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Systematic Review and Meta-Analysis

Effects of tea intake on blood pressure: a meta-analysis of randomised controlled trials

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Abstract

The effect of tea intake on blood pressure (BP) is controversial. We performed a meta-analysis of randomised controlled trials to determine the changes in systolic and diastolic BP due to the intake of black and green tea. A systematic search was conducted in MEDLINE, EMBASE and the Cochrane Controlled Trials Register up to May 2014. The weighted mean difference was calculated for net changes in systolic and diastolic BP using fixed-effects or random-effects models. Previously defined subgroup analyses were performed to explore the influence of study characteristics. A total of twenty-five eligible studies with 1476 subjects were selected. The acute intake of tea had no effects on systolic and diastolic BP. However, after long-term tea intake, the pooled mean systolic and diastolic BP were lower by −1·8 (95 % CI −2·4, −1·1) and −1·4 (95 % CI −2·2, −0·6) mmHg, respectively. When stratified by type of tea, green tea significantly reduced systolic BP by 2·1 (95 % CI −2·9, −1·2) mmHg and decreased diastolic BP by 1·7 (95 % CI −2·9, −0·5) mmHg, and black tea showed a reduction in systolic BP of 1·4 (95 % CI −2·4, −0·4) mmHg and a decrease in diastolic BP of 1·1 (95 % CI −1·9, −0·2) mmHg. The subgroup analyses showed that the BP-lowering effect was apparent in subjects who consumed tea more than 12 weeks (systolic BP −2·6 (95 % CI −3·5, −1·7) mmHg and diastolic BP −2·2 (95 % CI −3·0, −1·3) mmHg, both $P<0·001$). The present findings suggest that long-term (≥12 weeks) ingestion of tea could result in a significant reduction in systolic and diastolic BP.

Key words: Tea: Blood pressure: Meta-analysis: Randomised controlled trials

CVD is a leading cause of morbidity, mortality and disability worldwide[1]. Blood pressure (BP) has a strong and direct relationship with cardiovascular (CV) mortality[2,3]. More importantly, there is no evidence of a BP threshold. The risk of CV mortality increases progressively throughout the range of BP, including the range of pre-hypertensive BP (systolic BP 120–139 mmHg and diastolic BP 80–89 mmHg). Thus, small changes in BP due to dietary modification may have a significant impact on the prevalence of hypertension and the risk of CVD[2].

Tea, including black and green tea, is a popular beverage worldwide and is usually the major source of population flavonoid intake, often providing more than half of total intake[4]. Epidemiological studies have suggested that a high intake of both green and black tea is related to a reduction in the risk of CVD[5,6]. The reduction of CVD risk by tea intake may be largely due to the high levels of polyphenols, in particular flavonoids, present in both green and black tea. The beneficial effect of tea intake on endothelial function may suggest a mechanistic explanation for the reduced risk of CVD[7].

A substantial number of clinical trials have been performed to investigate the acute or chronic effects of tea beverages and extracts on the BP of subjects with CVD-related conditions as well as of healthy individuals[8–32]. However, the results of these trials were inconsistent, sample sizes were relatively

Abbreviations: BP, blood pressure; CV, cardiovascular.

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modest so studies were often underpowered to detect modest effects on BP, and most studies did not have BP as a primary outcome. Therefore, in the present study, we conducted a meta-analysis of all published randomised controlled trials to determine the acute and chronic effects of tea intake on systolic and diastolic BP.

Methods

Search strategy

According to the QUORUM (Quality of Reporting of Meta-analyses), we systematically searched PubMed (http://www.ncbi.nlm.nih.gov/pubmed; from 1967 to May 2014), EMBASE (http://www.embase.com; from December 1977 up to 2014), the Cochrane Library database (http://www.cochrane.org), and reviews and reference lists of relevant articles using the keywords 'tea', 'green tea', 'black tea', 'tea polyphenols', 'blood pressure', 'hypertension'. The search was restricted to human research studies. No limit was placed on language. In addition, a manual search of references from the reports of clinical trials or review articles was performed to identify the relevant trials. Attempts were also made to contact investigators for unpublished results and full-text articles.

Study selection

Studies were included in the present meta-analysis if they met the following criteria: (1) studies evaluated the acute (<1 week) or chronic (>1 week) effects of tea on BP; (2) studies were randomised controlled trials with either a parallel or cross-over design; (3) studies reported net changes in BP or only follow-up BP measures, and the associated standard deviations (or data to calculate them); (4) food intake control regimen of the experimental group was consistent with that of the control group; (5) tea extract was not given as part of a multi-component supplement in either the experimental or control group. Studies were excluded from the analysis if only abstracts were published. Data of multiple published reports from the same study population were included only once.

Data extraction and quality assessment

Search, data extraction and quality assessment were completed independently by two reviewers (G. L. and X.-N. M.) according to the aforementioned inclusion criteria. Any discrepancies between the two reviewers were resolved by discussion until a consensus was reached. Study characteristics (including authors, year of publication, sample size, study design, study duration, dose and type of intervention) and population information (age, ethnicity, sex and initial healthy status) were extracted. For continuous outcomes in parallel studies, the means and standard deviations of changes from baseline to endpoint (for both intervention and control groups) were extracted. In cross-over studies, the means and standard deviations were used separately for interventions and controls. This step provided a conservative estimate of the effects and reduced the power of cross-over studies to show the real influences of interventions[33].

Quality characteristics of the trials were assessed using the following criteria: (1) randomisation; (2) concealment of treatment allocation; (3) participant masking; (4) researcher masking; (5) reporting of withdrawals; (6) generation of random numbers. The Jadad score was also introduced in order to evaluate the quality of the included studies. Trials scored one point for each area addressed in the study design (randomisation, blinding, concealment of allocation, reporting of withdrawals and generation of random numbers), with a possible score ranging between 0 and 5 (highest level of quality)[34]. Higher numbers represented better quality (Jadad score ≥ 3).

Data synthesis and analysis

Net changes in each of the study variables, calculated from baseline and follow-up means and standard deviations (follow-up minus baseline), were used to estimate the principle effect. When the standard deviations were not available directly, they were calculated from standard errors or CI. If variances for net changes were not reported directly, they were calculated from CI, *P* values, or individual variances from the tea group and the control group. For trials in which variances for paired differences were reported separately for each group, we calculated a pooled variance for net changes using standard methods. Missing variances for paired differences were calculated from variances at baseline and at the end of the follow-up for each measure using correlation coefficient methods according to the Cochrane Handbook for Systematic Reviews of Interventions[33]. We assumed a correlation coefficient of 0·62[33].

The present meta-analysis and statistical analyses were performed using STATA 12.0 (STATA Corporation LP). A P value $<0{\cdot}05$ was considered as statistically significant for all analyses. Weighted mean differences and 95% CI were calculated for net changes in systolic and diastolic BP. The statistic heterogeneity of treatment effects between studies was formally tested with Cochran's test ($P<0{\cdot}1$). The I^2 statistic was also examined, and we considered $I^2>50\%$ to indicate significant heterogeneity between trials[35]. Results were obtained from a fixed-effects model if no significant heterogeneity was shown, and a random-effects model was selected for the analysis if significant heterogeneity was shown[36]. Publication bias was assessed with funnel plots and Egger's regression test. Previously defined subgroup analyses were performed to examine the effects of factors (ethnicity, type of tea, polyphenol dose, health status, study duration and caffeine controlled) on the primary outcomes after chronic intake of tea, and to identify the possible source of heterogeneity within these studies. To test the robustness of the results, we performed a one-way sensitivity analysis. The scope of the present meta-analysis was to evaluate the influence of individual studies by estimating pooled changes in BP in the absence of each study.

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Results

Results of the literature search

The method used for the selection of the studies is shown in Fig. 1. The initial search identified 714 reports, of which 682 were excluded because they were not clinical trials or because the interventions were not relevant to the purpose of the present meta-analysis. Through a manual reference search of primary and review articles, two additional articles were retrieved. Therefore, thirty-four potentially relevant articles were examined in more detail. Among them, nine were subsequently excluded. The reasons for the exclusion of the studies are presented in Fig. 1. Thus, a total of twenty-five articles were selected for the final analysis.

Study characteristics

A total of twenty-five eligible randomised controlled trials with 1476 subjects were included in the present meta-analysis[8–32]. The characteristics of the included trials are shown in Table 1. The studies of Hodgson *et al.*[13] and Duffy *et al.*[14] were both separated into two trials (acute and chronic effects of tea on BP). The trials varied in size from twelve to 240 subjects, and study duration varied from 1 h to 24 weeks. Of the twenty-five trials used in the meta-analysis, seven[9,11,12,17,26,27,30] were conducted in healthy adults, and eighteen[8,10,13–16,18–25,28,29,31,32] were conducted in patients with CV risk, among which, two[13,31] enrolled hypertensive patients and eleven[8,14,16,18,19,21–23,25,28,29] included subjects with high-normal BP. Caffeine intake was controlled in fourteen trials[8,12,13,17,18,21,24–30,32]. Of the included studies, eighteen studies[8–18,20,25–27,29,31,32] were performed in Whites, and the remaining seven[19,21–24,28,30] were carried out in Asians. Most of the trials (sixteen trials)[8,16,18–28,30–32] adopted parallel study designs and seventeen[8,9,12,17,18,20,21,23–32] were double-blinded. A low-energy diet was administered in one trial[20], and in the remaining twenty-four trials, investigators attempted to maintain the usual lifestyles of participants.

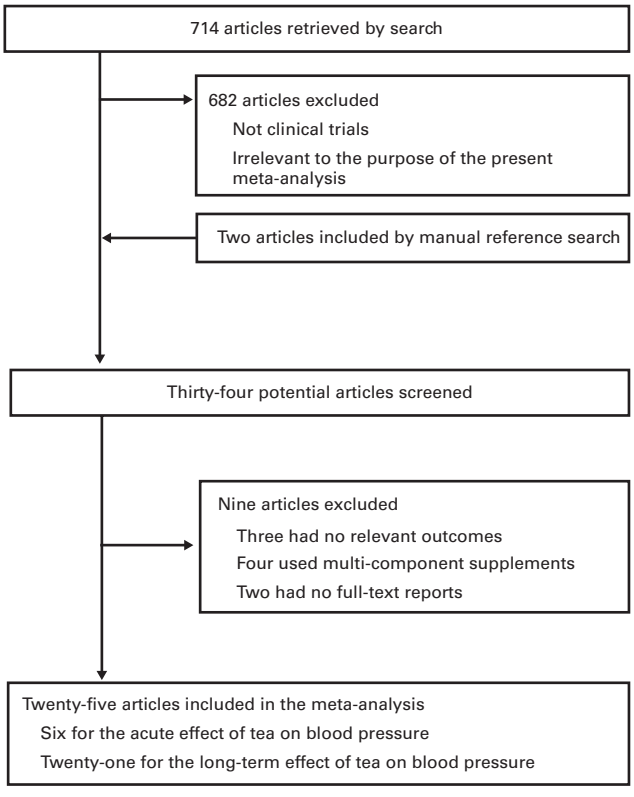

Fig. 1. Flow chart showing the number of citations retrieved by individual searches of trials included in the meta-analysis.

The results of the validity of the included trials are presented in Table 2. Most of the trials (eighteen trials)[8,9,12,14,16–18,21,23–32] were classified as high quality (Jadad score ≥ 3). Furthermore, twelve trials[8,12,14,16–18,23,25,27,29,30,32] reported the generation of random numbers, but only eight[8,16,18,23,25,29–31] reported details of allocation concealment. The details of dropouts were reported in twenty-four trials.

Main analysis

As shown in Fig. 2, the acute intake of tea had no effects on systolic and diastolic BP. The results of the long-term effects of tea intake on BP are shown in Fig. 3. Overall, compared with the tea-free control, the pooled mean decrease in systolic BP was −1·8 (95% CI −2·4, −1·1) mmHg ($I^2 = 17{\cdot}4\%$) and in diastolic BP was −1·4 (95% CI −2·2, −0·6) mmHg ($I^2 = 52{\cdot}5\%$) for tea intake. In addition, when stratified by type of tea, green tea exhibited a significant reduction in systolic BP of 2·1 (95% CI −2·9, −1·2) mmHg ($I^2 = 21{\cdot}8\%$) and a decrease in diastolic BP of 1·7 (95% CI −2·9, −0·5) mmHg ($I^2 = 59{\cdot}9\%$), and black tea showed a significant reduction in systolic BP of 1·4 (95% CI −2·4, −0·4) mmHg ($I^2 = 9{\cdot}7\%$) and a decrease in diastolic BP of 1·1 (95% CI −1·9, −0·2) mmHg ($I^2 = 22{\cdot}9\%$).

Subgroup and sensitivity analyses

The results of the subgroup analyses and sensitivity analyses on systolic and diastolic BP (long-term effects) are summarised in Table 3. The subgroup analyses by study duration suggested that tea intake over a median of 12 weeks had a pronounced reduction in systolic BP of −2·6 (95% CI −3·5, −1·7) mmHg and in diastolic BP of −2·2 (95% CI −3·0, −1·3) mmHg (Fig. 4), compared with the short-term subgroup (<12 weeks) (between groups $P<0{\cdot}05$). To explore the dose–effect relationship, polyphenol doses were divided into low (≤544 mg/d) and high (>544 mg/d) doses. The subgroup analyses found that the polyphenol doses were not an effect modifier. Meanwhile, we also stratified the subjects by health status into healthy and CV risk groups (overweight or obese, and diabetic), and found no significant difference between the two groups. In addition, the BP-lowering effects were not influenced by baseline BP status. To investigate whether the effects of tea intake were related to caffeine, the changes in BP were assessed separately between studies that controlled for caffeine intake and that did not. The pooled analysis indicated that tea ingestion with or without caffeine both significantly reduced systolic and diastolic BP, suggesting that

Table 1. Characteristics of the twenty-five included randomised controlled trials

Study	Design	Location	Sex (M/F) (*n*)	Age (years)	Duration	Subjects	Tea group	Control group	Baseline BP (intervention *v.* control)	Follow-up BP (intervention *v.* control)	Concurrent lifestyle modification
Acute effects of tea on BP											
Hodgson *et al.*[8]	RP, DB	Australia	84 (31/53)	56·1	24 h	High-normal BP	Black tea beverage (429 mg polyphenols, containing caffeine)	Placebo (matched with caffeine)	121·3/72 *v.* 121·1/72·3	121·8/72·9 *v.* 122·1/72·9	Maintaining the usual diet and exercise
Belza *et al.*[9]	RC, DB	Denmark	12 (12/0)	23·7	4 h	Healthy, normotensive	Green tea extract (125 mg polyphenols, containing no caffeine)	Placebo	114/61 *v.* 110/61	–	Maintaining the usual diet
Hodgson *et al.*[10]	RC, OL	Australia	20*	62·1	3·5 h	CAD, normotensive	Black tea beverage (900 mg polyphenols, containing caffeine)	Water	126·7/74·7 *v.* 128·1/77·2	136·31/77·7 *v.* 127·7/78	Maintaining the usual diet and exercise
Quinlan *et al.*[11]	RC, OL	UK	17 (8/9)	35	2 h	Healthy, normotensive	Black tea beverage (polyphenol intake: NR, containing caffeine)	Water	118/78 *v.* 118/78	124·2/84 *v.* 122·5/82·7	Maintaining the usual diet
Hodgson *et al.*[13]	RC, OL	Australia	20 (20/0)	56·2	1 h	Mild systolic hypertension	Black tea beverage (polyphenol intake: NR, containing caffeine)	Hot water (matched with caffeine)	111/66 *v.* 111·4/65·9	122·3/72·1 *v.* 118·1/70·9	Maintaining the usual diet
Duffy *et al.*[14]	RC, OL	USA	50 (39/11)	55	2 h	CAD, high-normal BP	Black tea beverage (675 mg polyphenols, containing caffeine)	Water	137/78 *v.* 137/78	141/80 *v.* 139/78	Maintaining the usual diet
Long-term effects of tea on BP											
Bingham *et al.*[12]	RC, DB	UK	65 (31/34)	40·7	4 weeks	Healthy, normotensive	Black tea beverage (polyphenol intake: NR, containing caffeine)	Placebo (matched with caffeine)	119·9/76·6 *v.* 119·9/76·6	119·9/74·0 *v.* 120·1/75·1	Maintaining the usual diet
Hodgson *et al.*[13]	RC, OL	Australia	13 (10/3)	59·8	1 week	Mild systolic hypertension	Black tea beverage (polyphenol intake: NR, containing caffeine)	Hot water (matched with caffeine)	136·6/76·2 *v.* 136·6/76·2	136·1/76·9 *v.* 135·5/77·5	Maintaining the usual diet
Duffy *et al.*[14]	RC, OL	USA	50 (39/11)	55	4 weeks	CAD, high-normal BP	Black tea beverage (1350 mg polyphenols, containing caffeine)	Water	137/78 *v.* 137/78	136/77 *v.* 137/77	Maintaining the usual diet
Hodgson *et al.*[15]	RC, OL	Australia	22 (16/6)	59·1	4 weeks	Dyslipidaemia	Black tea beverage (polyphenol intake: NR, containing caffeine)	Hot water	123/73 *v.* 127/75	120/71 *v.* 123/73	Maintaining the usual lifestyle
Mukamal *et al.*[16]	RP, OL	USA	28 (12/14)	65·8	24 weeks	Cardiovascular risk factors (CAD, hypertension, diabetes)	Black tea beverage (954 mg polyphenols, containing caffeine)	Water	–	–	Maintaining the usual lifestyle
Grassi *et al.*[17]	RC, DB	The Netherlands	19 (19/0)	32·9	1 week	Healthy, normotensive	Black tea beverage (400 mg polyphenols, containing caffeine)	Placebo (matched with caffeine)	128·3/81·4 *v.* 128·4/81·4	125·8/78·1 *v.* 128·8/80·8	Maintaining the usual diet and lifestyle
Hodgson *et al.*[18]	RP, DB	Australia	95 (33/62)	56·6	24 weeks	High-normal BP	Black tea beverage (429 mg polyphenols, containing caffeine)	Placebo (matched with caffeine)	121·2/71·5 *v.* 121·4/72·9	120·4/70·9 *v.* 122·4/73·1	Maintaining a low-flavonoid diet
Fukino *et al.*[19]	RP, OL	Japan	66 (53/13)	53·5	8 weeks	Diabetes, high-normal BP	Green tea beverage (544 mg polyphenols, containing caffeine)	No intervention	139·3/92·5 *v.* 138·6/87·8	131·6/83·3 *v.* 129·2/83·2	Maintaining the usual lifestyle

Table 1. *Continued*

Study	Design	Location	Sex (M/F) (*n*)	Age (years)	Duration	Subjects	Tea group	Control group	Baseline BP (intervention *v.* control)	Follow-up BP (intervention *v.* control)	Concurrent lifestyle modification
Diepvens *et al.*[20]	RP, DB	The Netherlands	46 (0/46)	41·7	12 weeks	Overweight, normotensive	Green tea extract (1207 mg polyphenols, containing caffeine)	Placebo	127·4/80·0 *v.* 122·5/78·6	117·3/76·0 *v.* 115·9/77·6	Maintaining a low-energy diet
Nagao *et al.*[21]	RP, DB	Japan	240 (140/100)	41·7	12 weeks	Overweight, high-normal BP	Green tea beverage (583 mg polyphenols, containing caffeine)	Green tea (96 mg polyphenols, matched with caffeine)	127/76·9 *v.* 129/77·9	124·3/75·8 *v.* 128/77·1	Maintaining the usual lifestyle
Fukino *et al.*[22]	RP, OL	Japan	64 (52/12)	–	8 weeks	Diabetes, high-normal BP	Green tea extract (544 mg polyphenols, containing caffeine)	No intervention	137·9/91·7 *v.* 137·6/87	130/81·9 *v.* 129/83·4	Maintaining the usual diet
Hsu *et al.*[23]	RP, DB	China	78 (0/78)	43·4	12 weeks	Obese, high-normal BP	Green tea extract (614 mg polyphenols, containing caffeine)	Placebo	134·9/82·9 *v.* 135·4/81·6	131/81·7 *v.* 132·5/79·4	Maintaining a normal diet
Matsuyama *et al.*[24]	RP, DB	Japan	40 (28/12)	11·7	24 weeks	Overweight/obese, normotensive	Green tea beverage (576 mg polyphenols, containing caffeine)	Green tea (75 mg polyphenols, matched with caffeine)	124·3/63·2 *v.* 120·5/64·8	122/66 *v.* 128/65	Maintaining the usual diet
Brown *et al.*[25]	RP, DB	UK	88 (88/0)	51·4	8 weeks	Overweight/obese, high-normal BP	Green tea extract (800 mg polyphenols, containing no caffeine)	Placebo	132·2/86·7 *v.* 138·2/87·2	–	Maintaining the usual lifestyle
Frank *et al.*[26]	RP, DB	UK	33 (33/0)	40·5	3 weeks	Healthy, normotensive	Green tea extract (714 mg polyphenols, containing caffeine)	Placebo (matched with caffeine)	125/78 *v.* 126/79	123/79 *v.* 125/77	Maintaining the usual diet and exercise
Nantz *et al.*[27]	RP, DB	USA	111 (46/55)	29·6	12 weeks	Healthy, normotensive	Green tea extract (400 mg polyphenols, containing no caffeine)	Placebo	131/80 *v.* 129/78	128/79 *v.* 129/80	Maintaining the usual lifestyle
Nagao *et al.*[28]	RP, DB	Japan	43 (18/25)	63·9	3 weeks	Diabetes, high-normal BP	Green tea beverage (583 mg polyphenols, containing caffeine)	Green tea (96 mg polyphenols, matched with caffeine)	138/78·2 *v.* 135/76·9	132/75·2 *v.* 131·1/76	Maintaining the usual lifestyle
Brown *et al.*[29]	RC, DB	UK	69 (69/0)	49·4	6 weeks	Overweight/obese, high-normal BP	Green tea extract (800 mg polyphenols, containing no caffeine)	Placebo	127·1/79·1 *v.* 127·7/79·5	–	Maintaining the usual lifestyle
Sone *et al.*[30]	RP, DB	Japan	51 (18/33)	–	9 weeks	Healthy, normotensive	Green tea beverage (400 mg polyphenols, containing caffeine)	Green tea (100 mg polyphenols, matched with caffeine)	123/75 *v.* 123/76	123·9/74 *v.* 123/76	Maintaining the usual lifestyle
Bogdanski *et al.*[31]	RP, DB	Poland	56 (28/28)	50·4	12 weeks	Obese, hypertension	Green tea extract (379 mg polyphenols, containing caffeine)	Placebo	145/88 *v.* 146/89	141/84 *v.* 146/89	Maintaining the usual diet and exercise
Suliburska *et al.*[32]	RP, DB	Poland	46 (23/23)	52·3	12 weeks	Obese, normotensive	Green tea extract (379 mg polyphenols, containing no caffeine)	Placebo	130·7/85·1 *v.* 129·6/84·2	128·2/84 *v.* 128·3/84	Maintaining the usual diet and exercise

M, male; F, female; BP, blood pressure; RP, randomised parallel; DB, double-blinded; RC, randomised cross-over; OL, open-labelled; CAD, coronary artery disease; NR, not reported.
* Information on the number of males and females was unavailable.

Table 2. Validity of the included trials

Study	Allocation concealment	Masking of participants	Masking of researchers	Generation of random number reported	Reporting of withdrawals	Jadad score
Hodgson *et al.*[8]	Adequate	Yes	Yes	Yes	Yes	5
Belza *et al.*[9]	Unclear	Yes	Yes	No	Yes	3
Hodgson *et al.*[10]	Unclear	No	No	No	Yes	2
Quinlan *et al.*[11]	Unclear	No	No	No	Yes	2
Bingham *et al.*[12]	Unclear	Yes	Yes	Yes	Yes	4
Hodgson *et al.*[13]	Unclear	No	No	No	Yes	2
Duffy *et al.*[14]	Unclear	No	No	Yes	Yes	3
Hodgson *et al.*[15]	Unclear	No	No	No	Yes	2
Mukamal *et al.*[16]	Adequate	No	No	Yes	Yes	4
Grassi *et al.*[17]	Unclear	Yes	Yes	Yes	Yes	4
Hodgson *et al.*[18]	Adequate	Yes	Yes	Yes	Yes	5
Fukino *et al.*[19]	Unclear	No	No	No	Yes	2
Diepvens *et al.*[20]	Unclear	Yes	Yes	No	No	2
Nagao *et al.*[21]	Unclear	Yes	Yes	No	Yes	3
Fukino *et al.*[22]	Unclear	No	No	No	Yes	2
Hsu *et al.*[23]	Adequate	Yes	Yes	Yes	Yes	5
Matsuyama *et al.*[24]	Unclear	Yes	Yes	No	Yes	3
Brown *et al.*[25]	Adequate	Yes	Yes	Yes	Yes	5
Frank *et al.*[26]	Unclear	Yes	Yes	No	Yes	3
Nantz *et al.*[27]	Unclear	Yes	Yes	Yes	Yes	4
Nagao *et al.*[28]	Unclear	Yes	Yes	No	Yes	3
Brown *et al.*[29]	Adequate	Yes	Yes	Yes	Yes	5
Sone *et al.*[30]	Adequate	Yes	Yes	Yes	Yes	5
Bogdanski *et al.*[31]	Adequate	Yes	Yes	No	Yes	4
Suliburska *et al.*[32]	Unclear	Yes	Yes	Yes	Yes	4

caffeine intake could not modify the pooled BP-lowering effects of tea. The sensitivity analyses showed that the significance in the pooled changes in BP were not altered after the removal of the six trials[12–15,17,29] with a cross-over design or the five trials[13,15,19,20,22] with low quality.

Publication bias

Publication bias of the trials was examined by analysing funnel plots and Egger's tests. As shown in Fig. 5, the funnel plots were symmetrical and Egger's tests indicated no significant publication bias ($P=0{\cdot}947$ for systolic BP and $P=0{\cdot}653$ for diastolic BP).

Discussion

The present meta-analysis showed that the acute intake of tea had no effects on BP. However, long-term consumption of black and green tea significantly reduced systolic and diastolic BP. Subgroup analyses indicated that the BP-lowering effects were apparent when the duration of the follow-up was over a median of 12 weeks. Differences in tea polyphenol doses, caffeine intake, study quality, ethnicity and health status of participants did not appear to significantly influence the pooled mean differences in BP.

A large population-based study that involved >40 000 middle-aged Japanese revealed that, compared with no tea drinking, habitual tea consumption (average of two cups (approximately 17 oz)/d for 10 years) was associated with a lower risk of death from CVD[5]. However, reports on the effects of tea on CVD risk factors have been mixed. Some clinical studies have shown that green tea intake lowers total and LDL-cholesterol, and blood glucose levels[37,38]; however, some randomised trials have shown the lack of the effects of black tea intake on lipids[12,14]. In addition, the BP-lowering effect of tea is also controversial. A previous meta-analysis has shown that tea intake had no significant effect on BP[39]; however, the sample sizes of that study were relatively modest (343 subjects) and the duration of the study was short (mean 4 weeks). In the present meta-analysis involving a total of 1323 subjects at a mean follow-up of 12 weeks, we confirmed that tea ingestion resulted in a significant reduction of BP. More importantly, there was no indication of heterogeneity for systolic BP, and only modest heterogeneity was observed for diastolic BP. Therefore, it is reasonable to speculate that the BP-lowering effect of tea is also a contributor to the reduced risk of CVD mortality.

The BP-lowering effect of tea may be associated with its antioxidant properties and endothelial protection. Tea and their flavonoids could act as antioxidants by scavenging reactive oxygen species and nitrogen species, and chelating redox-active transition metal ions[40,41]. Studies on hypertensive animal models have shown that tea intake effectively attenuated increases in BP and, meanwhile, reduced the formation of vascular reactive oxygen species and improved endothelium-dependent relaxation in the aorta, which could account for the amelioration of hypertension[42,43]. In addition, there has been compelling evidence showing that ingestion of tea leads to increments in brachial artery flow-mediated dilation and improvement in endothelial function[17,44]. However, the results from human intervention studies do not provide evidence that reduced reactive oxygen species formation contributes to the beneficial effects of tea intake on vascular health[45,46].

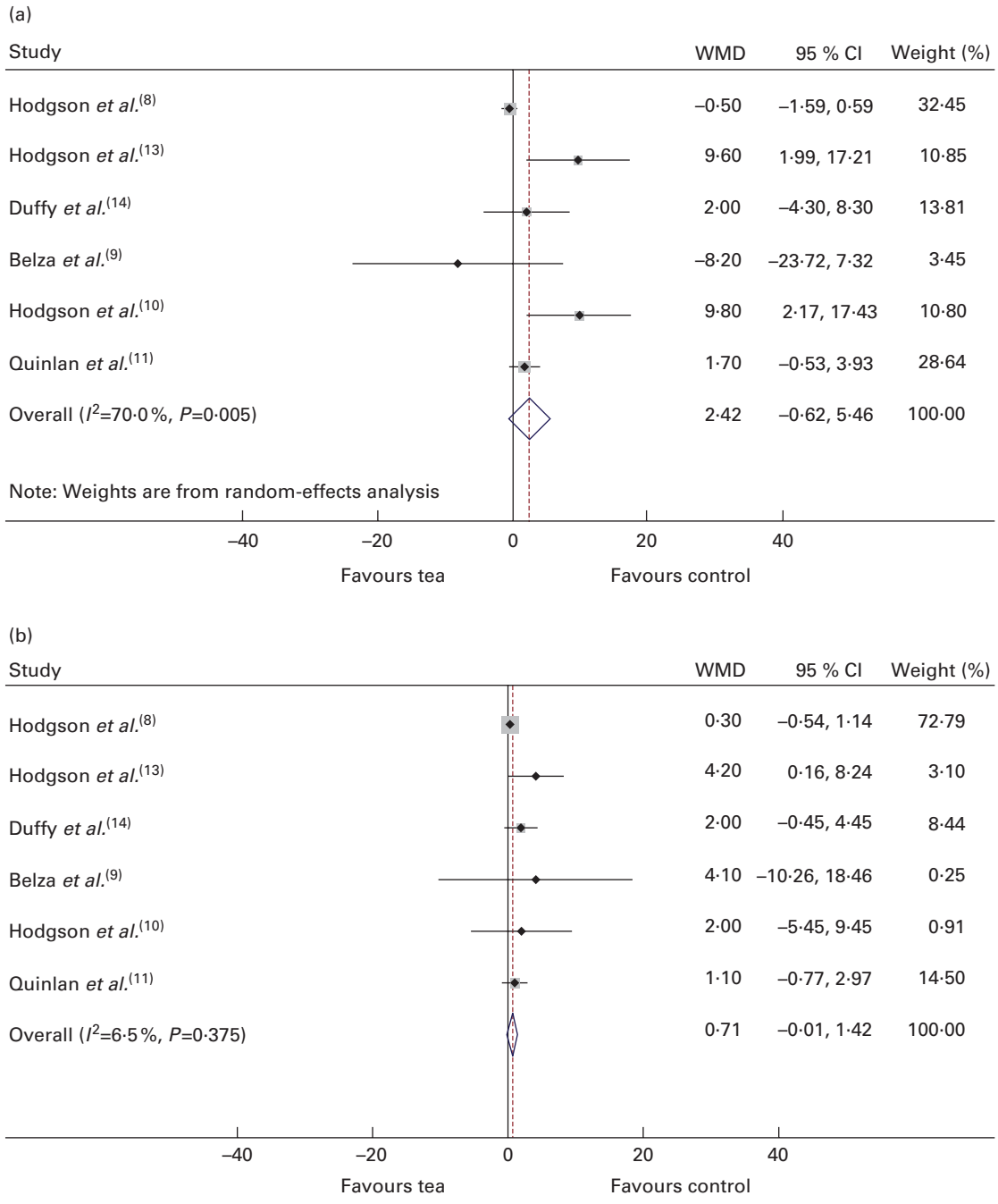

Fig. 2. Meta-analysis of the acute effects of tea intake on (a) systolic and (b) diastolic blood pressure compared with the control arms. WMD, weighted mean difference. (A colour version of this figure can be found online at http://www.journals.cambridge.org/bjn).

In the present meta-analysis, the beneficial effects of tea intake on BP were observed when the duration of consumption was slightly ≥12 weeks. We found that the acute intake of tea had no effects on BP. The results suggest that long-term benefits of tea intake on BP are unlikely to be due to acute changes. Because the improvement in endothelial function appears to be strongest in the hours after tea has been consumed[47], there may have been other mechanisms underlying the long-term benefits of tea ingestion in addition to the increase in the bioavailability of NO. Tea intake has been reported to have various beneficial effects on vascular function, such as anti-inflammatory effects, anti-platelet effects and anti-proliferative effects[48]. Thus, these effects may also be involved in potential mechanisms underlying the benefits of tea intake on BP. In the present subgroup analyses, the reduction in systolic BP by 2·6 mmHg after chronic intake of tea, as reported herein, would be expected to reduce stroke risk by 8 %, coronary artery disease mortality by 5 % and all-cause mortality by 4 % at a population level[49]. These are profound effects and must be considered seriously in terms of the

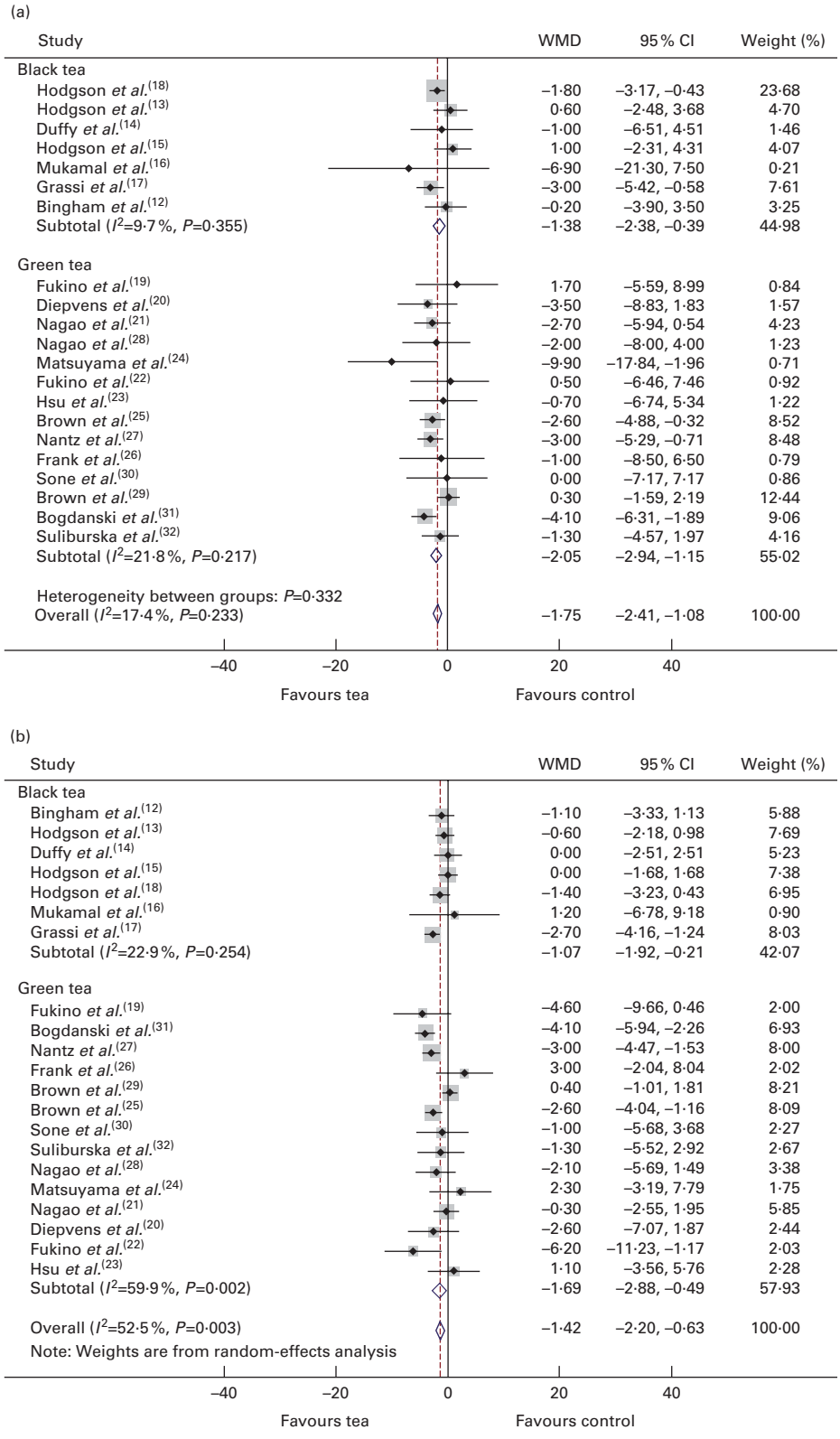

Fig. 3. Meta-analysis of the long-term effects of tea intake on (a) systolic and (b) diastolic blood pressure compared with the control arms. Subgroup analyses stratified by type of tea (black and green tea). WMD, weighted mean difference. (A colour version of this figure can be found online at http://www.journals.cambridge.org/bjn).

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Table 3. Subgroup analyses of systolic and diastolic blood pressure (BP) stratified by previously defined study characteristics (Mean differences and 95 % confidence intervals)

		Systolic BP (mmHg)				Diastolic BP (mmHg)			
Variables	Trials (*n*)	Mean difference	95 % CI	*P* for heterogeneity	*P* between groups	Mean difference	95 % CI	*P* for heterogeneity	*P* between groups
Duration									
<12 weeks	12	−0·81	−1·79, 0·16	0·557	0·010	−1·17	−1·77, −0·57	0·011	0·045
≥ 12 weeks	9	−2·57	−3·48, −1·65	0·445		−2·15	−2·98, −1·32	0·079	
Ethnicity									
Caucasian	14	−1·84	−2·52, −1·13	0·114	0·867	−1·51	−2·02, −0·99	0·002	0·677
Asian	7	−2·01	−4·12, 0·14	0·429		−1·18	−2·63, 0·26	0·179	
Polyphenol dose (mg/d)									
> 544	10	−2·30	−3·17, −1·42	0·663	0·352	−2·48	−3·20, −1·77	0·106	0·342
≤ 544	8	−1·58	−2·81, −0·36	0·171		−1·08	−1·59, − 0·56	0·103	
Caffeine controlled									
Yes	13	−1·66	−2·41, −0·92	0·251	0·388	−1·19	−1·76, −0·62	0·025	0·659
No	8	−2·38	−3·84, −0·93	0·205		−2·30	−3·21, −1·39	0·01	
Health status									
Healthy	5	−2·37	−3·82, −0·91	0·658	0·401	−2·11	−3·14, −1·09	0·146	0·129
CV risk	16	−1·67	−2·41, −0·93	0·104		−1·17	−1·83, −0·51	0·008	
Baseline BP status									
High-normal or hypertensive	12	−1·62	−2·43, −0·82	0·244	0·591	−1·37	−1·99, −0·74	0·005	0·495
Normotensive	9	−2·02	−3·20, −0·83	0·257		−1·71	−2·48, −0·95	0·066	
Sensitivity analysis									
Omitting cross-over trials	15	−2·49	−3·30, −1·69	0·672		−2·23	−2·91, −1·54	0·147	
High-quality studies	16	−1·84	−2·51, −1·17	0·130		−1·62	−2·17, −1·08	0·005	

CV, cardiovascular.

potential for dietary modification to modulate the risk of CVD. The beneficial effects of tea intake on endothelial function may more or less explain the reduced risk of CVD and stroke[7].

Tea intake has been shown to decrease BP in the present meta-analysis. However, the optimal dose that would best improve BP remains uncertain. The subgroup analyses found that the tea polyphenol dose was not an effect modifier. This finding should be interpreted with caution. Most of the polyphenols found in tea are flavonoids, and catechins constitute about 80 to 90 % of total flavonoids in green tea, whereas they only account for 20 to 30 % of total flavonoids in black tea because it can convert catechins into more complex condensed flavonoids, mainly thearubigins and theaflavins[50]. It is difficult to conclude the active constituents of green and black tea that needs to be explored in further studies. Moreover, the differences in tea preparations and ethnicity might affect the effectiveness of tea. Therefore, variations in the study characteristics of the included trials made it difficult to assess the true dose–response relationship between tea intake and its BP-lowering effects.

Because tea also naturally contains caffeine in addition to flavonoids or other compounds, another potential issue is whether caffeine intake affects the BP-lowering effects of tea. Data from human and animal studies have reported that caffeine alone could increase BP by influencing arterial compliance and increasing arterial stiffness[51,52], and therefore it may have a potential to reverse the BP-lowering effect. However, the present meta-analysis showed that intake of tea with or without caffeine both resulted in a significant reduction of BP, indicating that caffeine did not alter the effectiveness of tea and their flavonoids. This could be explained by the fact that the dosage of caffeine contained in tea is relatively low when compared with that of flavonoids; therefore, the negative effect of caffeine on BP cannot overcome the positive effect of tea and their flavonoids.

Although we believe that the present meta-analysis provides useful information, there are some potential limitations that need to be addressed. First, as with any meta-analysis, internal validity relies on the quality of individual studies. Although all studies were randomised and most of the studies described withdrawals, the lack of blinding of participants or investigators to the intervention in a number of studies[8–12,15,18] increased the risk of expectation bias. In addition, the potential lack of blinding even in studies that were described as 'double blind' could also bias the results reported herein due to the nature of the use of the product.

Second, the present meta-analysis did not pool safety data. The dosage of tea polyphenols consumed daily ranged from low (116·1 mg/d) to high (1207 mg/d) in the present meta-analysis, and no subjects experienced serious adverse events. However, concern has been raised about the safety of supplementation with high doses of tea polyphenols, such as the possibility of hepatotoxicity[53]. Therefore, safety issues need to be evaluated under conditions of long-term and high-dose exposure in the future.

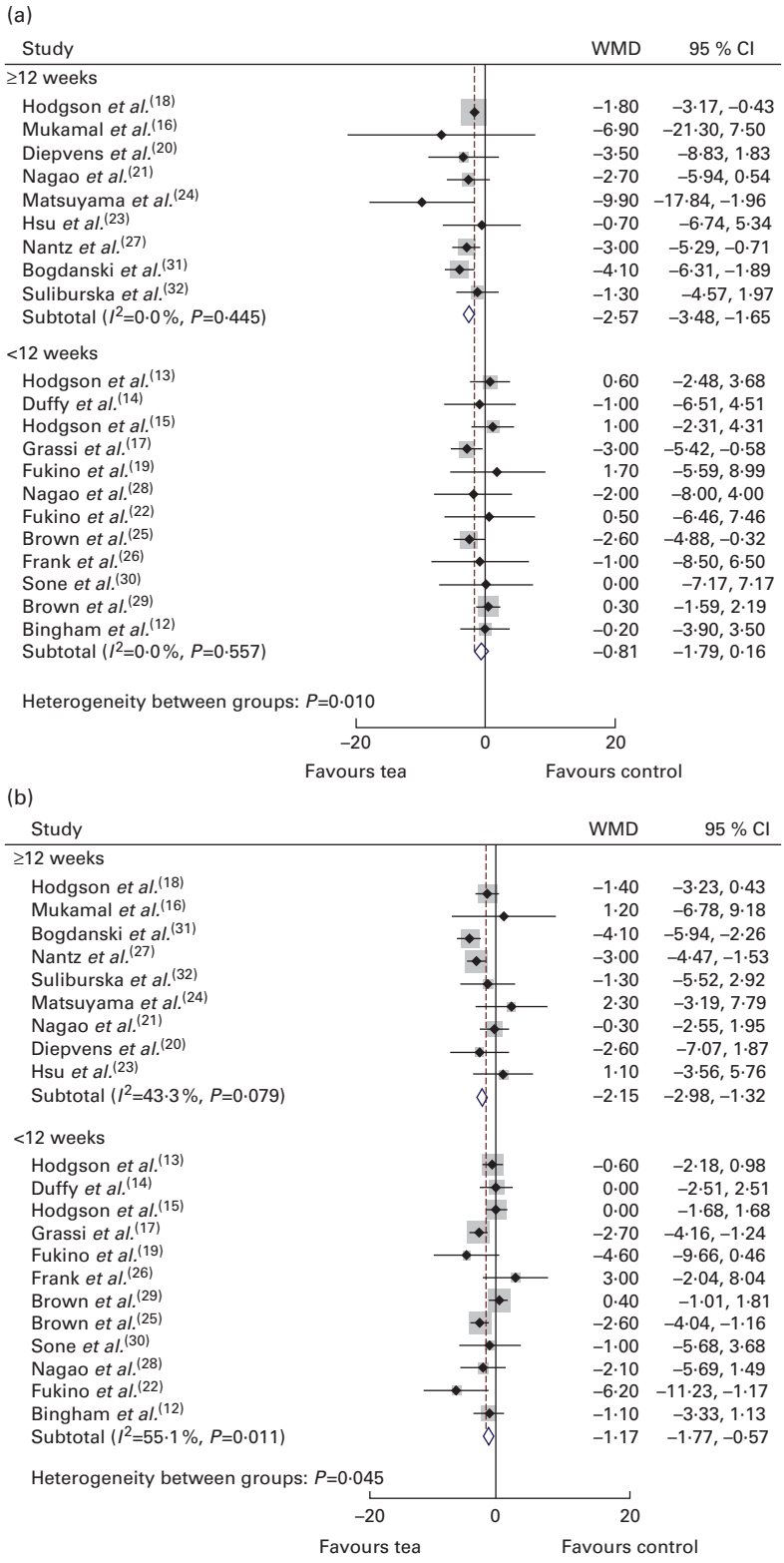

Fig. 4. Subgroup analyses of the effects of chronic intake of tea on (a) systolic and (b) diastolic blood pressure stratified by study duration (≥12 or <12 weeks). WMD, weighted mean difference. (A colour version of this figure can be found online at http://www.journals.cambridge.org/bjn).

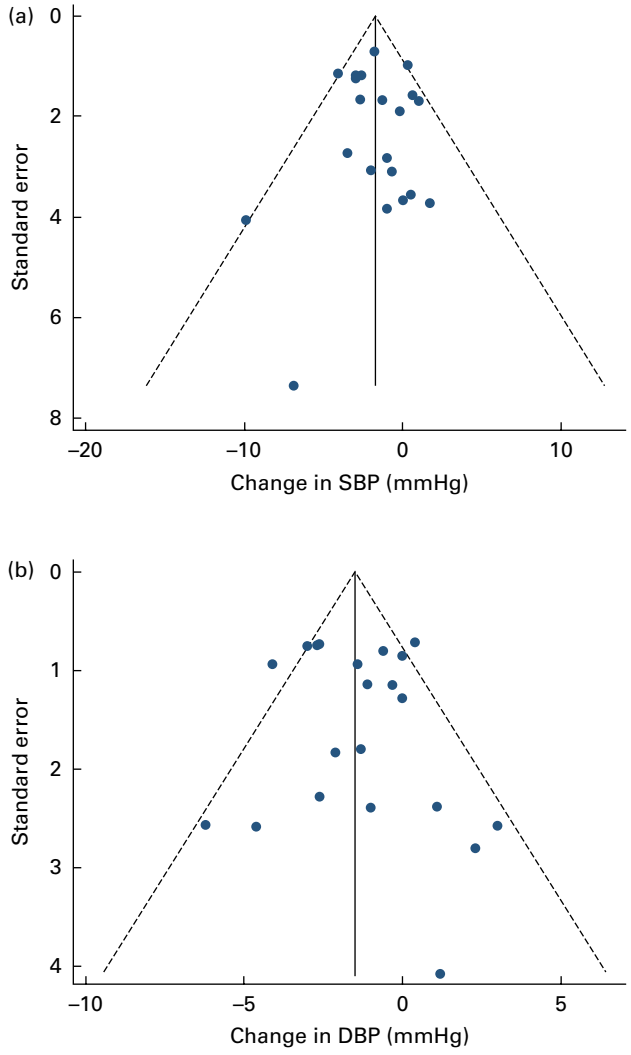

Fig. 5. Funnel plots of changes in (a) systolic (SBP) and (b) diastolic (DBP) blood pressure after chronic intake of tea. The vertical line represents the pooled mean effect size. (A colour version of this figure can be found online at http://www.journals.cambridge.org/bjn).

An additional limitation was the size of these trials, which ranged between twelve and 240 participants. Therefore, the present meta-analysis may have been underpowered to detect a true effect.

In conclusion, BP is a consistent, strong and independent risk of CV mortality, and small changes in BP may have a significant impact on the risk of CV mortality. The findings of the present meta-analysis suggest that long-term (≥12 weeks) ingestion of tea (green and black tea) resulted in a significant reduction of systolic and diastolic BP, and the BP-lowering effects of tea were not influenced by ethnicity, caffeine intake, tea polyphenol doses, health status of participants and study quality.

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The authors' contributions are as follows: X.-H. H. and G. L. were responsible for the study concept and design; G. L. and X.-N. M. summarised the data and conducted the research; G. L. and X.-N. M. analysed and interpreted the data. All authors read and approved the final version of the manuscript

None of the authors has any conflicts of interest to declare.

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