Tea drinking is associated with benefits on bone density in older women[1–3]

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ABSTRACT

Background: Impaired hip structure assessed by dual-energy X-ray absorptiometry (DXA) areal bone mineral density (aBMD) is an independent predictor for osteoporotic hip fracture. Some studies suggest that tea intake may protect against bone loss.

Objective: Using both cross-sectional and longitudinal study designs, we examined the relation of tea consumption with hip structure.

Design: Randomly selected women ($n = 1500$) aged 70–85 y participated in a 5-y prospective trial to evaluate whether oral calcium supplements prevent osteoporotic fractures. aBMD at the hip was measured at years 1 and 5 with DXA. A cross-sectional analysis of 1027 of these women at 5 y assessed the relation of usual tea intake, measured by using a questionnaire, with aBMD. A prospective analysis of 164 women assessed the relation of tea intake at baseline, measured by using a 24-h dietary recall, with change in aBMD from years 1 to 5.

Results: In the cross-sectional analysis, total hip aBMD was 2.8% greater in tea drinkers ($\bar{x}$: 806; 95% CI: 797, 815 mg/cm^2) than in non-tea drinkers (784; 764, 803 mg/cm^2) ($P < 0.05$). In the prospective analysis over 4 y, tea drinkers lost an average of 1.6% of their total hip aBMD (−32; −45, −19 mg/cm^2), but non-tea drinkers lost 4.0% (−13; −20, −5 mg/cm^2) ($P < 0.05$). Adjustment for covariates did not influence the interpretation of results.

Conclusion: Tea drinking is associated with preservation of hip structure in elderly women. This finding provides further evidence of the beneficial effects of tea consumption on the skeleton. *Am J Clin Nutr* 2007;86:1243–7.

KEY WORDS Tea drinking, cross-sectional study, prospective study, bone mineral density, fracture, elderly women

INTRODUCTION

Hip fractures are a major cause of morbidity in older women (1). Low areal bone mineral density (aBMD) is the most important risk factor for hip fractures in this population (2) after age and is independent of age. We and others have shown that dietary and lifestyle factors, including calcium, protein, and sodium intakes influence aBMD and the risk of hip fracture (3–7).

Previous studies have shown that drinking tea has been associated with a higher aBMD (8–10) and a reduced risk of hip fracture (3, 11). Because tea is consumed worldwide, it is important to replicate observational studies to evaluate the reproducibility of the effect and its size in different populations. The objective of the present study was to investigate, in a randomly selected population-based sample of elderly women, the relation of tea consumption with measures of hip structure determined by using dual-energy X-ray absorptiometry (DXA). Two studies were undertaken, a cross-sectional analysis of the relation between tea intake and aBMD and a prospective analysis of the relation between tea intake and change in aBMD over 4 y of follow-up.

SUBJECTS AND METHODS

Subjects

The participants involved in this study were recruited for a 5-y prospective, randomized, controlled trial of oral calcium supplements to prevent osteoporotic fractures. They were recruited from the general population of women aged >70 y in Western Australian by mail with the use of an electoral roll that included close to 100% of women of this age; 5586 women responded, and the first 1500 eligible women were enrolled in the study (12). Eligibility included not having any medical conditions likely to influence 5-y survival. Although the subjects entering the study were weighted in favor of those in higher socioeconomic categories, they did not differ from the whole population in terms of health resource utilization (13). Patients were randomly assigned to receive 1.2 g calcium carbonate/d or a matched placebo. Informed consent was obtained, and the Human Rights Committee of the University of Western Australia approved the study.

Demographics, physical activity, and clinical measurements

At baseline, the number of years since menopause was calculated for each subject on the basis of the reported age at the last menstrual period or the time of hysterectomy, ovariectomy, or onset of hot flushes. A positive smoking history was reported if

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≥1 cigarette/d had been smoked for ≥3 mo at any time. The subject's postal area code was recorded, and an index of socioeconomic status (range: 1–3) was derived according to the Australian Bureau of Statistics method (14). A higher index score indicated that the area had a higher proportion of families with a high income. Activity levels were calculated (in kJ/d) by using a validated method that combines body weight, answers to questions on the number of hours and type of physical activity, and energy costs of such activities with a response of "no" to the activity questions resulting in a score of 0 (6). At baseline and 5 y, weight and height were measured while the participants were wearing light clothes and no shoes.

Assessment of diet and beverage intake

For the cross-sectional study at 5 y, each subject completed a self-administered quantitative food-frequency questionnaire, developed by The Cancer Council of Victoria (Australia), from which the daily consumption of energy, calcium, and alcohol was derived (15). This questionnaire did not ascertain the intakes of nonalcoholic beverages, such as tea and coffee. The food-frequency questionnaire uses the NUTTAB95 database (Australian Government Publishing Service, Canberra, Australia). Dietary calcium was from food alone and did not include calcium from supplements. To determine the consumption of tea and coffee at 5 y, a separate questionnaire that asked "on average over the past 12 mo how many cups per day of particular beverages do you usually consume" was used. Beverages included were as follows: black tea (not including herbal teas because they are not derived from the *Camellia sinensis* plant), coffee (not including decaffeinated), and decaffeinated coffee.

For the prospective study at baseline, the self-administered quantitative food-frequency questionnaire developed by The Cancer Council of Victoria (Australia) was used as described above and did not ascertain the intake of nonalcoholic beverages, such as tea and coffee. At baseline, beverage consumption data were determined by using an interviewer-administered dietary recall completed for the 24-h period before the clinic visit in a randomly selected subset of 275 women recruited to the study. Tea intake was assessed as the number of cups and included all black tea and green tea consumed with and without additives such as milk and sugar, but not herbal teas. Tea intake was not further subcategorized because almost all tea consumed within this population was black tea with added milk. The food intake data were analyzed to obtain nutrient intakes by using FOODWORKS PROFESSIONAL (Xyris, Brisbane, Australia) based on the Australian Food Composition Database (NUTTAB 95; Australian Government Nutrient Database, Canberra, Australia). For the prospective analysis, all data, including baseline tea intake, nutrient intakes, bone density, demographics, physical activity, and clinical measurements, were available for 164 (60%) of these women.

Bone density

Because this was a 5-y study designed with fracture as the primary outcome, BMD assessment was delayed until the first year of follow-up and then measured again at 5 y at the hip with DXA fan-beam densitometer (Hologic Acclaim QDR 4500A; Hologic Corp, Waltham, MA). Measurements performed at the hip included total hip, femoral neck, trochanter, and intertrochanter. The CVs at the total hip and femoral neck were 1.2% and 1.4%, respectively (16). Because hip BMD was measured at 1 and 5 y after randomization to calcium or placebo, treatment was included in the analysis as a covariate.

Statistics

Statistical analyses were performed by using SPSS 11.5 software (SPSS Inc, Chicago, IL). Differences in characteristics between non-tea drinkers and tea drinkers assessed at baseline or 5 y were assessed by using analysis of variance for normally distributed variables, Mann-Whitney *U* test for skewed variables, and the chi-square test for categorical variables. $P < 0.05$ in a two-tailed test was considered significant.

Cross-sectional analyses

Differences were analyzed by using general linear models with BMD as the dependent variable and tea drinking status at 5 y as the fixed factor; potential confounding factors were included as covariates in the model.

Prospective analyses

Differences were analyzed by using general linear models, with change in BMD over 4 y as the dependent variable and tea drinking status at baseline as the fixed factor; potential confounding factors were included as covariates in the model.

RESULTS

Demographic, anthropometric, and dietary variables

There were some between- and within-study differences in the demographic, anthropometric, and dietary variables for the women included in the 2 studies (**Table 1**). In the cross-sectional study, 83% of the women were tea drinkers. Compared with non-tea drinkers, tea drinkers had higher energy and calcium intakes, were more likely to consume alcohol, and consumed less coffee. Tea drinkers who smoked, smoked for fewer years. In the prospective analysis, 75% of the women were tea drinkers. Fewer tea drinkers had ever smoked, and tea drinkers reported less coffee consumption; however, intakes of energy, calcium, and alcohol were not significantly different between the tea drinkers and the non-tea drinkers.

BMD in the cross-sectional study

Bone density data for the non-tea drinkers and tea drinkers are presented in **Table 2**. Tea drinking was associated with a significantly higher aBMD at the total hip and trochanter sites but not at the femoral neck and intertrochanter sites. Adjustment for potential confounding factors, including age, BMI, years since menopause, duration of cigarette smoking (y), physical activity (kJ/d), socioeconomic status (higher, medium, lower), treatment code (placebo or calcium), and intakes of alcohol, calcium, and coffee did not alter the estimated differences. For comparison with other studies, the percentage differences in aBMD for tea drinkers relative to non-tea drinkers at the various hip sites are presented in **Figure 1**.

To determine whether there was a dose relation between the amount of tea consumed and BMD, tea intake was divided according to cups of tea consumed each day. In age-adjusted and fully adjusted linear regression models, there was no linear relation between tea intake in cups per day and BMD of the total hip, femoral neck, trochanter, or intertrochanter (**Table 3**).

TABLE 1
Characteristics of women included in the cross-sectional and prospective analyses and according to tea-drinking status[1]

	Non-tea drinkers	Tea drinkers
Cross-sectional analysis (n = 1027)		
Percentage of women (%)	17	83
Age at 5-y assessment (y)	79.8 ± 2.7[2]	80.0 ± 2.6
BMI at 5-y assessment (kg/m^2)	27.3 ± 5.6	27.1 ± 4.4
Ever smoked (%)	36	36
Duration of smoking (y)	37 (18–45)[3]	26 (12–42)[4]
Physical activity (kJ/d)	447 (0–823)	489 (184–857)
Socioeconomic status (% higher)	55	51
Age at menopause (y)	50 (45–52)	50 (45–52)
Calcium treatment (% active)	56	48
Energy intake at 5-y assessment (MJ/d)	6.3 ± 1.9	6.8 ± 2.1[5]
Calcium intake at 5-y assessment (mg/d)	832 ± 308	909 ± 305[5]
Alcohol at 5-y assessment (% users)	70	78[4]
Alcohol intake at 5-y assessment (g/d)	4.1 (0.6–12.4)	4.3 (0.8–12.8)
Coffee intake at 5-y assessment (cups/d)	2 (0–3)	1 (0–2)[6]
Prospective analysis (n = 164)		
Percentage of women (%)	25	75
Age (y)	74.8 ± 2.8	74.8 ± 2.6
BMI (kg/m^2)	25.9 ± 4.0	27.0 ± 4.2
Ever smoked (%)	52	34[4]
Duration of smoking (y)	26 (12–42)	24 (9–36)
Physical activity (kJ/d)	594 (192–870)	494 (167–853)
Socioeconomic status (% higher)	62	57
Age at menopause (y)	50 (45–52)	50 (46–52)
Calcium treatment (% active)	45	44
Energy intake (MJ/d)	7.0 ± 2.2	7.1 ± 2.0
Calcium intake (mg/d)	978 ± 404	927 ± 307
Alcohol (% users)	86	86
Alcohol intake in users (g/d)	4.8 (1.0–14.1)	4.4 (0.7–11.6)
Coffee intake (cups/d)	2 (1–3)	1 (0–2)[6]

[1] Unless otherwise stated, assessments were performed at baseline. ANOVA was used for normally distributed variables, the Mann-Whitney U test was used for skewed variables, and the chi-square test was used for categorical variables.
[2] $\bar{x}$ ± SD (all such values).
[3] Median; 25th–75th percentiles in parentheses (all such values).
[4–6] Significantly different from non-tea drinkers: [4]$P < 0.05$, [5]$P < 0.01$, [6]$P < 0.001$.

BMD in the prospective study

BMD at the 1-y assessment and mean changes in aBMD in selected sites over 4 y of follow-up in the non-tea drinkers and the tea drinkers is presented in **Table 4**. Although the 1-y aBMD values at the various sites were not significantly different between the 2 groups, tea drinking was associated with a significantly lower reduction in aBMD at the total hip, trochanter, and intertrochanter than was no tea drinking. Adjustment for potential confounding factors did not alter the estimated differences. For comparison with other studies, the percentage differences in the change in aBMD in selected sites over 4 y of follow-up for tea drinkers relative to non-tea drinkers are presented in **Figure 2**.

The dose relation between the amount of tea consumption in cups per day and the loss of BMD over 4 y was studied in age-adjusted and fully adjusted linear regression models. There was a significant negative relation observed at the trochanter site ($P < 0.05$) but not at the total hip, femoral neck, or intertrochanter sites.

TABLE 2
Bone mineral density (BMD) in selected sites according to tea drinking status in a cross-sectional analysis in 1027 older postmenopausal women[1]

	BMD	
Site and model	Non-tea drinkers (n = 172)	Tea drinkers (n = 855)
	mg/cm^2	
Hip		
Age-adjusted model (mg/cm^2)	784 (764, 803)	806 (797, 815)[2]
Fully adjusted model (mg/cm^2)[3]	782 (764, 800)	806 (799, 814)[2]
Femoral neck		
Age-adjusted model (mg/cm^2)	667 (651, 683)	681 (673, 688)
Fully adjusted model (mg/cm^2)	665 (650, 680)	681 (674, 688)
Trochanter		
Age-adjusted model (mg/cm^2)	604 (587, 621)	630 (622, 637)[4]
Fully adjusted model (mg/cm^2)	603 (587, 620)	630 (623, 637)[4]
Intertrochanter		
Age-adjusted model (mg/cm^2)	928 (904, 953)	950 (939, 961)
Fully adjusted model (mg/cm^2)	927 (905, 949)	950 (941, 960)

[1] All values are $\bar{x}$; 95% CI in parentheses.
[2,4] Significantly different from non-tea drinkers: [2]$P < 0.05$, [4]$P < 0.01$.
[3] The fully adjusted model included variables assessed at 5 y (age, BMI, years since menopause, and intakes of alcohol, calcium, and coffee, and variables assessed at baseline [duration of cigarette smoking (y), physical activity (kJ/d), socioeconomic status (higher, medium, lower), and treatment code (placebo or calcium)].

DISCUSSION

In this population of elderly women, tea drinking was independently associated with higher aBMD in the cross-sectional study and with a lower reduction in aBMD over 4 y in the prospective study. The baseline data from the prospective study showed a trend similar to that of the cross-sectional analysis at 5 y; the lack of a significant difference was perhaps due to the smaller numbers of participants.

The lack of a consistent dose relation between number of cups of tea consumed and aBMD in the cross-sectional and longitudinal study, apart from at the trochanter site, raises concerns over the mechanism of effect. It raises the possibility of another factor

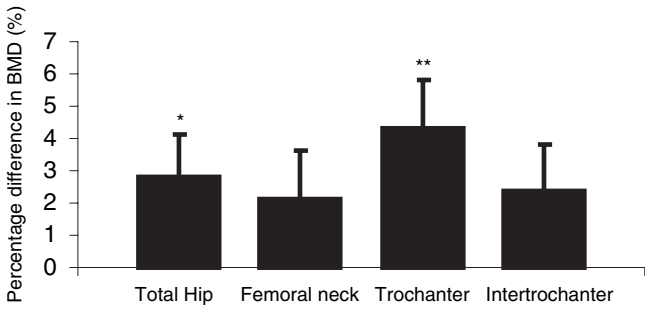

FIGURE 1. Mean (±SEM) percentage difference in bone mineral density (BMD) at selected sites between tea drinkers (n = 855) and non-tea drinkers (n = 172) in a cross-sectional analysis in older postmenopausal women. General linear models: [*]$P < 0.05$, [**]$P < 0.01$.

TABLE 3
Bone mineral density (BMD) of the hip according to tea intake and *P* values for the linear trend in a cross-sectional analysis in 1027 older postmenopausal women[1]

	BMD	
	Age-adjusted model	Fully adjusted model[2]
	mg/cm²	
Tea intake (cups/d)		
0 ($n = 172$)	784 (764, 803)[3]	782 (764, 800)
1 ($n = 122$)	801 (778, 824)	804 (783, 825)
2 ($n = 190$)	814 (796, 832)	812 (795, 828)
3 ($n = 217$)	805 (787, 822)	803 (788, 819)
4 ($n = 168$)	817 (797, 837)	815 (797, 833)
≥5 ($n = 158$)	790 (770, 811)	797 (779, 815)
P[4]	0.36	0.20

[1] Data were analyzed by using general linear models with BMD of the hip as the dependent variable and tea intake as the fixed factor. The reference category is non-tea drinkers, 0 cups/d (for all such). 1 cup = 237 mL.
[2] Adjusted for the following variables assessed at 5 y: age, BMI, years since menopause, and intakes of alcohol, calcium, and coffee; the following variables were assessed at baseline: duration of cigarette smoking (y), physical activity (kJ/d), socioeconomic status (higher, medium, lower), and treatment code (placebo or calcium).
[3] $\bar{x}$; 95% CI in parentheses (all such values).
[4] *P* for linear trend analyzed by using linear regression with BMD of the hip as the dependent variable and tea intake as the independent variable.

TABLE 4
Relation between tea drinking status and bone mineral density (BMD) at 1 y and change in bone mineral density over 4 y of follow-up[1]

	BMD	
Site	Non-tea drinkers ($n = 42$)	Tea drinkers ($n = 122$)
	mg/cm²	
Total-hip BMD		
At 1 y	792 (752, 852)	804 (784, 824)
4-y Change		
Age-adjusted model	−32 (−45, −19)	−13 (−20, −5)[2]
Fully adjusted model[3]	−37 (−51, −23)	−11 (−19, −3)[4]
Neck BMD		
At 1 y	684 (651, 715)	679 (661, 697)
4-y Change		
Age-adjusted model	−20 (−31, −9)	−14 (−20, −7)
Fully adjusted model	−23 (−35, −11)	−12 (−19, −6)
Trochanter BMD		
At 1 y	622 (587, 657)	638 (620, 656)
4-y Change		
Age-adjusted model	−35 (−48, −22)	−14 (−22, −6)[4]
Fully adjusted model	−39 (−53, −24)	−13 (−21, −5)[4]
Intertrochanter BMD		
At 1 y	926 (876, 976)	942 (916, 967)
4-y Change		
Age-adjusted model	−36 (−52, −20)	−11 (−20, −1)[4]
Fully adjusted model	−42 (−59, −24)	−9 (−9, 1)[4]

[1] All values are $\bar{x}$; 95% CI in parentheses.
[2,4] Significantly different from non-tea drinkers: [2]$P < 0.05$, [4]$P < 0.01$.
[3] The fully adjusted model included adjustment for age, BMI, duration of cigarette smoking (y), physical activity (kJ/d), socioeconomic status (higher, medium, lower), years since menopause, treatment code (placebo or calcium), and intakes of alcohol, calcium, and coffee from assessments performed at baseline.

for which tea is a marker that accounts for the difference. In addition, the small sample size in the prospective study, due to the limited data on beverage intake collected at baseline, was a limitation. However, despite the small sample size, the results are consistent with those of the cross-sectional study. Furthermore, 2 different methods were used to assess tea drinking: a 24-h dietary recall and a self-administered beverage questionnaire at year 5. The former method determines current intake and the latter method determines intake over the previous 12 mo. The possibility of measurement error with the latter method can be substantially greater than that of the former method, which can reduce the magnitude of the relation. Arguing against these concerns is the fact that the findings are consistent with those of previous cross-sectional studies of older women (9, 10) and younger men and women (8), which also suggest that regular ingestion of tea over the long term has a beneficial effect on BMD. Moreover, in the present study, the longitudinal data suggest that tea drinking protects to some extent against postmenopausal bone loss.

In relation to fracture, the results of the Mediterranean Osteoporosis Study (MEDOS) in women (3) and men (11) are consistent with this suggestion. However, other prospective studies have found no association of tea drinking with fracture risk (10, 17). Thus, it is possible that the effect of tea drinking on bone structure is not always large enough to alter the risk of fracture. Other factors, such as cultural differences in patterns of tea consumption, type of tea consumed, use of milk with tea, and consumption of other beverages such as coffee, could also influence the relation of tea with fracture risk.

If the relation of tea with BMD is causal, the components of tea that are responsible remain unknown. Calcium derived from the milk added to tea, which may provide a significant contribution to calcium intake, is one possible component. Most of the tea-drinking women in our study added milk to their tea. However, Hegarty et al (9) found that the mean BMD at most sites was not different between women who did and women who did not add milk to their tea. In addition, in populations from Taiwan (8), the United States (10), and southern Europe (11), where tea drinking is also associated with higher BMD, the addition of milk to tea is not the usual practice.

Phytochemicals present in tea have also been suggested to be important (9, 10). Tea is a major dietary source of flavonoids (18, 19) and lignans (18), some of which have estrogen-like activities (20). Synthetic phytoestrogens have been shown to benefit bone

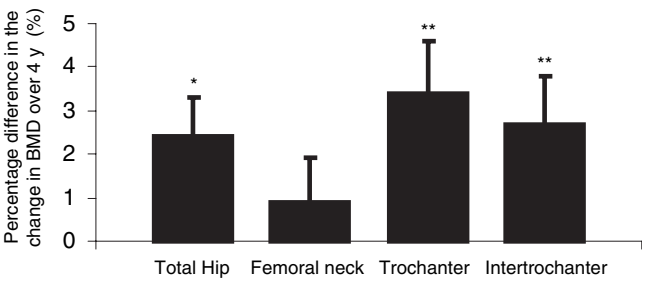

FIGURE 2. Mean (±SEM) percentage difference in the change in bone mineral density (BMD) at selected sites over 4 y of follow-up between tea drinkers ($n = 122$) and non-tea drinkers ($n = 42$) in a prospective analysis in older postmenopausal women. General linear models: $^{*}P < 0.05$, $^{**}P < 0.01$.

density (21, 22), but via a different mechanism than estrogen (21). The effect of isoflavones, phytoestrogens present in soy, on bone density remains unclear (23). Tea-derived flavonoids and lignans may be important in maintaining BMD (24), particularly in older women, who have low concentrations of endogenous estrogen. A recent review suggests that flavonoids from green tea may be associated with increases in BMD (25) via a potent stimulatory effect on osteoblast function. A major tea flavonoid, (−)-epigallocatechin-3-gallate, has been shown to increase the expressions of osteogenic genes, elevate bone marker activity, and augment mineralization in a murine bone marrow mesenchymal stem cell line (26). These findings suggest a stimulatory effect of the compound as a possible mechanism for the associated higher BMD seen in tea drinkers. Moreover, plasma concentrations of phytoestrogens may remain elevated throughout the day contributing to a sustained effect on bone.

Another bioactive component of tea is caffeine. Caffeine intake, mainly from coffee, has been associated with a reduced BMD (27, 28) and an increased risk of fracture (17, 29). Results of some studies suggest that this relation may be modified by calcium intake (17). Other studies reported no association between caffeine intake and bone loss (30, 31). The caffeine content of tea is usually less than half that of coffee. However, it is possible that at higher tea intakes, caffeine may attenuate any benefit of other bioactive components of tea.

The magnitude of the difference in BMD between tea drinkers and non-tea drinkers was between 3% and 4.5%. Tea drinkers also lost ≈3–4.5% less bone density over a 4-y period. This order of magnitude is greater than the protein effect on lower limb bone density observed by us in this population recently (5) and similar to the effect size of habitual high physical activity and calcium intake on hip BMD (6). Other variables, such as dietary calcium and coffee intake, physical activity, and smoking did not appear to be important confounders of the relation between tea and BMD. Thus, overall, our data support the concept that tea intake has beneficial effects on bone structure by reducing bone loss.

The authors' responsibilities were as follows—AD: study design, patient recruitment, data acquisition, preliminary data analysis, and manuscript preparation; JMH: data acquisition and analysis and manuscript preparation; IMD: study design and manuscript preparation; and RLP: study design, patient recruitment, data interpretation, and manuscript preparation. None of the authors had a conflict of interest.

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