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Lack of Influence of Calcium/Phosphorus Ratio on Hip and Lumbar Bone Mineral Density in Older Americans: NHANES 2005-2006 Cross-Sectional Data

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Objectives: We sought to ascertain the effect of a low dietary calcium/phosphorus (Ca:P) ratio on the bone health of older adults in the United States. The present analysis assessed whether a high dietary consumption of P, which generally leads to a low dietary Ca:P ratio, has an unfavorable effect on the bone mineral density (BMD) of the hip and lumbar vertebrae in a representative sample of older US men and women.

Design: For the 1228 men and women aged 50 to 70 and ≥71 years included in the National Health and Nutrition Examination Survey (NHANES) 2005 to 2006 cycle, quintiles of the dietary Ca:P ratio were tested for their association with hip and lumbar BMD after adjusting for body mass index (BMI). All data in this observational study were cross-sectional.

Results: Women typically have higher dietary Ca:P ratios than men and lower BMDs. No trend emerged for any age or sex group when studying the relationship between the dietary Ca:P ratio and BMD with adjustment for BMI.

Conclusions: A wide range of dietary Ca:P ratios in the diets of a cross-section of older adult men and women in the United States had little effect on the BMD of the hip (proximal femur) or the lumbar vertebrae (spine), even among those consuming large amounts of Ca supplements. Despite the lack of complete assessment of total P intake in the United States, these results suggest that high P consumption patterns and low dietary Ca:P ratios do not exert an adverse effect on BMD at major fracture sites in older adults.

Freeform/Key Words: dietary calcium-to-phosphorus ratio, bone mineral content, bone mineral density, calcium intake, phosphorus intake, femoral mineral density, lumbar mineral density, older Americans

Low calcium (Ca) intake as a part of a high-phosphorus (P) diet contributes to an acute increase in serum parathyroid hormone (PTH) which has been reported in short-term human studies [1–4]. Whether adverse effects of a usual low Ca:P diet occur in bone [*i.e.,* declines in bone mineral content and bone mineral density (BMD)] during chronic high P consumption

Abbreviations: Ca:P, calcium/phosphorus; BMD, bone mineral density; BMI, body mass index; DXA, dual-energy x-ray absorptiometry; FGF-23, fibroblast growth factor-23; NHANES, National Health and Nutrition Examination Survey; PTH, parathyroid hormone.

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has been difficult to establish, although bone turnover markers have been shown to be elevated after oral P administration [5]. A part of the reason for the uncertainty regarding high P-induced bone loss has been the previously limited understanding of the actions of fibroblast growth factor-23 (FGF-23), now considered a major phosphaturic hormone [6]. A main effect of FGF-23 is to increase renal elimination of excessive amounts of phosphate ions provided by foods and beverages, which helps maintain the serum P concentration within a fairly narrow range of normality [7–10]. Both PTH and FGF-23 reduce the renal reabsorption of P ions and increase their loss in urine [11].

The homeostatic control of serum Ca and P ions is at the crossroads of the rather rapid renal actions of FGF-23 and PTH and also has direct effects on bone [7–10]. Earlier analyses of National Health and Nutrition Examination Survey (NHANES) data revealed that the mean serum P concentration was not related to a P-rich diet but that an elevated serum P concentration was associated with an increased risk of mortality from other chronic conditions [12]. Questions, however, remain regarding the role of high P intake in affecting the mortality of other chronic conditions [13]. Despite consuming a diet enriched in P, including food fortificants, adults with normal renal function do not generate substantial increases in serum P concentration after a meal [14]. The net regulatory effects of FGF-23 and PTH on serum P suggest that modifications of BMC and BMD are minimal or nonexistent with a chronic diet of P-rich foods, including P fortificants. In addition, a diet high in P has not been demonstrated to increase the bone fragility that can lead to osteoporosis and fractures in older adults [15, 16].

The objective of the present secondary data analysis was to assess whether the usual intake of low amounts of Ca and high amounts of P from foods and supplements (*i.e.,* low dietary Ca:P ratios) will have long-term adverse effects on the bone composition of the lumbar vertebrae and hip of the proximal femur in older adults with normal renal function. A large cross-sectional population data set from the NHANES 2005 to 2006 has permitted examination of whether BMD is affected by the usual high-P consumption in old, reasonably healthy adults. The basic assumption of the present study was that the dietary patterns of the elderly study participants had been reasonably consistent throughout their previous adult years. The dietary intake of Ca and P in relation to BMD of the hip and spine and the calculated dietary Ca:P ratio data of this population sample have been previously reported [17]. These measurements were used in the statistical analyses of bone measurements in the present report.

In addition, Anderson *et al.* [18] found no evidence that a range of dietary Ca intake had an obvious effect on the BMD of the hip and spine. In the present report, a parallel analysis of dietary intake of P alone in relation to BMD of the hip and spine was conducted, again finding little evidence of effect.

1. Methods

A. Data Set

Observations were taken of the data from the 2005 to 2006 NHANES cycle (Centers for Disease Control, Atlanta, July 2008). The number of eligible participants was 1228. We applied inclusion and exclusion criteria for both femur and spinal dual-energy dual-energy x-ray absorptiometry (DXA) measurements and deleted the missing and zero values for Ca and P dietary intake. Exclusions included pregnant women, those with an amputation, participants with removable and nonremovable implants, those with highly variable DXA measurements (excessive x-ray "noise") due to obesity, and participants with jewelry and other objects not removed.

Of the eligible participants for the study age groups, 890 (72%) were adults aged 50 to 70 years, of whom 464 (52%) were men. Of the 338 older adults (aged ≥71 years), 200 (59%) were men. All the NHANES participants included in our study had complete and valid data available. A few individuals with a dietary Ca:P ratio of 0 or >5 were removed from the study.

The dietary analyses included the estimated amounts of daily dietary intake of Ca and P. The estimated total daily intake of these minerals, including daily Ca supplements, was used to

calculate the dietary Ca:P ratios. The dietary consumption data were collected using two 24-hour recall sessions, one at the mobile examination center and the other by telephone. In addition, the NHANES used dietary supplement questionnaires to collect the frequency, type, and amount taken during the past 30 days for each supplement, and the averages were calculated.

Blood samples were not available for measurements of PTH or FGF-23. The BMI values were calculated using the participants' height and weight as measured by trained personnel during the routine NHANES examination.

The NHANES study protocol document and data set were obtained from https://wwwn.cdc.gov/nchs/nhanes/search/nhanes05_06.aspx.

B. Statistical Analysis

Both descriptive techniques and regression analysis were used to examine the study goals. All analyses accounted for the complex survey designs used in the data collection [19]. Specifically, the post-stratified sampling weights (based on US Bureau of Census) were used to account for the unequal probability of sample selection. The final sampling weights also accounted for nonresponse in the data. A descriptive analysis of the key study variables (femoral and lumbar BMD and dietary Ca:P ratio) was conducted first. That analysis was followed by regression analysis to assess the association between femoral and lumbar BMD and dietary Ca:P ratio. The study questions were examined separately stratified by age and sex.

In the descriptive analysis, we examined the summary measures of BMD by quintile of dietary Ca:P ratio stratified by age and sex groups. Simple linear regression analysis was used to examine the association between the BMD and dietary Ca:P ratio. In all models, the subject's BMI was included as a control variable. The survey procedures in SAS, version 9.4, TS1M1 (SAS Institute, Cary, NC) were used in all analyses.

C. Femoral and Lumbar BMD and Dietary Ca:P Ratio

The NHANES 2005 to 2006 used DXA measurements of the proximal femur and lumbar vertebrae for adult US participants. In accordance with the Hip Structural Analysis Program [20], scans were taken, not only of the BMD of the hip, but also of the structural geometry of cross-sections traversing the proximal femur at three specific locations, the narrow neck, intertrochanteric region, and shaft. Trained and certified technologists performed the DXA measurements on the proximal and lumber scans, using the Hologic QDR-4500A fan beam densitometer (Hologic, Inc., Bedford, MA). These measurements were nationally representative of the US population with a BMI < 30 kg/m^2.

We derived quintiles for the dietary Ca:P ratio stratified by sex and age groups. Each quintile contained 20% of the subgroup's members. We tested the hypothesis that a low dietary Ca:P ratio would adversely affect the BMD at the two fracture specific sites in the quintiles of older adults using regression analysis with BMI as a covariate. We also performed BMI-adjusted regression analyses using dietary Ca:P ratio as a continuous variable rather than categorized into quintiles.

2. Results

A summary of the age and sex sample sizes and estimated mean values of dietary Ca:P ratios and BMD measurements of the proximal femur and lumbar vertebrae is presented in Table 1. Younger age groups tended to have greater BMD than the older groups. The mean values and variability in BMD tended to be greater in men. Women in each age group had a greater dietary Ca:P ratio than the men in the corresponding age group. Older men had a greater dietary Ca:P ratio than that of the younger men. Also, men had greater dietary Ca and P amounts than women and greater amounts in the younger age group. The shift in the distribution of the dietary Ca:P ratios was greater for women than for men (Table 2). Also, for

Table 1. Age- and Sex-Specific Femoral and Spinal BMDs and Dietary Ca:P Ratios

	Men		Women	
Variable	**Age 50-70 y**	**Age ≥71 y**	**Age 50-70 y**	**Age ≥71 y**
Sample size	464	200	426	138
Weighted mean ± standard deviation of total proximal BMD	1.00 ± 0.18	0.94 ± 0.24	0.88 ± 0.15	0.76 ± 0.09
Weighted mean ± standard deviation of total lumbar BMD	1.06 ± 0.16	1.08 ± 0.25	0.98 ± 0.15	0.90 ± 0.16
Weighted mean ± standard deviation of Ca:P ratio	0.74 ± 0.32	0.91 ± 0.79	1.10 ± 0.64	1.09 ± 0.57
Weighted mean ± standard deviation of dietary Ca intake	1135.4 ± 704.9	1105.5 ± 694.3	1243.5 ± 852.6	1136.6 ± 689.9
Weighted mean ± standard deviation of dietary P intake	1522.8 ± 630.0	1257.9 ± 507.6	1127.25 ± 469.6	1046.4 ± 271.1

The BMD tends to decrease with age, although not always, and more so for women than for men.
Men tend to have greater BMD than women.
The lumbar BMD is greater than the femoral BMD.
Women in each age group had a greater dietary Ca:P ratio than the men in the corresponding age group.
Low dietary Ca and high dietary P intake support bone health (BMD) in men and women.

each sex, the shift in the distribution of the dietary Ca:P ratio was greater for the older group, except for the highest quintile for women.

The results of the effects of the dietary Ca:P ratio on femoral and lumbar BMD, respectively, across the dietary Ca:P quintiles and controlling for BMI are shown in Figs. 1 and 2. These data generally show that the adjusted BMD levels differed between age and sex groups but not within these same groups.

In another analysis (data not shown), we categorized each participant as having low, medium, or high Ca consumption and low, medium, or high P consumption, with separate categorization for each age and sex group. For each of the nine combinations of age and sex groups, we calculated the mean weighted femoral and lumbar BMD. The results of the analysis were consistent with the data listed in Table 1. A greater proportion of men than women were more likely to be in a high Ca and/or high P category. In general, men consumed greater amounts of dietary Ca and P than did the women and greater amounts in the younger age group than in the older age group.

3. Discussion

The hypotheses that a low dietary Ca:P ratio in the usual diet of older adults adversely affects the BMD of the proximal femur and lumbar vertebrae were not supported by our analyses.

Table 2. Estimated Mean ± Standard Deviation of Dietary Ca:P Ratio Quintiles Stratified by Age and Sex Subgroups

	Men		Women	
Quintile	**Age 50-70 y**	**Age ≥71 y**	**Age 50-70 y**	**Age ≥71 y**
1	0.39 ± 0.11	0.49 ± 0.08	0.53 ± 0.15	0.57 ± 0.09
2	0.57 ± 0.04	0.65 ± 0.04	0.73 ± 0.06	0.75 ± 0.03
3	0.68 ± 0.04	0.75 ± 0.04	0.88 ± 0.08	1.00 ± 0.09
4	0.80 ± 0.04	0.90 ± 0.06	1.21 ± 0.12	1.31 ± 0.12
5	1.11 ± 0.37	1.57 ± 1.36	1.93 ± 0.65	1.89 ± 0.25

These weighted mean dietary Ca:P ratios within sex- and age-specific dietary Ca:P ratio quintiles illustrate that the shift in the dietary Ca:P ratio distribution was greater for women than for men; also, for each sex group, the shift in the dietary Ca:P ratio distribution was greater for the older group, except within the highest quintile for women.

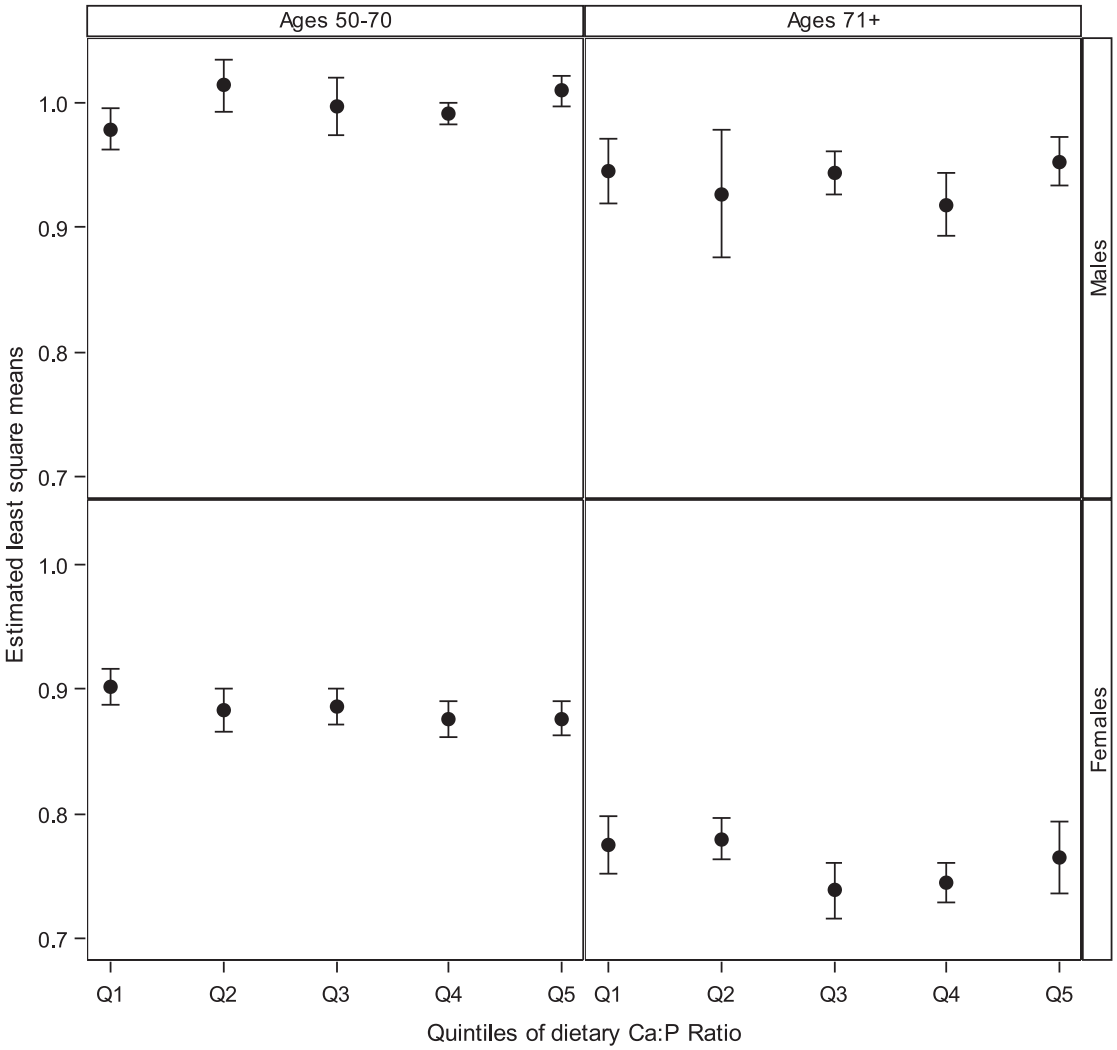

Figure 1. BMI-adjusted dietary Ca:P ratio least square mean for each quintile for femoral BMD. Although the BMI-adjusted least square mean values for femoral BMD varied by age group and sex, they did not vary much across the dietary Ca:P ratio quintile within each age and sex group. Overall, men had a higher dietary Ca:P ratio than women in both age groups, although little difference was found for each level within the quintile groups. Greater variability was observed in the mean dietary Ca:P ratios for men than for women in both age groups.

The weighted estimates for BMD measurements were not different when stratified by quintile of dietary Ca:P ratio within any of the four groups defined by age and sex. Despite a likely short-term elevated serum PTH response to a meal with a low dietary Ca:P ratio, the serum P concentration was apparently promptly and homeostatically corrected by both PTH and FGF-23 in the postmeal period, and the short-term elevation had little or no long-term effects on bone mass or density [6–10].

For both age groups, women had greater estimated mean dietary Ca:P ratios than did their male counterparts, and each sex had similar variability. As observed previously, women with high dietary Ca:P ratios typically consumed greater amounts of supplemental Ca [17].

Our analyses suggest that a broad range of dietary Ca and P intake is beneficial to the bone health of both older men and women. A low dietary Ca:P ratio did not contribute to low mean BMD measurements of the hip and spine in either age group.

In subgroup-specific BMI-adjusted models for BMD using quintiles of dietary Ca:P ratios, substantial differences in pairwise comparisons among the quintiles appeared only for lumbar BMD in older women, in whom the quintile 3 mean seemed anomalously low, most

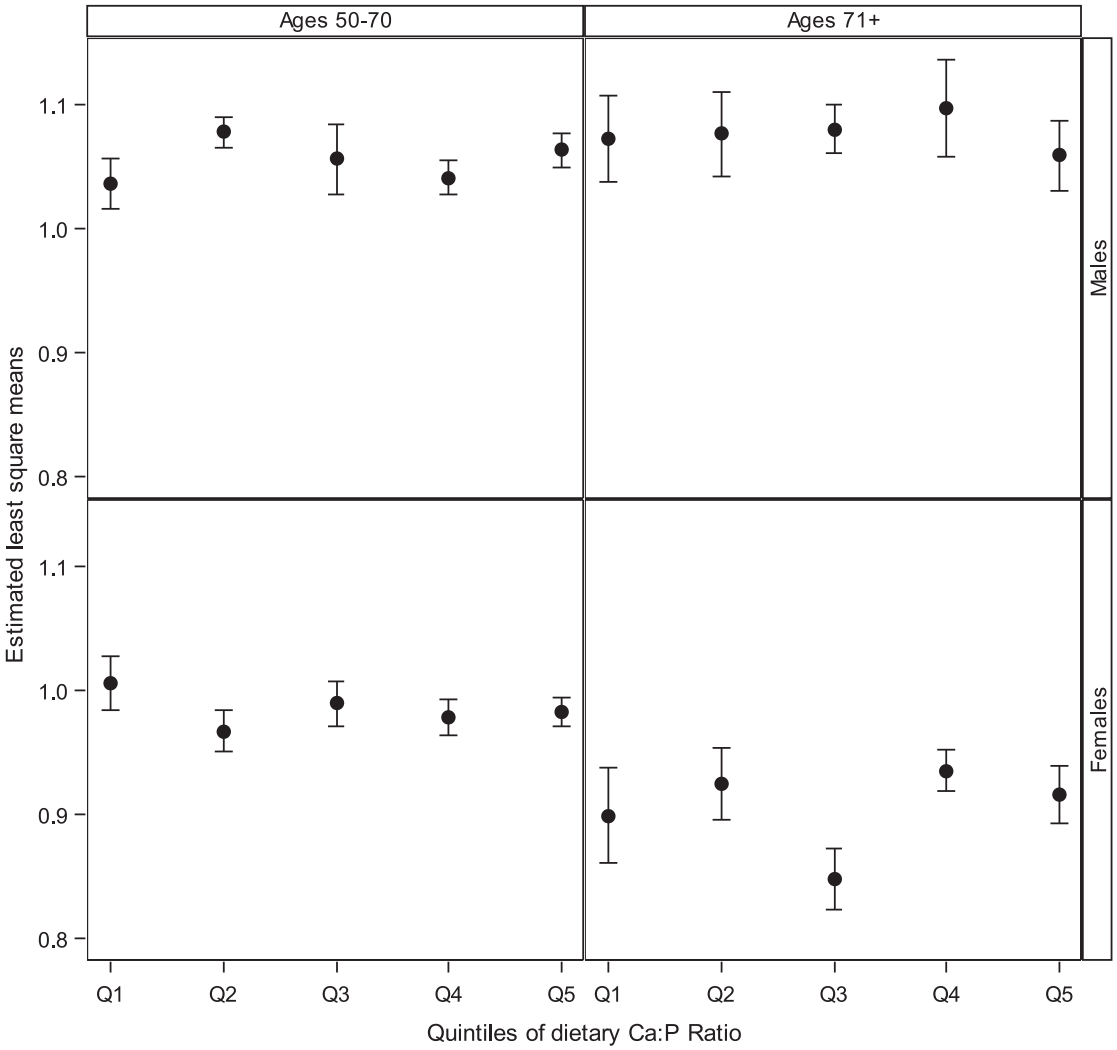

Figure 2. BMI-adjusted dietary Ca:P ratio least square mean for each quintile for spinal BMD. Greater variability in the least square mean estimates was observed compared with the data shown in Fig. 1. Although the BMI-adjusted least square mean values for lumbar BMD varied somewhat by age group and sex, they did not vary much across the dietary Ca:P ratio quintiles within each age and sex group. Similarly, men had comparable mean dietary Ca:P ratios in both age groups, with much greater variability in the older age group. Younger women had greater dietary Ca:P ratios than older women, also with greater variability.

probably by chance. In addition, no relationship between the BMD and dietary Ca:P ratio was found in our BMI-adjusted models using the dietary Ca:P ratio as a continuous variable. Although the BMI was an important predictor of both lumbar and femoral BMD for each subgroup, in no case, was the dietary Ca:P ratio an important predictor.

The study limitations included the reliance on cross-sectional data rather than prospective findings of the dietary intake of Ca and P in relation to the BMD measurements at the two critical skeletal sites where fractures are most prevalent. Also, the NHANES strategy of random sampling of participants did not permit longitudinal assessments. Additionally, the assumption that participants continued their long-term pattern of food consumption could not be ensured. Finally, the lack of FGF-21 and PTH measurements from the participants' blood samples limited our complete understanding of the roles of the two major potential homeostatic mechanisms regulating serum phosphate levels.

The major finding of the present cross-sectional analysis suggests that the dietary Ca:P ratio of the diets of older adults has little or no long-term effects on the BMD measurements at

the proximal hip and lumbar vertebrae in participants with normal renal function. Although the serum PTH and FGF-23 were not measured in the present study, we presumed that these two phosphate-regulating hormones operated appropriately in response to greater dietary intake of P and any Ca:P ratio. Comparing the quintiles of the mean dietary Ca:P intake for each sex and age group, younger adults had lower mean dietary Ca:P ratios for each quintile, although not with correspondingly less variability (Table 2). Our analyses of the femoral and vertebral BMD measurements of older adults across the dietary Ca:P ratio quintiles did not support the concept that high P intake contributes to bone loss and osteoporosis [21]. Earlier reports of this concept did not factor in the recently discovered phosphaturic effect of FGF-23.

4. Conclusions

The intake of Ca, including both food and supplement sources, had little or no influence on the homeostatic regulation of serum P [15, 16]. Furthermore, chronic low dietary Ca:P ratios did not contribute to a lower BMD in older adults. Older men typically maintained greater femoral and spinal BMD values than older women across the quintiles of dietary Ca:P ratios. In the present cross-sectional study, a more optimal dietary Ca:P ratio in which greater amounts of Ca are consumed, with or without supplements, did not result in greater BMD at the two skeletal sites of common fractures. The amount of P in the diet had relatively little influence on the BMD of the hip and lower spine of older adults when renal function remained normal.

The Recommended Dietary Allowances of calcium for older adults (*i.e.,* 1000 to 1200 mg/d) set by the Institute of Medicine [22] appear to be more than adequate for bone maintenance by elderly men and women. Although substantial differences were not found for the mean BMD measurements across the quintiles of increasing dietary Ca:P intake ratios, older adults did consume diverse amounts of Ca and P, which significantly modified their dietary Ca:P ratios. Neither low nor high dietary Ca:P ratios had an effect on the lumbar vertebra and proximal femoral hip BMD measurements in this older sample of NHANES participants.

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