The Journal of Nutrition
Nutritional Epidemiology

Differences in Bone Mineral Density between Adult Vegetarians and Nonvegetarians Become Marginal when Accounting for Differences in Anthropometric Factors

Nena Karavasiloglou,[1] Eliska Selinger,[2] Jan Gojda,[2] Sabine Rohrmann,[1] and Tilman Kühn[3]

[1]Division of Chronic Disease Epidemiology, Institute for Epidemiology, Biostatistics and Prevention, University of Zurich, Zurich, Switzerland; [2]Centre for Research on Diabetes, Metabolism and Nutrition of Third Faculty of Medicine, Charles University in Prague, Prague, Czech Republic; and [3]Division of Cancer Epidemiology, German Cancer Research Center (DKFZ), Heidelberg, Germany

ABSTRACT

Background: Persons following plant-based diets have lower bone mineral density (BMD) and higher fracture risk, possibly due to suboptimal nutrient supply. However, anthropometric measures were not considered as potential confounders in many previous studies, and body mass index (BMI) is positively associated with BMD but also generally lower among vegans and vegetarians.

Objectives: Our objective was to investigate if BMD measurements differ between vegetarians and nonvegetarians from the adult general population when accounting for important determinants of BMD, especially BMI and waist circumference.

Methods: Using data from the NHANES (cycles 2007–2008 and 2009–2010), we evaluated the differences in BMD (femoral neck, total femoral, and total lumbar spine) between adult vegetarians and nonvegetarians. Linear regression models were used to determine the associations between BMD and diet. Statistical models were adjusted for important factors, i.e., age, sex, race/ethnicity, smoking status, alcohol consumption, serum vitamin D and calcium concentrations, waist circumference, and BMI.

Results: In statistical models adjusted for age, sex, race/ethnicity, menopausal status, and education level, BMD values were significantly lower among vegetarians than among nonvegetarians ($P < 0.001$). These differences were attenuated upon adjustment for lifestyle factors, and became statistically nonsignificant upon adjustment for anthropometric variables (BMI and waist circumference) for femoral neck (0.77 compared with 0.79 g/cm^2 among vegetarians versus nonvegetarians, $P = 0.10$) and total femoral BMD (0.88 compared with 0.90 g/cm^2, $P = 0.12$). A small but statistically significant difference remained for total lumbar spine BMD (1.01 compared with 1.04 g/cm^2, $P = 0.005$).

Conclusions: These findings suggest that lower BMD among adult vegetarians is in larger parts explained by lower BMI and waist circumference. *J Nutr* 2020;00:1–6.

Keywords: vegetarians, plant-based diets, bone mineral density, diet, adults, body mass index, anthropometry

Introduction

Plant-based diets are becoming increasingly popular, and there is a growing number of vegetarians (persons who do not consume meat and fish) and vegans (persons who do not consume animal products at all) in many Western countries (1). Whereas epidemiological studies suggest cardiometabolic benefits of vegan and vegetarian diets (1, 2), a recent systematic review indicated lower bone mineral density (BMD) and higher fracture risk among adults following plant-based diets (3). However, it remained somewhat unclear whether these associations were due to dietary habits as such (i.e., potentially lower intakes of calcium, vitamin D, and other nutrients among vegetarians and vegans), or rather due to participant characteristics, particularly anthropometric parameters.

The lack of adjustment for anthropometric measures in the studies on plant-based diets and BMD included in the aforementioned meta-analysis seems crucial, because persons following plant-based diets have a lower BMI compared to nonvegetarians (2). Moreover, recent data from the large-scale

NK supported by Krebsliga Schweiz grant KFS 4114-02-2017 to SR.
Author disclosures: The authors report no conflicts of interest.
Supplemental Table 1 is available from the "Supplementary data" link in the online posting of the article and from the same link in the online table of contents at https://academic.oup.com/jn/.
Address correspondence to NK (e-mail: nena.karavasiloglou@uzh.ch).
Abbreviations used: BMD, bone mineral density; CAPI, Computer-Assisted Personal Interviewing; 25(OH)D, 25-hydroxycholecalciferol.

Copyright © The Author(s) 2020.
Manuscript received October 7, 2019. Initial review completed October 24, 2019. Revision accepted January 22, 2020.
First published online 0, 2020; doi: https://doi.org/10.1093/jn/nxaa018.

Downloaded from https://academic.oup.com/jn/advance-article-abstract/doi/10.1093/jn/nxaa018/5735637 by University of Liverpool user on 15 February 2020

population-based UK Biobank cohort suggest that, in addition to total body mass and fat mass, lean mass is also lower among vegans and vegetarians than among meat eaters (4). In turn, higher total body mass is related to higher BMD among adults (5). Heavier adults are often characterized by higher lean mass, with a greater mechanical loading and muscle-induced strain enhancing their bone mineralization and strength (5, 6). At the same time, positive associations between higher fat mass and BMD among adults have been observed in some studies, even when adjusting for muscle mass, or when comparing sarcopenic obese and sarcopenic nonobese elderly study participants (5, 7). Beyond additional mechanical loading by body fat, such associations could be due to an altered hormonal milieu in obesity. In this regard, increased insulin-like growth factor I, estrogen, and leptin concentrations have been shown to promote bone density and strength in some studies, although the evidence is conflicting and obesity-associated inflammation may also be related to lower BMD (5, 6). Nevertheless, the majority of studies suggests that both higher lean mass and higher fat mass are related to higher BMD among adults (5, 6).

In the present study, we investigated potential differences in BMD among vegetarian and nonvegetarian participants of the large-scale population-based NHANES, with comprehensive statistical adjustment for essential determinants of BMD, and especially BMI and waist circumference as measures of total body mass and obesity. Our goal was to evaluate if associations between diet (vegetarian compared with nonvegetarian) and BMD were independent of body mass and obesity, because higher BMD has been reported among persons with higher BMI (6), whereas vegetarians have generally lower BMI (2). With our analyses, we intended to find out whether lower BMI and waist circumference may be determinants of lower BMD among vegetarians rather than suboptimal dietary composition with plant-based diets, as suggested by the authors of the recent meta-analysis on plant-based diets and BMD (3).

Methods

Study population

Data from the continuous NHANES between 2007 and 2010 were used in the analyses. The methodology of the NHANES has been described in detail elsewhere (8, 9). In short, NHANES is a nationwide population-based survey conducted in the United States. NHANES collects nationally representative data on health and nutrition, using a complex, multistage probability sample of the US civilian and noninstitutionalized population. NHANES participants are interviewed and undergo physical examinations in a mobile examination center. The protocols for the conduct of NHANES were approved by the Institutional Review Board of the National Center for Health Statistics, US CDC. Informed consent was obtained from all participants. The NHANES files are publicly available and can be accessed (10). Therefore, institutional review board approval and oversight were not required for our study.

In this analysis, participants from two NHANES cycles (2007–2008 and 2009–2010) were included. Participants younger than 20 y old (n = 8533) were excluded because not all standard adult measurements and in particular alcohol consumption were assessed for these participants. Participants who used a proxy during either the interview or the medical examination and those who had missing information regarding proxy usage were also excluded (n = 1648). Further, participants who did not have either a valid lumbar spine or femoral DXA measurement were excluded (n = 1007). Participants who answered "refused" or "don't know" or had missing information on whether or not they perceived themselves as vegetarians were excluded (n = 2). Finally, participants with missing information on BMI or waist circumference were excluded (n = 80). The overall study population included 9416 participants.

Bone health markers

Our outcomes of interest were total lumbar spine, total femoral, and femoral neck BMD. DXA scans of the proximal femur and the spine were carried out in the NHANES mobile examination center. The left hip was routinely scanned unless the participant self-reported a fractured left hip, a left hip replacement, or a pin in the left hip; in these instances, the right hip was scanned. Participants were excluded from the femur scan if they had fractured both hips, had replacements of both hips, or had pins in both hips. Participants were excluded from the spine scan if they reported a Harrington Rod in the spine for scoliosis. Pregnant women, participants with self-reported history of radiographic contrast material (barium) use in the past 7 d, self-reported nuclear medicine studies in the past 3 d, or with self-reported weight >300 pounds (∼136 kg; the DXA table upper limit) were considered ineligible for DXA measurements. Measurements for participants with nonremovable objects, excessive X-ray noise due to obesity, insufficient scan area, movement during scanning, or degenerative diseases were considered invalid. The scans were acquired with Hologic QDR-4500A fan-beam densitometers (Hologic, Inc.) and Discovery version 12.4 software. Measurements included bone mineral content (g), bone area (cm^2), and BMD (g/cm^2). The DXA examinations were administered by trained and certified radiology technologists. Further details of the DXA examination protocol are located on the NHANES website (NHANES Body Composition Procedures Manual) (11).

Classification of vegetarians and nonvegetarians

Participants were considered as self-perceived vegetarians if they answered "yes" to the question, "Do you consider yourself to be a vegetarian?" Participants who answered "no" to the question were considered as non–self-perceived vegetarians.

Covariate assessment

Trained health technicians, accompanied by a recorder, performed the data collection of all body measurements. Measured BMI was reported in the NHANES as kg/m^2.

Alcohol consumption was assessed using the Alcohol questionnaire (12). The Alcohol questionnaire was administered in adults 20 y and older during the physical exam, at the examination center, using the Computer-Assisted Personal Interviewing (CAPI) (interviewer-administered) system. Participants were classified into sex-specific categories based on their self-reported average daily alcohol consumption as follows: nondrinker, moderate drinker (≤1 alcoholic drink per day), binge drinker (>1 and <4 alcoholic drinks per day), or heavy drinker (≥4 alcoholic drinks per day) for female participants; and nondrinker, moderate drinker (≤2 alcoholic drinks per day), binge drinker (>2 and <5 alcoholic drinks per day), or heavy drinker (≥5 alcoholic drinks per day) for male participants, similar to a previous analysis by Agrawal et al. (13).

Smoking status was assessed in adults 20 y and older during the home interview, by trained interviewers using the CAPI system. Participants responded to whether they had smoked ≥100 cigarettes in their lifetime, and whether they currently smoked cigarettes (daily, some days, or not at all). Participants were categorized as never-smokers (<100 cigarettes over their lifetime), former smokers (having smoked >100 cigarettes over their lifetime but do not currently smoke), and current smokers.

The physical activity questionnaire was based on the Global Physical Activity Questionnaire and included questions related to daily activities, leisure-time activities, and sedentary activities. Physical activity in adults was assessed during the home interview, using the CAPI system. Participants were asked whether they participated in moderate- and/or vigorous-intensity activities (including examples to help participants respond), outside of work or transportation, with a duration of ≥10 continuous minutes. Frequency of participation in physical activity was not considered. Participants who answered "yes" were classified as physically active, whereas those who answered "no" were classified

Downloaded from https://academic.oup.com/jn/advance-article-abstract/doi/10.1093/jn/nxaa018/5735637 by University of Liverpool user on 15 February 2020

as non–physically active, similarly to a previous study by Vásquez et al. (14).

Serum specimens were processed, stored, and shipped to the Division of Laboratory Sciences, National Center for Environmental Health, CDC (Atlanta, GA) for analysis. Detailed specimen collection and processing instructions have been described in detail elsewhere (NHANES Laboratory/Medical Technologists Procedures Manual) (15). Vials were stored under appropriate frozen (−30°C) conditions until they were shipped to the National Center for Environmental Health for testing. The analyses on serum calcium concentrations were performed using a Beckman Synchron LX20 and/or Beckman UniCel® DxC800 Synchron. Total serum 25-hydroxycholecalciferol [25(OH)D] was estimated via ultra-high performance LC-tandem MS.

Statistical analyses

Baseline categorical data were expressed as percentages and continuous data as means and SEs. Linear regression models were used to determine the associations between bone health markers and diet. Regarding confounders, the first model (Model 1) was adjusted only for age at study entry (continuous; years), race/ethnicity (non-Hispanic white, non-Hispanic black, Mexican-American, other), education (high school or less, some college or more, missing/unknown), sex, and menopausal status. The second model (Model 2) was further adjusted for a number of a priori determined confounders based on the existing literature including smoking (never, former, current smoker and missing/unknown), marital status [never married/widowed, divorced/separated, married/living as married, missing/unknown (16)], physical activity (active, inactive), and alcohol consumption (sex-specific cutoffs for nondrinkers, moderate drinkers, binge drinkers, and heavy drinkers or missing/unknown). The third model (Model 3) was further adjusted for total serum calcium (continuous; mg/dL) and total serum 25(OH)D (continuous; nmol/L) concentrations. The final model (Model 4) was additionally adjusted for BMI (continuous) and waist circumference (continuous; cm). The results were presented as adjusted mean BMD values (95% CIs) by dietary group (self-perceived vegetarians compared with non–self-perceived vegetarians) with corresponding *P* values for difference.

All statistical analyses were performed using SAS (version 9.3; SAS Institute, Cary, NC) and R (version 3.5.1; R Foundation for Statistical Computing, Vienna, Austria) softwares and significance levels were set at a 2-sided *P* value of 0.05. Sampling weights adapted to the inclusion of multiple NHANES cycles were used in all analyses to account for the complex survey design and survey nonresponse.

Results

Table 1 shows a description of the study population. Self-perceived vegetarians were more likely to have had some college education, to be non-Hispanic white, and to be women, than the non–self-perceived vegetarians. In addition, they were slightly younger, reported being more physically active and smoking less, and had lower BMI and 25(OH)D concentrations. Serum calcium concentrations were similar between both groups.

Figure 1 and **Supplemental Table 1** show the associations between the bone health parameters and self-reported vegetarianism. Self-perceived vegetarians had statistically significantly lower total lumbar spine BMD, femoral neck BMD, and total femoral BMD than non–self-perceived vegetarians in Model 1 (adjusted for age, sex, race/ethnicity, education and menopausal status), Model 2 (further adjusted for smoking status, marital status, alcohol consumption, and physical activity), and Model 3 [further adjusted for serum calcium and

TABLE 1 Baseline characteristics of the study population (NHANES cycles 2007–2008, 2009–2010)[1]

	Self-perceived vegetarians ($n = 207$)	Non–self-perceived vegetarians ($n = 9209$)
Age, y	44.4 ± 1.3	47.0 ± 0.4
Sex		
Women	65.1	49.9
Race/ethnicity		
Non-Hispanic white	61.4	70.4
Non-Hispanic black	7.2	10.6
Mexican American	6.8	8.5
Other ethnicity	24.6	10.6
Marital status		
Never married/widowed	25.3	22.7
Divorced/separated	17.7	12.5
Married/living with partner	57.0	64.8
Missing/unknown	—	0.06
Education		
High school or less	29.7	42.8
Some college or more	70.3	57.1
Missing/unknown	—	0.1
Smoking		
Never smoker	61.7	53.2
Former smoker	27.2	24.7
Current smoker	11.1	22.1
Missing/unknown	—	0.04
Physical activity[2]		
No physical activity	40.3	46.8
Moderate or vigorous physical activity	59.7	53.2
Alcohol[3]		
Nondrinker	12.1	15.9
Moderate drinker	37.0	35.3
Binge drinker	27.1	24.4
Heavy drinker	5.5	13.9
Missing/unknown	18.2	10.5
Menopausal status[4]		
Premenopausal	61.1	52.9
Postmenopausal	38.9	46.6
Missing/unknown	—	0.5
Serum total calcium,[5] mg/dL	9.5 ± 0.04	9.4 ± 0.02
Serum total 25(OH)D,[6] nmol/L	60.3 ± 3.7	64.9 ± 0.8
BMI, kg/m^2	25.5 ± 0.4	28.2 ± 0.1
Waist circumference, cm	88.9 ± 1.1	97.4 ± 0.3

[1]Values are means ± SEs or percentages. 25(OH)D, 25-hydroxycholecalciferol.
[2]Participants were asked whether they participated in moderate- and/or vigorous-intensity activities, outside of work or transportation, with a duration of ≥10 continuous minutes. If they answered "yes" they were classified as moderate or vigorous physical activity, if they answered "no" they were classified as no physical activity.
[3]Sex-specific categories based on participants' self-reported average daily alcohol consumption. Females: nondrinker, moderate drinker (≤1 alcoholic drink per day), binge drinker (>1 and <4 alcoholic drinks per day), or heavy drinker (≥4 alcoholic drinks per day); males: nondrinker, moderate drinker (≤2 alcoholic drinks per day), binge drinker (>2 and <5 alcoholic drinks per day), or heavy drinker (≥5 alcoholic drinks per day).
[4]Menopausal status was only pertinent for women.
[5]Information on total serum calcium was available for 203 vegetarians and 8832 nonvegetarians (unweighted counts).
[6]Information on total serum 25(OH)D was available for 195 vegetarians and 8335 nonvegetarians (unweighted counts).

Downloaded from https://academic.oup.com/jn/advance-article-abstract/doi/10.1093/jn/nxaa018/5735637 by University of Liverpool user on 15 February 2020

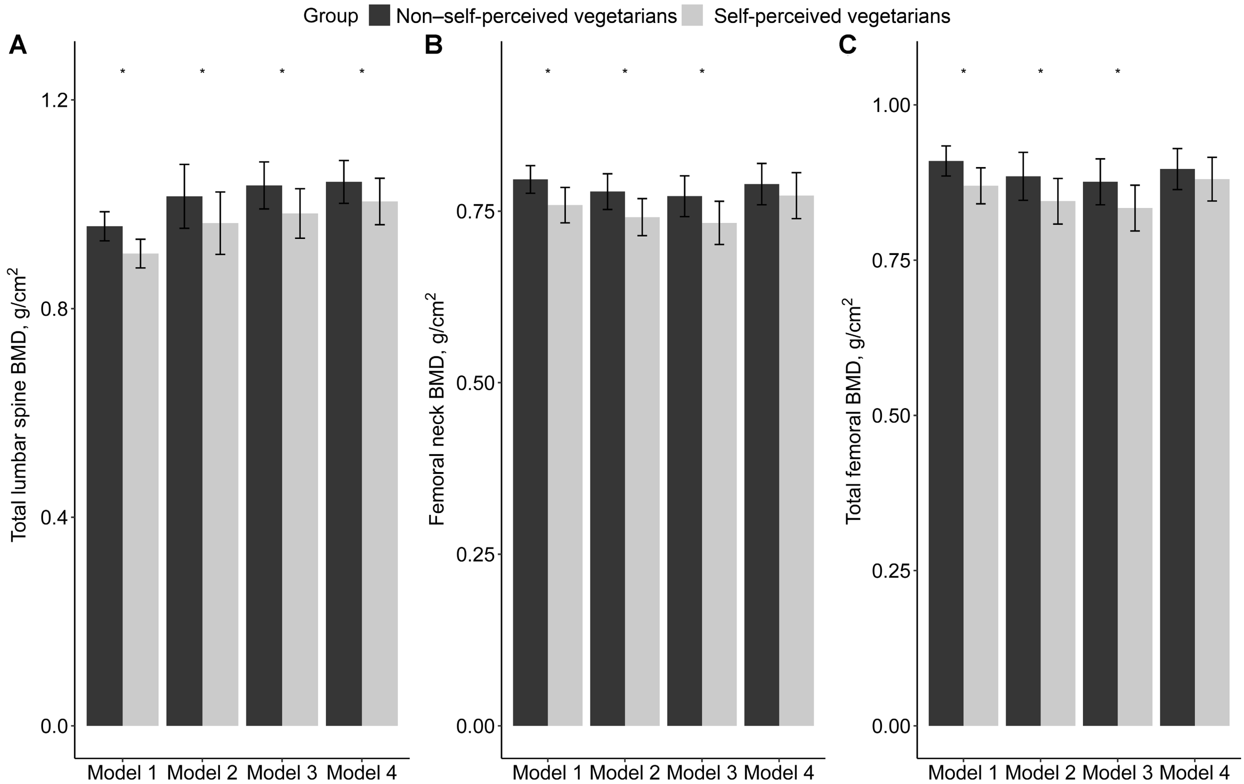

FIGURE 1 BMD measurements across body sites [(A) total lumbar spine, (B) femoral neck, and (C) total femoral] between dietary groups presented as adjusted least-square means, 95% CIs, and corresponding *P* values for difference. *Self-perceived vegetarian different from non–self-perceived vegetarian, $P < 0.05$. Participant counts were as follows (unweighted counts): (A) self-perceived vegetarians 169 (Models 1 and 2) and 158 (Models 3 and 4) compared with non–self-perceived vegetarians 7116 (Models 1 and 2) and 6392 (Models 3 and 4); (B, C) self-perceived vegetarians 201 (Models 1 and 2) and 189 (Models 3 and 4) compared with non–self-perceived vegetarians 8956 (Models 1 and 2) and 8077 (Models 3 and 4). In the linear regression models, the appropriate weights were used to account for the complex survey design and survey nonresponse. Model 1: adjusted for age at study entry (years), race/ethnicity (non-Hispanic white, non-Hispanic black, Mexican American, and other), education (high school or less, some college or more, unknown), sex, and menopausal status. Model 2: further adjusted for smoking (never, former, current smoker), marital status (never married/widowed, divorced/separated, married/living as married, unknown), physical activity (active, inactive, unknown), and alcohol consumption (sex-specific cutoffs for nondrinkers, moderate drinkers, binge drinkers, and heavy drinkers). Model 3: further adjusted for total serum calcium (continuous; mg/dL) and total serum 25-hydroxycholecalciferol (continuous; nmol/L) concentrations. Model 4: further adjusted for BMI (continuous; kg/m^2) and waist circumference (continuous; cm). BMD, bone mineral density.

25(OH)D]. However, when BMI and waist circumference were introduced into the analyses (Model 4), only the association with total lumbar spine BMD remained statistically significant, with adjusted mean BMD values of 1.01 g/cm^2 among self-perceived vegetarians compared with 1.04 g/cm^2 among non–self-perceived vegetarians ($P = 0.005$).

Further adjusting linear regression analyses for the use of oral contraceptives and menopausal hormone therapy among women, and for the use of bisphosphonates and glucocorticosteroids in sensitivity analyses only very marginally changed the results of Model 4 (data not shown). There were no statistically significant interactions between type of diet and sex in any of the regression models (data not shown).

Discussion

In the present analyses using data from the population-based NHANES (cycles 2007–2008 and 2009–2010), we confirmed previous observations of lower BMD values among vegetarians than among nonvegetarians. However, vegetarians were also more likely to be women, reported less frequent smoking and alcohol consumption, and had lower BMI and waist circumference values. Although differences in total lumbar spine, total femoral, and femoral neck BMD between vegetarians and nonvegetarians were statistically significant in linear regression models adjusted for age, sex, race/ethnicity, menopausal status, and education level, these differences were attenuated by additional adjustment for lifestyle factors. When further adjusting for BMI and waist circumference, differences in adjusted mean BMD values became marginal and were no longer statistically significant for total femoral and femoral neck BMD.

Our finding of a clear attenuation of associations between type of diet (vegetarian compared with nonvegetarian) and BMD after adjustment for anthropometric factors suggests that differences in BMD between vegetarians and nonvegetarians may largely depend on BMI and waist circumference, which is in line with previous reports of higher BMD among overweight and obese persons (6). In turn, lower rates of fractures among nonvegetarians that have recently been described (3) may be an example of an "obesity paradox," i.e., a more favorable health outcome among people with higher BMI (6). Thus, our results do not support the notion that dietary composition is the main reason for lower BMD among vegetarians.

Downloaded from https://academic.oup.com/jn/advance-article-abstract/doi/10.1093/jn/nxaa018/5735637 by University of Liverpool user on 15 February 2020

Another background factor that may to some degree explain lower BMD among vegetarians is lower vitamin D status (17, 18), and it is conceivable that the slightly lower 25(OH)D concentrations observed among vegetarian participants of NHANES than among nonvegetarians are due to lower vitamin D intake via animal foods rather than differential sun exposure (17, 19). However, statistical adjustment for serum vitamin D concentrations did not substantially attenuate the differences in BMD between vegetarians and nonvegetarians in the present analyses, as opposed to the adjustment for anthropometric measures of obesity, and it should be noted that the proportions of 25(OH)D concentrations <30 nmol/L (indicating deficiency) were low among both vegetarians (12.5%) and nonvegetarians (8.2%).

In contrast to many smaller previous studies on BMD among vegetarians and nonvegetarians summarized in a recent meta-analysis (3), the main strengths of the present study are its representativeness for the US adult population, its sample size, and the comprehensive statistical adjustment for important determinants of BMD. However, the sample size did not allow us to perform well-powered subgroup analyses. All analyses were cross-sectional, and we did not have the opportunity to evaluate diet in relation to fracture risk prospectively. We relied on self-identification of study participants as vegetarians and nonvegetarians, with the possibility of misclassifications, but differences in BMD values between the 2 groups are in line with previous reports (3) and a major misclassification of dietary preferences seems unlikely. We did not have information on the degree and duration of adherence to the diets, which may have diluted differences in BMD values between vegetarians and nonvegetarians. Moreover, we could not distinguish between vegans and vegetarians, and we therefore acknowledge that the present finding of lower BMI and waist circumference as potentially important determinants of lower BMD among vegetarians may not necessarily apply to lower BMD among vegans. To this end, future population-based studies with a higher number of vegan participants are needed to assess BMI compared with dietary preferences in relation to BMD and fracture risk.

Our findings of highly similar BMD values among vegetarians and nonvegetarians do not suggest that calcium intake among vegetarians may be critically low. In the present NHANES cycles, calcium intake was only assessed via one to two 24-h dietary recalls, which are not ideal for capturing an individual's habitual micronutrient intake. However, serum calcium, which we used for statistical models, is a suboptimal biomarker, given that it is under tight homeostatic control, with similar concentrations among vegans, vegetarians, and meat eaters (18). We did not have data on body composition or hormonal factors to disentangle possible distinct effects of lean and fat mass on BMD. Finally, there is no obvious explanation for the observation that the difference in lumbar spine BMD between vegetarians and nonvegetarians remained statistically significant in our fully adjusted model, unlike the differences in total femoral and femoral neck BMD, considering that strong discordances in BMD values across these sites are rare (20). Yet, upon adjustment for anthropometric factors the differences in lumbar spine BMD became small, with little clinical relevance (21).

In summary, our analyses of data from the NHANES cycles 2007–2008 and 2009–2010 indicate that only small diet-related differences in total lumbar spine BMD may exist between vegetarians and nonvegetarians; the present statistical models adjusted for important determinants of BMD, and particularly anthropometric measures, did not show differences in total femoral and femoral neck BMD between the 2 groups. Future studies are needed to evaluate whether lower BMD and higher fracture risk among vegans may also be in larger parts explained by anthropometric and body composition parameters.

Acknowledgments

The authors' responsibilities were as follows—NK and TK: conceptualized the study and wrote the original draft of the manuscript; NK: conducted the formal analysis; and all authors: reviewed and edited the manuscript and read and approved the final manuscript.

References

1. Segovia-Siapco G, Sabaté J. Health and sustainability outcomes of vegetarian dietary patterns: a revisit of the EPIC-Oxford and the Adventist Health Study-2 cohorts. Eur J Clin Nutr 2019;72: 60–70.
2. Appleby PN, Key TJ. The long-term health of vegetarians and vegans. Proc Nutr Soc 2016;75:287–93.
3. Iguacel I, Miguel-Berges ML, Gómez-Bruton A, Moreno LA, Julián C. Veganism, vegetarianism, bone mineral density, and fracture risk: a systematic review and meta-analysis. Nutr Rev 2019;77:1–18.
4. Tong TY, Key TJ, Sobiecki JG, Bradbury KE. Anthropometric and physiologic characteristics in white and British Indian vegetarians and nonvegetarians in the UK Biobank. Am J Clin Nutr 2018;107:909–20.
5. Savvidis C, Tournis S, Dede AD. Obesity and bone metabolism. Hormones (Athens) 2018;17:205–17.
6. Fassio A, Idolazzi L, Rossini M, Gatti D, Adami G, Giollo A, Viapiana O. The obesity paradox and osteoporosis. Eat Weight Disord 2018;23:293–302.
7. Santos VRD, Christofaro DGD, Gomes IC, Junior IFF, Gobbo LA. Relationship between obesity, sarcopenia, sarcopenic obesity, and bone mineral density in elderly subjects aged 80 years and over. Rev Bras Ortop 2018;53:300–5.
8. Borrud L, Chiappa MM, Burt VL, Gahche J, Zipf G, Johnson CL, Dohrmann SM. National Health and Nutrition Examination Survey: national youth fitness survey plan, operations, and analysis, 2012. Vital Health Stat 2 2014;(163):1–24.
9. Zipf G, Chiappa M, Porter KS, Ostchega Y, Lewis BG, Dostal J. National Health and Nutrition Examination Survey: plan and operations, 1999–2010. Vital Health Stat 1 2013;(56):1–37.
10. CDC. National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey data: continuous NHANES: what is continuous NHANES? [Internet]. Hyattsville (MD): US Department of Health and Human Services, CDC. [cited 2020 Jan 10]. Available from: https://wwwn.cdc.gov/nchs/nhanes/continuousnhanes/default.aspx.
11. CDC. National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey. Body Composition. Procedures Manual. [Internet]. Hyattsville (MD): US Department of Health and Human Services, CDC; 2018 [cited 2020 Jan 10]. Available from: https://wwwn.cdc.gov/nchs/data/nhanes/2017-2018/manuals/Body_Composition_Procedures_Manual_2018.pdf.
12. CDC. National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey data: 2007–2008 data documentation, codebook, and frequencies. [Internet]. Hyattsville (MD): US Department of Health and Human Services, CDC; 2009 [cited 2020 Jan 10]. Available from: https://wwwn.cdc.gov/Nchs/Nhanes/2007-2008/ALQ_E.htm.
13. Agrawal P, Mercer A, Hassanali J, Carmack C, Doss D, Murillo R. Gender differences in the association between alcohol use and sedentary behavior among adults. Am J Health Promot 2018;32:1576–81.
14. Vásquez E, Batsis JA, Germain CM, Shaw BA. Impact of obesity and physical activity on functional outcomes in the elderly: data from NHANES 2005–2010. J Aging Health 2014;26:1032–46.
15. CDC. National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey. Laboratory Procedures Manual. [Internet]. Hyattsville (MD): US Department of Health and Human Services, CDC; 2011 [cited 2020 Jan 10]. Available

Downloaded from https://academic.oup.com/jn/advance-article-abstract/doi/10.1093/jn/nxaa018/5735637 by University of Liverpool user on 15 February 2020

from: https://www.cdc.gov/nchs/data/nhanes/nhanes_11_12/2011-12_laboratory_procedures_manual.pdf.

16. Goldfarb-Rumyantzev AS, Rout P, Sandhu GS, Khattak M, Tang H, Barenbaum A. Association between social adaptability index and survival of patients with chronic kidney disease. Nephrology Dialysis Transplantation 2010;25: 3672–81.
17. Crowe FL, Steur M, Allen NE, Appleby PN, Travis RC, Key TJ. Plasma concentrations of 25-hydroxyvitamin D in meat eaters, fish eaters, vegetarians and vegans: results from the EPIC-Oxford study. Public Health Nutr 2011;14:340–6.
18. Hansen TH, Madsen MTB, Jorgensen NR, Cohen AS, Hansen T, Vestergaard H, Pedersen O, Allin KH. Bone turnover, calcium homeostasis, and vitamin D status in Danish vegans. Eur J Clin Nutr 2018;72:1046–54.
19. Hill KM, Jonnalagadda SS, Albertson AM, Joshi NA, Weaver CM. Top food sources contributing to vitamin D intake and the association of ready-to-eat cereal and breakfast consumption habits to vitamin D intake in Canadians and United States Americans. J Food Sci 2012;77:H170–5.
20. Johansson H, Oden A, Kanis JA, McCloskey EV, Morris HA, Cooper C, Vasikaran S. A meta-analysis of reference markers of bone turnover for prediction of fracture. Calcif Tissue Int 2014;94:560–7.
21. Ho-Pham LT, Nguyen ND, Nguyen TV. Effect of vegetarian diets on bone mineral density: a Bayesian meta-analysis. Am J Clin Nutr 2009;90:943–50.

Downloaded from https://academic.oup.com/jn/advance-article-abstract/doi/10.1093/jn/nxaa018/5735637 by University of Liverpool user on 15 February 2020