Public Health Nutrition: 24(14), 4490–4505 doi:10.1017/S1368980020003547

Associations between nutrient intakes and dietary patterns with different sarcopenia definitions in older Australian men: the concord health and ageing in men project

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Submitted 10 March 2020: Final revision received 28 July 2020: Accepted 7 September 2020: First published online 7 October 2020

Abstract

Objective: To assess the associations between nutrient intake and dietary patterns with different sarcopenia definitions in older men.
Design: Cross-sectional study.
Setting: Sarcopenia was defined using the Foundation for the National Institutes of Health (FNIH), the European Working Group on Sarcopenia in Older People (EWGSOP) and the European Working Group on Sarcopenia in Older People 2 (EWGSOP2). Dietary adequacy of fourteen nutrients was assessed by comparing participants' intakes with the Nutrient Reference Values (NRV). Attainment of NRV for nutrients was incorporated into a variable 'poor' (meeting ≤ 9) *v.* 'good' (meeting ≥ 10) using the cut-point method. Also, two different dietary patterns, monounsaturated:saturated fat and *n*-6:*n*-3 fatty acids ratio and individual nutrients were used as predictor variables.
Participants: A total of 794 men aged ≥75 years participated in this study.
Results: The prevalence of sarcopenia by the FNIH, EWGSOP and EWGSOP2 definitions was 12·9 %, 12·9 % and 19·6 %, respectively. With the adjustment, poor nutrient intake was significantly associated with FNIH-defined sarcopenia (OR: 2·07 (95 % CI 1·16, 3·67)), but not with EWGSOP and EWGSPOP2 definitions. The lowest and second-lowest quartiles of protein, Mg and Ca and the lowest quartiles of *n*-6 PUFA and *n*-3 PUFA intakes were significantly associated with FNIH-defined sarcopenia. Each unit decrease in *n*-6:*n*-3 ratio was significantly associated with a 9 % increased risk of FNIH-defined sarcopenia (OR: 1·09 (95 % CI 1·04, 1·16)).
Conclusions: Inadequate intakes of nutrients are associated with FNIH-defined sarcopenia in older men, but not with the other two sarcopenia definitions. Further studies are required to understand these relationships.

Keywords
Nutrient
Dietary pattern
Sarcopenia

Sarcopenia is characterised by the age-related loss of muscle mass, muscle strength and physical performance[1]. Inadequate nutrient intakes have been shown to play an important role in weight loss along with changes in muscle mass, strength and physical function[2]. Recent cross-sectional studies have shown inadequate intakes of some macro and micronutrients (i.e. protein, fat, *n*-3 fatty acid, K, Mg, Fe, Ca and vitamin B_6, folic acid and vitamins E and C) in older people with sarcopenia (using the European Working Group on Sarcopenia in Older People, EWGSOP) compared with non-sarcopenic individuals[3,4]. Also, a prospective study among Australian adults

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Public Health Nutrition

aged ≥50 years showed that poor dietary protein, Mg, Fe, P and Zn intakes were associated with a decline in appendicular lean mass (ALM), while a higher dietary retinol intake was associated with a decline in ALM over 2·6 years[5]. Furthermore, a systematic review showed that adequate intakes of Mg, Se and Ca reduced the risk of components of sarcopenia (poor muscle mass, muscle strength and physical performance) among the older population[6]. Adequate intakes of protein, long-chain PUFA, antioxidants and certain minerals (Mg, Fe, P and Zn) have also been reported for the prevention of muscle loss and improve physical function[7,8]. However, the findings for the association between nutrient intakes with the different measures of sarcopenia components have been inconsistent.

In addition to the individual nutrient intakes, it is also important to understand the effects of quality, quantity, proportion, variety or a combination of different foods (the dietary pattern approach[9]) on the age-related losses of muscle mass and function[2]. Several publications have suggested that higher adherence to the Mediterranean diet is inversely associated with sarcopenia (EWGSOP) in the older population[10,11,12]. The Mediterranean diet is characterised by a high intake of antioxidants, vitamin D and *n*-3 fatty acid, which can reduce the oxidative stress that is associated with the pathogenesis of sarcopenia[11]. A recent prospective study of a community-dwelling very old British population found that a traditional British dietary pattern (high in butter, red meat, gravy and potato) with high protein intake was associated with an increased risk of sarcopenia (EWGSOP)[13]. In terms of diet quality, a systematic review identified an association between 'healthier diets' and better physical performance (a component of sarcopenia) in the older population[14].

Based on these findings, most studies were limited to evaluating the associations between nutrient intakes or dietary patterns and sarcopenia (EWGSOP) or its separate components. In terms of the sarcopenia definition, there are two most widely used definitions: the Foundation for the National Institutes of Health (FNIH)[15] and the EWGSOP[1]. Recently, the EWGSOP has updated an operational definition of sarcopenia, EWGSOP2[16]. Although the majority of the above-mentioned studies used the EWGSOP definition[1], there is no broadly accepted clinical definition or consensus diagnostic criteria for sarcopenia. Therefore, the objectives of the current study were to examine associations between nutrient intakes and dietary patterns and sarcopenia in older Australian men aged ≥75 years using three different definitions of sarcopenia: the FNIH[15], EWGSOP[1] and EWGSOP2[16].

Methods

The Concord Health and Ageing in Men Project (CHAMP) is a longitudinal study of ageing in men. All participants in CHAMP were recruited from three local government areas (Burwood, Canada Bay and Strathfield) surrounding Concord Hospital in Sydney, New South Wales (NSW), Australia. Potential participants were selected from the NSW electoral roll (electoral registration is compulsory in Australia)[17]. At the first wave (January 2005 and June 2007), a total of 1705 study participants aged ≥70 years was recruited. Data were collected using self-reported and interviewer-administered questionnaires and a wide range of clinical assessments (physical performance measures, biological measures, medication inventory and neuropsychological testing). The study design has been reported in detail elsewhere[17].

Nutrition data were first collected at the third wave (between August 2010 and August 2013) of CHAMP follow-up. A total of 794 men participated in a diet history interview, providing baseline nutrition data for the study described in this paper. For the present study, data were included only for the participants who completed a diet history interview and had sarcopenia measurements.

Dietary intake

Research dietitians administered a standardised diet history questionnaire at the participants' residences. The Sydney South West Area Health Service outpatient's diet history form was used for the CHAMP diet history questionnaire (open-ended questions on food consumption at different meal times). A detailed description of the dietary data collection method has been reported elsewhere[18]. Participants were asked questions about their usual dietary intake during the previous 3 months, and quantities of foods consumed were estimated using food models, photographs[19] and household measures. The diet history interview took approximately 45 min to complete. If a spouse/partner or other family members were present during the interview, they were asked to assist participants with the recall of their dietary intake[20].

Dietary data were converted into nutrient intakes using FoodWorks 7 Professional for Windows (Xyris Software (Australia) Pty Ltd) and Nutrient Database 2007 (AUSNUT 2007). Dietary intake of fourteen nutrients, that is protein, linoleic, linolenic, dietary fibre, riboflavin, total vitamins A, C, E, folate, K, Mg, Ca, Fe and Zn in the CHAMP data, was compared with the Australian Nutrient Reference Values (NRV) for males aged ≥70 years[21]. Attainment of the NRV of fourteen nutrients was used as a categorical variable ('meeting' and 'not meeting' the NRV) and incorporated into a dichotomised variable (nutrient risk variable) 'not meeting' (≤9 nutrients) or 'meeting' (≥10 nutrients) NRV using the cut-point method[22]. The median number of NRV met by participants was 10. Meeting the NRV for ten nutrients was considered as 'good', and meeting the NRV for nine or fewer nutrients was considered as 'poor.'

Also, the ratio of monounsaturated:saturated and *n*-3:*n*-6 PUFA was assessed. The ratio of monounsaturated:saturated fat was calculated by incorporating the intake of all estimated MUFA and dividing by the intake of all estimated SFA. Similarly, the ratio of n-3:n-6 PUFA was calculated by accumulating the intake of an estimated n-3 PUFA divided by the intake of total estimated n-6 PUFA. The data presented on nutrient intakes refer to food consumption only; intake from nutritional supplements was not assessed as the level of detailed data was insufficient for detailed analyses.

Two continuous dietary pattern scores, the Australian Dietary Guideline Index (DGI) (original and revised) and the Mediterranean diet score, were generated. The original Australian DGI[23] is a food-based dietary index developed using data obtained through a 111-item FFQ to investigate the compliance of adults to the Dietary Guidelines for Australian Adults[24]. A detailed description of the adaptations of DGI criteria has been reported elsewhere[25]. In brief, the DGI-2013 comprised thirteen components and each scored out of 10 (overall possible maximum score = 130), where 0 considered as low compliance and 10 considered as better compliance or higher diet quality[25]. DGI includes components that are categorised into adequate intake and moderate intake (i.e. restricted intake recommended)[25]. An adapted version of the Mediterranean diet score (a continuous variable) was generated based on the previous literature, where it has defined absolute cut-off values for all Mediterranean diet score components and applied a three-tier scoring system with zero, one or two points given to participants for each component[26]. The only difference between the current study and the previous study is that we used the ratio of monounsaturated to saturated fat instead of the amount of olive oil consumed per day, including other food groups[26]. One point was for this component to those men who stated that they used monounsaturated to saturated fat for cooking, and zero point to those who reported cooking with any other type of oil. After accumulating the individual component scores, the range of overall Mediterranean diet score was 0 to 18 points[26].

Appendicular lean mass

Whole-body dual-energy X-ray absorptiometry scans were acquired using the fan beam Discovery-W scanner (Hologic Inc.). ALM was calculated as the sum of the lean mass of arms and legs (kg)[27].

Muscle strength

Upper body muscle strength was assessed by handgrip strength using a Jamar dynamometer (Promedics). Grip strength (kg) of the dominant hand (best of two trials) was used.

Gait speed

Gait speed was measured in the clinic assessment on a 6-meter course at the usual pace[28]. To maintain consistency with current low gait speed cut-points for sarcopenia, 6-meter walking speed was converted to 4-meter speed using a previously published formula[29].

Definitions of sarcopenia

Sarcopenia was defined according to FNIH, EWGSOP and EWGSOP2 definitions. Hand grip strength was assessed using a Jamar dynamometer (Promedics). Grip strength (kg) of the dominant hand (best of two trials) was used.

EWGSOP-defined sarcopenia

The EWGSOP defines sarcopenia in men as low ALM adjusted for height squared <7·25 kg/m^2 combined with low handgrip strength (<30 kg) and/or low gait speed (0·8 m/s)[1].

FNIH-defined sarcopenia

The FNIH-defined sarcopenia derived ALM and handgrip strength cut-points from nine different studies with a broad representation of community-dwelling older adults. The FNIH sarcopenia defines clinically relevant low lean mass criteria as ALM/BMI <0·789 for men and handgrip strength <26 kg[15]. Participants were dichotomised as sarcopenic or non-sarcopenic.

EWGSOP2-defined sarcopenia

The EWGSOP2 defines sarcopenia in men as low handgrip strength (<27 kg), ALM adjusted for height squared (<7·0 kg/m^2) and low gait speed (≤0·8 m/s)[16]. According to the EWGSOP2, participants were classified as sarcopenic if they met two of the criteria (low muscle strength and low muscle quantity or quality) and classified as having severe sarcopenia if they met three of the criteria (low muscle strength, low muscle quantity or quality and low physical performance).

Other measurements

Socio-demographic and economic measures

Socio-demographic variables included age (continuous), marital status (categorised as married/De facto *v.* divorced/separated/widowed/never married/other), living arrangements (lives alone *v.* lives with others), country of birth (categorised as Australia, UK, Italy, Greece and other countries-born) and income (categorised as reliant on a government pension only *v.* other sources of income).

Lifestyle factors

Smoking (categorised as a non-smoker, ex-smoker or current smoker) and alcohol consumption were assessed. Participants were categorised into safe-drinker (1–21 drinks/week), harmful drinkers (>21 drinks/week), lifelong abstainers and ex-drinkers[30].

Physical activity (Physical Activity Scale for the Elderly)

Physical activity was measured using the validated, self-administered Physical Activity Scale for the Elderly questionnaire[31]. Participants were categorised into low, moderate and high activity based on the Physical Activity Scale for the Elderly score.

Health measures

A co-morbidity score (continuous) was calculated as the sum of all conditions self-reported from the nineteen disorders listed in the questionnaire[32] (e.g. has a doctor or other health care provider ever told you that you had or have diabetes?): diabetes, thyroid dysfunction, osteoporosis, Paget's disease, stroke, Parkinson's disease, epilepsy, hypertension, heart attack, angina, congestive heart failure, intermittent claudication, chronic obstructive lung disease, liver disease, cancer (excluding non-melanoma skin cancers), osteoarthritis and gout. Self-rated health was obtained through response to the question 'compared to other people of your own age, how would you rate your own health?', and data were dichotomised into excellent/good *v.* fair/poor/very poor. Participants were assessed for cognitive impairment using the Mini-Mental State Examination[33].

Vitamin D supplement

Vitamin D supplement use was coded as 'yes.' Supplements included ergocalciferol-D_2, cholecalciferol-D3, alfacalcidol, and Ostevit-D (providing 25 μg/1000 IU of vitamin D).

Anthropometric measurements

BMI (weight/height^2, with units kg/m^2) was determined with height measurements (using the Harpenden Portable Stadiometer) and weight measurements (using Wedderburn digital scales) following standardised techniques. Based on BMI measurements, participants were categorised as underweight (<22 kg/m^2), normal weight (22–30 kg/m^2) and overweight/obese (>30·0 kg/m^2)[34].

Meal-related factors

Meal-related factors such as whether participants were able to prepare their own meal (categorised as yes or no), to shop for food (categorised as yes or no) and received any meal service (categorised as yes or no) were assessed.

Statistical analysis

The analysis was carried out using SPSS software version 24 (IBM Corp.). Comparisons between groups were performed using the χ^2 test for categorical data and the Wilcoxon rank-sum test for continuous variables. Logistic regression analysis was used to examine cross-sectional unadjusted and adjusted associations between sarcopenia (FNIH, EWGSOP and EWGSOP2) and the nutrient risk variable (i.e. meeting ≥10 nutrients *v.* meeting ≤9 nutrients) as the independent variable. Further analyses were conducted using sarcopenia predictors as dependent variables and nutrient risk variable as an independent variable. For each outcome, we included individual grip strength, walking speed, grip strength cut point (defined by grip strength <26 kg or <30 kg or <27 kg) and walking speed cut point (defined by walking speed <0·8 m/s) as the dependent variable and nutrient risk variable as an independent variable. Further, we conducted an analysis that combined grip strength (defined by grip strength cut points <27 kg, not adjusted for body size) and walking speed (defined by walking speed cut points <0·8/s) as a four-category variable (muscle weakness and slowness, not weak but slow, weak but not slow and not weak and not slow, which used as the reference category) with nutrient risk variable as the independent variable. In addition, linear regression analyses were performed using ALM, ALM adjusted for height, weight and BMI and nutrient risk variable as a predictor variable. Finally, logistic regression analyses were performed using each of the sarcopenia components (ALM/BMI <0·789 and ALM/height^2 <7·25 kg/m^2 or ALM/height^2 <7·00 kg/m^2) as dependent variables to determine the relative contributions made by each variable to the outcome variable. Models were adjusted by covariates, including socio-demographics, health and lifestyle factors, and energy intake. The default procedure of the logistic regression method was used, which utilises the list wise deletion technique when treating missing data.

Sensitivity analyses were performed to determine if there is an association between poor nutrient intake and sarcopenia after omitting dietary supplements (i.e. multivitamin and specific vitamin and mineral users were excluded) and vitamin D supplement users (*n* 226).

In addition, the associations between sarcopenia and intakes of the above-mentioned individual nutrients were assessed by logistic regression models. Each nutrient intake was categorised into four quartiles with the highest quartile as the referent category, and monounsaturated:saturated fat and *n*-6:*n*-3 fatty acid ratios were used as continuous independent variables.

Finally, analyses were carried out to evaluate the associations between dietary patterns (Australian DGI and the Mediterranean diet score) as continuous independent variables and sarcopenia.

Evidence against null hypotheses was considered statistically significant if *P*-values were <0·05. The goodness of fit of the final adjusted logistic regression models was assessed using the Hosmer–Lemeshow statistic.

Results

Socio-demographic, health status and meal-related information and these characteristics according to the FNIH, EWGSOP and EWGSOP2 definitions of sarcopenia are summarised in Table 1. The mean age of men was 81·1 (SD 4·5) years, and mean BMI was 27·7 (SD 4·0) kg/m^2.

The prevalence of sarcopenia was observed in 12·9 % (*n* 89) according to the FNIH definition, 12·9 % (*n* 84) using the EWGSOP definition and 13·8 % (*n* 93) using the EWGSOP2 definition. Probable and severe sarcopenia

Table 1 Characteristics of the study population according to the Foundation for the National Institutes of Health (FNIH), European Working Group on Sarcopenia in Older People (EWGSOP) and EWGSOP2 definitions

			FNIH-defined sarcopenia					EWGSOP-defined sarcopenia					EWGSOP2-defined sarcopenia								
	Total population		No sarcopenia, *n* 600 (87·1 %)		Sarcopenia, *n* 89 (12·9 %)			No sarcopenia, *n* 566 (87·1 %)		Sarcopenia, *n* 84 (12·9 %)			No sarcopenia, *n* 350 (52·1 %)		Probable sarcopenia, *n* 208 (31·0 %)		Sarcopenia, *n* 93 (13·8 %)		Severe sarcopenia, *n* 21 (3·1 %)		
Variables	*n*	%	Mean	SD	Mean	SD	*P* value	Mean	SD	Mean	SD	*P* value	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P* value
Age (years)	792		598	87·0	89	13·0		564	87·0	84	13·0		348	51·9	208	31·0	93	13·9	21	3·1	
75–79	334	42·2	274	92·3	23	7·7		257	87·7	36	12·3		187	64·5	80	27·6	21	7·2	2	0·7	
80–85	285	36·0	218	87·9	30	12·1		206	88·0	28	12·0		120	50·2	83	34·7	31	13·0	5	2·1	
85+	173	21·8	106	74·6	36	25·4		101	83·5	20	16·5		41	29·1	45	31·9	41	29·1	14	9·9	
Mean	81·1		80·6		83·3		<0·0001	80·6		81·4		0·17	79·0		80·4		82·3		84·4		0·25
SD	4·5		4·2		5·0			4·2		4·3			3·2		4·0		4·4		5·3		
Marital status	787		594	87·0	89	13·0		560	87·0	84	13·0		348	52·3	206	30·9	91	13·7	21	3·2	
Married/De facto	596	75·7	463	88·7	59	11·3		435	87·3	63	12·7		284	55·7	150	29·4	62	12·2	14	2·7	
Divorced/separated/widowed/never married/other	191	24·3	131	81·4	30	18·6	0·001	125	85·6	21	14·4	0·28	64	41·0	56	35·9	29	18·6	7	4·5	0·84
Living arrangement	791		598	87·0	89	13·0		564	87·0	84	13·0		350	52·2	208	31·0	91	13·6	21	3·1	
Living alone	161	20·4	118	85·5	20	14·5		110	89·4	13	10·6		64	48·9	43	32·8	21	16·0	3	2·3	
Living with others	630	79·6	480	87·4	69	12·6	0·41	454	86·5	71	13·5		286	53·1	165	30·6	70	13·0	18	3·3	0·85
Country of birth	794		600	87·1	89	12·9		566	87·1	84	12·9		350	52·1	208	31·0	93	13·8	21	3·1	
Australia	418	52·6	316	88·3	42	11·7		301	88·5	39	11·5		192	54·1	101	28·5	51	14·4	11	3·1	
UK	36	4·5	325	92·6	2	7·4		24	88·9	3	11·1		14	45·2	8	25·8	6	19·4	3	9·7	
Italy	162	20·4	119	83·8	23	16·2		109	82·0	24	18·0		71	54·6	43	33·1	13	10·0	3	2·3	
Greece	26	3·3	23	88·5	3	11·5		22	91·7	2	8·3		12	52·2	9	39·1	2	8·7	0	0·0	
*Other	152	19·1	117	86·0	19	14·0	0·77	110	87·3	16	12·7	0·22	61	45·9	47	35·3	21	15·8	4	3·0	0·09
Income	791		598	87·0	89	13·0		564	87·0	84	13·0		349	52·1	208	31·0	92	13·7	21	3·1	
Age pension only	315	39·8	234	84·8	42	15·2		217	85·4	37	14·6		126	48·3	89	34·1	38	14·6	8	3·1	
Age pension + another source	173	21·9	124	87·3	18	12·7		114	83·2	23	16·8		66	46·2	51	35·7	20	14·0	6	4·2	
Other source	303	38·3	240	89·2	29	10·8	0·24	233	90·7	24	9·3	0·03	157	59·0	68	25·6	34	12·8	7	2·6	0·08
BMI (kg/m^2)	774		594	87·2	87	12·8		564	87·3	82	12·7		348	52·0	207	30·9	93	13·9	21	3·1	
Underweight (<22)	46	5·9	29	85·3	5	14·7		30	100·0	0	0·0		3	7·1	21	50·0	12	28·6	6	14·3	
Normal (22–30)	521	67·3	406	88·5	53	11·5		389	88·8	49	11·2		241	52·7	147	32·2	55	12·0	14	3·1	
Overweight/Obese (>30)	207	26·7	159	84·6	29	15·4		145	81·5	33	18·5		104	61·2	39	22·9	26	15·3	1	0·6	
Mean	27·7		27·7		28·7		0·33	27·6		29·8		0·001	28·2		27·3		28·0		25·5		0·32
SD	4·0		3·8		4·4			3·8		3·9			3·5		3·9		4·6		4·2		
PASE	786		594	87·0	89 13·0)			560	87·1	83	12·9		346	52·0	207	31·1	92	13·8	21	3·2	
Low activity (≤76)	198	25·2	164	93·2	12	6·8		110	78·6	30	21·4		52	34·7	44	29·3	41	27·3	13	8·7	
Moderate activity (77–160)	390	49·6	311	89·1	38	10·9		292	90·7	30	9·3		183	53·7	108	31·7	42	12·3	8	2·3	
High activity (≥161)	198	25·2	119	75·3	39	24·7	<0·0001	158	87·3	23	12·7	<0·0001	111	63·4	55	31·4	9	5·1	0	0·0	0·47
Self-rated health	792		599	87·1	89	12·9		565	87·1	84	12·9		350	52·2	208	31·0	92	13·7	21	3·1	
Fair/poor/very poor	204	25·8	126	76·4	39	23·6		118	78·1	33	21·9		59	37·3	51	32·3	38	24·1	10	6·3	
Excellent/good	588	74·2	473	90·4	50	9·6	<0·0001	447	89·8	51	10·2	<0·0001	291	56·7	157	30·6	54	10·5	11	2·1	0·20

Table 1 *Continued*

	Total population		FNIH-defined sarcopenia					EWGSOP-defined sarcopenia					EWGSOP2-defined sarcopenia								
			No sarcopenia, *n* 600 (87·1 %)		Sarcopenia, *n* 89 (12·9 %)			No sarcopenia, *n* 566 (87·1 %)		Sarcopenia, *n* 84 (12·9 %)			No sarcopenia, *n* 350 (52·1 %)		Probable sarcopenia, *n* 208 (31·0 %)		Sarcopenia, *n* 93 (13·8 %)		Severe sarcopenia, *n* 21 (3·1 %)		
Variables	*n*	%	Mean	SD	Mean	SD	*P* value	Mean	SD	Mean	SD	*P* value	Mean	SD	Mean	SD	Mean	SD	Mean	SD	*P* value
Cigarette smoking	786		593	87·0	89	13·0		561	87·0	84	13·0		347	52·0	208	31·2	91	13·6	21	3·1	
Non-smoker	318	40·5	335	87·0	50	13·0		227	84·7	41	15·3		140	50·5	83	30·0	41	14·8	13	4·7	
Ex-smoker	440	56·0	237	86·2	38	13·8		314	89·0	39	11·0		202	54·7	110	29·8	49	13·3	8	2·2	
Current smoker	28	3·6	21	95·5	1	4·5	0·46	20	83·3	4	16·7	0·19	5	23·8	15	71·4	1	4·8	0	0·0	0·72
Alcohol consumption	786		690		114			560	87·1	83	12·9		347	52·2	206	31·0	91	13·7	21	3·2	
Safe-drinker	563	71·6	426	87·3	62	12·7		401	87·7	56	12·3		248	52·4	147	31·1	63	13·3	15	3·2	
Harmful drinker	39	5·0	26	78·8	7	21·2		51	85·0	9	15·0		33	55·0	21	35·0	5	8·3	1	1·7	
Ex-drinker	116	14·8	87	86·1	14	13·9		83	88·3	11	11·7		53	53·0	27	27·0	16	16·0	4	4·0	
Lifelong non-drinker	68	8·7	54	91·5	5	8·5	0·53	25	78·1	7	21·9	0·46	13	40·6	11	34·4	7	21·9	1	3·1	0·36
Co-morbidity (Continuous)	792		599		89			565	87·1	84	12·9		350	52·2	208	31·0	92	13·7	21	3·1	
Mean	2·5		2·33		3·30		<0·000	2·31		3·23		<0·000	2·19		2 44		3·18		3·19		0·89
SD	1·6		1·59		1·74			1·58		1·75			1·46		1·57		1·94		1·54		
MMSE score (Continuous)	747		570	87·7	80	12·3		538	87·5	77	12·5		337	53·1	194	30·6	86	13·5	18	2·8	
Minimum	15		17		15			15		17			16		15		17		19		
Maximum	30		30		30			30		30			30		30		30		29		
Mean	27·4		27·59		26·56		0·95	27·63		26·90		0·59	27·82		27·35		27·03		25·56		0·82
SD	2·8		2·69		3·05		87·5		2·99		2·44		3·04		2·78		2·77				
Able to prepare own meal	792		599	87·1	89	12·9		565	87·1	84	12·9		350	52·2	208	31·0	92	13·7	21	3·1	
No	32	4·0	13	59·1	9	40·9		10	71·4	4	28·6		5	29·4	3	17·6	4	23·5	5	29·4	
Yes	760	96·0	586	88·0	80	12·0	<0·000	555	87·4	80	12·6	0·04	345	52·8	205	31·3	88	13·5	16	2·4	0·97
Meal service (e.g. MOW)	792		599	87·1	89	12·9		565	87·1	84	12·9		350	52·2	208	31·0	92	13·7	21	3·1	
Yes	24	3·0	13	59·1	9	40·9		14	87·5	2	12·5		1	12·5	2	25·0	2	25·0	3	37·5	
No	768	97·0	586	88·0	80	12·0	0·51	551	87·0	82	13·0	0·82	349	52·6	206	31·1	90	13·6	18	2·7	0·91
Able to grocery shop	792		599	87·1	89	12·9		565	87·1	84	12·9		350	52·2	208	31·0	92	13·7	21	3·2	
No	15	1·9	7	70·0	3	30·0		5	83·3	1	16·7		7	38·9	7	38·9	4	22·2	0	0·0	
Yes	777	98·1	592	87·3	86	12·7	0·002	560	87·1	83	12·9	0·07	343	52·5	201	30·8	88	13·5	21	3·2	0·75

PASE, Physical Activity Scale for the Elderly; MMSE, Mini-mental State Examination; MOW, Meals on wheels.

were observed in 31 % (n 208) and 3·1 % (n 21), respectively, according to the EWGSOP2 definition. We also found that around 54 % (n 475) of older men had low ALM/BMI (<0·789) when using the FNIH cut-off, 41 % (n 389) men using the EWGSOP definition for low ALM/height^2 (<7·25 kg/m^2) and 33 % (n 315) men using the EWGSOP2 cut-off ALM/height^2 (<7·00 kg/m^2). About 27 % of men were categorised as overweight/obese, 67 % as normal and 6 % as underweight. The majority of men were married (76 %), lived with others (80 %), received an aged pension as a source of income (40 %) and were born in Australia (53 %). Most men considered their health as excellent or good (75 %), and half of them were moderately active (50 %). Very few men were current smokers (4 %), and most men had a safe level of alcohol consumption (72 %).

Median (IQR) daily intakes of macro and micronutrients and dietary adequacy of each nutrient intake according to the FNIH, EWGSOP and EWGSOP2 definitions are summarised in Table 2 and 3, respectively. The median intake of the majority of nutrients was significantly reduced according to the FNIH-defined sarcopenia compared with non-sarcopenia. These findings were in contrast with the two EWGSOP definitions (Table 2). Similarly, inadequate intake of the majority of nutrients was significantly reduced according to the FNIH-defined sarcopenia compared with non-sarcopenia (Table 3). There were no such significant differences observed for the two EWGSOP definitions (see online supplementary material, Supplemental Tables 1 and 2).

Just under half (49·3 %, n 341) of the participants had inadequate nutrient intakes (meeting nine or fewer of the fourteen above-mentioned nutrients) (Table 4). Using the FNIH definition, 46·3 % of participants classified as sarcopenic had inadequate intakes, as did 45·8 % of men with sarcopenia when using the EWGSOP definition. When using the EWGSOP2 definition, 41·2 % of participants classified as sarcopenic and 38·5 % classified as severely sarcopenic had inadequate intake of nutrients (Table 4). In addition, the FNIH definition was significantly associated with nutrient intake and Australian and Mediterranean diet scores. However, there were no significant associations for EWGSOP and EWGSOP2 definitions (Table 4).

Associations between nutrient intakes and three definitions of sarcopenia are presented in Table 5 and see online supplementary material, Supplemental tables 1 and 2. In unadjusted analyses, poor nutrient intakes were significantly associated with sarcopenia (FNIH) (OR: 2·21 (95 % CI 1·31, 3·72)). The association remained significant even after multivariable adjustment (OR: 2·07 (95 % CI 1·16, 3·67)) (Table 5). There were no statistically significant associations between poor nutrient intakes and the EWGSOP (OR: 1·44 (95 % CI 0·72, 2·87)) and EWGSOP2 (OR: 0·97 (95 % CI 0·47, 2·01)) defined sarcopenia.

The association between nutrient risk variable and the outcomes of muscle weakness (grip strength), slowness (walking speed), ALM and ALM standardised to body size (weight, height and BMI) is displayed in Supplemental Table 3. In multivariable-adjusted models, inadequate intake of nutrients was significantly associated with ALM adjusted for BMI ($\beta = 0·010$, $P < 0·0001$) and ALM adjusted for weight (β = -0·148, $P = 0·008$) but not with other outcomes (muscle weakness, slowness, ALM and ALM adjusted for height).

Supplementary Table 4 shows the associations between nutrient intake and cut points of outcomes: grip strength, walking speed, combined grip strength, walking speed variable, ALM/BMI and ALM/height^2. In multivariable-adjusted models, inadequate intake of nutrients was significantly associated with only ALM/BMI < 0·789 kg/m^2 of muscle mass indices (OR: 1·88 (95 % CI 1·16, 3·05)). No significant associations were observed for the other measures.

Sensitivity analyses omitting dietary supplement users did not change the results for sarcopenia (FNIH) in unadjusted (OR: 2·33 (95 % CI 1·34, 4·06)) and multivariable-adjusted (OR: 2·16 (95 % CI 1·17, 3·97)) analyses. Also, sensitivity analyses after omitting vitamin D supplement users (n 132) did not modify the results in unadjusted (OR: 2·18 (95 % CI 1·29, 3·68)) and multivariable-adjusted (OR: 2·13 (95 % CI 1·20, 3·76)) analyses.

Results of further analyses of the associations between sarcopenia (FNIH) and quartiles of individual nutrients are presented in Table 6 and see online supplementary material, Supplemental Table 5. In unadjusted analyses, the lowest and second-lowest quartiles of protein (lowest quartile ≤83·93 g/d and second quartile 83·94–99·89 g/d) and Mg (lowest quartile ≤282·7 mg/d and second quartile 282·71–354·92 mg/d) were significantly associated with sarcopenia (FNIH). Likewise, the lowest quartiles of n-6 PUFA (≤6·72 g/d), n-3 PUFA (≤0·89 g/d) and Ca (≤619·55 mg/d) were significantly associated with sarcopenia (FNIH) in the unadjusted model. After multivariable adjustment analyses, the lowest and second-lowest quartiles of protein, Mg and Ca remained significantly associated with FNIH definition. Similarly, the lowest quartile of n-6 PUFA and n-3 PUFA were significantly associated with FNIH definition. These associations remained significant after multivariable adjustment analyses. There were no significant associations between FNIH-defined sarcopenia and other nutrients (dietary fibre, riboflavin, vitamins A, C, E, folate, K, Fe and Zn).

In continuous analyses, each unit decrease in n-6:n-3 ratio was significantly associated with a 6 % increased risk of sarcopenia (FNIH) in unadjusted analyses (OR: 1·06 (95 % CI 1·01, 1·11)) and there was a 9 % increased risk of sarcopenia (FNIH) in the multivariable-adjusted analysis (OR: 1·09 (95 % CI 1·04, 1·16)) (data not shown). No such associations were observed between individual nutrient intake and EWGSOP and EWGSOP2 definitions. There were no significant associations between Australian (OR: 0·98 (95 % CI 0·96, 1·01)) as well as the Mediterranean diet scores (OR: 0·97 (95 % CI 0·83, 1·13)) and with FNIH

Public Health Nutrition

Table 2 Median nutrient intakes of sarcopenic and non-sarcopenic population according to the Foundation for the National Institutes of Health (FNIH), European Working Group on Sarcopenia in Older People (EWGSOP) and EWGSOP2 definitions *n* 692

	FNIH-defined sarcopenia					EWGSOP-defined sarcopenia					EWGSOP2-defined sarcopenia								
	No sarcopenia		Sarcopenia			No sarcopenia		Sarcopenia			No sarcopenia		Probable sarcopenia		Sarcopenia		Severe sarcopenia		
Nutrients	Median	IQR	Median	IQR	*P* value	Median	IQR	Median	IQR	*P* value	Median	IQR	Median	IQR	Median	IQR	Median	IQR	*P* value
Total energy (kJ/d)	8932·9	3147·1	7884·9	2393·5	<0·0001	9031·57	3145·68	8630·90	2990·97	0·44	9080·01	3670·63	8696·40	2953·89	8554·66	3356·65	8517·60	2387·41	0·19
Protein (g/d)	100·2	34·7	94·5	37·4	0·01	100·20	34·96	99·82	35·90	0·81	108·38	30·71	100·53	40·29	98·32	35·70	96·82	35·98	0·01
Linoleic acid (*n*-6 PUFA) (g/d)	10·1	7·2	8·7	6·4	0·05	10·12	7·12	10·07	7·23	0·61	10·08	8·08	9·62	7·44	9·51	4·43	8·95	6·42	0·50
Linolenic acid (*n*-3 PUFA) (g/d)	1·3	1·1	1·1	0·9	0·01	1·34	1·09	1·26	0·96	0·72	1·48	1·20	1·30	0·89	1·21	1·14	1·19	0·92	0·49
Dietary fibre (g/d)	26·5	12·0	24·4	14·7	0·02	26·45	10·28	26·48	10·28	0·62	27·64	12·98	26·05	11·25	26·04	11·40	25·50	10·71	0·80
Riboflavin (mg/d)	2·2	1·1	2·0	0·9	0·03	2·19	1·12	1·90	0·88	0·03	2·37	0·91	2·21	1·27	2·18	1·31	2·14	1·08	0·90
Folate (µg/d)	394·1	197·2	348·7	160·1	0·03	394·85	198·57	365·46	168·59	0·06	393·88	235·05	396·24	197·33	382·90	203·53	376·11	189·70	0·95
Vitamin A (µg/d)	1004·0	627·3	842·4	695·1	0·06	1007·06	626·42	917·56	679·22	0·49	1000·90	584·24	962·33	560·96	948·96	712·42	880·75	727·72	0·76
Vitamin C (mg/d)	111·3	83·7	91·5	70·1	0·009	110·89	84·42	104·71	68·61	0·47	146·41	74·58	111·24	80·44	101·18	75·29	103·52	74·35	0·48
Vitamin E (mg/d)	10·1	6·3	8·7	7·5	0·21	10·11	6·31	9·48	7·11	0·46	10·06	6·14	9·72	6·29	9·24	6·64	7·0	4·70	0·73
K (mg/d)	3360·1	1260·40	3107·3	960·8	<0·0001	3379·99	1263·03	3245·38	1050·76	0·10	3518·72	1413·71	3309·97	1372·99	3268·32	1112·55	3172·28	1064·74	0·55
Mg (mg/d)	361·9	155·2	310·2	120·3	<0·0001	362·85	153·95	337·10	149·87	0·05	388·84	107·16	376·38	173·82	346·89	148·60	355·34	153·08	0·34
Ca (mg/d)	818·9	431·0	725·0	291·0	0·03	818·97	424·94	730·01	314·96	0·07	853·13	353·90	819·97	427·51	798·04	435·33	796·17	423·4836	0·99
Fe (mg/d)	13·1	5·5	11·5	5·5	0·03	13·10	5·55	12·46	4·86	0·66	13·54	6·32	13·02	5·48	12·32	5·62	12·24	5·38	0·08
Zn (mg/d)	13·4	5·5	11·9	5·6	0·02	13·45	5·46	13·43	6·59	0·78	14·76	5·36	13·28	5·73	13·03	5·15	12·95	5·71	0·02

P-values by Wilcoxon rank-sum test.

Table 3 Proportion of participants meeting/not meeting the recommended intakes of nutrients according to the Foundation for the National Institutes of Health (FNIH), European Working Group on Sarcopenia in Older People (EWGSOP) and EWGSOP2 definitions *n* 692

			FNIH-defined Sarcopenia					EWGSOP-defined Sarcopenia					EWGSOP2-defined Sarcopenia								
	Total population		No sarcopenia		Sarcopenia			No sarcopenia		Sarcopenia			No sarcopenia		Probable sarcopenia		Sarcopenia		Severe sarcopenia		
Nutrients	Meeting NRV %	Not meeting NRV %	Meeting NRV %	Not meeting NRV %	Meeting NRV %	Not meeting NRV %	*P* value	Meeting NRV %	Not meeting NRV %	Meeting NRV %	Not meeting NRV %	*P* value	Meeting NRV %	Not meeting NRV %	Meeting NRV %	Not meeting NRV %	Meeting NRV %	Not meeting NRV %	Meeting NRV %	Not meeting NRV %	*P* value*
Protein (g/d)	93	7	93·8	6·2	87·6	12·4	0·03	95·2	4·8	93·8	6·2	0·61	95·9	4·1	94	6	90·7	9·3	93·8	6·3	0·38
Linoleic acid (*n*-6 PUFA)	67·7	30·3	75·3	24·7	68·8	31·2	0·22	71·4	28·6	68·9	31·1	0·64	87·5	12·5	73·6	26·4	68·5	31·5	69·6	30·4	0·36
Linolenic acid (*n*-3 PUFA)	50·1	49·9	63·6	36·4	52·2	47·8	0·006	54·9	45·1	51·3	48·7	0·3	58·3	41·7	53·3	46·7	51·7	48·3	52·3	47·7	0·43
Dietary fibre (g/d)	65·3	34·7	71·9	28·1	64·3	35·7	0·16	67·9	32·3	64·2	35·8	0·52	69·9	30·1	68·9	31·1	43·8	56·2	62·5	37·5	0·15
Riboflavin (mg/d)	89·1	10·9	89·5	10·5	86·4	13·6	0·38	93·6	6·4	91·7	8·3	0·56	92·3	7·7	92·1	7·9	91·7	8·3	93·3	6·7	0·99
Folate (μg/d)	69·2	30·8	69·7	30·3	66·3	33·7	0·52	70	30	67·9	32·1	0·7	70·5	29·5	68·5	31·5	62·5	37·5	63·9	36·1	0·5
Vitamin A (μg/d)	83·2	16·8	85·2	14·8	69·7	30·3	<0·001	85	15	77·4	22·6	0·08	93·8	6·3	83·6	16·4	78·1	21·9	82·5	17·5	0·45
Vitamin C (mg/d)	98·5	1·5	98·8	1·2	96·6	3·4	0·11	98·8	1·2	98·8	1·2	0·97	100	0	99·5	0·5	98·6	1·4	99·3	0·7	0·89
Vitamin E (mg/d)	50·6	49·4	62·9	37·1	51·3	48·7	0·01	52·4	47·6	51·3	48·6	0·52	55·5	44·5	52·8	47·2	68·8	31·3	52·3	47·7	0·38
K (mg/d)	68·2	31·8	80·9	19·1	66·3	33·7	0·006	73·8	26·2	66·1	33·9	0·16	75	25	72·6	27·4	63	37	67·2	32·8	0·33
Mg (mg/d)	50·5	49·5	64	36	52·7	47·3	0·003	54·8	45·2	52·8	47·2	0·19	62·5	37·5	57·5	42·5	51·6	48·4	51·9	48·1	0·44
Ca (mg/d)	80	20	88·8	11·2	78·7	21·3	0·03	83·3	16·7	79·2	20·8	0·37	93·8	6·3	80·9	19·1	79·4	20·6	79·5	20·5	0·56
Fe (mg/d)	98·7	1·3	98·8	1·2	97·8	2·2	0·4	0	100	98·8	1·2	0·31	100	0	100	0	98·6	1·4	98·2	1·8	0·32
Zn (mg/d)	65·8	34·2	68·2	31·8	50	50	0·001	68·1	31·9	63·4	36·6	0·4	83·1	16·9	68·8	31·3	64·4	35·6	60·4	39·6	0·007

*P-values by Chi-squared test.

Table 4 Nutrient risk variable, Australian Dietary Guideline Index and Mediterranean diet score according to the Foundation for the National Institutes of Health (FNIH), European Working Group on Sarcopenia in Older People (EWGSOP) and EWGSOP2 definitions

	Nutrient risk variable			Australian Dietary Guideline Index			Mediterranean diet score		
	Meeting the NRV %	Not meeting the NRV %	*P* value*	Mean	SD	*P* value†	Mean	SD	*P* value†
Total population	50·7	49·3	–	93·46	10·58	–	8·05	2·00	–
Sarcopenia (FNIH)									
Sarcopenia	53·7	46·3		90·68	11·37		7·69	2·06	
No sarcopenia	73·3	26·7	0·002	94·09	10·39	0·004	8·12	2·03	0·05
Sarcopenia (EWGSOP)									
Sarcopenia	54·2	45·8		92·73	8·62		8·32	1·83	
No sarcopenia	63·8	36·3	0·33	94·21	10·31	0·21	8·13	2·00	0·39
Sarcopenia (EWGSOP2)									
Severe sarcopenia	61·5	38·5		99·78	9·26		8·23	2·18	
Sarcopenia	58·8	41·2		93·60	11·18		8·09	2·00	
Probable sarcopenia	53·0	47·0		93·53	10·21		8·02	2·09	
No sarcopenia	50·4	49·6	0·33	93·10	9·96	0·09	7·96	1·83	0·92

Meeting the NRV, Meeting ≥10 nutrients; Not meeting the NRV, Meeting ≤9 nutrients.
**P*-values by χ^2 test.
†*P*-values by Wilcoxon rank-sum test.

Table 5 Associations between nutrient intake (nutrient risk variable) and the Foundation for the National Institutes of Health (FNIH)-defined sarcopenia*

	Model 1†			Model 2†			Model 3†			Model 4†		
	Sarcopenia			Sarcopenia			Sarcopenia			Sarcopenia		
	OR	95 % CI	*P* value	OR	95 % CI	*P* value	OR	95 % CI	*P* value	OR	95 % CI	*P* value
Nutrient risk variable (Meeting ≤ 9 nutrients)	2·21	1·31, 3·72	0·003	2·01	1·18, 3·41	0·01	2·09	1·18, 3·70	0·01	2·07	1·16, 3·67	0·01
Reference category: Meeting ≥ 10 nutrients												

*Reference category: Non-sarcopenia.
†Model 1: unadjusted; model 2: adjusted by age; model 3: adjusted by same variables as model 2 plus BMI, marital status, living arrangement, income, smoking status, MMSE score, alcohol intake, SRH, meal service, able to shop for groceries, meal preparation, no. of co-morbidities and PASE; model 4: adjusted by same variables as model 3 plus energy.

definition. Similarly, no associations were observed between diet scores and EWGSOP [Australian diet score: OR: 1·00 (95 % CI 0·97, 1·03); Mediterranean diet scores: OR: 0·55 (95 % CI 0·28, 1·09)] and EWGSOP2 [Australian diet score: OR: 1·01 (95 % CI 0·98, 1·03); Mediterranean diet scores: OR: 1·05 (95 % CI 0·90, 1·22)] definitions.

Discussion

In this study of community-dwelling older men, using different definitions, the prevalence of sarcopenia (i.e. 12·9 % for both the FNIH and EWGSOP definition and 13·8 % for the EWGSOP2 definition) was similar. When we compared nutrient risk variable and dietary patterns between sarcopenia and non-sarcopenia groups according to different sarcopenia definitions, surprisingly, there were significant differences in nutrient intake, Australian as well as Mediterranean diet scores between the men who had sarcopenia and those who did not (according to FNIH definition). However, there were no significant differences when we considered the other two definitions.

Furthermore, this present study demonstrated the associations between sarcopenia (FNIH) and poor nutrient intakes, particularly protein, *n*-6 PUFA, *n*-3 PUFA, *n*-6:*n*-3 ratio, Mg and Ca, whereas using the EWGSOP or EWGSOP2 definitions, there were no significant findings. There were no associations observed between any other nutrients, dietary patterns and any sarcopenia definitions. Additionally, when individual components of sarcopenia (i.e. grip strength, walking speed, ALM/BMI and ALM/Height^2) were assessed, inadequate intake of nutrients was significantly associated with only a low ALM/BMI (<0·789), whereas other components of sarcopenia did not show such associations. Even when we considered continuous variables, ALM/BMI remained

Table 6 Associations between individual nutrient intakes and the Foundation for the National Institutes of Health (FNIH)-defined sarcopenia*

	Model 1†			Model 2†			Model 3†			Model 4†		
	OR	95 % CI	*P* value	OR	95 % CI	*P* value	OR	95 % CI	*P* value	OR	95 % CI	*P* value
Sarcopenia												
Protein Reference category: highest quartile ≥ 119·15 g/d	1·00			1·00			1·00			1·00		
Third quartile 99·90–119·14 g/d	1·71	0·79, 3·70	0·18	1·78	0·81, 3·90	0·15	1·69	0·73, 3·88	0·22	1·63	0·70, 3·79	0·26
Second quartile 83·94–99·89 g/d	2·43	1·15, 5·11	0·02	2·56	1·20, 5·46	0·02	2·60	1·17, 5·80	0·02	2·73	1·21, 6·15	0·02
Lowest quartile ≤83·93 g/d	3·47	1·69, 7·11	0·001	3·07	1·48, 6·38	0·003	3·31	1·52, 7·21	0·003	3·21	1·47, 7·03	0·004
$P_{\text{for trend}}$	0·002	0·01	0·009	0·009								
n-6 PUFA reference category: highest quartile ≥ 13·73 g/d	1·00			1·00			1·00			1·00		
Third quartile 9·73–13·72 g/d	1·24	0·58, 2·64	0·58	1·19	0·55, 2·56	0·66	1·42	0·62, 3·24	0·41	1·55	0·66, 3·61	0·31
Second quartile 6·73–9·72 g/d	1·77	0·91, 3·44	0·09	1·49	0·75, 2·96	0·25	1·85	0·88, 3·87	0·10	1·90	0·89, 4·05	0·09
Lowest quartile ≤ 6·72 g/d	1·91	0·99, 3·69	0·05	1·82	0·93, 3·55	0·08	2·17	1·04, 4·53	0·04	2·22	1·05, 4·68	0·04
$P_{\text{for trend}}$	0·04			0·08			0·02			0·05		
n-3 PUFA reference category: highest quartile ≥ 1·90 g/d	1·00			1·00			1·00			1·00		
Third quartile 1·31–1·89 g/d	1·13	0·54, 2·37	0·74	1·16	0·55, 2·45	0·70	1·35	0·58, 3·09	0·48	1·26	0·54, 2·91	0·59
Second quartile 0·90–1·30 g/d	1·68	0·85, 3·35	0·14	1·69	0·84, 3·41	0·15	1·94	0·87, 4·30	0·11	1·60	0·70, 3·66	0·26
Lowest quartile ≤ 0·89 g/d	2·52	1·27, 5·00	0·008	2·58	1·33, 5·01	0·005	3·32	1·57, 6·99	0·002	2·77	1·28, 6·01	0·01
$P_{\text{for trend}}$	0·01			0·02			0·005		0·02			
Mg reference category: highest quartile ≥ 435·73 mg/d	1·00			1·00			1·00		1·00			
Third quartile 354·92–435·72 mg/d	1·96	0·87, 4·37	0·10	1·79	0·79, 4·05	0·16	1·53	0·65, 3·64	0·33	1·56	0·67, 3·66	0·30
Second quartile 282·71–354·91 mg/d	3·28	1·55, 6·98	0·002	2·86	1·33, 6·14	0·007	2·21	0·98, 5·01	0·06	2·33	1·04, 5·21	0·04
Lowest quartile <282·70 mg/d	3·55	1·69, 7·47	0·001	3·13	1·47, 6·66	0·003	2·56	1·16, 5·68	0·02	2·68	1·19, 6·04	0·02
$P_{\text{for trend}}$	0·001			0·007			0·002			<0·0001		
Ca reference category: highest quartile ≥1047·11mg/d	1·00			1·00			1·00			1·00		
Third quartile 805·68–1047·10 mg/d	1·49	0·71, 3·10	0·29	1·61	0·76, 3·39	0·21	1·74	0·77, 3·91	0·18	1·66	0·75, 3·69	0·22
Second quartile 619·56–805·67 mg/d	1·94	0·95, 3·93	0·07	2·04	0·99, 4·21	0·05	2·32	1·04, 5·21	0·04	2·45	1·12, 5·33	0·02
Lowest quartile <619·55 mg/d	2·56	1·34, 4·89	0·005	2·61	1·30, 5·27	0·007	2·80	1·30, 6·04	0·008	2·77	1·28, 6·01	0·01
$P_{\text{for trend}}$	0·03			0·04			0·02			0·03		

*Reference category: Non-sarcopenia was used as the reference category.
†Model 1: unadjusted; model 2: adjusted by age; model 3: adjusted by same variables as model 2 plus BMI, marital status, living arrangement, income, smoking status, MMSE score, alcohol intake, SRH, meal service, able to shop for groceries, meal preparation, no of co-morbidities and PASE; model 4: adjusted by same variables as model 3 plus energy.

positively associated with an inadequate intake of nutrients. Additionally, inadequate intake of nutrients was inversely associated with ALM/Weight. A recently published cross-sectional study reported that lower intake of total energy and protein was risk factors of low ALM/BMI in older men; however, this study did not examine micronutrient intake[35]. Interestingly, the FNIH cut-off for ALM/BMI appears to identify a higher number of older men with low muscle mass compared with the other two criteria, resulting in lower statistical power to identify a significant association. Moreover, the FNIH cut-offs were derived from the older population[15], while the EWGSOP and EWGSOP2 obtained data from the younger reference group[1,16]. Overall, these three definitions of sarcopenia are not directly comparable, since these definitions have considered a different determinant of body size.

To the best of our knowledge, this is the first population-based study that has investigated associations between nutrient intakes and three different sarcopenia algorithms: FNIH, EWGSOP and EWGSOP2. In contrast with our findings, previous studies which have shown significant associations between poor dietary intakes of protein, fat, *n*-3 PUFA, K, Mg, Ca, Fe, vitamins E and C and sarcopenia, all studies used either the components of sarcopenia or the EWGSOP definition[3,5,6,7,36,37,38,39]. Interestingly, our study is the first to report a significant association, albeit cross-sectional, between poor nutrient intake and sarcopenia (FNIH) in Australian older men. In accordance with previous studies, the current study indicates that each population needs its specific muscle mass indices, due to the variations of ethnicity and geographic region[1,40]. Although our study was not designed to define or evaluate the consensus on the best definition or diagnosis of sarcopenia for older Australian men, our results suggest that the FNIH definition using ALM/BMI influences the association between inadequate intake of nutrient and sarcopenia.

Our study found men with the lowest dietary intake of protein (≤99·89 g/d) had increased sarcopenia (FNIH). Contrary to our findings, two recent cross-sectional studies found that sarcopenic individuals (using the EWGSOP definition) consumed significantly lower amounts of dietary protein (mean intake 70·2 g/d and 68 g/d) compared with non-sarcopenic individuals (mean intake 85 g/d and 74 g/d)[3,4]. The much higher amount of protein intake in CHAMP men (mean intake 102·6 gm/d) may have limited the ability to detect a significant association between dietary protein intake and sarcopenia (EWGSOP). Dietary protein intake has shown to be associated with components of sarcopenia as it is important for the maintenance of muscle mass and strength[41]; it plays a crucial role in muscle homoeostasis by supplying essential amino acids and replacing those lost through catabolic pathways and support protein accumulation[41]. The Tasmanian Older Adult Cohort study showed Australian participants who failed to meet the NRV for protein intake (<65 g/d) had lower ALM at baseline[5]. In prospective analyses, the same study observed that total energy-adjusted dietary protein intake was a positive predictor of change in ALM over 2·6 years[5]. Similarly, the Health, Aging and Body Composition Study showed a greater loss of lean mass and ALM over 3 years among American older individuals who had the lowest quintile of energy-adjusted total protein intakes (11·2 % of energy) than participants in the highest quintile of energy-adjusted total protein intakes (18·2 % of energy) at baseline[37]. A recent case–control study also observed sarcopenic individuals had lower dietary protein intakes (mean intake 72·5 g/d) than non-sarcopenic individuals; however, the measure of sarcopenia was Short Physical Performance Battery, which was not comparable to our measures[42]. Several studies demonstrated an increased dietary intake of protein at baseline to be associated with muscle health over time[39,43,44]. A 5-year prospective study showed the highest tertile of dietary protein intake (>87 g/d) was associated with higher ALM among community-dwelling older women[39]. Two more prospective studies of American cohorts, the Women's Health Initiative[43] and the Framingham Offspring[44], have shown higher protein intakes (mean intake 81 7 g/d and median intake 94 g/d, respectively) are associated with reduced loss of grip strength.

In our study, the lowest quartiles of *n*-6 PUFA (≤6·72 g/d), *n*-3 PUFA (≤ 0·89 g/d) and the ratio of *n*-6:*n*-3 fatty acids were significantly associated with sarcopenia (FNIH). However, there were no such associations observed between *n*-3 PUFA, *n*-6 PUFA and the ratio of *n*-6:*n*-3 fatty acids and the other two sarcopenia definitions (EWGSOP and EWGSOP2). In contrast to our findings, a recent cross-sectional study of oldest-old men indicated an inverse association between dietary total PUFA and sarcopenia (EWGSOP2)[45]. Also, this study did not provide any detailed information about the dietary intake of *n*-3 or *n*-6 PUFA[45]. It appears that our study is the first study to describe the effects of dietary *n*-3, *n*-6 and the ratio of *n*-3:*n*-6 PUFA on sarcopenia (FNIH) in older men. In general, *n*-3 PUFA has protective effects on muscle, while *n*-6 PUFA is considered to have pro-inflammatory effects with detrimental effects on musculoskeletal health[46]. A recent systematic review and meta-analysis found a single study on *n*-6 PUFA study on gamma-linolenic acid supplementation, which did not suggest any effect on muscle mass, hand and leg muscle strength[46].

The effects of *n*-3 PUFA on musculoskeletal health and outcomes have investigated previously, but effects were inconclusive. For instance, the Maastricht Sarcopenia study found that sarcopenic individuals (using the EWGSOP definition) consumed 1·3 g/d of *n*-3 PUFA, while non-sarcopenic individuals consumed 2 g/d of *n*-3 PUFA[4]. However, our findings were not significant. The difference in findings may be explained by the lower intakes of *n*-3 PUFA intake in our Australian study, compared with Maastricht sarcopenic individuals. Observational and intervention studies have reported a beneficial effect of *n*-3 PUFA intakes on muscle mass and strength[47,48,49]. The Hertfordshire Cohort Study found higher consumption of oily fish to be associated with higher grip strength in older people[47]. A randomised controlled trial assessed the effect of *n*-3 fatty acid supplementation (1·86 g/d EPA and 1·50 g/d DHA) for 8 weeks on the rate of muscle protein synthesis in American older adults and suggested that *n*-3 fatty acid may be beneficial for the prevention of sarcopenia[48]. Another randomised controlled trial showed an increase of muscle strength in older Scottish women but not in men after 18 weeks of *n*-3 PUFA supplementation (fish oil derived, 2·1 g/d EPA and 0·6 g/d DHA) combined with resistance exercise training[49]. While another randomised controlled trial study evaluated the effects of a 12-week supplementation of 1·3 g/d n-3 PUFA on muscle strength and physical performance in Polish older people with decreased muscle mass which was unable to find any the effect of n-3 PUFA supplementation[50]. Inconsistent results from randomised controlled trials may be due to the differences in race, ethnicity, dose and duration of interventions, and also, it is unknown if participants were deficient in this nutrient. Furthermore, underlying mechanisms for the above-mentioned associations could be the composition of fatty acids within the sarcolemma (muscle membrane). Long-chain PUFA are nutrients that may positively affect sarcopenia outcomes due to their anti-inflammatory properties[51]. Considering the aforementioned findings, an increased intake of n-3 PUFA and a decreased consumption of n-6 PUFA may play a vital role in preserving muscle mass in older age. Clinical trials are required to strengthen the importance of individual n-3 or n-6 PUFA or the ratio of n-6:n-3 PUFA on musculoskeletal health in the older population.

Our study demonstrated a significant association between poor dietary intake of Mg (<355 mg/d) and increased risk of sarcopenia (FNIH). Evidence suggests that adequate Mg intake is important in the maintenance of ALM[4,5]. In comparison with our results, two recent cross-sectional studies in Belgium and Netherland reported that sarcopenic (using the EWGSOP definition) individuals had lower dietary intakes of Mg (mean intake 279 mg/d and 410·6 mg/d), respectively[3,4]. However, we found no such associations with <355 mg/d of Mg intake and the sarcopenia (EWGSOP) in CHAMP men. Furthermore, a recent case–control study observed that sarcopenic individuals (using SPPB: 4–9 scores and a group of measures that combines the results of the gait speed, chair stand and balance tests) had significantly lower intakes of Mg (average intake 260 mg/d) compared with the non-sarcopenic individuals (average intake 295 mg/d)[42]. Lower Mg intakes are also associated with components of sarcopenia. A prospective study of community-dwelling older Australian individuals showed dietary Mg intake below the NRV was associated with the loss of ALM[5]. Likewise, a cross-sectional study by Welch *et al.* indicated that an average 371 mg/d dietary Mg intake was associated with greater grip strength and measures of skeletal muscle mass in the British cohort[38]. These findings have been confirmed by an intervention study where 300 mg/d magnesium oxide supplementation for 12 weeks improved muscle strength and physical performance in older Italian women[52]. While another intervention study observed the lack of a significant improvement in muscle strength with 250 mg/d Mg supplementation for 8 weeks in Iranian middle-aged adults[53]. Contradictory findings from intervention studies may be due to chance findings, an insufficient dose of Mg, poor bioavailability of Mg supplements or short duration of supplementation. One potential mechanism linking Mg to sarcopenia is that it plays an important role in muscle function and metabolism, as well as being involved in more than 600 enzymatic reactions[6]. Mg is vital for the control of oxidative stress and confers a role in maintaining the normal function of muscle mitochondria[54].

The present study also identified a significant association between poor intakes of Ca (<805·67 mg/d) and sarcopenia (FNIH). In contrast, two other cross-sectional studies in Dutch cohorts found no association between dietary intake of Ca (mean intake 734·5 mg/d and 852 mg/d) and sarcopenia (EWGSOP)[4,42]. Findings on the associations between Ca intake and muscle mass have been contradictory. Two cross-sectional studies observed an association between lower Ca intakes (mean intake 316·37 mg/d and 282·47 mg/d, respectively) and increased prevalence of sarcopenia (defined as appendicular skeletal muscle mass divided by body weight, i.e. ASM/wt) among Korean older individuals[55,56]. However, a recent case–control study found no association between Ca intake (average 813 mg/d) and muscle mass (using SPPB score) in Dutch older women[42]. This could be explained by the differences in Ca intake in the study populations. Reduced Ca absorption and changes in Ca homoeostasis are suggested to be associated with muscle weakness in aged muscle[57,58]. Moreover, the absorption of dietary Ca depends on the presence of vitamin D[59]. It has been observed that serum 25-hydroxyvitamin D levels were significantly lower in sarcopenic older adults[55,56]. Consistently, a previous paper from the CHAMP study also reported a longitudinal association between lower serum 25D levels (<40 nmol/l) and incidence of sarcopenia (FNIH) over 5 years in older Australian mend[60].

Taken together, findings from previous studies and our study show that the associations between nutrient intakes and sarcopenia are conflicting. Several factors may explain the variability of the relationship, including gender, ethnicity, differences in sarcopenia definitions and its separate components, range of physical and functional status and the differences in the amounts of nutrient intakes.

In addition to macro and micronutrient intakes, an inverse association between the sarcopenia (EWGSOP) and different dietary patterns has been reported previously[10,11,12,13,14]. A cross-sectional study by Hashemi *et al.* observed a lower risk of sarcopenia among older Iranian individuals who consumed the highest tertile of the Mediterranean dietary pattern[12]. Adherence to the Mediterranean diet was also associated with a lower risk of frailty that is constant with sarcopenia findings[61,62]. While the Western dietary pattern was not associated with sarcopenia[3]. In this present study, there was no such association observed between the Australian DGI (considered as a healthy dietary pattern) or Mediterranean dietary pattern and three operational definitions of sarcopenia (FNIH, EWGSOP and EWGSOP2).

A unique strength of our study is that we were able to investigate the associations between sarcopenia and nutrient intakes as well as dietary patterns using three different definitions of sarcopenia. CHAMP includes a large and representative group of older Australian men, as demonstrated by similar socio-demographic and health characteristics compared with older men in the nationally representative MATeS study (Men in Australia Telephone Survey)[63]. We also used a validated diet history method to assess nutrient intake for our study participants[64].

There are some study limitations. The cross-sectional nature of this study makes it impossible to determine the investigation of causal mechanisms. There are missing data found in our analyses due to the different indices-defined sarcopenia and the cut-offs used for handgrip strength. We did not have any data on serum concentrations of micronutrients. The estimation of food intake may be under- or over-reported; hence, results should be interpreted with caution. The effect of social desirability bias may persist across diet data. Self-reported diet data may have been influenced by the participant's desire to gain approval from dietitian/researchers, which may consequently overestimate food and nutrient intake[65]. Finally, our study was limited to community-dwelling Australian older men, so our results may not be applicable to older women, institutionalised older people, or different ethnicities.

Conclusion

Our results suggest that inadequate intakes of certain nutrients, particularly protein, *n*-3 PUFA, *n*-6 PUFA, *n*-6:*n*-3 ratio, Mg and Ca, are associated with sarcopenia (FNIH) in community-dwelling older Australian men, but not when using EWGSOP and EWGSOP2 definitions. Additional longitudinal studies are required to provide insight into the associations between inadequate intakes of nutrients and incident sarcopenia (FNIH) in the older Australian population. These results also indicated that the association between nutrient intake and sarcopenia is likely to be influenced by definition applied, sex, differences in ethnicity, various geographic region and range of physical and functional state. Further research is required to establish appropriate cut-points for individual components of sarcopenia in the wider Australian population. Using an appropriate sarcopenia definition derived from specific ethnic populations would provide clear guidance to researchers and clinicians for the diagnosis and treatment of sarcopenia.

Acknowledgements

Acknowledgements: The authors thank all the staff working on the CHAMP and the participants in the project. *Financial support:* The work is funded and supported by the NHMRC Project Grant (No. 301916), Sydney Medical School Foundation, Ageing and Alzheimer's Institute and Centre for Oral Health Strategy, NSW Health. The lead author is funded by the University of Sydney and the ARC Centre of Excellence in Population Ageing Research. *Conflict of interest:* None reported. *Authorship:* A.D. and V.H. designed and developed the study concept. R.V.R.W. collected the nutritional data and A.D. performed the analyses and wrote the manuscript. R.G.C., V.N., F.B., D.L.C., D.J.H., L.M.W., R.V.R., S.J.S. and V.H. collaborated in writing. All authors reviewed and approved the final version of the manuscript. All authors reviewed the manuscript. *Ethics of human subject participation:* The study complied with the Declaration of Helsinki and all procedures involving human subjects were approved by the Concord Hospital Human Research Ethics Committee, Sydney, Australia. Written informed consent was provided by all study participants.

Supplementary material

For supplementary material accompanying this paper visit https://doi.org/10.1017/S1368980020003547

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