Clinical Nutrition xxx (2015) 1–8

Contents lists available at ScienceDirect

Clinical Nutrition

journal homepage: http://www.elsevier.com/locate/clnu

Original article

Nutritional status, body composition, and quality of life in community-dwelling sarcopenic and non-sarcopenic older adults: A case-control study

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ARTICLE INFO

Article history:
Received 22 September 2015
Accepted 22 November 2015

Keywords:
Protein
Micronutrient
Frailty
Observational
Sarcopenia

SUMMARY

Background & aim: Sarcopenia, the age-related decrease in muscle mass, strength, and function, is a main cause of reduced mobility, increased falls, fractures and nursing home admissions. Cross-sectional and prospective studies indicate that sarcopenia may be influenced in part by reversible factors like nutritional intake. The aim of this study was to compare functional and nutritional status, body composition, and quality of life of older adults between age and sex-matched older adults with and without sarcopenia.

Methods: In a multi-centre setting, non-sarcopenic older adults (n = 66, mean ± SD: 71 ± 4 y), i.e. Short Physical Performance Battery (SPPB): 11–12 and normal skeletal muscle mass index, were recruited to match 1:1 by age and sex to previously recruited adults with sarcopenia: SPPB 4–9 and low skeletal muscle mass index. Health-related quality of life, self-reported physical activity levels and dietary intakes were measured using the EQ-5D scale and index, Physical Activity Scale for the Elderly (PASE), and 3-day prospective diet records, respectively. Concentrations of 25-OH-vitamin D, α-tocopherol (adjusted for cholesterol), folate, and vitamin B-12 were assessed in serum samples.

Results: In addition to the defined components of sarcopenia, i.e. muscle mass, strength and function, reported physical activity levels and health-related quality of life were lower in the sarcopenic adults ($p < 0.001$). For similar energy intakes (mean ± SD: sarcopenic, 1710 ± 418; non-sarcopenic, 1745 ± 513, $p = 0.50$), the sarcopenic group consumed less protein/kg (−6%), vitamin D (−38%), vitamin B-12 (−22%), magnesium (−6%), phosphorus (−5%), and selenium (−2%) (all $p < 0.05$) compared to the non-sarcopenic controls. The serum concentration of vitamin B-12 was 15% lower in the sarcopenic group ($p = 0.015$), and all other nutrient concentrations were similar between groups.

Conclusions: In non-malnourished older adults with and without sarcopenia, we observed that sarcopenia substantially impacted self-reported quality of life and physical activity levels. Differences in nutrient concentrations and dietary intakes were identified, which might be related to the differences in muscle mass, strength and function between the two groups. This study provides information to help strengthen the characterization of this geriatric syndrome sarcopenia and indicates potential target areas for nutritional interventions.

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http://dx.doi.org/10.1016/j.clnu.2015.11.013

Please cite this article in press as: Verlaan S, et al., Nutritional status, body composition, and quality of life in community-dwelling sarcopenic and non-sarcopenic older adults: A case-control study, Clinical Nutrition (2015), http://dx.doi.org/10.1016/j.clnu.2015.11.013

1. Introduction

Sarcopenia is a syndrome that is defined predominantly by the simultaneous occurrence of low skeletal muscle mass, strength and function [1]. The definition of sarcopenia overlaps partially with physical frailty [2], and the consequences of both syndromes are increased incidence of falls and fractures, loss of independence, and increased rates of hospitalization. Poor dietary intake has been associated with individual components of sarcopenia, possibly due to dietary pattern changes, reduced response of ageing muscle to anabolic stimuli from meals (anabolic resistance), or oxidative stress from ageing and co-morbidities [3].

Higher dietary intake of protein has been consistently associated with greater muscle mass in older adults [3–5]. Consequently, a higher recommended protein intake of 1.0–1.2 g/kg body weight was recently proposed for healthy maintenance of ageing muscles and up to 1.2–1.5 g/kg body weight/day for older adults with acute or chronic disease [6,7]. Several serum nutrient deficiencies (or inadequacies) are associated with measures of sarcopenia through pathways that are still not well-understood [3]. The risk of becoming frail increases with the number of micronutrient deficiencies [8]. A low 25-OH-vitamin D level was cross-sectionally related to appendicular lean mass, leg strength and leg muscle quality [9], and also to functional outcomes such as increased rates of falls and nursing home admissions [10,11] among older adults. Vitamin B12, B6 and folate are nutrients that may have an impact on sarcopenia, since they help to reduce serum levels of homocysteine, higher levels of which are related to reduced muscle strength and gait speed [12–14].

Relatively little information is available comparing nutrient intake and serum nutrient concentrations between sarcopenic and healthy older adults [1]. Such knowledge can help to eventually guide health care professionals in identifying the most appropriate nutritional recommendations and interventions. The goal of this study was to compare functional and nutritional status, body composition, and quality of life of older adults between age and sex-matched older adults with and without sarcopenia.

2. Methods

2.1. Study design and participants

This study is based on a matched case-control observational cohort of older adults with sarcopenia and their non-sarcopenic controls.

Older adults with sarcopenia were selected from the PROVIDE study population. The PROVIDE study was a multi-centre randomized controlled trial investigating the effect of a vitamin D and leucine-enriched whey protein supplement on muscle mass, strength and function in older adults with sarcopenia. The PROVIDE study is registered under the Dutch trial register with the identifier: NTR2329. A total of 380 volunteers with sarcopenia participated in this 13-week intervention, which is published elsewhere [15]. The major eligibility criteria for the sarcopenic participants (i.e. cases) were: 1) Aged ≥65 years; 2) a short physical performance battery (SPPB) score of 4–9; 3) low skeletal muscle mass index (SMI: skeletal muscle mass/BW × 100): ≤37% (men) and ≤28% (women) measured using bioelectric impedance analysis (BIA 101 Akern, Florence, Italy) [16]; 4) a body mass index (BMI) between 20 and 30 kg/m^2; 5) were able and willing to provide written informed consent. A sub-sample of these sarcopenic participants (n = 66) who were screened and recruited between June 2010 and May 2013 from sites in the United Kingdom was matched with non-sarcopenic controls. Non-sarcopenic controls were identified through advertisements, contacts to organisations such as senior clubs, churches, sports centres and associations offering activities for older people, as well as by word of mouth through other potential volunteers who had expressed interest but did not meet the study criteria.

Non-sarcopenic older adults (n = 66) were recruited to match by age (- 1 year, + 2 years accepted) and sex with a ratio of 1:1 to the sarcopenic participants. They were identified from three sites in the United Kingdom (Manchester, Lancashire and Newcastle) between September 2013 and June 2014; using the following inclusion criteria: 1) Aged ≥ 65 years; 2) a SPPB score of 11–12; 3) Normal SMI defined as SMI ≤ one standard deviation below the sex-specific mean for young adults (aged 18–40), using BIA [16] or DXA [17]; 4) a body mass index (BMI) between 20 and 30 kg/m^2; 5) able and willing to provide written informed consent.

2.2. Outcome measures and data collection

All data from the sarcopenic older adults were collected at the screening or baseline visit of the intervention trial (i.e. before the start of the nutritional intervention). Data on background characteristics, nutritional status, anthropometrics and physical performance were collected on a single visit (in a few cases blood samples were collected during a second visit) from the non-sarcopenic controls.

2.2.1. Anthropometry

Body composition was assessed using dual energy x-ray absorptiometry (DXA, different models from Hologic, Bedford, USA; and Lunar, Fairfield, USA). Appendicular muscle mass (arms and legs) and fat mass (total) were measured and a central check was done to ensure uniformity in the analysis.

2.2.2. Muscle strength and function

Handgrip strength was measured using a hydraulic hand dynamometer (Jamar™, Preston, Jackson, Missouri, USA). Two consecutive measures of grip strength in each hand were recorded to the nearest kg with the participant in an upright position and the arm of the measured hand parallel to the body. Maximum grip strength was calculated by taking the average of the highest measurement from both hands.

SPPB consists of three components: gait speed (4-m walk at a usual pace), chair stand test (time taken to rise five consecutive times from a chair as quickly as possible without arm rests), and balance (feet side-by-side, semi-tandem and tandem) according to the method outlined by Guralnik et al. [18]. Each component was scored from 0 (not possible) to 4 (best performance) and summed in a total score ranging from 0 to 12.

2.2.3. Reported physical activity levels and health-related quality of life

Self-reported amount of physical activity was measured using the European version of the Physical Activity Scale for the Elderly (PASE). The Barthel index was used to measure the level of independence in activities of daily living with possible scores between 0 and 100 (highest scores best). Health-related quality of life was measured using the EQ-5D, both as an index and as a visual analogue scale (VAS) between 0 and 100.

2.2.4. Assessment of frailty status

Participants in both groups were categorized into non-frail, pre-frail, or frail based on adapted Fried [19] criteria. The following criteria were used: 1) involuntary weight loss; having responded "yes" to a question on the mini-nutritional assessment short-form about experiencing involuntary weight loss of 1–3 kg or more than 3 kg in the past 3 months; 2) exhaustion; having responded

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"no" to a question on the Geriatric Depression Scale (GDS 0–9 points considered normal) about whether they feel full of energy; 3) physical inactivity; having a PASE questionnaire score of <64 for men and <52 for women; 4) slow walking speed [19]; 5) low handgrip strength relative to BMI [19]. Participants were considered non-frail if none of the criteria were met, pre-frail if 1 or 2 of the criteria were met, and frail if 3–5 of the criteria were met.

2.2.5. Nutritional assessment

The mini nutritional assessment short form (MNA-SF®) was used to ask questions related to malnutrition. The answers to the questions resulted in a score from 0 to 14 points. Participants were then categorised into normal nutritional status (12–14 points), at risk for malnutrition (8–11 points), or malnourished (0–7 points).

2.2.5.1. Dietary intake. Participants in both the sarcopenic and non-sarcopenic groups were asked to complete 3-day dietary intake records over two weekdays and one weekend day. This dietary assessment took place after the study visit, and was returned by the participants within two weeks. Food diaries were quality checked and entered by trained dieticians, and portion sizes were translated to gram weight amounts using site-specific dietary data entry systems, which included: Windiets; CompEat (Pro Version 5.8.0.); and DietPlan (6.70.67). The gram weights of food intake were then converted to energy, macronutrient and micronutrient amounts using the following food composition tables: McCance and Widowson 5th and 6th edition, and the UKN UK Nutrient databank.

2.2.5.2. Serum nutrient concentrations. Serum samples were taken in a fasted state at the screening visit for the sarcopenic participants or during the single study visit for the non-sarcopenic controls. Samples were left at room temperature for 30 min and were then centrifuged. The alliquoted serum was stored at −20 or −80C°. Analytical testing for serum vitamin D (25-OH-D), vitamin B-12, and folate were performed at Reinier de Graaf Groep medical laboratory, Delft, the Netherlands using chemiluminescense microparticulate immunoassay (Abbott Laboratories, Wiesbaden, Germany) (25-OH-D), and competitive protein binding ligand (CPBL) (vitamin B-12 and folate). For 25-OH-D, compared to a chromatography-based reference method, the recovery of endogenous 25-OH-vitamin both D3 and D2 species were 105% and 85%, respectively. To evaluate the effect of season on serum 25-OH-D, we stratified the participants by season of blood draw: summer (June–November) and winter (December–May) [20]. Analytical testing of serum vitamin-E was performed at Nutricia Research, Utrecht, using HPLC and spectroflurometry, and total cholesterol was analysed enzymatically, followed by colometry at Reinier de Graaf Groep, Medical Laboratory.

Serum concentrations were considered inadequate or deficient if they were below: vitamin D (25-OH-D), 50 nmol/L [21]; vitamin B-12, 200 pmol/L [22]; folate, 10 nmol/L [23]; vitamin E:cholesterol ratio, 2.25 μmol/mmol [24].

2.3. Ethics

The study protocol was reviewed and approved by The Research Ethics Boards at each of the locations and was registered with the Dutch trials register with the identifier: NTR2329 [15] (http://www.trialregister.nl/trialreg).

2.4. Statistical analyses

Data were checked for normal distributions using the Shapiro-Wilk test and visual inspection of the group histograms. Continuous data that followed a normal distribution was described with means and standard deviations and between-group comparisons were performed by paired t-tests. When distributions were not normal, the data were described with medians and interquartile ranges and between-group comparisons were done using the Wilcoxon signed-rank test. Categorical variables were presented as percentages and either the Wilcoxon signed-rank test (ordinal data), McNemar (dichotomous data) or the Bhapkar test (nominal data) was performed to test for significant differences between the matched pairs. Only complete matched pairs for each outcome were used in the analyses. P-values <0.05 were considered statistically significant. All statistical analyses were performed in SAS (Version 9.4).

3. Results

In total, 253 non-sarcopenic older adults were screened according to the inclusion criteria, until 66 eventually met the inclusion criteria, agreed to participate, and were matched successfully to adults with sarcopenia based on age and sex (Fig. 1). All participants were reported to be living independently and both groups had similar low rates of fall incidents in the past year (Table 1).

In accordance with the inclusion criteria, gait-speed, balance score and chair-stand time were all significantly worse in the sarcopenic sample versus the non-sarcopenic controls. Handgrip strength was significantly lower in the sarcopenic sample than in the non-sarcopenic controls. The sarcopenic group had a significantly higher mean body weight by 3.5 kg ($p = 0.015$) and 6 kg more fat mass ($p < 0.001$) than the non-sarcopenic controls. Appendicular muscle mass was 1.4 kg lower in the sarcopenic sample than the non-sarcopenic controls ($p = 0.001$) (Table 2).

The sarcopenic participants reported significantly less physical activity than the non-sarcopenic adults (PASE) and significantly lower ability to perform daily activities (Barthel index) (Table 1). Sarcopenic older adults reported having a poorer health-related quality of life than the non-sarcopenic adults, both on the visual analogue scale and the 5-domain index (Table 1). The sarcopenic participants were more likely to be frail (14%) or pre-frail (71%) compared to the non-sarcopenic participants where none were frail and 30% were pre-frail ($p < 0.001$).

3.1. Nutritional parameters

The majority of participants in both groups were non-malnourished according to the MNA (Table 1). There were no significant differences in energy intake or intake of carbohydrate or fat. When expressed as percentages of energy, the sarcopenic sample had slightly lower percentage energy from carbohydrates, but the percentages of energy from fat (and all types of fatty acids) were not significantly different between the sarcopenic sample and the non-sarcopenic control sample. Protein intake relative to body weight was significantly lower in the sarcopenic group (−6% different), but no difference was observed when expressed as gram intake/day or as a percentage of energy. Vitamin B-12 (−22% different), Vitamin D (−38% different), phosphorus (−5% different), and selenium (−2% different) were all statistically significantly lower in the sarcopenic sample than the non-sarcopenic controls. Intakes of all other nutrients did not differ between the groups (Table 3).

Serum Vitamin B-12 concentrations were significantly lower in the sarcopenic versus the non-sarcopenic control group of older adults (mean ± SD 284 ± 107 pmol/L vs. mean ± SD 335 ± 120 pmol/L, $p = 0.015$). Likewise, a larger proportion of adults with sarcopenia was considered deficient in vitamin B-12 compared with the non-sarcopenic controls (26% vs. 11%, $p = 0.033$)

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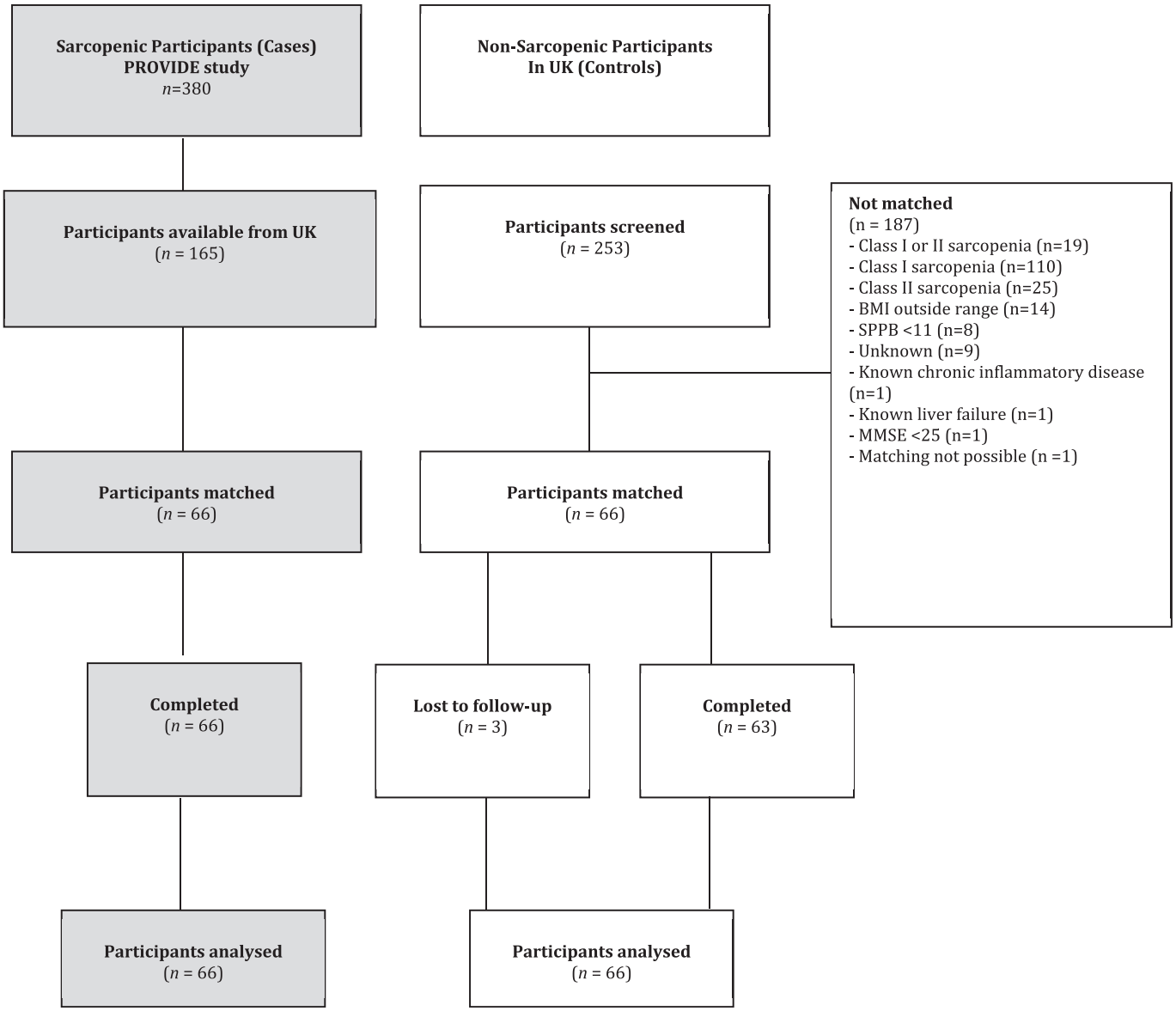

Fig. 1. Participant recruitment, screening and enrolment.

(Table 4). Mean serum 25-OH-vitamin D was not different between the two groups. There were more non-sarcopenic control blood draws in the winter (December–May) (n = 48) than in the summer (June–November) (n = 16), versus a relative balance in the number of blood draws of the sarcopenic older adults in the summer (n = 34) and winter (n = 29) seasons. 25-OH-Vitamin D concentrations were significantly different (p = 0.017) between non-sarcopenic and sarcopenic older adults in the summer, but not in the winter season (Fig. 2).

4. Discussion

Compared to age- and sex-matched non-sarcopenic seniors, older adults with sarcopenia reported significantly lower health-related quality of life and self-reported physical activity levels. These older adults with sarcopenia had higher body weights, lower appendicular muscle mass and higher fat mass than their non-sarcopenic controls, despite the dietary energy intakes being roughly equal between the groups. Dietary nutrient intakes of protein (g/kg/day) vitamin B-12, vitamin D, magnesium, phosphorus, and selenium were significantly lower in the sarcopenic sample. Serum vitamin B-12 was different between the groups, with a significantly lower concentration among sarcopenic older adults.

4.1. Quality of life and frailty

In agreement with previous studies, we found that adults with sarcopenia have significantly lower health-related quality of life compared to non-sarcopenic older adults [25]. We also observed that the sarcopenic adults had a slightly higher GDS score, although both groups were well within the “normal” range. Depression, a GDS score of 10 or greater, however, is associated with lower appendicular muscle mass and thus sarcopenia [26]. Likewise, the functional independence measured by the Barthel index was high in both groups, with significantly more sarcopenic adults with scores below 100 compared to the non-sarcopenic adults. Lower scores on the Barthel index are associated with sarcopenia likely

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Table 1
Characteristics and demographics of older adults with and without sarcopenia.

	Sarcopenic older adults n = 66	Non-sarcopenic older adults n = 66	p-value
Sex, female, n (%)[a]	39 (59.1)	39 (59.1)	
Age (y), mean (SD)[a]	71.1 (4.4)	71.0 (4.4)	
MNA non-malnourished n (%)[b]	62 (93.9)	64 (97.0)	0.625
MNA at risk for malnutrition n (%)	4 (6.1)	2 (3.0)	
Current smoker, n (%)[c]	14 (21.2)	3 (4.5)	0.001
Alcohol consumption, yes n (%)[b]	55 (84.6)	59 (89.4)	0.439
Number of medical visits, n (%)[b]			
1 visit in past month	11 (16.7)	18 (27.7)	0.004
2 visits in past month	2 (3.0)	7 (10.8)	
Frailty status, No frailty, n (%)[b]	10 (15.4)	45 (70.3)	<0.001
Pre-frail	46 (70.8)	19 (29.7)	
Frail	9 (13.8)	0 (0)	
Number of falls, none, n (%)[b]	60 (90.9)	61 (93.8)	0.590
Geriatric Depression Scale, median (IQR)[b]	1 (0, 2)	0 (0, 1)	<0.001
MMSE, median (IQR)[b]	29 (28, 30)	29 (28, 30)	0.966
PASE questionnaire, total score, mean (SD)[d]	148 (73.3)	193 (73.6)	<0.001
Health-related QOL (EQ-5D), index, points[d]	0.79 (0.16)	0.94 (0.09)	<0.001
Health-related QOL (EQ-5D), VAS, mm[d]	79.4 (13.3)	89.5 (7.8)	<0.001
Barthel index, highest score (score of 100), n (%)[b]	48 (72.7)	64 (98.5)	<0.001

[a] Participants were matched 1:1 by sex and age (- 1 year, +2 years allowed).
[b] Wilcoxon Signed-Rank test.
[c] Bhapkar test for paired nominal data.
[d] Paired t-test for matched pairs.

through poorer muscle strength [27]. We observed a small percentage of sarcopenic adults that were non-frail according to these criteria. This suggests that sarcopenia is a risk factor for frailty, but sarcopenia can occur without concurrent frailty.

4.2. Body composition

Body composition, lean body mass:fat mass ratio were different, regardless of height and BMI. This difference in body composition highlights the fact that sarcopenia may present itself either as a condition with malnutrition and weight loss, as also evidenced by the Hertfordshire cohort study [28], or alongside higher adiposity as shown in this study. High fat mass coinciding with sarcopenia poses greater risks for continued and hastened declines in mobility considering among other etiological factors as the associated fat infiltration of the muscle [29]. The different phenotypes of sarcopenia may have different requirements for energy, protein and micronutrient and may thus require specific nutritional interventions and recommendations.

4.3. Nutritional status

There was a small, but significant difference in the dietary intake of protein (g/kg body weight/day) between the sarcopenic and non-sarcopenic older adults. Although the mean intake in the sarcopenic group was within the low range of the most recent recommendations for healthy older adults (1.0–1.2 g/kg bw/day [6,7]), this intake level may still not be adequate to prevent or treat

Table 2
Body composition and Muscle Strength and Function.

	Sarcopenic older adults n = 66	Non-sarcopenic older adults n = 66	p-value
Body Composition			
Weight, kg, mean (SD)[a]	73.9 (11.1)	70.4 (11.3)	0.015
Height, m, mean (SD)[a]	1.67 (0.09)	1.65 (0.09)	0.192
BMI, kg/m[b], mean (SD)[a]	26.5 (2.2)	25.6 (2.8)	0.040
Appendicular Muscle Mass, kg, DXA, mean (SD)[a]	19.0 (4.4)	20.4 (5.0)	<0.001
Men, mean (SD)[a]	23.2 (3.0)	25.8 (2.6)	0.003
Women, mean (SD)[a]	16.0 (2.1)	16.6 (1.7)	0.130
Appendicular Muscle Mass/height[b], kg/m[b], DXA, mean (SD)[a]	6.8 (1.0)	7.4 (1.2)	<0.001
Men, mean (SD)[a]	7.6 (0.7)	8.6 (0.7)	<0.001
Women, mean (SD)[a]	6.2 (0.6)	6.5 (0.5)	0.010
Fat mass, kg, DXA, mean (SD)[a]	27.7 (5.6)	21.8 (6.0)	<0.001
Fat mass, %, DXA, mean (SD)[a]	37.4 (6.0)	31.1 (7.4)	<0.001
Muscle Strength and Function			
SPPB score, median (IQR)[b]	8.0 (7.0, 9.0)	12.0 (11.0, 12.0)	<0.001
4–6, n (%)[b]	14 (21.2)	0 (0)	
7-9	52 (78.8)	0 (0)	
10-12	0 (0)	66 (100)	
Handgrip strength, kg, mean (SD)[b]	23.2 (8.4)	29.4 (8.7)	<0.001
Men, mean (SD)[b]	29.8 (8.2)	37.5 (7.5)	0.002
Women, mean (SD)[b]	18.6 (4.6)	24.0 (4.0)	<0.001
Gait-speed, m/s, mean (SD)[a]	0.83 (0.20)	1.23 (0.19)	<0.001
Balance score, points, median (IQR)[b]	4 (3, 4)	4 (4, 4)	<0.001
Chair-stand time, seconds, median (IQR)[b]	19.3 (17.4, 23.0)	10.0 (9.2, 11.1)	<0.001

[a] Paired t-test for matched pairs.
[b] Wilcoxon Signed-Rank test.

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Table 3
Average daily dietary energy and nutrient intakes by sarcopenic and non-sarcopenic older adults.

	Mean (SD)[a]		p-value
	Sarcopenic older adults n = 66	Non-sarcopenic older adults n = 66	
Energy (kcal)	1710 (418)	1745 (513)	0.496
Macronutrients			
Protein (g)	72.5 (19.6)	75.3 (20.7)	0.359
Protein (g/kg BW)	0.99 (0.24)	1.09 (0.29)	0.044
% E from Protein	17.4 (3.8)	17.8 (3.7)	0.685
Carbohydrate (g)	212 (61)	208 (76)	0.906
% E from Carbohydrates	46.9 (6.3)	44.5 (7.3)	0.045
Total Fat (g)	63.3 (19.0)	65.8 (22.1)	0.403
% E from Fat	32.6 (5.7)	33.1 (5.9)	0.649
% E from Saturated fat	12.1 (3.2)	12.0 (3.1)	0.912
% E from Monounsaturated fat	10.8 (2.8)	10.9 (2.6)	0.856
% E from Polyunsaturated fat	5.5 (1.9)	5.5 (1.7)	0.731
Micronutrients			
Vitamin B-6 (mg)	2.0 (0.9)	2.0 (0.8)	0.871
Vitamin B-12 (μg), median (IQR)[b]	3.9 (2.6, 5.9)	5.3 (3.6, 6.9)	0.011
Folate (μg)	246 (107)	261 (101)	0.351
Vitamin C (mg)	92.1 (71.6)	98.6 (59.4)	0.543
Vitamin D (μg)	2.6 (2.1)	4.0 (3.4)	0.007
Vitamin E equivalent (mg)	7.4 (4.0)	8.0 (3.8)	0.493
Calcium (mg)	813 (301)	846 (289)	0.506
Magnesium (mg)	260 (96)	295 (86)	0.015
Phosphorus (mg)	1196 (330)	1325 (338)	0.014
Selenium (μg)	39.1 (17.1)	46.5 (21.2)	0.039
Zinc (mg)	8.2 (3.0)	9.0 (2.6)	0.087

[a] Paired t-test for matched pairs.
[b] Wilcoxon Signed-Rank test.

sarcopenia. Furthermore, there were significantly lower intakes of some micronutrients by the sarcopenic adults compared to the non-sarcopenic controls. Compared to the British daily reference nutrient intakes (RNIs) [30], both groups seemed to have "adequate" mean micronutrient intakes except vitamin D and selenium. This evident micronutrient "sufficiency" is not uncommon among the UK's older adults, where the national diet and nutrition survey (2008–2010) found that adults over 65 years met or exceeded all micronutrient RNIs except for vitamin D [31]. However, micronutrient sufficiency in terms of the RNI might not be sufficient to preserve functional outcomes of sarcopenia. For example, vitamin B-12 intakes in both groups were above the RNI, but the sarcopenic group had significantly lower intakes than the non-sarcopenic controls, which was reflected in the serum concentrations of vitamin B-12. There was a significantly higher percentage of sarcopenic older adults (26%) below the deficiency cut-off level of 200 pmol/L [22], versus 11% in the non-sarcopenic controls.

Both groups had mean daily vitamin D intakes below the RNI of 10ug, which is the same as the newest Institute of Medicine's estimated average requirement (EAR) [21]. Lower vitamin D levels, however, are also associated with components of sarcopenia. Considering the mobility limitations and subsequent lower physical activity levels (as confirmed by the PASE questionnaire) of the sarcopenic older adults, sun exposure and, consequently, 25-OH-D levels were expected to be lower in this group compared to the non-sarcopenic controls. The sarcopenic group in our study had significantly lower vitamin D intakes than the non-sarcopenic group, but we did not observe a difference in serum concentrations between the groups. This may due to a bias in our assessment given the greater number of non-sarcopenic adults sampled in the winter months. This seasonality of vitamin D concentrations, especially in the UK, is common [20,32] and is compounded by the fact that older adults spend more hours outdoors in the summer and autumn months [20].

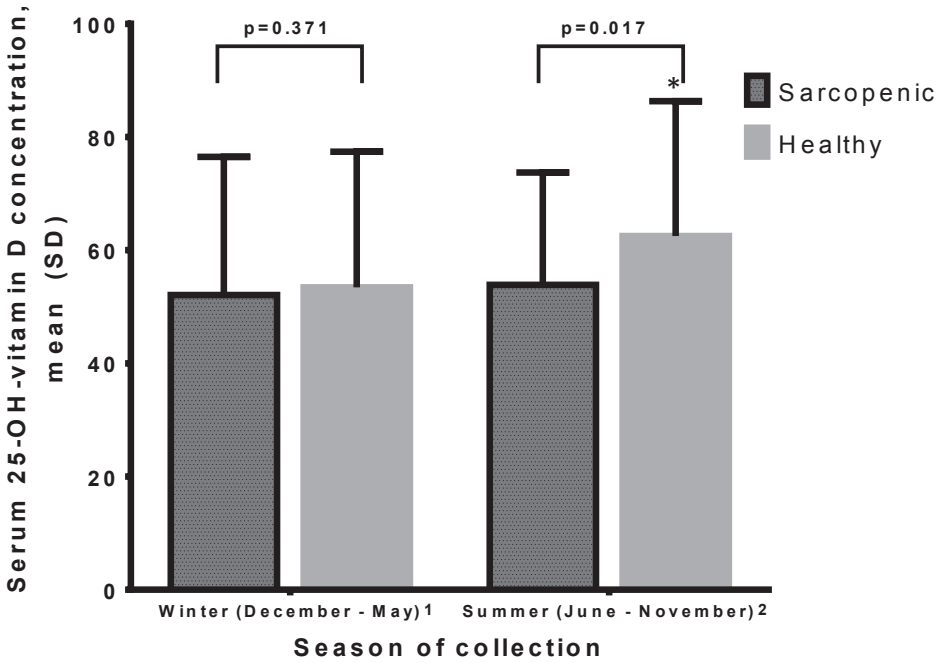
The generally lower micronutrient density of the sarcopenic group's diets and the nutrient intakes that were significantly lower (vitamin B-12, vitamin D, magnesium, phosphorus, and selenium) could signal a lower quality of the diet in the sarcopenic group. Thus, a group of nutrients rather than individual nutrients could also contribute to lower muscle mass, strength and function of sarcopenia. Scott et al. (2010), for example, showed that higher

Table 4
Descriptive statistics comparing serum biomarkers between adults with and without sarcopenia.

	Mean (SD)		p-value
	Sarcopenic older adults n = 66	Non-sarcopenic older adults n = 66	
Serum 25-OH-D, nmol/L, mean (SD, CV)[a]	52.9 (22.3, 42.1)	55.7 (24.1, 43.2)	0.399
Deficient (≤50.0 nmol/L), n (%)	33 (52.4)	30 (46.9)	0.336
Serum vitamin E: cholesterol μmol/mmol, mean (SD, CV)[a]	6.2 (1.2, 20.1)	6.5 (1.4, 21.3)	0.127
Deficient (≤2.25 μmol/mmol), n (%)	0	0	n/a
Serum vitamin B-12, pmol/L, mean (SD, CV)[a]	284 (107, 38)	335 (120, 36)	0.015
Deficient (≤200.0 pmol/L), n (%)	17 (26.2)	7 (10.9)	0.033
Serum folate, nmol/L, mean (SD, CV)[a]	22.1 (11.2, 50.7)	19.8 (8.8, 44.6)	0.211
Deficient (≤10 nmol/L), n (%)	9 (13.8)	6 (9.4)	0.439
Use of nutritional supplements, yes, n (%)[b]	13 (19.7)	12 (18.2)	0.827

[a] Paired t-test for matched pairs.
[b] Wilcoxon Signed-Rank test.

Please cite this article in press as: Verlaan S, et al., Nutritional status, body composition, and quality of life in community-dwelling sarcopenic and non-sarcopenic older adults: A case-control study, Clinical Nutrition (2015), http://dx.doi.org/10.1016/j.clnu.2015.11.013



[1] Sample size: sarcopenic, n=34, non-sarcopenic, n=48
[2] Sample size: sarcopenic, n=29, non-sarcopenic, n=16

Fig. 2. Total serum 25-OH-vitamin D concentration between group differences, stratified by season of sample collection.

intakes of calcium, magnesium, niacin, phosphorus, potassium, riboflavin and zinc, had positive increasing trends for increased appendicular muscle mass [5].

4.4. Limitations

Given the cross-sectional nature of the study, we cannot comment about causation and the directions in which the relationships we observe exist; i.e. whether sarcopenia causes changes in nutritional status or whether nutritional status causes changes in the development of sarcopenia. However, the data do provide a clinical snapshot of adults living with sarcopenia, and suggest that there are potential gaps in the diet. This information could help to build future nutrition interventions. In addition, we recognize that there is a wide range of clinical presentations of patients with sarcopenia and our results might not be widely generalizable outside the limits of our inclusion criteria and age-group.

4.5. Strengths

Having matched non-sarcopenic controls to sarcopenic adults on two of the strongest unmodifiable risk factors: age and sex (females have a higher risk of sarcopenia than men) [33], we were able to carefully examine other characteristics as potentially contributing to the pathogenesis of sarcopenia. Another strength of our study is that the outcomes were assessed using the same methods, after identical training and within a similar time frame. We used a robust and appropriate dietary assessment method for community-dwelling older adults, which likely improved the accuracy of our group means [34]. A 3-day food intake record is considered a strong assessment method [34] versus diet histories, food frequency questionnaires and even 24-h recalls since they allow the participants to directly record their food intake. This does not exclude potential omissions or intrusions on the records, but it prevents relying exclusively on memory to accurately recall all foods and drinks consumed [34], which must be an important consideration in older populations.

5. Conclusion

By comparing age and sex-matched older adults without protein-energy malnutrition, we observed that sarcopenia significantly impacts self-reported quality of life and physical activity level. There were differences in nutrient concentrations and dietary intakes, which might be related to differences in muscle mass, strength and function between the two groups. Certain groups of micronutrients and macronutrients and their relationship to sarcopenic parameters suggest that nutrients work in harmony with each other, and that isolating a single “problem” nutrient for sarcopenic interventions may not adequately address the problem. This study provides information to help strengthen the characterization of this geriatric syndrome sarcopenia and indicates potential target areas for nutritional interventions.

Author contributions

Study concept and design: Verlaan, Bauer, Brandt, Hill, Aspray, Seal, McPhee, Wijers, terBorg, Sieber, Cederholm

Analysis and interpretation of data: Verlaan, Bauer, Brandt, Hill, Aspray, Seal, McPhee, Piasecki, Hemsworth, Wijers, terBorg, Sieber, Cederholm

Drafting of the manuscript: Verlaan, Hemsworth, Wijers

Critical review of the manuscript for important intellectual content: Verlaan, Bauer, Brandt, Hill, Aspray, Seal, McPhee, Piasecki, Hemsworth, Wijers, terBorg, Sieber, Cederholm

Obtained funding: Verlaan

The project was sponsored by Nutricia Research, Nutricia Advanced Medical Nutrition.

Please cite this article in press as: Verlaan S, et al., Nutritional status, body composition, and quality of life in community-dwelling sarcopenic and non-sarcopenic older adults: A case-control study, Clinical Nutrition (2015), http://dx.doi.org/10.1016/j.clnu.2015.11.013

Conflict of interests

Verlaan, Hemsworth, terBorg, and Wijers are employees of Nutricia Research, Nutricia Advanced Medical Nutrition.

Acknowledgements

We would like to warmly thank the participants for their time and energy in volunteering for this study. We are grateful to Carolyn Taylor for her assistance in the implementation of the trial and participant recruitment. We kindly thank the staff at Synexus, Newcastle University, Manchester University, and Nutricia Research for their efforts in the study performance.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.clnu.2015.11.013.

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