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Updated association of tea consumption and bone mineral density

A meta-analysis

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Abstract

Background: Current studies evaluating the association of tea consumption and bone mineral density (BMD) have yielded inconsistent findings. Therefore, we conducted a meta-analysis to assess the relationship between tea consumption and BMD.

Methods: The PubMed, Embase, and Cochrane Library databases were comprehensively searched, and a meta-analysis performed of all observational studies assessing the association of tea consumption and BMD. Forest plots were used to illustrate the results graphically. The Q-test and I^2 statistic were employed to evaluate between-study heterogeneity. Potential publication bias was assessed by the funnel plot.

Results: Four cohort, 1 case–control, and 8 cross-sectional studies including a total of 12,635 cases were included. Tea consumption was shown to prevent bone loss [odds ratio (OR): 0.66; 95% confidence interval (CI), 0.47–0.94; $P=0.02$], yielding higher mineral densities in several bones, including the lumbar spine [standardized mean difference (SMD): 0.19; 95% CI, 0.08–0.31; $P=0.001$], hip (SMD: 0.19; 95% CI, 0.05–0.34; $P=0.01$), femoral neck [mean difference (MD): 0.01; 95% CI, 0.00–0.02; $P=0.04$], Ward triangle (MD: 0.02; 95% CI, 0.01–0.04; $P=0.001$), and greater trochanter (MD: 0.03; 95% CI, 0.02–0.04; $P<0.00001$), than the non-tea consumption group.

Conclusion: This meta-analysis provided a potential trend that tea consumption might be beneficial for BMD, especially in the lumbar spine, hip, femoral neck, Ward triangle, and greater trochanter, which might help prevent bone loss.

Abbreviations: AHRQ = Agency for Healthcare Research and Quality, BMD = bone mineral density, CI = confidence interval, EGCG = epigallocatechin gallate, MD = mean difference, NOS = Newcastle–Ottawa scale, OR = odds ratio, SMD = standardized mean difference.

Keywords: bone mineral density, meta-analysis, osteoporosis, tea consumption

1. Introduction

Osteoporosis, a serious hazard to human health,[1] is a systemic skeletal disease caused by decreased bone mass and micro-architectural degradation of the bone tissue; it produces increasing physical illness and pain.[1–5] Bone mineral density (BMD) is a major indicator of osteoporosis, and determines its severity.

Tea is the most popular beverage in the world; the health advantages of this beverage have been reported in cardiovascular diseases, rheumatoid arthritis, influenza, and cancer.[6–10] The association of tea consumption with BMD has been investigated since the 1990s.[11] However, previous studies have yielded inconsistent conclusions. Indeed, some researchers claim a positive relationship between tea consumption and BMD,[12–14] while others support an inverse relationship between them.[11] Meanwhile, no correlation was found in some studies.[15–17]

To clarify the relationship of tea consumption and BMD more exactly and systematically, a meta-analysis of all available studies was performed.

2. Methods

2.1. Literature search

Electronic databases, including Embase, PubMed, and Cochrane Library, were searched comprehensively for all relevant literature, without restriction to regions, languages, or publication types. The following MeSH-free words and their combinations were searched in all fields: (("Tea" [MeSH]) or ("Tea" [Free words])) AND ((("Osteoporosis" [MeSH]) or ("Osteoporosis" [Free words])) or (("Bone Density" [MeSH]) or ("Bone Density" [Free words]))). In addition, the reference lists of the selected literature were also used to expand the search. Two investigators independently searched for articles, and reviewed all the retrieved studies. Disagreement between the 2 investigators was resolved by consensus, involving a third reviewer.

2.2. Inclusion and exclusion criteria

Inclusion criteria were as follows: observational studies with cohort, case–control, and cross-sectional designs, respectively (there was no relevant double-blind, placebo controlled trials); tea

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consumption as exposure; BMD or osteoporosis as outcome; results including means and standard deviations or dichotomous data, or providing sufficient information to derive the latter. Exclusion criteria were reviews, repeated, or overlapped publications; herbal tea; no measurement locations of BMD; animal studies; and studies with unavailable data.

2.3. Data extraction

Relevant information from each eligible study was extracted independently by 2 reviewers (Zhang and Yang) using a standardized form. Information included study name (first author), publication year, study location, study design, sample size, tea type, measurement locations of BMD, and study results.

2.4. Quality assessment

The Newcastle–Ottawa scale (NOS), with scores of 0 to 9 (allocated as stars), was used to assess the methodological quality of cohort and case–control studies,[18,19] and high quality was considered for articles with 6 or more stars. In addition, cross-sectional studies were assessed by an 11-item checklist recommended by Agency for Healthcare Research and Quality (AHRQ).[20] An "UNCLEAR" or "NO" answer conferred a score of "0" to the item, and "YES" a score of "1." The quality of the article was assessed as follows: low quality, 0 to 3; medium quality, 4 to 7; high quality, 8 to 11.[20]

2.5. Ethical statement

All results and analyses were from previous published studies; thus, no ethical approval and patient consent are required.

2.6. Statistical analysis

All statistical analyses were performed with Review Manager 5.3 (The Cochrane Collaboration, Copenhagen, Denmark). In the pooled results, mean difference (MD) and odds ratio (OR) were used to compare continuous and dichotomous variables, respectively; standardized MD (SMD) were used for different units. All results were expressed with 95% confidence interval (CI). Heterogeneity was measured by the Q-test with I^2 statistics, with $P < 0.10$ and $I^2 > 50\%$ indicating high heterogeneity.[21,22] The random-effects model was used, when there was significant heterogeneity between-studies; otherwise, the fixed-effects model was employed.[23] Sensitivity analyses were used to evaluate the impact of each study on the pooled results by removing each study in turn,[10,24] assessing whether the quality of articles affected the overall results.[25] Funnel plots were used to assess potential publication bias.

3. Results

3.1. Study selection

A total of 364 relevant articles were obtained in the initial literature search. Then, 82 articles were excluded because of duplication; 248 others which were obviously irrelevant, reviews, or animal studies were also excluded by screening titles or abstracts. Studies with unavailable data or assessing herbal tea were also removed after full text reading. Finally, 13 articles were included in this study, evaluating 12,635 cases (6059 and 6576 individuals in the tea- and non-tea consumption groups) (Fig. 1).

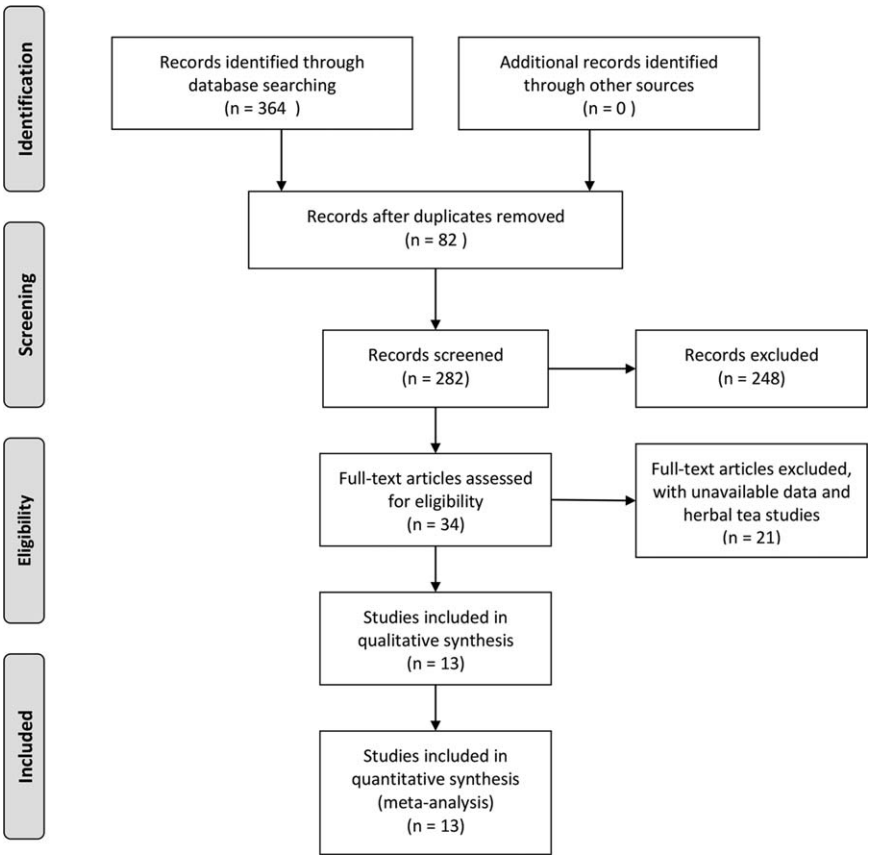

Figure 1. Flow diagram of screened, included, and excluded studies.

Table 1

Characteristics of included studies (continuous data).

Study ID	Study location	Study design	Tea types	Measurement locations (BMD)	Non-tea consumption (means ± SDs, except:†,‡)	Tea consumption (means ± SDs,except:†,‡)	Quality score
Wang et al[32]	China	Cohort	Oolong tea	(g/cm^2)	n = 556	n = 124	7
				L_{2-4}	0.745 ± 0.05	0.767 ± 0.010	
				Femoral neck	0.796 ± 0.121	0.796 ± 0.108	
				Greater trochanteric	0.759 ± 0.116	0.793 ± 0.119	
				Ward triangle	0.637 ± 0.135	0.668 ± 0.133	
Hsiao et al[33]	Taiwan	Cross-sectional	Tea	Hip	n = 55	n = 45	3
					−1.35 ± 0.94*	−0.89 ± 0.93*	
Muraki et al[35]	Japan	Cross-sectional	Green tea	(g/cm^2)	n = 52	n = 580	7
				Lumbar spine	0.733 ± 0.182	0.807 ± 0.187	
Hossein et al[34]	Iran	Cross-sectional	Tea	(g/cm^2)	n = 705	n = 125	9
				Spine (L_{2-4}) men	1.2 ± 0.2 (n = 290)	1.2 ± 0.2 (n = 35)	
				women	1.1 ± 0.2 (n = 415)	1.15 ± 0.0 (n = 90)	
				Hip men	1.01 ± 0.1 (n = 290)	1.01 ± 0.1 (n = 35)	
				women	0.95 ± 0.1 (n = 415)	0.99 ± 0.11 (n = 90)	
Devine et al[31]	Australian	Cross-sectional	Tea	(mg/cm^2)	n = 172	n = 855	10
				Hip	782 (764, 800)†	806 (799, 814)†	
				Femoral neck	665 (650, 680)†	681 (674, 688)†	
				Trochanter	603 (587, 620)†	630 (623, 637)†	
				Intertrochanter	927 (905, 949)†	950 (941, 960)†	
Hamdi et al[30]	Turkey	Cross-sectional	Tea	Phalanges	n = 60	n = 393	7
					−1.51 ± 1.68*	−1.09 ± 1.66*	
Chen et al[17]	United States	Cohort	Tea	(g/cm^2)	<1 cup/day (n = 3683)	1 cup/day (n = 566)	8
				Total body	1.021 (1.020, 1.022)†	1.019 (1.016,1.022)†	
				Total hip	0.846 (0.845, 0.847)†	0.847 (0.844,0.850)†	
				Lumbar spine	0.989 (0.988, 0.991)†	0.991 (0.986,0.995)†	
				Total body		2–3 cups/day (n = 588)	
				Total hip		1.024 (1.021,1.027)†	
				Lumbar spine		0.848 (0.845,0.851)†	
				Total body		0.995 (0.991,0.999)†	
				Total hip		≥4 cups/day (n = 142)	
				Lumbar spine		1.029 (1.023,1.036)†	
						0.846 (0.840,0.850)†	
						0.990 (0.981,0.998)†	
Wu et al[14]	Taiwan	Cohort	Tea	(g/cm^2)	n = 535	1–5 y (n = 226)	6
				Total body	1.150 ± 0.007‡	1.155 ± 0.008‡	
				Spine (L_{1-4})	1.114 ± 0.014‡	1.127 ± 0.015‡	
				Hip neck	0.851 ± 0.011‡	0.851 ± 0.012‡	
				Ward triangle	0.741 ± 0.012‡	0.748 ± 0.014‡	
				Total body		6–10 y (n = 152)	
				Spine (L_{1-4})		1.158 ± 0.009‡	
				Hip neck		1.150 ± 0.017‡	
				Ward triangle		0.865 ± 0.013‡	
				Total body		0.758 ± 0.015‡	
				Spine (L_{1-4})		>10 y (n = 124)	
				Hip neck		1.174 ± 0.009‡	
				Ward triangle		1.162 ± 0.018‡	
						0.891 ± 0.014‡	
						0.787 ± 0.016‡	
Hegarty et al[13]	United Kingdom	Cohort	Tea	(g/cm^2)	n = 122	n = 1134	6
				Lumbar spine	0.889 ± 0.16	0.917 ± 0.17	
				Femoral neck	0.660 ± 0.10	0.669 ± 0.11	
				Greater trochanter	0.588 ± 0.09	0.612 ± 0.15	
				Ward triangle	0.454 ± 0.12	0.476 ± 0.13	

BMD = bone mineral density, L = lumbar, SDs = standard deviations.

* T score.

† Mean, 95% confidence interval in parentheses.

‡ Mean, standard error.

3.2. Characteristics of the included studies

Ten studies were from PubMed, 3 from Embase, and none from the Cochrane Library. All included articles had available full texts. There were 5 studies with count data (3 and 2 studies with ordinal and dichotomous data, respectively)[26–30]; 9 studies had continuous data,[13,14,17,30–35] with, 1 presenting both dichotomous and continuous data.[30] Besides, for continuous data, BMD values of the femoral neck, Ward triangle, greater trochanter, total body, intertrochanteric hip, lumbar spine, hip, and phalanges were presented in the 9 studies. No further evaluation study was found in the reference lists of these studies. In addition, the reference lists of relevant articles did not produce further studies for evaluation. The characteristics of all studies are presented in Tables 1 and 2.

Table 2

Characteristics of included studies (dichotomous data).

Study ID	Study location	Study design	Tea types	Measurement locations	Degree	Non-tea consumption (n)	Tea consumption (n)	Quality score
Keskin et al[28]	Turkey	Cross-sectional	Tea	Phalanges	Normal	226	306	8
					Osteoporosis	52	36	
Chan et al[29]	Malaysia	Cross-sectional	Tea	Hip	Normal	23	11	7
					Osteopenia	31	11	
Alquaiz et al[27]	Saudi Arabia	Cross-sectional	Green tea	Spine (L_{1-4})	Normal	10	140	6
				and dual femur	Osteopenia	27	185	
Wang et al[26]	China	Case–control	Tea	Left femur	Normal	81	29	7
					Osteopenia	97	40	
					Osteoporosis	59	18	
Hamdi et al[30]	Turkey	Cross-sectional	Tea	Phalanges	Normal	36	265	8
					Osteopenia	20	169	
					Osteoporosis	34	178	

L = lumbar.

3.3. Meta-analysis results

Data from 5 studies with dichotomous variables (1 study both dichotomous and continuous data), including 1398 and 696 in the tea- and non-tea consumption groups, were assessed in this meta-analysis. Two of the studies claimed tea consumption to have a beneficial impact on BMD compared with non-tea consumption[28,29]; no correlation between them was found in the remaining 3 studies.[26,27,30] The pooled results showed that tea consumption could reduce the occurrence of low bone mass (OR = 0.66, 95% CI = 0.47–0.94, $P = 0.02$) (Fig. 2).

We also performed a meta-analysis for continuous variables according to BMD at different locations in the 9 studies.[13,14,17,30–35] The pooled results showed that BMD values of the femoral neck (MD: 0.01, 95% CI, 0.00–0.02; $P = 0.04$), Ward triangle (MD: 0.02, 95% CI, 0.01–0.04, $P = 0.001$), greater trochanter (MD: 0.03, 95% CI, 0.02–0.04, $P < 0.00001$), lumbar spine (SMD: 0.19, 95% CI, 0.08–0.31, $P = 0.001$), and hip (SMD: 0.19, 95% CI, 0.05–0.34, $P = 0.01$) were higher in the tea consumption group than in the non-tea consumption group (Figs. 3 and 4). However, no statistically significant differences in BMD values of the total body (MD: 0.00, 95% CI, -0.00 to 0.00, $P = 0.06$), intertrochanteric hip (MD: 0.02, 95% CI, -0.01 to 0.05, $P = 0.06$), and phalanges (SMD: 0.25, 95% CI, -0.02 to 0.52, $P = 0.07$) were obtained (Figs. 3 and 4).

3.4. Sensitivity and publication bias

Sensitivity analysis was performed by sequentially excluding each study in order to examine the influence of individual studies on the overall assessment. Interestingly, none of the studies fairly affected the overall findings. In addition, sensitivity analysis was conducted to access high-quality studies, and the results did not obviously change. Figure 5 shows a funnel plot for continuous variables, with slight asymmetry.

4. Discussion

Tea is the most frequently consumed beverage in daily life, and its protective or harmful impacts on human health are a major public issue. This was the first meta-analysis to address this subject. Our analysis of 4 cohort, 1 case–control, and 8 cross-sectional studies with 12,635 cases indicated a potential trend that tea consumption might result in higher BMD at the femoral neck, Ward triangle, greater trochanter, lumbar spine, and hip than non-tea consumption, and might prevent bone loss.

These findings corroborate many other studies.[12,36,37] For instance, a study including 2016 cases reported that tea consumption has protective effects on the femoral neck and lumbar spine with T scores >–0.75.[36] In addition, Hoover et al[12] conducted a study of 62 postmenopausal women, and found that tea consumption yields 10% and 14% higher BMD values in the lumbar spine and femoral neck, respectively, than the non-tea consumption group. Similar results were found in animal experiments. Indeed, studies showed that tea polyphenols increase femoral BMD of female rats.[38–41] However, others reported that tea consumption has no effect on BMD.[11,42] Hernández et al[11] found no association of tea consumption with BMD, and even an inverse correlation. In addition, a study

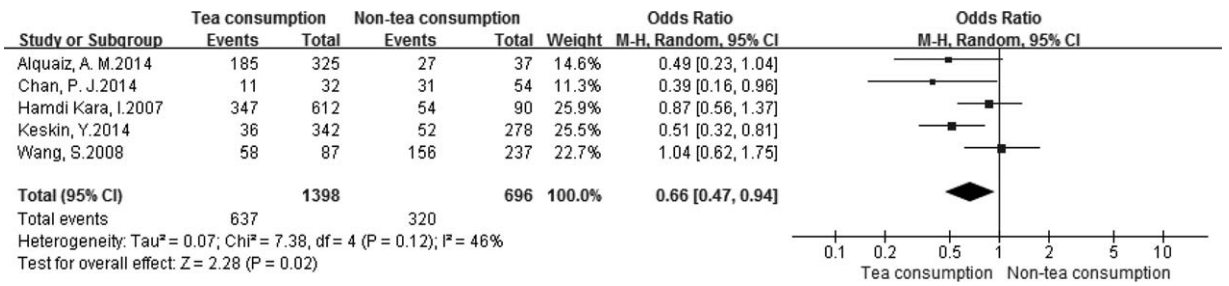

Figure 2. Forest plot and meta-analysis of dichotomous variables. CI = confidence interval, M-H = Mantel-Haenszel method.

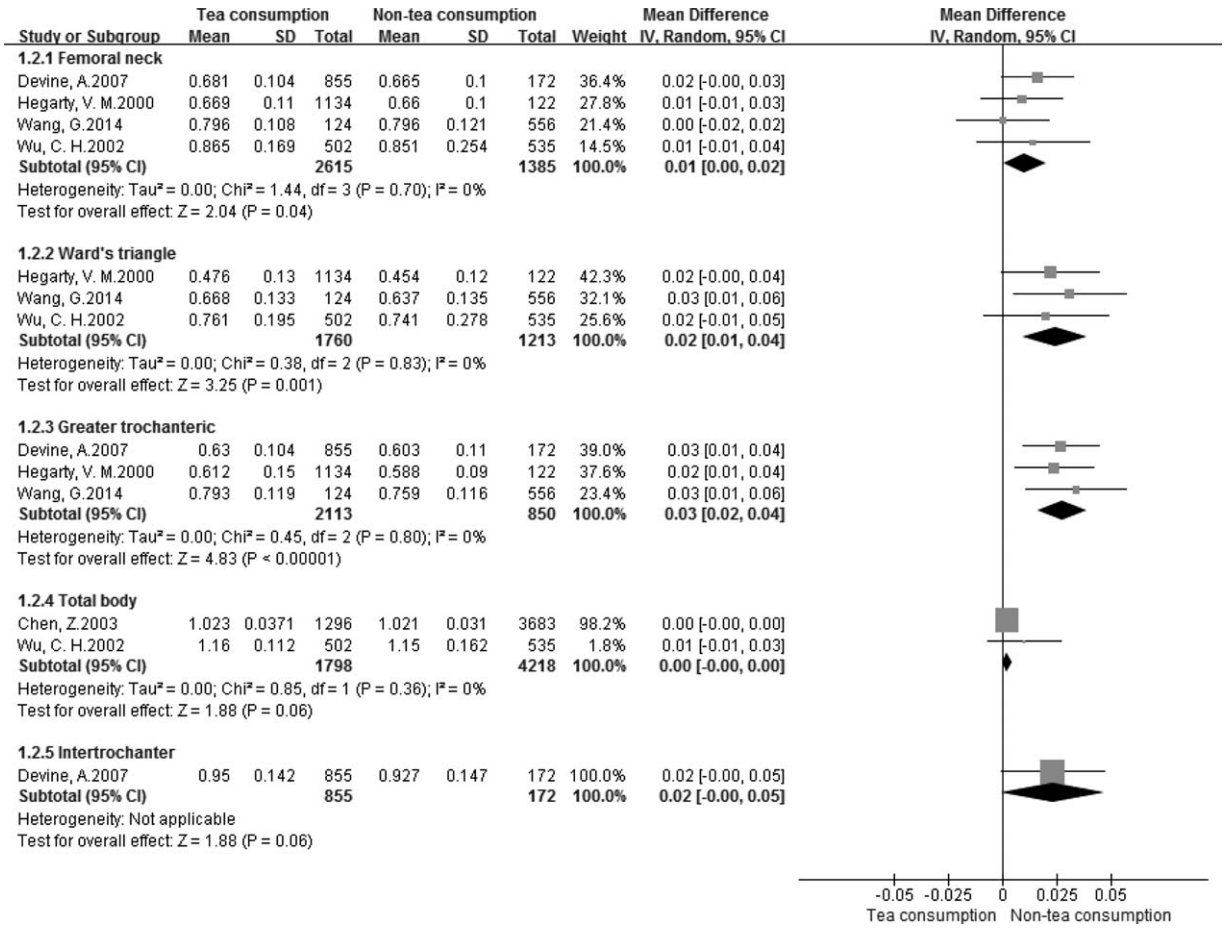

Figure 3. Forest plot and meta-analysis of BMD in the femoral neck, Ward triangle, greater trochanteric, total body, and intertrochanteric hip. CI = confidence interval, IV = inverse variance method, SD = standard deviation.

evaluating 201 cases with osteoporosis or osteopenia in Turkey reported no association of tea consumption with BMD of the lumbar spine, and a negligible correlation with the femoral neck.[42] The above 2 studies, which were not adjusted, were inconsistent with our series. Besides, a prospective randomized controlled study also found no correlation between tea and BMD,[43] the main reason likely being the small sample size.

Tea polyphenols contain abundant epigallocatechin gallate (EGCG) as the main component of tea.[44,45] EGCG has been widely studied. Its beneficial effects on bone formation are mainly through increasing alkaline phosphatase activity at both the protein and gene expression levels in osteoblastic-like cells, including SaOS-2 cells[46] and MC3T3-E1 cells, and increased formation of mineralized bone.[47] Moreover, tea polyphenols significantly promote osteoblastic survival and decrease osteoblastic apoptosis,[46] thereby leading to elevated cell proliferation and differentiation.[48] This was the theoretical basis of our research.

In this meta-analysis, no correlation was found between tea consumption and BMD of the whole body, intertrochanteric hip, and phalanges. This finding might be unreliable because only 1 or 2 studies assessing these entities were included. Meanwhile, 5 studies of dichotomous variables were included in this meta-analysis; the pooled results indicated that tea consumption could prevent bone loss. However, we did not analyze the effects of tea consumption on BMD at each location due to insufficient data provided in the above 5 studies.

Means and standard deviations were not provided for continuous data in some included articles; means and standard deviations were derived on the basis of the Cochrane Handbook. Furthermore, other studies provided ordinal data, such as normal, osteopenia, and osteoporosis; osteopenia and osteoporosis were combined into low bone mass to generate dichotomous data, as they all belong to bone mass reduction; the pooled results were similar to those of continuous data. In addition, considering that T values reflect the true levels of BMD, we included 2 studies that provided only T values.[30,33] We combined T values with BMD values using SMD, and only BMD values using MD.

Next, we performed sensitivity analysis, including only high-quality studies in order to evaluate any impact of study quality on the effect estimates. The results did not change obviously. Consequently, the low-quality studies included had no significant effects on the overall results. Moreover, between-study heterogeneity was not significant for dichotomous and continuous variables, but significant for the lumbar spine and hip. The main reason for the heterogeneity might be from different locations, populations, tea types, or study designs. These studies used the random-effects model to reduce the effect of heterogeneity; however, it was not eliminated.

This meta-analysis had the following limitations that must be taken into account. First and foremost, it included a limited

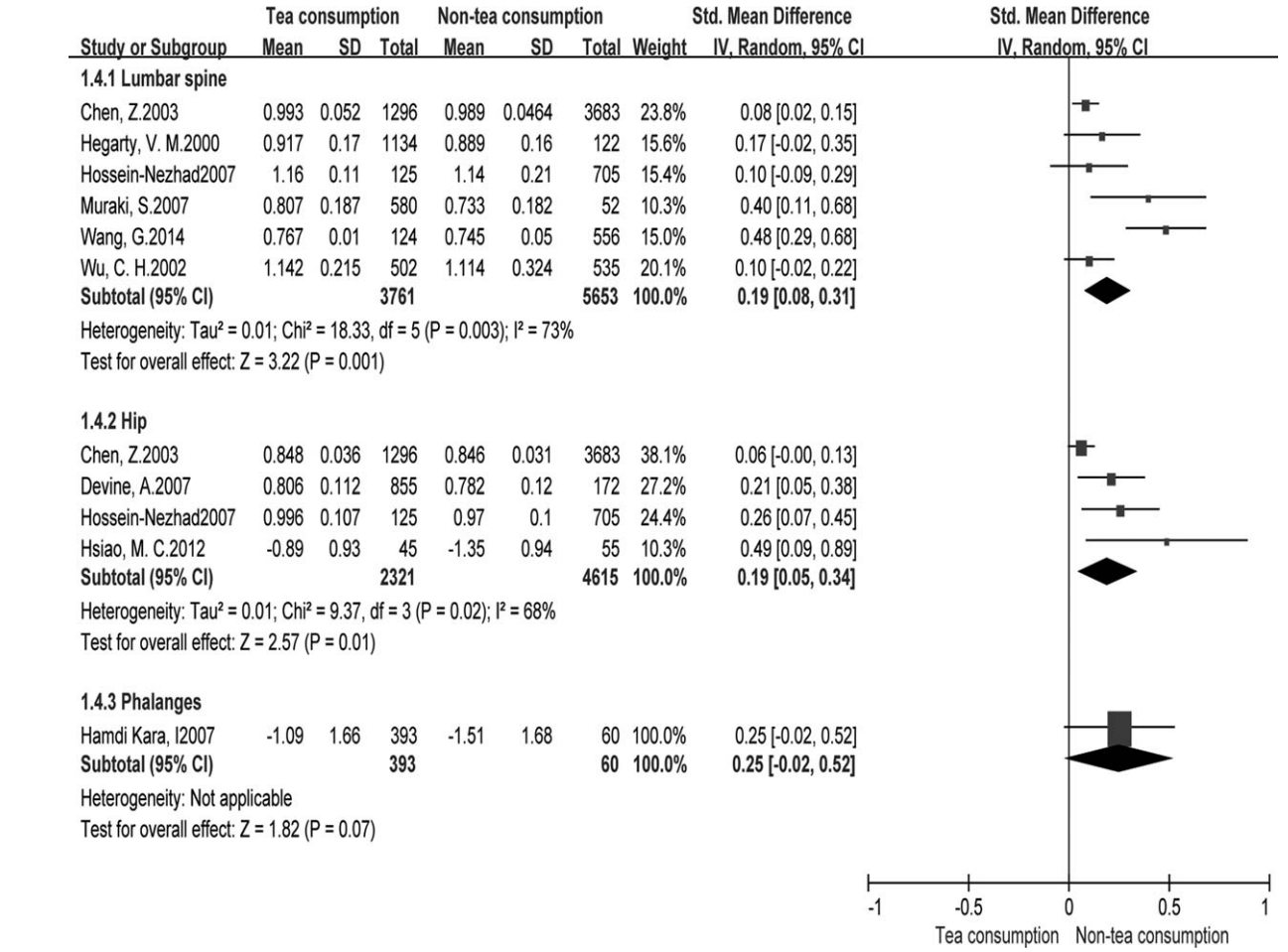

Figure 4. Forest plot and meta-analysis of BMD in the lumbar spine, hip, and phalanges. ; CI = confidence interval, IV = inverse variance method, SD = standard deviation.

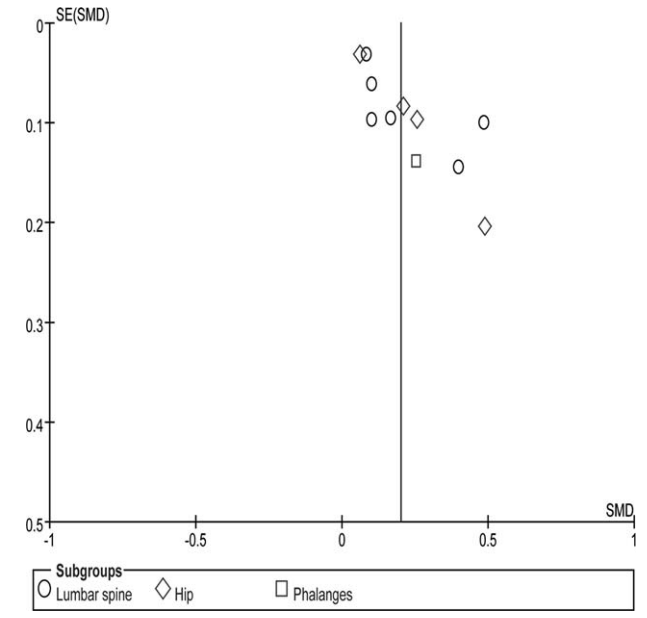

Figure 5. Funnel plot. SE = standard error, SMD = standardized mean difference.

number of observational trials with some being low and medium-quality studies, which might result in selective and performance bias owing to the absence of random allocation, allocation concealment, and blinding. Secondly, subgroup analysis of age, tea types, and tea in cups was not performed because of few included studies.

In summary, these findings provide a potential trend of beneficial effects of tea consumption on BMD, especially in the lumbar spine, hip, femoral neck, Ward triangle, and greater trochanter, which might help prevent bone loss.

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