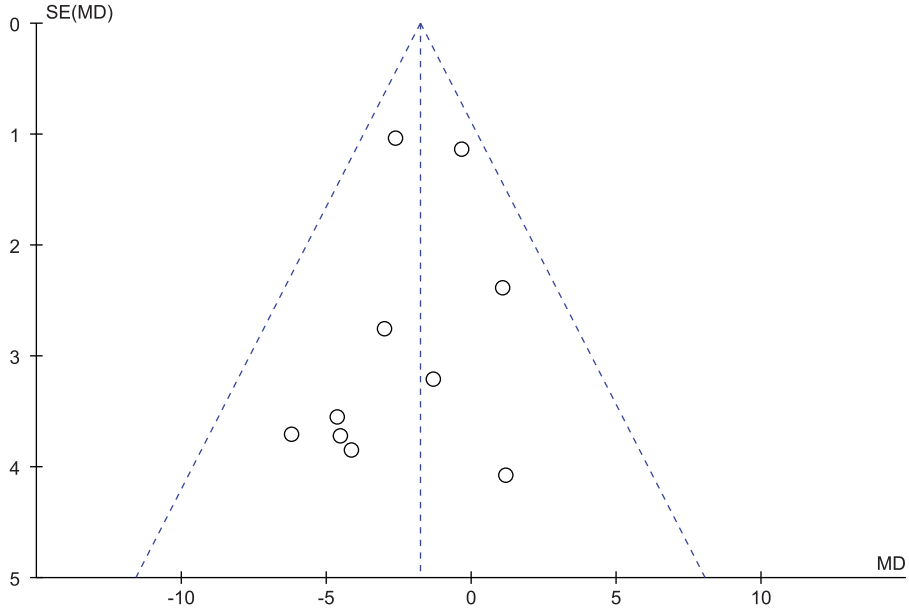

Figure 6 **Funnel plot of trials examining the effect of green or black tea consumption on diastolic blood pressure.** Dotted lines are pseudo 95%CIs. Large trials at the top and smaller trials at the bottom of the plot were both roughly symmetrical, suggesting low evidence of publication bias.

risk of bias due to allocation concealment removed all but 1 trial from these subgroup analyses.

Since the trials in this review were determined to be at some risk of bias (mainly unclear risk and some high risk), it is imperative to interpret the findings with caution. Despite these risks of bias, however, a sensitivity analysis performed by removing all trials at unclear or high risk of bias from allocation concealment did not alter the results for the main analysis, so these trials were left in. Furthermore, through the sole inclusion of RCTs, many of the other biases and confounding associated with observational studies should have, hypothetically, been limited or eliminated.

Several other issues in this review warrant discussion. The absence of data on standard deviation of change for 4 trials meant that standard deviations of change were imputed for some trials, resulting in only approximate analyses. The effect of duration of

intervention on the results could not be adequately assessed because of the low heterogeneity of trial duration in the included studies. Additionally, the effectiveness of black tea could not be rigorously assessed because only 1 trial examined blood pressure changes with this type of intervention. Adverse effects were also not reported for most of the trials (and it is unclear whether they were monitored in the first place). Since many small trials were included, funnel plots were generated and Egger's test was run to assess publication bias. Both failed to find evidence of publication bias, but since the Egger's test has low power, the possibility of publication bias cannot be ruled out completely.

It is believed that this is the first systematic review to assess the evidence from RCTs for an effect of green and black tea on blood pressure for the secondary prevention of CVD. A recent review examined the effect of green and black tea on blood pressure for the primary prevention of CVD,[18] and findings from the present review are in line with the results from the primary prevention review. In their review of the effect of black and green teas on primary prevention of CVD in 290 participants from 4 trials, Hartley et al.[18] reported a net SBP change of −2.95 mmHg (95%CI −3.39 to −1.11) and a net DBP change of −2.81 mmHg (95%CI −3.77 to −1.86) after a median follow-up of 3 months. The 95%CIs for the effect of black and green teas on blood pressure between that review and the present review consequently overlap. Pooled results from the present review, while having significantly more participants, had intentionally wider 95%CIs in order to provide a conservative magnitude of effect in light of missing standard deviation data for 4 trials. The slightly higher effect sizes found by Hartley et al.[18] may reflect a minimum follow-up of 3 months and/or the more favorable effect of tea on blood pressure among normotensive populations.

More long-term studies are necessary to determine if effect size is influenced by the duration of tea intake. Since 75% of total tea consumed is black, there is an additional need for more trials on black tea.[35] There is also a need for more high-quality large-scale RCTs. Moreover, subgroup analyses from this review suggest a potential differential effect between caffeinated and decaffeinated tea products on blood pressure, which should be explored further, for example, with a multifactorial design. Most studies in this review assessed the effect of tea intake in the form of a beverage or a capsule. As some evidence suggests small, but significant, differences in the bioavailability of green tea antioxidants and black tea antioxidants depending on the method of intake, further research is needed to help identify a possible clinically optimal form of tea intake in relation to its effect on blood pressure.[36] Finally, larger trials of longer duration may help identify any potential adverse effects that may arise from long-term tea consumption.

Current guidelines for hypertension suggest that dietary and lifestyle interventions be enacted to help lower blood pressure. At the population level, reductions in SBP and DBP of 2–3 mmHg are associated with reductions in the incidence of coronary artery disease and stroke of 8% and 15%, respectively.[37] This is particularly significant, as tea is regularly consumed worldwide. While medical interventions are routinely provided for those within hypertensive ranges, such interventions are not recommended for those with prehypertension.[38] Dietary and lifestyle modifications are normally suggested, potentially making the results from this review particularly applicable to individuals with prehypertension.

CONCLUSION

This systematic review and meta-analysis found tentative evidence of a favorable effect of green and black tea intake, for a median duration of 3 months, on both systolic and diastolic blood pressure among individuals whose blood pressure was within hypertensive and prehypertensive ranges. However, only a small number of trials contributed to the analyses, and the methodological quality of many studies was, in many cases, unclear. Thus, a need remains for more large-scale RCTs of green and (especially) black tea of longer duration and stronger methodological quality to confirm the findings presented here.

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SUPPORTING INFORMATION

The following Supporting Information is available through the online version of this article at the publisher's website:

Table S1. Complete PubMed search strategy.

Figure S1. Mean differences and 95% CIs (individual and pooled) for fixed-effects models examining effect of green or black tea consumption on systolic blood pressure by subgroup of flavonoid dosage (<500 mg/day or ≥500 mg/day).

Figure S2. Mean differences and 95% CIs (individual and pooled) for fixed-effects models examining the effect of green or black tea consumption on diastolic blood pressure by flavonoid dosage (<500 mg/day or ≥500 mg/day).

Figure S3. Mean differences and 95% CIs (individual and pooled) for fixed-effects models examining the effect of green or black tea consumption on systolic blood pressure by caffeine presence (present or absent).

Figure S4. Mean differences and 95% CIs (individual and pooled) for fixed-effects models examining the effect of green or black tea consumption on diastolic blood pressure by caffeine presence (present or absent).

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