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Factors associated with skeletal muscle mass, sarcopenia, and sarcopenic obesity in older adults: a multi-continent study

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Abstract

Background The aim of this study was to evaluate the factors associated with low skeletal muscle mass (SMM), sarcopenia, and sarcopenic obesity using nationally representative samples of people aged ≥65 years from diverse geographical regions of the world.

Methods Data were available for 18 363 people aged ≥65 years who participated in the Collaborative Research on Ageing in Europe survey conducted in Finland, Poland, and Spain, and the World Health Organization Study on global AGEing and adult health survey conducted in China, Ghana, India, Mexico, Russia, and South Africa, between 2007 and 2012. A skeletal muscle mass index (SMI) was created to reflect SMM. SMM, SMI, and percent body fat (%BF) were calculated with specific indirect population formulas. These estimates were based on age, sex, weight, height, and race. Sarcopenia and sarcopenic obesity were defined with specific cut-offs.

Results The prevalence of sarcopenia ranged from 12.6% (Poland) to 17.5% (India), and that of sarcopenic obesity ranged from 1.3% (India) to 11.0% (Spain). Higher %BF was associated with lower SMM in all countries, and with sarcopenia in five countries ($p < 0.001$). Compared to high levels of physical activity, low levels were related with higher odds for sarcopenia [OR 1.36 (95%CI 1.11–1.67)] and sarcopenic obesity [OR 1.80 (95%CI 1.23–2.64)] in the overall sample. Also, a dose-dependent association between higher numbers of chronic diseases and sarcopenic obesity was observed.

Conclusions Physical activity and body composition changes such as high %BF are key factors for the prevention of sarcopenia syndrome.

Keywords Skeletal muscle mass; Sarcopenia; Sarcopenic obesity; Older adults

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Introduction

According to the World Health Organization (WHO), population ageing will occur at an unprecedented speed globally. Specifically, from 1970 to 2025, a demographic growth of more than 200% is expected in the group of older adults.[1] Ageing is a global problem affecting both developed and developing countries. For example, the global proportion of those aged 60 years and older residing in developing countries is projected to increase from current figures of approximately 65% to 80% by 2050.[2]

Ageing is accompanied by various physiological changes [e.g. decrease in skeletal muscle mass (SMM) and increase in fat mass] as well as with various co-morbidities,[3–5] of

which muscle mass decline is one of the most prominent features. For example, compared to younger populations, octogenerians have 50% less muscle mass.[6] Because SMM is the constituent of almost half of total body mass and has an important role in mobility as well as various metabolic functions,[4,5] low lean mass is known to have adverse effects on health. Indeed, the maintenance of muscle mass in old age has been pointed out to be a key factor for independent living in old age.[4,5]

Previously, this age-related loss of muscle mass alone was often referred to as sarcopenia, but more recent definitions have incorporated the concept of muscle strength as it has been shown that although low muscle mass can precede sarcopenia, it is not the equivalent of low muscle strength.[7,8] Specifically, sarcopenia syndrome has been related with the decline in type II muscle fibres and the replacement of lean mass by different kinds of tissues that have reduced capacity to synthesise protein, thereby leading to reduced muscle strength.[9] Sarcopenia is associated with various adverse health outcomes such as disability, mental disorders, poor quality of life, and mortality,[10–13] and previously reported predictors of sarcopenia include advanced age, low financial status, smoking habits, low physical activity, atherosclerosis, and lung disease.[14]

The coexistence of high accumulation of fat mass and low SMM has been termed sarcopenic obesity.[3] Increase in fat mass has been suggested to be a significant risk factor for low muscle mass tissue,[15] possibly through the chronic inflammatory state induced by high body fat which contributes to the decline in muscle mass and strength. According to recent data, obesity and high muscle mass decline act synergistically in the development of chronic diseases.[16,17]

Despite rapid population ageing and the global obesity epidemic,[18] there are no global epidemiological data on sarcopenia and sarcopenic obesity. Specifically, although studies from high-income settings do exist,[6] there are only a few studies on the epidemiology of sarcopenia and sarcopenic obesity from low- and middle-income countries,[14] and the majority of these studies are small and do not always focus exclusively on individuals over the age of 65. Furthermore, there are no multi-country studies using nationally representative datasets on sarcopenia and sarcopenic obesity which allow for comparisons between a variety of settings.

Thus, the aim of the present study was to evaluate the role of various determinants on SMM, sarcopenia, and sarcopenic obesity in nine countries (China, Finland, Ghana, India, Mexico, Russia, South Africa, and Spain) using nationally representative data from the Collaborative Research on Ageing in Europe (COURAGE) and WHO Study on global AGEing and adult health (SAGE) surveys. These surveys are among the few large population-based nationally representative health studies that apply standard design and procedures across all survey populations. Because evidence is emerging from recent well-designed studies that targeted intervention programs can prevent progressive muscle mass loss in the older population, the information derived from our study will be important for effective global public health planning.

Research design and methods

Materials and methods

Data from the COURAGE and the SAGE surveys were analysed. The COURAGE was conducted between 2011 and 2012 in Finland, Poland, and Spain, while the SAGE was undertaken in China, Ghana, India, Mexico, Russia, and South Africa between 2007 and 2010. Using the World Bank classification at the time of the survey, these countries corresponded to high-, and middle-/low-income countries, respectively.[19] In particular, the SAGE countries broadly represented different geographical locations and levels of economic and demographic transition. The aim of these surveys was to create comparable databases with valid and reliable information on health and well-being in adult populations across the world.

Details of the survey methodology have been published elsewhere.[20,21] In brief, in order to obtain nationally representative samples, a multistage clustered sampling design method was used. The sample consisted of adults aged ≥18 years with oversampling of those aged ≥50 years. Following a common research protocol across countries, all data were collected through face-to-face interviews and measurements by trained interviewers. A stadiometer and a routinely calibrated electronic weighting scale were used to measure height and weight, respectively. Blood pressure was measured 2 and 3 times in the COURAGE and SAGE, respectively with a ≤1min interval using standard protocols. Grip strength was measured twice for both hands in the SAGE and only for the dominant hand in the COURAGE with the use of the Smedley's hand dynamometer. If the participant had any surgery in the last three months or arthritis or pain in the hand, grip strength was not measured for that hand. Gait speed was based on a 4 m timed walk and was measured by asking the participant to walk at a rapid pace, as fast as he/she safely can. A cane or other walking aids were allowed if the participant was more comfortable with it. The interviewer recorded the time to completion of the 4 m walk.

If the respondent was unable to undertake the interview because of limited cognitive function, a separate questionnaire was administered to a proxy respondent. The survey response rate ranged from 51% (Mexico) to 93% (China). Sampling weights were constructed to adjust for the population structure as reported by the National Institute of Statistics and the United Nations Statistical Division for the COURAGE and SAGE, respectively. Ethical approval for the COURAGE and SAGE was obtained from the WHO Ethical Review Committee and local ethics research review boards.

Anthropometric, lifestyle, and clinical factors

Body mass index (BMI) was calculated as weight in kilogrammes divided by height in metres squared. Percent body fat (%BF) was calculated using the following formula which has been validated in a variety of populations and races[22]: $\%BF = 1.20 \times BMI + 0.23 \times age - 10.8 \times sex - 5.4$ (where female = 0 and male = 1). SMM was calculated as the appendicular skeletal muscle mass (ASM) based on the equation proposed by Lee *et al.*[23]: $ASM = 0.244 \times weight + 7.8 \times height + 6.6 \times sex - 0.098 \times age + race - 3.3$ [where female = 0 and male = 1; race = 0 (White and Hispanic), race = 1.9 (Black), and race = −1.6 (Asian)]. ASM was further divided by BMI to create a skeletal muscle mass index (SMI).[24] Following the criteria used in previous publications, we defined sarcopenia as having low SMM as reflected by lower SMI and either a slow gait speed or weak handgrip. Low SMM was defined as the lowest quintile of the SMI based on sex-stratified values, and slow gait speed referred to the lowest quintile of walking speed based on height, age, and sex-stratified values.[25–27] Country-specific cut-offs were only used to determine low SMI, as this indicator is likely to be affected by racial differences in body composition.[28] Weak handgrip was defined as <30 kg for men and <20 kg for women using the average value of the two handgrip measurements of the dominant hand.[29] Sarcopenic obesity referred to the sex-standardized highest quintile of %BF in addition to the presence of sarcopenia.[8,27] The specific cut-offs used for slow gait speed, high %BF, and SMI, and the country-wise prevalence of low SMM [based on previously recommended SMI cut-offs (0.789 for men and 0.512 for women)[25]] and low handgrip strength[25] are presented in the web appendix.

Previous literature was used as a guide for the selection of variables used for adjustment. These included sex, age, completed education level (≤primary, secondary, ≥tertiary), wealth (assessed by quintiles based on country-specific income), physical activity, smoking status, alcohol consumption, and the number of chronic conditions.[6,14] The Global Physical Activity Questionnaire was used to assess the level of physical activity using conventional cut-offs and it was categorised as low, moderate, and high (http://www.who.int/chp/steps/GPAQ/en/). For smoking, respondents were asked 'Do you currently use (smoke, sniff or chew) any tobacco products such as cigarettes, cigars, pipes, chewing tobacco or snuff?' Those who answered 'yes' were categorised as current smokers. Current drinkers were defined as those who answered affirmatively to the question 'Have you consumed alcohol in the last 30 days?' The number of chronic conditions was based on seven chronic conditions (angina, arthritis, asthma, chronic lung disease, diabetes, hypertension, and stroke). Combined criteria for the diagnosis of chronic conditions were used with the exception of diabetes for which no information other than self-report was available. The combined criteria referred to self-reported diagnosis and/or diagnosis based on past 12 months symptoms with the exception of hypertension which was based on blood pressure measurement, and stroke which was based on lifetime symptoms. The symptom-based algorithms were based on WHO's SAGE study, clinical guidelines, and references publications, and the details may be found in a previous publication using the same dataset.[30] The number of chronic conditions was categorised as 0, 1, 2, and ≥3.

Statistical analysis

The analysis was restricted to those aged 65 years or older because of the age-related nature of sarcopenia. Individuals whose information was collected through a proxy respondent were excluded from the analysis because data on some of the variables pertaining to the current analysis were not collected. Finland was excluded from the analysis on sarcopenia and sarcopenic obesity as gait speed was not measured.

The prevalence of baseline characteristics by the presence of sarcopenia or sarcopenic obesity was calculated. We used multivariable regressions to assess the correlates of SMI, sarcopenia, and sarcopenic obesity. Linear regression analysis was used when SMI was the outcome, and logistic regression analysis was used when sarcopenia or sarcopenic obesity was the outcome. The covariates included in the models were sex, age, education, wealth, %BF, alcohol consumption, smoking, physical activity, and number of chronic conditions. %BF was not included in the analysis with sarcopenic obesity as the outcome because of potential overlap with the outcome. In addition, we did not adjust for sex when sarcopenia or sarcopenic obesity was the outcome as all the indicators used to define sarcopenia were already sex-adjusted. We conducted analyses using the overall sample including all countries while adjusting for country by including dummy variables for each country in the model. Furthermore, country-wise analyses were conducted with SMI and sarcopenia as the outcome but this was not conducted for sarcopenic obesity because its prevalence was too low to obtain stable estimates. In order to generate nationally representative estimates, in all analyses, the sample weighting and the complex study design were taken into account with Taylor linearization methods. The analyses were performed with Stata version 12.1 (Stata Corp LP, College Station, Texas). The level of statistical significance was set at $P < 0.05$.

Results

After the exclusion of those <65 years, the sample size was 18 363 (China 5350, Finland 708, Ghana 1975, India 2441, Mexico 1367, Poland 1313, Russia 1861, South Africa 1483, and Spain 1865). Of the total sample, 15.2% and 4.7% had sarcopenia and sarcopenic obesity, respectively. The prevalence of sarcopenia and sarcopenic obesity by country is illustrated in

Table 1 Prevalence of sarcopenia and sarcopenic obesity among adults aged ≥ 65 years

Country	Sarcopenia	Sarcopenic obesity
China	15.0 [13.3,16.9]	2.9 [2.3,3.7]
Ghana	13.6 [11.8,15.6]	5.4 [4.0,7.2]
India	17.5 [15.0,20.4]	1.3 [0.8,2.1]
Mexico	16.7 [12.8,21.4]	10.2 [7.3,14.1]
Poland	12.6 [10.5,15.2]	8.5 [6.7,10.7]
Russia	14.0 [10.4,18.7]	8.3 [6.4,10.8]
South Africa	12.9 [9.4,17.5]	10.3 [7.0,15.0]
Spain	13.8 [12.0,15.9]	11.0 [9.2,13.0]

Data are % [95% confidence intervals] based on weighted sample.

Table 1. The prevalence of sarcopenia ranged from 12.6% (Poland) to 17.5% (India), and that of sarcopenic obesity ranged from 1.3% (India) to 11.0% (Spain). *Table* 2 presents the baseline characteristics of the sample by the presence of sarcopenia and sarcopenic obesity. Those with sarcopenia or sarcopenic obesity had lower levels of physical activity, and multi-morbidity was most common among those with sarcopenic obesity.

The association between SMI (ASM/BMI), which reflects SMM, and a variety of factors, estimated by multivariable linear regression, is demonstrated in *Table* 3. In the overall sample, lower levels of education and wealth, higher %BF, current drinking, and having one chronic condition were significantly associated with lower SMI (i.e. lower SMM). Higher %BF was consistently associated with lower SMI in all the countries, and higher levels of education were significantly associated with higher SMI in six countries.

The association between sarcopenia and various factors, estimated by multivariable logistic regression, is shown in *Table* 4. In the overall sample, lower levels of wealth and physical activity, and higher %BF were significantly associated with sarcopenia. Higher education was significantly protective against sarcopenia in China, Mexico, Poland, and South Africa. Lower levels of wealth were significantly associated with higher odds for sarcopenia in China, Ghana, and India, but a U-shaped association was observed in Poland where both the rich and poor had significantly lower odds for sarcopenia. Higher %BF was associated with higher odds for sarcopenia in Ghana, India, Mexico, South Africa, and Spain, while lower levels of physical activity were significantly associated with greater likelihood of sarcopenia in India, Mexico, Russia, Poland, and South Africa. The association between sarcopenic obesity and various factors, estimated by multivariable logistic regression, is shown in *Table* 5. Lower levels of physical activity and greater numbers of chronic conditions were significantly associated with sarcopenic obesity.

Discussion

The present work showed between-country variability in the prevalence of sarcopenia and sarcopenic obesity among

Table 2 Baseline characteristics of the study sample

Characteristic	Category	No sarcopenia	Sarcopenia only[a]	Sarcopenic obesity
Age (years)	65–69	41.3	17.9	14.2
	70–74	30.2	22.9	19.3
	75–79	18.6	26.0	24.7
	≥80	9.8	33.1	41.8
Sex	Female	54.1	58.9	47.0
	Male	45.9	41.1	53.0
Education	≤ Primary	63.5	83.2	63.2
	Secondary	29.4	14.5	30.6
	≥ Tertiary	7.2	2.3	6.1
Wealth	Poorest	20.6	33.9	23.8
	Poorer	20.8	23.1	26.5
	Middle	20.5	16.8	22.6
	Richer	19.0	15.4	13.5
	Richest	19.1	10.7	13.6
Current drinker	No	80.6	89.6	80.1
	Yes	19.4	10.4	19.9
Current smoker	No	71.9	67.5	88.3
	Yes	28.1	32.5	11.7
Physical activity	High	38.6	29.6	21.4
	Middle	27.2	26.2	27.4
	Low	34.3	44.2	51.2
Number of chronic conditions	0	18.4	19.5	6.0
	1	34.3	36.9	28.4
	2	27.1	26.9	31.7
	≥3	20.2	16.7	34.0

Data are % based on the weighted sample.
[a]Sarcopenia only refers to having sarcopenia but not sarcopenic obesity.

Table 3 Correlates of skeletal muscle mass index among adults aged ≥ 65 years estimated by multivariable linear regression

Characteristics	Categories	Overall	China	Finland	Ghana	India	Mexico	Russia	Poland	S. Africa	Spain
Age (year)[a]		−0.005*** [−0.005, −0.004]	−0.006*** [−0.006, −0.005]	−0.005*** [−0.006, −0.004]	−0.004*** [−0.004, −0.003]	−0.005*** [−0.006, −0.005]	−0.004*** [−0.005, −0.003]	−0.004*** [−0.006, −0.003]	−0.005*** [−0.006, −0.004]	−0.002 [−0.003, 0.000]	−0.004*** [−0.005, −0.004]
Sex	Female	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.
	Male	0.364*** [0.355, 0.374]	0.356*** [0.347, 0.365]	0.347*** [0.329, 0.364]	0.264*** [0.247, 0.282]	0.462*** [0.440, 0.484]	0.329*** [0.306, 0.352]	0.294*** [0.273, 0.315]	0.302*** [0.287, 0.318]	0.209*** [0.178, 0.240]	0.292*** [0.277, 0.308]
Education	≤ Primary	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.
	Secondary	0.023*** [0.014, 0.032]	0.032*** [0.024, 0.040]	0.005 [−0.008, 0.018]	0.028** [0.010, 0.046]	−0.0003 [−0.023, 0.022]	0.032* [0.004, 0.060]	−0.014 [−0.036, 0.008]	0.005 [−0.007, 0.017]	0.022 [−0.022, 0.067]	0.016** [0.004, 0.027]
	≥ Tertiary	0.025*** [0.014, 0.035]	0.042*** [0.029, 0.054]	0.023* [0.004, 0.043]	−0.009 [−0.053, 0.036]	−0.015 [−0.044, 0.014]	0.023 [−0.004, 0.050]	−0.011 [−0.035, 0.012]	0.023** [0.006, 0.039]	0.019 [−0.026, 0.063]	0.044** [0.012, 0.076]
Wealth	Poorest	−0.016** [−0.026, −0.005]	−0.024*** [−0.032, −0.015]	0.007 [−0.015, 0.028]	−0.016 [−0.033, 0.000]	−0.023 [−0.047, 0.001]	−0.032** [−0.056, −0.008]	−0.006 [−0.026, 0.015]	0.024** [0.007, 0.041]	−0.012 [−0.055, 0.031]	0.009 [−0.003, 0.021]
	Poorer	−0.004 [−0.013, 0.006]	0.002 [−0.005, 0.008]	−0.004 [−0.022, 0.014]	0.001 [−0.015, 0.017]	−0.004 [−0.027, 0.018]	−0.013 [−0.039, 0.013]	−0.016 [−0.034, 0.003]	0.009 [−0.008, 0.025]	0.002 [−0.024, 0.029]	0.009 [−0.005, 0.023]
	Middle	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.
	Richer	0.004 [−0.007, 0.015]	0.005 [−0.001, 0.012]	0.012 [−0.012, 0.037]	−0.007 [−0.023, 0.010]	0.005 [−0.022, 0.033]	0.011 [−0.012, 0.034]	0.004 [−0.020, 0.027]	0.003 [−0.015, 0.020]	0.011 [−0.015, 0.037]	0.009 [−0.005, 0.022]
	Richer	0.012* [0.002, 0.022]	0.003 [−0.008, 0.014]	0.022 [−0.004, 0.049]	−0.001 [−0.020, 0.018]	0.025* [0.004, 0.046]	0.009 [−0.012, 0.030]	0.012 [−0.011, 0.034]	0.011 [−0.013, 0.034]	−0.005 [−0.043, 0.033]	0.005 [−0.017, 0.027]
Body fat (%)[a]		−0.005*** [−0.006, −0.005]	−0.004*** [−0.005, −0.003]	−0.005*** [−0.006, −0.004]	−0.011*** [−0.013, −0.010]	−0.005*** [−0.007, −0.004]	−0.006*** [−0.007, −0.004]	−0.006*** [−0.007, −0.004]	−0.006*** [−0.007, −0.004]	−0.008*** [−0.010, −0.007]	−0.005*** [−0.006, −0.004]
Current drinking	Yes vs. no	−0.016*** [−0.023, −0.009]	−0.001 [−0.009, 0.007]	0.011 [−0.004, 0.026]	0.022*** [0.009, 0.035]	−0.005 [−0.027, 0.017]	−0.005 [−0.020, 0.010]	−0.002 [−0.022, 0.019]	0.002 [−0.010, 0.014]	0.029 [−0.008, 0.066]	−0.003 [−0.016, 0.009]
Current smoking	Yes vs. no	0.006 [−0.002, 0.014]	0.002 [−0.006, 0.010]	0.017 [−0.004, 0.039]	0.023** [0.006, 0.040]	−0.005 [−0.018, 0.008]	0.016 [−0.005, 0.036]	0.003 [−0.024, 0.029]	0.028*** [0.012, 0.044]	0.005 [−0.028, 0.039]	−0.003 [−0.020, 0.015]
Physical activity	High	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.
	Moderate	0.001 [−0.005, 0.006]	0.007* [0.001, 0.014]	−0.002 [−0.015, 0.011]	−0.011 [−0.024, 0.003]	−0.002 [−0.013, 0.010]	−0.021* [−0.041, −0.002]	−0.006 [−0.024, 0.011]	0.009 [−0.006, 0.023]	−0.007 [−0.039, 0.024]	0.007 [−0.004, 0.018]
	Low	−0.002 [−0.010, 0.006]	0.005 [−0.002, 0.012]	0.0004 [−0.017, 0.016]	0.006 [−0.006, 0.018]	−0.006 [−0.020, 0.008]	−0.008 [−0.024, 0.007]	−0.009 [−0.026, 0.007]	0.010 [−0.004, 0.023]	0.017 [−0.016, 0.049]	0.002 [−0.010, 0.014]
Number of chronic conditions	0	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.
	1	−0.008* [−0.016, −0.001]	−0.005 [−0.013, 0.002]	−0.021 [−0.048, 0.006]	−0.002 [−0.015, 0.011]	−0.008 [−0.022, 0.007]	−0.015 [−0.038, 0.009]	−0.006 [−0.025, 0.013]	−0.015 [−0.036, 0.006]	0.010 [−0.019, 0.039]	−0.009 [−0.022, 0.005]
	2	−0.004 [−0.012, 0.004]	0.001 [−0.008, 0.009]	−0.020 [−0.044, 0.004]	0.001 [−0.014, 0.016]	−0.010 [−0.027, 0.006]	−0.015 [−0.041, 0.011]	−0.003 [−0.024, 0.019]	−0.013 [−0.034, 0.007]	−0.014 [−0.049, 0.020]	−0.006 [−0.020, 0.009]

(Continued)

Table 3 (continued)

Characteristics	Categories	Overall	China	Finland	Ghana	India	Mexico	Russia	Poland	S. Africa	Spain
	≥3	0.003 [−0.008, 0.014]	0.007 [−0.002, 0.017]	−0.017 [−0.045, 0.010]	−0.007 [−0.027, 0.013]	0.004 [−0.021, 0.029]	−0.001 [−0.028, 0.027]	−0.007 [−0.028, 0.014]	−0.015 [−0.036, 0.006]	0.020 [−0.029, 0.068]	−0.009 [−0.023, 0.005]

Abbreviations: S. Africa South Africa; ref. reference category.
Data are coefficients [95% confidence intervals].
Models are adjusted for all the covariates in the table. The model using the overall sample is also adjusted for country.
[a]Age and percent body fat were included in the models as continuous variables.
$^{*}p < 0.05$
$^{**}p < 0.01$
$^{***}p < 0.001$

adults aged ≥65 years. Higher %BF was associated with sarcopenia and lower SMM in almost all countries. In addition, in the pooled sample, lower physical activity was significantly associated with both sarcopenia and sarcopenic obesity, while a dose-dependent relationship between the number of chronic diseases and sarcopenic obesity was observed. The present study has several strengths. To the best of our knowledge, this is the first multi-continent study to evaluate the association between a variety of factors (clinical, anthropometric, socio-demographic, and lifestyle) and low SMM, sarcopenia, or sarcopenic obesity among older adults using large nationally representative datasets with standardised data, including data from both developing and developed countries. This allowed for a global comparison of different settings which has not been done previously.

The prevalence of sarcopenia ranged from 12.6% (Poland) to 17.5% (India) and the range for sarcopenic obesity was 1.3% (India) to 11.0% (Spain). These figures were close to previously reported figures. For example, the prevalence of sarcopenia has been reported to be between 5 to 13% for older adults 60 to 70 years old, and 11 to 50% for the oldest old,[31] while the prevalence of sarcopenic obesity for the population over 60 has been reported to be between 3% and 12%.[32,33] To the best of our knowledge, our study is the first to report the prevalence of sarcopenia or sarcopenic obesity in countries such as Russia, South Africa, and Ghana.

The predictors of low SMM and sarcopenia were similar. This may be because of the overlap between low SMM and sarcopenia where low SMM is considered to be an initial stage of muscle weakness preceding sarcopenia.[34] Across all analyses on sarcopenia and SMM, the most consistent predictors were high %BF and low socio-economic status as reflected by lower education and/or wealth. Most of the findings are in line with previous studies. Several researchers have reported an association between sarcopenia[6] or low lean mass with lower socio-economic status.[14] The finding that lower socio-economic status was associated with low SMM and sarcopenia could be attributed to its interfering role on healthy dietary consumption, physical activity, as well as various health outcomes (e.g. obesity and diabetes mellitus).[18] The U-shaped association observed in Poland where both the rich and poor had lower odds for sarcopenia has not been reported previously and is an area for further research. Low physical activity was clearly associated with sarcopenia but not with low SMM. Specifically, it is well known that muscle mass preservation depends on protein turnover and the balance between protein breakdown and synthesis.[35] However, the relation between SMM and low physical activity has a complex pathway. Various studies have proposed that physical inactivity at extreme levels (e.g. bed rest) is related with low lean mass, while other studies have indicated that protein breakdown in the entire human body is not influenced by inactivity levels.[36,37] In addition, it has been reported that even

Table 4 Correlates of sarcopenia among adults aged ≥ 65 years estimated by multivariable logistic regression

Characteristics	Categories	Overall	China	Ghana	India	Mexico	Russia	Poland	S. Africa	Spain
Age (year)[a]		1.13*** [1.11,1.14]	1.15*** [1.13,1.18]	1.08*** [1.06,1.11]	1.11*** [1.08,1.15]	1.14*** [1.09,1.18]	1.12*** [1.08,1.17]	1.18*** [1.13,1.24]	1.02 [0.97,1.08]	1.19*** [1.15,1.23]
Education	≤ Primary	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.
	Secondary	0.80 [0.62,1.03]	0.46*** [0.31,0.67]	0.88 [0.46,1.68]	1.44 [0.84,2.46]	0.57 [0.16,2.02]	0.97 [0.47,2.03]	0.73 [0.43,1.24]	0.97 [0.37,2.57]	0.59 [0.32,1.09]
	≥ Tertiary	0.74 [0.51,1.08]	0.50* [0.28,0.89]	0.92 [0.29,2.84]	1.07 [0.43,2.68]	0.18* [0.04,0.79]	1.39 [0.58,3.30]	0.20*** [0.08,0.48]	0.01*** [0.00,0.07]	1.01 [0.28,3.71]
Wealth	Poorest	1.57** [1.17,2.10]	1.92*** [1.35,2.72]	1.86* [1.09,3.17]	1.58 [0.79,3.16]	1.38 [0.68,2.81]	1.47 [0.68,3.18]	0.49* [0.25,0.99]	1.37 [0.36,5.14]	0.81 [0.44,1.51]
	Poorer	1.21 [0.90,1.63]	1.14 [0.84,1.54]	1.27 [0.73,2.22]	0.99 [0.46,2.13]	0.69 [0.25,1.89]	1.79 [0.80,4.01]	0.82 [0.40,1.68]	0.68 [0.25,1.89]	1.32 [0.81,2.16]
	Middle	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.
	Richer	0.89 [0.67,1.17]	0.92 [0.62,1.35]	1.56 [0.85,2.86]	1.04 [0.56,1.91]	0.57 [0.20,1.62]	0.59 [0.24,1.49]	0.45* [0.20,0.99]	0.41 [0.14,1.22]	0.93 [0.49,1.76]
	Richest	0.61** [0.45,0.85]	0.94 [0.64,1.37]	1.84 [0.99,3.42]	0.41** [0.24,0.72]	0.55 [0.23,1.32]	0.75 [0.23,2.46]	0.15** [0.05,0.49]	1.03 [0.34,3.14]	1.09 [0.45,2.64]
Body fat (%)[a]		1.03*** [1.02,1.04]	1.01 [1.00,1.03]	1.06*** [1.04,1.08]	1.03*** [1.01,1.05]	1.07*** [1.03,1.11]	1.04 [1.00,1.09]	1.02 [0.99,1.06]	1.07*** [1.05,1.09]	1.08*** [1.05,1.11]
Current drinker	Yes vs. no	1.06 [0.80,1.41]	0.90 [0.66,1.23]	0.83 [0.53,1.31]	1.16 [0.39,3.44]	1.46 [0.71,3.01]	0.82 [0.34,1.98]	1.09 [0.56,2.09]	0.82 [0.23,2.95]	1.52* [1.00,2.30]
Current smoker	Yes vs. no	1.10 [0.86,1.39]	1.20 [0.88,1.63]	0.69 [0.36,1.32]	1.01 [0.70,1.48]	1.43 [0.73,2.81]	1.25 [0.47,3.34]	0.89 [0.36,2.19]	0.50 [0.22,1.14]	1.35 [0.70,2.62]
Physical activity	High	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.
	Moderate	1.17 [0.98,1.40]	0.86 [0.68,1.09]	0.72 [0.42,1.25]	1.23 [0.83,1.81]	1.68 [0.67,4.24]	1.69* [1.02,2.81]	2.75** [1.45,5.22]	21.68*** [6.45,72.88]	1.04 [0.62,1.76]
	Low	1.36** [1.11,1.67]	0.86 [0.65,1.13]	1.34 [0.92,1.95]	1.67* [1.11,2.51]	2.18* [1.04,4.54]	1.56 [0.79,3.11]	2.13* [1.20,3.78]	15.02*** [4.65,48.55]	1.13 [0.66,1.93]
Number of chronic conditions	0	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.	ref.
	1	1.13 [0.89,1.43]	1.35 [0.97,1.88]	0.90 [0.57,1.43]	1.02 [0.68,1.54]	1.18 [0.53,2.65]	1.30 [0.46,3.68]	0.91 [0.27,3.12]	1.88 [0.73,4.85]	1.55 [0.79,3.05]
	2	1.17 [0.90,1.51]	1.40 [0.98,1.99]	1.28 [0.77,2.11]	1.11 [0.71,1.73]	1.11 [0.41,2.97]	1.49 [0.49,4.53]	1.08 [0.34,3.40]	2.84* [1.06,7.59]	0.99 [0.49,1.98]
	≥3	1.11 [0.86,1.43]	1.12 [0.78,1.61]	1.20 [0.59,2.45]	0.83 [0.50,1.36]	1.18 [0.42,3.28]	1.82 [0.66,5.00]	0.92 [0.28,3.02]	2.34 [0.68,8.05]	1.55 [0.80,2.99]

Abbreviations: S. Africa South Africa; ref. reference category.
Data are odds ratio [95% confidence intervals].
Models are adjusted for all the covariates in the table. The model using the overall sample is also adjusted for country.
[a]Age and percent body fat were included in the models as continuous variables.
*$p < 0.05$
**$p < 0.01$
***$p < 0.001$

Table 5 Correlates of sarcopenic obesity among adults aged ≥ 65 years estimated by multivariable logistic regression

Characteristic	Category	Overall
Age (year)[a]		1.12*** [1.10,1.15]
Education	≤ Primary	ref.
	Secondary	0.93 [0.64,1.37]
	≥ Tertiary	1.02 [0.58,1.79]
Wealth	Poorest	1.01 [0.67,1.51]
	Poorer	1.12 [0.81,1.56]
	Middle	ref.
	Richer	0.68 [0.46,1.02]
	Richest	0.85 [0.54,1.35]
Current drinker	Yes vs. no	1.01 [0.74,1.38]
Current smoker	Yes vs. no	0.79 [0.55,1.14]
Physical activity	High	ref.
	Moderate	1.57* [1.11,2.21]
	Low	1.80** [1.23,2.64]
Number of chronic conditions	0	ref.
	1	1.79* [1.08,2.98]
	2	2.18** [1.31,3.62]
	≥3	2.48*** [1.50,4.10]

Abbreviations: ref. reference category.
Data are odds ratio [95% confidence intervals].
Model is adjusted for all the covariates in the table and country.
[a]Age was included in the model as a continuous variable.
*$p < 0.05$
**$p < 0.01$
***$p < 0.001$

minimum levels of physical activity may be sufficient to inhibit the loss of muscle mass.[37] On the other hand, low physical activity has been associated with low muscle strength which is one of the key components of the sarcopenia syndrome.[38] All the aforementioned factors may explain the discrepancy observed in our study where no associations were observed between physical activity and SMM while a significant association was found for sarcopenia. Alternatively, because the definition of sarcopenia also includes the concept of muscle function and strength in addition to muscle mass, it may have been that those with low muscle function were unable to engage in higher levels of physical activity.

Higher %BF was associated with both low SMM and sarcopenia. The patho-physiological pathway of inflammation and various bio-molecules could explain the association between increased body fat tissue, low lean mass, and the presence of sarcopenia. Specifically, a strong correlation between increased adipose tissue and various markers such as tumour necrosis factor-a (TNF-a), IL-6, C-reactive protein, and leptin, which influence insulin resistance and growth hormone and finally interfere with the syndrome of sarcopenia, has been reported.[39]

Lower physical activity and multi-morbidity were the only potentially modifiable factors, which were significantly associated with sarcopenic obesity. While sarcopenia was not related with multi-morbidity, sarcopenic obesity was strongly associated with accumulation of chronic diseases. Sarcopenic obesity is a syndrome that comprises the rise of body fat mass in parallel with excessive low muscle mass tissue.[8] The concept of sarcopenic obesity is complex with various underlying elements such as endocrine, inflammatory, and lifestyle factors.[3,39] The presence of obesity concomitant with low muscle mass tissue or strength is highly related with metabolism-related diseases, such as metabolic syndrome and functional disabilities.[33]

Several researchers have reported that sarcopenia and sarcopenic obesity are modifiable health concepts.[40] In our analysis, low/moderate physical activity was associated with sarcopenia and sarcopenic obesity. Together with undernutrition, physical inactivity is one of the factors that could be possible targets for interventions to avoid the excessive decline in lean mass. Intervention studies have shown that well-planned exercise programs could increase muscle strength as well as muscle mass in older adults.[41] These associations, together with the global population ageing and obesity epidemic, and the high healthcare expenditures for sarcopenia and sarcopenic obesity,[42] highlight the urgent need for early preventive measures (e.g. physical exercise that could prevent muscle mass loss, obesity prevention, and dietary patterns with protein adequacy) in order to promote healthy ageing and minimize the risk for sarcopenia and sarcopenic obesity.

Strengths and limitations

The present study has several strengths. To the best of our knowledge, this is the first multi-continent study that evaluated the effect of various factors (clinical, anthropometric, socio-demographic and lifestyle) on low SMM, sarcopenia, and sarcopenic obesity, using large nationally representative samples of older people around the world. In terms of limitations, the fact that this is a cross-sectional study limits the potential for aetiological conclusions. Also, estimates of %BF and ASM were based on population equations and not direct assessment. However, these formulas have been validated against gold standard methods such as magnetic resonance imaging and dual-energy X-ray absorptiometry in diverse populations, and good concordance rates have been reported.[23,43,44] Also, the use of indirect assessments of lean mass is common in population-based studies[14,32] as most of these direct methods are too costly or impractical for community-based research. Next, we used fast walking speed

rather than usual walking speed as an indicator of muscle performance whereas most previous research has used the latter.[25] Thus, our results may not be totally comparable with previous studies. Finally, despite the fact that nutrition and specific food component consumption, such as protein intake, are strongly associated with muscle mass, the survey did not include a detailed dietary assessment.

Conclusions

The present work investigated the role of various determinants on low SMM, sarcopenia, and sarcopenic obesity among older populations in countries at different stages of the socio-economic, nutritional, and epidemiological transition. It is of major interest nowadays, with the growth of the older population globally, to study the body composition transition in order to understand the dynamics and the transforming nature of ageing. In the present study, lower socio-economic status and higher %BF were associated with low muscle mass and sarcopenia in almost all the countries studied. Our results suggest that physical activity might be one of the major modifiable factors related with sarcopenia and sarcopenic obesity across countries. Moreover, the fact that multi-morbidity is related with sarcopenic obesity emphasizes the importance of the role of prevention planning (e.g. obesity prevention), while further exploration is needed in order to understand the role of socio-economic status on sarcopenia. Considering the complexity of sarcopenia syndrome and sarcopenic obesity for older individuals, among whom various co-morbidities exist, the promotion of well-designed and targeted health promotion programs (e.g. physical activity promotion and obesity prevention) may constitute effective means for the goal of healthy ageing.

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Conflicts of interest

The authors report no relationships that could be construed as a conflict of interest.

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