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SYSTEMATIC REVIEW ARTICLE

Association Between Sarcopenic Obesity and Metabolic Syndrome in Adults: A Systematic Review and Meta-Analysis

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Abstract: ***Background*:** In the last two decades, a new phenotype termed Sarcopenic Obesity (SO), in which sarcopenia and obesity coexist, has emerged.

***Objective*:** The aim of this systematic review and meta-analysis was first to assess the prevalence of Metabolic syndrome (Mets) among individuals with and without SO, and second, to determine if SO may increase the relative risk of Mets.

***Methods*:** This study was conducted in adherence to the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines and the data were collated by means of meta-analysis and narrative synthesis.

***Results*:** Twelve studies including a total of 11,308 adults with overweight or obesity of both genders met the inclusion criteria and were reviewed, revealing two main findings. First, a similar overall prevalence of Mets in individuals with SO (61.49%; 95% CI: 52.19-70.40) when compared to those without SO (56.74%; 95% CI: 47.32-65.93) was identified. Second, the presence of SO appears not to increase the risk of Mets with respect to those without SO (RR = 1.08, 95% CI: 0.99-1.17, p = 0.07).

***Conclusion*:** No higher prevalence of Mets among individuals with SO when compared to those with obesity only, nor a significant association between SO and a higher risk of Mets was found.

Keywords: Obesity, overweight, sarcopenia, sarcopenic obesity, metabolic syndrome, reduced lean body mass.

1. INTRODUCTION

A new phenotype characterized by the coexistence of sarcopenia and obesity has been termed as sarcopenic obesity (SO) [1-7]. There is still a debate regarding the negative impact of SO on health outcomes, especially weight-related comorbidities (*i.e.* metabolic and cardiovascular diseases) [5, 6, 8-15], with the speculation that the two components of SO, namely the increase of fat deposition and the reduction in muscle mass and strength, seem to act synergistically to increase the adverse consequences on health, but this hypothesis has not been confirmed [16-18]. For this reason, scientific bodies dealing with obesity, such as the European Society for Clinical Nutrition and Metabolism (ESPEN) and the European Association for the Study of Obesity (EASO), recently invited researchers and health professionals to consider SO a scientific and clinical priority [17].

In the same direction, several studies have been conducted with the aim of assessing the association between SO and Metabolic syndrome (Mets), where some speculates that coexistence of both obesity and sarcopenia under the so-called phenotype "SO", may have a synergistic effect with chronic inflammation being a common "denominator" seen in both conditions, and known to play an important role in the pathogenesis of Mets, to exacerbate further the presence of Mets in individuals affected by SO, rather than obesity alone, however, the findings from these reports appear to be contradictory [12, 19-29]. In addition, to the best of our knowledge, no systematic review on this topic as a primary outcome has yet been conducted in order to provide a clear interpretation of the published literature. For this reason, we aimed to review the available literature in order to determine the prevalence of Mets among adults with SO and whether it significantly exceeds that in individuals with only obesity

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(*i.e*. not sarcopenia). Moreover and in order to extend the scope of this study, we set out to examine whether SO is associated with a higher risk of Mets, in adherence to the PICO statement as follows [30-32].

P - population: individuals in the overweight or obesity category, defined in terms of BMI, body fat percentage, waist circumference criteria [33]; I - individuals recruited from any setting (*i.e*. clinical setting, seeking treatment or from the general population); C - comparison: comparison between individuals SO *vs*. those without SO; O - outcome: (i) SO was, however, defined and assessed by authors using several methods, *i.e*. Computed Tomography (CT), Dual-energy X-ray Absorptiometry (DXA), Bioimpedence Analysis (BIA), 24-hour urinary creatinine excretion, handgrip, dynamometer and gait speed among the entire obesity groups in the two genders; (ii) Mets in the SO and non-SO groups was defined according to one of the following definitions, *i.e*. World Health Organization (WHO), the European Group for the study of Insulin Resistance (EGIR), the National Cholesterol Education Program Adult Treatment Panel III (NCEP: ATP III), the American Association of Clinical Endocrinology (AACE), the International Diabetes Federation (IDF) and the American Heart Association/National Heart, Lung, and Blood Institute (AHA/NHLBI) [34].

2. MATERIALS AND METHODS

The review was prepared in adherence to the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) guidelines [35-37].

2.1. Inclusion and Exclusion Criteria

All studies on SO and Mets in adults of both genders were included if they met the following criteria: (i) written in English language; and (ii) original research with any of the following designs; cross-sectional or longitudinal, prospective, retrospective observational, experimental or quasi-experimental controlled or non-controlled, reporting clearly the prevalence of SO and Mets among their samples. Narrative, clinical and expert reviews or articles such as case reports, editorials, 'Letters to the Editor' and book chapters were excluded.

2.2. Information Source, Search Strategy, Study Selection and Quality Appraisal

The PubMed and Scopus databases were screened using the MeSH term combinations. Moreover, a manual search was used to find papers identified by their titles in the bibliographies of the studies found *via* the initial search strategy. No publication date was considered as an exclusion criterion. The Newcastle-Ottawa Scale (NOS) was used to perform quality appraisal [38]. Briefly, it relies on a nine-star rating system whereby scores of 0-3, 4-6 and 7-9 are considered poor, moderate and good quality, respectively [38].

2.3. Data Collection Process and Data Items and Data Synthesis

An initial assessment in terms of each paper's title and abstract was undertaken to assess the papers' language suitability and subject matter relevance. The selected studies were then checked for suitability for inclusion and the quality of the methodology. The studies that passed both rounds of screening are presented in Table **1**.

The 12 studies that met the inclusion criteria have been presented through a narrative synthesis. In addition, a meta-analysis of the included studies was performed using Med Calc. software [39]. Mantel Haenszel fixed and random effect models were used to estimate the overall effect size and 95% CI. The outcomes of interest for the meta-analysis were the prevalence of Mets and its relative risk with SO as an exposure factor, and the pooled estimate and 95% CI of the prevalence of Mets among patients with or without SO. A heterogeneity measure (I^2), reflecting the percentage of observed total variation across the studies was also calculated.

3. RESULTS

3.1. Narrative Synthesis

Twelve articles were included in the systematic review and underwent narrative synthesis and meta-analysis (Fig. **1**). The Newcastle-Ottawa Scale checklist indicated that the studies were of high quality (n = 12) (mean score = 7.16 points) (Table **2**).

Table 1. Studies included in the systematic review.

Study	Design	Definition of SO	Body Composition	Gender	Sample	Mean Age	Mean BMI	Prevalence SO	Criteria and Prevalence of Mets
Sénéchal *et al*. 2012 [19]	Cross-sectional	DO defined as low leg muscle strength, combined with abdominal obesity	Kin- Com dynamometer	M-F	T= 1963	Non DO: 65.5 ± 9.6 DO: 65.4 ± 9.9	Non DO: 30.8 ± 4.5 DO: 29.9 ± 4.6	DO: N = 566	Mets according to IDF criteria: DO = 183/566 Non DO = 469/1,397
Chung *et al*. 2012 [20]	Cross-sectional	Defined as ASM/Wt. < 1SD (M = 32.5%; F = 25.7%) combined with BMI ≥ 25 kg/m^2	DXA	M-F	T=1003	M = 67.3±6.3 F = 68.7±5.9	M: 27.0 ± 1.6 F: 27.3 ± 2.1	SO: N = 666	Mets according to ATPIII criteria: Non SO = 192/337 SO = 449/666

(Table 1) Contd…

Study	Design	Definition of SO	Body Composition	Gender	Sample	Mean Age	Mean BMI	Prevalence SO	Criteria and Prevalence of Mets
Kim *et al*. 2013 [21]	Cross-sectional	Defined as SMI <1 SD the sex-specific mean value for a young reference group, combined with visceral fat area (VFA) ≥100 cm^2	DXA CT	M-F	T = 279	SO M=57·2 ± 15·3 F=61·1 ± 11·2	SO M: 26·7 ± 3·0kg/m^2 F: 27·0 ± 3·6 kg/m^2	SO: N=110	Mets according to ATPIII criteria: Non SO = 73/169 SO = 53/110
Moon 2013 [22]	Cross-sectional	ASM/Wt. < 1 SD for the mean reference group, and BMI ≥ 27.5kg/m^2	DXA	M-F	T364	SO (among entire sample of N = 444): 59.8 ± 14.3	SO (among entire sample of N = 444): 27.2 ± 3.7	SO: N=100	Mets according to ATPIII criteria: Non SO = 214/264 SO = 71/100 in SO
Baek *et al*. 2013 [12]	Cross-sectional	ASM/Wt. < 1 SD for the mean reference group, and BMI ≥ 25kg/m^2	DXA	M-F	T = 2163	Non SO M = 69.5 + 0.4 F = 71.1 + 0.3 SO M = 71.4 + 0.3 F = 72.6 + 0.3	Non SO M = 26.2 + 0.1 F = 26.7 + 0.1 SO M = 27.1 + 0.1 F = 27.8 + 0.1	SO N=752	Mets according to ATPIII criteria: Non SO = 259/356 SO = 602/752
Baek *et al*. 2013 [12]	Cross-sectional	ASM/ht^2 < 1 SD for the mean reference group, and BMI≥25kg/m^2	DXA	M-F	T = 2163	Non SO M = 70.8 + 0.3 F = 72 + 0.2 SO M = 72.1 + 1.5 F = 73.3 + 1.0	Non SO M = 27 ± 0.1 F = 27.5 ± 0.1 SO M = 26.4 + 0.4 F = 26.9 + 0.9	SO N=62	Mets according to ATPIII criteria: Non SO = 811/1,041 SO = 52/62
Park *et al*. 2013 [23]	Cross-sectional	ASM/wt <2 SD the mean of the reference group, combined with abdominal obesity	DXA	M-F	T = 2384	Not reported, but only WC (cm) NO SO M = 95.2 ± 4.6 F = 87.1 ± 5.9 SO M = 98.7 ± 6.4 F = 93.1 ± 9.1	NO SO M = 46.2 ± 13.4 F = 51.6 ± 15.1 SO M = 51.4 ± 18.1 F = 58.5 ± 15.4	SO N=290	Mets according to ATPIII criteria: Non SO N = 1087 SO N = 204
Choudhary *et al*. 2015 [24]	Cross-sectional	was defined as muscle mass < normal range combined with obesity as BMI > 25 kg/m^2 and visceral fat mass > normal range	BIA	M-F	T = 82	Non-SO: 51.4 ± 16.7 SO: 50.1 ± 9.6	Non-SO: 23.9 ± 4.6 SO: 28.2 ± 3.8	SO N=72	Mets according to ATPIII criteria: Non- SO: N = 2/10 SO: N = 41/72
Poggiogalle *et al*. 2016 [25]	Cross-sectional	Defined by ASMM/h^2 or ASM/wt. <2SD of sex specific mean combined with assessment of FM and FFM.	DXA	M-F	T = 727 M = 141 F = 586	46.49 ± 13.73 46.99 ± 13.76	38.85 ± 5.88 38.84 ± 5.79	SO N = 418	Mets according to ATPIII criteria: Non SO = 106/309 SO = 199/418

(Table 1) Contd…

Study	Design	Definition of SO	Body Composition	Gender	Sample	Mean Age	Mean BMI	Prevalence SO	Criteria and Prevalence of Mets
Ma *et al.* 2016 [26]	Retrospective Cross-sectional	SO: BMI > 30kg/m^2 and 24h-UC < median	Sex-specific 24-h urinary creatinine excretion	M-F	T = 310 M = 144 F = 166	71.8 ± 7.6	34.1 ± 4.0	SO: N = 106	Mets according to ATPIII criteria: Non SO = 128/204 SO =70/106
Kang *et al.* 2017 [27]	Cross-sectional	ASM/wt <1 SD the mean of the reference group, and BMI ≥ 25 Kg/m^2	DXA	F	T=1555	Non SO: 61.05 ± 0.44 SO: 62.91 ± 0.44	Non SO: 26.80 ± 0.07 SO: 27.93 ± 0.11	SO: N = 855/1555	Mets according to ATPIII criteria: Non SO = 411/700 SO = 580/855
Aubertin-Leheudre *et al.* 2017 [28]	Cross-sectional	DO defined as low handgrip strength (≤ 19.9 in females; ≤ 31.9 in males), combined with BMI ≥ 30 Kg/m^2	Jamar Hand-held Dynamometer	M-F	T = 670 M = 213 F = 457	Non SO: 76.3 ± 4.7 SO: 78.0 ± 4.6	Non SO: 35.6 ± 4.8 SO: 34.9 ± 4.8	SO: N = 256	Mets according to ATPIII criteria: Non SO = 284/414 SO = 168/256
Scott *et al.* 2018 [29]	Cross-sectional (includes a longitudinal part)	ALM/ht^2 < 7.26 kg/m^2 combined with handgrip strength < 30 kg and/or low gait speed ≤0.8 m/s. Obesity was defined as body fat percentage ≥ 30%	DXA Handgrip strength Gait speed	M	T = 525	Non SO: 75.9 ± 4.7 SO: 80.3 ± 6.5	Non SO: 30.7 ± 3.4 SO: 27.2 ± 2.3	SO: N = 80	Mets according to ATPIII criteria: Non SO=245/445 SO=30/80

Abbreviations: SO: sarcopenic obesity; DO: dynapenic obesity; BMI: body mass index; Mets: metabolic syndrome; IDF=international diabetes federation; ATPIII= Adult Treatment Panel III; M=male; F=female; T=total; DXA= dual-energy X-ray absorptiometry; CT=Computerized Tomography; BIA= bioimpedence analysis; ASM= appendicular skeletal mass; SMI= skeletal mass index; ALM= appendicular lean mass; Wt= weight; Ht= height; FM= fat mass; FFM= free fat mass.

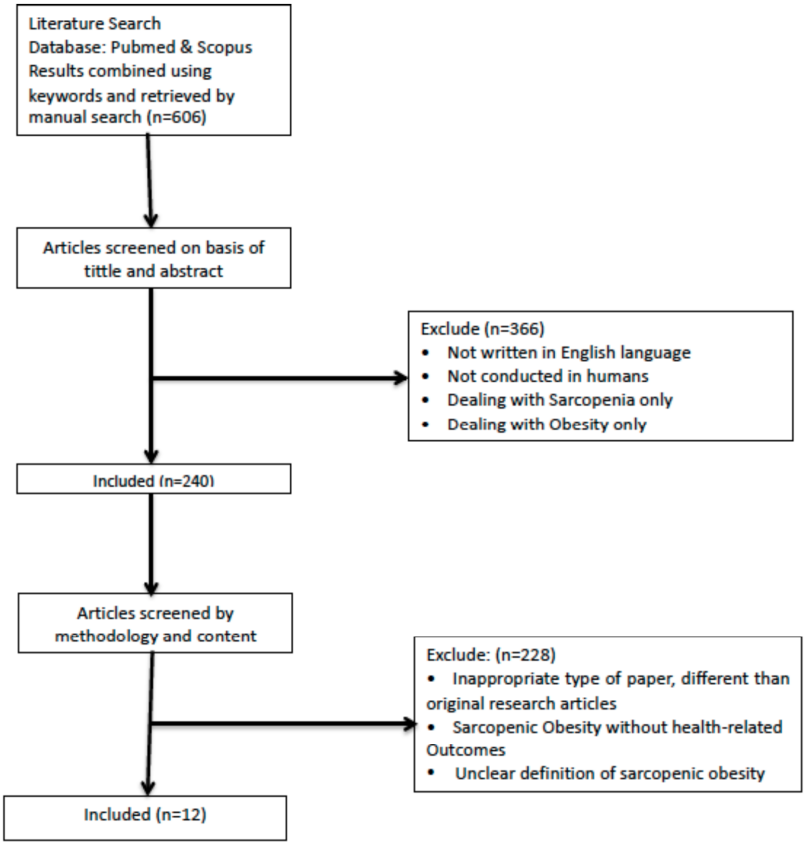

Fig. (1). The flowchart summarizing the study selection procedure.

Table 2. Quality assessment of the included studies.

Study	Sénéchal 2012 [19]	Chung 2012 [20]	Kim 2013 [21]	Moon 2013 [22]	Baek 2013 [12]	Park 2013 [23]	Choudhary 2015 [24]	Poggiogalle 2016 [25]	Ma 2016 [26]	Kang 2017 [27]	Aubertin-Leheudre 2017 [28]	Scott 2018 [29]
Selection												
Represents cases with independent validation	1	1	1	1	1	1	1	1	1	1	1	1
Cases are consecutive or obviously representative	1	1	1	1	1	1	0	1	1	1	1	1
Controls from the community	1	1	1	1	1	1	1	1	1	1	1	1
Controls have no history of SO	1	1	1	1	1	1	1	1	1	1	1	1
Comparability												
Controls are comparable for the most important factors	1	1	1	0	1	1	0	1	1	1	1	1
Control for any additional factor	0	0	0	0	0	0	0	1	0	1	0	0
Ascertainment of Exposure												
Secured record or structured interview where blind to /control status	1	1	1	1	1	1	1	1	1	1	1	1
Same method of ascertainment for cases and controls	1	1	1	1	1	1	1	1	1	1	1	1
Cases and controls have completed follow up	0	0	0	0	0	0	1	0	1	0	0	1
Total score	**7**	**7**	**7**	**6**	**7**	**7**	**6**	**8**	**8**	**8**	**7**	**8**

Newcastle-Ottawa Scale (NOS) for longitudinal and cross-sectional studies. Yes=1, No (not reported, not available) =0; Studies with scores of 0-3,4-6,7-9 were considered as low, moderate and high quality, respectively. SO= sarcopenic obesity.

In 2012, Sénéchal *et al*. [19] performed a cross-sectional evaluation on 1,963 adults with abdominal obesity and those with dynapenic obesity (DO), defined as low leg muscle strength assessed *via* a Kin-Com dynamometer, combined with abdominal obesity. Among the entire sample, 566 had DO and 1,397 did not. The mean age and mean BMI in the DO and non-DO groups were 65.4 ± 9.9 years and 29.9 ± 4.6 kg/m^2 and 65.5 ± 9.6 years and 30.8 ± 4.5 kg/m^2, respectively. Furthermore, 183 out of 566 in DO group had Mets defined according to IDF, compared to the non-DO group in which 469 out of 1,397 had Mets.

In the same year, Chung *et al.* [20] conducted a cross-sectional study to examine the relationship between SO and cardiometabolic risk factors in females and males. This study was conducted by the Korean Ministry of Health and Welfare in Korea. The authors defined SO as the coexistence of appendicular skeletal mass (ASM)/Weight of < 1 SD below the mean of a reference group combined with a BMI of ≥ 25 kg/m^2 using DXA. The sample of 1,003 adults with obesity (335 males and 668 females) had a mean age and mean BMI of 67.3 ± 6.3 years and 27.0 ± 1.6 kg/m^2 for males, in comparison to 68.7 ± 5.9 years and 27.3 ± 2.1 kg/m^2 for females. Moreover, the prevalence of SO in both men and women was 230 out of 1,003 and 436 out of 1,003, respectively. Furthermore, in the SO group, 449 out of 666 had Mets according to the ATP III criteria, while 192 out of 337 individuals had Mets in the non-SO group.

One year later, a cross-sectional study which included 493 adults (180 males and 313 females) enrolled in the Korean Sarcopenic Obesity Study was conducted by Kim *et al*. [21]. Sarcopenic obesity was defined as a combination of a skeletal mass index (SMI) of < 1 SD of a sex-specific mean value for a young reference group and a visceral fat area (VFA) of ≥ 100 cm^2 assessed using DXA and CT, respectively. From the total sample, 279 individuals were classified with obesity *(i.e*., visceral) (138 males and 141 females). Of the 138 males included in the sample, 32 had SO compared to 78 of the 141 females, the mean age and BMI in the SO group were 57.2 ± 15.3 years and 26.7 ± 3.0 kg/m^2 in males and 61.1 ± 11.2 years and 27.0 ± 3.6 kg/m^2 in females. Moreover, 53 of the 110 individuals in the SO group had Mets defined according to ATP III criteria, compared to 73 of the 169 in the non-SO group.

In 2013, Moon [22] performed a cross-sectional study based on the Korea National Health and Nutrition Examination Survey that included 10,432 adults (4,558 males and 5,874 females) aged ≥ 20 years, who underwent body composition measurement using DXA. Sarcopenic obesity was considered to be the coexistence of sarcopenia defined as the ASM divided by weight (%) of <2 SD below the sex-specific mean for young adults and obesity, defined as a BMI of ≥ 27.5 kg/m^2. Data were extractable only for participants with an age of ≥ 60 years, of a total of 364 individuals with obesity, 100 had SO. The prevalence of Mets (according to ATP III criteria) in the non-SO group was 214 out of 264 and 71 out of 100 in the SO group.

In 2013, Baek *et al*. [12] performed a cross-sectional study based on data collected during the 2008-2010 Korea National Health and Nutrition Examination Survey, and included 3,483 (1,466 males and 2,017 females) individuals aged ≥ 65 years. This study used two definitions for sarcopenia: (i) weight-adjusted ASM; and (ii) height-adjusted ASM measured by DXA; and obesity was defined as a BMI of ≥ 25 kg/m^2. Of the entire sample, 1,103 individuals were affected by obesity according to the first definition and 752 had SO, including 602 individuals with Mets (ATP III criteria) and of 356 non-SO patients, 259 had Mets. According to the second definition, 62 had SO, including 52 with Mets and 1,041 had non-SO, including 811 with Mets.

In the same year, Park *et al*. [23] performed a cross-sectional study based on the Korea National Health and Nutrition Examination Survey that included 6,832 (2982 males and 3850 females) aged 19 years and over, using the same approach to body composition assessment by means of DXA, as well as the definition of sarcopenia as an ASM/Wt that was < 2 SD from the mean of a sample of healthy young adults. From the total sample, 2,384 were categorized as having abdominal obesity due to high waist circumference, of whom 290 had SO. Of those 290 with SO, 204 had Mets (according to ATP III criteria) compared to 2,094 with non-SO, of whom 1,087 had Mets.

In 2015, Choudhary *et al*. [24] investigated the association between SO and Mets as a newly recognized entity following living donor liver transplantation in a longitudinal study conducted in India. Sarcopenic obesity was defined as a muscle mass lower than the normal range in combination with a BMI of > 25 kg/m^2 (modified BMI cut-off for Asian Indians) and a greater than normal visceral fat mass as measured by BIA. The total number of individuals with obesity was 82, the mean age and mean BMI of the non-SO group was 51.4 ± 16.7 years and 23.9 ± 4.6 kg/m^2, and it was 50.1 ± 9 .6 years and 28.2 ± 3.8 kg/m^2 in the SO group. The size of the SO group was n = 72. Furthermore, the number of individuals with Mets according to ATP III criteria in the non-SO group was 2 out of 10, while those with SO comprised 41 out of 72.

In early 2016, Poggiogalle *et al*. [25] performed a cross-sectional study in which the authors assessed SO using DXA, with SO defined as the coexistence of obesity (BMI ≥ 30 kg/m^2) and sarcopenia (ASM/$height^2$ < 6.54 and < 4.82 kg/m^2 for males and females, respectively) or (ASM/weight < 0.2827 and < 0.2347 for males and females, respectively). This study enrolled a sample of 727 individuals with obesity (141 males and 586 females), with mean ages of 45.63 ± 13.53 and 45.76 ± 13.58 years, and a mean BMI of 37.56 ± 5.99 and 37.80 ± 5.77 kg/m^2, respectively, for males and females. Of the 141 male patients, 68 had SO, while 350 of the 586 females had the condition. In addition, 199 of the 418 patients had Mets according to ATP III criteria in the SO group, compared to 106 of the 309 patients in the non-SO group.

In the same year, Ma *et al*. [26] conducted a cross-sectional evaluation on SO defined by a BMI of > 30 kg/m^2 and reduced sex-specific 24-hour urinary creatinine excretion in 310 patients (166 females and 144 males) with obesity (BMI ≥ 30 kg/m^2). Fifty-four of the 144 males and 52 of the 166 females had SO. The mean BMI and age of the SO group were 34.1 ± 4.0 kg/m^2 and 71.8 ± 7.6 years, while they were 34.9 ± 4.4 kg/m^2 and 67.8 ± 6.8 years in the non-SO group, respectively. Furthermore, 70 of the 106 patients had Mets (according to ATP III criteria) in the SO group, in comparison to 128 of the 204 patients in the non-SO group.

In 2017, Kang *et al*. [27] assessed the association between SO and Mets in postmenopausal women through a large cross-sectional study. Sarcopenic obesity was defined as the coexistence of sarcopenia (ASM/weight < 1 SD below the mean of the reference group assessed by DXA) and a BMI cut-off point for obesity which referred to a score of ≥ 25 kg/m^2 on the basis of the Asia-Pacific obesity criterion. The study included 1,555 females with obesity, of whom 855 had SO, with a mean age of 62.91 ± 0.44 years and a mean BMI of 27.93 ± 0.11 kg/m^2, while 700 did not have SO and had a mean age of 61.05 ± 0.44 years and a mean BMI of 26.80 ± 0.07 kg/m^2. Five hundred and eighty of the 855 patients had Mets (according to ATP III criteria) in the SO group, while 411 of the 700 patients in the non-SO group had Mets.

In the same year, a cross-sectional study by Aubertin-Leheudre *et al*. [28] aimed to examine the association between DO and metabolic risk factors in older adults (age ≥ 70 years). Dynapenic obesity was defined as low handgrip strength (≤ 19.9 in females; ≤ 31.9 in males) combined with a BMI of ≥ 30 kg/m^2. The study included 670 participants with obesity (213 males and 457 females), of whom 256 had DO, with a mean age of 78.0 ± 4.6 years and a mean BMI of 34.9 ± 4.8 kg/m^2, and 414 did not have DO, with a mean age of 76.3 ± 4.7 years and a mean BMI of 35.6 ± 4.8 kg/m^2.

Furthermore, 168 of the 256 individuals in the DO group had Mets (according to ATP III criteria), while 284 of 414 individuals in the non-DO group had Mets.

Finally, in 2018, Scott *et al*. [29] investigated the cross-sectional association between SO and components of Mets in a large sample study of community-dwelling older men. Sarcopenic obesity was defined by the coexistence of sarcopenia as an appendicular lean mass (ALM)/height of < 7.26 kg/m^2 measured by DXA combined with a handgrip strength of < 30 kg and/or a low gait speed of ≤ 0.8 m/s, while obesity was defined as a body fat percentage of ≥ 30%. The study included 525 males with obesity, of whom 80 had SO, with a mean age of 80.3 ± 6.5 years and mean BMI of 27.2 ± 2.3 kg/m^2, and 445 did not have SO, with a mean age of 75.9 ± 4.7 years and mean BMI of 30.7 ± 3.4 kg/m^2. Furthermore, 30 of the 80 individuals in the SO group had Mets (according to ATP III criteria), in comparison to 245 of the 445 individuals in the non-SO group.

3.2. Meta-Analysis

The meta-analysis estimated the pooled relative risk and overall prevalence of Mets among patients with SO. With the high-observed heterogeneity (I^2 > 80%) among the included studies, a random effect model was considered for the estimation of the outcome measures. The forest plots in Figs. (**2** and **3**) reveal a similar prevalence of Mets among individuals with SO (61.49%; 95% CI: 52.19-70.40) and those without (56.74%; 95% CI: 47.32-65.93). The relative risk for Mets with SO is shown in the forest plot in Fig. (**4**). The random effect weighted pooled relative risk for Mets indicated similar risk in both groups (RR = 1.08, 95% CI: 0.99-1.17, p = 0.07).

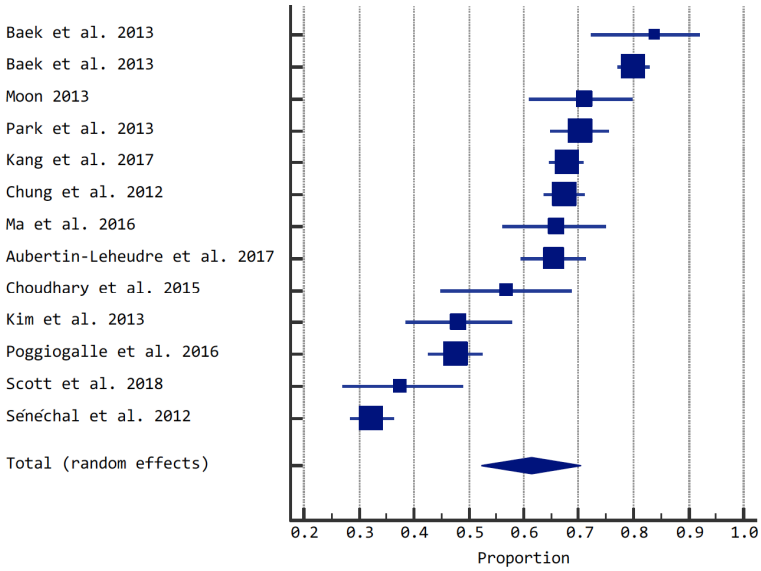

Fig. (2). Forest plot for the overall prevalence of Mets among patients with SO. *(A higher resolution / colour version of this figure is available in the electronic copy of the article).*

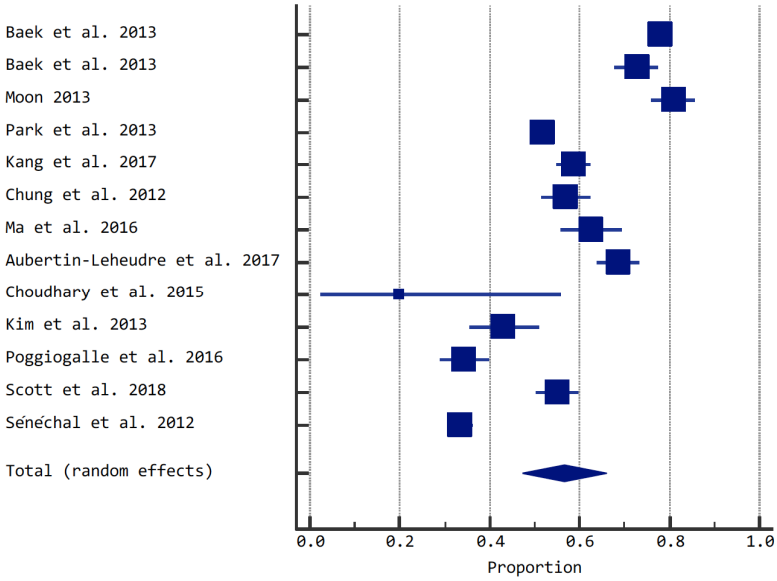

Fig. (3). Forest plot for the prevalence of Mets among patients without SO. *(A higher resolution / colour version of this figure is available in the electronic copy of the article).*

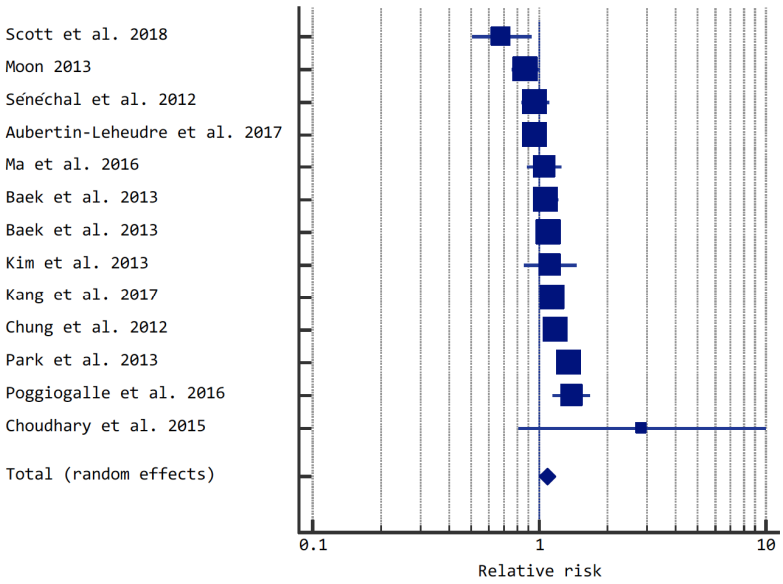

Fig. (4). Forest plot for random effect model pooled relative risk for Mets with SO. *(A higher resolution / colour version of this figure is available in the electronic copy of the article).*

4. DISCUSSION

In this systematic review and meta-analysis, we aimed to provide benchmark data on the prevalence of Mets among individuals with SO, as well as the potential association between the presence of SO and the higher risk of Mets in individuals with overweight or obesity. The major finding is the relatively similar prevalence of Mets among adults with SO when compared to those without SO. In fact, the coexistence of sarcopenia and excess weight/obesity appears not to increase the risk of Mets when compared with those with excess weight or obesity alone as confirmed by the meta-analysis.

This finding has clinical implications, as health providers, especially clinicians, should be aware of the high prevalence of Mets in individuals with obesity (55-60%), however, the coexistence of sarcopenia appears not to increase the risk of Mets in this population (*i.e*. SO).

This systematic review has certain strengths. Foremost, to the best of our knowledge, this is the first systematic review to assess the association between SO and Mets. Second, the included studies were predominantly large sample studies and in total account for more than 11,000 individuals across all ages, including both genders. Third, the major part of the included studies used the ATPIII criterion to define Mets and this provides consistency of categorization across the studies and permits comparison. Similarly, DXA has mainly been used for body composition assessment and consequently to define SO and this is considered as a strength, since this approach is considered to represent a precise method for the assessment of body composition. Finally, the quality of the included studies was judged to be good according to an objective quality appraisal tool (*i.e*., Newcastle-Ottawa Scale).

However, this study also has certain limitations. Foremost, our results need to be interpreted with caution with regard to the association between SO and Mets, since the cross-sectional design of the major part of studies included in our systematic review indicates only simple associations between SO and Mets at best and does not provide solid information regarding any causal relationships between the two conditions [40, 41]. In other words, these studies are not able to determine if SO may lead to the onset or deterioration of Mets, since very few studies have longitudinally investigated the 'real' effects of SO on health [42]. Finally, the high-observed heterogeneity ($I^2 > 80\%$) among the included studies is to be considered as a further limitation.

CONCLUSION AND NEW DIRECTIONS

We were not able to find a higher prevalence of Mets among individuals with SO compared to those with only obesity (non-SO), nor an association between the latter and a higher risk of Mets. However, due to the limitations of the included studies in our systematic review, foremost the cross-sectional design of most of the included studies, our finding needs to be replicated through longitudinal studies to clarify the real effect of SO on the onset and progression of Mets before drawing any firm conclusion.

AUTHOR CONTRIBUTIONS

All authors claim authorship, and have approved and made substantial contribution to the conception, drafting and final version of the paper.

CONSENT FOR PUBLICATION

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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