Review

Critical appraisal of definitions and diagnostic criteria for sarcopenic obesity based on a systematic review

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SUMMARY

Background: Sarcopenic obesity is a clinical and functional condition characterized by the coexistence of excess fat mass and sarcopenia. Currently, different definitions of sarcopenic obesity exist and its diagnostic criteria and cut-offs are not universally established. Therefore, the prevalence and sensitivity of this condition for any disease risk prediction is affected significantly.
Aim: This work was conducted under the auspices of the European Society for Clinical Nutrition and Metabolism (ESPEN) and the European Association for the Study of Obesity (EASO). An international expert panel performed a systematic review as an initial step to analyze and summarize the available scientific literature on the definitions and the diagnostic criteria for sarcopenic obesity proposed and/or applied in human studies to date.
Methods: The present systematic review was performed according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement. The search was conducted in April 2018 in three databases (PubMed, Scopus, Web of Science). Human studies conducted in both sexes, irrespective of ethnicity, and published from 2007 to 2018 were included; cohorts of individuals with obesity and

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acute or chronic conditions and treatments reported to negatively influence skeletal muscle mass and function independently of obesity were excluded from final analyses. The quality of the studies was evaluated using the Newcastle–Ottawa Scale (NOS) adapted for cross sectional studies.
Results: The electronic search retrieved 2335 papers of which 75 met the eligibility criteria. A marked heterogeneity in definitions and approaches to diagnose sarcopenic obesity was observed. This was mainly due to differences in the definitions of obesity and sarcopenia, in the methodologies used to assess body composition and physical function, and in the reference values for the variables that have been used (different cut-offs, interquartile analysis, diverse statistical stratification methods). This variability may be attributable, at least in part, to the availability of the methodologies in the different settings, to the variability in specialties and backgrounds of the researcher, and to the different settings (general population, clinical settings, etc.) where studies were performed.
Conclusion: The results of the current work support the need for consensus proposals on: 1) definition of sarcopenic obesity; 2) diagnostic criteria both at the level of potential gold-standards and acceptable surrogates with wide clinical applicability, and with related cut-off values; 3) methodologies to be used in actions 1 and 2. First steps should be aimed at reaching consensus on plausible proposals that would need subsequent validation based on homogeneous studies and databases, possibly based on analyses of existing cohorts, to help define the prevalence of the condition, its clinical and functional relevance as well as most effective prevention and treatment strategies.

List of abbreviations

AFFM	appendicular fat-free mass
ASM	appendicular skeletal muscle
BIA	bioelectrical impedance analysis
BMI	body mass index
CT	computed tomography scan
DXA	dual-energy X-ray absorptiometry
EASO	European Association for the Study of Obesity
ESPEN	European Society for Clinical Nutrition and Metabolism
EWGSOP	European Working Group on Sarcopenia in Older People
FFM	fat-free mass
FM	fat mass
HGS	handgrip strength
MAMC	mid-arm muscle circumference
NOS	Newcastle–Ottawa Scale
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
WC	waist circumference
WT	weight

1. Background

Sarcopenic obesity is a clinical and functional condition characterized by the coexistence of excess fat mass (FM) and sarcopenia. The latter literally refers to reduced skeletal muscle mass or myopenia, while muscle dysfunction with low muscle strength (dynapenia) and performance were also part of the concept when the term sarcopenia was introduced [1] and have been notably included in accepted consensus initiatives to define the condition in the geriatric community [2–4]. Sarcopenic obesity tends to be more common in older subjects but it can also be found in younger obese patients with disability, during acute (ICU) or chronic disease [*chronic kidney disease, chronic obstructive pulmonary disease, congestive heart* failure, cancer, after bariatric surgery (particularly in the absence of nutritional supervision)], or submitted to long-lasting incongruous dietary regimens and weight cycling. It is also likely that this condition may be present across the age spectrum in non-clinical scenarios [5,6]. Indeed, the aetiology of sarcopenia is multi-factorial, and obesity *per se* may represent an additional independent determinant for development of muscle loss and dysfunction due to the negative impact of obesity-related metabolic derangements, such as systemic and skeletal muscle oxidative stress, inflammation and insulin resistance [7]; higher prevalence in the obese population of chronic non-communicable diseases with nutritional and metabolic muscle-catabolic impact; sedentary lifestyle which is exacerbated by comorbidities. On the other hand, sarcopenia may facilitate fat accumulation, meaning that it may be difficult to establish whether a subject with obesity has sarcopenia as primary or secondary condition.

From the clinical standpoint, sarcopenic obesity potentially leads to the cumulative risk derived from the two individual body composition phenotypes [8–11]. Strong evidence demonstrated worse outcomes for individuals with obesity, under many different heterogeneous clinical conditions, ranging from cancer to chronic organ failures [12]. In the field of obesity, an emerging awareness of the importance of physical function to patient risk stratification has translated into composite tools including comorbidities and disabilities, that may ultimately reflect the presence of muscle dysfunction (e.g. Edmonton Obesity Staging System) [13]. In the clinical nutrition community, simple clinical malnutrition diagnostic criteria have been launched recently in a global consensus document, which allows for a malnutrition diagnosis when low skeletal muscle mass is present, irrespective of body mass index (BMI), when additional non-anthropometric pathophysiological criteria are fulfilled [14]. Although it is outside the context of this work, some evidence suggests that overweight-obesity may be protective in chronically ill and older individuals. A clear definition of sarcopenic obesity and, in particular, an understanding of the role that the different components of body composition have on functional parameters, comorbidity and mortality can clarify the extent and importance of the so-called obesity paradox.

Different definitions of sarcopenic obesity have been used in research and its diagnostic criteria and cut-offs are not established. Hence, the published prevalence of this condition ranges from 2.75% to over 20%, depending on the applied diagnostic criteria and the methods of body composition assessment [15,16]. Moreover, the lack of a universally accepted definition, diagnostic criteria and cut-offs significantly affect the sensitivity of any disease risk prediction work for sarcopenic obesity. Conflicting data also exist

regarding the link between low skeletal muscle mass and functional impairment since skeletal muscle mass and strength or performance are not consistently related [17,18], and its relationship may differ between primary and secondary sarcopenia. However, as an association between obesity *per se* and poor physical performance has been demonstrated, long-term consequences of reduced skeletal muscle mass on physical performance are potentially more severe in individuals with obesity than in subjects without obesity with the same amount of skeletal muscle [19–21]. In obesity, an imbalance between fat-free mass (FFM), excess FM, and total body size may indeed appear earlier than the onset of old age [15,22], leading to relatively low FFM even when skeletal muscle mass is preserved [6]. In addition, as mentioned above, low skeletal muscle function related to sarcopenic obesity may not only result from an imbalance between FM and skeletal muscle, but it may also be the consequence of impaired skeletal muscle metabolic capacities together with biological effects of excess fat on contractile skills [21,23–25].

2. Aim

In recent years, the European Society for Clinical Nutrition and Metabolism (ESPEN) and the European Association for the Study of Obesity (EASO) have issued joint statements calling for further collaborative efforts aimed at overcoming existing hurdles towards clinical applicability of the sarcopenic obesity concept [26,27]. Under the extended auspices of ESPEN and EASO, the current initiative involved an international expert panel who performed a systematic review as an initial step to analyze and summarize the available scientific literature about the definitions and the diagnostic criteria for sarcopenic obesity proposed and/or applied so far in human studies. For the mainly methodological purpose of the current work, we focused our search on studies primarily involving obese individuals in the absence of acute or chronic conditions or treatments with potential independent negative impact on skeletal muscle metabolism and mass (such as surgery, cancer, kidney disease).

3. Materials and methods

The present systematic review was registered in the PROSPERO database (https://www.crd.york.ac.uk/PROSPERO/) (registration number: CRD42019133328) and performed applying the following steps according to the PRISMA procedure [28].

3.1. Literature search

A pool of international experts was initially created, consisting of delegates from the European Association for the Study of Obesity (EASO) and the European Society for Clinical Nutrition and Metabolism (ESPEN) with expertise in body composition, sarcopenia and obesity. Three members of the Expert Group (LMD, LB and RB) coordinated the activities undertaken within the group to conduct the systematic review. The search was conducted in April 2018 in three databases: PubMed, Scopus and Web of Science. Additional articles of potential relevance were also manually searched. The search was conducted based on pre-defined key words including “sarcopenia”, “obesity”, “sarcopenic obesity”, “sarcopenic adiposity”, “lipotoxic sarcopenia”. Boolean operators (AND, OR), to establish logical associations between the different terms and the search used in the systematic review was: [keywords and MeSH (medical subject heading) terms] were combined as: (“sarcopenia” [MeSH Terms] OR “sarcopenia” [All Fields]) AND (“obesity” [MeSH Terms] OR “obesity” [All Fields]) OR (sarcopenic [All Fields] AND (“obesity” [MeSH Terms] OR “obesity” [All Fields])) OR (Sarcopenic [All Fields] AND (“adiposity” [MeSH Terms] OR “adiposity” [All Fields])) OR (Lipotoxic [All Fields] AND (“sarcopenia” [MeSH Terms] OR “sarcopenia” [All Fields])) OR (Osteosarcopenic [All Fields] AND (“obesity” [MeSH Terms] OR “obesity” [All Fields])) AND (“2008/04/08” [PDat]: “2018/04/05” [PDat] AND “humans” [MeSH Terms] AND (“adult” [MeSH Terms] OR “adult” [MeSH Terms:noexp] OR “aged” [MeSH Terms])). The searches from the three independent databases were combined and duplicates were removed to create a master file used for titles and abstracts screening. In addition, no language restrictions were applied in searching the databases.

3.2. Study selection

Human studies conducted in male and female adult populations, irrespective of ethnicity, and published in from 2007 to 2018 were included in the systematic review. Publications in all languages were included. The selection of the studies was performed in a three-step selection process involving the evaluation of 1) titles, 2) abstracts and 3) full texts. Two investigators independently screened for eligibility at each step. If consensus was reached, articles were either excluded or moved to the next stage. In case of a discrepancy between investigators, a third investigator from the coordinating team resolved each case by discussion with the reviewers until a consensus was reached.

Main reasons for exclusion of articles from the systematic review were: 1) undefined classification of sarcopenic obesity; 2) papers not reporting original research data, such as narrative reviews or commentaries, 3) duplicate analyses conducted on the same samples (first published paper was included), 4) inadequate description of methods used to assess body composition or define sarcopenic obesity cases and 5) clinical studies including patient groups with diagnosis of chronic and acute diseases or undergoing treatments that could *per se* cause catabolic changes in protein turnover with independent negative impact on skeletal muscle mass and/or function [such as cancer, hemodialysis, surgery).

3.3. Data extraction and quality assessment

The following information was extracted from the eligible articles: author, year of publication, study type, sample size, participants' characteristics (nationality, age, sex), sarcopenic obesity definition, diagnostic criteria (methods, parameters and cut-off points) used to define sarcopenic obesity, and the aim(s) of the study. In addition, the quality of the studies was evaluated using the Newcastle–Ottawa Scale (NOS) adapted for cross sectional studies [29]. The NOS assesses the quality of the studies in three key areas: 1) selection of the study group in terms of clinical examination (score 0–5 stars); 2) comparability of the groups such as the use of matching or multivariate techniques (score 0–2 stars); 3) ascertainment of outcome such as the use of standardized or validated measures (score 0–3 stars).

4. Results

4.1. Search results

The study selection process is presented in Fig. 1. The electronic search retrieved 2335 references. After removing duplicate references, a total of 2134 titles and abstracts were screened for eligibility. 160 references were selected for full text evaluation and 75 articles [5,12,24,30–55,56–86,87–101] were included in the systematic review. A quantitative synthesis (meta-analysis) was not performed since the data did not allow conduct of a formal meta-analysis due to the heterogeneity in the definitions of sarcopenic

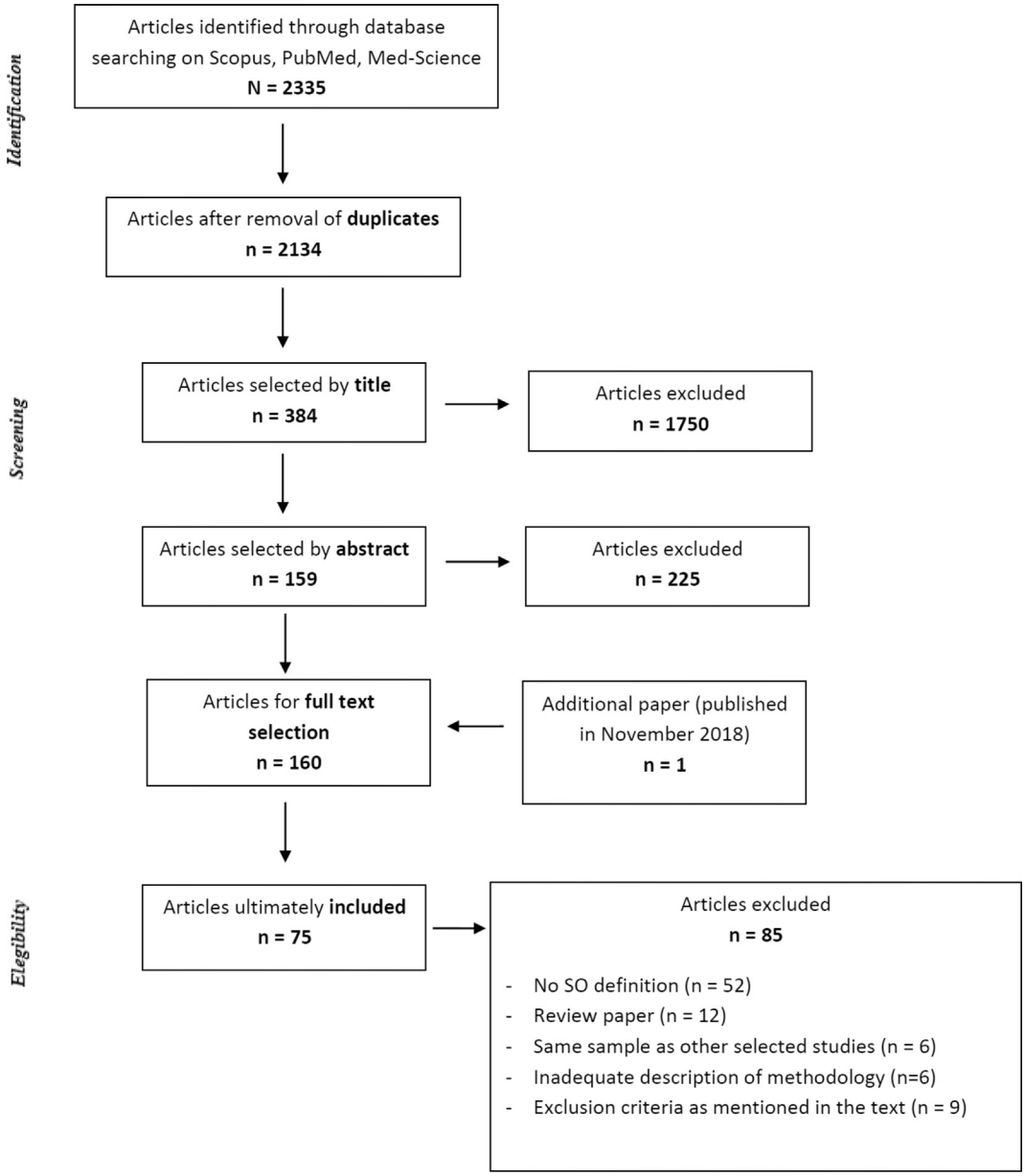

Fig. 1. PRISMA flow diagram. SO: sarcopenic obesity.

obesity, application of diagnostic cut offs and use of different body composition methods.

4.2. Study characteristics

The main characteristics of the 75 articles selected in the systematic review are summarized in Tables 1 and 2. All were published between 2007 and 2018 and the total number of participants included in this systematic review was 217,973, with a sample size ranging from 17 to 15,132 participants. We observed a greater inclusion of women (54.3%) and the mean age of the participants was 64.8 ± 4.5 years (range: 20–92). Studies were conducted in different continents including Asia [Japan, China, Korea, Thailand and Taiwan (1 study) [71], Japan (3 studies) [55,58,63], Korea (22 studies) [24,32,34,35,46,47,54,59–62,64–67,70,72,79,80,83,88,96], Taiwan (4 studies) [44,69,73,75]], Oceania [Australia (4 studies) [53,92–94]]; North and South America [Brazil (7 studies) [49,50,76,81,89,90,99]; United States (11 studies) [5,36–40,68,86,95,97,100]; Canada (1 study) [42]] and Europe [France (1 study) [12], Germany (1 study) [57], United Kingdom (3 studies) [30,33,52], Italy (9 studies) [43,48,74,78,82,85,87,91,98], Spain (3 studies) [31,77,84], Italy and Slovenia (1 study) [41], Turkey (1 study) [51]]. Three studies were conducted simultaneously in different continents: [Finland, Poland, Spain, China, Ghana, India, Mexico, Russia and South Africa (1 study) [101]; United Kingdom and Korea (1 study) [45]; United Kingdom, United States and Canada (1 study) [56]].

Study design were predominantly cross-sectional (64 studies, one of which was nested in a retrospective cohort [57]) followed by prospective cohort studies (6 studies) [33,40,43,52,92,93] and randomized clinical trials (5 studies) [36,44,58,69,78]. The aims of the studies were different and a summary of key areas of investigation of these studies is summarized in Fig. 2. Briefly, 9 studies explored the role of biological and lifestyle factors in the

Table 1
General characteristics of the studies included in the systematic review.

	Country	Sample size (n)	Gender (n)		Age (M±SD)	Study design
			M	F		
Aggio DA et al. (2016) [30]	UK	1286	1286	0	83.1 ± 5.2	cross-sectional
Aibar-Almazán A et al. (2018) [31]	Spain	235	0	235	70.65 ± 19.86	cross-sectional
An KO et al. (2016) [32]	Korea	10,118	4887	5231	58.7 ± 0.3	cross-sectional
Atkins JL et al. (2014) [33]	UK	4051	4051	0	70.3 ± 5.5	prospective cohort study
Baek J et al. (2013) [34]	Korea	1150	618	532	43.55 ± 11.45	cross-sectional
Baek SJ et al. (2014) [35]	Korea	3483	1466	2017	>64	cross-sectional
Bahat G et al. (2018) [51]	Turkey	992	308	684	M = 76.3 ± 6.9; F = 74.3 ± 7.2	cross-sectional
Balachandran A et al. (2014) [36]	USA	17	1	16	Circuit training = 71.6 ± 7.8; hypertrophy = 71 ± 8.2	RCT
Batsis JA et al. (2013) [37]	USA	4984	2452	2532	M = 70.3; F = 71.3	cross-sectional
Batsis JA et al. (2014) [38]	USA	4652	2283	2369	M = 70.0 ± 0.2; F = 71.1 ± 0.34	cross-sectional
Batsis JA et al. (2015) [39]	USA	2025	756	1269	68.2 ± 5.4	prospective cohort study
Batsis JA et al. (2016) [40]	USA	4984	2452	2532	71.1 ± 0.19	cross-sectional
Biolo G et al. (2015) [41]	Italy & Slovenia	200	89	111	M = 48 ± 12; F = 51 ± 12	cross-sectional
Bouchard DR et al. (2009) [42]	Canada	904	439	465	68–82	cross-sectional
Cesari M et al. (2009) [43]	Italy	934	421	513	74.5 ±7.0	prospective cohort study
Chen HT et al. (2017) [44]	Taiwan	60	10	50	65–75	RCT
Cho Y et al. (2015) [45]	Korea, UK	11,521	4934	6587	Normal = 43.3 ± 0.1; SO = 48.4 ± 0.5	cross-sectional
Chung JH et al. (2016) [46]	Korea	6889	3385	3504	M = 60.5 ± 0.2; F = 63.1 ± 0.2	cross-sectional
Chung JY et al. (2013) [47]	Korea	2943	1250	1693	M = 69.0 ± 6.3; F = 69.3 ± 6.4	cross-sectional
De Rosa E et al. (2015) [48]	Italy	131	51	80	M: 50 ± 5 F: 50 ± 4	cross-sectional
Domiciano DS et al. (2013) [49]	Brazil	611	0	611	73.22 ± 5.21	cross-sectional
dos Santos EP et al. (2014) [50]	Brazil	149	0	149	67.2 ± 6.1	cross-sectional
Hamer M et al. (2017) [52]	UK	6864	3129	3735	66.2 ± 9.5	prospective cohort study
Huo YR et al. (2016) [53]	Australia	680	238	442	79 ± 9	cross-sectional
Hwang B et al. (2012) [54]	Korea	2221	964	1257	M = 69.4 ± 6.6; F = 69.8 ± 6.8	cross-sectional
Ishii S et al. (2016) [55]	Japan	1731	875	856	>65	cross-sectional
Joppa P et al. (2016) [56]	UK, USA, Canada	2548	1586	962	63.5 ± 7.1	cross-sectional
Kemmler W et al. (2016) [57]	Germany	1325	0	1325	76.4 ± 4.9	cross-sectional (retrospective cohort)
Kim H et al. (2016) [58]	Japan	307	168	139	>70	RCT
Kim JH et al. (2015) [59]	Korea	3320	1458	1862	54.3 ± 0.3	cross-sectional
Kim TN et al. (2014) [60]	Korea	298	119	179	40.1 ± 11.2	cross-sectional
Kim TN et al. (2009) [24]	Korea	526	198	328	M = 52.2 ± 14.4; F = 51.2 ± 14.8	cross-sectional
Kim YS et al. (2012) [61]	Korea	10,485	4486	5999	M = 31.0 ± 5.5; F = 30.8 ± 5.6	cross-sectional
Kim MK et al. (2011) [62]	Korea	3169	1380	1789	63.6	cross-sectional
Kohara K et al. (2011) [63]	Japan	782	303	479	M = 67.9 ± 8.5; F = 66.3 ± 8.2	cross-sectional
Kwon SS et al. (2017) [64]	Korea	8707	4192	4515	M = 45.63 ± 0.23; F = 44.31 ± 0.21	cross-sectional
Lee J et al. (2016) [65]	Korea	309	85	224	M = 70.7 ± 6.3 F = 66.4 ± 7.2	cross-sectional
Lee S et al. (2012) [66]	Korea	2893	1249	1644	66	cross-sectional
Lee YH et al. (2015) [67]	Korea	15,132	5617	9515	≥20	cross-sectional
Levine ME et al. (2012) [68]	USA	2287	1002	1285	70.60 ± 7.9	cross-sectional
Liao CD et al. (2017) [69]	Taiwan	46	0	46	67.3 ± 5.2	RCT
Lim KI et al. (2010) [70]	Korea	264	126	138	47–54	cross-sectional
Lim JP et al. (2015) [71]	Asia (Japan, China, Korea, Thailand, Taiwan)	143	44	99	68 ± 8.2	cross-sectional
Lim S et al. (2010) [72]	Korea	565	287	278	≥65	cross-sectional
Lu CW et al. (2013) [73]	Taiwan	600	144	456	63.6 ± 10.1	cross-sectional
Marini E et al. (2012) [74]	Italy	207	75	132	M = 75.8 ± 6.9; F = 70.8 ± 4	cross-sectional
Meng P et al. (2014) [75]	Taiwan	101	101	0	88.8 ± 3.7	cross-sectional
Moreira MA et al. (2016) [76]	Brazil	491	0	491	49.95 ± 5.56	cross-sectional
Muñoz-Arribas A et al. (2013) [77]	Spain	306	76	230	82.5 ± 2.3	cross-sectional
Muscariello E et al. (2016) [78]	Italy	1030	0	1030	obese = 30.9 ± 7.9; normal-weight = 28.5 ± 7.6	RCT
Oh C et al. (2017) [79]	Korea	4452	1929	2523	>60	cross-sectional
Oh C. et al. (2015) [80]	Korea	1433	658	775	>60	cross-sectional
Oliveira RJ et al. (2011) [81]	Brazil	607	0	607	44.8 ± 19.9	cross-sectional
Park SH et al. (2013) [83]	Korea	6832	3409	3423	49.3	cross-sectional
Pedrero-Chamizo R et al. (2015) [84]	Spain	2747	645	2102	M = 72.4 ± 5.4; F = 72 ± 5.2	cross-sectional
Perna S et al. (2017) [82]	Italy	639	196	443	80.9 ± 7.77	cross-sectional
Poggiogalle E et al. (2016) [85]	Italy	727	141	586	45.72 ± 13.56	cross-sectional
Prado CM et al. (2014) [5]	USA	13.236	6580	6.656	M = 44.57 ± 0.33; F = 46.8 ± 0.36	cross-sectional

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Table 1 (*continued*)

	Country	Sample size (n)	Gender (n)		Age (M±SD)	Study design
			M	F		
Ramachandran R et al. (2012) [86]	USA	539	280	259	71.1 ± 0.1	cross-sectional
Rolland Y et al. (2009) [12]	France	1308	0	1308		cross-sectional
Rossi AP et al. (2017) [87]	Italy	846	370	476	74.5 ± 6.9	cross-sectional
Ryu M et al. (2013) [88]	Korea	2264	940	1324	73.2	cross-sectional
Santos VRD et al. (2017) [89]	Brazil	116	47	69	83.3 ± 2.7	cross-sectional
Santos VRD et al. (2017) [90]	Brazil	113	41	72	83.4 ± 2.9	cross-sectional
Schrager et al. (2007) [91]	Italy	871	378	493	74.0 ± 7.1	cross-sectional
Scott D et al. (2016) [92]	Australia	1089	534	555	62	prospective cohort study
Scott D et al. (2017) [93]	Australia	1486	1486	0	>70	prospective cohort study
Scott, D et al. (2018) [94]	Australia	168	75	93	67.7 ± 8.4	cross-sectional
Sénéchal M et al. (2012) [95]	USA	3007	1515	1492	65.4 ± 10	cross-sectional
Seo JA et al. (2012) [96]	Korea	484	216	268	72.1 ± 4.7	cross-sectional
Sharma D et al. (2014) [97]	USA	11,643	5785	5858	>20	cross-sectional
Siervo M et al. (2012) [98]	Italy	763	0	763	45.4 ± 16.8	cross-sectional
Silva Neto LS et al. (2012) [99]	Brazil	56	0	56	64 ± 5.74	cross-sectional
Srikanthan P et al. (2010) [100]	USA	14,528	7017	7511	45.0	cross-sectional
Tyrovolas S et al. (2015) [101]	Finland, Poland, Spain, China, Ghana, India, Mexico, Russia, South Africa	18,363	8303	10,060	>65	cross-sectional

M = Male; F = Female; SO = Sarcopenic Obesity; RCT: randomized clinical trial.

pathogenesis of sarcopenic obesity [vitamin D levels (3 studies) [62,79,96], inflammation (1 study) [91], cardiorespiratory fitness (1 study) [60], leptin (1 study) [63] or physical activity (3 studies) [54,84,88]]. A large proportion of studies evaluated the association of sarcopenic obesity with risk of comorbidities [inflammation (5 studies) [39,71,82,85,91], metabolic syndrome (6 studies) [47,65,70,72,73,85], altered lipid (2 studies) [34,90] or glucose metabolism (5 studies) [47,54,64,86,100], non-alcoholic fatty liver disease (1 study) [67], cardiovascular diseases and function (7 studies) [33,35,47,50,59,60,83], chronic kidney diseases (1 study) [97], multimorbidity (1 study) [32]], impaired physical function [physical activity level/function (9 studies) [12,30,42,54,68,75,76,79,89], disability or impaired exercise capacity (3 studies) [56,87,101], balance (1 study) [94], risk (1 study) [93] or fear (1 study) [31] of falling], musculoskeletal disorders [bone health (1 study) [94], fractures (1 study) [92], osteoarthritis (1 study) [66], osteoporosis (2 studies) [46,92]], mental health [depression (1 study) [55] and psychological health (1 study) [45]], low quality of life (3 studies) [40,45,99], hospitalization (1 study) [87] and risk of mortality (4 studies) [33,38,52,75]. Finally, 6 studies tested clinical interventions in sarcopenic obesity populations including exercise training to improve physical function (3 studies) [36,44,69], effects of exercise and nutrition on recovery from sarcopenic obesity (2 studies) [58,80] and protein intake for the prevention of lean-mass loss in older individuals (1 study) [78].

4.3. Definitions of sarcopenic obesity

The definition of sarcopenic obesity in the majority of the studies (66 studies) was based on the co-existence of obesity and sarcopenia (used as a synonymous of low or reduced skeletal muscle mass), which were regarded as two distinct categories (Table 2). Less frequently (only 3 studies [50,81,99]) sarcopenic obesity was defined by calculating the population distribution of the residuals of linear regression models applied to predict appendicular fat-free mass (AFFM) using independent variables such as height (in meters) and fat-mass (FM) (in kg). Two studies used the FM to FFM or the visceral adipose tissue area to thigh muscle area ratios to identify cases of sarcopenic obesity [41,70].

Different studies defined sarcopenia among individuals with obesity as a low muscle strength (also defined as dynapenia by some of the authors) [52] characterized by a reduction of handgrip strength (HGS). However, the term dynapenic obesity was used in three studies only [40,87,95].

No study defined sarcopenia according to a co-existence of reduced muscle strength and mass [1].

4.4. Diagnostic criteria and measurement methods

Studies were characterized by a large variability in the application of physiological measurements used to define sarcopenia and obesity. Specifically, 19 different measurements of sarcopenia and 10 measurement of adiposity were applied across the studies (Table 3) with appendicular skeletal muscle (ASM) divided by weight (ASM/wt) or adjusted by height in meters squared (ASM/h^2) and BMI being the most frequently applied measurements of sarcopenia and obesity, respectively. In addition, the heterogeneity of the diagnostic assessment of sarcopenic obesity was further increased by the application of different cut-off points for the same measurements (Table 4). These cut off points were often borrowed from established guidelines (i.e., BMI $\geq$30 kg/m^2 for obesity), whereas in other studies population-specific cut-offs were derived by calculating specific parameters from the distributions of the individual measurements (i.e., n-tiles, SDs or z scores).

Diagnostic procedures for the assessment of body composition and functional status were:

- dual-energy X-ray absorptiometry (DXA) for the definition of sarcopenia (44 studies) [5,12,24,32,34,37,39,42,45–47,49,50,53,54,58–62,64,66–69,71,72,74,75,79–83,85,88–90,92–94,96,97,99] and for the assessment of excess adiposity (17 studies) [5,12,24,37,39,42,46,50,58,69,74,82,89,90,92–94];
- anthropometry [BMI, *mid-arm muscle circumference* (*MAMC*), waist circumference (WC)] for the definition of sarcopenia (1 study) [30] and for the assessment of excess adiposity (44 studies) [12,30,32,34–37,40,43–45,47–49,51,53,54,57,59,61,62,64,66–68,71,73,75,76,78–80,83,85–88,91,94,95,97,98,100,101];

Table 2
Definition and diagnostic criteria adopted in the studies included in the systematic review.

	SO Definition	Diagnostic Criteria (parameters)	Diagnostic Criteria (cut-off)	Methods for diagnosis (procedures)	Outcome
Aggio DA et al. (2016) [30]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: MAMC, GS, HGS; Obesity: WC	Sarcopenia: lowest two-fifths of the MAMC distribution plus GS < 30 kg or GS ≤ 0.8 m/s; Obesity: WC > 102 cm	Anthropometry, dynamometer, 3 m walking test	association with low physical functions
Aibar-Almazán A et al. (2018) [31]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: EWGSOP criteria (SMI, GS, HGS); Obesity: FM%	Sarcopenia: ASM/h^2 < 6.42 kg/m^2 plus HGS < 20 kg or GS < 0.8 m/s; Obesity: FM > 35%	BIA, dynamometer, 3 m walking test with Up and Go (TUG) test	association with fear of falling
An KO et al. (2016) [32]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/Wt; Obesity: WC	Sarcopenia: SMI 1 SD below the mean of a young population reference group (<30.1% M and 21.2% F). Obesity: WC sex-specific cutoff point for Asians (≥90 cm M and 80 cm F)	Anthropometry, DXA	association with multimorbidity
Atkins JL et al. (2014) [33]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: FFMI; Obesity: WC	Sarcopenia: lowest two-fifths of the FFMI (≤16.7 kg/m^2); Obesity: those above the percentile point of FMI corresponding to the WC obesity cutoff (28.7th percentile) (>11.1 kg/m^2).	Anthropometry, BIA	association with cardiovascular disease and mortality
Baek J et al. (2013) [34]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2 or ASM/Wt; Obesity: BMI	Sarcopenia: ASM/h^2 or ASM/Wt 1 SD below the mean of the young reference group; Obesity: BMI ≥ 25 kg/m^2	Anthropometry, DXA	association with dyslipidemia
Baek SJ et al. (2014) [35]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2; Obesity: BMI	Sarcopenia: ASM/h^2 ≤ 2 SD below reference values from young (10.7 kg/m^2 M and 8.6 kg/m^2 F); Obesity: BMI > 25 kg/m^2	Anthropometry, BIA	association with cardiac autonomic nervous dysfunction
Bahat G et al. (2018) [51]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: EWGSOP criteria (SMI, GS, HGS); Obesity: FM or BMI	Sarcopenia: SMI < 9.2 kg/m^2 M, 7.4 kg/m^2 F and HGS < 22 kg F, < 32 kg M or GS < 0.8 m/s; Obesity: FM above 60th percentile or BMI ≥ 30 kg/m^2	Anthropometry, BIA, dynamometer, 4 m walking test	prevalence
Balachandran A et al. (2014) [36]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: EWGSOP criteria (SMI, GS, HGS); Obesity: BMI	Sarcopenia: ASM/h^2 < 10.76 kg/m^2 M, 6.76 kg/m^2 F plus GS < 1 m/s or HGS < 30 kg M and <20 kg F; Obesity: BMI > 30 kg/m^2	Anthropometry, BIA, dynamometer, 4 m walking test	improving of physical functin through different type of training
Batsis JA et al. (2013) [37]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2; Obesity: FM% or WC;	8 different definitions for sarcopenia: 1)ASM/h^2: <7.26 kg/m^2 M, <5.45 kg/m^2 F; 2) Total body skeletal mass/m^2 < 9.12 kg/m^2 M− 6.53 kg/m^2 F; 3) Total body skeletal mass/h^2: <5.7 kg/m^2 F; 4) ASM/h^2: <8.51−6.29 kg/m2 M; 5) ASM/body mass: <25.7% M, <19.4% F; 6) ASM/h^2: <7.4 −5.14 kg/m^2 M; 7) Total skeletal muscle mass/Wt: <0.7%; 8) ASM/h^2: <8.81 kg/m^2 M, <7.36 kg/m^2 F; Obesity, 6 different definitions: 1) FM > 27% M, 38% F; 2) FM > 37.16% M, 40.01% F; 3) FM: >42.9% F; 4) FM > 28% M, 35% F; 5) WC: >102 cm M, 88 cm F; 6) FM: >20.7% M, 31.7% F	DXA, BIA, Anthropometry	prevalence
Batsis JA et al. (2014) [38]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2; Obesity FM%	Sarcopenia: SMI (ASM/h^2). M: class I: 8.51−10.75 kg/m^2; class II: ≤8.50 kg/m^2; F: class I: 5.76−6.75 kg/m^2; class II: ≤5.75 kg/m^2); Obesity: FM ≥ 27% M and ≥38% F	BIA	association with mortality
Batsis JA et al. (2015) [39]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ALM; ALM/BMI ratio; Obesity: FM%	Sarcopenia: ALM <19.75 kg M and <15.02 kg F OR ALM/BMI ratio <0.789 M and <0.512 F; Obesity: FM > 25% M and 35% F	DXA	association with inflammation
Batsis JA et al. (2016) [40]	dynapenic obesity	Dynapenia: HGS; Obesity: BMI	Dynapenia: knee extensor strenght in the lowest tertile (M: 365.8−458.2 N; F 235.3−304.1 N); Obesity: BMI >30 kg/m^2	Anthropometry, Maximal knee extensor strenght	impact of SO on physical function and QoL in patients with osteoarthritis
Biolo G et al. (2015) [41]	Sarcopenic obesity	SO: FM/FFM RATIO	SO: FM/FFM RATIO > 0,8	BIA	assessment of predictive power of ABSI on the FFMI
Bouchard DR et al. (2009) [42]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2; Obesity: FM%	Sarcopenia: ASMI 2 SD below the mean of a cohort of young adults (<6.29 kg/m^2 F and <8.51 kg/m^2 M); Obesity: FM ≥ 35% F and ≥28% M	DXA	association with low physical functions
Cesari M et al. (2009) [43]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: calf CSA; Obesity: BMI	Sarcopenia: calf CSA in the lowest tertile; Obesity: BMI>30 kg/m^2	Anthropometry, CT	skeletal muscle and fat mass are not significant risk factors for mortality
Chen HT et al. (2017) [44]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/Wt; Obesity: BMI and VFA	Sarcopenia = ASM/Wt ≤ 32,5 M; ≤25,7 F; Obesity = BMI ≥ 25 kg/cm^2 and VFA ≥ 100 cm^2	Anthropometry, BIA, CT	effects of different types of exercise

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Table 2 (*continued*)

	SO Definition	Diagnostic Criteria (parameters)	Diagnostic Criteria (cut-off)	Methods for diagnosis (procedures)	Outcome
Cho Y et al. (2015) [45]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/Wt; Obesity: WC	Sarcopenia: ASM/Wt < 23,8% F, < 30,3% M (<1 SD below the mean value of the reference group); Obesity: WC ≥ 90 cm M, ≥ 85 cm F	Anthropometry, DXA	association with adverse psychological health and lower QoL
Chung JH et al. (2016) [46]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2; Obesity: FM%	Sarcopenia: ASM/h^2 < 7,26 kg/m^2 M, <5,45 kg/m^2 F (<2 SDs below the sex-specific mean of a young reference group); Obesity: FM >30% M, >40% F	DXA	association with osteoporosis
Chung JY et al. (2013) [47]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/Wt; Obesity: BMI	Sarcopenia: ASM/Wt < 32,5% M, <25,7% F (1 SD below the mean of a reference group); Obesity: BMI ≥ 25 kg/m^2	Anthropometry, DXA	association with insulin resistance, metabolic syndrome and cardiovascular disease risk factors
De Rosa E et al. (2015) [48]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2; Obesity: BMI	Sarcopenia: MODERATE (between 1 and 2 SD) SMI 8.44 −9.53 kg/m^2 and SEVERE (below 2 SD) SMI ≤8.43 kg/m^2 M, MODERATE SMI 6.49−7.32 kg/m^2 and SEVERE SMI ≤6.48 kg/m^2 F; Obesity: BMI ≥ 30 kg/m^2	Anthropometry, BIA	prevalence and definition
Domiciano DS et al. (2013) [49]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2; Obesity: BMI	Sarcopenia: SMI < 5,45 kg/m^2 F; Obesity: BMI ≥ 30 kg/m^2; The 20th percentile was defined as the cutoff point for sarcopenia, corresponded to a residual of −1.45 in the population studied	Anthropometry, DXA	definition
dos Santos EP et al. (2014) [50]	Sarcopenic obesity	Sarcopenia: SMI (ASM/h^2); SO: prediction equation for AFFM	Sarcopenia: SMI < 5,45 kg/m^2 F; SO: the residual values of a regression equation that predicts AFFM based on height (m) and FM (kg). The equation: predicted AFFM = 14.529 + (17.989 × h) + (0.1307 × FM). The cutoff value corresponds to a residual ≤3.4	Anthropometry, DXA	absent of an association with cardiometabolic risk
Hamer M et al. (2017) [52]	Sarcopenic obesity	SO: obese individuals in the lowest tertile of sex-specific HGS	SO: BMI >30 kg/m^2 in the lowest tertile of sex-specific HGS (35.3 kg M and 19.6 kg F)	Dynamometer, anthropometry	SO did not confer any greater risk than sarcopenia alone; weight loss combined with sarcopenia presented the greatest risk of mortality
Huo YR et al. (2016) [53]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcoepnia: EWGSOP criteria; Obesity: BMI	Sarcopenia: ALM/h^2 < 5.5 kg/m^2 F and <7.26 kg/m^2 M plus GS < 80 cm/s or HGS <20 kg F and <30 kg M; Obesity: BMI ≥ 30 kg/m^2	Anthropometry, DEXA, Dynamometer, Gait rite	definition
Hwang B et al. (2012) [54]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/Wt; Obesity: WC	Sarcopenia: ASM/Wt 2 SD below mean value of sex-specific young normal people; Obesity: WC ≥ 90 cm M and ≥85 cm F	Anthropometry, DEXA	prevalence of SO and association with medical conditions as insulin resistance, inappropriate nutrition, low physical activity
Ishii S et al. (2016) [55]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2, HGS, GS; Obesity: FM%	Sarcopenia: ASM/h^2 2 SD below the mean values of young reference groups (<7.0 kg/m^2 M, < 5.8 kg/m^2 F) plus HGS < 30 kg M, < 20 kg F or GS < 1,26 m/s M and F; Obesity: FM% in the highest quintile (cutoff values: 29.7% M, 37.2% F)	BIA, dynamometer, 5 m walking test	association with depressive symptoms
Joppa P et al. (2016) [56]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: FFMI; Obesity: FMI	Sarcopenia: FFMI < 10th percentile of the reference values; Obesity: FMI ≥ 90th percentile of the reference values	BIA	valutation of effects of SO on exercise capacity, health status, systemic inflammation in patients with COPD
Kemmler W et al. (2016) [57]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: EWGSOP and IWGS; Obesity: BMI, FM%	Sarcopenia: EWSGOP: ASM/h^2 ≤ 5.45 kg/m^2 plus GS ≤ 0,8 m/s or HGS at <20 kg; IWGS = GS ≤ 1.0 m/s and ASM/h^2 in the lowest quintile; Obesity: BMI ≥ 30 kg/m^2 and FM ≥ 35%	Anthropometry, BIA, dynamometer, 10 m GS test	prevalence
Kim H et al. (2016) [58]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: SMI or HGS or GS; Obesity: FM%	Sarcopenia: SMI < 5,67 kg/m^2 or HGS < 17.0 kg or GS < 1.0 m/s; Obesity: FM ≥ 32%	DXA, dynamometer, 5 m walking test	effects of exercise and nutrition
Kim JH et al. (2015) [59]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/Wt; Obesity: BMI	Sarcopenia: ASM/weight < 1 sd below the mean of the sex-specific healthy reference group. Cutoff point 31.30% M and 24.76% F. Obesity: BMI ≥25.0 kg/m^2	Anthropometry, DXA	association with cardiovascular disease
Kim TN et al. (2014) [60]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/Wt; Obesity: VFA	Sarcopenia: SMI < 36,3% M, < 28,5% F (1 SD below the sex-specific mean value for a young reference group); Obesity: VFA ≥100 cm^2 F, ≥130 cm^2 M	DXA, CT	low cardiorespiratory fitness increase risk of SO
Kim TN et al. (2009) [24]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2; Obesity: FM%	Sarcopenia: ASM < 7,40 kg/m^2 M, < 5,14 kg/m^2 F (2 DS below the sex-specific normal mean of a reference group); Obesity: FM > 20,21% M, 31,71% F (upper two quintiles). 4	DXA	prevalence

			differents groups: 1) normal body fat and muscle mass, 2) sarcopenia, 3) obesity, 4) SO		
Kim YS et al. (2012) [61]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2 or ASM/Wt; Obesity: WC	Sarcopenia: ASM/h^2 < 7,50 kg/m^2 M, <5,38 kg/m^2 F or ASM/Wt < 32,2% M, <25,6% F (<1SD below mean of young reference group); Obesity: WC > 90 cm M, >85 cm F	Anthropometry, DXA	prevalence
Kim MK et al. (2011) [62]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: AMS/Wt; Obesity: BMI	Sarcopenia: ASM/Wt < 29,5% M, < 23,2% F (<2 SD of young reference population); Obesity: BMI $\geq$ 27.5 kg/m^2;	Anthropometry, DXA	vitamin D levels lower in subjects with sarcopenia, regardless of obesity
Kohara K et al. (2011) [63]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: thigh CSA/Wt; Obesity: VFA	Sarcopenia: tight CSA/Wt < 1SD below young reference group (<1,9 cm^2/kg M, < 1,6 cm^2/kg F); Obesity: VFA > 100 cm^2 for M and F	CT	leptin may link visceral obesity and sarcopenia
Kwon SS et al. (2017) [64]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/Wt; Obesity: BMI	Sarcopenia: ASM/Wt < 30,98 M, <24,81 F (- 1 SD below the mean of a reference group); Obesity: BMI $\geq$ 25 kg/m^2	Anthropometry, DXA	association with insulin resistance
Lee J et al. (2016) [65]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/Wt; Obesity: FM%	Sarcopenia: ASM/Wt. Class I between 42,9−38,2% M, between 35,6−32,2% F (between 1 and 2 SD of young reference group); Class II < 38,2% M, < 32,2% F (below 2 SD); Obesity: FM > 25.8% M and 36.5% F (2 highest quintiles); SO was defined as class II sarcopenia plus obesity	BIA	association with metabolic syndrome
Lee S et al. (2012) [66]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/Wt; Obesity: BMI	Sarcopenia: ASM/Wt < 26,8% M, <21% F (<2SD of mean in a young reference group); Obesity: BMI $\geq$ 27.5 kg/m^2	Anthropometry, DXA	association with osteoarthritis
Lee YH et al. (2015) [67]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/Wt; Obesity: BMI	Sarcopenia: SMI $\leq$ 32.2% M and $\leq$25.5% F (<1 SD below mean sex-especific reference group). Obesity: BMI $\geq$25 kg/m^2	Anthropometry, DXA	sarcopaenia have an increased risk of NAFLD regardless of obesity
Levine ME et al. (2012) [68]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ALM/Wt; Obesity: WC	Sarcopenia: ASM < 25.72% M and 19.43% F (<2 SD below the mean of a young reference group); Obesity: WC > 102 cm M, >88 cm F.	Anthropometry, DXA	association with low physical functions
Liao CD et al. (2017) [69]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: SMI, HGS, GS; Obesity: FM%	Sarcopenia: SMI < 7.15 kg/m^2 plus HGS < 14.3 kg or GS < 1.0 m/s; Obesity: FM >38%	DXA, dynamomenter, 6 m GS test	elastic resistance exercise exerted benefits on the body composition, muscle quality and physical function in patients with SO
Lim KI et al. (2010) [70]	Sarcopenic obesity	SO: VFA (visceral fat area)/ TMA (thigh muscle area) Median	VFA/TMA Median higher 50th percentile (0,90 F and 0,93 M)	CT	association with metabolic syndrome
Lim JP et al. (2015) [71]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2 from AWSG; Obesity: WC	Sarcopenia: ASM/h^2 < 7.0 kg/m^2 M, <5.4 kg/m^2 F, HGS <26 kg M, <18 kg F, GS < 0.8 m/s; Obesity: WC > 90 cm M, >85 cm F	Anthropometry, DXA	association with inflammation
Lim S et al. (2010) [72]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2 and ASM/Wt; Obesity: VFA	Sarcopenia: ASM/h^2 < 7.09 kg/m^2 in M, <5.27 kg/m^2 in F and ASM/Wt < 29.9% in M and 25.1% in F (1 SD below the sex-specific mean for a young reference group); Obesity: VFA >100 cm^2	Abdominal CT, DXA	prevalence and association with metabolic syndrome (ASM/Wt is more associated)
Lu CW et al. (2013) [73]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/Wt; Obesity: BMI	Sarcopenia: SMI <37% M, <27.6% F; Obesity: BMI $\geq$ 25 kg/m^2	Anthropometry, BIA	association with metabolic syndrome
Marini E et al. (2012) [74]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2; Obesity: FM%	Sarcopenia: SMI < 7.26 kg/m^2 M, <5.45 kg/m^2 F; Obesity: FM > 27% M, >38% F	BIVA, DXA	BIVA (bioelectrical impedence vector analysis) discriminates SO individuals
Meng P et al. (2014) [75]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: EWGSOP criteria (SMI, HGS, GS); Obesity: BMI	Sarcopenia: SMI% < 28.0% M plus GS $\leq$ 0.8 m/s or HGS < 22.4 kg M; Obesity: BMI > 27.5 kg/m^2	Anthropometry, Dynamometer, 6 m walking test, DXA	prevalence of SO and association with low physical functions
Moreira MA et al. (2016) [76]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2; Obesity: WC	Sarcopenia: SMI < 6.08 kg/m^2 (<20th percentile of the sample); Obesity: WC $\geq$ 88 cm	Anthropometry, BIA	association with low physical functions
Muñoz-Arribas A et al. (2013) [77]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: total muscle mass; Obesity: FM%	Sarcopenia: total muscle mass $\leq$ 8.11 kg M, $\leq$5.80 kg F (2 lowest quintile). Obesity: FM $\geq$ 33.08% M, $\geq$43.91% F (2 highest quintile)	BIA	adequate physical conditions are associated with a low risk of SO

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Table 2 (*continued*)

	SO Definition	Diagnostic Criteria (parameters)	Diagnostic Criteria (cut-off)	Methods for diagnosis (procedures)	Outcome
Muscariello E et al. (2016) [78]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: Muscle mass index (MMI); Obesity: BMI	Sarcopenia: Class I, Muscle mass index (MMI) < 8.3 kg/m^2, Class II < 7,3 kg/m^2 (if BMI ≥30 kg/m^2), Class I MMI < 7,4 kg/m^2, Class II < 6,8 (if BMI < 25 kg/m^2) (2 standard deviations below the mean of the reference group); Obesity: BMI ≥30 kg/m^2	Anthropometry, BIA	adequate protein intake could contribute to the prevention of lean-mass loss in obese older people
Oh C et al. (2017) [79]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/Wt; Obesity: BMI	Sarcopenia: ASM/Wt < 1 SD below the mean value of a reference group; Obesity: BMI ≥ 25 kg/m^2	Anthropometry, DXA	sarcopenia association with metabolic related factors, physical activity, vitamin D levels
Oh C. et al. (2015) [80]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/Wt; Obesity: BMI	Sarcopenia: ASM/Wt < 44% M, 52% F (less than 1 SD below the mean of a reference sample); Obesity: BMI ≥ 25 kg/m^2	Anthropometry, DXA	body composition changes are related to nutrient intakes in elderly men but not elderly women; women have a higher prevalence of SO than men
Oliveira RJ et al. (2011) [81]	Sarcopenic obesity	SO: prediction equation for AFFM	Sarcopenia: FFM ≤ 2 SD of the mean of the reference sample consisting of young woman; SO: the residual values of a regression equation that predicts AFFM based on h (m) and FM (kg). The equation: predicted AFFM = −14.529 + (17.989 × h) + (0.1307 × FM). The cutoff value corresponds to a residual ≤3.4	DXA	cut-off proposal based on reduced functional capacity
Park SH et al. (2013) [83]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/Wt; Obesity: WC	Sarcopenia: ASM/Wt < 29,5% M, <23,2% F; Obesity: WC ≥ 90 cm M, ≥85 cm F	Anthropometry, DXA	association with hypertension
Pedrero-Chamizo R et al. (2015) [84]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: RMM% (relative muscle mass = Sketetal muscle mass/Wt%); Obesity: FM%	Sarcopenia: RMM < 6,20% F, <8,62% M (lower 2 quintiles); Obesity: FM > 40,90% F, >30,33% M (upper 2 quintiles of the reference group). 4 Groups: 1)Normal, 2)Obesity, 3) Sarcopenia, 4)SO.	BIA	physical activity and reduced risk of SO
Perna S et al. (2017) [82]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2; Obesity: FM%	Sarcopenia: SMI (ASM/h^2) below the 5th centile for age- and gender-matched healthy subjects; Obesity: FM > 38% F, >27% M	DXA	sarcopenic subjects appears more vulnerable than SO for fractures, edema, inflammation, malnutrition
Poggiogalle E et al. (2016) [85]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2 or ASM/Wt; Obesity: BMI	Sarcopenia: ASMM/h^2 < 6.54 kg/m^2 M, <4.82 kg/m^2 F or ASMM/Wt < 0.2827 M, <0.2347 F (<2 SD than the sex-specific mean of a young population). Obesity: BMI ≥30 kg/m^2	Anthropometry, DXA	association with metabolic syndrome and low-grade inflammation
Prado CM et al. (2014) [5]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2; Obesity: FMI (FM/h^2)	4 specific body-composition phenotypes: 1)LA-HM (low adiposity hight muscle: ASMI 50−100 kg/m^2; FMI 0 −49,99 kg/m^2); 2)HA-HI (high adiposity high muscle: ASMI 50−100 kg/m^2; FMI 50−100 kg/m^2); 3) LA-LM (low adiposity low muscle: ASMI 0−49.99 kg/m^2; FMI: 0 −49,99 kg/m^2); 4) HA-LM (high adiposity low muscle ASMI 0−49,99 kg/m^2; FMI: 50−100 kg/m^2). The HA-LM cutoffs were as follows: class I (ASMI: 40−49.99 kg/m^2; FMI: 60 −100 kg/m^2), class II (ASMI: 20−39.99 kg/m^2; FMI: 80 −100 kg/m^2), and class III (ASMI: 0−19.99 kg/m^2; FMI: 80 −100 kg/m^2).	DXA	definition
Ramachandran R et al. (2012) [86]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: thigh CSA; Obesity: BMI, WC	Sarcopenia: adjusted thigh muscle area <93,8 cm^2 F, <110,7 cm^2 M (lowest sex-specific tertile); Global adiposity = BMI > 27 kg/m2; Central adiposity = WC > 88 cm F, >102 cm M; 8 different groups	Anthropometry, CT	obesity association with glucose intolerance, unrelated to low muscle mass
Rolland Y et al. (2009) [12]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2; Obesity: FM%	Sarcopenia: ASM/h^2 < 5,45 kg/m^2 F (<2 SD below young ref group from Rosetta study); Obesity: FM% > 60th percentile	DXA	association with low physical functions
Rossi AP et al. (2017) [87]	dynapenic obesity	Dynapenia: HGS; Obesity: WC	Dynapenia: HGS < 33 kg M, <19 kg F (lowest tertile); Obesity: WC > 99 cm M, 95 cm F	Anthropometry, Dynamometer	association with disability and hospitalization
Ryu M et al. (2013) [88]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/Wt; Obesity: WC	Sarcopenia: ASM/Wt < 2 SD. Obesity: WC ≥ 90 cm for M and ≥85 cm for F	Anthropometry, DXA	physical activity and reduced risk of SO

Santos VRD et al. (2017) [89]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ALM/h^2, GS; Obesity: FM%	Sarcopenia: ALM/h^2 < 7.59 kg/m^2 M and 5.57 kg/m^2 F (2 SD below the mean of a reference group) + GS < 0.8 m/s; Obesity: FM% > 60th percentile (34.1 M and 44.2% F)	DXA, 3 m walking test	association with low physical functions
Santos VRD et al. (2017) [90]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2; Obesity: FM%;	Sarcopenia: SMI < 7.59 kg/m^2 M and 5.57 kg/m^2 F (2 SD below the mean of a reference group); Obesity: FM%>27% M and 38% F	DXA	hight FM is associated with high blood concentration of TG and low MM show lowel mean levels of LDL-c
Schrager et al. (2007) [91]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sacopenia: HGS; Obesity: BMI, WC	Sarcopenia: HGS in lowest tertiles: <33 kg M and 19 kg F; Obesity: GLOBAL = BMI>30 kg/m^2, CENTRAL = WC in upper sex specific tertile (>98 M and 95 F)	Anthropometry, Dynamometer	contribution of inflammation in developmant and progression of SO
Scott D et al. (2016) [92]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM; Dynapenia: limb muscle strenght; Obesity: FM	Sarcopenia: ASM in the lowest sex-specific tertile (M ≤ 1.09; F ≤ 0.92); Dynapenia: the lowest sex-specific tertile for lower-limb muscle strength (M ≤ 112 kg; F ≤ 47.5 kg); Obesity: highest sex-specific tertile for FM (M > 27.02 kg; F > 32.83 kg)	DXA, dynamometer	association with osteoporosis
Scott D et al. (2017) [93]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: EWSGOP and FNIH; Obesity: FM%	Sarcopenia: EWGSOP: ALM/h^2 < 7.25 kg/m^2 plus HGS <30 kg or GS < 0.8 m/s; FNIH: ALM/BMI <0.789 plus HGS <26 kg; Obesity: FM > 30%	DXA, Dynamometer, 4 m walking test	EWGSOP-defined sarcopenic obesity is associated with increased fall rates over 2 years, and FNIH-defined sarcopenic obese men have increased fracture risk over 6 years compared with non-sarcopenic obese men.
Scott, D et al. (2018) [94]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: FNIH definition (ALM/BMI plus HGS); Obesity: BMI, FM%	Sarcopenia: ALM/BMI < 0.789 M, <0.512 F plus HGS <26 kg M, < 16 kg F; Obesity: BMI ≥ 30, FM% ≥ 30 M, ≥40 F	DXA, CT, Dynamometer, Anthropometry	higher level of ALM association with better bone health and balance
Sénéchal M et al. (2012) [95]	dynapenic obesity	Dynapenia: HGS; Obesity: WC	Dynapenia: Lowest Leg Muscle strength tertile (M: 31.0 ± 8.4 Nm; F: 21.0 ± 5.3 Nm); Obesity: Sex- and Ethnicity-Specific WC cutoffs;	Anthropometry, Dynamometer	association with metabolic risk factors
Seo JA et al. (2012) [96]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2; Obesity: VFA on CT	Sarcopenia: ASM/h^2 < 1 SD below the sex-specific mean of a young reference group (<6.75 kg/m^2 M and <4.96 kg/m^2 F). Obesity: VFA ≥100 cm^2.	DXA, CT	greater VFA and lower MM are associated with lower 25(OH)D; SO do not have an additive association
Sharma D et al. (2014) [97]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/h^2; Obesity: BMI	Sarcopenia: ASMI < 5.45 kg/m^2 F and <7.26 kg/m^2 M (2 SD below the sex-specific means for a reference group); Obesity: BMI > 30 kg/m^2	Anthropometry, DEXA	association with CKD
Siervo M et al. (2012) [98]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopania: ALM/h^2; Obesity: BMI, FM%, WC, FMI.	Sarcopenia: SMI <6,76 kg/m^2 (2 SD below the means of a reference group); Obesity: BMI ≥ 30.0 kg/m^2, WC > 88.0 cm, FM% ≥ 35.0%, FMI ≥ 9.5 kg/m^2.	Anthropometry, BIA	prevalence
Silva Neto LS et al. (2012) [99]	Sarcopenic obesity	SO: prediction equation for AFFM	The prediction equation for AFFM was: AFFM = −14.529 + (17.989 × h) + (0.1307 × FM). The cutoff point corresponded to a residual value (the measured AFFM minus the AFFM predicted by the equation) ≤-3.4 (≤2 SD from the mean of the reference group). Who showed a residual value ≤ -3.4 was classified as having inadequate FFM for their body area, which indicates sarcopenic obesity	DEXA	association with low QoL
Srikanthan P et al. (2010) [100]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/Wt according to Janssen; Obesity: BMI	Sarcopenia: SMI < 2 SD below the sex specific (31.0% M, 22.0% F); Obesity: BMI > 30 kg/m^2	Anthropometry, BIA	sarcopenia, independent of obesity, is associated with adverse glucose metabolism
Tyrovolas S et al. (2015) [101]	coexistence of obesity and sarcopenia (distinct diagnosis)	Sarcopenia: ASM/BMI, HGS, GS; Obesity: BMI	Sarcopenia: ASM/BMI in the lowest quintile (differents cut off for contry) plus GS in lowest quintile or HGS < 30 kg M, < 20 kg F; Obesity: BMI ≥ 30 kg/m^2	Anthropometry, dynamomenter, 6 m GS test	association of low muscle mass with disability

Legend: M = Male; F = Female; SO = Sarcopenic Obesity BMI = Body Mass Index; FM = Fat Mass; FFM = Fat Free Mass: FFMI = Fat Free Mass Index; FMI = Fat Mass Index = FM/h^2; HGS = Hand Grip Strenght; GS = Gait Speed; WC = Waist Circumference; ALM = Appendicular Lean Mass; ASM = Appendicular Skeletal Muscle Mass; AFFM = Appendicular Fat Free Mass; SMI = Skeletal Muscle Mass Index; ASMI = Appendicular Muscle Mass Index; VFA = Visceral Fat Area; CSA = Cross Sectional Area; ABSI = A Body Shape Index (WC/(BMI^2/3xheight^1/2)); NAFLD = Nonalcoholic Fatty Liver Disease; CKD = Cronic Kidney Disease; QoL = Quality of Life; AWSG = Asian Working Group for Sarcopenia.

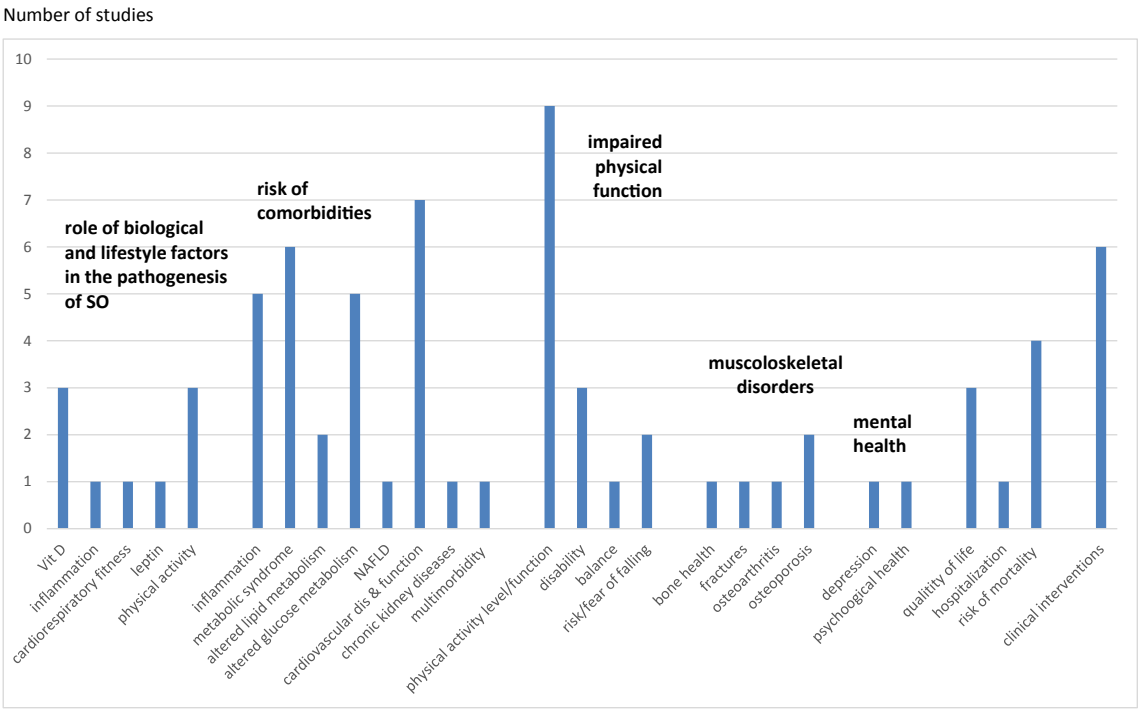

Fig. 2. Abbreviated description of Aims of N = 75 studies included in the analysis. SO: sarcopenic obesity; NAFLD: non-alcoholic fatty liver disease.

- muscle strength measures [hand dynamometry (18 studies) [30,31,36,51–53,55,57,58,69,75,87,91–95,101], maximal knee extensor strength (1 study) [40]];
- measures of physical performance: gait speed [6-min walk test (6MWT) (3 studies) [69,75,101]; 4-m walking test (3 studies) [36,51,93]; 3 m walking test (2 studies) [30,89], 3 m Timed Get Up and Go (1 study) [31], 5 m walking test (2 studies) [55,58], gait-rite (1 study) [53], 10-m walking test [57]];
- bioelectrical impedance analysis (BIA) for the definition of sarcopenia (21 studies) [12,31,35–38,44,48,51,55–57,65,73,74,76–78,84,98,100] and for the assessment of excess adiposity (12 studies) [31,37,38,51,55–57,65,74,77,84,98]; - computed tomography scan (CT) for the definition of sarcopenia (5 studies) [43,63,70,86,94] and for the assessment of excess adiposity (6 studies) [44,60,63,70,94,96].

4.5. Quality assessment

The average score obtained from the application of the Newcastle–Ottawa scale (Table 5) was 8.3 (range: 6–10). All studies employed validated measurement procedures, provided a clear description of assessment of the outcome and appropriately described the statistical approaches used to analyze the data. The majority of studies adopted effective sampling strategies to enhance the representativeness of the study population, the analysis controlled for both the most important factor and for confounding factors.

5. Discussion

Although the term sarcopenic obesity has been widely used and the electronic search retrieved 2335 papers, the main result of this systematic review was the demonstration of the marked heterogeneity in definitions and approaches to diagnose sarcopenic obesity. Therefore, despite mounting awareness of its pathophysiological and clinical relevance, clinical research on sarcopenic obesity has been performed using markedly heterogeneous approaches for both definition and diagnostic criteria. This may be due to differences in the definitions of obesity and sarcopenia, in the methodologies used to assess body composition and physical function, and in the reference values for the variables that have been used (different cut-offs, interquartile analysis, diverse statistical stratification methods). In regards to the choice of the methodologies that have been adopted in sarcopenic obesity diagnosis, the variability may be attributable, at least partially, to the availability of procedures in different settings, to the variability in specialties and backgrounds of the researchers who worked in this field, and the different settings where studies were performed. Such a relevant heterogeneity prevents the authors from drawing firm conclusions for the phenotypical diagnosis of sarcopenic obesity at the clinical and functional levels. The present systematic review, in fact, poses more questions than those which it can answer.

1) How to define and diagnose sarcopenic obesity - role of skeletal muscle function and of different measures of obesity

For diagnosis of both obesity and sarcopenia, variable phenotypical components and criteria have been employed in analyzed papers. Ensuing variability represents a primary hurdle for clinical approaches to sarcopenic obesity.

SARCOPENIA: SKELETAL MUSCLE MASS AND FUNCTION: Although the term sarcopenia literally refers to lack of flesh (low muscle mass), from its inception it named a condition of low muscle mass and impaired function. Nevertheless, it has been used widely to define low skeletal muscle mass with no functional evaluation. Widely accepted definitions and diagnostic algorithms for sarcopenia proposed by the geriatrics, nutrition and cachexia scientific communities [102], however, notably require coexistence of both low skeletal muscle mass and function for diagnosis. In a recent consensus statement, the European Working Group on

Table 3
Parameters considered in the different studies to define sarcopenia and obesity.

Sarcopenia		Obesity	
Parameter	N° of studies	Parameters	N° of studies
ASM/Wt	20	BMI	23
ASM/h^2	18	FM	19
ASM/h^2 plus GS or HGS (EWGSOP criteria)	7	WC	10
ASM/h^2 or ASM/Wt	3	VFA	4
FFMI	2	BMI or FM	3
MM (calculated with MAMC) plus GS or HGS	1	BMI or WC	2
ASM	1	FMI	2
ASM/h^2 and GS (IWGS criteria)	1	BMI and VFA	1
HGS	1	BMI, FM, WC, FMI	1
ASM/h^2 and ASM/Wt	1	FM or WC	1
ASM/h^2 or GS or HGS	1		
Thigh muscle CSA/Wt	1		
Thigh muscle CSA	1		
ALM or ALM/BMI ratio	1		
ALM/BMI plus HGS	1		
ALM/BMI plus HGS or GS	1		
ALM/BMI plus HGS (FNIH definition) and ALM/h^2 plus HGS or GS (EWGSOP definition)	1		
calf CSA	1		
MMI	1		
SMI plus HGS or GS (EWGSOP criteria) and SMI plus GS (IWGS criteria)	1		
TMM	1		

ALM = appendicular lean mass (kg); ASM = appendicular skeletal mass (kg); BMI = body mass index; CSA = cross sectional area (cm^2); FFMI = fat free mass index; FM = fat mass (%); FMI = fat mass index; GS = gait speed (m/s); h = height; HGS = hand grip strength (kg); MM: muscle mass (kg); MAMC = mid-upper arm muscle circumference (cm); SMI = skeletal mass index; VFA = visceral fat area (cm^2); WC = waist circumference (cm); Wt = weight (Kg); TMM = Total Muscle Mass (kg).

Sarcopenia in Older People (EWGSOP) further suggested that functional parameters should become increasingly relevant to diagnose sarcopenia in older adults [3]. This suggestion appears to stem from the well-established lack of consistent associations between skeletal muscle mass and function, whereas impaired functional status retains an obvious independent clinical value and prognostic impact in these population. In fact, all methods used for the measurement/estimation of skeletal muscle mass (anthropometry, DXA, BIA) have shown major limitations. Additionally, lean mass assessed with these methods may not be strongly related with functional or other clinical relevant outcomes [6], although more recent and promising procedures (e.g. D_3-creatine dilution) may show a better association with functional impairment or clinical consequences [103,104]. Finally, low muscle mass is also part of the definition of malnutrition and cachexia, so this finding is not specific of sarcopenia [14,102].

The current systematic review, however, demonstrated lack of systematic approaches to these fundamental issues in the available literature: the vast majority of papers indeed utilized muscle mass surrogates, with very limited use of functional parameters. With regards to the analysis of body composition, different compartments were measured (FFM, appendicular lean mass, ASM) and diverse terms were used to define sarcopenia (reduced FFM, lean mass, ASM). In addition, even the most utilized parameter, ASM, has been used with different normalization factors. Based on commonly accepted requirement of both skeletal muscle mass and function impairment to define sarcopenia in aging (primary sarcopenia), the terms sarcopenic obesity would become highly questionable when functional parameters are missing; myopenic obesity would become more appropriate, thereby leading to a potential terminology issue. The above inconsistencies clearly represent a limitations for clinical applicability of the sarcopenic obesity concept.

OBESITY: Most articles defined and stratified obesity based on BMI values, most likely for its simple evaluation and wide utilization. FM was, however, employed in a number of studies implementing body composition analysis techniques, and WC was selected in studies supporting the assumption that excess visceral abdominal adiposity may directly contribute to low muscle mass and function through related metabolic derangements. In fact, obesity is linked with adverse outcomes both from a clinical and a functional point of view. Also importantly, awareness of the inadequacy of body mass parameters is also emerging in the obesity community, leading to an increasingly endorsement of composite clinical tools to define and stratify patient risk and prognosis. This includes functional status (e.g. disability level) [105] that might be *per se* considered a surrogate for risk or presence of low muscle mass and-or function [106,107]. Clearly, such discrepancies should be addressed in future studies and consensus statements.

2) How to define and diagnose sarcopenic obesity: diagnostic criteria based on a single (or composite) parameter vs separate obesity and sarcopenia criteria

One important question is whether sarcopenic obesity is the coexistence of two distinct diseases that can be individually assessed in a given individual, or whether low skeletal muscle mass and higher FM interact synergistically to determine a clinical phenotype with its own specific identity. In the latter scenario, diagnostic procedures that concomitantly evaluate both body composition parameters would be needed (e.g. the ratio between FM and FFM). Since the amount of skeletal muscle mass that defines sarcopenia may be different in obese compared to non-obese persons, relative measures including both muscle and fat compartments could better define sarcopenic obesity. It should however be pointed out that only a minority of studies selected in the present systematic review have employed unified parameters with both fat and muscle measurements related in a single criterion. Among available examples, studies conducted by Siervo et al. [6,108] have shown that the ratio of visceral FM/ASMI is a better predictor of mortality and diabetes risk compared to the more simple FM/FFM ratio. Similar results were found in the K-NHANES and the sarcopenic obesity cohorts in East Asia, where visceral adipose tissue and thigh muscle ratios from CT scans were used [63,70].

Conversely, it is more complex to envision single composite parameters also including skeletal muscle function, and the use of separate diagnostic criteria for sarcopenia and obesity could allow to better differentiate different degrees of individual body composition disturbances and, potentially, their association with functional impairment.

It should be finally pointed out that the definition of true predictive capacity for any given outcome needs a proper risk prediction approach in large and prospective cohorts. Moreover, it is important to consider that parameters must be derived in the same population and possibly externally validated at least once in an independent cohort.

3) What are reference cut-offs for body composition and functional parameters

Body composition is affected by ethnicity and sex. On the one hand, setting specific reference values for different age groups and populations belonging to different ethnic groups is, therefore, a necessity and would increase the accuracy and reliability of

Table 4
Cut-points considered in the papers included in the systematic review for the definition of sarcopenia and obesity.

	Diagnostic Criteria (cut-points)	
	Sarcopenia	Obesity
Aggio DA et al. (2016) [30]	lowest two-fifths of the MAMC distribution plus HGS <30 kg or GS ≤ 0.8 m/s	WC > 102 cm
Aibar-Almazán A et al. (2018) [31]	ASM/h^2 < 6.42 kg/m^2 plus HGS < 20 kg or GS < 0.8 m/s	FM > 35%
An KO et al. (2016) [32]	SMI 1 SD below the mean of a young population reference group (<30.1% M and 21.2% F)	WC sex-specific cutoff point for Asians (≥90 cm M and 80 cm F)
Atkins JL et al. (2014) [33]	lowest two-fifths of the FFMI (≤16.7 kg/m^2)	those above the percentile point of FMI corresponding to the WC obesity cutoff (28.7th percentile) (>11.1 kg/m^2)
Baek J et al. (2013) [34]	ASM/h^2 or ASM/Wt 1 SD below the mean of the young reference group	BMI ≥ 25 kg/m^2
Baek SJ et al. (2014) [35]	ASM/h^2 ≤ 2 SD below reference values from young (10.7 kg/m^2 M and 8.6 kg/m^2 F)	BMI > 25 kg/m^2
Bahat G et al. (2018) [51]	SMI < 9.2 kg/m^2 M, 7.4 kg/m^2 F and HGS < 22 kg F, <32 kg M or GS < 0.8 m/s	FM above 60th percentile or BMI ≥ 30 kg/m^2
Balachandran A et al. (2014) [36]	ASM/h^2 < 10.76 kg/m^2 M, 6.76 kg/m^2 F plus GS < 1 m/s or HGS < 30 kg M and <20 kg F	BMI > 30 kg/m^2
Batsis JA et al. (2013) [37]	8 different definitions: 1)ASM/h^2: <7.26 kg/m^2 M, < 5.45 kg/m^2 F; 2) Total body skeletal mass/m^2 < 9.12 kg/m^2 M– 6.53 kg/m^2 F; 3) Total body skeletal mass/h^2: <5.7 kg/m^2 F; 4) ASM/h^2: <8.51–6.29 kg/m^2 M; 5) ASM/body mass%: <25.7% M, < 19.4% F; 6) ASM/h^2: <7.4–5.14 kg/m^2 M; 7) Total skeletal muscle mass/Wt: < 30.7%; 8) ASM/h^2: <8.81 kg/m^2 M, <7.36 kg/m^2 F	6 different definitions:1) FM > 27% M, 38% F; 2) FM > 37.16% M, 40.01% F; 3) FM: > 42.9% F; 4) FM > 28% M, 35% F; 5) WC: > 102 cm M, 88 cm F; 6) FM: > 20.7% M, 31.7% F
Batsis JA et al. (2014) [38]	SMI (ASM/h^2). M: class I: 8.51–10.75 kg/m^2; class II: ⩽8.50 kg/m^2; F: class I: 5.76–6.75 kg/m^2; class II: ⩽5.75 kg/m^2	FM ⩾ 27% M and ⩾ 38% F
Batsis JA et al. (2015) [39]	ALM <19.75 kg M and <15.02 kg F OR ALM/BMI ratio <0.789 M and <0.512 F	FM > 25% M and 35% F
Batsis JA et al. (2016) [40]	Dynapenia: knee extensor strenght in the lowest tertile (M: 365.8 –458.2 N; F 235.3–304.1 N)	BMI ≥ 30 kg/m^2
Biolo G et al. (2015) [41]	SO: FM/FFM RATIO > 0,8	
Bouchard DR et al. (2009) [42]	ASMI 2 SD below the mean of a cohort of young adults (<6.29 kg/m^2 F and <8.51 kg/m^2 M)	FM ≥ 35% F and ≥28% M
Cesari M et al. (2009) [43]	calf CSA in the lowest tertile	BMI>30 kg/m^2
Chen HT et al. (2017) [44]	ASM/Wt ≤ 32,5 M, ≤25,7 F	BMI ≥ 25 kg/cm^2 and VFA ≥ 100 cm^2
Cho Y et al. (2015) [45]	ASM/Wt < 23,8% F, <30,3% M (<1 SD below the mean value of the reference group)	WC ≥ 90 cm M, ≥ 85 cm F
Chung JH et al. (2016) [46]	ASM/h^2 < 7,26 kg/m^2 M, <5,45 kg/m^2 F (<2 SDs below the sex-specific mean of a young reference group)	FM >30% M, >40% F
Chung JY et al. (2013) [47]	ASM/Wt < 32,5% M, <25,7% F (1 SD below the mean of a reference group)	BMI ≥ 25 kg/m^2
De Rosa E et al. (2015) [48]	MODERATE (between 1 and 2 SD) SMI 8.44–9.53 kg/m^2 and SEVERE (below 2 SD) SMI ≤8.43 kg/m^2 M, MODERATE SMI 6.49–7.32 kg/m^2 and SEVERE SMI ≤6.48 kg/m^2 F	BMI ≥ 30 kg/m^2
Domiciano DS et al. (2013) [49]	SMI < 5,45 kg/m^2 F	BMI ≥ 30 kg/m^2
dos Santos EP et al. (2014) [50]	Sarcopenia: SMI < 5,45 kg/m^2 F; SO: the residual values of a regression equation that predicts AFFM based on height (m) and FM (kg). The equation: predicted AFFM = 14.529 + (17.989 × h) + (0.1307 × FM). The cutoff value corresponds to a residual ≤3.4	
Hamer M et al. (2017) [52]	SO: BMI >30 kg/m^2 in the lowest tertile of sex-specific HGS (35.3 kg M and 19.6 kg F)	
Huo YR et al. (2016) [53]	ALM/h^2 < 5.5 kg/m^2 F and <7.26 kg/m^2 M plus GS < 80 cm/s or HGS <20 kg F and <30 kg M	BMI ≥ 30 kg/m^2
Hwang B et al. (2012) [54]	ASM/Wt 2 SD below mean value of sex-specific young normal people (29.53% M and 23.20% F)	WC ≥ 90 cm M and ≥85 cm F
Ishii S et al. (2016) [55]	ASM/h^2 2 SD below the mean values of young reference groups (<7.0 kg/m^2 M, < 5.8 kg/m^2 F) plus HGS < 30 kg M, < 20 kg F or GS < 1,26 m/s M and F	FM% in the highest quintile (cutoff values: 29.7% M, 37.2% F)
Joppa P et al. (2016) [56]	FFMI < 10th percentile of the reference values	FMI ≥ 90th percentile of the reference values
Kemmler W et al. (2016) [57]	EWSGOP: ASM/h^2 ≤ 5.45 kg/m^2 plus GS ≤ 0,8 m/s or HGS at <20 kg; IWGS: GS ≤ 1.0 m/s, and ASM/h^2 in the lowest quintile	BMI ≥ 30 kg/m^2 and FM ≥ 35%
Kim H et al. (2016) [58]	SMI < 5,67 kg/m^2 or HGS < 17.0 kg or GS < 1.0 m/s	FM ≥ 32%
Kim JH et al. (2015) [59]	ASM/Wt < 1 sd below the mean of the sex-specific healthy reference group. Cutoff point 31.30% M and 24.76% F	BMI ≥25 kg/m^2
Kim TN et al. (2014) [60]	ASM/h^2 < 7,50 kg/m^2 M, <5,38 kg/m^2 F or ASM/Wt < 32,2% M, <25,6% F (<1SD below mean of young reference group)	WC > 90 cm M, >85 cm F
Kim TN et al. (2009) [24]	ASM < 7,40 kg/m^2 M, < 5,14 kg/m^2 F (2 DS below the sex-specific normal mean of a reference group). 4 differents groups: 1) normal body fat and muscle mass, 2) sarcopenia, 3) obesity, 4) SO	FM > 20,21% M, 31,71% F (upper two quintiles)
Kim YS et al. (2012) [61]	ASM/Wt < 29,5% M, < 23,2% F (<2 SD of young reference population)	BMI ≥ 27.5 kg/m^2
Kim MK et al. (2011) [62]	SMI < 36,3% M, < 28,5% F (1 SD below the sex-specific mean value for a young reference group)	VFA ≥100 cm^2 F, ≥130 cm^2 M
Kohara K et al. (2011) [63]	tight CSA/Wt < 1SD below young reference group (<1,9 cm^2/kg M, <1,6 cm^2/kg F)	VFA >100 cm^2
Kwon SS et al. (2017) [64]	ASM/Wt < 30,98 M, <24,81 F (- 1 SD below the mean of a reference group)	BMI ≥ 25 kg/m^2

Table 4 (*continued*)

	Diagnostic Criteria (cut-points)	
	Sarcopenia	Obesity
Lee J et al. (2016) [65]	ASM/Wt. Class I between 42,9−38,2% M, between 35,6−32,2% F (between 1 and 2 SD of young reference group); Class II < 38,2% M, <32,2% F (below 2 SD); SO was defined as class II sarcopenia plus obesity	FM > 25.8% M and 36.5% F (2 highest quintiles)
Lee S et al. (2012) [66]	ASM/Wt < 26,8% M, <21% F (<2SD of mean in a young reference group)	BMI ≥ 27.5 kg/m^2
Lee YH et al. (2015) [67]	SMI ≤ 32.2% M and ≤25.5% F (<1 SD below mean sex-especific reference group)	BMI ≥ 25 kg/m^2
Levine ME et al. (2012) [68]	ASM < 25.72% M and 19.43% F (<2 SD below the mean of a young reference group)	WC > 102 cm M, >88 cm F
Liao CD et al. (2017) [69]	SMI < 7.15 kg/m^2 plus HGS < 14.3 kg or GS < 1.0 m/s	FM >38%
Lim KI et al. (2010) [70]	ASM/h^2 < 7.0 kg/m^2 M, <5.4 kg/m^2 F, HGS <26 kg M, <18 kg F, GS < 0.8 m/s	WC > 90 cm M, > 85 cm F
Lim JP et al. (2015) [71]	VFA/TMA Median higher 50th percentile (0,90 F and 0,93 M)	
Lim S et al. (2010) [72]	ASM/h^2 < 7.09 kg/m^2 in M, < 5.27 kg/m^2 in F and ASM/Wt < 29.9% in M and 25.1% in F (1 SD below the sex-specific mean for a young reference group)	VFA >100 cm^2
Lu CW et al. (2013) [73]	SMI <37% M, <27.6% F	BMI ≥ 25 kg/m^2
Marini E et al. (2012) [74]	SMI < 7.26 kg/m^2 M, <5.45 kg/m^2 F	FM > 27% M, > 38% F
Meng P et al. (2014) [75]	SMI% < 28.0% M plus GS ≤ 0.8 m/s or HGS < 22.4 kg M	BMI > 27.5 kg/m^2
Moreira MA et al. (2016) [76]	SMI < 6.08 kg/m^2 (<20th percentile of the sample)	WC ≥ 88 cm
Muñoz-Arribas A et al. (2013) [77]	total muscle mass ≤ 8.11 kg M, ≤ 5.80 kg F (2 lowest quintile)	FM ≥ 33.08% M, ≥43.91% F (2 highest quintile)
Muscariello E et al. (2016) [78]	Class I: Muscle mass index (MMI) < 8.3 kg/m$^{2;}$ Class II: < 7,3 kg/m^2 (if BMI ≥30 kg/m^2); Class I: MMI < 7,4 kg/m$^{2;}$ Class II < 6,8 (if BMI < 25 kg/m^2) (2 standard deviations below the mean of the reference group)	BMI ≥30 kg/m^2
Oh C et al. (2017) [79]	ASM/Wt 1 SD below the mean value of a reference group	BMI ≥ 25 kg/m^2
Oh C. et al. (2015) [80]	ASM/Wt < 44% M, 52% F (less than 1 SD below the mean of a reference sample)	BMI ≥ 25 kg/m^2
Oliveira RJ et al. (2011) [81]	Sarcopenia: FFM ≤ 2 SD of the mean of the reference sample consisting of young woman; SO: the residual values of a regression equation that predicts AFFM based on h (m) and FM (kg). The equation: predicted AFFM = −14.529 + (17.989 × h) + (0.1307 × FM). The cutoff value corresponds to a residual ≤3.4	
Park SH et al. (2013) [83]	ASM/Wt < 29,5% M, <23,2% F	WC ≥ 90 cm M, ≥ 85 cm F
Pedrero-Chamizo R et al. (2015) [84]	RMM < 6,20% F, <8,62% M (lower 2 quintiles) 4 Groups: 1)Normal, 2) Obesity, 3)Sarcopenia, 4)SO.	FM > 40,90% F, > 30,33% M (upper 2 quintiles of the reference group).
Perna S et al. (2017) [82]	SMI (ASM/h^2) below the 5th centile for age- and gender-matched healthy subjects	FM > 38% F, > 27% M
Poggiogalle E et al. (2016) [85]	ASMM/h^2 < 6.54 kg/m^2 M, < 4.82 kg/m^2 F or ASMM/Wt < 0.2827 M, <0.2347 F (<2 SD than the sex-specific mean of a young population)	BMI ≥ 30 kg/m^2
Prado CM et al. (2014) [5]	4 specific body-composition phenotypes: 1)LA-HM (low adiposity hight muscle: ASMI 50−100 kg/m^2; FMI 0−49,99 kg/m^2); 2)HA-HI (high adiposity high muscle: ASMI 50−100 kg/m^2; FMI 50−100 kg/m^2); 3) LA-LM (low adiposity low muscle: ASMI 0−49.99 kg/m^2; FMI: 0−49,99 kg/m^2); 4) HA-LM (high adiposity low muscle ASMI 0−49,99 kg/m^2; FMI: 50−100 kg/m^2). The HA-LM cutoffs were as follows: class I (ASMI: 40−49.99 kg/m^2; FMI: 60−100 kg/m^2), class II (ASMI: 20−39.99 kg/m^2; FMI: 80−100 kg/m^2), and class III (ASMI: 0−19.99 kg/m^2; FMI: 80−100 kg/m^2).	4 specific body-composition phenotypes: 1)LA-HM (low adiposity hight muscle: ASMI 50−100 kg/m^2; FMI 0−49,99 kg/m^2); 2)HA-HI (high adiposity high muscle: ASMI 50−100 kg/m^2; FMI 50−100 kg/m^2); 3) LA-LM (low adiposity low muscle: ASMI 0−49.99 kg/m^2; FMI: 0−49,99 kg/m^2); 4) HA-LM (high adiposity low muscle ASMI 0−49,99 kg/m^2; FMI: 50−100 kg/m^2). The HA-LM cutoffs were as follows: class I (ASMI: 40−49.99 kg/m^2; FMI: 60−100 kg/m^2), class II (ASMI: 20−39.99 kg/m^2; FMI: 80−100 kg/m^2), and class III (ASMI: 0−19.99 kg/m^2; FMI: 80−100 kg/m^2).
Ramachandran R et al. (2012) [86]	adjusted thigh muscle area <93,8 cm^2 F, < 110,7 cm^2 M (lowest sex-specific tertile); 8 different groups	BMI > 27 kg/m^2; WC > 88 cm F, > 102 cm M
Rolland Y et al. (2009) [12]	ASM/h^2 < 5,45 kg/m^2 F (<2 SD below young ref group from Rosetta study)	FM% > 60th percentile
Rossi AP et al. (2017) [87]	Dynapenia: HGS < 33 kg M, < 19 kg F (lowest tertile)	WC > 99 cm M, 95 cm F
Ryu M et al. (2013) [88]	ASM/Wt < 2 SD	WC ≥ 90 cm for M and ≥85 cm for F
Santos VRD et al. (2017) [89]	ALM/h^2 < 7.59 kg/m^2 M and 5.57 kg/m^2 F (2 SD below the mean of a reference group) + GS < 0.8 m/s	FM% > 60th percentile (34.1 M and 44.2% F)
Santos VRD et al. (2017) [90]	SMI < 7.59 kg/m^2 M and 5.57 kg/m^2 F (2 SD below the mean of a reference group)	FM%>27% M and 38% F
Schrager et al. (2007) [91]	HGS in lowest tertiles: < 33 kg M and 19 kg F	GLOBAL = BMI>30 kg/m^2, CENTRAL=WC in upper sex specific tertile (>98 M and 95 F)
Scott D et al. (2016) [92]	Sarcopenia: ASM in the lowest sex-specific tertile (M ≤ 1.09; F ≤ 0.92); Dynapenia: the lowest sex-specific tertile for lower-limb muscle strength (M ≤ 112 kg; F ≤ 47.5 kg)	highest sex-specific tertile for FM (M > 27.02 kg, F > 32.83 kg)
Scott D et al. (2017) [93]	EWGSOP: ALM/h^2 < 7.25 kg/m^2 plus HGS <30 kg or GS < 0.8 m/s; FNIH = ALM/BMI <0.789 plus HGS <26 kg	FM > 30%
Scott, D et al. (2018) [94]	ALM/BMI < 0.789 M, <0.512 F plus HGS <26 kg M, <16 kg F	BMI≥30 kg/m^2, FM%≥ 30 M, ≥ 40 F
Sénéchal M et al. (2012) [95]	Dynapenia: Lowest Leg Muscle strength tertile (M: 31.0 ± 8.4 Nm; F: 21.0 ± 5.3 Nm)	Sex- and Ethnicity-Specific WC cutoffs
Seo JA et al. (2012) [96]	ASM/h^2 < 1 SD below the sex-specific mean of a young reference group (<6.75 kg/m^2 M and <4.96 kg/m^2 F)	VFA ≥ 100 cm^2

(*continued on next page*)

Table 4 (*continued*)

	Diagnostic Criteria (cut-points)	
	Sarcopenia	Obesity
Sharma D et al. (2014) [97]	ASMI < 5.45 kg/m^2 F and <7.26 kg/m^2 M (2 SD below the sex-specific means for a reference group)	BMI > 30 kg/m^2
Siervo M et al. (2012) [98]	SMI < 6,76 kg/m^2 (2 SD below the means of a reference group)	BMI ≥ 30.0 kg/m^2, WC > 88.0 cm, FM% ≥ 35.0%, FMI ≥ 9.5 kg/m^2
Silva Neto LS et al. (2012) [99]	The prediction equation for AFFM was: AFFM = −14.529 + (17.989 × h) + (0.1307 × FM). The cutoff point corresponded to a residual value (the measured AFFM minus the AFFM predicted by the equation) ≤−3.4 (≤2 SD from the mean of the reference group). Who showed a residual value ≤ −3.4 was classified as having inadequate FFM for their body area, which indicates sarcopenic obesity	
Srikanthan P et al. (2010) [100]	SMI < 2 SD below the sex specific (31.0% M, 22.0% F)	BMI > 30 kg/m^2
Tyrovolas S et al. (2015) [101]	ASM/BMI in the lowest quintile (differents cut off for contry) plus GS in lowest quintile or HGS < 30 kg M, <20 kg F	BMI ≥ 30 kg/m^2

M = Male; F = Female; SO = Sarcopenic Obesity BMI = Body Mass Index; FM = Fat Mass; FFM = Fat Free Mass: FFMI = Fat Free Mass Index; FMI = Fat Mass Index = FM/h^2; HGS = Hand Grip Strenght; GS = Gait Speed; WC = Waist Circumference; ALM = Appendicular Lean Mass; ASM = Appendicular Skeletal Muscle Mass; AFFM = Appendicular Fat Free Mass; SMI = Skeletal Muscle Mass Index; ASMI = Appendicular Muscle Mass Index; VFA = Visceral Fat Area; CSA = Cross Sectional Area; ABSI = A Body Shape Index (WC/(BMI^2/3 × height^1/2)); NAFLD = Nonalcoholic Fatty Liver Disease; CKD = Cronic Kidney Disease; QoL = Quality of Life; AWSG = Asian Working Group for Sarcopenia.

Table 5
Quality assessment of the papers included in the systematic review [Modesti Pa et al. Plos One 2016 [29]].

	Selection (0–5 stars)	Comparability (0–2 stars)	Outcome (0–3 stars)	Total score
Aggio DA et al. (2016) [30]	4	2	3	9
Aibar-Almazán A et al. (2018) [31]	3	2	3	8
An KO et al. (2016) [32]	4	2	3	9
Atkins JL et al.. (2014) [33]	4	2	3	9
Baek J et al. (2013) [34]	2	2	3	7
Baek SJ et al. (2014) [35]	4	2	3	9
Bahat G et al. (2018) [51]	2	2	3	7
Balachandran A et al. (2014) [36]	4	2	3	9
Batsis JA et al. (2013) [37]	4	2	3	9
Batsis JA et al. (2014) [38]	4	2	3	9
Batsis JA et al. (2015) [39]	2	2	3	7
Batsis JA et al. (2016) [40]	4	2	3	9
Biolo G et al. (2015) [41]	4	2	3	9
Bouchard DR et al. (2009) [42]	4	2	3	9
Cesari M et al. (2009) [43]	2	2	3	7
Chen HT et al. (2017) [44]	4	2	3	9
Cho Y et al. (2015) [45]	4	2	3	9
Chung JH et al. (2016) [46]	4	2	3	9
Chung JY et al. (2013) [47]	2	1	3	6
De Rosa E et al. (2015) [48]	2	2	3	7
Domiciano DS et al. (2013) [49]	2	2	3	7
dos Santos EP et al. (2014) [50]	2	1	3	6
Hamer M et al. (2017) [52]	5	2	3	10
Huo YR et al. (2016) [53]	5	1	3	9
Hwang B et al. (2012) [54]	5	2	3	10
Ishii S et al. (2016) [55]	5	2	3	10
Joppa P et al. (2016) [56]	5	2	3	10
Kemmler W et al. (2016) [57]	5	2	3	10
Kim H et al. (2016) [58]	4	2	3	9
Kim JH et al. (2015) [59]	5	2	3	10
Kim TN et al. (2014) [60]	3	2	3	8
Kim TN et al. (2009) [24]	5	2	3	10
Kim YS et al. (2012) [61]	5	2	3	10
Kim MK et al. (2011) [62]	2	2	3	7
Kohara K et al. (2011) [63]	5	2	3	10
Kwon SS et al. (2017) [64]	2	1	3	6
Lee J et al. (2016) [65]	5	2	3	10
Lee S et al. (2012) [66]	5	2	3	10
Lee YH et al. (2015) [67]	5	2	3	10
Levine ME et al. (2012) [68]	3	1	3	7
Liao CD et al. (2017) [69]	2	1	3	6
Lim KI et al. (2010) [70]	2	1	3	6
Lim JP et al. (2015) [71]	2	1	3	6
Lim S et al. (2010) [72]	2	1	3	6
Lu CW et al. (2013) [73]	3	1	3	7
Marini E et al. (2012) [74]	3	2	3	8
Meng P et al. (2014) [75]	3	1	3	7
Moreira MA et al. (2016) [76]	2	2	3	7

Table 5 (*continued*)

	Selection (0–5 stars)	Comparability (0–2 stars)	Outcome (0–3 stars)	Total score
Muñoz-Arribas A et al. (2013) [77]	3	2	3	8
Muscariello E et al. (2016) [78]	3	2	3	8
Oh C et al. (2017) [79]	5	2	3	10
Oh C. et al. (2015) [80]	3	2	3	8
Oliveira RJ et al. (2011) [81]	3	2	3	8
Park SH et al. (2013) [83]	5	2	3	10
Pedrero-Chamizo R et al. (2015) [84]	5	2	3	10
Perna S et al. (2017) [82]	3	2	3	8
Poggiogalle E et al. (2016) [85]	5	2	3	10
Prado CM et al. (2014) [5]	3	2	3	8
Ramachandran R et al. (2012) [86]	4	2	3	9
Rolland Y et al. (2009) [12]	5	2	3	10
Rossi AP et al. (2017) [87]	5	2	3	10
Ryu M et al. (2013) [88]	2	1	3	6
Santos VRD et al. (2017) [89]	2	1	3	6
Santos VRD et al. (2017) [90]	4	2	3	9
Schrager et al. (2007) [91]	4	2	3	9
Scott D et al. (2016) [92]	5	2	3	10
Scott D et al. (2017) [93]	2	1	3	6
Scott, D et al. (2018) [94]	5	1	3	9
Sénéchal M et al. (2012) [95]	2	2	3	7
Seo JA et al. (2012) [96]	5	1	3	9
Sharma D et al. (2014) [97]	3	1	3	7
Siervo M et al. (2012) [98]	2	1	3	6
Silva Neto LS et al. (2012) [99]	4	2	3	9
Srikanthan P et al. (2010) [100]	3	1	3	7
Tyrovolas S et al. (2015) [101]	5	2	3	10

sarcopenic obesity diagnosis. On the other hand, this would inevitably lead to higher difficulties in consensus procedures and when comparing data collected in different populations and settings. Additionally, age plays a pivotal role in body composition alterations. In geriatric settings, it must be considered whether the reference value to define excess FM or reduced muscle mass is a young (normative population) or a contemporary (coeval) group.

4) Do we need sarcopenic obesity criteria for research or daily clinical practice (or both)?

Methodological variability with different techniques employed also clearly emerged from the current results and strongly contributed to inconsistencies. In sarcopenic obesity research, technologically advanced instruments (e.g. Nuclear Magnetic Resonance - NMR), not usually available in clinical practice, can be used in order to achieve gold-standard, highly accurate assessment of different components of body composition. The situation in clinical practice is obviously different, as easily applicable tools are needed. In the obesity and clinical nutrition field, unlike other areas of medicine, surrogate measurements have been commonly used (e.g. BMI) that have important limitations and are unable to capture abnormalities in body composition, especially those that cause sarcopenic obesity.

From a methodological point of view, a reasonable and rational approach would imply the definition of optimal methods and diagnostic approaches to define sarcopenic obesity in an effort to establish a reference against which, at a later time, simple clinical measurements can be tested for diagnostic sensitivity and specificity. It is conceivable that different approaches could be then recommended with gold standard techniques established for more accurate studies in limited subsets of patients, while acceptable less demanding, clinically reproducible and validated surrogates could be employed for large population studies or routine clinical practice. The issue of consensus on tools of choice for both approaches remains however an unmet priority, and these fundamental questions should be addressed in the near future by experts and clinicians in the field. Since existent epidemiological data, although partially discordant, indicate a high prevalence and clinical and functional consequences of sarcopenic obesity, it is probably appropriate to suggest that relatively sophisticated instruments (e.g. BIA and DXA) should be eventually made more widely available and used to achieve a reliable diagnosis.

5) Role of different clinical factors in the pathogenesis of sarcopenic obesity

Last but certainly not least question, the pathogenesis of sarcopenic obesity is still partially unknown. As also summarized above, aging, inflammation, sedentary lifestyle, complex hormonal and metabolic derangements, genetics all seem to play a role [109,110]. Other clinical factors have been implied (e.g. disability, bariatric surgery without nutritional supervision, long-lasting incongruous dietary regimens) and their role in the pathogenesis of sarcopenic obesity needs to be further investigated. It appears therefore necessary to conduct exploratory association studies, although a consensus on the definition of sarcopenic obesity may be primarily needed since the role of predictors may vary depending on how sarcopenic obesity is operationalized. It seems generally reasonable to hypothesize that sarcopenia in obesity may have different trajectories in terms of natural history when compared to sarcopenia in individuals without obesity: indeed, changes in body compartments are interconnected, as shown by recent review articles by Dulloo et al. [111,112]. As a rule of thumb, evidence suggests that FFM and FM may be subject the so-called “one quarter rule”: for any increment in body fat, a parallel change in FFM occurs, corresponding approximately to 25%. The initial paradigm for sarcopenia proposing an initial decline in skeletal muscle quantity (formerly referred to as presarcopenia) followed by loss of strength and function is currently being questioned [101] and could all the more be less applicable and generalizable for sarcopenic obesity. Moreover, subjects with obesity may present with alterations in glucose metabolism often linked to muscle dysfunction regardless of the loss of FFM. Natural history of

sarcopenia coupled to obesity clearly needs to be further elucidated by future research. An important aspect concerning sarcopenic obesity is weight cycling and body composition trajectory [113] as it may induce repeated FFM loss which is not completely recovered during weight regain in relation to post-restriction metabolic and hormonal alterations during refeeding [114].

5.1. Limitations and strengths

It should be pointed out that the current systematic review has some relevant limitations. Firstly, it included literature from the last ten years. In addition, for the methodological purpose of the current work, that does not address general or disease-specific clinical outcomes, the authors decided to focus on studies in obese individuals in the absence of acute or chronic conditions and treatments reported to negatively influence skeletal muscle mass and function independently of obesity (such as surgery, cancer, kidney disease). We, however, consider this decision not to affect the ability to address the aim of our paper, i.e. to analyze definitions and diagnostic criteria adopted in the literature to investigate sarcopenic obesity. In addition, it should be pointed out that under the current exclusion criteria, the search still resulted in selection of a large number of papers with a large sample of subjects. The latter indeed appears to be a remarkable strength of the current review, as well as the overall high study quality.

6. Conclusions and open questions

In conclusion, the current systematic review demonstrated the profound inadequacy of available research on sarcopenic obesity in terms of consistency of definition, diagnostic criteria and methodological issues. Results indeed do not allow definitive conclusions on the prevalence and relevance of sarcopenic obesity from a clinical and functional standpoint. The above limitations negatively impact general awareness and implementation of the sarcopenic obesity concept. The authors of this systematic review as well as ESPEN, and EASO call for action to reach consensus proposals on 1) definition of sarcopenic obesity 2) diagnostic criteria both at the level of potential gold-standards and acceptable surrogates with wide clinical applicability, with related cut-off values that may importantly need regional differentiation; 3) methodologies to be used in actions 1 and 2. Since pathogenetic mechanisms underlying the onset of sarcopenic obesity are still incompletely understood, efforts towards their elucidation including both clinical and preclinical research will also be needed and likely to improve results of actions 1, 2 and 3. The authors are aware that first steps should be aimed at reaching consensus on plausible proposals that would need subsequent validation based on homogeneous studies and databases, possibly based on analyses of existing cohorts, to help define the prevalence of the condition, its clinical and functional relevance, as well as most effective prevention and treatment strategies.

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Author contribution

LM Donini, L Busetto and R Barazzoni coordinated the study, analyzed the data and wrote the manuscript; E Parrinello collected the data and built the tables; JM Bauer, S Bischoff, Y Boirie, T Cederholm, AJ Cruz-Jentoft, D Dicker, G Frühbeck, A Giustina, MC Gonzalez, HS Han, SB Heymsfield, T Higashiguchi, A Laviano, A Lenzi, E Poggiogalle, CM Prado, J Salvador Rodriguez, Y Rolland, F Santini, M Siervo, F Tecilazich, R Vettor, J Yu, M Zamboni: selected the papers, extracted the data and analyzed the results, reviewed the manuscript.

Conflict of interest

The authors declare no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clnu.2019.11.024.

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