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Title: Sarcopenic obesity diagnosis by different criteria mid-to long-term post-bariatric surgery

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ABSTRACT

Background/Aims: The aim of this study was to apply the European Society for Clinical Nutrition and Metabolism/European Association for the Study of Obesity (ESPEN/EASO) consensus to identify sarcopenic obesity (SO) in adults mid to long-term post-Roux-en-Y gastric bypass (RYGB) using both dual-energy x-ray absorptiometry (DXA) and bioelectrical impedance analysis (BIA). Further, this approach was compared to accepted sarcopenia diagnostic criteria (Revised European Working Group on Sarcopenia in Older People [EWGSOP2] and Sarcopenia Definition and Outcomes Consortium [SDOC]). **Methods:** This cross-sectional study included adults ≥2 years post-RYGB surgery. Obesity was diagnosed by excess fat mass (FM) for all diagnostic criteria. Agreement was evaluated using Cohen's Kappa. **Results:** We evaluated 186 participants (90.9% female, median age 43.9 years, 6.8 years post-surgery), of which 60.2% (BIA), and 83.3% (DXA) had excess FM. Low muscle strength was not identified using absolute handgrip strength. The prevalence of SO by BIA or DXA, respectively, was 7.9% (95%CI 3.9-12.5), and 23.0% (95%CI 17.1-30.3) [ESPEN/EASO SO consensus]; 0.7% (95%CI 0-2.0), and 3.3% (95%CI 0.7-5.9) [EWGSOP2]; and 27.0% (95%CI 19.7-34.2), and 30.3% (95%CI 23.0-37.5) [SDOC]. Agreement between the ESPEN/EASO SO consensus and other diagnostic criteria was none to slight using DXA: EWGSOP2 k=0.19; 95% CI 0.04-0.34, or SDOC k=0.16; 95% CI -0.01-0.32. Moderate agreement was observed within the ESPEN/EASO SO consensus for BIA and DXA (k=0.43; 95% CI 0.26-0.60). **Conclusions:** This is the first study to explore the prevalence of SO using the ESPEN/EASO criteria. We identified a high but variable prevalence of SO in post-bariatric surgery patients (7.9-23.0%), depending on the body composition technique used; prevalence was higher using DXA. Little agreement was observed for the diagnosis of SO using

the three diagnostic criteria. Future studies are needed to explore the relationship between SO identified by the ESPEN/EASO consensus and health status/outcomes.

Keywords: sarcopenic obesity, bariatric surgery, sarcopenia, obesity, body composition, physical function

Abbreviations:

6MWD: 6-minute walk distance

30-CST: 30-second chair stand test

ALST: Appendicular lean soft tissue

BC: body composition

BIA: bioelectrical impedance analysis

BMI: body mass index

BS: bariatric surgery

DXA: dual-energy x-ray absorptiometry

EASO: European Association for the Study of Obesity

ESPEN: European Society for Clinical Nutrition and Metabolism

EWGSOP2: European Working Group on Sarcopenia in Older People

EWL: excess weight loss

FM: fat mass

HGS: handgrip strength

LST: lean soft tissue

RYGB: Roux-en-Y gastric bypass

SDOC: Sarcopenia Definition and Outcomes Consortium

SMM: skeletal muscle mass

SO: sarcopenic obesity

TUG: timed-up and go test (TUG),

TWL: total weight loss

INTRODUCTION

Sarcopenia is a generalised and progressive skeletal muscle disease, characterized by concomitant low muscle mass and function, and associated with increased adverse outcomes such as physical disability, frailty and mortality [1,2]. Sarcopenia can coexist with obesity, being termed sarcopenic obesity (SO), [3] a condition that has been associated with even worse adverse outcomes [4,5]. Both sarcopenia and SO have a multifactorial etiology and increased prevalence with aging [1]. However, SO can occur at any life stage, particularly in the presence of risk factors such as diseases with an inflammatory component[6], and after bariatric surgery (BS), the latter being particularly important for individuals with inadequate nutritional supervision [7].

Despite the known benefits of BS for improving adiposity-related metabolic comorbidities, severe energy and protein restriction may occur. This may be compounded by malabsorption observed after Roux-en-Y gastric bypass (RYGB), ultimately compromising nutritional status [8,9]. In addition, rapid and substantial weight loss can lead to significant losses in lean mass [10]. There is also risk for weight regain as a long-term complication, potentially leading to re-emergence of comorbidities [11], and development of body composition (BC) abnormalities such as low muscle mass and high fat mass (FM) (i.e., SO) [12]. As such, this patient population requires close monitoring of post-surgery nutrition status after BS, including the risk of onset or progression of SO.

BC assessment can identify individuals with low muscle mass and high FM (i.e., SO) that may go undetected using simple anthropometric measurements[13]. Dual-energy x-ray absorptiometry (DXA) and bioelectrical impedance analysis (BIA) have been the most commonly used techniques and have substantially advanced our understanding of SO prevalence and significance. DXA is recognized as the first choice and most used in research settings due to its

high precision and low measurement errors[14]. BIA is an alternative in clinical practice due to its lower cost, and higher accessibility[15]. Nonetheless, these measurements have acknowledged limitations that could lead to misinterpretations, especially for individuals with obesity.

There has been a lack of universally-recognized diagnostic criteria for SO[16], with prior studies in post-BS patients using BC alone[7], or adapting sarcopenia criteria from the Revised European Working Group on Sarcopenia in Older People[1] (EWGSOP2)[17]. However, the European Society for Clinical Nutrition and Metabolism (ESPEN) and the European Association for the Study of Obesity (EASO) published the first specific SO consensus definition in 2022[18], recommending the presence of three components (low muscle mass, high FM, and low physical function) for SO identification.

The objective of this study was to apply and explore the ESPEN/EASO SO consensus criteria to identify SO in adults mid to long-term post-BS using both DXA and BIA, and to further compare it with commonly used sarcopenia diagnostic criteria. This is a critical step to improve the identification, prevention and treatment of SO in at-risk individuals following BS. Further, the comparison of BC assessment methods (DXA and BIA) may guide discussions of their potential benefits and limitations in SO classification in this clinical population.

MATERIAL & METHODS

Study design

This study comprises a cross-sectional analysis from two Brazilian bariatric research protocols: The CINTO cross-sectional study (Food Consumption, Lifestyle, Control of Comorbidities and Nutritional Status of Patients Undergoing Bariatric Surgery), and baseline data

from The NERO clinical trial study (Nutrition and Resistance Exercise in Obesity). More information about their methodology, including design, sample, participants, and all data collected has been described elsewhere [19,20]. Both studies were approved by the local Research Ethics Committee and informed consent was obtained from all participants. Recruitment was conducted through an open call on social media, and public and private BS clinics, using a convenience sample. Data collection took place between July 2017 and March 2020. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist was followed to present the results (Supporting information).

Participants

Adult participants, 18 to 65 years old, who had RYGB surgery two or more years prior, and who had BC assessed by both BIA and DXA were included. Women currently pregnant or breastfeeding, and individuals with a pacemaker were excluded.

Surgical and sociodemographic data

Clinical and sociodemographic data were collected with a questionnaire regarding age, sex, education level, surgery date, preoperative body mass index (BMI), and weight changes after surgery.

Postoperative years are presented in 3 categories: ≥ 2 to ≤ 5 years, > 5 years to ≤ 10 years, and > 10 years. BS leads to a substantial and sustained long-term weight loss for at least 10 to 20 years[21]. However, after 2 years of surgery patients usually reach a plateau with weight stabilization, and potential for weight regain to occur[21,22]. Postoperative lifestyle and nutritional behaviours after BS are associated with greater weight loss after surgery[23].

Body composition (BC) and anthropometry assessment

BC was assessed using multifrequency BIA (InBody720®, Biospace, Seoul, Korea), and DXA (GE Lunar DPX-IQ®, Madison, WI, USA), with participants wearing light clothing and barefoot. The BIA assessments took place in the morning, in a standing position, and participants were requested to fast for at least 8 hours, refrain from physical activity and caffeine 24 hours prior, and to empty their bladders before the test; women were assessed in any phase of the menstrual cycle excluding menstruation. No special pre-test preparation was required for DXA.

Appendicular lean soft tissue (ALST – the sum of lean soft tissue of both arms and legs) and skeletal muscle mass (SMM) were estimated by BIA, and ALST was measured by DXA. Muscle mass parameters were adjusted by height squared and/or weight percentage. Notably, we chose to use lean soft tissue as the correct terminology to depict the compartment being measured; this is often called appendicular skeletal muscle mass or appendicular lean mass in the literature. For simplicity, we also refer to these compartments as "muscle mass". BIA predictive equations to estimate body composition are proprietary.

Body weight was obtained using the BIA device, height was measured using a portable stadiometer (Sanny®, American Medical of Brazil, São Paulo, Brazil). Both measures were used to calculate current BMI (kg/m^2), and classified with obesity when $\geq 30 kg/m^2$ [24]. Total weight loss (%TWL) and excess weight loss [%EWL=(post-surgical weight loss x 100)/(preoperative weight – ideal body weight)] were calculated[25], using a BMI of 25 kg/m^2 as ideal body weight. Weight regain was calculated as a percentage from the nadir weight after surgery, and considered relevant when greater than 10%.

Physical function parameters

Handgrip strength (HGS), 30-second chair stand test (30-CST), timed-up and go test (TUG), and 6-minute walk distance (6MWD) were conducted as measures of physical function. All procedures were performed by trained assessors, and included an explanation and demonstration. Maximal HGS was assessed with the participant seated with arms at 90º and slightly away from the trunk. Participants were instructed to squeeze the dynamometer (JAMAR®, Columbia, MD, USA) as tightly as possible. Three attempts in each hand were performed with an interval of 60 seconds rest between, with the highest score recorded [26]. For the 30-CTS, participants were seated in a standard height chair with arms crossed on the chest and instructed to stand up and sit down completely as many times as possible within 30-seconds. Only complete movements were recorded [27]. For the TUG, participants were seated in a standard height chair with both arms resting alongside the body, both feet on the ground, and their back against the chair. They were instructed to get up and walk three meters forward, turn around a cone, and sit down again on the chair as fast as possible, without running. After three attempts with 60 seconds of rest between, the lowest time was recorded [28]. For the 6MWD, participants were instructed to walk as far as possible at their own pace, without running, in a circuit of 50 meters in length marked by cones. The total distance covered in 6-minutes was recorded in meters [27].

Sarcopenic obesity (SO) classification and cut-off points

Three diagnostic criteria were used to define SO from distinct international working groups. First, we applied the 2022 SO-specific consensus developed by ESPEN/EASO[18]. For comparison, we used EWGSOP2[1], the most widely used to define sarcopenia, and the Sarcopenia Definition and Outcomes Consortium (SDOC)[29], which contrasts the others by using

only physical function to define sarcopenia (i.e., excluding BC). As endorsed in the BC field, when available we adapted the diagnostic criteria to use cut-off points developed for Brazilian adults (Table 1). Obesity was classified by excess FM according to age and sex-specific DXA cut-off points proposed per Gallagher et al.[30], and endorsed by ESPEN/EASO SO consensus recommendations. As such, we compared sarcopenia definition in the context of SO. SO was diagnosed using any of the specific criteria combination (Table 1). This approach not only simplifies data presentation but was also based on the fact that both EWGSOP2 and SDOC did not propose a definition for obesity. Therefore, we uniformly used the definition endorsed by ESPEN/EASO SO consensus recommendations for all three diagnostic criteria.

Table 1. Sarcopenic obesity/sarcopenia classifications and cut-off points

	STAGE 1		STAGE 2	
ESPEN/ EASO[18] **Sarcopenic Obesity**	Low muscle mass ***AND*** low physical function		Sarcopenic obesity + at least one complication attributable to sarcopenic obesity (i.e. functional disability, assessed by altered timed-up and go ***OR*** 6MWD)[18]	
	DXA: ALST/weight x 100, 18-65y [31]: <28.27% ♂; <23.47% ♀ ***OR*** BIA: SMM/weight x 100, 18-39y [32] Class I 31.5-37.0% ♂; 22.1-27.6%♀ Class II <31.5% ♂; <22.1% ♀	Handgrip strength, Brazilian 30y [33] <30kg ♂; <16kg ♀ ***OR*** 30-Chair stand test, Brazilian [34] 20-29y: <14rep ♂; <15rep ♀ 30-39y: <14rep ♂; <13rep ♀ 40-49y: <13rep ♂; <13rep ♀ 50-59y: <13rep ♂; <11rep ♀ 60-69y: <13rep ♂; <11rep ♀	Timed-up and go, Brazilian [34] 20-29y: >6.56s ♂; >6.96s ♀ 30-39y: >6.75s ♂; >7.41s ♀ 40-49y: >7.46s ♂; >7.59s ♀ 50-59y: >8.42s ♂; >8.24s ♀ 60-69y: >8.26s ♂;>10.60s♀	Predicted 6MWD 40-80y [35] ♂ (7.57 x $height_{cm}$) – (5.02 x age_{years}) – (1.76 x $weight_{kg}$) – 309 ♀ (2.11 x $height_{cm}$) – (5.78 x age_{years}) – (2.29 x $weight_{kg}$) + 667 Lower limit of normal: Subtract 153♂ or 139♀ from predicted
EWGSOP2[1]	Low muscle mass ***AND*** low physical function		Sarcopenia + low physical performance (altered timed-up and go ***OR*** 6MWD)[1]	
	ALST/$height^2$, Brazilian 30y [36] <7.5kg/m^2 ♂ <5.5kg/m^2 ♀	Handgrip strength, Brazilian 30y [33] <30kg ♂; <16kg ♀ ***OR*** 30-Chair stand test, Brazilian [34] 20-29y: <14rep ♂; <15rep ♀ 30-39y: <14rep ♂; <13rep ♀ 40-49y: <13rep ♂; <13rep ♀ 50-59y: <13rep ♂; <11rep ♀ 60-69y: <13rep ♂; <11rep ♀	Timed-up and go, Brazilian [34] 20-29y: >6.56s ♂; >6.96s ♀ 30-39y: >6.75s ♂; >7.41s ♀ 40-49y: >7.46s ♂; >7.59s ♀ 50-59y: >8.42s ♂; >8.24s ♀ 60-69y: >8.26s ♂;>10.60s♀	Predicted 6MWD 40-80y [35] ♂ (7.57 x $height_{cm}$) – (5.02 x age_{years}) – (1.76 x $weight_{kg}$) – 309 ♀ (2.11 x $height_{cm}$) – (5.78 x age_{years}) – (2.29 x $weight_{kg}$) + 667 Lower limit of normal: Subtract 153♂ or 139♀ from predicted
SDOC [29]	Low physical function (muscle mass assessment not recommended)		Staging not recommended	
	Handgrip strength/BMI [29] <1.05kg/m^2 ♂; <0.79kg/m^2 ♀ ***OR*** Handgrip strength/fat mass[29] <1.66kg/kg ♂; <0.65kg/kg ♀ ***OR*** Handgrip strength/weight[29] <0.45kg/kg ♂; <0.34kg/kg ♀			

*The diagnosis classifications were taken from the respective consensus, however cut-off points were adapted for the study population
ALST: appendicular lean soft tissue; BIA: bioelectrical impedance analysis; BMI: body mass index; cm: centimeters; DXA: dual-energy x-ray absorptiometry; EASO: European Association for the Study of Obesity; ESPEN: European Society for Clinical Nutrition and Metabolism; EWGSOP2: The Revised European Working Group on Sarcopenia in Older People; kg: kilograms; m: meters; rep: repetitions; s: seconds; SDOC: Sarcopenia Definition and Outcomes Consortium; SMM: skeletal muscle mass; y: years; 6MWD: 6-minute walk distance

Data analysis

Kolmogorov-Smirnov test was applied to assess the normality of the distribution. Categorical variables are presented as percentage and 95% confidence interval, with Chi-square test used for comparisons. Continuous variables are presented as median and interquartile range. Only participants with all diagnostic criteria measures available were included in prevalence

calculations (BC available n=186: 169♀ and 17♂; BC + physical function available for SO prevalence n=152: 138♀ and 14♂).

Cohen's Kappa was calculated to determine the SO identification agreement between diagnostic criteria and BC methods[37]. SO prevalence was investigated by postoperative time categories as an exploratory analysis. Data was analyzed using IBM SPSS Statistics for Mac, version 25 (IBM Corp., Armonk, NY, USA).

RESULTS

A total of 186 participants were included (median age=43.6 years, postoperative time=6.8 years; 169♀). Participants' %TWL was 27.1 (95% CI 19.6-32.7) and current BMI was 30.6 (95% CI 27.6-34.6) kg/m^2. Weight regain >10% was observed in 66.1% of the sample (Table 2); mostly in between >5 to ≤10 years and >10 years post BS. Two females presented low absolute HGS. However, this number increased when HGS was adjusted by body size or BC (based on BMI, FM, or weight per SDOC recommendation[29]). Low 30-CST was present in 27.6% (95% CI 20.4-34.6); and ≤7.2% presented with low physical performance by TUG and 6MWD (Table 2).

Table 2. Patient characteristics and physical function of adults post-bariatric surgery, according to sex

	Females n=169	Males n=17	Total n=186
Patient characteristics			
Age (years)	43.7 (36.9-51.0)	43.5 (37.9-52.2)	43.6 (37.0-51.0)
Education level			
0 to 8 years (%, CI)	6.5 (3.0-10.1)	5.9 (0-17.6)	6.5 (3.2-10.2)
9 to 11 years (%, CI)	24.9 (18.3-32.5)	17.6 (0-35.3)	24.2 (17.8-30.1)
12 or more years (%, CI)	68.6 (60.9-75.1)	76.5 (52.9-94.1)	69.4 (62.9-76.3)
Preoperative BMI (kg/m^2)	41.8 (38.4-45.8)	46.4 (43.3-47.9)	42.1 (38.6-46.5)
Postoperative years	6.9 (4.2-9.6)	6.0 (3.2-9.7)	6.8 (4.1-9.5)
2 to 5 years (%, CI)	29.6 (22.5-36.7)	35.3 (11.8-58.8)	30.1 (23.7-36.6)
> 5 to 10 years (%, CI)	49.7 (42.0-57.4)	47.1 (23.5-70.6)	49.5 (41.9-57.0)
> 10 years (%, CI)	20.714.8-27.2)	17.6 (0-41.2)	20.4 (15.1-26.3)
Height (m)	1.60 (1.57-1.65)	1.73 (1.67-1.80)	1.61 (1.57-1.67)
Current weight (kg)	79.3 (71.6-88.7)	98.5 (86.1-116.6)	80.8 (72.7-91.8)
Current BMI (kg/m^2)	30.2 (27.4-34.5)	32.9 (29.8-35.7)	30.6 (27.6-34.6)
BMI ≥ 30kg/m^2 (%, CI)	51.5 (43.8-58.6)	76.5 (52.9-94.1)	53.8 (46.8-60.2)
Absolute weight loss (kg)	28.9 (20.6-36.2)	41.3 (34.9-48.0)	29.9 (21.7-37.2)
Excess weight loss (%)	67.7 (48.3-84.9)	61.8 (52.6-75.9)	67.4 (49.7-84.6)
Total weight loss (%)	27.0 (19.1-32.7)	29.4 (23.6-34.9)	27.1 (19.6-32.7)
Weight regain (kg)	10.1 (5.3-15.2)	10.6 (4.1-14.2)	10.2 (5.0-15.1)
Weight regain ≥ 10% (%, CI)	67.5 (60.9-74.6)	52.9 (29.4-76.5)	66.1 (59.7-73.1)
Physical function variables	**Females n=138**	**Males n=14**	**Total n=152**
Absolute HGS (kg)	30.0 (26.8-34.0)	45.0 (42.0-52.5)	30.5 (27.3-36.0)
Low absolute HGS (%, CI)	1.4 (0-3.6)	0	1.3 (0-3.3)
HGS/BMI (kg/m^2)	1.00 (0.86-1.14)	1.40 (1.24-1.65)	1.00 (0.88-1.18)
Low HGS/BMI (%, CI)	18.8 (12.3-25.4)	7.1 (0-21.4)	17.8 (12.5-23.7)
HGS/FM BIA (kg/kg)	0.95 (0.76-1.13)	1.42 (1.07-1.73)	0.97 (0.77-1.18)
Low HGS/FM BIA (%, CI)	16.7 (10.9-23.2)	78.6 (57.1-100.0	22.4 (15.8-29.6)
HGS/FM DXA (kg/kg)	0.84 (0.68-0.99)	1.27 (1.08-1.44)	0.87 (0.70-1.04)
Low HGS/FM DXA (%, CI)	18.8 (13.0-25.4)	85.7 (64.3-100.0)	25.0 (17.8-32.2)
HGS/weight (kg/kg)	0.386 (0.340-0.430)	0.490 (0.438-0.514)	0.393 (0.346-0.442)
Low HGS/weight (%, CI)	23.9 (17.4-31.9)	35.7 (14.3-64.3)	25.0 (17.8-32.2)
30-CST (rep)	14.0 (12.0-16.0)	13.0 (11.0-16.0)	14.0 (12.0-16.0)
Low 30-CST (%, CI)	26.1 (18.8-33.3)	42.9 (14.3-64.3)	27.6 (20.4-34.9)
TUG (s)	6.23 (5.59-6.87)	5.97 (5.50-6.56)	6.17 (5.61-6.86)
*Altered TUG (%, CI)	5.1 (2.2-8.7)	14.3 (0-35.7)	5.9 (2.6-9.9)
6MWD (m)	555.0 (500.0-620.7)	602.3 (537.5-677.9)	560.0 (500.0-624.5)
Low 6MWD (%, CI)	7.2 (2.9-12.3)	7.1 (0-21.4)	7.2 (3.3-11.8)

Note: Data are presented as median (interquartile range) or otherwise established; *Altered refers to a higher time to complete TUG, representing poorer physical function based on established cut-offs;
30-CST: 30 seconds chair stand test; 6MWD: 6-minute walk distance test; BIA: bioelectrical impedance analysis; BMI: body mass index; CI: 95% confidence interval; DXA: dual-energy x-ray absorptiometry; FM: fat mass; HGS: handgrip strength; kg: kilograms; m: meters; rep: repetitions; TUG: timed-up and go test;

Using BMI, 53.8% were classified as having obesity (BMI >30 kg/m^2, 87♀ and 13♂). BMI underestimated the presence of excess FM by DXA by approximately 30% (Figure 1). Using DXA, obesity defined by excess FM was observed in all individuals classified with obesity by BIA, plus 43 additional individuals (BIA 60.2%: 98♀ and 14♂; DXA 83.3%: 139♀ and 16♂). When assessing height-adjusted ALST according to EWGSOP2, 1.6% (BIA) - 8.1% (DXA) were considered as having low muscle mass. In contrast, when analyzing ALST and SMM adjusted by weight percentage as per ESPEN/EASO, almost 80% of the sample was classified with low muscle

mass when evaluated by DXA (i.e. ALST). The prevalence of low muscle mass was lower when evaluated by BIA, independent of the adjustment made (Table 3).

Table 3. Fat and muscle mass variables of adults post-bariatric surgery, according to sex and body composition methodology

	BIA			DXA		
	Females n=169	**Males n=17**	**Total n=186**	**Females n=169**	**Males n=17**	**Total n=186**
Fat mass variables						
Fat mass (kg)	32.4 (27.1-41.9)	34.2 (29.3-41.7)	32.5 (27.1-41.9)	36.8 (30.4-44.3)	37.5 (33.2-43.6)	37.0 (30.5-44.1)
Fat mass (%)	42.2 (36.9-47.0)	33.7 (30.7-37.8)	41.4 (35.5-46.3)	47.6 (42.5-51.6)	39.3 (35.3-41.8)	47.1 (41.5-51.3)
Excess fat mass (%, CI)	58.0 (50.3-65.1)	82.4(64.7-100.0)	60.2 (52.7-66.7)	82.2 (76.3-87.6)	94.1(82.4-100.0)	83.3 (77.4-88.7)
Muscle mass variables						
ALST (kg)	18.4 (16.6-20.7)	26.6 (24.5-31.0)	18.7 (16.9-21.4)	16.8 (15.3-18.4)	24.8 (22.4-27.5)	17.0 (15.5-19.0)
ALST/height^2 (kg/m^2)	7.1 (6.7-7.7)	9.0 (8.5-9.6)	7.2 (6.7-7.9)	6.4 (5.9-7.0)	8.4 (7.9-8.8)	6.5 (6.0-7.2)
ALST/weight x 100 (%)	*	*	*	21.1 (19.4-23.1)	25.2 (23.8-27.3)	21.4 (19.5-23.7)
SMM (kg)	24.7 (22.8-28.0)	35.7 (32.9-40.6)	25.1 (23.1-28.4)	*	*	*
SMM/weight X 100 (%)	31.6 (29.0-34.3)	36.8 (34.9-38.6)	31.8 (29.4-35.2)	*	*	*
****Low muscle mass**						
EWGSOP2 (%, CI)	1.2 (0-3.0)	5.9 (0-17.6)	1.6 (0-3.8)	7.7 (4.1-11.8)	11.8 (0-29.4)	8.1 (4.3-12.4)
ESPEN/EASO (%, CI)	Class I 18.3 (12.4-23.7) Class II 0	Class I 41.2 (23.5-64.7) Class II 11.8 (0-29.4)	Class I 20.4 (15.1-27.4) Class II 1.1 (0-2.7)	78.7 (72.2-84.6)	88.2(70.6-100.0)	79.6 (73.7-85.5)

Notes: Data are presented as median (interquartile range) or otherwise established; *Diagnostic criteria does not use this muscle mass variable assessed by this body composition method; **Values presented are based on body composition alone, and do not represent sarcopenic obesity diagnostic prevalence

ALST: appendicular lean soft tissue; BIA: bioelectrical impedance analysis; CI: 95% confidence interval; DXA: dual-energy x-ray absorptiometry; EASO: European Association for the Study of Obesity; ESPEN: European Society for Clinical Nutrition and Metabolism; EWGSOP2: The Revised European Working Group on Sarcopenia in Older People; kg: kilograms; SMM: skeletal muscle mass;

The step-by-step application of the ESPEN/EASO SO consensus is shown in Figure 1. BMI screening favored the non-identification of individuals potentially diagnosed with SO. For SO diagnosis, low physical function was classified solely by CST, since only 2 individuals presented with low absolute HGS and both had normal muscle mass. The Venn diagram represents the overlap of the parameters evaluated for SO definition (Figure 2).

SO was more prevalent when BC was assessed by DXA (Table 4). The prevalence of SO was highest when using the SDOC criteria (assessed solely by low physical function; without muscle mass evaluation), and lowest when using the EWGSOP2 criteria. The prevalence of SO

appeared to be related to length of postoperative period; the longer the postoperative period, the higher the prevalence of SO (Figure 3).

Table 4. Sarcopenic obesity prevalence by diagnostic criteria, sex, and body composition methodology in adults post-bariatric surgery

Sarcopenic obesity classification	BIA			DXA		
	Females n=138	Males n=14	Total n=152	Females n=138	Males n=14	Total n=152
Sarcopenic obesity ESPEN/EASO	6.5 (2.9-10.9)	21.4 (0-42.9)	7.9 (3.9-12.5)	21.7 (15.2-29.0)	35.7 (7.1-57.1)	23.0 (17.1-30.3)*
Stage I	4.3 (1.4-8.0)	7.1 (0-21.4)	4.6 (1.3-7.9)	17.4 (10.9-24.6)	21.4 (0-42.9)	17.8 (11.8-24.3)
Stage II	2.2 (0-5.1)	14.3 (0-35.7)	3.3 (1.3-6.6)	4.3 (1.4-8.0)	14.3 (0-35.7)	5.2 (2.0-9.2)
Sarcopenia + obesity EWGSOP2	0	7.1 (0-21.4)	0.7 (0-2.0)	2.2 (0-5.1)	14.3 (0-35.7)	3.3 (0.7-5.9)*
Stage I	0	0	0	1.5 (0-3.6)	0	1.3 (0-3.3)
Stage II	0	7.1 (0-21.4)	0.7 (0-2.0)	0.7 (0-2.2)	14.3 (0-35.7)	2.0 (0-4.6)
Sarcopenia + obesity SDOC	21.7 (15.2-29.0)	78.6(50.0-100.0)	27.0 (19.7-34.2)	24.6 (18.1-31.9)	85.7(64.3-100.0)	30.3 (23.0-37.5)*

Note: Data are presented as percentage and 95% confidence interval; * p<0.001 chi-square test when compared to BIA for the same consensus; BIA: bioelectrical impedance analysis; DXA: dual-energy x-ray absorptiometry; EASO: European Association for the Study of Obesity; ESPEN: European Society for Clinical Nutrition and Metabolism; EWGSOP2: The Revised European Working Group on Sarcopenia in Older People; SDOC: Sarcopenia Definition and Outcomes Consortium

When evaluated by the same BC assessment method, agreement between SO prevalence using the ESPEN/EASO SO consensus versus EWGSOP2 or SDOC was considered none to slight (Table 5). The agreement between BIA and DXA for SO prevalence within the same diagnostic criteria was considered fair to moderate for the ESPEN/EASO SO consensus and the EWGSOP2; agreement was almost perfect for the SDOC as was only related to FM assessment.

Table 5. Agreement of sarcopenic obesity prevalence between diagnostic criteria and body composition methodology in individuals post-bariatric surgery

	Kappa	95% CI
Different diagnostic criteria, same body composition assessment method:		
ESPEN/EASO sarcopenic obesity consensus		
vs EWGSOP2; BIA	0.14	-0.11; 0.40
vs EWGSOP2; DXA	0.19	0.04; 0.34
vs SDOC; BIA	0.27	0.12; 0.42
vs SDOC; DXA	0.16	-0.01; 0.32
Same consensus, different body composition assessment method:		
BIA vs DXA: ESPEN/EASO Sarcopenic Obesity consensus	0.43	0.26; 0.60
BIA vs DXA: EWGSOP2	0.30	-0.15; 0.75
BIA vs DXA: SDOC	0.92	0.87; 0.98

BIA: bioelectrical impedance analysis; DXA: dual-energy x-ray absorptiometry; EASO: European Association for the Study of Obesity; ESPEN: European Society for Clinical Nutrition and Metabolism; EWGSOP2: The Revised European Working Group on Sarcopenia in Older People; SDOC: Sarcopenia Definition and Outcomes Consortium

DISCUSSION

To our knowledge, this is the first study to explore the prevalence of SO using the ESPEN/EASO SO consensus in individuals post-BS. The ESPEN/EASO SO consensus identified a high prevalence of SO in post-BS patients with little agreement with commonly used diagnostic criteria. SO prevalence was higher when assessed by DXA (23.0%) compared to BIA (7.9%); fair to moderate agreement. Low muscle strength was only identified using 30-CST, rather than absolute HGS. EWGSOP2 identified the lowest and SDOC the highest SO prevalences. Of note, our population included predominantly middle-aged adults, whereas EWGSOP2 and SDOC were developed for older adults. This highlights the need for criteria more appropriate for younger at-risk individuals post-BS, such as the ESPEN/EASO SO consensus and assessment of BC by DXA. Post-BS patients diagnosed with SO should receive targeted treatment to improve muscle mass and function.

SO prevalence comparisons

Patients undergoing BS are at high risk for muscle loss. During the first postoperative year after BS, 8.23kg of fat-free mass (LST + bone), 8.13kg of LST, and 3.18kg of SMM are lost on average[10]. Two years after surgery, fat free-mass accounted for approximately 21.71% of total weight loss[38], highlighting the increased risk for SO during the extended follow-up period. Voican et al.[7] observed that SO prevalence by computed tomography increased from 8% pre-BS to 32% one-year post-surgery. Vassilev et al.[39] investigated sarcopenia by SMM index from magnetic resonance imaging before and after 6, 12 and 24 weeks of BS, and found that the prevalence increased with increasing postoperative time (12%, 17%, 45%, 57%, respectively). Pekar et al.[12] assessed the risk for sarcopenia 24-months post-BS by ALST/height^2 derived from DXA and could not identify any individuals with low ALST. Of note, the prior three studies only

assessed BC; diagnostic criteria that considered low physical function parameters were not used. Coral et al.[17] applied the EWGSOP2 using BIA to evaluate sarcopenia before and six months post-BS, and found no participants met the diagnostic criteria. In our sample of individuals more than 2-years post-BS, we also found a low prevalence of SO using EWGSOP2 criteria (0.7-3.3%). Comparably, a higher proportion (7.9%–23%) were identified as having SO by the 2022 ESPEN/EASO SO consensus diagnostic criteria. Differences between our study and others, especially in relation to postoperative time or diagnostic criteria, preclude meaningful comparisons. However, our findings suggest the use of specific parameters developed for younger individuals with obesity, and special consideration regarding BC methodology for SO clinical identification. Estimations of the global prevalence of sarcopenia in adults <60 years of age with no history of BS range from 8–36%, depending on diagnostic criteria and cut-off points used[40].

Muscle mass and physical function analysis

Muscle mass is in theory correlated with body size, which indicates that individuals with larger bodies may have more muscle mass[41]. However, unfavourable clinical/functional consequences may be present in people who have low relative muscle mass and excess FM without low absolute muscle mass[42]. The height squared adjustment is also correlated with BMI, therefore it can underestimate sarcopenia in individuals with obesity[43], especially when cut-off points developed for older people are used in younger populations. The preferred adjustment for muscle mass (i.e. by height, weight or BMI) is still not well established[18,44], and there is a need to investigate if different adjustments are better correlated with clinically relevant impairments in populations having different health conditions, age and/or sex.

Absolute HGS cut-points did not identify low muscle strength in our study population. Muscle strength has been correlated with body size[45,46], therefore it is expected that individuals

with larger bodies present higher absolute values, highlighting the need for body size adjustments in muscle strength evaluation. When we evaluated the HGS adjusted for BMI, FM, or weight, we did identify low muscle strength in our participants. Contrarily, SDOC does not endorse the BC component of sarcopenia diagnosis, recommending that only physical function should be used, since muscle mass was not a good indicator of adverse health-related functional outcomes (variable associations)[29]. Regardless, SO prevalence using SDOC was higher compared to other diagnostic criteria in this study, suggesting a low accuracy to identify true SO cases.

DXA versus BIA

As mentioned, almost a third less of participants were classified with SO using BIA compared to DXA (7.9% vs 23%). This suggests that BC techniques are highly relevant when determining prevalence rates. For this study, we used cut-off points for excess FM provided by the ESPEN/EASO consensus. However, these cut-off points are independently of body composition technique performed and could lead to misinterpretation. Muscle-related compartments are technically difficult to measure accurately, and all methods have some degree of limitations[47]. DXA is not always clinically accessible, does not directly measure skeletal muscle, and may have reduced accuracy in people with obesity[48]. However, BIA may have greater limitations. BIA only measures impedance (resistance and reactance), and these raw measurements are used to estimate BC using predictive equations derived from gold standard methods that are device and population-specific[49]. These equations have reduced accuracy in the presence of altered fluid and obesity, which may result in underestimation of FM and overestimation of fat-free mass[50]. Moreover, special conditions such as different populations (ethnicity, age) and the presence of comorbidities influence the accuracy of BIA equations and cut-off points to identify BC abnormalities[51]. These are usually not available in BIA devices, and may be proprietary. Special

attention in interpretation of findings is needed. However, phase angle, body cell mass, and even LST estimated by BIA demonstrated a strong correlation with SMM index from magnetic resonance imaging in individuals post-BS[39]. Despite these limitations, BIA may play an important role in clinical practice especially exploring change over time post-BS, and providing information to support SO prevention and treatment longitudinally.

Exploratory analyses

While we were unable to complete sex-specific comparisons due to the limited sample, our findings suggest a higher SO prevalence in males. Prior studies have found that males were more likely to be classified with sarcopenia and SO than females[7,52], however sex differences may be influenced by age[53] and diagnostic criteria[40]. Interestingly, we found that the prevalence of SO was higher in individuals with a longer postoperative time. At the same time, they also presented with higher BMI, weight regain, and age. This may be explained by challenges in long-term nutrition management, limited availability of follow-up support[54], higher weight regain risk over time[55], and increased risk of SO with aging[1]. A more in-depth assessment of the postoperative time effect in SO risk is needed in future studies, however our study highlights the need for continued monitoring for SO post-BS.

Strengths and limitations

To our knowledge we are the first to apply the ESPEN/EASO SO definition and comparison in this post-BS population, comparing it with previously established diagnostic criteria using a variety of BC and physical function tests. As an additional study strength, when available, population-specific cut-off points were used (i.e., Brazilians adults). Furthermore, our study focuses on a poorly studied population: mid to long-term post-BS individuals who are at high risk for new onset or worsening of SO. Limitations include the non-representative convenience sample,

limited availability of data in males, the sample size loss when all criteria for SO definition were combined, and the non-availability of raw BIA measurements for the use of specific equations to estimate BC. Because of a lack of a standardized post-surgical timeline and non-BS comparable group, we were unable to determine whether the prevalence reflects an outcome from the procedure itself. However, despite their younger age, the prevalence of SO is comparable to rates reported in older adults[40]. The impact of the BS technique (particularly with a malabsorptive component), physical activity level and protein intake on SO prevalence post-BS remain to be analyzed through future studies.

CONCLUSION

The ESPEN/EASO SO consensus identified a high and variable prevalence of SO in post-BS patients (7.9-23.0%), depending on the BC technique used; SO prevalence was higher when assessed by DXA. The ESPEN/EASO SO consensus presented little agreement when compared to commonly used sarcopenia diagnostic criteria. Our findings support that a specific SO criteria may be more appropriate for this at-risk population, as sarcopenia criteria may not identify relative low muscle mass and low function alongside high FM. Special attention should be given to postoperative time after BS, since SO prevalence could increase with increasing time post-surgery. Future studies are needed to explore how varying definitions of obesity (in combination with definitions of sarcopenia) can impact SO diagnosis. Furthermore, it is important to explore the relationship between SO identified by the ESPEN/EASO consensus with health status/outcomes.

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Author contributions: KMBC coordinated the two main studies. KMBC, ESD, RML, FL, MMA were responsible for writing and designing the initial protocol of the studies. FTV, FL and MMA were responsible for conducting data collection, transferring and review. FTV and ESD were responsible for designing this study protocol. KG and CMP contributed to the analysis plan. FTV was responsible for data analysis and writing the first draft of the manuscript. All authors contributed to the manuscript and provided final approval.

Data Availability Statement: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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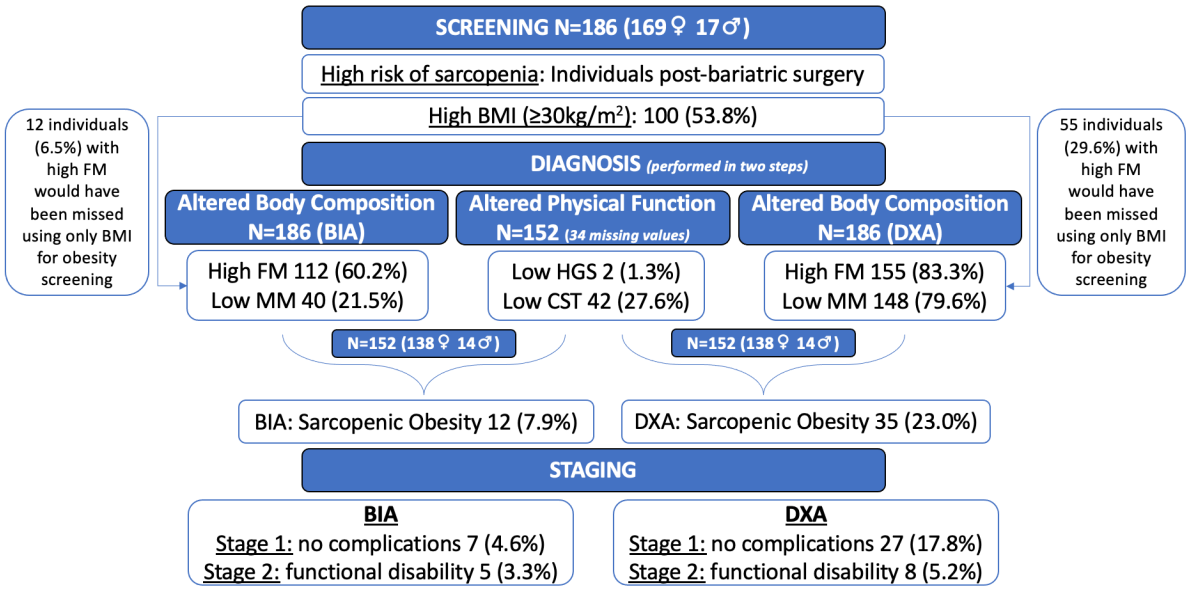

Figure 1. Diagnostic procedure of the ESPEN/EASO sarcopenic obesity consensus using BIA and DXA in adults post-bariatric surgery

Legend: BIA: bioelectrical impedance analysis; BMI: body mass index; CST: 30-seconds chair stand test; DXA: dual-energy x-ray absorptiometry; EASO: European Association for the Study of Obesity; ESPEN: European Society for Clinical Nutrition and Metabolism; FM: fat mass; HGS: handgrip strength; MM: muscle mass (used as a generic term).

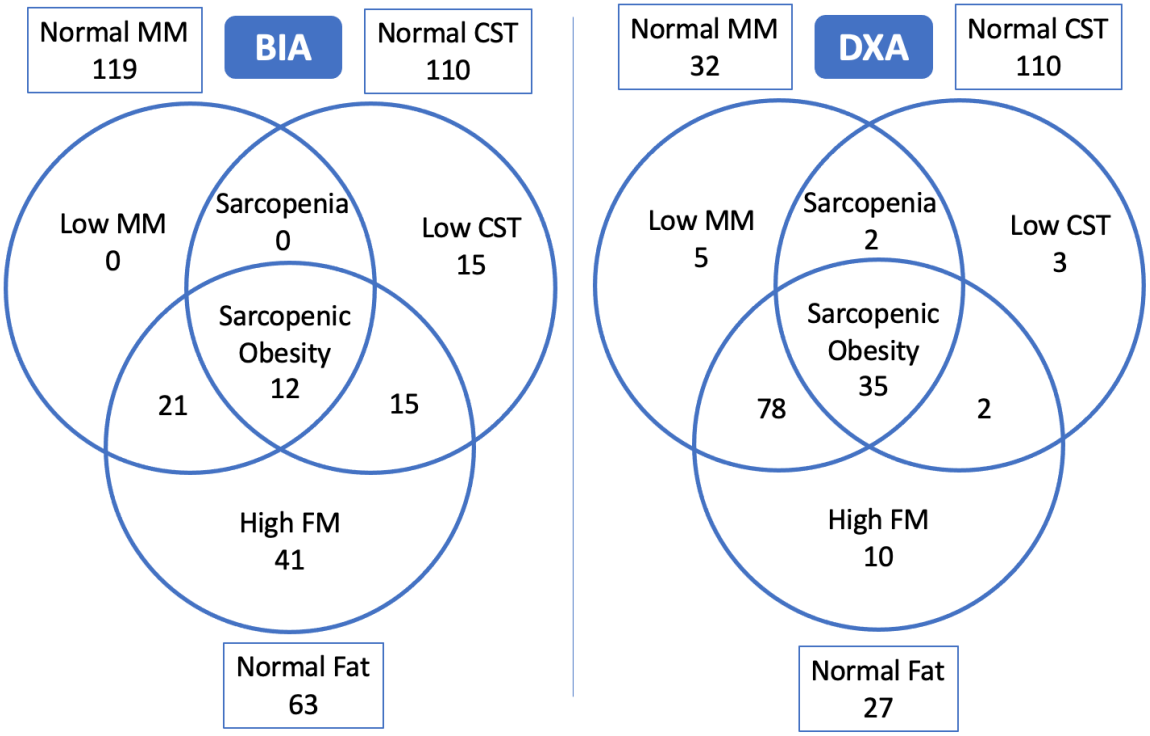

Figure 2. Venn diagram of the parameters evaluated by the ESPEN/EASO sarcopenic obesity consensus using BIA and DXA in adults post-bariatric surgery

Legend: Venn diagram was built for the 152 individuals with both body composition and physical function data for sarcopenic obesity diagnostic evaluation. BIA: bioelectrical impedance analysis; CST: 30-seconds chair stand test; DXA: dual-energy x-ray absorptiometry; EASO: European Association for the Study of Obesity; ESPEN: European Society for Clinical Nutrition and Metabolism; FM: fat mass; MM: muscle mass (used as a generic term).

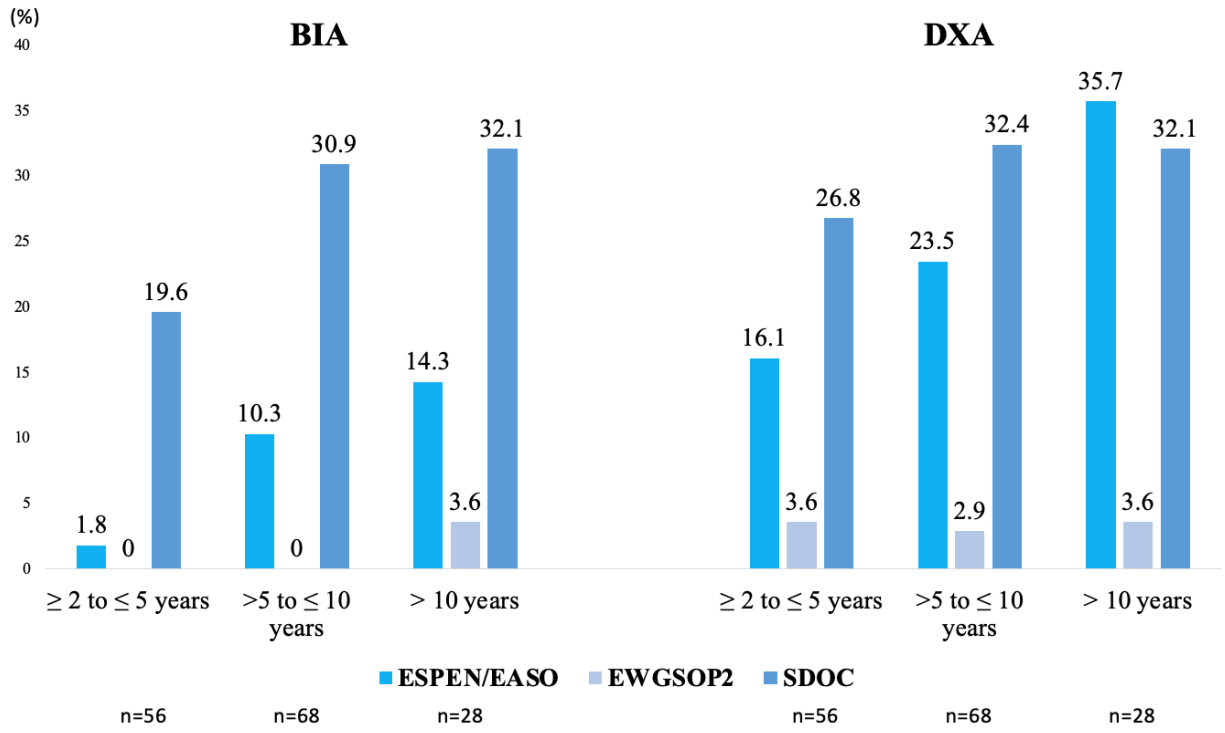

Figure 3. Sarcopenic obesity prevalence by diagnostic criteria, body composition methodology, and post-bariatric surgical timepoints

Legend: BIA: bioelectrical impedance analysis; DXA: dual-energy x-ray absorptiometry; EASO: European Association for the Study of Obesity; ESPEN: European Society for Clinical Nutrition and Metabolism; EWGSOP2: The Revised European Working Group on Sarcopenia in Older People; SDOC: Sarcopenia Definition and Outcomes Consortium

Supporting Information Table 1. STROBE checklist for cross-sectional studies

	Item No	Recommendation	Location in main text
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	Abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Abstract
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Introduction Paragraphs 1-4
Objectives	3	State specific objectives, including any prespecified hypotheses	Introduction Paragraph 5
Methods			
Study design	4	Present key elements of study design early in the paper	Methods Study Design
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Methods Study Design
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	Methods Participants
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Methods Sarcopenic obesity classification and cut-off points
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Methods Surgical and sociodemographic data; body composition and anthropometric assessment; physical function parameter; sarcopenic obesity classification and cut-off points
Bias	9	Describe any efforts to address potential sources of bias	Methods Sarcopenic obesity classification and cut-off points
Study size	10	Explain how the study size was arrived at	Methods Study design
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Methods Data analysis
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	Methods Data analysis
		(*b*) Describe any methods used to examine subgroups and interactions	Methods Data analysis Paragraph 2
		(*c*) Explain how missing data were addressed	Methods Data analysis Paragraph 1
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	NA
		(*e*) Describe any sensitivity analyses	NA
Results			
Participants	13	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for	Results Paragraph 1

		eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	
		(b) Give reasons for non-participation at each stage	Results Figure 1
		(c) Consider use of a flow diagram	NA
Descriptive data	14	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Results Table 2
		(b) Indicate number of participants with missing data for each variable of interest	Results Figure 1
Outcome data	15	Report numbers of outcome events or summary measures	Results Figure 1
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Results Table 4
		(*b*) Report category boundaries when continuous variables were categorized	Results Table 2, 3, and 4
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	Results Figure 3
Discussion			
Key results	18	Summarise key results with reference to study objectives	Discussion Paragraph 1
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Discussion Paragraph 7
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Conclusions
Generalisability	21	Discuss the generalisability (external validity) of the study results	Conclusions
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Funding statement; after conclusions

Information on the STROBE Initiative is available at www.strobe-statement.org.