

Research article

Open Access

Cognitive function in relation with bone mass and nutrition: cross-sectional association in postmenopausal women

Rhonda A Brownbill and Jasminka Z Ilich*

Address: University of Connecticut, Division of Health and Human Development, School of Allied Health, Storrs, CT, USA

Email: Rhonda A Brownbill - brownbillr@cs.com; Jasminka Z Ilich* - jasminka.ilich@uconn.edu

* Corresponding author

Published: 26 May 2004

Received: 06 February 2004

BMC Women's Health 2004, 4:2

Accepted: 26 May 2004

This article is available from: <http://www.biomedcentral.com/1472-6874/4/2>

© 2004 Brownbill and Ilich; licensee BioMed Central Ltd. This is an Open Access article: verbatim copying and redistribution of this article are permitted in all media for any purpose, provided this notice is preserved along with the article's original URL.

Abstract

Background: It has been suggested that bone loss and cognitive decline are co-occurring conditions, possibly due to their relationship with estrogen. Cognitive decline has been associated with various nutritional deficiencies as well. The purpose of this study was to determine if cognitive function is related to bone mineral density of various skeletal sites as well as to various dietary components.

Methods: Cross-sectional study with 97 healthy, Caucasian, postmenopausal women (59.4–85.0 years) enrolled in a larger longitudinal study, investigating the effects of sodium on bone mass. The subjects were divided into two groups based on cognition scores. Group 1 represented lower and Group 2 higher scores on cognitive function. Bone mineral density from the whole body, lumbar spine, femur and forearm were measured with the Lunar DPX-MD instrument. Anthropometry was measured by standard methods. Cognition was assessed using the Mini Mental State Examination. Cumulative (over 2 years) dietary intake from 3-day records was analyzed by Food Processor® (ESHA Research, Salem, OR) and cumulative physical activity was assessed using Allied Dunbar National Fitness Survey for older adults.

Results: Subjects' cognition scores ranged from 22–30 (normal, 27–30), indicating all subjects had either mild or no cognitive impairment. Multiple Analysis of Covariance adjusted for age, height, weight, physical activity, alcohol, calcium, sodium and energy intake, showed a statistically significant association between cognition and bone mineral density of all measurable sites ($\eta^2 = 0.21$, $P < 0.01$). However, after Analysis of Covariance follow-up tests and Bonferroni correction, the differences for individual bone sites diminished, though Group 2 had higher adjusted means for all sites except for the femoral neck, Ward's triangle and trochanter. There was a positive significant association between cognition score and carbohydrate and potassium intake ($\eta^2 = 0.07$, $P = 0.050$). Group 2 did have a significantly higher potassium intake ($P = 0.023$). In multiple regression, saturated fat had a significant negative relationship with cognitive function.

Conclusions: It appears mild degree of cognitive impairment may be a marker for lower bone mineral density as well as for a diet lower in carbohydrate and potassium intake, and higher in saturated fat. Consequently, older women with cognitive impairment may benefit of being screened for potential bone loss and poor nutrition.

Background

It is well known that a decline in estrogen is related to bone loss and possibly a loss in cognitive function as well. It has been suggested that bone loss and cognitive decline are co-occurring conditions, likely due to their relationship with estrogen [1,2]. Recent studies suggest estrogen replacement therapy may benefit cognitive function in postmenopausal women without memory impairment [3]. Other studies report estrogen therapy may benefit women with Alzheimer's disease (AD) [4] or those at risk for AD [5]. Conversely, studies also report estrogen deficiency is not associated with poor cognitive function [6]. These conflicting results could be due to various reasons, including the type of cognitive assessment tool, inclusion (or not) of confounders, degree of cognitive decline, age of the subjects, to name just a few.

Few studies have examined the relationship between cognitive function and bone mineral density (BMD), both as possible markers of cumulative estrogen exposure. Two studies found a positive relationship with total hip BMD [1,2] and femoral neck BMD [1] and cognitive function in older adults presumably due to higher cumulative exposure to estrogen [1,2]. Women with osteoporosis were found to have poorer cognitive function (presumably due to lower estrogen exposure) [2]. However, both of these studies used elderly subjects with significant cognitive impairment and/or history of osteoporotic fractures and one of them [1] did not control for physical activity, a significant predictor of both BMD [7] and cognitive function [8].

Both cognitive function and BMD also depend on various nutrients in food. Studies have found elderly people who performed better on cognitive tests had higher intakes of energy, fruits, vegetables, fiber, carbohydrate, protein, B-vitamins, vitamins A and C, calcium, phosphorus and iron [9-11], and overall better healthy diet score [12]. In general, it appears a more balanced diet that contains more vitamins and minerals is associated with better cognitive function. Substantial research in the past decade has focused on the relationship between antioxidants from diet and/or supplements and cognitive function. However, no clear consensus has been reached as to whether taking antioxidant supplements will help preserve cognitive function and prevent the development of dementia. Some studies suggest vitamin E [13,14], vitamin C [15] and beta-carotene [15,16] positively benefit cognitive function, while other studies have not found a relationship between vitamin E [16,17], vitamin C [13,14,16-18] or beta-carotene [13,17,18] and cognitive function. There is also controversy as to whether particular fats in the diet are beneficial or potentially harmful to cognitive function due to their relation to the development of atherosclerosis,

thrombosis, and inflammation of arterial walls [17,19].

Due to the above inconsistencies and uncertainties in the literature we investigated cognitive function and its relationship with bone, as well as with nutrients from both diet and supplements, in healthy postmenopausal women with either no or mild cognitive impairment. Our research questions were as follows: 1) Does bone mass in various skeletal sites differ by cognitive function among postmenopausal women when controlling for confounders known to impact bone, such as age, height, weight, hours of total activity, alcohol consumption and total energy, sodium and calcium intake? 2) How do various nutrients in the diet relate to cognitive function in postmenopausal women when controlling for the above confounders?

Methods

Subjects

This cross-sectional evaluation included 97 currently non-smoking, Caucasian, postmenopausal women free of chronic diseases (including severe osteoporosis) and medications (including estrogen) known to affect bone. All subjects reported at least 12 years of education (high school graduate), with many having additional college education. Subjects were part of a larger longitudinal study investigating the effects of a reduced sodium intake on bone, as described previously [20] and were randomly asked to participate in this study. Subjects were instructed to maintain a calcium intake of 1200 mg a day, the current recommended adequate intake [21], and were given calcium citrate supplements, if necessary, to assure adequate calcium intake throughout the study (as per the protocol of a larger study). All data for this study were collected by one person, a registered dietitian (RAB). The Institutional Human Subjects Review Board approved study protocol and subjects signed informed consent.

Anthropometry and bone densitometry

Weight and height were measured by standard procedures in indoor clothes without shoes. BMD (g/cm^2) was measured by dual X-ray absorptiometry with a Lunar DPX-MD instrument (GE Medical Systems, Madison, WI, USA) using specialized software for whole body, lumbar spine, femur (neck, trochanter, Ward's triangle and shaft) and forearm (including radius and ulna), as described previously [22]. The BMD and anthropometries, were measured every 6 months throughout the study, but only those obtained at the time when cognition test was given (usually in a second year of the study) were used in analyses and in relation to cognitive status. Quality assurance of our densitometer was performed daily and coefficients of variation and precision of the instrument were reported previously [22].

Cognitive assessment

Cognition was assessed using the Mini Mental State Examination (MMSE) [23]. The MMSE is a brief, commonly used screening tool to assess cognitive status. It consists of various graded questions and tasks generating a maximum of 30 possible points. Each subject was asked a series of questions from eleven categories; orientation to time, orientation to place, registration, attention and calculation, recall, naming, repetition, comprehension, reading, writing and drawing. Scores are classified as: normal cognitive function with a score of 27–30; mild cognitive impairment with a score of 21–26; moderate cognitive impairment with a score of 11–20; and severe cognitive impairment with a score of 0–10 [24]. Cognitive function for each subject was assessed one time, usually in the second year of the study, and evaluated with the corresponding bone and anthropometric measurements conducted at that time, or with the cumulative average of other variables of interest.

Dietary and alcohol consumption assessment

Subjects were instructed by a registered dietitian to record 3 days of dietary intake (2 week and 1 weekend day) every 6 months during the study. Food models and pictures were used for instruction. After the records were completed, the same dietitian followed-up and rechecked every record with each participant, particularly about additional food or snacks consumed, portion sizes, and ways of preparation. The same dietitian analyzed nutrient intake from the records using Food Processor® (ESHA Research, Salem, OR). Mean daily intake, including total energy and all other macro- and micronutrients (vitamins, minerals and fatty acids) was calculated. Supplement use was recorded during each visit, as well. The detailed description of diet assessment is reported earlier [20]. Cumulative average intake of each considered nutrient, to the point of the cognition assessment (usually in a second year), was used to assess its relationship with cognitive functioning. Alcohol consumption was assessed using questionnaire designed to determine long-term (at least for a last year and extending back to several years), frequency, amount, and source of intake, with the help of the same dietitian. It was expressed as drinks per day, from which g/day of alcohol was calculated, as described previously [25].

Physical activity

Physical activity (PA) was assessed using the modified Allied Dunbar National Fitness Survey for older adults [26] and was collected every 6 months. A measure of total activity was assessed based on minutes per week engaged in weight bearing activities of a moderate intensity defined as an activity of at least 4 kcal/min, such as recreational activities (tennis, hiking, weight lifting), walking, heavy housework, gardening and do-it-yourself activities.

Data collected included frequency and duration of each activity and were expressed as number of hours per week engaged in the above activities. The questionnaire was filled with the participants on the site and with the help of a dietitian. We used this questionnaire in our previous studies in postmenopausal women and found it reliable and easy to complete [27]. Cumulative average activity score to the point of the cognitive assessment was used in the subsequent analyses.

Data analysis

Data analysis was conducted with SPSS statistical software (version 8.0). Pearson's *r* was calculated among all variables, as a preliminary analysis. To determine the relationship between cognitive function and BMD, subjects were divided into two groups based on the mean (27.9) for the MMSE score. Group 1 comprised of subjects below and group 2 of subjects above the mean. One-way Analysis of Variance (ANOVA) was conducted for various bone sites and covariates to determine if there were significant group differences. Multiple Analysis of Covariance (MANCOVA) with univariate follow-up tests and Bonferroni corrections to the alpha level were used to check for group differences in BMD of the whole body, all sites of the hip (neck, trochanter, Ward's triangle and shaft), lumbar spine and forearm. Subjects' age, height, weight, hours of total activity, alcohol consumption and total energy, calcium and sodium intake were included in the analysis as confounders. The use of these confounders was based on scientifically proven and theoretically presumed evidence for their possible effects on bones and memory.

To determine the relationship between cognitive function and diet, subjects were divided into two groups based on MMSE criteria for normal cognitive function (score of ≥ 27). Group 1 (< 27), was considered to have mild cognitive impairment while Group 2 (≥ 27), was considered to have normal cognitive function. Multiple regression models were calculated to find the best model using various nutrients to predict cognitive function. ANOVA was conducted for all nutrients and covariates. MANCOVA with confounders (described above) and univariate follow-up tests were used to check for group differences in nutrient intake. Significance level was set at $P \leq 0.05$.

Declaration of sources of funding

This work was funded in part by the NRI/USDA 2001-00836, Donaghue Medical Research Foundation DF98-056, University of Connecticut Office for Sponsored Programs and Mission Pharmacal®, San Antonio, TX, USA. The financial sponsors played no role in the design, execution, analysis and interpretation of data, or in writing the study.

Table 1: Mean $\pm$ SD for descriptive characteristics of all subjects and for each group¹

Variable	Group 1 n = 34	Group 2 n = 63	All Subjects n = 97
Age	69.7 $\pm$ 6.9	69.7 $\pm$ 6.7	69.7 $\pm$ 6.7
Weight (kg) ²	63.9 $\pm$ 9.0	70.7 $\pm$ 11.9	68.3 $\pm$ 11.4
Height (cm)	160.6 $\pm$ 6.1	161.6 $\pm$ 7.3	161.2 $\pm$ 6.9
MMSE score ³	25.4 $\pm$ 1.5	29.2 $\pm$ 0.8	27.9 $\pm$ 2.1
Alcohol (drinks/day)	0.4 $\pm$ 0.6	0.3 $\pm$ 0.5	0.3 $\pm$ 0.5
Energy (kcal/day)	1596 $\pm$ 252	1645 $\pm$ 345	1628 $\pm$ 315
Total calcium (food and supplements) (mg/day)	1426 $\pm$ 350	1438 $\pm$ 279	1434 $\pm$ 304
Sodium (mg/day)	2114 $\pm$ 661	2322 $\pm$ 955	2249 $\pm$ 866
Total Activity (hr/wk)	5.4 $\pm$ 3.7	6.3 $\pm$ 6.0	6.0 $\pm$ 5.3

¹Groups were stratified to below (Group 1) and above (Group 2) the mean for cognitive function score of 27.9 ²statistically significant difference between groups, $P < 0.01$ ³ Mini Mental State Examination score

Results

Cognitive function and BMD

All bone sites, whole body, hip (neck, trochanter, Ward's triangle and shaft), spine and forearm, were sufficiently highly correlated with each other, as expected (r ranged from 0.43–0.98, $P = 0.0001$), to justify the use of MANCOVA for this data set. Subjects' mean MMSE score was 27.9, with a range of 22–30, indicating all subjects had either mild or no cognitive impairment (Table 1). Descriptive statistics for each group and all subjects combined are presented in Table 1. ANOVA was conducted to assess group differences for age, height, weight, total activity, alcohol consumption, and energy, sodium and calcium intake. Group 2 had significantly higher body weight ($F_{1,95} = 8.57$, $P = 0.004$) than Group 1, while other variables of interest were not significantly different.

MANCOVA was conducted for the above groups to determine the relationship between cognitive function and BMD for whole body, all sites of the hip, lumbar spine and forearm. Box-M test was not significant indicating the observed covariance matrices of the dependent variables were equal across both groups: Box-M = $F(28,15625) = 30.11$, $P = 0.502$. Levene test revealed the error variance of the dependent variables was equal across both groups, P ranged from 0.407 to 0.948. MANCOVA results revealed statistically significant differences between the two groups of subjects, Wilks' $\Lambda = 0.79$, $F(7,77) = 2.96$, $P = 0.009$, multivariate $\eta^2 = 0.21$. Several of the covariates significantly influenced the combined dependent variables: total activity, Wilks' $\Lambda = 0.79$, $F(7,77) = 2.93$, $P = 0.009$, multivariate $\eta^2 = 0.21$; weight, Wilks' $\Lambda = 0.73$, $F(7,77) = 4.11$, $P = 0.001$, multivariate $\eta^2 = 0.27$; and age, Wilks' $\Lambda = 0.72$, $F(7,77) = 4.28$, $P = 0.001$, multivariate $\eta^2 = 0.30$. ANCOVA with Bonferroni correction to the alpha level (P , 0.05/7 variables = 0.007) was conducted on each dependent variable as a follow-up test to MANCOVA. The significance between groups slightly diminished, but the trend

remained. Table 2 lists the adjusted and unadjusted means of BMD for each group at each bone site. Group 2 had higher unadjusted BMD for all sites except for the Ward's triangle, and higher adjusted means for all sites except for the femoral neck, Ward's triangle, and trochanter. Groups were significantly different using Bonferroni correction to the alpha level for several of the covariates: weight was significantly different for all sites of the hip BMD; total activity was significantly different for the femoral neck and Ward's triangle BMD; and age was significantly different for forearm BMD.

Cognitive function and diet

To explore the relationship between diet and cognitive function we calculated Pearson's r for all variables. Both carbohydrate and total potassium intake (food and supplements) were significantly correlated to MMSE score, $r = 0.22$, $P = 0.029$ and $r = 0.20$, $P = 0.048$, respectively. In a multiple regression model containing age, height, total activity, alcohol consumption, and total vitamins B₆, B₁₂, C, A, and E intake, the latter implied in some studies to having influence on cognition) weight and energy were positive predictors and saturated fat intake (mean $\pm$ SD = 18.8 g $\pm$ 8.0 g) was a negative predictor of MMSE, with multiple $R^2_{\text{adjusted}} = 0.071$.

Subjects were divided into two groups based on MMSE criteria for normal and impaired cognition, with Group 1 classified as mild cognitive impairment (MMSE score < 27), and Group 2 classified as normal cognitive impairment (MMSE score ≥ 27). ANOVA was conducted to assess group differences for age, height, weight, total activity, alcohol consumption and energy intake. Body weight was significantly higher in group 2, ($F_{1,95} = 8.57$, $P = 0.004$), whereas other variables of interest were not different between groups, P ranged from 0.235 to 0.980.

Table 2: Adjusted¹ (in bold) and unadjusted means $\pm$ SD, with corresponding P values of bone mineral density (BMD) of each bone site for two groups² of subjects

Bone Site (BMD) (g/cm ²)	Group 1	Group 2	P-values
Femoral Neck	0.825 0.795 $\pm$ 0.09	0.822 0.838 $\pm$ 0.12	0.883 0.093
Ward's Triangle	0.731 0.700 $\pm$ 0.11	0.678 0.691 $\pm$ 0.14	0.042 0.820
Trochanter	0.758 0.719 $\pm$ 0.12	0.742 0.761 $\pm$ 0.13	0.776 0.093
Femoral Shaft	1.036 0.999 $\pm$ 0.13	1.041 1.057 $\pm$ 0.17	0.838 0.062
Lumbar Spine ³	1.082 1.057 $\pm$ 0.16	1.099 1.113 $\pm$ 0.21	0.659 0.237
Forearm ⁴	0.431 0.426 $\pm$ 0.05	0.445 0.448 $\pm$ 0.67	0.265 0.173
Whole Body	1.083 1.067 $\pm$ 0.08	1.090 1.098 $\pm$ 0.92	0.672 0.101

¹ Adjusted for age, height, weight, total hours of current activity a week, alcohol consumption, and total energy, calcium and sodium intake, ²Groups were stratified to below (Group 1) and above (Group 2) the mean for cognitive function score of 27.9 ³BMD of the second, third and fourth lumbar vertebrae ⁴BMD of the ulna and radius

MANCOVA for the above groups was conducted to determine the relationship between cognitive function and carbohydrate and total potassium intake, as combined dependent variables. MANCOVA results revealed a statistically significant difference among the two groups of subjects, Wilks' $\Lambda = 0.93$, $F(2,86) = 3.11$, $P = 0.050$, multivariate $\eta^2 = 0.07$. Energy intake was significantly related to carbohydrate and total potassium intake, Wilks' $\Lambda = 0.38$, $F(2,86) = 69.61$, $P = 0.0001$, multivariate $\eta^2 = 0.62$. ANCOVA was conducted for potassium and carbohydrate as a follow-up test to MANCOVA. After Bonferroni correction to the alpha level (P , 0.05/2 variables = 0.025), total potassium intake was significantly different between groups, $P = 0.023$, with multivariate $\eta^2 = 0.058$. Table 3 lists the adjusted and unadjusted means of carbohydrate and total potassium intake for each group. Group 2 had higher unadjusted and adjusted means for both variables. Groups were significantly different using Bonferroni correction to the alpha level in energy intake for both carbohydrate and total potassium intake, $P = 0.0001$.

Discussion

Our results suggest subjects with lower MMSE scores had overall lower bone mass than subjects with higher MMSE scores. MANCOVA results indicated a moderate effect ($\eta^2 = 0.21$), or 21% of generalized variability in BMD from the whole body, all sites of hip, spine and forearm is accounted for by differences in MMSE scores after correcting for subjects' age, height, weight, total activity, alcohol consumption, and total energy, calcium and sodium intake. Unadjusted group means were lower in Group 1 (MMSE score <27.9) for all bone sites except the Ward's

Table 3: Adjusted¹ (in bold) and unadjusted means $\pm$ SD for average intake of carbohydrates and total potassium for two groups² of subjects

Nutrient	Group 1	Group 2
Carbohydrate (g/day)	206 200 $\pm$ 36	216 218 $\pm$ 44
Total Potassium (mg/day) ³	2527 2478 $\pm$ 522	2831 2846 $\pm$ 553

¹ Adjusted for age, height, weight, total hours of activity/week, alcohol consumption and total energy intake ²Groups were stratified to below (Group 1) and above (Group 2) the normal cognitive function score of 27 ³significantly different between groups, $P = 0.02$

triangle (Table 2). However, with the ANCOVA follow-up tests to MANCOVA the group differences for individual bone sites diminished. Several of the confounders had a significant influence on various bone sites, which might have accounted for the diminished significance with ANCOVA. Additionally, stronger statistical significance may have been reached in other bone sites with more subjects in each group.

Our results based on unadjusted means, agree with Yaffe et al, who also found older women with poor cognitive function to have lower total hip BMD [2]. Zhang et al, found elderly men and women with moderate verbal memory impairment (a measure of cognitive function) to also have lower femoral neck BMD [1]. Lui et al [28] in a large prospective cohort study of over 4000 women found

those with more rapid total hip bone loss were more likely to have a decline in cognitive function than those who had lower rates of bone loss. It therefore appears based on the above evidence lower levels of cognitive function are associated with lower hip BMD. The above researchers did not measure the whole body, lumbar spine or forearm to assess their relationship with cognitive function. In our study, these bone areas were significantly lower in subjects with lower MMSE scores although the statistical significance slightly diminished after the univariate follow-up tests.

We attribute the diminished difference between the groups to several factors. First, the average score on the MMSE in our subjects was 27.9, which is considered normal cognitive function [24], indicating on average our subjects were not cognitively impaired. Group 1 (MMSE score of <27.9) had only 34 subjects, and 10 of them had a score of 27, which is considered normal. Therefore out of 97 subjects only 24 had a MMSE score between 22–26 (mild cognitive impairment), and 73 were in the normal range for cognition. If there were more subjects with mild cognitive impairment, stronger significant group differences may have been reached even after the correction tests. Second, subjects in Group 1 had significantly lower weight than those in Group 2. Lower weight is associated with lower bone mass [27,29]. In this data set weight was a stronger predictor for BMD than MMSE score, and when entered as a co-variate in MANCOVA, statistical significance was diminished in univariate follow-up tests. Third, the MMSE only measures overall cognitive function. Measuring verbal memory specifically, similarly to Zhang et al [1], may have shown a stronger positive relationship with BMD.

Regarding diet, the main finding was that total potassium intake was significantly higher in subjects with normal cognitive function compared to subjects with mild cognitive impairment. When comparing adjusted means, it appears about 300 mg of additional potassium a day may positively benefit cognitive function. MANCOVA results indicated a small effect ($\eta^2 = 0.07$), or about 7% of generalized variability in both potassium and carbohydrate intake was accounted for by differences in MMSE scores after correcting for subjects age, height, weight, total activity, average daily alcohol consumption and vitamins intake. Adjusted means for both potassium and carbohydrate intake were higher in Group 2 (normal cognitive function). It is possible that both carbohydrate and total potassium intake may have served as markers for a diet higher in fruits and vegetables (excellent sources of both carbohydrates and potassium). Such kind of diet may benefit cognitive function in older women. This research supports the findings of other studies, which found older people who consume more of the above foods to have

better cognitive function than people who consume less [9-12]. None of the other nutrients in our study examined by MANCOVA were significant predictors of cognitive function.

Saturated fat was a significant negative predictor of MMSE score in multiple regression analysis, which agrees with the findings of Ortega et al [9]. They found elderly people with scores of 28 or higher on the MMSE to have lower intakes of saturated fat. The Rotterdam study found no significant relationship with any type of fat in the diet and risk of dementia or its subtypes in a prospective evaluation in over 5,000 elderly subjects [19]. These subjects had a normal cognition at baseline and the diet was compared with the incidence of a diagnosis of dementia after a mean follow-up of 6 years. However, the researchers did not measure cognitive function in their subjects so it is not known whether milder cases of cognitive decline such as in our study may be related negatively to saturated fat intake.

There are a few limitations to our study. Although some variables were expressed as cumulative averages collected within 2-year period, this is a cross-sectional evaluation with respect of cognitive functioning that was evaluated only once. Therefore all findings have to be taken within that context and within the limitations of cross-sectional study. Education level was not controlled for, which has been found to affect individual scores on the MMSE [24]. However, this study population did report having at least a high school education and many reported having a college education as well. None of the subjects were currently using estrogen but 14 reported past estrogen use for a short time (up to 1 year). The past-estrogen use was not controlled for, however, in our previous analyses, it did not influence BMD or MMSE scores for those individuals [20,27]. We used two criteria for determining the cut-off levels for MMSE scores on which to stratify subjects into groups. One was the internal criterion (mean for MMSE score of 27.9) and was used for the evaluation of the relationship between BMD and cognition. Another was an external criterion distinguishing normal from cognitively impaired subjects (MMSE score of 27) and was used for the evaluation of the relationship between diet and cognition. We performed all analyses with each cut-off level, and although the results were similar, those based on above described stratification showed slightly higher significance and therefore they are reported.

Our study also has several strengths and is distinct with respect to a comprehensive approach in measuring and evaluating BMD of various skeletal sites, precise identification and inclusion of covariates and analysis of their independent effect on bone and/or cognition, as well as the comprehensive dietary and activity assessment. By

using MANCOVA we were able to simultaneously evaluate all measurable skeletal sites and their relationship with MMSE scores and consequently strengthen the overall conclusion. An important issue in this context is possible interaction among age, BMD, cognitive function and dietary intake and physical activity. For example, age alone may be responsible for both the decline in BMD and cognitive function, hence the association between the two. A similar case could be made for dietary intake and physical activity. In order to overcome these effects, all our analyses were performed with taking into account the variables that might interact, be co-linear, and/or independently influence either BMD or cognition. The dietary and activity assessment was a result of a cumulative average over a 2-year period. This provides additional strength to the data and the assurance that both assessments are fairly accurate and representative of subjects' long term intake and activity, not necessarily a case in some other studies.

Conclusions

It appears based on the findings of this study and others, mild degrees of cognitive impairment may be associated with lower levels of BMD specifically in the hip. Lumbar spine and forearm BMD seems to be slightly lower (2–3%) in subjects with lower MMSE scores, based on adjusted means in our study, but clearly more research is needed to determine these relationships. Our findings also indicate a diet containing carbohydrate sources that are also high in potassium such as fruits and vegetables may benefit cognitive function, while saturated fat may influence it negatively. A prudent action (if practical and possible) may be the evaluation of bone status and dietary intake in older women presenting with cognitive impairment, for both potential bone loss and poor diet lacking in good sources of potassium and containing excess amounts of saturated fat.

Competing interests

None declared.

Authors' contributions

RAB carried out the nutritional assessment and analysis, bone and anthropometric measurements and cognitive and physical activity surveys, as well as wrote the draft of the manuscript. JZI conceived and designed the study, obtained the funding, and wrote the final version. Both authors contributed in the statistical analysis and read and approved the final manuscript

Acknowledgements

This work was funded in part by the NRI/USDA 2001-00836, Donaghue Medical Research Foundation DF98-056, University of Connecticut Office for Sponsored Programs and Mission Pharmacal®, San Antonio, TX, USA. The financial sponsors played no role in the design, execution, analysis and interpretation of data, or in writing the study.

References

1. Zhang Y, Seshadri S, Ellison RC, Heeren T, Felson DT: **Bone mineral density and verbal memory impairment: Third National Health and Nutrition Examination Survey (NHANES III).** *Am J Epidemiol* 2001, **154**:795-802.
2. Yaffe K, Browner W, Cauley J, Launer L, Harris T: **Association between bone mineral density and cognitive decline in older women.** *J Am Geriatr Soc* 1999, **47**:1176-1182.
3. Maki PM, Zonderman AB, Resnick SM: **Enhanced verbal memory in nondemented elderly women receiving hormone-replacement therapy.** *Am J Psychiatry* 2001, **158**:227-233.
4. Asthana S, Baker LD, Craft S, Stanczyk FZ, Veith RC, Raskind MA, Plymate SR: **High-dose estradiol improves cognition for women with AD: results of a randomized study.** *Neurology* 2001, **57**:605-612.
5. Marks SJ, Batra RR, Frishman WH: **Estrogen replacement therapy for cognitive benefits: viable treatment or forgettable "senior moment"?** *Heart Dis* 2002, **4**:26-32.
6. Kritiz-Silverstein D, Barrett-Connor E: **Hysterectomy, oophorectomy, and cognitive function in older women.** *J Am Geriatr Soc* 2002, **50**:55-61.
7. Marcus R: **Role of exercise in preventing and treating osteoporosis.** *Rheum Dis Clin North Am* 2001, **27**:131-141.
8. Yaffe K, Barnes D, Nevitt M, Lui L, Covinsky K: **A prospective study of physical activity and cognitive decline in elderly women.** *Arch Intern Med* 2001, **161**:1703-1708.
9. Ortega RM, Requejo AM, Andres P, Lopez-Sobaler AM, Quintas ME, Redondo MR, Navia B, Rivas T: **Dietary intake and cognitive function in a group of elderly people.** *Am J Clin Nutr* 1997, **66**:803-809.
10. Lee L, Kang SA, Lee HO, Lee BH, Park JS, Kim JH, Jung IK, Park YJ, Lee JE: **Relationships between dietary intake and cognitive function level in Korean elderly people.** *Public Health* 2001, **115**:133-138.
11. La Rue A, Koehler KM, Wayne SJ, Chiull SJ, Haaland KY, Garry PJ: **Nutritional status and cognitive function in a normally aging sample: a 6-yr reassessment.** *Am J Clin Nutr* 1997, **65**:20-29.
12. Correa Leite ML, Nicolosi A, Cristina S, Hauser WA, Nappi G: **Nutrition and cognitive deficit in the elderly: A population study.** *Eur J Clin Nutr* 2001, **55**:1053-1058.
13. Morris MC, Evans DA, Bienias JL, Tangney CC, Wilson RS: **Vitamin E and cognitive decline in older persons.** *Arch Neurol* 2002, **59**:1125-1132.
14. Grodstein F, Chen J, Willet WC: **High-dose antioxidant supplements and cognitive function in community-dwelling elderly women.** *Am J Clin Nutr* 2003, **77**:975-984.
15. Perrig WJ, Perrig P, Stahelin HB: **The relation between antioxidants and memory performance in old and very old.** *J Am Geriatr Soc* 1997, **45**:718-724.
16. Warsama Jama JW, Launer LJ, Witterman JH, den Breeijen JH, Breteler MMB, Grobbee DE, Hofman A: **Dietary antioxidants and cognitive function in a population-based sample of older persons. The Rotterdam Study.** *Am J Epidemiol* 1996, **144**:275-280.
17. Kalmijn S, Feshens EJ, Launer LJ, Kromhout D: **Polyunsaturated fatty acids, and cognitive function in very old men.** *Am J Epidemiol* 1997, **145**:33-41.
18. Perkins AJ, Hendrie HC, Callahan CM, Gao S, Unverzagt FW, Xu Y, Hall KS, Hui SL: **Association of antioxidants with memory in a multiethnic elderly sample using the Third National Health and Nutrition Examination Survey.** *Am J Epidemiol* 1999, **150**:37-44.
19. Engelhart MJ, Geerlings MI, Ruitenberg A, van Swieten JC, Hofman A, Witteman JCM, Breteler MMB: **Diet and risk of dementia: Does fat matter? The Rotterdam Study.** *Neurology* 2002, **59**:1915-1921.
20. Ilich JZ, Brownbill RA, Tamborini L: **Bone and nutrition in elderly women: protein, energy, and calcium as main determinants of bone mineral density.** *Eur J Clin Nutr* 2003, **57**:554-565.
21. Institute of Medicine: **Dietary Reference Intakes for calcium, phosphorus, magnesium, vitamin D, and fluoride.** Washington, DC: National Academy Press; 1997.
22. Ilich JZ, Zito M, Brownbill RA, Joyce M: **Change in bone mass after Colles' fracture: a case report of unique data collection and long term implications.** *J Clin Densitom* 2000, **3**:383-389.

23. Folstein MF, Folstein SE, McHugh PR: **'Mini-Mental State': A practical method for grading the cognitive state of patients for the clinician.** *J Pshyc Res* 1975, **12**:189-198.
24. Folstein MF, Folstein SE, McHugh PR, Fanjian G: **Mini-Mental State Examination user's guide.** *Psyc Ass Res* 2001.
25. Ilich JZ, Brownbill RA, Tamborini L, Cvijetic-Orlic Z: **To drink or not to drink: How are alcohol, caffeine, and past smoking related to bone mineral density in elderly women?** *J Am College Nutr* 2002, **21**:536-544.
26. Health Education Authority of London: Sports Council: **The Allied Dunbar National Fitness Survey.** *London: Sports Council* 1992.
27. Ilich-Ernst JZ, Brownbill RA, Ludemann MA, Fu R: **Critical factors for bone health in women across the age span: How important is muscle mass?** [On-line] *Medscape Women's Health eJournal* 2002, **7**: [<http://www.medscape.com/viewarticle/432910>].
28. Lui L, Stone K, Cauley JA, Hillier T, Yaffe K: **Bone loss predicts subsequent cognitive decline in older women: The study of osteoporotic fractures.** *J Am Geriatr Soc* 2003, **51**:38-43.
29. Uusi-Rasi K, Sievanen H, Pasanen M, Oja P, Vuori I: **Maintenance of body weight, physical activity and calcium intake helps preserve bone mass in elderly women.** *Osteoporos Int* 2001, **12**:373-379.

Pre-publication history

The pre-publication history for this paper can be accessed here:

<http://www.biomedcentral.com/1472-6874/4/2/prepub>

Publish with **BioMed Central** and every scientist can read your work free of charge

"BioMed Central will be the most significant development for disseminating the results of biomedical research in our lifetime."

Sir Paul Nurse, Cancer Research UK

Your research papers will be:

- available free of charge to the entire biomedical community
- peer reviewed and published immediately upon acceptance
- cited in PubMed and archived on PubMed Central
- yours — you keep the copyright

Submit your manuscript here:
http://www.biomedcentral.com/info/publishing_adv.asp

