Summary measure of dietary musculoskeletal nutrient (calcium, vitamin D, magnesium, and phosphorus) intakes is associated with lower-extremity physical performance in homebound elderly men and women[1–3]

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ABSTRACT

Background: Nutritional intake has been overlooked as a possible contributing factor to lower-extremity physical performance, especially in homebound elderly persons.

Objectives: Our objectives were to examine the association of a summary measure of calcium, vitamin D, magnesium, and phosphorus intakes with *1*) the inability to perform lower-extremity physical performance tests and *2*) declining levels of summary lower-extremity physical performance.

Design: Baseline data from the Nutrition and Function Study were used to calculate a summary musculoskeletal nutrient (SMN) score as a measure of nutrient intake (factor analysis) and to examine the association of SMN intake with physical performance (multivariable regression models) among recipients of home-delivered meals who completed an in-home assessment (anthropometric measures and performance-based physical tests) and three 24-h dietary recalls.

Results: Among the 321 participants, elderly age, black race, body mass index (in kg/m^2) ≥ 35, arthritis, frequent fear of falling, and lowest SMN intake were independently associated with being unable to perform functional tests. The lowest SMN intake and the highest BMI were both significantly associated with increasingly worse levels of lower-extremity physical performance, after adjustment for health and demographic characteristics.

Conclusions: Considering the importance of identifying short- and long-term outcomes that help elderly persons maintain adequate nutritional status and remain functionally independent at home, the results of this study suggest the need to identify intervention strategies that target the improvement of dietary intake and physical performance. Further investigation is indicated to identify the manner in which nutritional status contributes to the preservation or deterioration of physical performance in homebound elderly persons. *Am J Clin Nutr* 2003;77:847–56.

KEY WORDS Physical performance, musculoskeletal nutrients, body mass index, home-delivered meals, homebound elderly

INTRODUCTION

As an elderly person's life expectancy grows and a disease burden accumulates (1), concern about maintaining functional independence becomes paramount (2, 3). In light of these concerns, families, caregivers, the health care system, and home- and community-based service providers share the burden of the consequences of an elderly person's disability. These consequences include greater demands on individual, family, and community resources; higher hospital use rates; increased levels of disability; and greater utilization of an increasing number of health care and home- and community-care programs for a longer period of time (4, 5). Modifiable factors that are associated with an increased burden of disability in elderly persons have been identified, including nutritional risk, overweight, low dietary intake and physical inactivity, and chronic disease (6–10). Chronic health conditions, poor nutritional status, and functional decline are disproportionately prevalent in the more vulnerable subgroups of elderly persons in the community: women, minorities, the poor, and the homebound (1, 5, 7, 11–15).

Physical disability is often characterized by the inability to independently carry out essential activities of daily living such as bathing, dressing, transferring, walking, shopping for groceries or personal items, preparing meals, cleaning, and housework (16). The performance of these activities requires physical actions and depends on some level of lower-extremity physical performance (strength, mobility, balance, and endurance) (16–18).

Although lower-extremity physical performance is influenced by age, disease, and vision impairment (19), physical performance depends in large part on the musculoskeletal system because adequate muscle and bone strength are necessary requirements for

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full function (3). Two of the factors that may adversely affect muscle function and bone strength and resultant lower-extremity physical performance are poor nutrition (eg, inadequate or excessive intake) and physical inactivity (8, 20–22). However, nutrition has been overlooked as a potential contributing factor for lower-extremity physical performance, especially in homebound elderly men and women (23).

Therefore, the purpose of this study was to examine the independent association of dietary intake on measures of lower-extremity physical performance among a diverse sample of homebound elderly men and women. Because specific nutrients (ie, calcium, vitamin D, magnesium, and phosphorus) are associated with structural and muscular function (20, 24–29) and are considered by the Food and Nutrition Board of the Institute of Medicine to be key nutrients in the development and maintenance of bone (30), we hypothesized that a low relative intake of a summary measure of these 4 musculoskeletal nutrients would be independently associated with *1*) the inability to perform lower-extremity functional tasks and *2*) increasingly worse overall lower-extremity physical performance.

SUBJECTS AND METHODS

Study population

In this analysis we used baseline data from the Nutrition and Function Study (NAFS), a 2-wave collaborative project between the School of Public Health at the University of North Carolina at Chapel Hill and the Older Americans Act Nutrition Program's (also known as the Elderly Nutrition Program) home-delivered meals service providers in 4 North Carolina counties. Recipients of the home-delivered meals were aged ≥60 y and were homebound as a result of disability, illness, or isolation (5). The objective of the NAFS was to examine the influence of dietary intake and body mass index (BMI; in kg/m^2) on prevalent functional limitations among a probability sample of home-delivered meal recipients. Eligibility requirements included an age ≥ 60 y, a score of >6 on the telephone version of the Mini-Mental State Examination (31), and the ability to answer questions without the use of a proxy respondent. After recruitment of a representative sample (n = 348; 81% of those eligible) from the homebound recipients of home-delivered meals, baseline home interviews and telephone-administered dietary recalls were completed by 345 persons (99%). A detailed description of the recruitment, including sample comparisons (eg, eligible compared with noneligible participants and eligible participants compared with eligible nonparticipants) and data collection procedures (October 2000 to May 2001), is reported elsewhere (32, 33). Informed consent was obtained from all participants, and the study was approved by the University of North Carolina at Chapel Hill's School of Public Health Institutional Review Board. Data are from the baseline home interviews.

Baseline assessments involved a home visit, which included interviewer-administered questionnaires and physical performance–based measures, and three 24-h dietary recalls (one face-to-face and 2 that were telephone-administered). Because one of the variables of interest in this analysis was BMI, 24 (7%) participants were excluded from the analysis if they were nonambulatory (n = 14) or otherwise unable to stand for a weight measurement at the time of the home visit (n = 10). Complete baseline data on all putative risk factors were available for 321 participants.

Data collection

Sociodemographic characteristics

From questionnaires administered during the in-home interview, self-reports of sex, age, race (white and black), education level (<8 y, 9–11 y, and >11 y), monthly income (<$750, $750 to <$1000, and ≥$1000), and living arrangement (lives with others or lives alone) were collected.

Dietary intake

On randomly selected, nonconsecutive days, trained interviewers collected three 24-h dietary recalls that represented food intake on 1 weekend day and 2 weekdays for each participant. The details of the dietary-recall protocol, including administration and portion size estimation, were described elsewhere (33). The Nutrition Data System for Research (version 4.03, Food and Nutrient Database 31, released November 2000; developed by the Nutrition Coordinating Center, University of Minnesota, Minneapolis) was used to calculate nutrient intakes (34). Three-day mean nutrient intakes of 4 key musculoskeletal nutrients (calcium, vitamin D, magnesium, and phosphorus) were calculated for each participant with the use of equal weighting for each of the 3 d of dietary recall (30, 33). Although other nutrients may be of biological significance, these 4 nutrients were selected because of their key role in the maintenance of the musculoskeletal system (20, 30). Because the focus of this research was on dietary intake, nutrient estimates were based exclusively on the consumption of foods, including meal supplements such as Ensure (Ross Products Division, Abbott Laboratories Inc, Columbus, OH). Intakes of vitamin and mineral supplements did not contribute to the reported nutrient intakes because the use of multiple vitamin and calcium–vitamin D supplements was determined from a visual inspection of all prescription and over-the-counter medications present at the time of the in-home assessment.

To keep the same metric for the 4 nutrients, relative nutrient intake as a proportion of newly released age- and sex-specific recommended dietary allowances (RDAs) or adequate intakes (AIs) of calcium and vitamin D were calculated by using individual mean values (30). For calcium and vitamin D, the Food and Nutrition Board found information inadequate for the establishment of an estimated average requirement, on which the RDA is based. As a result, an AI was established to indicate an intake of adequacy when an RDA was not available. Usual intake at or above the RDA or AI suggests that an individual has a low probability for inadequacy (35). On the basis of quartiles of relative nutrient intake in this sample, a 4-category score was created for each nutrient (0 = the lowest relative nutrient intake and 3 = the highest relative nutrient intake). Then, a summary musculoskeletal nutrient (SMN) score was calculated by summing the categories (quartiles) of relative intake for calcium, vitamin D, magnesium, and phosphorus. Because such a summary measure of relative nutrient intake has not been previously reported in the literature, Cattel's scree test (a factor extraction criterion that involves the plotting of variance) and iterative common factor analysis were conducted on the 4 musculoskeletal nutrients to determine whether a summary measure would explain the overall relative intake of these nutrients, from the lowest (score = 0) to the highest (score = 12) relative intake (36). One factor was identified that explained 90.1% of the shared variance among the 4 musculoskeletal nutrients. Factor loadings ranged from 0.67 for magnesium to 0.90 for phosphorus (0.72 for vitamin D and 0.86 for calcium). A Cronbach's α of 0.86

suggested very good internal reliability for this scale (36). On the basis of this distribution of the SMN scores, a 3-category variable indicating levels of relative nutrient intake (lowest to highest) was constructed.

Current nutritional health status

BMI was used to give a general picture of nutritional health status (37). A detailed protocol for the measurement of weight and knee height was described elsewhere (33). With the use of sex- and race-specific formulas for the appropriate computation of stature from knee height in elderly persons (38), BMI was calculated as weight (kg)/height^2 (m). Although guidelines from the National Institutes of Health identify 6 categories for BMI (39), few NAFS participants were in the lowest and highest categories (n = 13 with a BMI < 18.5; n = 14 with a BMI ≥ 40). As a result, a 4-category BMI variable was constructed: 0 = < 25, 1 = 25.0–29.9, 2 = 30.0–34.9, and 3 = ≥ 35.

Health-related factors

Burden of disease. The burden of disease was assessed with a self-report of the presence of a specific disease diagnosis and its current effect on daily activities ("no impact," "little impact," or a "large impact") (33, 40). Fourteen disease conditions associated with lower-extremity physical function (41, 42) were grouped as follows: cardiovascular diseases (myocardial infarction, angina pectoris, congestive heart failure, stroke, and other heart diseases), musculoskeletal diseases (arthritis, osteoporosis, hip fracture, and muscle disease), and other comorbidities (hypertension, diabetes, pulmonary conditions, kidney disease, and cancer). Each disease condition was coded as a dummy variable ("not present/present and no impact" = 0 and "present and little/large impact" = 1). A summary comorbidity score (multiple disease conditions) was constructed for each of the 3 disease groupings: cardiovascular diseases (range: 0–4), musculoskeletal diseases (range: 0–3), and other comorbidities (range: 0–5).

Medication use. The actual prescription-medication containers were visually inspected and listed. Because the distribution of total medications was highly skewed (range: 0–31), the distribution was divided into tertiles (0–4, 5–7, and ≥ 8). A dichotomous medication variable was created: 0 = 0–4 medications and 1 = ≥ 5 medications). Separate variables for the presence of multiple vitamins and calcium (or calcium and vitamin D) supplements were constructed: 0 = no and 1 = yes.

Depression, vision impairment, current tobacco use, and fear of falling. Depression was assessed with the 15-item Geriatric Depression Scale–Short Form (possible scores of from 0 to 15); scores at the higher end of the range indicate more depressive symptoms (Cronbach's α = 0.80) (43, 44). Depression was defined as the presence of ≥ 6 depressive symptoms and was recoded as dichotomous: 0 = 0–5 and 1 = 6–15 (41). Vision impairment was operationalized from self-rated vision along a 5-point Likert scale ranging from 1 (excellent) to 5 (poor) (45). A dichotomous variable was constructed: 0 = "excellent/very good/good" and 1 = "fair/poor." The current use of any tobacco product (eg, cigarettes, cigars, pipe tobacco, chewing tobacco, and snuff) was determined from self-report: 0 = no and 1 = yes. Although the fear of falling is common in elderly adults and may affect confidence in engaging in daily activities without falling or losing balance and restrict functional activities (46, 47), few studies of overall lower-extremity physical performance have included this potential confounder in their analysis. In the current study, we asked about the frequency over the past 12 mo that the participant felt afraid of falling: "everyday/almost everyday" (n = 77), "1–2 times per week" (n = 35), "1–2 times per month" (n = 32), "only a few times during the year" (n = 98), and "never" (n = 79). A dichotomous variable was constructed: 0 = less frequent than weekly and 1 = weekly or more frequent.

Lower-extremity physical performance

Similar to the approach of Guralnik et al (48), performance-based measures of lower-extremity function were selected on the basis of specific criteria: *1*) able to be administered by a single interviewer; *2*) used previously in the home setting, *3*) able to be used in limited space, and *4*) limited respondent burden. Lower-extremity physical performance, which is important for independent mobility, was assessed through timed performance tests that measured balance (static and dynamic balance), gait (usual walk speed), and strength (repeated chair stands). Because of the variety of balance requirements in daily living, it was important to include measures of both static and dynamic balance (49). Measured times for these tests were considerably slower than prior reports of independent and moderately to severely disabled community-dwelling samples, so we calculated quartiles of actual times to identify variable categories (48, 50, 51).

Static balance. Static (standing) balance was measured by having each participant hold 2 increasingly difficult standing positions for 10 s without the assistance of a person or device (41): *1*) stand with feet together (side-by-side position), and *2*) stand with the side of the heel of one foot touching the big toe of the opposite foot (semitandem position). The semitandem position was only attempted if the participant was successful with the side-by-side position. A 3-category static balance score was created: 0 = able to hold a side-by-side standing position for 10 s without assistance (eg, cane or walker), 1 = able to maintain the side-by-side position for 10 s but unable to maintain the semitandem position, and 3 = able to hold the semitandem position for 10 s (highest level of performance).

Dynamic balance. Dynamic balance was tested with the best of 2 times for a participant to make a 360-degree turn (turning in a full circle), one to the right and one to the left (50). Of the 268 participants who were able to complete at least one 360-degree turn (83.5%), 217 completed both turns. A 5-category dynamic balance score that included those unable to perform the test was created. Participants who were unable to complete this test were given a score of 0 (n = 53). The 4 remaining categories were scored according to quartiles of timed performance: 1 = > 10.2 s (worst performance), 2 = 6.7–10.2 s, 3 = 5.1–6.6 s, and 4 = < 5.1 s (best performance). These cutoffs represent considerably slower times than the quartile cutoffs reported by Gill et al (50): ≥ 3.9, 3.0–3.8, 2.5–2.9, and < 2.5 s. NAFS participants were allowed to use assistive devices to complete this test: 20.9% (n = 56) used a cane for assistance, 11.9% (n = 32) used a walker, and 1.5% (n = 4) used other forms of assistance (eg, furniture).

Usual walk speed. Because most of the residences were small houses or apartments, an 8-ft (≈244-cm) walk was selected to test usual walk speed. An unobstructed 8-ft course was measured, with the start and finish lines clearly marked. Participants were positioned 1 ft (30.48 cm) behind the start line, and the timing of a normal (ie, comfortable) pace began when the foot crossed the start line and stopped when the foot crossed the finish line. The time taken to complete one walk (n = 60) or the faster time to

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completion of 2 walks (n = 206), with the use of walking aids if necessary, was used to define a 5-category gait score, with 0 representing the inability to complete the walk test (n = 55). The remaining 4 categories were calculated according to quartiles of performance among participants who completed the test: 1 = > 8.11 s, 2 = 6.11–8.81 s, 3 = 4.60–6.10 s, and 4 = < 4.60 s (category of best times). Of the 266 participants who completed at least one walk, 34% required assistance: cane (n = 52), walker (n = 31), and other (n = 7). These times compare with the cutoffs in the Established Populations for the Epidemiologic Study of the Elderly: ≥ 5.7, 4.1–5.6, 3.2–4.0, and ≤ 3.1 s (52).

Repeated chair stands. Chair stands, which assess leg strength and balance, were performed with the use of an armless straight-back chair found in the participant's home (48). Participants were asked to place their arms across their chest and then to stand once from a sitting position. If successful, they were asked to stand up and sit down as quickly as possible 5 times in a row, with time stopped at the final standing position at the end of the fifth stand (48). Timed quartiles of performance for repeated chair stands were used to create a 5-category score, with 0 representing the inability to complete 5 chair stands: 1 = > 24.9 s, 2 = 21.0–24.9 s, 3 = 17.5–20.9 s, and 4 = < 17.5 s. The category indicating the inability to complete 5 repeated chair stands included 9 participants who were able to complete a single chair stand but were unable to complete 5 chair stands. These quartile cutoffs indicate much slower times than those in the Established Populations for the Epidemiologic Study of the Elderly population (> 16.7, 13.7–16.6, 11.2–13.6, and ≤ 11.1 s) (52); the Health, Aging and Body Composition Study cohort of healthy men and women (> 16.1, 13.8–16.1, 11.6–13.7, and < 11.6 s) (53); and the Women's Health and Aging Study of the one-third most disabled women living in the community (≥ 17.4, 14.2 to < 17.4, 12.3 to < 14.2, and < 12.3 s) (51).

Summary lower-extremity performance score. A summary score for overall lower-extremity physical performance was created by summing the category scores for the tests of static and dynamic balance, usual walk speed, and repeated chair stands. Catell's scree test and iterative common factors analysis identified one factor, which accounted for 95.4% of the shared variance in the 4 tests. The factor loadings ranged from 0.61 for static balance to 0.88 for usual gait speed (0.69 for repeated chair stands and 0.85 for dynamic balance). Internal reliability was determined by Cronbach's α (54) at 0.83. Summary lower-extremity performance scores (SLEPS) in this homebound sample ranged from 0 (worst performance) to 14 (best performance). Because the SLEPS was highly skewed, we used the strategy of Ferrucci et al (12) to construct a 3-category variable for levels of lower-extremity performance: worst performance (SLEPS: 0−4), intermediate performance (SLEPS: 5−9), and best performance (SLEPS: 10−14).

Statistical analysis

All statistical analyses were performed with the use of STATA statistical software, release 6 (55). Demographic and health characteristics, relative musculoskeletal nutrient intake, and individual and summary measures of lower-extremity physical performance were calculated for the entire sample. The difference between men and women in the prevalence (categorical variables) and distribution (continuous variables) of these variables was assessed with contingency tables by using the chi-square statistic and by comparing the means by using Student's t test.

The correlates of an inability to complete lower-extremity physical performance tests were determined from multivariable logistic regression by using robust (White-Huber–corrected) SEs. To build the multivariable models, we used the subset of significant bivariate associations (P < 0.10) between any of the individual lower-extremity physical performance tests and the candidate variables displayed in **Table 1**: age group, sex, race, income, education level, living arrangement, BMI, depression, burden of individual and grouped diseases, medication use, supplement use, tobacco use, vision, and fear of falling. Then, separate regression models of the inability to complete each of the 4 lower-extremity physical performance tests were run on categories of SMN intake and selected correlates.

Multivariable-ordered logistic regression was used to examine the correlation of nutrient intake with a 3-category ordinal dependent variable for the level of overall lower-extremity physical performance. Two intercept parameters (ie, number of categories − 1) were estimated and labeled in **Table 2** as cutoffs δ_0 and δ_1, which correspond to thresholds that model categorization of the ordinal dependent variable. For each predictor variable, a single parameter was estimated. This model controlled for potential confounding by demographic characteristics (age group, race, income, living arrangement, and sex), BMI, and health characteristics [fear of falling, depression, medication use, multiple vitamin and calcium supplement use, and burden of individual diseases (angina, arthritis, diabetes, and stroke)] that were identified in bivariate analyses. On the basis of the results from the ordered logistic regression, predicted probabilities for each of the 3 levels of lower-extremity physical performance were calculated.

RESULTS

Demographic and health characteristics

As shown in Table 1, many study participants were poor, black, undereducated, and lived alone. Obesity, as determined on the basis of measured BMI, was highly prevalent; proportionally more women than men were obese (BMI: 30–34.99) and severely obese (BMI ≥ 35). The most prevalent diagnoses that had an effect on daily activities were arthritis, hypertension, diabetes, pulmonary disease, and myocardial infarction. Proportionately more women than men reported the lowest income, reported diseases or conditions (congestive heart failure, arthritis, and osteoporosis) that affected current activities, used ≥ 5 prescription medications, took calcium supplements, and were frequently afraid of falling. Proportionately fewer women than men were current tobacco users.

Relative intake of musculoskeletal nutrients

Given that the newly released dietary reference intakes (30) identify age- and sex-specific nutrient intake recommendations for elderly persons, mean and median nutrient intakes (from 3 dietary recalls) are reported as a proportion of the RDA (magnesium and phosphorus) and AI (calcium and vitamin D) in **Table 3**. In terms of relative intake, 75% of the total sample consumed < 69% of the recommended amount of calcium, < 44% of the sample consumed the recommended amount of vitamin D, and < 77% of the sample consumed the recommended amount of magnesium. The mean and median relative intakes of calcium, vitamin D, and phosphorus were significantly lower in women than in men. Mean nutrient intakes of calcium, vitamin D, and phosphorus in women did not differ significantly between multiple vitamin or calcium supplement

TABLE 1
Demographic and health characteristics of the homebound elderly study population by sex

	Men (n = 64)	Women (n = 257)
Demographic characteristics		
Age (y)[1]	78.5 ± 8.4[2]	78.2 ± 8.3
Age group (%)		
60–74 y	34.4	32.3
75–84 y	45.3	40.1
≥85 y	20.3	27.6
Black race (%)	45.3	46.3
Income (%)		
<$750/mo	45.3	68.9[3]
$750–$1000/mo	26.6	17.9
>$1000/mo	28.1	13.2
Education, time completed (%)		
0–8 y	37.5	29.6
9–11 y	25.0	30.7
>11 y	37.5	39.7
Lives alone (%)	56.2	60.3
Health characteristics		
BMI (%)		
<25 kg/m^2	39.1	27.2[4]
25–29.99 kg/m^2	43.7	30.7
30–34.99 kg/m^2	9.4	25.7[5]
≥35 kg/m^2	7.8	16.3[6]
Depression, GDS ≥6 (%)[7]	25.0	29.6
Cardiovascular disease (%)[8]	0.59 ± 1.05	0.80 ± 1.0
Myocardial infarction	25.0	19.8
Angina pectoris	7.8	14.0
Congestive heart failure	6.2	15.94[4]
Stroke	10.9	18.7
Other	9.4	11.7
Musculoskeletal disease (%)[9]	0.64 ± 0.63	1.05 ± 0.68[3]
Arthritis	56.2	77.8[3]
Osteoporosis	0.0	19.5[3]
Hip fracture	4.7	5.4
Muscle	3.1	2.7
Other comorbidity (%)[10]	1.06 ± 1.05	1.06 ± 1.05
Hypertension	31.2	39.3
Diabetes	26.6	26.1
Pulmonary conditions	17.2	22.6
Kidney	14.1	11.7
Cancer	17.2	6.6[5]
Use of ≥5 prescription medications (%)	43.7	63.8[5]
Vitamin supplementation (%)		
Calcium	1.6	16.7[5]
Multiple vitamins	17.2	24.5
Current tobacco use (%)[11]	26.6	14.8[4]
Self-rated vision of fair to poor (%)	56.2	56.0
Fear of falling (%)[12]	17.2	39.3[3]

[1] Age range was 61–98 y.
[2] $\bar{x}$ ± SD.
[3–6] Significantly different from men (Student's t and chi-square tests): [3] $P < 0.001$, [4] $P < 0.05$, [5] $P < 0.01$, [6] $P < 0.09$.
[7] Modified version (15-item) of the Geriatric Depression Scale.
[8] Summary of self-reported cardiovascular diseases with perceived "little/great impact" on current activities: myocardial infarction, angina pectoris, congestive heart failure, stroke, and other heart diseases.
[9] Summary of self-reported musculoskeletal diseases with "little/great impact" on current activities: arthritis, osteoporosis, hip fracture, and muscle disease (eg, fibromyalgia, muscular dystrophy, and fibromyositis).
[10] Summary of other self-reported comorbidities with "little/great impact" on current activities: hypertension, diabetes mellitus, pulmonary disease, kidney diseases, and cancer.
[11] Tobacco use includes cigarettes, cigars, pipe tobacco, chewing tobacco, and snuff.
[12] Fear of falling: felt afraid of falling ≥time/wk compared with <1 time/wk.

TABLE 2
Coefficients and odds ratios from ordered logistic regression models correlating musculoskeletal nutrient intake, BMI, and health and demographic characteristics with lower-extremity physical performance[1]

Independent variables	Coefficients	Odds ratio[2] (95% CI)
Musculoskeletal nutrients[3]		
0–4, lowest relative intake	0.63[4]	1.88 (1.08, 3.27)
5–8	0.63[4]	1.88 (1.07, 3.28)
BMI[5]		
25–29.9 kg/m^2	−0.15	
30–34.9 kg/m^2	−0.26	
≥35 kg/m^2	1.12[6]	3.08 (1.39, 6.83)
Health characteristics		
Fear of falling	0.79[6]	2.21 (1.36, 3.61)
Depression	0.54[4]	1.72 (1.00, 2.96)
Medication use	0.18	
Multiple vitamin use	−0.40	
Calcium supplement use	−0.19	
Angina	−0.89[4]	0.41 (0.20, 0.84)
Arthritis	0.67[6]	1.96 (1.16, 3.32)
Diabetes	0.60[4]	1.82 (1.05, 3.18)
Stroke	0.81[6]	2.25 (1.17, 4.31)
Demographic characteristics		
Age 75–84 y[7]	0.38	
Age ≥85 y[7]	0.71[4]	2.03 (1.09, 3.81)
Black race	−0.11	
Low income	−0.35	
Lives alone	−0.36	
Women	0.61[4]	1.84 (1.02, 3.48)
Cutoffs[8]		
δ_0, cutoff 1	0.42	
δ_1, cutoff 2	2.32	
Pseudo R^2 of model	0.12	
Significance of χ^2 in model	$P < 0.001$	

[1] n = 321. Three-category dependent variable of levels of lower-extremity physical performance: 0 = best performance, 1 = intermediate performance, 2 = worst performance.
[2] Odds of having the worst level of lower-extremity physical performance.
[3] The highest relative bone nutrient intake (summary score: 9–12) is the omitted category.
[4] $P \leq 0.05$.
[5] A BMI <25 kg/m^2 is the omitted category.
[6] $P \leq 0.01$.
[7] Age 60–74 y is the omitted category.
[8] Cutoffs separate the 3 levels of the dependent variable: a fitted value $\leq \delta_0$ indicates the best lower-extremity physical performance; a fitted value $> \delta_0$ but $\leq \delta_1$ indicates an intermediate level of lower-extremity performance; and a fitted value $> \delta_1$, indicates the worst lower-extremity physical performance. Cutoffs are a crucial piece of information necessary for the calculation of predicted probabilities for each of the outcomes (levels of dependent variable).

users and nonusers (data not reported). In men, the only significant difference found was a greater magnesium intake in multiple vitamin users than in nonusers. A comparison of mean SMN scores and overall intakes indicated significantly lower relative intakes in women than in men.

Individual tests and overall lower-extremity physical performance

The timed performance on individual tests of lower-extremity physical performance in the current sample of homebound elderly men and women was much slower than that in prior studies in independent and disabled community samples (48, 51, 56). Sex

TABLE 3
Mean, median, and prevalence of relative intake of musculoskeletal nutrients from food sources, by sex and quartile[1]

	Men (n = 64)	Women (n = 257)
Individual nutrient		
Calcium[2]		
$\bar{x}$ ± SD (% of AI)	69.3 ± 26.9	52.8 ± 22.8[3]
Median (% of AI)	64.6	50.1[3]
Quartile (%)[4]		
1, <39.7%	10.9 [7]	28.4 [73][3]
2, 39.7–52.1%	14.1 [9]	27.2 [70]
3, 52.2–68.6%	29.7 [19]	24.1 [62]
4, >68.6%	45.3 [29]	20.2 [52]
Vitamin D[5]		
$\bar{x}$ ± SD (% of AI)	43.9 ± 19.0	32.8 ± 17.7[3]
Median (% of AI)	42.8	28.9[3]
Quartile (%)[4]		
1, <22.4%	12.5 [8]	28.4 [73][3]
2, 22.4–31.3%	18.7 [12]	26.5 [68]
3, 31.4–43.4%	23.4 [15]	25.3 [65]
4, >43.4%	45.3 [29]	19.8 [51]
Magnesium[6]		
$\bar{x}$ ± SD (% of RDA)	61.9 ± 19.1	66.8 ± 21.7
Median (% of RDA)	62.3	62.5
Quartile (%)[4]		
1, <51.7%	34.4 [22]	21.8 [56][7]
2, 51.7–62.5%	15.6 [10]	28.0 [72]
3, 62.6–76.3%	34.4 [22]	23.3 [60]
4, >76.3%	15.6 [10]	26.8 [69]
Phosphorus[8]		
$\bar{x}$ ± SD (% of RDA)	161.6 ± 46.3	124.8 ± 39.2[3]
Median (% of RDA)	157.5	121.9[3]
Quartile (%)[4]		
1, <105%	6.2 [4]	30.3 [78][3]
2, 105–126.3%	15.6 [10]	25.7 [66]
3, 126.4–154.1%	25.0 [16]	25.7 [66]
4, >154.1%	53.1 [34]	18.3 [47]
SMN score[9]		
$\bar{x}$ ± SD	7.7 ± 3.4	5.6 ± 3.7[3]
Category of SMN score[10]		
0–4, lowest relative intake	20.3 [13]	41.2 [106][3]
5–8	31.2 [20]	32.3 [83]
9–12, highest relative intake	48.4 [31]	26.5 [68][3]

[1] n in brackets. SMN, summary musculoskeletal nutrient. Mean and median intakes are expressed as a percentage of age- and sex-specific recommended dietary allowances (RDA) and adequate intakes (AI). Because of rounding, proportions may not total 100%. Differences in means and medians were tested by using Student's t test and Wilcoxon's rank-sum test, respectively.
[2] AI = 1200 mg.
[3,7] Significantly different from men (Student's t and chi-square tests): [3] $P < 0.001$, [7] $P < 0.01$.
[4] Percentage of sex-specific subgroups by quartile of individual nutrient intake as a proportion of age- and sex-specific RDAs (AIs).
[5] AI = 10 µg for ages 51–70 y and 15 µg for ages >70 y.
[6] RDA = 420 mg for men and 320 mg for women.
[8] RDA = 700 mg.
[9] Quartiles recoded asa 0 = 1st, 1 = 2nd, 2 = 3rd, and 3 = 4th and summed (range: 0–12).
[10] Reference group for category comparisons is "all others."

TABLE 4
Individual and summary measures of lower-extremity physical performance by sex[1]

	Men (n = 64)	Women (n = 257)
	%	
Static balance		
0 = Unable	15.6 [10]	28.8[2] [74]
1 = Side by side only	43.7 [28]	49.8 [128]
2 = Semitandem	40.6 [26]	21.4 [55]
Usual walk test (s)[3]		
0 = Unable	9.4 [6]	19.1[4] [49]
1 = >8.81, slowest	9.4 [6]	23.3 [60]
2 = 6.11–8.81	20.3 [13]	21.0 [54]
3 = 4.60–6.10	23.4 [15]	19.8 [51]
4 = <4.60	37.5 [24]	16.7 [43]
Chair stands (s)		
0 = Unable[5]	53.1 [34]	73.1[6] [188]
1 = >24.9, slowest	14.1 [9]	6.2 [16]
2 = 21.0–24.9	7.8 [5]	7.8 [20]
3 = 17.5–20.9	10.9 [7]	7.0 [18]
4 = <17.5	14.1 [9]	5.8 [15]
360-degree turn		
0 = Unable	17.8 [5]	18.7 [48]
1 = >10.2, slowest	15.6 [10]	22.2 [57]
2 = 6.7–10.2	29.7 [19]	18.7 [48]
3 = 5.1–6.6	21.9 [14]	20.2 [52]
4 = <5.1	25.0 [16]	20.2 [52]
SLEPS, 0–14[7]		
$\bar{x}$ ± SD	7.5 ± 4.0	5.5 ± 3.9[4]
Median	8	5
Levels of lower-extermity physical performance[8]		
Worst, summary score 0–4	20.3 [13]	47.1[4] [121]
Intermediate, summary score 5–9	48.4 [31]	32.3 [83]
Best, summary score 10–14	31.2 [20]	20.6 [53]

[1] n in brackets. Group comparisons for categorical variables were made with chi-square tests and with Student's t test for continuous variables.
[2,4,6] Significantly different from men: [2] $P \leq 0.05$, [4] $P \leq 0.001$, [6] $P \leq 0.01$.
[3] The length of the walk was 8 ft (244 cm).
[5] Includes 9 participants who were able to complete a single chair stand and unable to complete 5 repeated chair stands.
[7] Summary lower-extemity physical performance score.
[8] From summary lower-extremity performance score. Note: intermediate and high levels of lower-extermity performance are relative for this sample.

differences in 3 aspects of lower-extremity performance (individual tests, mean SLEPS, and levels of overall physical performance) are shown in **Table 4**. The proportion of women with the worst level of lower-extremity physical performance was large and significantly different from that of men (47% compared with 20%; $P < 0.001$). A significantly higher proportion of women than men were unable to complete the static balance test, usual walk test, and repeated chair stands.

Nutrient intake, BMI, and inability to complete performance tasks

The inability to complete a specific lower-extremity function is a common fear of frail elders, so we used multivariable logistic regression models to identify significant correlates for the inability to complete individual performance measures (**Table 5**). Although none of the disease groupings (ie, cardiovascular, musculoskeletal, and other comorbidities) were correlated (bivariate analysis not shown) with any of the physical-performance tests, 2 of the specific diseases were reported to affect daily activity: arthritis and stroke ($P = 0.09$). Older age, black race, a BMI ≥ 35, arthritis, frequent fear of falling, and lowest relative SMN intake

TABLE 5

Logistic regression of the inability to complete lower-extremity physical performance tests on demographic characteristics, BMI, musculoskeletal nutrient intakes, depression, fear of falling, and selected diseases[1]

Variable[2]	Static balance[3]	Dynamic balance	Walk	Chair stands[4]
Age [≥60–74 y]				
75–84 y	1.03 (0.52, 2.07)	1.08 (0.51, 2.29)	0.91 (0.43, 1.89)	1.35 (0.73, 2.51)
≥85 y	2.23 (1.03, 4.79)[5]	0.91 (0.37, 2.23)	0.51 (0.20, 1.32)	2.37 (1.10, 5.12)[5]
Sex [Male]				
Female	1.33 (0.59, 3.03)	2.62 (0.97, 7.05)[5]	2.37 (0.88, 6.41)[5]	1.47 (0.79, 2.73)
Race [White]				
Black	1.18 (0.64, 2.16)	2.57 (1.23, 5.38)[5]	2.05 (0.96, 4.40)[5]	0.95 (0.55, 1.63)
Income [≥$750/mo]				
<$750/mo	0.91 (0.49, 1.66)	0.80 (0.37, 1.69)	0.50 (0.24, 1.04)[5]	0.61 (0.34, 1.08)
Living arrangement [lives with others or alone]	0.99 (0.57, 1.74)	0.88 (0.48, 1.61)	0.72 (0.38, 1.36)	0.52 (0.28, 0.95)[5]
BMI [<25 kg/m^2]				
25–29.9 kg/m^2	1.24 (0.59, 2.61)	0.64 (0.28, 1.48)	0.44 (0.19, 0.99)[5]	1.28 (0.67, 2.45)
30–34.9 kg/m^2	0.90 (0.41, 1.95)	0.42 (0.16, 1.08)	0.34 (0.13, 0.85)	1.51 (0.72, 3.16)
≥35 kg/m^2	3.61 (1.53, 8.54)[6]	1.24 (0.50, 3.08)	0.76 (0.31, 1.87)	4.63 (1.59, 13.50)[6]
Arthritis[7]	1.81 (0.92, 3.58)[8]	0.73 (0.36, 1.50)	1.01 (0.49, 2.09)	2.56 (1.42, 4.60)[6]
Stroke[7]	1.63 (0.77, 3.45)	0.80 (0.32, 1.96)	1.03 (0.46, 2.29)	2.21 (0.97, 5.05)[8]
Musculoskeletal nutrient intake [9–12, highest relative risk][9]				
0–4, lowest	1.28 (0.63, 2.60)	1.81 (0.81, 4.03)	2.04 (0.89, 4.69)[8]	2.26 (1.19, 4.29)[6]
5–8	1.42 (0.69, 2.94)	1.29 (0.53, 3.16)	1.63 (0.67, 3.93)	1.98 (1.02, 3.84)[5]
Depression[10]	1.65 (0.87, 3.11)	1.70 (0.84, 3.46)	1.00 (0.49, 2.04)	1.88 (0.98, 3.61)[5]
Fear of falling[11]	2.51 (1.46, 4.30)[12]	1.54 (0.82, 2.91)	1.96 (1.06, 3.62)[5]	1.87 (1.03, 3.41)[5]

[1] Values are adjusted odds ratios; 95% CIs in parentheses. $n = 321$. Robust SEs with White-Huber correction were used in the regression. Subsets of diseases were selected on the basis of significant ($P < 0.10$) bivariate associations with any of the lower-extremity physical performance tests.

[2] Reference categories in brackets.

[3] Unable to maintain side-by-side position for 10 s.

[4] Nine participants were unable to complete 5 chair stands but were able to complete 1 chair stand.

[5] $P \leq 0.05$.

[6] $P \leq 0.01$.

[7] Presence of health condiiton with "little/great impact" on current activities compared with health condition "not present/present" and "no current impact" on activities.

[8] $P \leq 0.09$.

[9] Categories of summary score of relative musculoskeletal nutrient intake.

[10] Self-report of ≥6 depressive symptoms compared with <6 depressive symptoms.

[11] Felt afraid of falling at least once per week or "less frequent/never."

[12] $P \leq 0.001$.

were associated with being unable to complete individual measures of lower-extremity function. In particular, the lowest level of nutrient intake was associated with being unable to complete 2 of the 4 lower-extremity measures after the following covariates were controlled for: usual walk [odds ratio (OR): 2.04, $P < 0.09$] and repeated chair stands (OR: 2.26; $P \leq 0.01$). After nutrient intake and other covariates were controlled for, a BMI ≥35 was significantly associated with an increased odds for the inability to complete the static balance test (OR: 3.61) and repeated chair stands (OR: 4.63). The independent associations of female sex, after control for all covariates, with the inability to complete the dynamic balance and usual walk tests were nearly significant ($P = 0.074$ and $P = 0.089$, respectively). Although depression was not associated with any of the outcomes, frequent fear of falling increased the odds for static balance (OR: 2.51), usual walk (OR: 1.96), and repeated chair stands (OR: 1.87).

Nutrient intake, BMI, and increasingly worse lower-extremity physical performance

The results from multivariable-ordered logistic analysis indicate that the lowest SMN intakes and highest BMIs in the homebound elderly were both significantly associated with increasingly worse levels of lower-extremity physical performance, after adjustment for health and demographic characteristics and multiple vitamin and calcium supplement use (Table 2). In addition, specific health and demographic characteristics, namely fear of falling, depression, arthritis, diabetes, stroke, age, and female sex were also significantly correlated with diminishing physical performance. ORs were calculated for significant variables ($P \leq 0.05$) and are reported in the last column of Table 2. Compared with the homebound elderly in the highest category of SMN intake, those with a reported intake in the 2 lowest categories were at higher odds (OR: 1.88) of the having the worst level of lower-extremity physical performance. At this same level of physical performance, the ORs were 3-fold for elders with a BMI ≥35 and between 1.82 and 2.25 for homebound participants with diabetes, arthritis, and stroke.

DISCUSSION

Our study of 321 homebound elderly men and women showed that, regardless of BMI and other factors, a summary measure of calcium, vitamin D, magnesium, and phosphorus intakes from food was associated with individual and summary measures of lower-extremity physical performance. This is the first study, to our knowledge, that evaluates the relation of dietary intake of multiple nutrients to the inability to complete individual performance-based tests of lower-extremity function and to increasingly worse overall lower-extremity physical performance, especially among the more vulnerable of the homebound elderly in the community.

As important as calcium, vitamin D, magnesium, and phosphorus are to the maintenance of the musculoskeletal system in elderly persons (20, 24, 25, 29, 57), the newly released age- and sex-specific nutrient recommendations provide disparate sets of DRIs: AIs for calcium and vitamin D and estimated average requirements and RDAs for magnesium and phosphorus (30). This makes it particularly difficult to construct a summary measure to reflect overall intakes of these key nutrients. In the current study, we provide a novel approach that incorporates factor analysis and compares usual intake from food with the recommended RDAs and AIs and calculates the relative intakes of calcium, vitamin D, magnesium, and phosphorous in the same metric. Three important findings warrant further comment.

First, our findings indicate that relative intake was low, lower in the homebound women than in the homebound men. Homebound women were more likely to report the lowest nutrient intakes in individual and summary measures. These results may be partially explained by the significantly higher proportion of women who reported the lowest income. In addition, prior reports identified a greater number of physical limitations in meal preparation and consumption in homebound women (33).

Second, the results of multivariable logistic regression models extend our knowledge by identifying dietary intake as an independent correlate of the inability to complete physical performance tests (58). Specifically, the lowest level of musculoskeletal nutrient intake was associated with the inability to complete tests of mobility (walk test, OR: 2.04) and strength (chair stands, OR: 2.26) after adjustment for covariates. In addition to nutrient intake, the effect of obesity (BMI $\geq$35) on balance (static balance, OR: 3.61) and strength (chair stands, OR: 4.63) was great. Because walking aids were not allowed in these 2 tests, the greater reliance on walking aids among the severely obese (compared with subjects with a BMI < 35) in the usual walk test (60% compared with 30%; $P < 0.001$) and the dynamic balance test (58% compared with 31%; $P < 0.01$) may partly explain this finding.

Third, our findings indicate that the lowest level of nutrient intake was significantly associated with increasingly worse levels of measured physical performance, after control for BMI and health and demographic characteristics. Clearly, the odds for lower-extremity physical performance at the worst level were 1.88 times greater for homebound elders who reported SMN intakes in the lowest category. Given that dietary intake is modifiable, this finding is especially important in beginning to understand the functional importance of dietary intake among homebound elders. In the same multivariable regression model, the OR for the worst level of physical performance was 3 times greater for those with a BMI $\geq$35 and greater for elderly with specific health and demographic characteristics. For both men and women, and regardless of BMI, the lowest nutrient intake dramatically increased the predicted probability for the worst level of lower-extremity physical performance, when all other variables were held constant at their means.

There are many particular strengths of this study. First, complete data were collected during a comprehensive baseline assessment of dietary intake, BMI, physical performance, and demographic and health characteristics on a large and diverse random sample of home-delivered meal recipients. Second, our strategy of relative nutrient intake allowed us to examine the association of a summary measure of overall intake of calcium, vitamin D, magnesium, and phosphorus to physical performance. To the limited number of studies that have shown conflicting results regarding an association of serum concentrations of individual nutrients (eg, vitamin D) to muscular function, this study contributes information on dietary intake, which may underpin muscular function, lower-extremity physical performance, and biochemical indicators (57, 59, 60). Finally, to our knowledge, no other study of homebound elderly included fear of falling as a potential correlate of lower-extremity physical performance. Because this particular variable may have served as a proxy for motivation and physical inactivity, it was necessary for it to be included as a covariate in the multivariable regression models.

The limitations to the current study also warrant mention. First, the cross-sectional design prevented us from making causal or even temporal inferences. Longitudinal work will be required to determine whether decreased nutrient intake is a cause or result of physical performance or whether some other factor influences both nutrient intake and physical performance. Second, biochemical measures of nutrient inadequacy and clinical measures of muscle mass were unavailable. In future studies, the inclusion of these measures will help determine independent, joint, and threshold effects of nutrient intake. Third, physical activity, which has been shown to correlate with lower-extremity physical performance, was not measured (41). Because 3 of the contributors to muscle weakness in the elderly are burden of disease and concomitant medication use, muscle atrophy from disuse, and undernutrition (20), future prospective investigations, especially in the homebound elderly, should include a self-report and performance-based measure of physical activity with a device such as an accelerometer. This would provide an opportunity to understand how 3 potentially modifiable factors (nutrient intake, BMI, and physical activity) may interact to predict and mediate change in lower-extremity physical performance over time. Finally, the small number of men in the study sample limits our ability to generalize to a larger population of homebound men.

The role of poor nutritional intake in the acceleration of functional decline is unclear (61–63). The present study suggests that dietary intake, specifically musculoskeletal nutrients, is linked to performance-based measures of lower-extremity function. These findings further extend knowledge by identifying demographic and health characteristics that are related to progressively lower levels of physical performance among homebound elderly men and women. An increased prevalence of individual and multiple health conditions, many of which are nutrition-related, may lead to a diminished level of physical performance and increased rates of disability (64–66), especially with the co-occurrence of low nutrient intakes and high BMIs. As a result, many of these conditions will impose an extraordinary burden on individuals and informal caregivers and will challenge the resources of home- and community-based service organizations to respond to an increasing demand for long-term assistance to homebound elderly (64, 66).

Many elderly persons, who rely on supportive services such as the Older Americans Act Nutrition Program's home-delivered meals, are at great risk of an increased burden of disease, poor nutritional health, and functional decline. Considering the importance of identifying short- and long-term outcomes that help elderly persons maintain adequate nutritional status while remaining independent and at home (67), the results of the current study suggest the need to explore strategies that target the improvement of dietary intake and physical performance. Further investigation is required to delineate the interrelations of nutritional status and physical performance in contributing to the functional decline in homebound elderly persons (68).

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