Impact of seafood and fruit consumption on bone mineral density

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Abstract

Objectives: Over the past decade, dietary choices and nutrition have proven to be major modulators of bone mineral density (BMD) in men and women. We investigated environmental determinants, specifically dietary habits, of BMD by using multiple regression models in a rural Chinese population.

Methods: BMDs were measured at the hip and total body in 5848 men and 6207 women, aged 25–64. Dietary and supplemental intakes were assessed by a simple, one-page questionnaire tailored to collect nutritional information from large rural populations. Another questionnaire was used to collect information on the subjects’ age, disease history, smoking, alcohol consumption, physical activity as well as women’s menstrual status and reproductive history. Multiple regression models were used to assess the relationships among dietary variables and BMD, after adjusting for age, BMI (body mass index), weight, occupation, smoking status, and alcohol consumption.

Results: Increasing seafood consumption was significantly associated with greater BMD in women (p < 0.001), especially those consuming more than 250 g per week of seafood. One thousand and three hundred and twenty-four men and 1479 women consumed >250 g of fruit per week. Higher fruit intake was found to be significantly associated with higher BMD in both sexes (p < 0.05). High vegetable consumption, however, did not positively impact BMD.
Conclusions: This study with its large population size has identified preventive measures, as well as some risk factors, involved in bone loss and osteoporosis. Our results highlight the importance of several dietary variables as significant determinants of BMD. It also emphasizes the role of dietary intake in general and shows that specific foods, such as fruits and seafood, can positively impact BMD.

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Keywords: BMD; Fruit; Menopause; Nutrition; Osteoporosis; Seafood

1. Introduction

Osteoporosis is a major cause of disability throughout the world. It is estimated that 10 million Americans are currently affected with this disorder and another 18 million have low bone mass, placing them at future risk [1]. There is now evidence indicating that osteoporosis has quietly become an epidemic in China with its aging population. According to a recent survey of 5593 people aged above 40 years in five administrative areas in China, it was found that the total prevalence rate of osteoporosis was 16.1%, 11.5% for males and 19.9% for females [2]. Bone mineral density (BMD) is an important predictor of fracture. A patient with BMD that is reduced by ≥2.5 standard deviations below peak bone mass is considered to have osteoporosis [3]. Strong efforts have been recently undertaken to understand the factors that influence BMD.

It is well known that genetic factors influence peak bone mass, but many environmental factors also play a role in altering genetic effects [4–7]. Proper nutrition plays a role in the prevention and treatment of osteoporosis. One of the most important nutritional factors in prevention of osteoporosis is adequate intake of calcium and Vitamin D [8]. In addition to calcium and Vitamin D, inadequate intake of phosphorus, magnesium, fluoride, boron, vitamins (K, C, B6), potassium, and protein has been linked to a predisposition to osteoporosis [9–11].

Several studies suggest that dietary habits and nutrition play a crucial role in modulating BMD. It is plausible that prevention of bone loss through diet is possible, yet it involves many nutrients and food components like milk, fruits, vegetables, meat, sea food and shellfish [12–14]. Also of interest, is the effect of nutrients like minerals, vitamins and macronutrients on bone status [15]. Most studies to date have focused on the effect of calcium and Vitamin D on bone health [16], neglecting other important nutrients that may be crucial to bone development and maintenance of BMD.

Foods and food components, including dairy products, fruits and vegetables, dietary fibers, mineral water, soy products, carbonated beverages, caffeine and alcohol have only recently been investigated [17]. In a study of 907 elderly men and women from the Framingham study, Tucker et al. [18] demonstrated that both potassium and magnesium intake significantly contribute to maintenance of BMD. From their food frequency questionnaires and content estimates of dietary source, the authors determined that the major sources of these electrolytes were fruits, vegetables and whole grain. The authors also report that increased intake (servings/day) of fruits and vegetables, especially in men, is associated with diminished decline in BMD.

Results from many studies evaluating the dietary impact on bone health [15,19,20], remain inconclusive or even contradictory. What is clear, however, is that nutrients and food constituents interact to affect bone status. This study, with its large population size, aims at identifying some dietary factors that may influence bone loss and osteoporosis. This study also aims at recommending preventive measures that might improve bone health in a population where the use of hormone replacement therapy is not practiced.

2. Material and methods

2.1. Subjects

A total of 12,055 individuals (5848 men and 6207 women) were included in this study. Subjects were recruited from October 2003 to January 2004. Subjects were composed of four major groups; Group I consisted of ≤45-year-old men, Group II consisted of >45-year-old men, Group III of premenopausal women and, Group IV consisted of postmenopausal women. This
study is part of an ongoing community-based osteoporosis project conducted in Anhui Province, China [31]. Men and women aged 25–64 years old, who come from families with a minimum of three participating siblings were considered eligible for recruitment. Participants with a documented medical condition, i.e. type 1 diabetes, end stage renal disease, cancer, metabolic bone disease, chronic pathogenic infections, were excluded from the study. Women who could not rule out pregnancy were also excluded.

This study was approved by the Human Subjects Committee (the institutional review board, IRB) of the Harvard School of Public Health and by the Ethics Committee of Anhui Medical University. A written informed consent was carefully explained to, read to/by and signed by each participant.

2.2. BMD measurement

Dual-energy X-ray absorptiometry (DXA) (Prodigy Advance Bone Densitometer, GE Medical Systems LUNAR) was used to measure the bone mineral content (g) and the area BMD (g/cm²) through whole body and total hip scans. All BMD measurements were conducted in a single study center. Daily calibration with a phantom was performed. We randomly selected 71 subjects for re-measurements at whole body and total hip. The maximum interval between the two DXA measurements was 30 days. The coefficient of variability (CV%) of the reproducibility is 1.34 and 2.05 at whole body and total hip, respectively.

2.3. Anthropometry

Each participant underwent a general physical examination performed by a trained clinician. During the examination, height, weight, waist and hip circumferences were measured and recorded. Height was measured to the nearest 0.1 cm on a portable stand meter and weight to the nearest 0.1 kg with the subject standing motionless in the center of the scale. BMI was calculated as weight/height² (kg/m²). Waist to hip ratio was determined by obtaining tape measurements around the waist and hips.

2.4. Nutritional questionnaire

A nutritional questionnaire was used to collect data on each participant’s consumption of local food items/groups, such as milk, seafood, preserved food, meat (mainly pork), vegetables, fruits, and Vitamin D supplementation. This questionnaire was part of a much larger questionnaire that included personal, health, smoking, employment and reproductive history sections. Reported intake frequency of the dietary variables was summed to obtain the total amount in grams consumed per week for each individual. Based on a dietary information survey conducted prior to the study on potential subjects the thresholds for nutrient intake were assigned.

2.5. Other covariates

A comprehensive questionnaire was used to collect each participant’s demographic, occupational and lifestyle information, disease history, consumption of alcohol and cigarette smoking, physical activity, fracture history, and family history of fractures. For women, an additional reproductive questionnaire was administered to collect data on menstrual and reproductive history, including age at menarche, typical menstrual cycle characteristics, history of menstrual dysfunctions, age at menopause, number of pregnancies, breast-feeding, as well as current and past oral contraceptive use. Postmenopausal women were defined as women without menstruation for at least 12 months.

2.6. Statistical analysis

Since age, gender and menopause status are three of the most important predictors of bone mass, osteoporosis and fractures, we reported analyses separately for these three variables. The SAS 8.2 software package (SAS Institute, Cary, NC) was used to perform all statistical analyses. Analysis of variance test (ANOVA) and χ² tests were used to compare the base-line characteristics of the subjects among the four study groups. The Tukey test was also used to perform pairwise-comparisons among groups when there was significance for an ANOVA. χ² test was used to compare the dietary intake variables between men and women. We then further divided subjects into quartiles according to their total body BMD. We defined subjects in the lowest quartile as the extreme low BMD group, and subjects in the highest quartile as the extreme high BMD group. Multivariate logistic regression models
adjusted for age, weight, BMI, occupation, smoking status, and alcohol consumption were used to assess the dietary determinants of extreme BMD. A log likelihood ratio test was used to test the interaction among covariates. Generalized estimating equation models were used to adjust for intraclass-correlation within family members. A \( p \)-value of less than 0.05 was considered significant.

3. Results

3.1. General characteristics of the study population

There were a total of 2409 men in Group I and 3439 in Group II. Four thousand and two hundred and sixteen women were premenopausal (Group III) and 1991 were postmenopausal (Group IV). The mean age and standard deviation in Group I were 39.0 ± 3.77, 52.0 ± 4.63 in Group II, 41.3 ± 5.33 in Group III and 52.4 ± 4.88 in Group IV. The BMI and standard deviation were calculated for each of the four groups, and the mean in kg/m\(^2\) was 21.60 ± 2.56 for Group I, 21.29 ± 2.48 for Group II, 22.36 ± 2.80 for Group III and 21.86 ± 2.87 for Group IV. Characteristics of the study sample are summarized in Table 1.

### Table 1

BMD and baseline characteristics of the study population stratified by gender, age and menopausal status

<table>
<thead>
<tr>
<th>Variables</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Age ≤ 45 (N = 2409)</td>
<td>Age &gt; 45 (N = 3439)</td>
</tr>
<tr>
<td></td>
<td>[mean (S.D.)]</td>
<td>[mean (S.D.)]</td>
</tr>
<tr>
<td>Age (years)</td>
<td>39.0 (3.77)</td>
<td>52.0 (4.63)</td>
</tr>
<tr>
<td>Age range (years)</td>
<td>24.4–45.0</td>
<td>45.1–65.0</td>
</tr>
<tr>
<td>BMI (kg/m(^2))****</td>
<td>21.60 (2.56)c</td>
<td>21.29 (2.48)d</td>
</tr>
<tr>
<td>BMD (g/cm(^2))</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole body(^c)</td>
<td>1.14 (0.07)f</td>
<td>1.12 (0.07)f</td>
</tr>
<tr>
<td>Total hip(^c)</td>
<td>0.99 (0.11)f</td>
<td>0.95 (0.12)f</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variables</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Age ≤ 45 (N = 2409)</td>
<td>Age &gt; 45 (N = 3439)</td>
</tr>
<tr>
<td></td>
<td>[number (%)]</td>
<td>[number (%)]</td>
</tr>
<tr>
<td>Cigarette smoking(^a,***)</td>
<td>1802 (74.9)f</td>
<td>2821 (82.2)f</td>
</tr>
<tr>
<td>Passive smoking(^a,***)</td>
<td>382 (15.9)f</td>
<td>1099 (32.0)d</td>
</tr>
<tr>
<td>Alcohol consumption(^a,***)</td>
<td>1029 (42.7)d</td>
<td>1612 (46.9)d</td>
</tr>
<tr>
<td>Regular exercise(^a)</td>
<td>21 (0.8)</td>
<td>23 (1.1)</td>
</tr>
<tr>
<td>Occupation (farmer/worker)(^***)</td>
<td>2092 (87.0)f</td>
<td>3123 (91.8)d</td>
</tr>
<tr>
<td>Heavy physical activity(^b,(^c))</td>
<td>406 (16.8)d</td>
<td>645 (18.7)d</td>
</tr>
</tbody>
</table>

\( ^a \) \( p < 0.05; \) \( ^b \) \( p < 0.001; \) \( ^c \) \( p < 0.0001; \) compared the difference between Groups I–IV. ANOVA test was used for continuous variables, and \( \chi^2 \) test was used for categorical variables. Tukey test was used to perform the pairwise-comparison among groups when there were significance for ANOVA test. \( \chi^2 \) test was used for categorical variables. \( p < 0.05 \) for pairwise-comparison if the letters (c,d,e,f) are different between groups.

\(^a\) Cigarette smoking: current cigarette smoking defined as more than one pack per month. Passive smoking: non-cigarette smokers whose spouse or other close family members are current smokers. Alcohol consumption: current alcohol consumption of more than one drink per week. Regular exercise: frequency of one or more times per week.

\(^b\) More than 5 h per day carrying (on back or shoulder), riding (bicycle or other man powered vehicle), dragging, hand-pulled cart, raising, lifting or moving a load with more than 20 kg.

3.2. Dietary variables

3.2.1. Milk consumption

Five thousand and seven hundred and sixty men and 6127 women consumed \( \leq 250 \) g of milk per week whereas, 76 men and 62 women had between 250 and 1500 g of milk per week in their usual diet. Increased milk consumption did not show a significant effect on...
Table 2

<table>
<thead>
<tr>
<th>Consumption per week</th>
<th>Men number (%)</th>
<th>Women number (%)</th>
<th>Total number (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Milk</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤250 g</td>
<td>5760 (98.7)</td>
<td>6127 (99.0)</td>
<td>11887 (98.9)</td>
</tr>
<tr>
<td>&gt;250 g</td>
<td>76 (1.3)</td>
<td>62 (1.0)</td>
<td>138 (1.1)</td>
</tr>
<tr>
<td><strong>Seafood</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤250 g</td>
<td>3425 (58.8)</td>
<td>4344 (70.2)</td>
<td>7769 (64.7)</td>
</tr>
<tr>
<td>&gt;250 g</td>
<td>2399 (41.2)</td>
<td>1842 (29.7)</td>
<td>4241 (33.3)</td>
</tr>
<tr>
<td><strong>Preserved food</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤250 g</td>
<td>2414 (41.4)</td>
<td>2296 (37.1)</td>
<td>4710 (39.1)</td>
</tr>
<tr>
<td>&gt;250 g</td>
<td>3424 (58.6)</td>
<td>3905 (62.9)</td>
<td>7329 (60.9)</td>
</tr>
<tr>
<td><strong>Meat</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤250 g</td>
<td>1853 (31.7)</td>
<td>3765 (60.7)</td>
<td>5618 (46.7)</td>
</tr>
<tr>
<td>&gt;250 g</td>
<td>3987 (68.3)</td>
<td>2428 (39.2)</td>
<td>6415 (53.3)</td>
</tr>
<tr>
<td><strong>Fruit</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤250 g</td>
<td>4503 (77.3)</td>
<td>4706 (76.1)</td>
<td>9209 (76.7)</td>
</tr>
<tr>
<td>&gt;250 g</td>
<td>1324 (22.7)</td>
<td>1479 (23.9)</td>
<td>2803 (23.3)</td>
</tr>
<tr>
<td><strong>Vegetables</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤1500 g</td>
<td>141 (2.4)</td>
<td>173 (2.8)</td>
<td>314 (2.6)</td>
</tr>
<tr>
<td>&gt;1500 g</td>
<td>5668 (97.6)</td>
<td>6012 (97.2)</td>
<td>11680 (97.4)</td>
</tr>
</tbody>
</table>

**** \( p < 0.0001 \): \( \chi^2 \) test was used to compare the food consumption between men and women.

a Fish or shellfish.
b Canned or pickled foods.
c Pork.

BMD at the measured sites among the different groups studied (Table 2). The small number of subjects (1\%) who consumed more than 250 g of milk a week severely limited the ability of the study to detect the effect of higher intake of calcium rich milk on BMD.

3.2.2. Seafood consumption

Increased seafood consumption, however, was significantly associated with greater BMD in women, and it was most noticeable in the premenopausal group. One thousand and eight hundred and forty-two women

![Fig. 1. Effect of seafood intake on total body and total hip BMD. Group I: ≤45-year-old men; Group II: >45-year-old men; Group III: premenopausal women; Group IV: postmenopausal women; \( * p < 0.05, ~** p < 0.01 \) by \( t \)-test.](image)
who had more than 250 g per week of seafood in their diet showed an improvement in their total body BMD. Fig. 1 shows the effect of seafood intake on total body and hip BMDs.

Further, we determined the odds ratio (OR) for seafood consumption on total body BMD across Groups I–IV (Table 3). The OR was adjusted for age, weight, BMI, smoking status, alcohol consumption, and occupation. BMD was stratified into quartiles, with only the bottom and top quartiles being used in the analysis. For premenopausal women, the number of participants with higher seafood consumption (≥250 g) in the bottom and the top BMD quartiles was 265 (25.5%) and 359 (34.4%), respectively; and the number of participants with lower seafood consumption (<250 g) in the bottom and the top quartiles of the total body BMD was 773 (74.5%) and 684 (65.6%), respectively. When the subjects with higher seafood consumption were compared to those with lower seafood consumption, the OR of having the BMD at lowest quartile was 0.66 ($p < 0.001$).

3.2.3. Fruits and vegetable consumption

In the study groups, 4503 men and 4706 women consumed ≤250 g of fruit per week, 1324 men and 1479 women consumed >250 g of fruit per week. Higher fruit intake was found to be significantly associated with higher total body BMD in both sexes (Fig. 2). Unexpectedly men with lower consumption of fruits in Group I had significantly higher hip BMD than subjects with higher fruit consumption.

As with seafood consumption, we determined the adjusted odds ratio (OR) for fruit consumption on total body BMD across Groups I–IV (Table 3). BMD was stratified into quartiles, with only the bottom and top quartiles being used in the analysis. When the subjects with higher fruit consumption were compared to those with lower fruit consumption, the ORs of having the BMD at lowest quartile were 0.87 (0.62–1.23), 0.73 (0.53–0.93), and 0.74 (0.57–0.98) for Groups II–IV, respectively.

In 5668 men and 6012 women consuming >1500 g of vegetables per week, higher vegetable intake did
Fig. 2. Effect of fruit intake on total body and total hip BMD. Group I: ≤45-year-old men; Group II: >45-year-old men; Group III: premenopausal women; Group IV: postmenopausal women; *p < 0.05 by t-test.

not seem to have a detectable statistical impact on BMD.

3.2.4. Preserved food consumption
Two thousand and two hundred and ninety-six women and 2414 men had ≤250 g of preserved food in their weekly diet. It is surprising to see that higher consumption of the salt rich preserved food did not seem to have any effect on BMD.

3.2.5. Meat consumption
Increased pork intake did not affect BMD in women or men. Table 2 shows the distribution of food consumption in both men and women.

3.2.6. Vitamin D supplementation
We failed to show association between Vitamin D supplementation and greater BMD, but this may be due to the relatively small number (<1%) of participants who took Vitamin D supplementation.

3.3. Multiple variable analysis
We further tested the multiple impact on BMD of seafood and fruit consumption. There was a significantly positive correlation between seafood and fruit consumption between the Groups. The Spearman’s correlation coefficients between seafood consumption and fruit intake for Groups I–IV were 0.2438, 0.2457,

<table>
<thead>
<tr>
<th>Food consumption</th>
<th>N</th>
<th>% of extreme low BMD</th>
<th>Crude OR 95% CI</th>
<th>Adjusted OR 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seafood</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Group III (premenopausal)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Low</td>
<td>1212</td>
<td>53.8</td>
<td>Referent</td>
<td>Referent</td>
</tr>
<tr>
<td>Low High</td>
<td>240</td>
<td>48.8</td>
<td>0.82</td>
<td>0.62–1.08</td>
</tr>
<tr>
<td>High Low</td>
<td>325</td>
<td>40.9</td>
<td>0.58****</td>
<td>0.46–0.76</td>
</tr>
<tr>
<td>High High</td>
<td>297</td>
<td>44.1</td>
<td>0.69*</td>
<td>0.53–0.88</td>
</tr>
<tr>
<td><strong>Group IV (postmenopausal)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Low</td>
<td>590</td>
<td>54.1</td>
<td>Referent</td>
<td>Referent</td>
</tr>
<tr>
<td>Low High</td>
<td>91</td>
<td>37.4</td>
<td>0.51*</td>
<td>0.32–0.80</td>
</tr>
<tr>
<td>High Low</td>
<td>200</td>
<td>49.5</td>
<td>0.83</td>
<td>0.60–1.15</td>
</tr>
<tr>
<td>High High</td>
<td>113</td>
<td>41.6</td>
<td>0.60*</td>
<td>0.40–0.91</td>
</tr>
</tbody>
</table>

*p < 0.05; ****p < 0.0001.

a Models adjusted for age, weight, BMI, smoking status, alcohol consumption and occupation.
Table 4 shows the combinatorial effect of seafood and fruit consumption on total body BMD. The multiple regression models adjusted for age, weight, BMI, cigarette smoking, alcohol intake, and occupation were used. Among women in the top and bottom quartiles of BMD within strata of menopausal status, we assigned women to four groups based on low or high seafood and fruit consumption. In Group III, the odds of being in the bottom quartile of BMD (extreme low BMD) relative to subjects with low seafood and low fruit consumption was lower in those with high seafood and low fruit consumption (Odds ratio (OR): 0.59; 95% confidence interval (CI): 0.45, 0.78; \( p < 0.0001 \)) and those with high seafood and high fruit consumption after adjustment for important covariates (OR: 0.68; 95% CI: 0.51, 0.91; \( p < 0.001 \)). In Group IV, the odds of extreme low BMD relative to subjects with low seafood and low fruit consumption was lower in those with low seafood and high fruit consumption (OR: 0.49; 95% CI: 0.27, 0.87; \( p < 0.05 \)) and those with high seafood and high fruit consumption after adjustment for important covariates (OR: 0.88; 95% CI: 0.52, 0.98; \( p < 0.001 \)).

These results support the earlier observation that the consumption of fruit and seafood has a positive effect on BMD.

4. Discussion

Dietary choices and nutrition have proven in the last decade to be major modulators of BMD in both men and women [10]. The identification of some dietary components that may directly affect BMD has become of great importance, especially with an aging world population.

A unique feature to our study is that it evaluates the effect of different food types on bone status in a large population sample, thus permitting stratification by gender and menopausal status. In contrast, other studies focused on the effect of specific nutrients like calcium, Vitamin D, magnesium, phosphorous, protein, Vitamin A, Vitamin K and phytoestrogens.

It is long established and well understood that milk and milk products are good sources of nutrients needed in growth and maintenance [16]. Dairy products are the principal source of calcium. However, in our study, milk intake and Vitamin D supplementation are not a significant part of the regional diet of the population studied as compared to the dairy and protein rich Western-style diet, and thus were not significantly shown to positively impact BMD. We found that only a very small percentage of the study population (1.3% men and 1% women) consumed >250 g milk/week or had Vitamin D supplements (0.6% men and 0.5% women) as part of their diet.

In the population studied, seafood was a large dietary component and was significantly associated with increased BMD in women. These results can be attributed to the high content of essential fatty acid (EFA) present in fish and other seafood. Recent evidence has shown that similar to the lack of calcium and Vitamin D3, a deficiency in certain fatty acids in the diet may also contribute to bone loss [21–23]. EFAs are believed to enhance Vitamin D effects thus facilitating calcium absorption from the gut, which in turn leads to a reduction of calcium excretion in the urine. This process may result in increased calcium deposition in bone, enhanced synthesis of bone collagen and, improved bone health [24].

Coetzer et al. showed that the relative content of fish oil derived polyunsaturated fatty acids in the intestinal membranes may change fluidity and increase calcium absorption by enhancing the action of Vitamin D3 [25]. Fernandes et al. found a significant bone loss reduction in ovariectomized mice when placed on a fish oil (FO) rich diet. No such reduction was observed when similar mice were fed corn oil or casein rich diets [26].

The detailed mechanisms by which FO exerts its protective function are not yet fully understood. It is, however, well established that FO decreases urinary calcium loss. It has been hypothesized that FO rich in n-3 fatty acids plays an important role in regulating T-cell function and the synthesis of pro-inflammatory cytokines. Both of these effects are closely implicated in osteoclastogenesis, as well as in the pathogenesis of osteoporosis [26]. Sun et al. showed that dietary FO can prevent bone loss in ovariectomized mice by down regulating pro-inflammatory cytokine (TNF-α and IL-6) synthesis. These cytokines increase the production of prostaglandin E (PGE-2) by increasing the expression of cyclo-oxygenase II (COX-II) in osteoblastic and stromal cells. Elevated levels of PGE-2, as well as TNF-α, induce the expression of the receptor acti-
vator of NF-kB ligand (RANKL) and in turn stimulate the differentiation of osteoclast progenitors into mature osteoclasts and may result in osteoporosis [27]. Another mechanism by which n-3 fatty acid improves bone health is that it enhances the formation of nitric oxide (NO), which plays an important role in bone metabolism [27].

A deeper understanding of the mechanism of action of EFA on calcium metabolism may offer novel approaches to the management of osteoporosis as well as to the ectopic calcification that is often associated with osteoporosis and seems to be responsible for many deaths. This current study supports indirectly the protective effects of EFA on bone. However, it also does not rule out the positive effect on BMD of factors other than EFA that are present in seafood, like Vitamin D, selenium, iron and calcium. Furthermore, EFA is mainly present in oily fish and the current study with its limited questionnaire does not differentiate between the types of fish consumed.

Diets high in fruits and vegetables produce a more alkaline urine by contributing a variety of compounds that accept hydrogen ions during metabolism [28,29]. In our study there are significant associations between intake of fruits and BMD in both men and women. These findings are compatible with several studies that concluded that potassium, magnesium, and Vitamin C rich fruits were associated with greater BMD [18]. The protective effect of fruit intake was significantly noticeable in the postmenopausal women group in our study. Estrogen deficiency has been hypothesized to cause loss of tissue magnesium which in turn disrupts calcium metabolism [30]. It is worth noting here that when taken alone, men ≤45 years (Group I) with lower consumption of fruits had significantly higher BMD than subjects with higher fruit consumption. One explanation is that the total body fat percentage (total body fat/body weight) in these men was significantly lower than in men with higher fruit intake. The total body fat percentage was negatively associated with total body BMD in our study population [31]. In addition, the majority (90.22%) of the men in Group I who consumed less fruit were in the occupational category of farmer/worker, which correlated positively with higher total body BMD in our study population.

Improved calcium balance, increased serum osteocalcin concentrations, and decreased urinary hydroxyproline excretion have been documented when post-menopausal women were given potassium bicarbonate to neutralize endogenous acid loads from normal diets [32]. Potassium plays a regulating role in calcium balance and through this regulator effect may influence bone resorption. It is important that this potassium be in the form of an organic salt that metabolizes to carbon dioxide with regard to neutralizing endogenous acidity that is generated from acid producing foods. This buffering effect of potassium may play a key role in protecting the skeleton [13,33].

Magnesium also plays an essential role in calcium metabolism. It was shown that lower bone resorption was associated with a higher intake of magnesium. It is now believed that magnesium deficiency may be a cause of osteoporosis. Low magnesium decreases the activity of a skeletal ATPase that is responsible for transporting potassium ions into the skeletal interstitium in exchange for hydrogen ion extrusion. This decreased activity could result in pH imbalance, which leads to enhanced bone resorption. These results support previous findings of the positive influence of a high long-term consumption of alkaline-forming foods on bone health in postmenopausal women. Fruit are important sources of potassium and magnesium and this finding supports their potential role in the prevention of osteoporosis.

However, unlike several studies where vegetables had also a positive effect on BMD [18], our analysis failed to document any such positive effect on BMD. These results, while initially surprising may be explained by the fact that unlike fruits, vegetables tend to be consumed cooked in Chinese diets. During the cooking process, many nutrients and essential vitamins that can positively influence BMD may be lost or greatly reduced.

Studying this rural Chinese population allowed for the very first time the effect of pickled food on BMD to be investigated. Greater consumption of preserved food was not associated with lower BMD. These results were not expected since pickled foods are rich in sodium content (salt). Studies have shown that calciuria can be induced by salt. As a result of this physiological process, a diet rich in Na (salt) can be considered as a risk factor for osteoporosis [10,17,34]. Although unexpected, these results can be explained by the fact that pickled food do not constitute on their own a major food source and are always consumed along with other major nutrients that may mask their effect on BMD. Our
results warrant further investigations on the relationship between salt intake and bone health that require an in depth focus on reliable measures of salt intake, and improved subject characterization.

Because the use of hormone replacement therapy as a managing regimen for osteoporosis has been associated with several undesirable effects, more studies on the effects of foods and nutrients on bone metabolism are required. Because dietary habits vary widely, studies conducted on specific populations can be very useful. As an example, studies on dietary effects on bone metabolism may be particularly useful for the population studied, in the prevention of osteoporosis and provide the added benefit of decreasing the reliance on drug therapy to prevent osteoporosis. Our results emphasize the role of dietary intake in general and show its impact on BMD in a rural Chinese population. This study with its large population size proves highly beneficial in identifying measures, such as fruit and seafood intake, in preventing bone loss and osteoporosis.

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