Epidemiological Evidence of Increased Bone Mineral Density in Habitual Tea Drinkers

Chih-Hsing Wu, MD; Yi-Ching Yang, MD; Wei-Jen Yao, MD; Feng-Hwa Lu, MD; Jin-Shang Wu, MD; Chih-Jen Chang, MD

Background: Researchers have hypothesized that bone mineral density (BMD) may be influenced by chemical compounds such as caffeine, phytoestrogen, fluoride, and many compounds that are contained in tea extracts. Hence, the relationship between habitual tea consumption and BMD is an interesting issue.

Methods: Based on an epidemiological survey, we enrolled 497 men and 540 women, 30 years and older, in our study. All subjects were questioned about their habit of tea consumption and other lifestyle characteristics by means of a structured questionnaire. Dual-energy x-ray absorptiometry was used to measure the BMD of the total body, lumbar spine (L1-L4), hip neck, and Ward triangle regions.

Results: Five hundred two subjects (48.4%) were habitual tea drinkers, with a mean duration of tea consumption of approximately 10 years. Compared with nonhabitual tea drinkers, subjects with habitual tea consumption of 6 to 10 years showed higher lumbar spine BMDs, and those with consumption of more than 10 years showed the highest BMDs of all measured regions. Under the multiple stepwise regression models, sex, age, body mass index, total physical activity, and habit of tea consumption were the major significant variables for the different BMD regions. Regarding the behavioral characteristics of tea consumption, the duration of tea consumption was the only independent determinant for the BMDs.

Conclusion: Habitual tea consumption, especially for more than 10 years, has significant beneficial effects on BMD of the total body, lumbar spine, and hip regions in adults.

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Tea, an extract of the leaves of the Camellia sinensis, is commonly consumed throughout the world. According to the different levels of fermentation, tea is categorized into green (nonfermented), oolong (partially fermented), and black (fermented) types. In most Western countries, black tea with milk is preferred, whereas in China, green or oolong tea is usually consumed without milk. Tea contains more than 4000 chemical compounds that may affect the human body in many aspects.1 Recent studies have demonstrated that tea and tea polyphenols have many positive effects on the prevention of cardiovascular disease, atherosclerosis, and cancer.2 However, tea extracts also contain high concentrations of caffeine, fluoride, flavonoids, and phytoestrogen. These compounds have all been supposed to have detrimental or beneficial effects on bone mineral density (BMD) and risk for fracture in different studies.3-5 After water, tea is the most common drink consumed regularly by most adults in the world. Any effect of tea on bone metabolism would represent a major public health concern, but information about the effects of tea consumption on bone mass is limited and unclear. An inverse association between BMD of the ultradistal radius and tea drinking in women has been noted,3 but positive associations between tea drinking and BMD of the lumbar or the femoral neck region were reported recently.6,7 Meanwhile, the Mediterranean Osteoporosis (MEDOS) Study also hypothesized the protective effect of tea drinking on hip fracture.8,9 These varying findings may result from different study designs (epidemiological or hospital based), inconsistent definition of tea intake categories, and incomplete adjustment of the confounding effect of lifestyle characteristics such as exercise, alcohol intake, smoking, and even the intake of other nutrients. However, only white subjects who drink black tea have been studied in these reports, which is a major shortcoming. Furthermore, except for the male MEDOS Study,10 only female tea...
MATERIALS AND METHODS

SUBJECTS

The study population was enrolled from a prospective epidemiological survey of chronic diseases in Tainan, a city located in southern Taiwan with a population of 700,000. The selection procedure was a stratified, systematic, step-by-step cluster sample of households throughout Tainan. First, the city was grouped formally into 7 administrative districts. One area (Li, an administrative unit, subdivided from districts of the city) was randomly selected from each district. Second, every fifth household within each of the 7 selected areas was identified systematically. Third, all of the sampled subjects 20 years or older according to the government population register in 1995 were included in the study. Finally, this cohort consisted of 2416 eligible Chinese subjects (47.6% men) who underwent systematic sampling from Tainan. From January 13, 1996, through December 1, 1996, 1638 subjects older than 20 years had participated in the first screening survey. In this study, 1225 men and women who completed the second follow-up survey from September 24, 1998, through January 22, 2000, underwent analysis. As the physiological peak bone mass is usually achieved after 30 years of age, we enrolled a total of 1037 subjects (497 men and 540 women) 30 years or older for final analysis. These subjects had no bone-remodeling disease and had received no bone-remodeling agents. Written consents were obtained from all the subjects. The research committee of National Cheng Kung University Hospital, Tainan, approved this study.

QUESTIONNAIRE OF LIFESTYLE COVARIATES

All subjects were interviewed according to the structured questionnaires. Total physical activity, including leisure activity, occupational activity, and walking for exercise, was calculated as metabolic equivalent (MET)-hours per week for all activities for the past year. Smoking was dichotomized into nonsmoking (never, former, and <1 pack per month smokers) and current smoking (≥1 pack per month). Subjects who had drunk alcohol, coffee, or milk more than once a week for 6 months or longer were recorded as habitual drinkers; otherwise, they were classified as nonhabitual drinkers. Calcium supplementation was also recorded if subjects regularly used supplements more than 3 times a week for 6 months or more. Personal medical history, including estrogen replacement therapy, menopausal status, use of bone-remodeling agents, or presence of related diseases, was checked accordingly.

TEA CONSUMPTION

The level of tea consumption was assessed using a modified questionnaire at the 1996-1997 and 1998-2000 surveys. The first question was: “Have you drunk tea habitually once a week for at least 6 months?” Subjects who answered yes were coded as habitual tea drinkers in this study. The habitual tea drinkers then completed the following questions: (1) What kind of tea (green, black, or oolong) was mostly consumed? (2) Do you regularly add milk to your tea? (3) How often do you drink tea each week? (4) How many times do you drink tea each day? (5) How much tea (in milliliters) do you drink each time? (6) How many years have you been drinking tea in this way? The average daily tea consumption (in milliliters) was calculated using the following formula:

\[ \text{Average daily tea consumption} = \frac{\text{Days per Week} \times \text{Times per Day} \times \text{Volume of Tea Extracts Each Time}}{7} \]

For example, if someone drinks 350 mL of tea twice a day and 3 days per week, the average daily tea consumption would be \((3 \times 2 \times 350) / 7 = 300\) mL.

BONE MINERAL DENSITY

With each subject wearing light indoor clothes, we measured body height and weight and calculated body mass index (BMI; weight in kilograms divided by the square of height in meters). During the 1998-2000 follow-up survey, the BMDs, including total body, lumbar spine (L1-L4), and hip neck and Ward triangle regions, were measured by means of dual-energy x-ray absorptiometry (DPX-L; Lunar Radiation Corporation, Madison, Wis). The analyzing software (version 1.3z; Lunar Radiation Corporation) was used to calculate the body composition and was not changed during this study period, as it could provide consistent results with similar high coefficients of variation compared with a newer version of the software. In this study, the coefficients of variation of BMDs were 0.5% for total body, 2.0% for spine, and 0.9% for legs.

STATISTICAL ANALYSIS

Data were analyzed using SPSSWIN software (Version 8.0; SPSS Inc, Chicago, Ill). We categorized subjects into the following 4 subgroups according to duration of tea consumption: nonhabitual, 1 to 5 years, 6 to 10 years, and more than 10 years. We subjected the differences of BMDs among the 4 subgroups to analysis of covariance, which adjusted for age, BMI, sex, and all other lifestyle covariates. We analyzed the independent effects of tea consumption, the different characteristics of tea consumption, and all other lifestyle covariates on BMDs using multiple stepwise linear regression models. Each independent variable was expressed with standardized regression coefficients. Statistical significance was defined as \(P<.05\) for 2-tailed analysis.
Table 1. Basic Characteristics of Nonhabitual and Habitual Tea Drinkers in 1037 Study Subjects*

<table>
<thead>
<tr>
<th>Characteristics of tea habit</th>
<th>Nonhabitual Tea Drinkers (n = 535)</th>
<th>Habitual Tea Drinkers, Duration, y</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1-5 (n = 226)</td>
<td>6-10 (n = 152)</td>
</tr>
<tr>
<td>Male†</td>
<td>209 (39.1)</td>
<td>93 (41.2)</td>
</tr>
<tr>
<td>Age, mean ± SD, y‡</td>
<td>51.86 ± 13.89g</td>
<td>47.06 ± 12.67</td>
</tr>
<tr>
<td>Body mass index, mean ± SD, kg/m²‡</td>
<td>24.02 ± 3.36</td>
<td>24.10 ± 3.14</td>
</tr>
<tr>
<td>Total physical activity, mean ± SD, MET-h/wk‡</td>
<td>76.27 ± 60.77</td>
<td>76.06 ± 55.05</td>
</tr>
<tr>
<td>Habitual smoking†</td>
<td>89 (16.6)§</td>
<td>48 (21.2)</td>
</tr>
<tr>
<td>Alcohol drinking†</td>
<td>62 (11.6)§</td>
<td>34 (15.0)</td>
</tr>
<tr>
<td>Coffee drinking†</td>
<td>41 (7.7)§</td>
<td>32 (14.2)</td>
</tr>
<tr>
<td>Habitual milk intake†</td>
<td>318 (59.4)</td>
<td>131 (58.0)</td>
</tr>
<tr>
<td>Calcium supplement†</td>
<td>42 (7.3)§</td>
<td>22 (8.7)</td>
</tr>
<tr>
<td>Green/oolong tea†</td>
<td>. . .</td>
<td>202 (89.4)</td>
</tr>
<tr>
<td>Milk addition†</td>
<td>. . .</td>
<td>54 (23.9)§</td>
</tr>
<tr>
<td>Daily drinking†</td>
<td>. . .</td>
<td>84 (37.2)§</td>
</tr>
<tr>
<td>Daily consumption, mean ± SD, mL‡</td>
<td>. . .</td>
<td>340.1 ± 403.2§</td>
</tr>
<tr>
<td>Duration, mean ± SD, y‡</td>
<td>. . .</td>
<td>3.11 ± 1.47§</td>
</tr>
</tbody>
</table>

*Unless otherwise indicated, data are given as number (percentage). MET indicates metabolic equivalent.
†Comparison among subgroups by χ² test.
‡Comparison among subgroups by analysis of covariance.
§P<.001.
¶P<.01.
‖P<.05.

RESULTS

Of the 1037 subjects, 48.4% were habitual tea drinkers; 26.0%, current smokers; 19.3%, habitual alcohol drinkers; 37.0%, habitual milk drinkers; 11.3%, habitual coffee drinkers; and 7.2%, habitual calcium supplement users. To assess the dose-response effect of tea consumption on BMD, the following numbers of subjects were categorized into the 4 subgroups by duration of tea consumption: 535 as nonhabitual, 226 as 1 to 5 years, 152 as 6 to 10 years, and 124 as more than 10 years (Table 1). Among the 502 habitual tea drinkers, 45 (9.0%) were black tea drinkers and 457 (91.0%) were green or oolong tea drinkers. Two hundred fifty-three habitual tea drinkers consumed tea daily, but only 96 subjects had the habit of adding milk during tea consumption. The mean ± SD duration of habitual tea drinking was 9.5 ± 9.4 years (range, 1-60 years), with a mean ± SD daily tea consumption of 414.4 ± 452.4 mL.

In the Figure, a positive linear effect correlating to duration of habitual tea consumption was found in the BMD of the 4 body regions. After adjustment for sex, age, BMI, and lifestyle covariates, the BMD for the total body, lumbar spine, and hip neck regions was clearly demonstrated. To the best of our knowledge, this is the first study of the relationship between consumption of 3 kinds of tea (green, black, and oolong) and BMD in both sexes concomitantly. Similar to previous reports,18-21 we also demonstrated that younger men, those with higher BMIs, and those who expend higher total physical activity have higher BMDs. Furthermore, even after adjustment for menopausal status, tea consumption was still an independent factor for BMD in women (data not shown). However, the effect of smoking and intake of alcohol, milk, coffee,22 and calcium supplements10 on BMD was obscure in our study, which was also compatible with the various findings in previous studies.12,13,20,23 Generally speaking, the similarity of major findings between other reports and ours suggested that our study population is not a unique group.

The independent effects of other covariates on BMD are shown in Table 3. Men had higher BMDs than women. The BMD increased along with the increment of BMI, but decreased with the increment of age. Total physical activity also had a positive effect on BMD of the total body and hip neck. After analysis with all of the covariates, tea consumption was still a small but significantly positive variable on BMD of the total body, lumbar spine, and hip (hip neck and Ward triangle regions). In other words, the habit of tea consumption can predict a 0.5% to 5.1% variation in BMD in the different 4 body regions. Moreover, after adjustment for all covariates, no significant differences of BMD could be found between those who drank green or oolong tea compared with those who drank black tea (data not shown).

COMMENT

Consistent with the findings of other studies,10,11 the protective effect of tea on BMD of the total body, lumbar spine, and hip regions was clearly demonstrated. To the best of our knowledge, this is the first study of the relationship between consumption of 3 kinds of tea (green, black, and oolong) and BMD in both sexes concomitantly. Similar to previous reports,18-21 we also demonstrated that younger men, those with higher BMIs, and those who expend higher total physical activity have higher BMDs. Furthermore, even after adjustment for menopausal status, tea consumption was still an independent factor for BMD in women (data not shown). However, the effect of smoking and intake of alcohol, milk, coffee,22 and calcium supplements10 on BMD was obscure in our study, which was also compatible with the various findings in previous studies.12,13,20,23 Generally speaking, the similarity of major findings between other reports and ours suggested that our study population is not a unique group.
and that our findings could be extrapolated to other populations.

Although several studies may have suggested the positive effect of tea consumption on bone mass,10-13 no consistent methods in defining the categorization of tea consumption have been used. In previous studies, “cups of tea consumed”10-13 was the most common definition of the level of tea consumption. However, we found that the duration of tea consumption, not the amount of daily tea consumption, was the only independent determinant of BMD. As we know, the change of BMD is always gradual. If BMD could be affected by tea consumption, the exposure must be long enough to have a significant cumulative effect on BMD, ie, long-term, moderate tea consumption will influence BMD more than short-term consumption of high amounts of tea. Therefore, the duration of tea consumption was the major determinant of BMD among all the characteristics of tea consumption. Nevertheless, whether this unique finding could be a bias due to different drinking habits between Asians and other populations is debatable and needs further investigation.

Another important issue was to determine the threshold or range of tea consumption likely to be beneficial.

Table 2. Multiple Stepwise Regression Models of Tea Consumption, Associated Lifestyle Factors, and BMD in 1037 Subjects*

<table>
<thead>
<tr>
<th>Region</th>
<th>Adjusted R²</th>
<th>Age</th>
<th>BMI</th>
<th>Sex</th>
<th>Total Physical Activity</th>
<th>Duration of Habitual Tea Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total body</td>
<td>0.392</td>
<td>-0.433†</td>
<td>0.381†</td>
<td>-0.272†</td>
<td>0.061‡</td>
<td>0.086§</td>
</tr>
<tr>
<td>Lumbar spine (L1-L4)</td>
<td>0.179</td>
<td>-0.390†</td>
<td>0.204†</td>
<td>-0.063‡</td>
<td>. . .</td>
<td>0.113†</td>
</tr>
<tr>
<td>Hip</td>
<td>0.266</td>
<td>-0.468†</td>
<td>0.246†</td>
<td>-0.106‡</td>
<td>0.060‡</td>
<td>0.099§</td>
</tr>
<tr>
<td>Neck</td>
<td>0.339</td>
<td>-0.580†</td>
<td>0.211†</td>
<td>. . .</td>
<td>. . .</td>
<td>0.084§</td>
</tr>
<tr>
<td>Ward triangle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Independent variables were age, body mass index (BMI), sex (male = 0; female = 1), duration of habitual tea consumption, tea type (black or nonblack), frequency of tea drinking (nondaily or daily), daily tea consumption in milliliters, milk addition to tea, total physical activity, smoking status, alcohol drinking habit, milk intake, coffee intake, and use of calcium supplements. Dependent variable was bone mineral density (BMD). Only significant variables are shown with standardized regression coefficients. MET indicates metabolic equivalent; ellipses, not significant.

†P<.001
‡P<.05
§P<.01
or detrimental for BMD effects. Although tea consumption (cups of tea consumed and recorded on a 4-point score) was found to have a protective effect on hip fracture, the dose-response effect has not been discussed in the MEDOS Study or in other studies. In our study, we found that subjects with habitual tea consumption from 6 to 10 years’ duration had significantly higher BMD of the lumbar spine than did nonhabitual tea drinkers. When the duration of tea consumption was more than 10 years, the significant increment in BMD of the total body, lumbar spine, and hip regions was recorded when compared with that of nonhabitual tea drinkers (Figure). Hence, it is plausible to believe that a graded association between increasing duration of tea consumption and elevation of BMD for the total body, lumbar spine, and hip regions existed in our study. The difference between the BMDs in black tea and green or oolong tea drinkers may also be of interest. After adjustment for covariates, no significant differences of BMDs could be found between green or oolong tea and black tea drinkers (data not shown). Perhaps relatively too few black tea drinkers were included (n=45) to have a balanced comparison of their BMDs with those of green/oolong tea drinkers (n=457), especially with adjustment for other covariates.

Several hypotheses have been proposed to explain the bone-protective effects of tea. These hypotheses may work independently or in concert. First, tea is an important source of dietary fluoride. Fluoride intake can alleviate the osteoporotic progression. Therefore, the relatively high fluoride content of tea leaves may enhance the protective effect on BMD. Second, flavonoids (including phytoestrogen and ipriflavone) have all been supposed to improve the BMD. Because tea contains relatively high amounts of flavonoids and phytoestrogen, increasing the BMD by consuming tea habitually is possible. Third, experiments have also found that tea extracts could inhibit bone resorption and protect against clastogenic activity of mouse bone in vivo. Finally, the different effects of tea infusions (eg, polyphenols and tannins) on the milieu of elemental mineral metabolism may also indirectly influence BMD. These hypotheses may work independently or in concert and could explain the protective effect of tea consumption on BMD.

In this study, a range of lifestyle cofactors predicted the BMD, but together these factors explain only a small proportion of the overall BMD (the highest adjusted R² is 0.392). Many unknown factors such as genetic factors may influence BMD and need to be studied in the future. Our results suggest a possible way of reconciling the disparate reports from previous studies, ie, habitual tea consumption, especially when maintained for more than 10 years, has a significantly beneficial effect on BMD of the total body, lumbar spine, and hip regions in men and women.

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Table 3. Multiple Stepwise Regression Models of Tea Consumption, Associated Lifestyle Factors, and BMD Density in 1037 Subjects

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<tr>
<th>Region</th>
<th>Adjusted R²</th>
<th>Age</th>
<th>BMI</th>
<th>Sex</th>
<th>Total Physical Activity</th>
<th>Tea Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total body</td>
<td>0.389</td>
<td>-0.415†</td>
<td>0.379†</td>
<td>-0.282†</td>
<td>0.058‡</td>
<td>0.061†</td>
</tr>
<tr>
<td>Lumbar spine (L1-L4)</td>
<td>0.175</td>
<td>-0.366†</td>
<td>0.202†</td>
<td>-0.075‡</td>
<td>0.068§</td>
<td></td>
</tr>
<tr>
<td>Neck</td>
<td>0.258</td>
<td>-0.446†</td>
<td>0.347†</td>
<td>-0.143†</td>
<td>0.060‡</td>
<td>0.054‡</td>
</tr>
<tr>
<td>Ward triangle</td>
<td>0.336</td>
<td>-0.562†</td>
<td>0.210†</td>
<td>-0.143†</td>
<td>0.060‡</td>
<td>0.054‡</td>
</tr>
</tbody>
</table>

*Independent variables were age, body mass index (BMI), sex (male = 0; female = 1), tea consumption (nonhabitual = 0; habitual = 1), total physical activity, smoking status, alcohol drinking, milk intake, coffee intake, and use of calcium supplements. Dependent variable was bone mineral density (BMD). Only significant variables are shown with standardized regression coefficients. MET indicates metabolic equivalent; ellipses, not significant.
†P<.001.
‡P<.05.
§P<.01.