



Tea consumption and bone health in Chinese adults: a population-based study

X. Li¹ · Y. Qiao¹ · C. Yu¹ · Y. Guo² · Z. Bian² · L. Yang³ · Y. Chen³ · S. Yan⁴ · X. Xie⁵ · D. Huang⁵ · J. Chen⁶ · Z. Chen³ · J. Lv^{1,7}  · L. Li^{1,2} · on behalf of the China Kadoorie Biobank Collaborative Group

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Abstract

Summary Tea is a worldwide drink with controversial effect on bone health. The sex-specific associations are unrevealed among general population. This study showed that prolonged moderate tea consumption benefited bone health in women, while no additional benefit with stronger tea. However, tea consumption was not associated with bone health in men.

Introduction Tea consumption has been shown a potentially beneficial effect on bone health in postmenopausal women. However, little is known about such association in men, and whether stronger tea instead harms bone health due to elevated urinary excretion of calcium associated with caffeine in the tea. The aim of this study was to examine the association between various metrics of tea consumption and bone health.

Methods The present study included 20,643 participants from the China Kadoorie Biobank (CKB), who have finished both baseline survey (2004–2008) and a re-survey (2013–2014). They were aged 38–86 years at re-survey. Tea consumption was self-reported at both baseline and re-survey. Bone mineral density (BMD) was measured using calcaneal quantitative ultrasound once at re-survey.

Results Compared with non-consumers, prolonged weekly tea consumers in women was associated with higher calcaneus BMD measures, with β (95% CI) of 0.98 (0.22, 1.74) for BUA, 4.68 (1.74, 7.61) for SOS, and 1.95 (0.81, 3.10) for SI. Among prolonged weekly tea consumers, no linear increase in BMD measures with the amount of tea leaves added was observed. The SOS and SI were higher in consumers with tea leaves 3.0–5.9 g/day than in those with < 3.0 g/day, but were reduced to non-significant for those with ≥ 6.0 g/day. Tea consumption was not associated with calcaneus BMD measures in men.

Conclusion Prolonged moderate tea consumption benefited bone health in women but not in men. For stronger tea consumption with more tea leaves added, neither benefit nor harm to bone health was observed.

Keywords Bone mineral density · Epidemiologic study · Quantitative ultrasound · Tea consumption

X. Li and Y. Qiao contributed equally to this work.

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✉ J. Lv
epi.lvjun@vip.163.com

¹ Department of Epidemiology and Biostatistics, School of Public Health, Peking University Health Science Center, Beijing, China

² Chinese Academy of Medical Sciences, Beijing, China

³ Clinical Trial Service Unit & Epidemiological Studies Unit (CTSU), Nuffield Department of Population Health, University of Oxford, Oxford, UK

⁴ Heilongjiang Center for Disease Control and Prevention, Harbin, China

⁵ The People's Hospital of Pengzhou, Pengzhou, Sichuan, China

⁶ China National Center for Food Safety Risk Assessment, Beijing, China

⁷ Peking University Institute of Environmental Medicine, Beijing, China

Introduction

Maintaining bone health has gained increasing attention because it is important for healthy aging. Loss of bone mineral density (BMD) occurs naturally as part of the aging process, along with increased risk of osteoporosis and osteoporotic fractures [1]. The major concerns for fractures include its potential results of long-term disability, medical care costs, and social burden [2]. To aim at reducing the risk of osteoporosis or low bone mass in later life, optimization of lifestyle factors, which are known to influence peak bone mass and strength, is an important strategy [3]. Diet is one of the primary modifiable factors associated with bone health.

Tea is a popular drink around the world, particularly in Asia. Experimental studies have indicated that flavonoids—an abundant polyphenol in tea—may have the ability to increase the differentiation of osteoblasts, while inhibiting the differentiation and activation of osteoclasts via antioxidant and estrogen-like effect [4]. However, caffeine in the tea is a concern because it is associated with elevated urinary excretion of calcium and may reduce BMD [5]. Most of the previous observational studies on the association between tea consumption and BMD were performed in postmenopausal women, with pooled results showing a potential beneficial effect of tea consumption on BMD [6, 7]. Only two studies included both men and women [8, 9]. Also, the association of BMD with various metrics of tea consumption, like frequency, amount of tea leaves added, types of tea, and years of tea consumption, and potential effect modification by sociodemographic characteristics and other lifestyle factors have not yet to be examined.

The present study was based on the China Kadoorie Biobank (CKB). Although dual-energy X-ray absorptiometry (DXA) is the gold standard for quantifying BMD in clinical practice, its application in large-scale population studies is very limited. We instead used quantitative ultrasound (QUS) [10]—a low-cost, portable, and radiation-free method—to assess BMD in a sub-sample of about 25,000 CKB participants. The QUS has been used in another large cohort study named UK Biobank to measure bone health [11]. In the present analysis, we aimed to examine the association between various metrics of tea consumption and bone health in both male and female adults, especially for men, who were more likely to consume tea than women in the Chinese population. We further examined whether this association held across various population subgroups.

Methods

Study population

Between 2004 and 2008, 512,891 participants aged 30–79 years were recruited from five urban and five rural regions

across China to the CKB cohort and surveyed for baseline information. Briefly, study design of the CKB and characteristics of the study participants have been previously described [12, 13]. During 2013–2014, a re-survey involving ~5% of randomly chosen surviving participants was conducted, with the administrative unit of the rural village or urban residential committee as the primary sampling unit. Apart from a few new questions and physical measurements, the data collection and survey procedures were much the same as in the baseline survey. Signed informed consent was obtained from all participants at both surveys.

The present study was performed in 25,045 participants who finished the re-survey during 2013–2014, in which calcaneal QUS measurements were first added to the survey. We excluded participants who had missing data on any measures of BMD ($n = 360$) and waist or hip circumferences ($n = 9$) at re-survey; those who reported having a history of kidney disease ($n = 306$), osteoporosis ($n = 544$), fracture ($n = 2290$), or rheumatic arthritis ($n = 1165$) at re-survey; and those who developed multiple myeloma and malignant plasma cell neoplasms (10th revision of the International Statistical Classification of Diseases, ICD-10: C90; $n = 4$) since enrollment. The reason to exclude participants with kidney or bone diseases is that their pathology of bone might have differed from the general population. We also excluded participants who reported to be a new tea consumer since baseline, yet had a starting age of tea consumption earlier than their baseline age ($n = 258$). The final analyses included 20,643 participants.

Assessment of tea consumption

Tea consumption was assessed by an interviewer-administered questionnaire at both baseline and re-survey. Asking the same questions at an average interval of 8.0 years allowed us to know potential changes in tea consumption habit over a long period of time. All CKB participants reported their frequency of tea consumption during the past 12 months (never, only occasionally, only at certain seasons, monthly but less than weekly, and at least once a week). Participants who consumed tea weekly were further asked about days consuming in a typical week (1 to 2 days, 3 to 5 days, or almost every day), cups (in 300 mL size) of tea consumed and amount (in gram) of tea leaves added in one consuming day, type of tea consumed most commonly (green tea, oolong tea, black tea, or others), and age when starting their tea consumption habit. To help with gauging the amount of tea leaves, a pictorial guide was provided to each participant. Years of tea consumption was calculated as the difference between age at re-survey and age of starting tea consumption.

In the present analyses, all participants were grouped into five categories according to their reported tea consumption at

baseline and re-survey: never consumers, former consumers, recent new consumers, prolonged consumers, and prolonged weekly consumers (Table 1). Prolonged weekly tea consumers were further categorized, according to the amount of tea leaves added per consuming day reported at re-survey, as < 3.0, 3.0–5.9, and \geq 6.0 g/day

Assessment of covariates

Covariate information collected from the re-survey was used in the present study. Questionnaire information included sociodemographic characteristics (age, sex, region, education, occupation, household income, and marital status), lifestyle behaviors (alcohol consumption, tobacco smoking, physical activity, and intakes of red meat, fresh fruits, vegetables, milk, yoghurt, other dairy foods, fish oil or cod liver oil, vitamins, calcium, iron, or zinc supplements, and coffee), personal medical history (diabetes, chronic hepatitis or cirrhosis, peptic ulcer, and gallstones or cholecystitis, etc.), and women's menopausal status. Daily level of physical activity was calculated by multiplying the metabolic equivalent tasks (METs) value for a particular type of physical activity by hours spent on that activity per day and then summing the MET-hours for all activities. Habitual dietary intake in the past year was assessed by a qualitative food frequency questionnaire. Trained staff undertook measurements of body weight, height, waist, and hip circumferences. Body mass index (BMI) was defined as the body weight divided by the square of the height, and waist-hip ratio as the ratio of waist circumference to hip circumference.

Assessment of BMD

At re-survey, participants had two feet measured for BMD in a seated position based on a calcaneus QUS measurement, using an Achilles EXP II Operator (GE Medical Systems Lunar, USA). Trained staff implemented daily quality control and cleaning procedures following manufacturer's instruction. Parameters directly measured from QUS included broadband ultrasound attenuation (BUA, in dB/MHz) and speed of sound

(SOS, in m/s). The parameter of stiffness index (SI) was calculated from BUA and SOS in the Achilles system by the following equation: $SI = (0.67 \times BUA + 0.28 \times SOS) - 420$. For the present analyses, the QUS measurements were averaged between both calcanei for each participant.

Statistical analysis

General linear regression was used to estimate the regression coefficients (β) and 95% confidence intervals (CIs) for the associations between tea consumption and BMD measures. Multivariable models were adjusted for established and potential confounders: age, sex, study regions, marital status, occupation, household income, alcohol consumption, smoking status, physical activity, intake frequencies of red meat, fresh fruits, vegetables, milk, yoghurt, and other dairy foods, menopausal status (for women only), BMI, and waist-hip ratio. Tests for linear trend were only conducted in prolonged weekly consumers by assigning the median amount of tea leaves added to each category and then modeling tea consumption as a continuous variable in a separate model. Analyses were performed in all participants and separately in men and women.

Further, we examined the associations between tea consumption and BMD measures according to three types of tea (green tea, oolong tea, or black tea) and years of tea consumption (≤ 20 , or > 20), all as compared with those never consumers who did not consume tea during the past 12 months at both baseline and re-survey. We also examined whether the associations of prolonged weekly tea consumption with BMD measures differed according to several characteristics at re-survey: age, study regions, alcohol consumption, smoking status, the level of physical activity, dairy food consumption, BMI, and menopausal status (in women). In the subgroup analyses, we included only never and prolonged weekly consumers and tested for interaction using likelihood ratio test, which involved comparing models with and without interaction term between the stratifying variable and tea consumption as an ordinal variable.

The statistical analyses were performed with Stata (version 14.0, Stata). All *P* values were two-sided, and statistical

Table 1 Classification of participants according to frequencies of tea consumption

Baseline (2004–08)	Re-survey (2013–14)	Classification
Never	Never	Never consumers
Less than weekly ^a , or weekly	Never	Former consumers
Never	Less than weekly ^a , or weekly	Recent new consumers
Less than weekly ^a	Less than weekly ^a , or weekly	Prolonged consumers
Weekly	Less than weekly ^a	Prolonged consumers
Weekly	Weekly	Prolonged weekly consumers

^a Including participants who reported consuming tea only occasionally, only at certain seasons, or monthly but less than weekly

significance was defined as $P < 0.05$. For testing of three outcomes, a Bonferroni correction was applied to the significance level that divided 0.05 by 3.

Data availability

Study protocol: Cohort description and questionnaires are available at www.p3gobservatory.org/questionnaire/list.htm. *Statistical code:* Available from Dr. Lv (e-mail, lvjun@bjmu.edu.cn). *Data set:* See study Web Site (www.cckbiobank.org) for data access policy and procedures.

Results

Of the 7910 male and 12,733 female participants aged 38–86 years in the present study, 2898 (36.6%) men and 1322 (10.4%) women reported as prolonged weekly consumers, respectively. Compared with participants who were identified as never tea consumers, prolonged weekly consumers were more likely to be men and urban residents, and more likely to smoke tobacco and drink alcohol (Table 2, and Supplemental Tables 1 and 2). Green tea was the most common type of tea consumed in the present population. Prolonged weekly consumers usually had tea consumption habit for about 30 years. The means (standard deviations) for calcaneus BMD measures of BUA (dB/MHz), SOS (m/s), and SI were 113.5 (11.6), 1562.4 (43.0), and 93.0 (17.8) for men and 107.9 (12.6), 1552.1 (45.8), and 86.4 (18.6) for women, respectively.

After adjustment for potential confounders, compared with female never consumers, prolonged weekly consuming tea in women was associated with higher calcaneus BMD measures, with β (95% CI) of 0.98 (0.22, 1.74) for BUA, 4.68 (1.74, 7.61) for SOS, and 1.95 (0.81, 3.10) for SI (all P values < 0.0167) (Fig. 1, and Supplement Table 3). Both the former and prolonged consumers in women also showed higher BUA and SI than never consumers, with slightly lower SI than that in the prolonged weekly consumers. In men, we found no statistically significant differences in three BMD measures between any groups of tea consumers and never consumers. Sex difference in the associations between tea consumption and calcaneus BMD measures was observed for BUA ($P_{\text{interaction}} = 0.016$), but not for SI ($P_{\text{interaction}} = 0.040$) and SOS ($P_{\text{interaction}} = 0.148$).

Several sensitivity analyses were performed to assess the robustness of the findings. The associations of tea consumption with BMD measures did not change appreciably with additional adjustment for coffee consumption, regular intakes of fish oil or cod liver oil, vitamins, and calcium, iron, or zinc supplements; or additional adjustment for histories of diabetes, chronic hepatitis or cirrhosis, peptic ulcer, and gallstone or

cholecystitis; or inclusion of participants who reported having a history of fracture (data not shown).

Among prolonged weekly tea consumers, we examined whether the BMD measures followed any linear trend with the amount of tea leaves added (Fig. 2, Supplement Table 4). No linear trend was observed for all measures (all $P_{\text{trend}} > 0.05$). The SOS and SI were higher in consumers with tea leaves 3.0–5.9 g/day than in those with < 3.0 g/day, but were reduced to non-significant for those with ≥ 6.0 g/day. The results were similar between men and women (all $P_{\text{interaction}} > 0.05$).

In the subgroup analysis of the type of tea commonly consumed, female oolong tea consumers exhibited higher SOS ($P = 0.007$) as compared with green or black tea consumers (Table 3). We also observed that participants whose tea consumption habit had persisted for more than 20 years had slightly higher values of SOS and SI than those for a shorter period of time.

Further, we analyzed the associations of prolonged weekly tea consumption with BMD measures according to several characteristics at re-survey (Supplemental Table 5). The associations were generally similar across subgroups stratified according to alcohol consumption, smoking status, dairy food consumption, BMI, and menopausal status in women. Statistically significant differences in associations with two or three BMD measures across strata were observed for age, region, and physical activity, with higher measures associated with prolonged weekly tea consumption seen among participants who were older than 70 years, resided in rural regions, and were less physically active.

Discussion

In the present middle-aged-to-elderly Chinese population with a consumer preference for green tea, prolonged tea consumption since young adults was associated with better bone health in women. However, stronger tea with ≥ 6.0 g/day of tea leaves showed neither benefit nor harm to bone health. Tea consumption was not associated with calcaneus BMD measures among men in this population.

Our findings were consistent with previous observational studies, mostly conducted in postmenopausal women from European, [14, 15] Asian, [8, 9, 16–18] Australian, [19], and American populations [20]. However, a randomized clinical trial conducted in postmenopausal women who were overweight or obese showed that daily consumption of caffeine-free green tea extract for 12 months was not associated with a change in BMD [21]. The positive findings in the present study, after careful control of potential confounders, might indicate the long-term effect, if any, of tea consumption on bone health.

Table 2 Characteristics of study participants at re-survey according to tea consumption among 20,643 participants

	Never consumers	Former consumers	Recent new consumers	Prolonged consumers	Prolonged weekly consumers			P_{trend}^c
					< 3.0 g/day	3.0–5.9 g/day	≥ 6.0 g/day	
Participants (<i>n</i>)	5935	4755	1216	4517	1418	1519	1283	
Men	1079	1645	314	1974	912	1058	928	
Women	4856	3110	902	2543	506	461	355	
Male (%)	18.2	34.6	25.8	43.7	64.3	69.7	72.3	< 0.001
Urban (%)	37.9	30.7	57.1	45.7	43.0	49.1	51.1	< 0.001
Age (year)	59.9	58.4	57.4	56.6	60.8	60.2	58.1	< 0.001
Middle school and higher (%)	40.7	47.3	47.6	51.4	50.1	52.1	52.9	< 0.001
Married (%)	86.9	87.7	86.5	88.5	88.1	88.0	88.2	0.684
Agricultural and industrial workers (%)	40.9	39.0	38.4	39.4	38.7	37.6	34.2	< 0.001
Household income > 50,000 CNY/year (%)	36.9	42.4	41.6	45.7	44.5	46.7	49.6	< 0.001
Current smoking (%)	18.7	19.8	18.6	23.1	27.6	28.2	30.6	< 0.001
Daily alcohol drinking (%)	4.9	6.1	8.1	8.3	11.4	12.0	11.5	< 0.001
Physical activity (MET-h/day)	18.2	18.5	18.7	18.5	17.8	17.8	17.4	0.066
Average weekly consumption (day)								
Red meat	4.0	4.2	4.1	4.3	4.3	4.3	4.5	< 0.001
Fresh vegetables	6.9	6.9	6.9	6.9	6.9	6.9	6.9	0.508
Fresh fruits	3.3	3.6	3.6	3.8	3.8	3.9	3.7	< 0.001
Milk	0.8	0.8	1.0	1.0	1.0	1.1	1.0	0.001
Yoghurt	0.3	0.4	0.5	0.5	0.5	0.6	0.5	0.011
Other dairy foods	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.311
Body mass index (kg/m ²)	23.8	24.1	24.1	24.3	24.2	24.4	24.7	< 0.001
Waist hip ratio	0.897	0.899	0.895	0.904	0.902	0.904	0.909	< 0.001
Postmenopause in women (%)	75.8	75.0	75.5	74.6	75.0	71.9	75.5	0.505
Tea consumption metrics ^a								
Weekly tea consumption (%)	–	29.7 ^b	16.5	27.7	100.0	100.0	100.0	–
Starting age of tea consumption (year)	–	31.2 ^b	48.7	36.7	31.3	29.0	27.5	< 0.001
Years of tea consumption (year)	–	19.9 ^b	10.5	22.6	27.9	30.2	31.7	< 0.001
Green tea consumer (%)	–	82.0 ^b	69.0	74.6	76.3	74.0	73.9	0.439
Cups of tea consumed (cups/day)	–	2.9 ^b	2.8	2.9	2.9	3.7	5.2	< 0.001
Calcaneus BMD measures								
BUA (dB/MHz)	109.0	110.1	110.0	110.6	110.7	110.8	110.4	0.059
SOS (m/s)	1554.5	1556.1	1556.3	1556.3	1558.2	1559.1	1555.5	0.600
SI	87.8	89.0	89.0	89.3	90.0	90.3	89.0	0.620

The results are presented as adjusted means or percentages, with adjustment for age, sex, and study region, as appropriate

MET, metabolic equivalent of task; *BMD*, bone mineral density; *BUA*, broadband ultrasound attenuation; *SOS*, speed of sound; *SI*, stiffness index

^a Only weekly tea consumers provided information on starting age of tea consumption and type of tea consumed most commonly

^b Based on information provided at baseline

^c P_{trend} is tested only within prolonged weekly consumers compared with never consumers

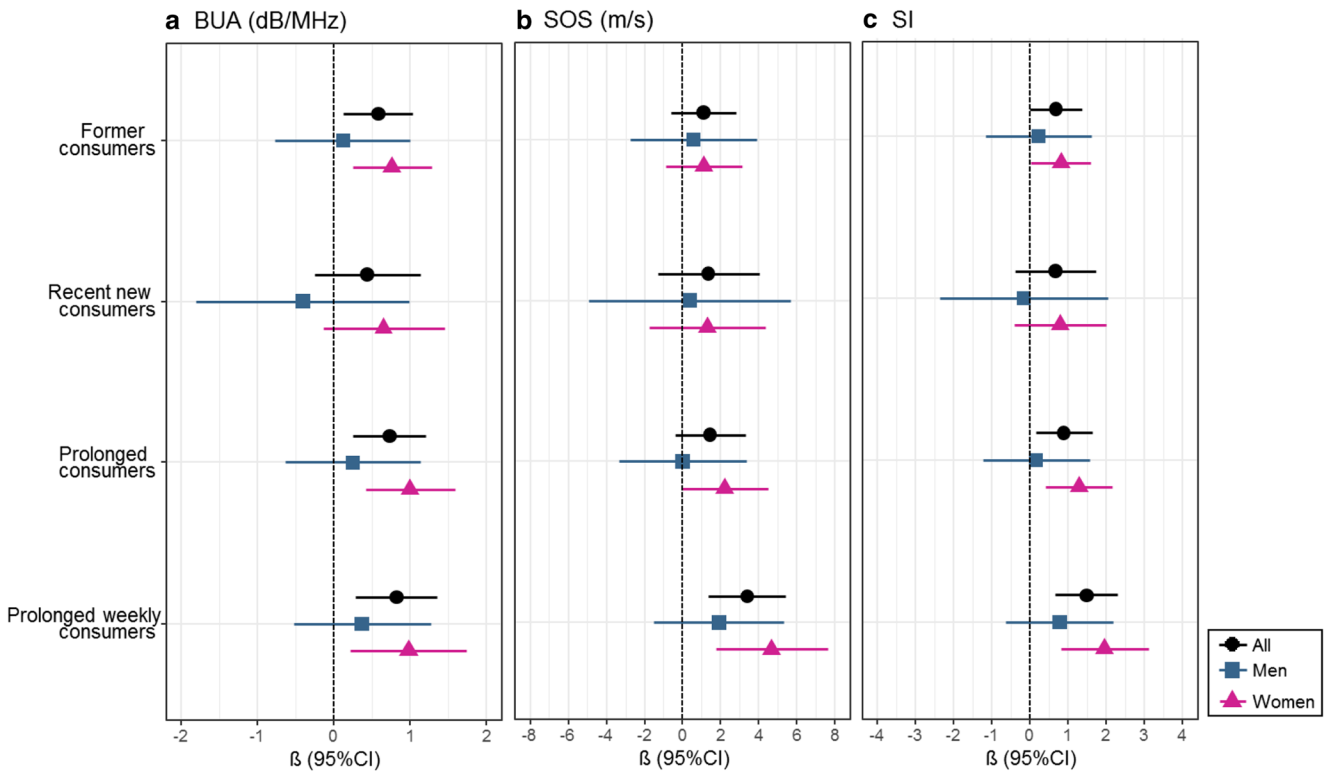


Fig. 1 Associations between tea consumption and calcaneus BMD measures among 20,643 participants. BMD, bone mineral density; BUA, broadband ultrasound attenuation; SOS, speed of sound; SI, stiffness index. Multivariable models were adjusted for: age; sex; study regions; level of education; marital status; occupation; household income;

alcohol consumption; smoking status; physical activity(MET-h/day); intake frequencies of red meat, fruits, vegetables, milk, yoghurt, and other dairy foods; body mass index(kg/m²); waist-hip ratio; and menopause status in female analyses

A linear increase in BMD measures with tea consumption was observed in a previous study conducted in American women, in which ≥ 4 cups/day (1 cup = 237 ml) was the upper

group [20]. In the present female population, we observed an increase in the calcaneus BMD measures from less frequent consumers to frequent consumers adding low-to-medium

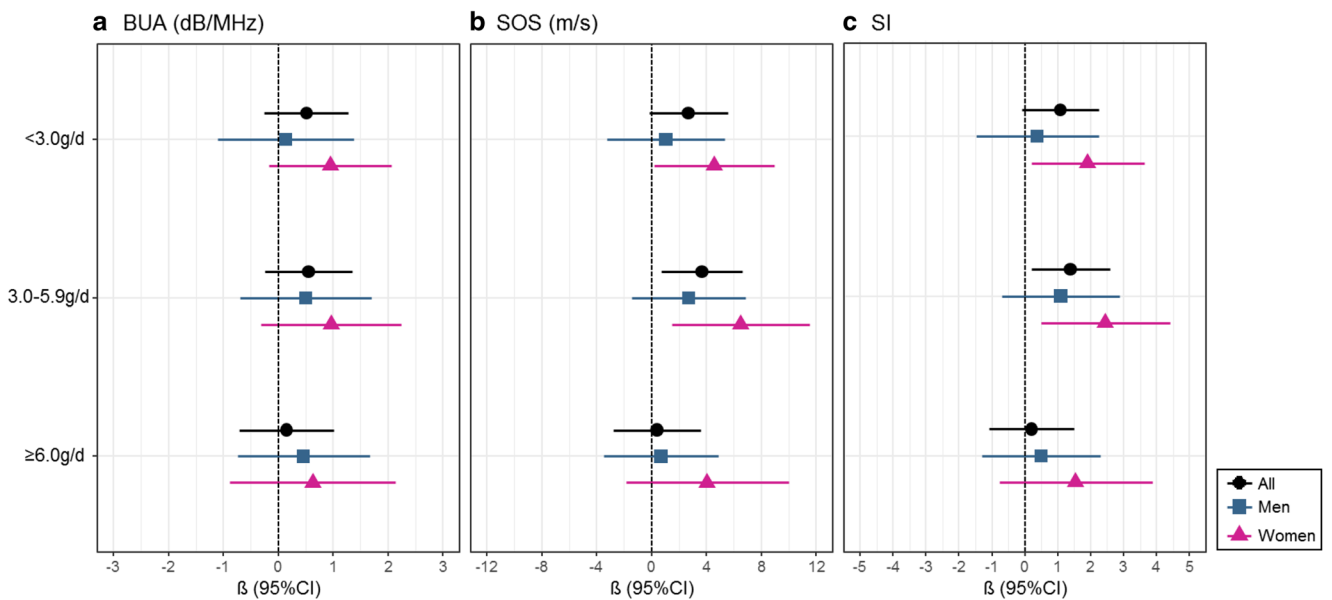


Fig. 2 Associations between amount of tea leaves added and calcaneus BMD measures among 4220 prolonged weekly consumers. BMD, bone mineral density; BUA, broadband ultrasound attenuation; SOS, speed of

sound; SI, stiffness index. Multivariable models were adjusted for the same set of covariates as in the Fig. 1

Table 3 Subgroup analyses of associations between tea consumption and calcaneus BMD measures according to types of tea and years of tea consumption among 4220 prolonged weekly consumers

BMD	Never consumers	Type of tea (<i>n</i> = 3994) ^a			Years of tea consumption (<i>n</i> = 4220)	
		Green tea	Oolong tea	Black tea	≤ 20	> 20
Participants (<i>n</i>)						
All	5935	3179	397	418	1225	2995
Men	1079	2141	273	359	741	2157
Women	4856	1038	124	59	484	838
BUA (dB/MHz)						
All	0.00	0.53 (−0.15, 1.22)	0.18 (−1.28, 1.63)	−0.01 (−1.24, 1.22)	0.09 (−0.71, 0.89)	0.65 (−0.06, 1.35)
Men	0.00	0.51 (−0.61, 1.64)	0.41 (−1.59, 2.41)	−0.07 (−1.81, 1.66)	0.11 (−1.14, 1.36)	0.50 (−0.60, 1.61)
Women	0.00	1.01 (−0.02, 2.04)	1.15 (−1.13, 3.43)	−1.00 (−3.76, 1.75)	0.90 (−0.24, 2.04)	0.91 (−0.26, 2.09)
SOS (m/s)						
All	0.00	1.99 (−0.55, 4.54)	3.78 (−1.62, 9.19)	3.63 (−0.95, 8.21)	1.69 (−1.27, 4.66)	2.93 (0.30, 5.55)
Men	0.00	1.55 (−2.35, 5.44)	0.86 (−6.07, 7.80)	1.15 (−4.87, 7.16)	1.07 (−3.27, 5.42)	1.67 (−2.16, 5.49)
Women	0.00	3.27 (−0.78, 7.31)	12.31 (3.35, 21.27)	10.53 (−0.30, 21.35)	4.85 (0.37, 9.34)	5.40 (0.78, 10.02)
SI						
All	0.00	0.91 (−0.13, 1.94)	1.17 (−1.03, 3.37)	1.00 (−0.86, 2.87)	0.53 (−0.68, 1.74)	1.24 (0.17, 2.31)
Men	0.00	0.77 (−0.90, 2.45)	0.51 (−2.47, 3.50)	0.27 (−2.32, 2.86)	0.37 (−1.50, 2.24)	0.80 (−0.85, 2.44)
Women	0.00	1.58 (0.00, 3.16)	4.19 (0.68, 7.69)	2.25 (−1.98, 6.49)	1.95 (0.20, 3.70)	2.11 (0.30, 3.91)

BMD, bone mineral density; BUA, broadband ultrasound attenuation; SOS, speed of sound; and SI, stiffness index

Values are regression coefficient (β) (95% confidence intervals) unless stated otherwise

Multivariable models were adjusted for: age, sex, and study regions; level of education; marital status; occupation; household income; alcohol consumption; smoking status; physical activity (MET-h/day); intake frequencies of red meat, fruits, vegetables, milk, yoghurt, and other dairy foods; body mass index (kg/m^2); waist-hip ratio; and menopause status in female analyses

^a The results of other type of tea group were not shown in the table (*n* = 226)

amount of tea leaves. The benefit for bone health disappeared when more tea leaves were consumed, which corresponded to about more than five cups of tea (1 cup = 300 ml) per day. A possible explanation might be that urinary calcium increases with the consumption of caffeine in tea, which counteracts the beneficial effect from tea polyphenols [4]. However, for our participants who preferred stronger tea, we at least did not observe any detrimental effect of tea consumption on bone health compared with non-consumers of tea.

In the present study, we also observed a statistically significantly increased level of calcaneus BMD measures in former female consumers, but not in recent new consumers. The difference of BMD measures in these two groups of consumers might be due to shorter duration of tea consumption or small sample size for recent new consumers. However, we also considered the possibility that former consumers benefited from the effect of tea consumption since their young adult years on the development of peak bone mass and reaped gains later in life [3].

The effect of tea consumption on BMD for men was less well studied than for women. There was no correlation seen between tea consumption and BMD measures in men of four studies that may be underpowered, each with less than 500 male participants [8, 9, 22, 23]. The present study, with a

much larger sample size of men than previous studies, still did not show any association of habitual tea consumption with bone health. The prevalence of smoking is very high in Chinese men. Also, male tea drinkers are more likely to smoke than non-drinkers, as shown in our population. A previous study has shown that smoking was deleterious for bone health [24]. Thus, the concurrence of smoking and tea drinking in our male participants may counteract any potential protective effect of tea consumption on bone health.

In terms of different types of tea leaves, only one previous study compared green/oolong tea consumers (*n* = 457) with black tea consumers (*n* = 45) and found no significant differences in BMD [9]. Intriguingly, the present study observed oolong tea consumption appeared to earn female consumers a bigger benefit on calcaneus BMD measures of SOS and SI. Few women consumed black tea regularly in the present population, resulting in wide confidence intervals for the effect estimates. Also, a significant difference in BMD measures between types of tea leaves was seen for SOS but not for BUA. The measure of SOS was not only correlated with BMD but also with microarchitecture of the bone [10]. Oolong tea undergoes the intermediate level of the fermentation process, i.e., oxidation, and green tea undergoes the least. The amount and type of tea polyphenols change during

fermentation, while caffeine contents largely remain the same [25, 26]. Whether different types of tea leaves have different effects on bone health and what chemical compounds in tea may influence the quantity and quality of the bone merit further population-based and experimental research.

Previous studies found that the association between tea consumption and BMD was consistent across subgroups defined by ethnicity, hormone replacement therapy, the addition of milk, and coffee consumption [15, 20]. In the present analyses, we found higher calcaneus BMD measures in rural residents and less physically active participants. It is possible that the flavonoids are easily accessible to urban residents through other various food sources such as vegetables and fruits [27]; thus, tea consumption added only modestly auxiliary effect on bone health. Participants with high physical activity, a known protective factor for bone health [3], were likely to possess better bone measures no matter whether they consumed tea regularly.

The present study is so far the largest study assessing the association between tea consumption and bone health, including both genders and geographically diverse participants in China. We measured tea consumption by various metrics. The inquiry of tea consumption history and performing assessment twice at an interval of 8 years allowed us to capture the changes in tea consumption over a long time. Also, we have carefully controlled for established and potential risk factors for BMD. The present study adds compelling evidence about the effect of tea consumption on bone health in men and the potential impact that stronger tea may do to the bone health.

There are several limitations in this study that should be considered. Tea consumption was self-reported, raising the possibility of misclassification. The present analysis used the amount of tea leaves reported at re-survey, which might have temporal changes. QUS was used to measure BMD in the present study, albeit DXA is the gold standard for BMD assessment and osteoporosis diagnosis. However, BMD measures derived from QUS were found to be correlated with those from DXA and associated with fracture [28, 29]. Despite the overall large sample size, an evident preference for green tea in the present population led to relatively low statistical power to ascertain the effect of other types of tea on bone health. Residual confounding by other unmeasured or unknown factors was still possible.

In conclusion, this large study of Chinese adults showed that prolonged moderate tea consumption benefited bone health in women. However, for stronger tea consumption with more tea leaves added, neither benefit nor harm to bone health was observed. Tea consumption was not associated with BMD in Chinese men. Further studies in other populations, especially in those consuming semi-fermented or fully fermented tea, are needed. Also, the potential influence of tea consumption during young adulthood on peak bone mass merits further studies.

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Compliance with ethical standards

Conflict of interest None.

Ethical approval The Ethical Review Committee of the Chinese Center for Disease Control and Prevention (Beijing, China), Chinese Academy of Medical Science/Peking Union Medical College (Beijing, China), and the Oxford Tropical Research Ethics Committee, University of Oxford (UK) approved the study.

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