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Dietary Pattern and Bone Density Changes in Elderly Women: A Longitudinal Study

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Abstract

Objective: Few data are available on the effect of the diet in general on bone health. The objective of this study was to identify dietary patterns and to evaluate the association between such patterns and bone mineral density (BMD) changes over time.

Methods: We analyzed a sample of women aged ≥65 years participating in the InCHIANTI Study. BMD was evaluated using computed tomography of the tibia and nutritional intake using the EPIC questionnaire. We used a cluster analysis to identify patterns of dietary intake. The clusters were compared with respect to nutritional intake; risk factors for osteoporosis; comorbidity; total, trabecular, and cortical BMD; and BMD changes over 6 years.

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Results: The sample size was 434, with a mean age of 75.2 years (SD, 7.01 years; range, 65–94 years). Based on dietary variables, 2 clusters were identified with a marked difference in energy intake (30 kcal/kg of ideal body weight [IBW] in cluster 1 vs 44 kcal/kg IBW in cluster 2). We found no meaningful differences between clusters with regard to nondietary risk factors for osteoporosis, BMD measured at baseline, and changes in BMD over the 6-year follow-up; cluster 2 showed a greater increase in cortical BMD (+30.2 mg/cm^3 vs +16.7 mg/cm^3). Members of cluster 2 were less likely to have a lower cortical BMD increase (adjusted odds ratio, 0.452; 95% confidence interval, 0.215–0.950).

Conclusions: Cortical BMD increases more in participants eating a diet exceeding the RDA for macronutrients. Cortical BMD may be more sensitive to diet and dietary interventions than trabecular bone.

INTRODUCTION

Several risk factors for the accelerated decline of bone mineral density (BMD) over time have been reported. Among nutritional factors, only the intake of calcium and vitamin D has been consistently reported to predict changes in BMD [1]. Effects of other nutrients (e.g., sodium, magnesium, alcohol, and caffeine) on bone health have been reported but at a lower level of evidence [2]. A small intervention study, however, showed that a full-spectrum dietary intervention could improve BMD more than only supplementation of Ca and vitamin D alone [3]; thus, a well-balanced diet may prevent bone loss. Furthermore, selected nutrients such as polyunsaturated fatty acids (PUFA) have been reported to protect from bone loss in animal models [4].

Since the dietary intake of a given nutrient is always variously related to the intake of other nutrients potentially affecting bone health, to disentangle the role of an individual nutritional item from that of the general dietary pattern is not easy. Accordingly, to better understand the effect of nutrition on BMD, it seems more logical to focus on the relationship between the general dietary pattern and changes of BMD over time.

The objective of this study is to identify different dietary patterns in a population of elderly women and to evaluate whether these patterns are associated with changes in BMD over 6 years. Previous analysis of this population showed only a weak direct relationship between PUFA intake and trabecular BMD, but no nutrient was found to predict changes in either trabecular or cortical BMD at 6 years [5]. In this study, we tried to gain more insight using a different analytic approach based on clustering procedures to disclose constructs that are not evident at a conventional analysis.

METHODS

Study Sample

We used data from the InCHIANTI study, which was designed to investigate the factors contributing to the decline of mobility in older persons [6]. The participants in the study were randomly selected from the populations of 2 towns in the Chianti region. The Italian National Institute of Research and Care on Aging ethical committee approved the study protocol. Participants received an extensive description of the study and signed an informed

participation consent that included permission to analyze the biological specimens collected and stored. For those unable to fully consent because of cognitive or physical problems, surrogate consent was also obtained from a close relative. The eligible participants were interviewed at their homes by a trained study researcher using a structured questionnaire aimed at investigating participants' health status, their physical and cognitive performance, and other factors possibly related to loss of independence in late life. The interview was followed by a physical examination at the study clinic. Evaluation of patients was repeated at 3 and 6 years from baseline; for the present study, we used only the data from the 6-year follow-up.

Traditional risk factors for osteoporosis are extensively collected in the InChianti database, making it possible the interpretation of loss of BMD in dietary clusters.

Assessment of the Nutritional Intake

The InCHIANTI study included an evaluation of the dietary intake estimated using the questionnaire developed by the European Prospective Investigation into Cancer and Nutrition (EPIC) [7], which has been validated in its Italian version [8,9]. The questionnaire is divided into 2 parts: the first investigates the general dietary pattern and the frequency of meals consumed away from home. The second investigates the intake frequency of 236 specific foods, along with the average size of the serving selected from a range as shown in photographs. The EPIC questionnaire was developed as a self-administered instrument. However, a preliminary study showed that older persons were prone to misunderstanding some of the questions. Therefore, trained interviewers administered the questionnaire. The information derived from the questionnaire was automatically converted into data on energy, micronutrient intake, and macronutrient intake, by software specifically designed for the EPIC study. The EPIC nutritional assessment has been successfully validated in the population being studied by comparing the dietary intake estimated by this method with the dietary intake estimated with a direct method of measure, the weighing and recording of 7-day food consumption [10].

Estimation of BMD

BMD was estimated using peripheral quantitative computed tomography (pQCT) using an XCT 2000 device (Stratec Medizin-technik, Pforzheim, Germany). The tibio-talar joint was identified using a pQCT longitudinal scout and used as an anatomic marker for the identification of measurements sites. Standard (2.5-mm thickness) transverse scans were obtained at 4% and 38 of tibial length to measure trabecular and cortical bone density, respectively. The cross-sectional images obtained by pQCT were analyzed using BonAlyse software (BonAlyse Oy, Jyvaskyla, Finland) that automatically identifies cortical and trabecular bone and assesses its density. Areas with density values >710 mg/cm^3 were considered as cortical bone [11], whereas areas with a density between 180 and 710 mg/cm^3 were considered as trabecular bone. Tibial volumetric density measured using high-resolution pQCT has been shown to be associated with number and severity of vertebral fractures [11,12].

Analytic Approach

From the initial sample of 726 female participants with both interview and clinical data, we excluded those not having pQCT (n=64) or nutritional assessment (n=4), those younger than 65 years (n = 138), and those with diabetes, with hyperthyroidism, taking estrogen replacement therapy, or taking corticosteroids (n = 86).

As a first step, we performed a cluster analysis using the FASTCLUS procedure in SAS after standardization to the Z distribution of the variables of interest [13]. We only included in this analysis only the following nutritional variables related to the overall quality of the diet or bone metabolism [5,14,15]: energy intake, animal and vegetal protein intake, calcium, phosphorus, vitamin D, magnesium, folate, PUFA, and alcohol. Energy and protein intake were expressed as a function of ideal body weight (IBW), calculated using the formula proposed by Lorentz [16]:

$$\text{IBW(men)} = \text{Height} - 100 - (\text{Height} - 150)/4$$

$$\text{IBW(women)} = \text{Height} - 100 - (\text{Height} - 150)/2$$

The cluster analysis allow the categorization of objects (in this case, participants) into groups suggested by the data, not defined a priori, such that participants in a given cluster tend to be similar to each other with respect to the nutritional variables included in the analysis and dissimilar, with respect to the same variables, from participants assigned to other clusters.

People in the clusters obtained from this procedure were compared with respect to the nutritional variables used for the cluster analysis and for other factors known to affect bone density [17,18]: age, body mass index (BMI), cumulative smoking exposure (pack-year), creatinine clearance measured using the 24-hour urine collection method, serum concentration of 25-OH vitamin D, and serum C-reactive protein. We also analyzed an index of physical activity, considering sedentary those performing less than 1 to 2 hours per week of moderate or less then 4 hours per week of light physical exercise. The clusters were also compared with respect to total BMD estimated at 4% of the tibia length, trabecular BMD estimated at the same site, and cortical BMD estimated at 38% of the tibial length and with respect to BMD modification over the 6-year follow-up.

To provide an estimate of the risk of experiencing greater bone loss associated with cluster membership, we also planned a priori to calculate the odds ratio (OR) of being in the bottom quartile of the distribution of the difference between follow-up and baseline BMD. Lacking validated cutoff points, we used the bottom quartile of BMD loss because we deemed it was a sensible choice to identify people with a clinically meaningful variation. This analysis was then adjusted for age, BMI, and creatinine clearance using a logistic regression model. We did not take into account the years elapsed since menopause because of the collinearity of this variable with age.

All analyses were performed using SAS version 9 for Windows (SAS Institute, Cary, NC). A p value <.05 was considered statistically significant.

RESULTS

We studied 434 women with a mean age of 75.2 years (SD, 7.01 years; range, 65–94 years). The overall energy intake was 34 kcal/kg IBW, 52% of which came from carbohydrates and 32% from lipids. We first tried to obtain a 3-cluster solution from the cluster analysis, but one of the clusters obtained in this way included only 1 observation; therefore, we resolved for a 2-cluster solution. Table 1 shows the main characteristics of the participants belonging to each cluster. Participants in cluster 1 were slightly older and characterized by a lower energy intake (30 kcal/kg IBW vs 44 kcal/kg IBW in cluster 2) with matching lower intake of all of the other nutrients taken into account. We found no meaningful differences between clusters with regard to renal function, serum concentration of 25-OH vitamin D, or Creactive protein. The 2 clusters were also similar with respect to comorbid conditions, while participants in cluster 2 showed a lower prevalence of sedentary behavior in the year preceding the follow-up assessment (89.1% vs 95.4% in cluster 1, p=.03).

Weight and BMI remained stable over the follow-up (–1.2 kg in cluster 1 vs–1.1 kg in cluster 2;–0.36 kg/m^2 in cluster 1 vs 0.22 kg/m^2 in cluster 2 for weight and BMI, respectively). We found no difference in the BMD measured at baseline (Table 2) or in the variation of BMD over the 6-year follow-up; however, cluster 2 showed a greater increase in cortical BMD (+30.2 mg/cm^3 vs +16.7 mg/cm^3). In the same way, the 2 clusters were no different in the odds of having higher total or trabecular BMD loss over 6 years (Table 3), while members of cluster 2 were less likely than members of cluster 1 to have higher cortical BMD loss (adjusted OR, 0.467; 95% confidence interval, 0.223–0.979).

DISCUSSION

Our exploratory analysis identified 2 groups of elderly women with marked differences in the intake of total energy, proteins, and nutrients affecting bone health, such as calcium and vitamin D. These groups showed a different evolution of the cortical BMD over a 6-year period; the difference was more evident when the BMD variation was dichotomized using the bottom quartile as a cutoff, suggesting a nonlinear relationship between dietary factors and BMD. Thus, our results are consistent with the hypothesis that alimentary factors may contribute to BMD changes over time. The fact that dietary clusters were generated on the basis of nutrient intake only without any classificatory contribution from nonalimentary variables makes the observed cluster-BMD relationship a sound one. It should be noted, however, that nonalimentary risk factors for osteoporosis taken into account were more prevalent in the cluster with lower nutrient intake, and this might confound the relationship we observed. However, the relationship between nutrient intake and longitudinal changes in cortical BMD remained true in the analysis adjusted for potential confounders. Furthermore, although older age is associated with lower nutritional intake [19], the age difference of 2 years between clusters is unlikely to justify the largest differences observed in the dietary pattern, such as the one in calcium intake (680 mg/d and 1094 mg/d in the lower and higher nutrient intake clusters, respectively, with a recommended daily allowance [RDA] of 1200

mg/d [20]). Finally, clusters had comparable prevalence of comorbid conditions potentially affecting dietary intake or bone health metabolism (heart failure, chronic obstructive pulmonary diseases, cancer, diabetes, etc.), lending support to a direct role of nutrient intake.

It is of interest that lower dietary intake was related to loss of cortical BMD but not to trabecular BMD. Trabecular and cortical bone evolve differently as a function of age [21], and our data show that age is related more strongly with trabecular than with cortical BMD loss. This is not surprising, as it is known that a clear-cut inverse relationship links age and trabecular BMD, while cortical BMD seems to be less exposed to the negative effect of age, especially in men [22]. These data and the differences in structure and hormonal sensitivity indicate that trabecular and cortical bone are biologically and functionally distinct entities, although strictly integrated to form the bone as a whole [23]. In this perspective, our finding of a protective effect of a richer diet against the loss of cortical BMD suggests that the bone compartment less exposed to the negative effect of age is also the one more influenced by the diet. This hypothesis might open the way to a better understanding of biological factors regulating this bone compartment. The cluster with lower dietary intake was in line with the RDA with respect to macronutrients, with about 30 kcal and more than 1 g of protein for kg IBW. The cluster with higher intake, instead, largely exceeded the RDA, with 44 kcal and 1.79 g of protein for kg IBW. On the other hand, clusters had comparable BMI, indicating that a diet largely exceeding the RDA was not associated with the risk of obesity. Given that clusters differed marginally in the level of self-reported physical activity, it might be concluded that different metabolic patterns likely allowed seemingly overnourished women to maintain a BMI within the normal range. Incidentally, this observation cautions against overzealously conforming to current nutritional recommendations when dealing with elderly people. Indeed, fighting overnutrition and obesity is a primary objective in young and adult people. On the opposite hand, there is robust evidence that lower BMI is a risk factor for mortality in elderly persons [24] and that even a BMI over the normal may be a protective factor. In a population of home-dwelling elderly people (aged >70 years) followed up for 8 years, a BMI >28.5 was independently associated with better quality of life and longer survival [25]. Relevant to the topic of this study is the finding that only the cluster with higher nutrient intake had a satisfactory intake of calcium and vitamin D. Thus, a diet strictly meeting the RDA for macronutrients, such as the one of the lower intake cluster, seems unable to provide the RDA for calcium and vitamin D, at least in a rural area of Tuscany. Collaterally, it remains debatable whether the average greater dietary intake or the related higher intake of calcium and vitamin D accounted for the protective effect of a richer diet against the loss of cortical BMD. Only dedicated studies assessing the compartmental effect of calcium and vitamin D supplementation would allow clarification of this issue.

One limitation of this study is that nutritional intake was evaluated at baseline and we cannot exclude that dietary habits have changed over the 6-year follow-up period. Furthermore, BMD might have also been measured as part of the standard care provided to participants, and diet modification might have been prescribed. The nutritional intake of macronutrients and micronutrients that we have found to have a positive effect on BMD, however, is much higher than the one usually recommended, and therefore this bias is unlikely to have affected our results. Finally, it should be noted that we have no information on fractures, and

therefore the clinical implication of our findings should be verified in studies that take into account this outcome.

CONCLUSIONS

This exploratory study shows for the first time that cortical bone density declines less with age in persons eating a diet exceeding the RDA for macronutrients and that well-recognized risk factors for accelerated BMD loss are unlikely to indirectly explain this relationship. Accordingly, cortical bone might be more sensitive to diet and dietary interventions than trabecular bone is. Dedicated research is needed to confirm this hypothesis.

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Table 1.

Main Characteristics of Participants According to Cluster Membership

	Cluster 1 (n = 310), Mean (SD)	Cluster 2 (n = 124), Mean (SD)	*p*
Variables included in cluster analysis			
Energy intake, kcal/kg IBW	30.06 (5.89)	44.11 (7.77)	—
Animal protein intake, g/kg IBW	0.77 (0.19)	1.16 (0.25)	—
Vegetal protein intake, g/kg IBW	0.43 (0.12)	0.63 (0.16)	—
Calcium intake, g/d	682.73 (197.95)	1097.96 (343.18)	—
Phosphorous intake, mg/d	964.68 (181.84)	1480.33 (265.27)	—
Vitamin D intake, μg/d	1.49 (0.55)	2.31 (1.26)	—
Magnesium intake, mg/d	197.53 (39.69)	296.06 (54.87)	—
Folic acid intake, μg/d	213.56 (53.41)	313.88 (71.31)	—
Polyunsaturated fatty acids intake, g/d	5.82 (1.51)	9.00 (2.15)	—
Alcohol intake, g/d	5.96 (8.88)	10.03 (12.45)	—
Variables not included in cluster analysis			
Age, years	75.78 (7.20)	73.92 (6.36)	0.012
Years since menopause	25.71 (8.45)	23.81 (8.56)	0.042
Body mass index, kg/m^3	27.33 (4.45)	28.08 (4.89)	0.126
Cigarette smoking, pack-year	2.77 (8.79)	2.68 (7.51)	0.915
Creatinine clearance, mL/min	67.71 (23.36)	73.50 (22.88)	0.023
Serum 25-OH vitamin D, nmol/L	44.60 (38.04)	42.36 (27.60)	0.563
C-reactive protein, μg/mL	4.22 (6.17)	4.78 (5.38)	0.377
Low physical activity in the year preceding follow-up assessment, %	95.4	89.1	0.032

IBW = ideal body weight.

Table 2.

Comparison of Bone Mineral Density (BMD) at Baseline and Follow-Up

	Cluster 1 (n = 310), Mean (SD)	Cluster 2 (n = 124), Mean (SD)	*p*
Total BMD, mg/cm^3	243.99 (32.76)	250.41 (34.44)	0.077
Trabecular BMD, mg/cm^3	241.71 (35.57)	249.01 (36.79)	0.061
Cortical BMD, mg/cm^3	977.53 (92.04)	986.43 (73.51)	0.291
Variation in total BMD	–37.64 (30.15)	–35.31 (29.63)	0.581
Variation in trabecular BMD	–75.52 (37.26)	–76.58 (32.94)	0.829
Variation in cortical BMD	16.75 (106.07)	30.90 (61.81)	0.204

Table 3.

Multivariable Analysis: Odds Ratios for Higher Bone Mineral Density (BMD) Loss *

	Unadjusted OR (95% CI)	Adjusted** OR (95% CI)
Higher loss of total BMD		
Cluster 2 vs 1	0.624 (0.316–1.231)	0.658 (0.313–1.384)
Age (5-year increments)	1.850 (1.393–2.456)	1.115 (1.049–1.184)
Body mass index	0.901 (0.836–0.971)	0.918 (0.846–0.996)
Creatinine clearance	0.979 (0.964–0.995)	0.990 (0.974–1.007)
Low physical activity	1.846 (0.518–6.583)	1.220 (0.326–4.569)
Higher loss of trabecular BMD		
Cluster 2 vs 1	0.880 (0.459–1.688)	0.901 (0.448–1.813)
Age (5-year increments)	1.432 (1.095–1.874)	1.071 (1.011–1.135)
Body mass index	0.939 (0.874–1.008)	0.944 (0.874–1.020)
Creatinine clearance	0.996 (0.981–1.011)	1.004 (0.988–1.019)
Low physical activity	3.016 (0.775–13.478)	2.440 (0.535–11.122)
Higher loss of cortical BMD		
Cluster 2 vs 1	0.482 (0.237–0.978)	0.467 (0.223–0.979)
Age (5-year increments)	1.221 (0.935–1.595)	1.045 (0.987–1.106)
Body mass index	0.973 (0.908–1.043)	0.979 (0.910–1.054)
Creatinine clearance	1.007 (0.993–1.021)	1.010 (0.995–1.025)
Low physical activity	1.250 (0.397–3.932)	1.034 (0.319–3.356)

*Bottom quartile of BMD difference between follow-up and baseline.

**Adjusted for all the variables in the table.