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ORIGINAL PAPER

Association between dietary nutrient intake and sarcopenia in the SarcoPhAge study

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Abstract

Background It has been suggested that a balanced nutritional intake may be useful in preventing or even reversing sarcopenia.
Aim To describe cross-sectional associations between dietary nutrient intake and sarcopenia.
Methods Subjects recruited from the *SarcoPhAge* study population completed a food frequency questionnaire. The micronutrient and macronutrient intake was evaluated in both sarcopenic and non-sarcopenic participants. The Nutritional Belgian Recommendations of 2016 were used, i.e., adequate intake and estimated average requirement (EAR). For micronutrients, the prevalence of insufficient intake was estimated as the proportion of subjects whose intake was below the EAR.
Results A total of 331 subjects (mean age of 74.8 ± 5.9 years, 58.9% women) had complete data and were included in this study. Among them, 51 were diagnosed with sarcopenia (15.4%). In the fully adjusted model, analyses revealed that sarcopenic subjects consumed significantly lower amounts of two macronutrients (proteins, lipids) and five micronutrients (potassium, magnesium, phosphorus, iron, and vitamin K) than non-sarcopenic subjects (all p values < 0.005). A significantly increased prevalence of insufficiency was found for sarcopenic subjects compared to non-sarcopenic subjects for potassium, magnesium, iron, calcium and vitamins E and C (all p values < 0.005). The prevalence of sarcopenic subjects who were also below the Nutritional Belgian Recommendations for protein and lipids was significantly higher than that of non-sarcopenic subjects.
Discussion and conclusions Sarcopenic subjects seem to consume significantly reduced amounts of many micronutrients and macronutrients compared to non-sarcopenic subjects. These results suggest that a poorly balanced diet may be associated with sarcopenia and poor musculoskeletal health, although prospective studies are needed to confirm these findings.

Keywords Sarcopenia · Micronutrient · Macronutrient · Nutrition · Diet · Muscle health

Introduction

Sarcopenia is the progressive loss of muscle mass, strength and muscle function that occurs after the fifth decade of life [1–3]. Sarcopenia is now well recognized with a consensual new European definition [4] and with an ICD code (ICD-10-CM) [5]. Sarcopenia, which has a prevalence of 1–30% in people aged 65 years or older [6], is associated with multiple consequences, such as a decreased quality of life, decreased mobility, falls, fractures, hospitalization and prematurated death [7–10].

Some other changes occur with ageing. For example, it is now well known that total energy and food intake decline with age and, as a consequence, macro- and micronutrient intake declines as well [11]. Often, multiple diseases, polypharmacy, loss of appetite (anorexia of ageing), loss of acuity in taste or smell, chewing or swallowing difficulties as well

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as difficulties in preparing or having access to food are factors responsible for impaired dietary intake and malnutrition [11–13]. Declining food intake in old age may lead to weight loss, loss of muscle mass and quality, loss of muscle strength and loss of muscle function. Indeed, the energy provided by food is necessary for organ function and muscle activity by stimulating muscle anabolism and limiting muscle catabolism. Therefore, an inadequate intake of proteins, creatine or even some micronutrients such as vitamin D or vitamin E, for example, leads to an imbalance between the needs and the supply that can potentially be devastating for muscle health [14–17].

For these reasons, currently, nutrition is considered one of the most important pillars, together with physical activity, for the treatment and prevention of sarcopenia. Multiple studies have also shown that dietary supplementation associated with physical activity, and more specifically resistance training, is particularly efficient for muscle mass, strength and function of a geriatric population [6, 18–23]. Since most studies are performed on older subjects in general and not specifically on a population of sarcopenic subjects, it is not completely clear what role nutrition plays in the prevention and treatment of sarcopenia itself. Moreover, the dietary intake of sarcopenic subjects compared with non-sarcopenic subjects has been poorly investigated. Nevertheless, it is a valid starting point for research. To fill this gap, and because the SarcoPhAge (for *Sarco*penia and *Ph*ysical Impairment with Advancing *Age*) cohort population [24] is composed of not only sarcopenic subjects but also a population of controls, this study aims to describe the association between dietary nutrient intake and sarcopenia through two different objectives: (1) assessing the difference in micro- and macro-nutrient consumption between sarcopenic and non-sarcopenic subjects through a food frequency questionnaire; (2) assessing the proportion of subjects with an insufficient intake of those micronutrients and macronutrients in both populations, as compared to the official Belgian recommendations.

Methods

Participant characteristics

Participants in the SarcoPhAge study were included in the present study. The SarcoPhAge study is an observational study, which started in 2013 in Liège, Belgium, that includes community-dwelling adults aged 65 years or older with an annual follow-up. Written informed consent was provided by participants, and the study was approved by the Ethics Committee of our institution (reference 2012/277). The full methodology and protocol of the SarcoPhAge study have already been described in detail elsewhere [24]. The present cross-sectional study is based on the population still participating in the SarcoPhAge study after 2 years of follow-up. Among the 534 participants included in the SarcoPhAge study, 337 were still present after 2 years of follow-up and were proposed to participate in this ancillary study. Indeed, between baseline and the 2-year follow-up, 197 subjects (36.9%) were not reviewed for various reasons: death ($n=20$); physical or cognitive inability to attend the annual follow-up ($n=59$); unable to contact ($n=12$); and refusal to participate again ($n=106$) (Fig. 1).

Data collection

Participants were seen in the Polyclinique Lucien Brull in Liège, Belgium, by two different clinician research assistants (CB and ML, first two authors of this paper) for a mean time of 1 h during which they went throughout a series of tests and evaluations. Among these tests and evaluations, participants were evaluated for sarcopenia, and they completed a food frequency questionnaire.

Sarcopenia diagnosis

The diagnostic definition proposed by the European Working Group on Sarcopenia in Older People (EWGSOP) was used to diagnose sarcopenia [1]. The following evaluations were, therefore, applied to all participants:

- A measurement of muscle mass: dual-energy X-ray absorptiometry (DEXA) (Hologic Discovery A, USA), calibrated daily, was used to determine a skeletal muscle mass index (SMI), calculated by dividing the appendicular lean mass by the height squared (kg/m^2). The

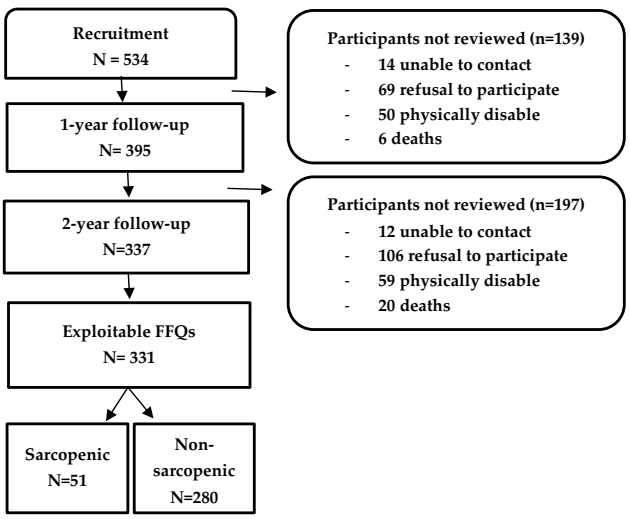

Fig. 1 Flow diagram of the 2-year follow-up of the SarcoPhAge study

proposed cut-offs of 7.26 kg/m^2 for men and 5.50 kg/m^2 for women [25] were used to diagnose a low SMI.

- A measurement of muscle strength: a hand-held hydraulic dynamometer (Saehan Corporation, MSD Europe Bvba, Belgium) was used to obtain handgrip strength. Following the protocol published by Roberts et al. [26], subjects had to squeeze as hard as possible three times with each hand, and the highest result was recorded. Impaired handgrip strength was characterized by a score lower than 30 kg for men and 20 kg for women [1].
- A measurement of physical performance: the short physical performance battery (SPPB) test [27] was used to evaluate the physical performance of the participant through the evaluation of three components: balance, walking speed and chair-and-stand test. A score less than or equal to 8 points (out of 12) is synonymous with decreased performance [1].

Energy and nutrient intake

Each of the participants was asked to complete a self-administered food frequency questionnaire (FFQ) to evaluate their usual dietary intake during the month preceding the survey. For each of the 78 food/drink items displayed throughout the questionnaire (bread, vegetables, meat, fish, oil, pasta, eggs, candy, water, wine, etc.), participants had to specify the frequency of which they consumed it during the last month (never consumed, 1–3 times a month, 1–2 times a week, 3–5 times a week, 1 time a day, 2 or more times a day). When a participant declared to consume a piece of food/drink two or more times a day, two times per day was chosen as a default value. Participants were asked to complete the FFQ alone but were free to ask one clinical research assistant (CRA) for clarification if needed. Moreover, each questionnaire, once completed, was carefully screened by the same CRA to ensure that the data were complete and relevant. The FFQ was developed in the author's research department by a group of experts in the field and according to the population of interest and our research objectives. The full French version of this questionnaire is available in the Supplementary files (S1).

Since our analyses were intended to be quantitative, two sets of meal pictures were also displayed at the end of the questionnaire to obtain a global estimation of the portion size of food consumed daily by each participant. For each item of the food frequency questionnaire, the quantity consumed was calculated by multiplying the frequency of consumption, expressed in number of times per day, by the size of the portion. This value was expressed in g/d for foods or mL/d for beverages. The portion size was either a standard portion (e.g., a bowl of milk = 350 mL, a cup of coffee = 250 mL, a glass of water = 150 mL, a tablespoon of vegetable oil = 15 mL), or the portion corresponding to the picture chosen by the participant in the questionnaire (e.g., for composite dishes). Nutritional intakes were then calculated using the published NutriNet-Santé food composition table [28]. For each aggregated food item of the frequency questionnaire, a composition was calculated as the mean composition of all corresponding food items of the NutriNet-Santé composition table, weighted by sex-specific frequency of consumption of each food item among the adults participants of the NutriNet-Santé study who provided at least three 24-h dietary records.

Total energy intake was measured as well as the consumption of micronutrients (proteins, lipids and carbohydrates) and macronutrients [sodium, potassium, magnesium, phosphorus, iron, calcium and vitamins (D–A–E–C–K)]. References values from the Nutritional Belgian Recommendations of 2016 (available: https://www.health.belgium.be/sites/default/files/uploads/fields/fpshealth_theme_file/css_9285_avis_rec_nutr.pdf) were retained [i.e., adequate intake (AI) and estimated average requirement (EAR)]. For *macronutrients*, the prevalence of population below the recommended daily allowance (RDA) computed from the Nutritional Belgian Recommendations was estimated. For *micronutrients*, the prevalence of insufficient intake was estimated as the proportion of subjects whose intake was below the EAR. It was established that, at the population level, this proportion represents an unbiased estimate of the proportion of subjects whose intake is below their respective requirements [29]. Since the EAR was not available in the Nutritional Belgian Recommendations, we used the following formulae to compute it:

- $\text{EAR} = 0.77 \times \text{RDA}$ (for iron, calcium, potassium, sodium, phosphorus, Vit D, Vit A, Vit E, Vit K)
- $\text{EAR} = 0.83 \times \text{RDA}$ (for magnesium and Vit C).

Whenever available, recommendations adapted to populations older than 60 years were used; otherwise, the recommendations for adults (+ 18 years) were used. All cut-offs used for micronutrients and macronutrients are displayed in the Supplementary files (Table S2).

Covariate data collection

During the annual follow-up, in addition to the diagnosis of sarcopenia and the FFQ questionnaire, the following information was collected for all participants:

- Body mass index (BMI);
- Number of conditions that the subjects were affected by and number of drugs consumed, self-reported by each individual;
- Cognitive function was assessed with the Mini-Mental State Examination (MMSE) [30];

- Level of depression using the 15-item Geriatric Depression Scale [31];
- Level of physical activity based on a self-reported PAQ-E questionnaire [32].

Statistical analyses

The data were processed using the SPSS Statistics 24 (IBM Corporation, Armonk, NY, USA) software package. For both the characteristics of the population and the consumption of micronutrients and macronutrients, the results were expressed as the mean ± standard deviation (SD) for continuous variables that followed a Gaussian distribution and expressed as the median (percentile 25 and 75) for those that did not followed a Gaussian distribution. The normality of the variables was checked by examining the histogram, the quantile–quantile plot, the Shapiro–Wilk test, and the difference between the mean and the median values. Absolute and relative (%) frequencies were described for qualitative variables.

A global evaluation of all subjects' baseline characteristics was performed, and the sarcopenic subjects' characteristics were compared to other subjects using a univariable analysis. Student's *t* test, Mann–Whitney *U* test or Chi squared test were used when appropriate.

Differences in micronutrient and macronutrient consumption between sarcopenic subjects and non-sarcopenic subjects were investigated first through univariable Student's *t* tests or Mann–Whitney *U* tests when appropriate; (2) through logistic regression using age and sex as covariates; and (3) through logistic regression using multiple covariates (all clinical characteristics that differed between groups) to ensure that the nutrient intake differences between groups were related to sarcopenia and not to any participant characteristics. Difference of prevalence of insufficient intake/population below the Nutritional Belgian Recommendations between sarcopenic and non-sarcopenic was tested with a Chi squared test.

The overall results were statistically significant at the 0.05 critical threshold.

Results

Characteristics of participants

A total of 331 subjects (mean age of 74.8 ± 5.9 years, 58.9% of women) had complete data and were included in this study. Among them, 51 were diagnosed with sarcopenia (prevalence of 15.4%). Some characteristics were different between sarcopenic subjects and non-sarcopenic subjects (Table 1); sarcopenic subjects were older, with a lower BMI, consumed more drugs, and had a higher GDS score. As expected, they also presented lower strength, lower muscle mass and lower physical activity test scores, which confirmed the difference in sarcopenia status between the groups.

Dietary nutrient consumption

The dietary and nutrient intake of the SarcoPhAge population are shown in Table 2. Overall, FFQ analyses revealed that sarcopenic subjects had a lower total energy intake compared to non-sarcopenic subjects (1596.1 kcal/day vs 1820 kcal/day, crude p value = 0.005, sex and age-adjusted p value = 0.008). In the fully adjusted model, the difference was no longer significant.

In the crude model as well as in the age and sex-adjusted model, sarcopenic subjects consumed significantly lower amounts of macronutrients (proteins and lipids, comprising saturated fatty acids) and micronutrients (sodium, potassium, magnesium, phosphorus, iron, calcium and vitamins (D–A–E–C–K)) compared to non-sarcopenic subjects.

After adjusting for multiple covariates (age, sex, GDS score, MMSE score, number of drugs consumed, and BMI), the consumption of several micronutrients, sodium, calcium and vitamins D, A, E and C, no longer differed between groups. Regarding macronutrients, only saturated fatty acid consumption was no longer differ between the sarcopenic and non-sarcopenic groups after multiple adjustment ($p = 0.16$).

Prevalence of insufficient intake

For the whole population, whatever the sarcopenic status, the prevalence of insufficient intake was 55.3% for vitamin C, 40.5% for vitamin E, 30.2% for calcium, and 16.3% for vitamin A and potassium. Prevalence of insufficiency was lower than 10% for vitamin K, iron, sodium, magnesium and phosphorus. An excessive intake of sodium (98.8% of the population) and vitamin K (86.4% of the population) is also observed. For macronutrients, 93.7% of the population was below the Nutritional Belgian Recommendations for carbohydrates and 16.6% for proteins. More than 40% of the population were above the Nutritional Belgian Recommendations cut-offs in regard to the consumption of lipids.

Significantly higher prevalence of insufficiency was found for sarcopenic subjects compared to non-sarcopenic for potassium (29.4% of sarcopenic vs 13.9% of non-sarcopenic, $p = 0.006$), magnesium (9.8% of sarcopenic vs 3.6% of non-sarcopenic, $p = 0.049$), iron (9.8% of sarcopenic, 2.5% of non-sarcopenic, $p = 0.01$), calcium (49.0% of sarcopenic vs 26.8% of non-sarcopenic, $p = 0.001$), vitamin E (52.9% of sarcopenic vs 38.2% of non-sarcopenic, $p = 0.049$) and vitamin C (72.5% of sarcopenic vs 52.1% of non-sarcopenic, $p = 0.007$). No other significant difference between

Table 1 Characteristics of SarcoPhAge study participants (331 participants remained at the 2-year follow-up)

	Sarcopenic ($n=51$)	Non-sarcopenic ($n=280$)	p value
Age (years)	77.6 ± 6.58	74.4 ± 5.64	< 0.001
Sex			0.54
Women	32 (9.67)	163 (49.2)	
Men	19 (5.74)	117 (35.3)	
BMI (kg/m^2)	23.2 ± 3.53	27.5 ± 4.56	< 0.001
Number of concomitant diseases	4.71 ± 2.48	4.18 ± 2.57	0.18
Number of drugs	7.55 ± 3.44	6.19 ± 3.50	0.01
Mini-mental state examination (/30 points)	29.0 (28.0–30.0)	29 (28.0–30.0)	0.04
PAQ-E	15.7 ± 4.48	16.9 ± 4.75	0.083
GDS	4.00 (2.00–5.75)	2.00 (1.00–5.00)	0.015
Grip strength (kg)			
Women	15.8 ± 4.41	20.8 ± 5.84	< 0.001
Men	24.3 ± 4.68	39.6 ± 7.83	< 0.001
Walking speed (m/s)	0.88 ± 0.28	1.14 ± 0.29	< 0.001
Total lean mass (kg)			
Women	33.8 (30.9–35.3)	38.6 (35.1–42.6)	< 0.001
Men	45.5 (40.9–51.9)	56.4 (51.7–61.6)	< 0.001
Appendicular muscle mass index (SMI)			
Women	5.09 ± 0.37	6.26 ± 0.80	< 0.001
Men	6.66 ± 0.44	8.07 ± 0.93	< 0.001
Fat mass (kg)			
Women	21.2 (14.9 – 26.3)	25.9 (21.2–31.4)	0.036
Men	20.5 (15.2 – 26.7)	24.7 (19.7–29.6)	0.15

Table 2 Consumption of micro- and macro-nutriments of sarcopenic and non-sarcopenic subjects

	Sarcopenic ($n=51$)	Non-sarcopenic ($n=280$)	p value[†]	p value[‡]	p value[‖]
Total energy intake (kcal/day)	1596.1 ± 446.2	1820 ± 526.8	0.005	0.008	0.1
Macronutrients					
Proteins (g/day)	70.2 ± 20.2	85 ± 28.3	< 0.001	0.001	0.03
Carbohydrates (g/day)	145.5 ± 49.1	157.4 ± 47.2	0.1	0.1	0.64
Lipids (g/day)	71.4 ± 22.8	84.1 ± 28.9	0.003	0.005	0.03
Saturated fatty acids (g/day)	28.5 ± 10.5	32.5 ± 12.4	0.031	0.043	0.16
Micronutrients					
Sodium (mg/day)	2445.1 ± 746.3	2797.6 ± 878.8	0.007	0.01	0.13
Potassium (mg/day)	2809.7 ± 824.6	3331.9 ± 1014.2	0.001	0.002	0.04
Magnesium (mg/day)	410.6 ± 146.8	486.9 ± 155.7	0.001	0.005	0.03
Phosphorus (mg/day)	1121.6 ± 337.4	1325.3 ± 415.5	0.001	0.002	0.04
Iron (mg/day)	12.5 ± 3.74	15.4 ± 5.16	< 0.001	0.001	0.005
Calcium (mg/day)	734.5 (596.8–1040.9)	905.1 (716.1–1138.3)	0.07	0.041	0.23
Vitamin D	2.04 (1.55–2.67)	2.43 (1.68–3.40)	0.035	0.043	0.05
Vitamin A (µg/day)	728.2 (533.1–931.1)	881.9 (668.7–1098.6)	0.035	0.01	0.18
Vitamin E (mg/day)	8.82 (6.65–11.1)	10.1 (7.87–13.3)	0.035	0.02	0.14
Vitamin C (mg/day)	75.5 (48.4–96.3)	89.7 (65.8–128.9)	0.035	0.006	0.14
Vitamin K (µg/day)	91.1 (67.3–123.5)	123.6 (92.6–164.6)	0.003	0.001	0.01

[†] p values obtained from Student's t test or the Mann–Whitney U test when appropriate

[‡] p values obtained from logistic regressions with age and sex used as covariates

[‖] Fully adjusted model. p values obtained from logistic regressions with age, sex, GDS score, MMSE score, number of drugs consumed and BMI as covariates

groups was found for the rest of the micronutrients. Regarding macronutrients, significantly more sarcopenic subjects were below the Nutritional Belgian Recommendations for proteins compared to non-sarcopenic (29.4% of sarcopenic vs 14.3% of non-sarcopenic, $p=0.008$) as well as for lipids (13.7% of sarcopenic vs 5.7% of non-sarcopenic, $p=0.039$) (Table 3).

Discussion

In the SarcoPhAge population, taking into account the analyses adjusted on multiple covariates, sarcopenic subjects had a lower intake of two macronutrients, proteins and lipids, and five micronutrients, potassium, magnesium, phosphorus, iron and vitamin K.

Proteins represent the most important macronutrient in counteracting muscle mass loss in the elderly. Indeed, protein provides the essential amino acids that are needed for the synthesis of muscle protein as well as acts as an anabolic stimulus with direct effects on protein synthesis. Based on the general cut-offs of 61 g/day for men and 55 g/day for women, provided by the 2016 Nutritional Belgian Recommendation, almost 17% of our population was defined as deficient in protein intake. Not surprisingly, sarcopenic subjects consumed significantly less protein than non-sarcopenic subjects, and a significantly higher proportion of sarcopenic subjects were below the Belgian Nutritional Recommendation in terms of protein intake. Comparable results were also observed in a study similar to this one, performed in Maastricht, which found that non-sarcopenic subjects consumed approximately 74 ± 20 g of protein/day while sarcopenic subjects consumed 68 ± 22 g of protein/day ($p=0.048$) [33]. The amount of protein intake is important to maximize the anabolic response. Approximately 35% of total calories should be composed of proteins, and regarding the amino acid composition of proteins, it has been suggested that proteins rich in leucine seem to be the best amino acid in terms of anabolic properties [34]. An intake of 3 g of leucine at each meal has been proposed by different authors as an efficient nutritional strategy to maintain muscle health [35]. Indeed, an increased protein intake at baseline has been linked to muscle health in several studies; for example, the Health, Ageing and Body Composition Study [36] observed a reduced loss of lean mass over 3 years of follow-up among older people, and the Women's Health initiative study [37] and the Framingham Offspring Cohort [38] observed a reduced loss of muscle strength.

Less evidence linked lipid intake and sarcopenia. In our study, although most of the subjects consumed a sufficient amount of lipids with only 7% below the Nutritional Belgian Recommendation, we showed a reduced consumption of lipids in sarcopenic subjects compared to non-sarcopenic subjects, which was still significant, even after adjusting for multiple covariates. We also observed a significant difference between groups regarding the consumption of saturated fatty acids. However, this difference was no longer significant after the multivariable adjustment. Unfortunately, we did not obtain data regarding polyunsaturated fatty acids. These data would have been interesting because n-3 fatty acids have been suggested to have positive age-related effects on anabolic resistance and, therefore, enhance gains in muscle mass in older adults. It could, therefore, be expected to find a lower intake of n-3 fatty acids in sarcopenic subjects, as has been shown in the Maastricht Sarcopenia study (1.7 ± 0.7 g for sarcopenic subjects vs 2.0 ± 0.8 g for non-sarcopenic subjects, $p=0.007$).

Regarding micronutrients, we found a significantly reduced consumption of potassium, magnesium, phosphorus, iron and vitamin K in sarcopenic subjects even after accounting for multiple covariates. High prevalence of sarcopenic subjects were below the EAR for potassium, calcium, vitamin A, vitamin E and vitamin C. It is known that several minerals can play a role in muscle metabolism and muscle function. Among others, potassium plays a role in nerve activity, and magnesium is involved in protein synthesis, ATP synthesis and is responsible for muscle relaxation. Low iron and phosphorus blood serum concentrations have been linked to poor physical performance and muscle weakness [39–42]. Regarding the direct effect of these micronutrients on sarcopenia, evidence from a very recent systematic review [43] highlighted the following: (1) magnesium intake was significantly associated with sarcopenia in three observational studies [33, 44, 45], as it is also the case in our study; (2) the link between sarcopenia and potassium as well as with phosphorus remains unclear given the low number of studies reporting such results ($n=1$ for phosphorus, showing a significant association between phosphorus and the prevalence of sarcopenia [46], $n=0$ for potassium); and (3) the link between iron and sarcopenia is controversial since two studies showed an association between iron and physical performance and lean mass [47, 48] while three others were unable to find an association with sarcopenia outcomes [33, 45, 49]. Other minerals not analysed in our SarcophAge study were also highlighted in the systematic review by Van Dronkelaar et al. [43] as being associated with sarcopenia, including selenium, which different studies showed a positive association with muscle mass, muscle performance and sarcopenia [33, 45, 50–53] and zinc, which can be linked with oxidative stress, one of the causes of muscle degeneration and a reduction of muscle strength [47, 48, 54, 55]. To our knowledge, however, no interventional studies using these two nutrient supplements have been performed to assess the effect of such supplementation on muscle health and sarcopenia. Overall,

Table 3 Adequation of consumption of macronutrients and micronutrients

Macronutrients	Total population			Sarcopenic population			Non-sarcopenic population		
	% of population with an adequate intake	% of population below the Nutritional Belgian recommendations	% of population above the Nutritional Belgian recommendations	% of population with an adequate intake	% of population below the Nutritional Belgian recommendations	% of population above the Nutritional Belgian recommendations	% of population with an adequate intake	% of population below the Nutritional Belgian recommendations	% of population above the Nutritional Belgian recommendations
Proteins	83.4	16.6	0.00	70.6	29.4	0.00	85.7	14.3	0.00
Carbohydrates	6.3	93.7	0.00	11.8	88.2	0.00	5.4	94.6	0.00
Lipids	52.6	6.9	40.5	62.7	13.7	23.6	50.7	5.7	43.6
Saturated fatty acids	26.0	0.00	74.0	31.4	0.00	68.6	25.0	0.00	75.0
Micronutrients	Total population			Sarcopenic population			Non-sarcopenic population		
	% of population with an adequate intake	% of population with an insufficient intake	% of population with an excessive intake	% of population with an adequate intake	% of population with an insufficient intake	% of population with an excessive intake	% of population with an adequate intake	% of population with an insufficient intake	% of population with an excessive intake
Sodium	0.9	0.3	98.8	2.0	0.00	98.0	0.7	0.4	98.9
Potassium	28.4	16.3	55.3	35.3	29.4	35.3	27.1	13.9	59.0
Magnesium	95.5	4.5	0.00	90.2	9.8	0.00	96.4	3.6	0.00
Phosphorus	97.0	3.0	0.00	94.1	5.9	0.00	97.5	2.5	0.00
Iron	96.4	3.6	0.00	90.2	9.8	0.00	97.5	2.5	0.00
Calcium	69.8	30.2	0.00	51.0	49.0	0.00	73.2	26.8	0.00
Vitamin A	83.7	16.3	0.00	78.4	21.6	0.00	84.6	15.4	0.00
Vitamin E	59.5	40.5	0.00	47.1	52.9	0.00	61.8	38.2	0.00
Vitamin C	44.7	55.3	0.00	27.5	72.5	0.00	47.9	52.1	0.00
Vitamin K	7.6	6.0	86.4	19.6	9.8	70.6	5.3	5.4	89.3

in the literature and the data from our study, mixed results are found regarding the association between micronutrient intake and sarcopenia. Even for magnesium, for which the results seem slightly more convergent, the interpretation has to consider the restricted number of studies highlighting this association.

In addition to individually evaluating nutrients, the linkage between sarcopenia and dietary patterns has not been extensively studied. In 2015, Hashemi et al. [56] studied, through a cross-sectional study, different dietary patterns and their association with sarcopenia. They found a lower risk of sarcopenia for subjects in the highest tertile of the Mediterranean pattern (higher consumption of olive oil, fruits, vegetables, fish and nuts). Sarcopenia was not found to be associated with the Western dietary pattern (higher consumption of sugar, soy and fast food) or with the mixed dietary pattern (higher consumption of animal proteins, potatoes and refined grains). One hypothesis raised by the authors is that a increased intake of antioxidants is found across the Mediterranean pattern, which can reduce the oxidative stress that is involved in the pathogenesis of sarcopenia. Moreover, an increased intake of vitamin D and omega-3 fatty acids is also present in this dietary pattern, which benefits muscle function. The Mediterranean diet has also been shown to be associated with a lower risk of frailty, which is consistent with findings on sarcopenia [57, 58]. Unfortunately, we did not assess dietary patterns in the present work.

Other limitations must be considered in our study as well. One of them is its cross-sectional design. Indeed, no causal relationship can be drawn from a cross-sectional study, and this study design may, therefore, limit the knowledge of the importance of the role of nutrition in muscle health decline with advancing age. Prospective data are truly missing to assess the incidence of sarcopenia, considering nutrient intake in baseline and across years. Longitudinal studies could also highlight the importance of optimal nutrition during life as a strategy to prevent sarcopenia and physical disability in older age. Indeed, early interventions and adequate diet throughout life are of huge importance since muscle mass and strength in later life depend on both the rate of muscle loss and the peak achieved in early life. Another limitation of this study is the questionnaire we used in our analyses. Even if our FFQ has been developed by a group of experts in the field, it has not been validated in a population of older people. Moreover, this kind of questionnaire relies on the participant's memory and can, therefore, introduce a bias in the data reporting. Finally, the last limitation is our population. The SarcoPhAge population is not representative of the Belgian population aged 65 years or older since we recruited a majority of voluntary subjects which defined our sample as a convenience sample. Additionally, 26.6% of the baseline population was not interviewed again at the 1-year follow-up. A selection bias may, therefore, be present, as individuals who return for a follow-up are likely to be in better health than those whose who did not.

One of the strengths of our study is the area of research itself. As mentioned before, nutrition is one of the main targets identified for the prevention/treatment of sarcopenia. Paradoxically, only a handful of studies have already shown an interest in the dietary intake of a population suffering from sarcopenia. Previously performed studies differed in their methodology, questionnaires used to assess intakes and nutrients analysed. Within our SarcoPhAge study, we offered a comprehensive assessment of micronutrient and macronutrient intake in sarcopenic subjects. For the diagnosis of sarcopenia, we used a well-validated definition and well-validated tools for the measurement of sarcopenia components. Finally, our data allowed us to estimate the prevalence of insufficient intake of micronutrients (% of participants with intake below EAR) and the prevalence of population who were below the Nutritional Belgian Recommendations for macronutrients, which is a scientific positive of our work, as this has very rarely been conducted.

Conclusion

In the SarcoPhAge population, sarcopenic subjects had a lower intake of two macronutrients, proteins and lipids, and five micronutrients, potassium, magnesium, phosphorus, iron and vitamin K. Although additional confirmative studies as well as longitudinal studies are needed before drawing any strong conclusions regarding dietary intake in terms of prevention and treatment of sarcopenia, these observational data are in favour of a key role of nutrition in maintaining an adequate muscle mass, muscle strength and muscle function. A poorly balanced diet is undoubtedly partially responsible for the decline of muscle health with ageing.

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Compliance with ethical standards

Conflict of interest Authors declare that they have no conflicts of interest.

Ethical approval All procedures performed in the studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee as well as with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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