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Adherence to a Vegetable-Fruit-Soy Dietary Pattern or the Alternative Healthy Eating Index Is Associated with Lower Hip Fracture Risk among Singapore Chinese[1,2]

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Abstract

Data on overall dietary pattern and osteoporotic fracture risk from population-based cohorts are limited, especially from Asian populations. This study examined the relation between overall diet and hip fracture risk by using principal components analysis (PCA) to identify dietary pattern specific to the study population and by using the Alternative Healthy Eating Index (AHEI) 2010 to assess dietary quality. The Singapore Chinese Health Study is a prospective population-based cohort that enrolled 63,257 Chinese men and women (including both pre- and postmenopausal women) aged 45–74 y between 1993 and 1998 in Singapore. Habitual diet was assessed by using a validated food-frequency questionnaire. Two dietary patterns, the vegetable-fruit-soy (VFS) pattern and the meat-dim-sum (MDS) pattern, were derived by PCA. Overall dietary quality was assessed according to the AHEI 2010, which was defined a priori for chronic disease prevention. A Cox regression model was applied with adjustment for potential confounders. In both genders, higher scores for the VFS pattern and the AHEI 2010 were associated with lower risk of hip fracture in a dose-dependent manner (all *P*-trend $\leq$ 0.008). Compared with the lowest quintile, participants in the highest quintile had a 34% reduction in risk (HR: 0.66; 95% CI: 0.55, 0.78) for the VFS pattern and a 32% reduction in risk (HR: 0.68; 95% CI: 0.58, 0.79) for the AHEI 2010. The MDS pattern score was not associated with hip fracture risk. An Asian diet rich in plant-based foods, namely vegetables, fruit, and legumes such as soy, may reduce the risk of hip fracture. J. Nutr. 144: 511–518, 2014.

Introduction

Hip fracture constitutes the most serious complication of osteoporosis (1) and accounts for the majority of fracture-related mortality, morbidity, and health care costs among individuals ≥50 y (2). Additionally, the incidence of hip fracture is escalating worldwide, and 50% of the total hip fracture incidence is projected to occur in Asia by 2050 (3). Diet is one of the important modifiable risk factors that can influence bone mass, bone strength, and subsequent fracture risk (4). Various nutrients and dietary components have been suggested to have favorable impacts on maintaining bone health and reducing risk of osteoporotic fractures (4,5). These foods and nutrients may strongly correlate with one another or interact along similar pathways important for fracture protection (6). An evaluation of the overall dietary pattern may therefore provide a more practical strategy for the prevention of osteoporotic fractures.

A few observational studies have been conducted on the association between dietary patterns and bone health, and findings have been inconsistent. For example, although an unhealthy dietary pattern characterized by high consumption of refined sugar/cereals, red meat or processed meat, processed foods, and fried foods was associated with lower bone mineral density (BMD)[8] (7–10), there was no association with fracture risk (11). Similarly, a healthy dietary pattern characterized by higher dietary intakes of fruit and vegetables was associated with positive bone health outcomes in some (7,9,12) but not all (13,14) studies. In most of these studies, dietary patterns were identified through a posteriori analytic methods [i.e., factor analysis and principal components analysis (PCA)], which may

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[8] Abbreviations used: AHEI, Alternative Healthy Eating Index; BMD, bone mineral density; MDS, meat-dim-sum; PCA, principal components analysis; VFS, vegetable-fruit-soy.

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be subjective in nature and not be easily generalizable across study populations (15).

Previously, we used PCA to identify 2 distinct Chinese dietary patterns in the Singapore Chinese Health Study cohort, namely the vegetable-fruit-soy (VFS) pattern, characterized by vegetables, fruit, and soy foods, and the meat-dim-sum (MDS) pattern, which is rich in meat and refined starchy foods (16). As a complementary a priori method, we also generated scores to evaluate the overall dietary quality according to the Alternative Healthy Eating Index (AHEI) 2010 in the whole cohort. The AHEI 2010 measures dietary intake of 7 food groups (vegetables, fruit, whole grains, juices, nuts and legumes, red/processed meat, and alcohol) and 4 nutrients (*trans* fat, long-chain n–3 FAs, PUFAs, and sodium) on the basis of the scoring criteria predictive of chronic disease risk in cohorts in the United States (17). Our rationale in choosing the AHEI 2010 in this Chinese cohort was based on the VFS pattern and the AHEI 2010 having similar associations with disease prevention and common beneficial food groups. We hypothesized that the VFS pattern and AHEI 2010 may be associated with lower hip fracture risk among Chinese men and women in our study population.

Participants and Methods

Study population. We used data from the Singapore Chinese Health Study, a population-based prospective cohort study established to investigate the influence of diet and lifestyle factors on the risk of chronic diseases (18). Briefly, 63,257 Chinese men and women, aged 45–74 y, were enrolled between April 1993 and December 1998. The study participants were restricted to 2 major dialect groups in Singapore: the Hokkiens and the Cantonese, who originated from Fujian and Guangdong provinces in Southern China, respectively. During the enrollment period, all of our study participants resided in government housing estates, where 86% of the Singapore population resided at the time of recruitment. This study was approved by the Institutional Review Board at the National University of Singapore, and all participants gave written informed consent.

Baseline assessment of diet and other covariates. Baseline assessment at recruitment was conducted through a face-to-face interview by a trained interviewer using a structured questionnaire, which included questions on demographic characteristics, medical history, cigarette smoking, alcohol consumption, physical activity, and detailed menstrual and reproductive history (women only). Habitual diet of the study participants over the past year was recorded by using a 165-item semiquantitative FFQ, which incorporated common and distinct food items in Singapore. The dietary intake of each nutrient was derived on the basis of the Singapore Food Composition Database developed specially for this cohort (18). The FFQ had been validated subsequently by using two 24-h recalls that included 1 weekday and 1 weekend among a subset of 858 participants from this cohort, as well as a readministration of the FFQ to 810 consenting participants in this subset. The validation study that used the two 24-h dietary recalls and the readministration of the FFQ showed that most mean pairs for energy and selected nutrients assessed using these 2 different methods were very comparable and within 10% of each other's values (18). The correlation coefficients for energy intake and selected nutrients from the FFQ versus the 24-h recalls ranged from 0.24 to 0.79, which is comparable with a previous validation study in diverse populations (19).

The intake of soy isoflavones and long-chain n–3 FAs, such as EPA and DHA, were computed by using data obtained via the FFQ. The main dietary sources of EPA and DHA were fish and seafood, and the total intake was computed from a list of 14 seafood items commonly consumed in this population. We have previously published associations between intake of long-chain n–3 FAs and the risk of breast cancer (20) and cardiovascular death in this cohort (21). Total soy protein intake was the summation of the protein contents of soy foods listed in the FFQ. Additionally, we previously measured concentrations of genistein, daidzein, and glycitein in market samples of common soy foods in Singapore. Soy isoflavone intake for a given participant was computed on the basis of the summation of the genistein, daidzein, and glycitein content of all 7 soy foods in the FFQ (22). We also previously published a statistically significant association between isoflavonoid concentrations in spot urine samples and the frequency of dietary soy intake by using the FFQ in this cohort (23).

Dietary patterns were derived on the basis of the baseline dietary intake of each participant by using PCA conducted among the whole cohort (n = 63,257). Details on the identification of the 2 dietary patterns were described previously (16). Briefly, the 165 food items in the FFQ were first standardized to the same frequency of intake per month before applying factor extraction, followed by orthogonal rotation. The 2 dietary patterns used in this study were determined on the basis of eigenvalues (>1.0), scree plot, factor interpretability, and the percentage of variance explained by each dietary pattern (principal component). The dietary pattern scores were linear variables and computed by the unweighted sum of standardized frequencies of intake for each food associated with the pattern, with zero as the mean. PCAs were conducted by using the Factor Procedure in SAS version 9 (SAS Institute) (24). The 2 pattern scores were then divided into quintiles on the basis of the distribution of the overall cohort.

In the present study, we adopted the AHEI 2010 as an a priori method to assess the overall dietary quality. The scoring criteria for AHEI 2010 were described in detail elsewhere (17). Briefly, dietary quality was assessed by the absolute intake per day of vegetables, fruit, whole grains, juices, nuts and legumes, red/processed meat, long-chain n–3 FAs, sodium and alcohol, and percentage of energy for *trans* fat and PUFAs. The intake of each dietary component was scored from 0 (worst diet) to 10 (best diet) on the basis of the predetermined scoring criteria. For example, higher dietary intakes of vegetables and fruit and lower sodium consumption were associated with lower risk of cardiovascular disease, and thus assigned higher component scores. The lack of information on *trans* fat intake in our study population precluded us from counting this nutrient toward the computation of the AHEI 2010 score. Hence, the AHEI 2010 score in our study was the sum of the scores from the 10 food and nutrient components and ranged from 0 (minimum) to 100 (maximum). The scores were then divided into quintiles on the basis of the distribution in the whole cohort. The distribution of the AHEI 2010 score was similar by gender.

Case ascertainment. Hip fracture cases were identified through 31 December 2010 via the record linkage with the nationwide hospital discharge database, which captures inpatient discharge information from all public and private hospitals in Singapore. All hip fracture cases were verified by surgical or medical records. The survival status of all cohort participants was ascertained via record linkage with the population-based Singapore Registry of Births and Deaths. Only 47 individuals from this cohort were known to be lost to follow-up due to migration out of Singapore or for other reasons up to 31 December 2010.

Statistical analysis. For each study participant, person-years were counted from the date of baseline interview to the date of diagnosis of hip fracture, death, loss to follow-up, or 31 December 2010, whichever occurred first. After excluding 4 cases of traumatic fractures from road traffic accidents and 1 case due to cancer metastasis in the femur, 1733 hip fracture cases were identified through the record linkage. We further excluded 103 prevalent cases of hip fracture that had occurred before recruitment in our analysis.

Baseline characteristics and dietary intakes were analyzed across quintiles of each dietary pattern score for the overall cohort and for each gender separately. Cox proportional hazards regression models were used to assess the association of dietary pattern scores with hip fracture risk by using the lowest quintile score as the reference group. The strength of the association between each dietary pattern and risk of hip fracture was estimated by HRs and their corresponding 95% CIs. To examine linear trend, the median values of the quintiles of the dietary pattern score were entered as a continuous variable in the Cox proportional hazards model.

All models in the analyses included the following covariates: age (continuous), year at recruitment (1993–1995 and 1996–1998), dialect group (Hokkien, Cantonese), level of education (no formal education, primary school, secondary school or higher), BMI (<20, 20–23.9, 24–27.9, ≥28 kg/m^2), smoking status (never-smokers, ex-smokers, current smokers), moderate physical activity (none, 0.5–4 h/wk, >4 h/wk), total energy intake (kcal/d), baseline self-reported physician-diagnosed history of diabetes mellitus (yes or no) and stroke (yes or no), menopause status (women only; yes or no), and use of hormone replacement therapy at recruitment (women only; yes or no). All statistical analysis was conducted by using SAS version 9.2 (SAS Institute). All reported *P* values were 2-sided; $P < 0.05$ was considered significant.

Results

After a mean (±SD) time interval between the cohort enrollment and hip fracture diagnosis of 9.9 ± 4.5 y, we identified 1630 hip fracture incident cases and 61,524 participants without fractures. The mean age at fracture was 74.4 ± 7.5 y. Women accounted for 72.4% of all hip fractures, and the age-standardized incidence rate of hip fractures in women was 234/ 100,000 person-years, which was twice that in men (123/ 100,000 person-years). Among the women in this cohort, 72.4% were postmenopausal at recruitment, and only 4.1% of postmenopausal women used hormone replacement therapy. The proportion using vitamin/mineral supplements was also low in this study population. Less than 5% of men and <8% of women used supplements at least weekly in this cohort. Baseline characteristics were summarized for men and women separately for the VFS and the MDS pattern scores by quintile (**Table 1**). For each dietary pattern in both genders, those with higher scores were younger and more educated. Both men and women with higher VFS pattern scores consumed more vitamin B-6, vitamin D, soy isoflavones, β-carotene, calcium, and vegetables and fruit from the diet compared with those with lower scores. Also, those who had higher VFS scores had higher AHEI 2010 scores. Conversely, those with higher MDS pattern scores consumed less β-carotene, vegetables and fruits and had lower AHEI 2010 scores. For men, those with higher scores for either dietary pattern had higher BMI and were physically more active than those with lower scores, and those with lower VFS but higher MDS scores were more likely to be ever-smokers or daily drinkers. The proportion using vitamin/ mineral supplements at least weekly was higher in men with higher VFS pattern scores. For women, those had higher VFS but lower MDS scores were physically more active, and those with higher scores for either dietary pattern were more likely to use hormone replacement therapy or to use vitamin/mineral supplements at least weekly. The distribution of these baseline characteristics with AHEI 2010 score was similar to the distribution with the VFS pattern score (data not shown). Additionally, no difference was found in the distribution of the pattern scores (VFS/MDS or AHEI 2010) between genders.

The association for the VFS and the MDS dietary patterns in relation to hip fracture risk is presented in **Table 2**. The VFS pattern score was inversely associated with risk of hip fracture in a strong dose-dependent manner for the overall cohort, as well as for men and women separately (all *P*-trend ≤ 0.008). Compared with the lowest quintile of the VFS pattern score, participants in higher quintiles had a 21–34% reduction in hip fracture risk across quintiles 2–5 for the overall cohort (all *P*s < 0.05). In contrast, the MDS pattern score was not related to hip fracture risk in either gender. The dietary pattern–hip fracture risk associations were consistent for men and women (the *P*-interaction between gender and VFS pattern score was 0.53 and that for interaction between gender and MDS pattern score was 0.56).

The mean scores for each dietary component constituting the AHEI 2010 score for men and women in this cohort are shown in **Table 3**. A higher intake of vegetables, soy foods, and fruit is a common characteristic of the VFS pattern and of a high AHEI 2010 score. The partial energy-adjusted Pearson correlation coefficient between the AHEI 2010 and VFS pattern scores was 0.49 for ($P < 0.0001$). Conversely, the coefficients were −0.20 for the correlation between the AHEI 2010 and MDS pattern ($P < 0.0001$) and −0.09 for the correlation between the VFS and MDS pattern ($P < 0.0001$).

Table 4 presents the association between the AHEI 2010 scores and risk of hip fracture. We observed a dose-dependent inverse association between higher AHEI 2010 scores and hip fracture risk (all *P*-trend ≤ 0.005). Compared with the lowest quintile, increasing quintile values of AHEI 2010 scores were associated with reduced hip fracture risk by 23% to 32% (all *P*s ≤ 0.0007). Results were similar for men and women analyzed separately (the *P*-interaction between genders and AHEI 2010 score was 0.36). The risk estimates using gender-specific pattern scores (VFS/MDS or AHEI 2010) and the pattern scores generated from the whole cohort were essentially the same (data not shown)

We also conducted sensitivity analysis by excluding 1657 participants with extreme caloric intakes (≤600 and ≥3000 kcal), and all of the results were materially unchanged. When we included only age as a covariate in our models to estimate the HR for the VFS and MDS patterns, and for the AHEI 2010 scores, the magnitude of difference in the risk estimates between the age-adjusted and fully adjusted models shown in Tables 2 and 3 was <10%. Further adjustment for intakes of calcium and vitamin D and the use of vitamin/mineral supplements at least weekly did not change the results materially.

We considered age distribution in quartile (45–50, 50–56, 56–63, and >63 y), BMI (<20, 20–23.9, 24–27.9, ≥28 kg/m^2), physical activity (none, 0.5–4 h/wk, >4 h/wk), and dietary intake of vitamin D (in quartiles) and calcium (in quartiles) as potential effect modifiers for the VFS/MDS pattern or the AHEI 2010 score in relation to hip fracture risk. We did not observe any difference in the diet-hip fracture association in these stratified analyses (all *P*-interaction >0.05). We also conducted stratified analysis on the basis of the baseline history of diabetes or stroke, and the significant inverse associations of hip fracture risk with the VFS pattern and AHEI 2010 scores remained essentially the same in both groups of participants with and without these chronic conditions (data not shown).

We previously identified the intake of 3 nutrients, namely soy isoflavones, vitamin B-6, and β-carotene, to have statistically significant inverse associations with risk of hip fracture either in women or men in this cohort (25–27). To assess whether these nutrients may account for the associations with each of the dietary patterns in relation to risk of hip fracture, we included dietary intake of soy isoflavones, vitamin B-6, and β-carotene as covariates in the multivariate regression models. There was a weak to moderate correlation between each of these nutrients and the VFS pattern and AHEI 2010 scores; the lowest correlation coefficient was between soy isoflavones and the AHEI 2010 score ($r = 0.32$); the highest correlation coefficient was between β-carotene and the VFS pattern score ($r = 0.62$). In contrast, the Pearson correlation coefficients between MDS pattern scores and intake of soy isoflavones, vitamin B-6, and β-carotene were 0.004, 0.03, and −0.08, respectively. Although the HRs were slightly attenuated, the dietary pattern–hip fracture association remained significant for both the VFS pattern and the AHEI 2010 score. Compared with the lowest quintile, participants in the highest quintile had a 26% lower risk (HR: 0.74; 95% CI: 0.59, 0.92; *P*-trend = 0.05) for the VFS pattern and a 26% lower risk (HR: 0.74; 95% CI: 0.62, 0.88; *P*-trend = 0.002) for the AHEI 2010 score.

TABLE 1 Distribution of baseline characteristics by quintile of VFS and MDS pattern score for men and women separately[1]

	Men (n = 27,913)						Women (n = 35,241)					
	VFS pattern			MDS pattern			VFS pattern			MDS pattern		
Baseline characteristics	Q1	Q3	Q5	Q1	Q3	Q5	Q1	Q3	Q5	Q1	Q3	Q5
Age at recruitment, *y*	57.7 ± 8.2	56.6 ± 7.9	55.9 ± 7.8	60.0 ± 7.9	57.1 ± 7.9	54.4 ± 7.5	57.9 ± 8.4	56.1 ± 7.9	55.3 ± 7.8	58.8 ± 8.1	55.8 ± 7.9	53.7 ± 7.4
BMI, *kg/m²*	22.7 ± 3.2	23.0 ± 3.2	23.1 ± 3.2	22.8 ± 3.2	22.9 ± 3.2	23.1 ± 3.3	23.3 ± 3.3	23.2 ± 3.3	23.1 ± 3.4	23.1 ± 3.2	23.3 ± 3.4	23.2 ± 3.4
Secondary school or higher in education, %	6.3	7.7	8.9	4.3	7.1	11.9	2.6	4.3	5.4	3.7	4.3	4.0
Ever-smoker, %	14.8	11.0	10.2	7.2	11.4	16.5	2.4	1.6	1.4	2.2	1.7	1.3
Daily alcohol consumption, %	8.2	5.4	6.1	3.1	5.6	9.2	1.4	0.9	1.5	0.8	1.2	1.8
Moderate physical activity of ≥0.5 h/wk, %	4.1	5.1	5.6	4.0	4.8	6.4	2.4	4.3	5.3	5.4	4.0	2.6
History of diabetes mellitus, %	1.9	1.7	1.8	1.4	1.8	2.1	2.0	1.8	1.7	2.7	1.7	1.1
History of stroke, %	0.45	0.4	0.3	0.5	0.4	0.3	0.3	0.3	0.2	0.5	0.2	0.1
Postmenopausal at baseline (women only), %	—	—	—	—	—	—	77.4	71.9	68.8	82.0	70.1	61.5
Use of hormone replacement therapy (postmenopausal women only), %	—	—	—	—	—	—	2.8	4.4	5.5	3.0	4.5	5.4
Intake of												
Soy isoflavones, *mg/1000 kcal*	7.4 ± 7.5	10.5 ± 7.5	15.3 ± 9.6	10.7 ± 10.0	10.6 ± 8.2	11.2 ± 7.5	8.7 ± 8.6	12.2 ± 8.6	17.5 ± 11.1	11.6 ± 10.4	12.8 ± 9.5	14.1 ± 9.0
Vitamin B-6, *mg/1000 kcal*	0.64 ± 0.14	0.71 ± 0.14	0.77 ± 0.14	0.68 ± 0.18	0.70 ± 0.14	0.71 ± 0.12	0.64 ± 0.14	0.71 ± 0.14	0.78 ± 0.15	0.70 ± 0.16	0.71 ± 0.14	0.72 ± 0.12
β-Carotene, *mg/1000 kcal*	0.71 ± 0.44	1.21 ± 0.59	1.84 ± 0.90	1.39 ± 0.90	1.23 ± 0.72	1.13 ± 0.63	0.98 ± 0.56	1.52 ± 0.75	2.27 ± 1.09	1.68 ± 1.05	1.58 ± 0.89	1.45 ± 0.78
Calcium, *mg/1000 kcal*	204 ± 93	240 ± 97	281 ± 88	261 ± 125	240 ± 101	234 ± 76	250 ± 154	290 ± 135	339 ± 122	304 ± 160	289 ± 134	282 ± 105
Vitamin D, *IU/1000 kcal*	57.1 ± 37.2	61.6 ± 35.1	67.1 ± 34.4	57.1 ± 44.6	62.2 ± 36.7	64.2 ± 28.5	64.9 ± 46.8	70.0 ± 42.7	75.6 ± 40.0	66.0 ± 50.0	71.6 ± 40.3	73.3 ± 33.4
Vegetables, *g/1000 kcal*	39 ± 17	63 ± 22	96 ± 36	70 ± 37	64 ± 31	61 ± 26	51 ± 22	77 ± 27	113 ± 43	83 ± 43	79 ± 36	75 ± 30
Fruit, *g/1000 kcal*	77 ± 72	124 ± 85	163 ± 99	137 ± 109	122 ± 91	113 ± 76	89 ± 86	136 ± 97	183 ± 114	144 ± 117	136 ± 100	133 ± 89
Soy products, *g/1000 kcal*	44 ± 39	63 ± 40	93 ± 55	65 ± 57	63 ± 45	68 ± 42	51 ± 44	72 ± 45	105 ± 62	69 ± 58	76 ± 52	84 ± 48
Red meat, *g/1000 kcal*	20 ± 12	20 ± 11	20 ± 12	12 ± 10	19 ± 10	27 ± 11	18 ± 11	18 ± 11	17 ± 11	12 ± 10	19 ± 10	26 ± 11.0
Using vitamin/mineral supplements at least weekly, %	3.3	5.0	6.7	5.0	4.3	5.1	4.9	7.7	10.0	6.6	7.5	8.4
AHEI 2010	48.6 ± 7.6	56.2 ± 7.3	61.0 ± 8.1	57.0 ± 9.3	55.7 ± 8.6	53.5 ± 8.5	49.9 ± 7.1	57.0 ± 7.2	62.1 ± 7.9	57.4 ± 8.6	56.9 ± 8.3	54.9 ± 8.2

[1] Values are means ± SDs or percentages. AHEI, Alternative Healthy Eating Index; MDS, meat-dim-sum; Q, quintile; VFS, vegetable-fruit-soy.

TABLE 2 HRs for the VFS and the MDS pattern in relation to hip fracture incidence by gender: the Singapore Chinese Health Study, 1993–2010[1]

Pattern score quintile [median (IQR)]	Overall (n = 63,154)			Men (n = 27,913)			Women (n = 35,241)		
	Cases	HR	95% CI	Cases	HR	95% CI	Cases	HR	95% CI
	n			*n*			*n*		
VFS pattern									
1 [−13.3 (−15.9, −11.5)]	438	1.00		132	1.00		306	1.00	
2 [−7.5 (−8.8, −6.3)]	340	0.79	0.68, 0.91	90	0.78	0.60, 1.02	250	0.79	0.67, 0.93
3 [−2.6 (−3.8, −1.2)]	287	0.72	0.62, 0.84	70	0.63	0.47, 0.85	217	0.76	0.63, 0.91
4 [3.6 (1.8, 5.7)]	325	0.84	0.72, 0.98	97	0.92	0.70, 1.21	228	0.81	0.68, 0.98
5 [16.4 (11.6, 24.5)]	240	0.66	0.55, 0.78	61	0.57	0.41, 0.80	179	0.70	0.57, 0.86
P-trend		<0.0001			0.008			0.004	
MDS pattern									
1 [−10.7 (−11.8, −9.8)]	475	1.00		73	1.00		402	1.00	
2 [−7.2 (−8.1, −6.3)]	366	1.02	0.89, 1.17	101	1.33	0.98, 1.80	265	0.95	0.81, 1.11
3 [−3.2 (−4.3, −2.0)]	323	1.09	0.94, 1.26	105	1.29	0.95, 1.76	218	1.04	0.87, 1.23
4 [2.4 (0.7, 4.4)]	249	0.99	0.84, 1.17	81	1.00	0.72, 1.39	168	1.02	0.84, 1.24
5 [14.4 (9.9, 22.5)]	217	1.15	0.95, 1.40	90	1.12	0.78, 1.60	127	1.24	0.98, 1.56
P-trend		0.23			0.68			0.07	

[1] HRs were adjusted for age at recruitment (y), year of recruitment (1993–1995, 1995–1998), gender, dialect group (Hokkien, Cantonese), BMI (<20, 20–23.9, 24–27.9, ≥28 kg/m^2), level of education in categories (no formal education, primary school, secondary school or higher), total energy intake (kcal/d), smoking status (never-smoker, ex-smoker, current smoker), physical activity (none, 0.5–4 h/wk, >4 h/wk), menopausal status (women only; yes or no), use of hormone replacement therapy at recruitment (women only; yes or no), and baseline self-reported physician-diagnosed history of diabetes mellitus and stroke. MDS, meat-dim-sum; VFS, vegetable-fruit-soy.

Discussion

In the present study, we examined the relation between overall dietary pattern and hip fracture risk in a large prospective cohort in an Asian population. We observed an inverse association with a diet characterized by higher intakes of vegetables, fruit, and soy foods in both men and women. Additionally, a diet with greater adherence to healthy food choices for prevention of chronic diseases defined by the AHEI 2010 also reduced risk of hip fracture in both genders. Because factors such as age, gender, BMI, level of education, physical activity, or history of diabetes and stroke did not modify the effect of diet on hip fracture risk, we feel that our results are therefore generalizable to other populations that may be different in the distribution of these factors.

Most of the previous observational studies have used an a posteriori approach to explore the association of dietary patterns with relevant outcomes of bone health by using factor analysis and PCA (7–13,28). In some of these studies, a dietary pattern characterized by higher intakes of fruit, vegetables, nuts/cereal, and/or fish, but low in red meat and processed meat, was associated with higher hip and lumbar spine BMD (7,10) and lower bone resorption (9). In our study, a greater adherence to the VFS pattern or the AHEI 2010 was also characterized by a diet with a high consumption of vegetables, soy foods, and fruit and a low intake of red and processed meat. The inverse association between the healthy dietary pattern defined by the VFS pattern or the AHEI 2010 scores and hip fracture risk in the current study is consistent with those reported in cohort studies

TABLE 3 Dietary intake of AHEI 2010 food components and the AHEI 2010 mean scores for men and women in the Singapore Chinese Health Study[1]

Component	Criteria for minimum score (0)	Criteria for maximum score (10)	AHEI 2010 score	
			Men	Women
Vegetables, *servings/d*	0	≥5	6.8 ± 2.4	7.1 ± 2.2
Fruit, *servings/d*	0	≥4	3.1 ± 2.3	3.1 ± 2.2
Whole grains, *g/d*	0	90 for men, 75 for women	1.9 ± 2.7	2.3 ± 4.0
Sugar-sweetened beverages and fruit juice, *servings/d*	≥1	0	8.4 ± 2.8	8.8 ± 2.3
Nuts and legumes, *servings/d*	0	≥1	7.6 ± 2.8	7.6 ± 2.8
Red/processed meat, *servings/d*	≥1.5	0	6.1 ± 2.7	6.5 ± 2.6
Long-chain n–3 fats (EPA + DHA), *mg/d*	0	250	9.95 ± 0.70	9.91 ± 0.91
PUFAs, *% of energy*	≤2	≥10	4.8 ± 1.8	5.2 ± 1.9
Sodium, *mg/d*	Highest decile	Lowest decile	3.9 ± 2.8	5.0 ± 2.7
Alcohol, *drinks/d*			3.8 ± 2.4	2.8 ± 1.2
Women	≥2.5	0.5–1.5		
Men	≥3.5	0.5–1.0		
Total score			46.5 ± 8.4	48.3 ± 8.0

[1] Values are means ± SDs unless otherwise indicated; n = 63,257. Note: *trans* fat consumption was not included in the computation for the AHEI 2010 score because of missing information. AHEI, Alternative Healthy Eating Index.

TABLE 4 HRs for the AHEI 2010 in relation to hip fracture risk by gender: the Singapore Chinese Health Study, 1993–2010[1]

Pattern score quintile [median (IQR)]	Overall (n = 63,154)			Men (n = 27,913)			Women (n = 35,241)		
	Cases	HR	95% CI	Cases	HR	95% CI	Cases	HR	95% CI
	n			*n*			*n*		
1 [45.8 (42.4, 48.4)]	362	Ref		116	Ref		246	Ref	
2 [52.0 (50.5, 53.5)]	333	0.77	0.66, 0.90	97	0.85	0.65, 1.12	236	0.74	0.62, 0.88
3 [56.3 (55.0, 57.6)]	319	0.74	0.64, 0.86	94	0.83	0.63, 1.10	225	0.71	0.59, 0.85
4 [60.5 (59.1, 62.1)]	326	0.75	0.65, 0.87	74	0.68	0.50, 0.91	252	0.77	0.65, 0.92
5 [67.4 (65.1, 70.9)]	290	0.68	0.58, 0.79	69	0.69	0.51, 0.94	221	0.67	0.56, 0.81
P-trend		<0.0001			0.005			0.0002	

[1] HRs were adjusted for age at recruitment (y), year of recruitment (1993–1995, 1995–1998), gender, dialect group (Hokkien, Cantonese), BMI (<20, 20–23.9, 24–27.9, ≥28 kg/m^2), level of education in categories (no formal education, primary school, secondary school or higher), total energy intake (kcal/d), smoking status (never-smoker, ex-smoker, current smoker), physical activity (none, 0.5–4 h/wk, >4 h/wk), menopausal status (women only; yes or no), use of hormone replacement therapy at recruitment (women only; yes or no), and baseline self-reported physician-diagnosed history of diabetes mellitus and stroke. AHEI, Alternative Healthy Eating Index; Ref, reference.

in Western populations (11,12) and a case-control study in a Chinese population (28). In a retrospective Canadian cohort, using exploratory factor analysis, 2 dietary patterns, a nutrient-dense diet with higher intakes of fruit, vegetables, and whole grains and an energy-dense diet with a high consumption of soft drinks, potato chips, French fries, meats, and desserts, were identified. The nutrient-dense diet was inversely associated with lower fracture risk in women, whereas the energy-dense diet was not related to fracture risk (11). Another study in European men and women showed that a greater adherence to the Mediterranean diet was related to lower risk of hip fracture (12). In a case-control study in elderly Chinese men and women, 4 dietary patterns were identified by using PCA. Their findings suggested that a diet with a high intake of fruit and vegetables and a prudent diet rich in nuts, mushrooms, algae, and seafood were associated with lower risk of hip fracture, whereas a diet high in fat was related to higher hip fracture risk (28).

Although some studies found that a dietary pattern high in red or processed meat, starch, and fried foods was related to lower BMD (8,9) or bone mineral content (10), other studies failed to show any association between the similar dietary patterns and BMD (7,14) or fracture risk (11). The latter concurred with our finding that the MDS pattern in this cohort, which was characterized by a higher intake of meats, sodium, and refined carbohydrates, was not associated with risk of hip fracture in either gender.

A higher dietary intake of vegetables, soy foods, and fruit in this study, which characterizes the VFS pattern and a diet with a high AHEI 2010 score, supported evidence for the beneficial effects of these foods on bone health. Interestingly, both the VFS pattern and high AHEI 2010 score were previously reported as dietary patterns associated with a lower risk of other chronic diseases such as cancers (16,17,29), type 2 diabetes (17,30), and cardiovascular diseases (17,31). Consistent with our findings, a recent cross-sectional study in 933 Puerto Ricans aged 47 to 79 y suggested that greater adherence to the American Heart Association Diet and Lifestyle Recommendations, intended to reduce cardiovascular disease risk, was significantly associated with higher BMD at the femoral neck, trochanter, total hip, and lumbar spine (32). Diabetes mellitus (33–35) and stroke (36–39) have, in turn, been found to be risk factors of hip fracture. Mechanistic factors such as vascular calcification, hormone deficiency, inflammation, and oxidative stress were suggested to be common to the pathophysiologic pathways of both cardiovascular disease and osteoporotic fractures (38,40). Thus, the inverse relation between the VFS pattern or AHEI 2010 scores and hip fracture risk may reflect the beneficial effects of the healthful foods or nutrients common to these 2 patterns on bone health and the cardiovascular system. Also, in vitro evidence showed that insulin signaling in osteoblasts could affect bone resorption (41,42), and insulin resistance could reduce bone strength (43,44), which, in turn, would explain the increase in fracture risk for patients with diabetes (33–35).

Although it is plausible that a healthy dietary pattern may reduce hip fracture risk via its favorable impact on insulin sensitivity or cardiovascular health, significant inverse associations of hip fracture risk with the VFS pattern and AHEI 2010 scores remained essentially the same in both groups of participants with and without these chronic conditions in our study. This suggests that a healthy dietary pattern may have effects on the prevention of osteoporotic fractures independent of its benefits on diabetes and cardiovascular disease. Similarly, because additional statistical adjustment for dietary intake of soy isoflavones, vitamin B-6, and β-carotene, which were nutrients reported previously to reduce hip fracture risk in this cohort (25–27), did not materially change the results with the VFS pattern and AHEI 2010 scores, our findings suggest that these 2 dietary patterns could have other previously unidentified nutrients, apart from soy isoflavones, vitamin B-6, and β-carotene, that might have additional effects in reducing fracture risk. Moreover, different beneficial vitamins, minerals, and phytochemicals enriched in such a diet may interact collectively to influence bone turnover. Additionally, a diet high in vegetables, fruit, and other plant-based foods may also have effects on the acid-base status and mineral balance of bone. Foods such as fruit and vegetables with a low potential renal acid load may supply organic molecules such as potassium and bicarbonate to decrease calciuria (45–47), and this, in turn, may improve calcium balance in the bone. In contrast, evidence from animal studies showed that a high-fat and/or high-sucrose diet impaired the strength and density of cortical bones (48,49) or cancellous bones (50), suggesting possible detrimental effects from saturated fat and refined sugar on bone health. Together, these mechanisms may partially explain our finding that dietary patterns rich in vegetables and other plant-based foods had a favorable impact on lowering fracture risk.

A strength of this study includes its prospective study design in a population-based cohort, thereby minimizing the likelihood of differential recall bias because information on diet and other risk factors of hip fracture were collected at baseline before the occurrence of fractures. Another strength is the large sample size and number of fracture cases during a long period of follow-up. Also, migration among participants was negligible and follow-up of vital statistics was virtually complete. Singapore is a small city-state with good accessibility to medical care, and hip fracture cases would most likely seek immediate medical attention and be hospitalized. Hence, case ascertainment via linkage with the nationwide hospital database can also be considered complete. We also included all established and potential risk factors of hip fracture as covariates in our regression-based risk models to minimize the likelihood of spurious associations resulting from insufficient control of confounding. Specifically, those who have a healthy dietary pattern are more likely to follow a healthy lifestyle, such as maintaining a healthy body weight, exercising more, and smoking less. We have previously reported that lean individuals with a BMI <20 kg/m^2 (26) and current smokers (25) had significantly higher risk of hip fracture. In this study population, although there was no apparent relation between physical activity and risk of hip fracture in men, women who had a higher level of physical activity had a lower risk of hip fracture (data not shown). Hence, BMI, level of physical activity, and smoking status were all included as covariates in our risk models.

A major limitation of this study is that dietary intake was recorded only at baseline and dietary changes during the follow-up were not captured. Any subsequent change in diet could lead to nondifferential misclassification and potentially underestimate the diet–hip fracture risk association. Another limitation is the use of estimated food intake from FFQs to create the dietary pattern score. Again, this could lead to nondifferential misclassification that would underestimate the diet–hip fracture risk association. The identification of dietary patterns by using PCA may also not be easily generalizable across study populations. Additionally, the lack of information on *trans* fat intake in our questionnaire prohibited us from assessing its association with risk of hip fracture as a component of the AHEI 2010 score. Finally, we were not able to assess whether BMD at baseline may confound the relation between the dietary pattern and hip fracture risk. Nevertheless, because this is an observational study, causality should be interpreted cautiously and residual/unmeasured confounding (e.g., other nondietary protective factors that we have not considered) may still be unaccounted for.

In conclusion, we observed that a Chinese diet rich in vegetables, fruit, and soy products was associated with a substantially lower risk of hip fracture. Additionally, consuming a plant-based diet enriched with vegetables, fruit, and soy foods, which has been recommended for the prevention of chronic diseases such as cancer, cardiovascular disease, and diabetes, may also contribute importantly to the prevention of osteoporotic hip fractures. It would be of public health interest and benefit to examine the combination of lifestyle factors that include diet, physical activity, BMI, smoking status, and alcohol consumption in association with the risk of hip fracture in further studies. Future intervention studies are also warranted to investigate the efficacy and feasibility of such dietary modification in the prevention of osteoporosis.

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