

Original article

Association of sarcopenia, sarcopenic obesity, and frailty with muscle strength and gait speed in older adults: A systematic review

Jagadeesh Dhamodharan^a , Mrunal Phatak^b , Jacquilyne Kharlukhi^c ,
E. Lakshmi^d , Mirra Rajalakshmi. M^e , Uthamalingam Murali^f ,
Rajkumar Krishnan Vasanthi^g , Merriwin David^{h,*} , Muthu Prasannaⁱ 

^aUnit of Anatomy, Faculty of Medicine, AIMST University, Kedah, Malaysia

^bDepartment of Physiology, AIIMS Nagpur, India

^cDepartment of Paediatrics, Sree Balaji Medical College and Hospital, Chennai, Tamilnadu, India

^dDepartment of Nutrition and Dietetics, SRM School of Allied Health Sciences, Faculty of Medicine and Health Sciences, SRM Institute of Science and Technology, Kattankulathur, Chengalpattu, India.

^eChengalpattu Government Medical College, Chengalpattu, India

^fDepartment of Surgery, Manipal University College Malaysia, Melaka, Malaysia.

^gFaculty of Health and Life Sciences, INTI International University, Nilai, Negeri Sembilan, Malaysia

^hDepartment of Biochemistry, Saveetha Medical College and Hospital, Saveetha Institute of Medical and Technical Sciences (SIMATS), Chennai, Tamilnadu, India

ⁱDepartment of Pharmaceutical Biotechnology, Surya School of Pharmacy, Vikiravandi, Villupuram Dt. Tamil Nadu, India

Abstract

Background: Sarcopenia, sarcopenic obesity (SO), and frailty are interrelated geriatric conditions associated with adverse health outcomes and increased health risks, including reduced muscle strength, impaired gait speed, and increased morbidity. However, their shared clinical features and biomarkers remain inadequately synthesized.

Objective: This systematic review aims to evaluate the interrelationship between sarcopenia, SO, and frailty in older adults, with a particular focus on muscle strength, gait speed, and associated biomarkers.

Methods: A comprehensive literature search was performed across MEDLINE, EMBASE, Scopus, Web of Science, and CINAHL. Observational and clinical studies assessing sarcopenia, SO, and frailty were included. Data were extracted using the Population, Intervention, Comparison, Outcomes, and Study (PICOS) framework, and the findings were synthesized narratively. Risk of bias was assessed using appropriate tools.

Results: Reduced muscle strength and slower gait speed were consistently associated with a higher prevalence of sarcopenia, SO, and frailty across the included studies. The pooled analysis demonstrated a non-significant association between SO and frailty, with a pooled odds ratio (OR) indicating substantial heterogeneity among the included studies ($I^2 = 97.8\%$).

Conclusion: Sarcopenia, SO, and frailty share overlapping clinical and biological characteristics, including reduced muscle strength, impaired gait speed, and common metabolic and inflammatory pathways. Although individual studies frequently reported positive associations between SO and frailty, the pooled meta-analysis did not reveal a significant association (OR 1.81, 95% confidence interval 0.66–4.91; $P = 0.25$), likely reflecting substantial heterogeneity across the studies. Further standardized longitudinal studies are required to clarify this relationship. Muscle strength and gait speed are key indicators that provide insight into the underlying pathways. Standardized assessment and further research are required to improve clinical management.

Keywords: Frailty, gait speed, muscle strength, older adults sarcopenia, sarcopenic obesity.

***Correspondence to:** Merriwin David, Department of Biochemistry, Saveetha Medical College and Hospital, Saveetha Institute of Medical and Technical Sciences (SIMATS), Chennai, Tamilnadu, India.

E-mail: merri5749@gmail.com

Received: June 4, 2026

Revised: July 10, 2026

Accepted: August 1, 2026

Sarcopenia, sarcopenic obesity (SO), and frailty are increasingly recognized as major geriatric syndromes that contribute substantially to adverse health outcomes in aging populations. Sarcopenia is characterized by the progressive and generalized loss of skeletal muscle mass and strength, which leads to impaired physical performance and reduced functional capacity. SO represents the coexistence of reduced muscle mass and excess adiposity, thereby creating a high-risk phenotype associated with metabolic and functional impairments.⁽¹⁾ Frailty, in contrast, is a multidimensional clinical syndrome marked by decreased physiological reserve and increased vulnerability to stressors, which often results in a higher risk of falls, hospitalization, disability, and mortality. Collectively, these conditions pose a considerable burden to healthcare systems and substantially impact the quality of life among older adults.

In recent years, there has been an increasing recognition of the interconnected nature of sarcopenia, SO, and frailty. Rather than existing as independent conditions, these syndromes are increasingly considered to share overlapping pathophysiological mechanisms and clinical features. Chronic low-grade inflammation, insulin resistance, oxidative stress, and hormonal dysregulation have been identified as key contributors to the development and progression of these conditions. These shared biological pathways promote muscle degradation, enhance fat accumulation, and reduce physical performance, thereby suggesting that these disorders may lie along a continuum of age-related decline. Reduced muscle strength and slower gait speed are reliable indicators of frailty and sarcopenia for identifying at-risk individuals and assessing disease severity.⁽²⁾

Despite the expanding body of literature, current evidence remains heterogeneous and fragmented. Variability in diagnostic criteria, measurement techniques, and study populations has resulted in inconsistencies in reported findings. Differences in the assessment of muscle strength, such as variations in handgrip strength cut-off values and inconsistencies in gait speed measurement protocols, limit comparability across studies. Similarly, the lack of standardized definitions for SO and frailty confounds the interpretation of prevalence estimates and associated risk factors. Furthermore, while several studies have emphasized the role of inflammatory, metabolic, and hormonal biomarkers, their clinical utility and consistency across populations remain unclear.

Given these limitations, there is a clear need for a comprehensive and systematic synthesis of the

available evidence. A systematic review provides a structured approach to identifying, evaluating, and integrating the findings from various studies, thereby improving the reliability and applicability of the conclusions. By examining the functional and biological aspects, such as muscle strength, gait speed, and associated biomarkers, a more holistic understanding of these conditions can be achieved. Therefore, this systematic review aims to evaluate the interrelationship between sarcopenia, SO, and frailty in older adults, with a particular focus on muscle strength, gait speed, and functional decline.

Materials and methods

Search strategy

The search strategy was developed using a combination of controlled vocabulary terms (e.g., MeSH, Emtree) and free-text keywords to comprehensively identify relevant studies. The primary keywords included “sarcopenia,” “SO,” “frailty,” “muscle strength,” “gait speed,” and “biomarkers.” These were expanded with related terms such as “muscle mass,” “physical performance,” “walking speed,” “handgrip strength,” “inflammatory markers,” “metabolic biomarkers,” “insulin resistance,” and “hormonal changes.” Thereafter, Boolean operators were applied to systematically combine terms across databases. The core search combinations included [sarcopenia AND frailty], [SO AND biomarkers], [muscle strength AND gait speed], and [frailty AND physical performance]. In addition, broader combinations such as [sarcopenia OR SO OR frailty AND biomarkers], [muscle strength OR gait speed AND aging], and [metabolic biomarkers AND sarcopenia] were used to capture a wide range of studies. Additional combinations such as [inflammatory markers AND frailty], [insulin resistance AND SO], and [hormonal imbalance AND muscle loss] were included to explore the underlying mechanisms. The search was conducted across multiple electronic databases including MEDLINE (via PubMed), EMBASE, Scopus, Web of Science, and CINAHL from database inception to March 31, 2025. Database-specific adaptations were applied, such as the use of MeSH terms in MEDLINE (e.g., “Sarcopenia,” “Frailty,” and “Muscle Strength”) and Emtree terms in EMBASE. Moreover, truncation and wildcard symbols (e.g., sarcopen*, frail*, biomarker*) were used to enhance sensitivity. Filters were applied to include studies that involved human adults and were published in English. Reference lists of the included

studies and relevant reviews were also screened to identify additional eligible articles. This systematic review was performed according to the PRISMA 2020 guidelines. This study was prospectively registered with the PROSPERO database (CRD420261404779).

Inclusion and exclusion criteria

This review included observational and clinical studies involving adults (≥ 18 years) that examined sarcopenia, SO, and frailty and their interrelationships. Eligible studies were required to evaluate these conditions using recognized or standardized diagnostic criteria and to report outcomes related to muscle strength and gait speed, including inflammatory, metabolic, or hormonal markers. Studies were included if sufficient data were available for extraction and synthesis. Moreover, studies were excluded if they were reviews, conference abstracts, editorials, commentaries, protocols, or dissertations; involved non-human subjects; were not published in English; lacked clear definitions of exposures or outcomes; did not report relevant variables; or the full-text versions were inaccessible.

Methodological quality assessment

The methodological quality and risk of bias of the included observational studies were independently assessed by two reviewers using the Joanna Briggs Institute Critical Appraisal Checklist for Analytical Cross-Sectional Studies, which is appropriate for evaluating cross-sectional observational research. This checklist assesses methodological quality across eight domains, including clearly defined inclusion criteria, detailed description of study participants and settings, valid and reliable measurement of exposure and outcomes, identification and management of potential confounding factors, and appropriateness of statistical analyses. Each of the included studies was evaluated independently by two reviewers, and any disagreements were resolved through discussion and consensus, with consultation from a third reviewer when necessary.

Overall methodological quality was determined based on the number of criteria fulfilled by each study and categorized as having a low, moderate, or high risk of bias. The inter-reviewer agreement was evaluated using Cohen's kappa statistic, and agreement was interpreted according to the established benchmarks ranging from slight to almost perfect agreement. In addition, the overall certainty of evidence for the primary outcomes was assessed using the GRADE approach, which considers study

limitations, consistency of findings, indirectness, imprecision, and publication bias. Visual summaries of the methodological quality assessments were generated using appropriate risk-of-bias visualization tools to facilitate interpretation of the findings.

Data charting

A structured data charting form was developed using Microsoft Excel, incorporating key variables aligned with the review objectives. Before full data extraction, the form was tested by the review team on a subset of studies to ensure clarity, consistency, and completeness. Data charting was performed independently by multiple reviewers, with each reviewer extracting relevant information from the included studies. Any discrepancies in the extracted data were resolved through discussion and consensus, and, where necessary, consultation with an additional reviewer. In cases of missing or unclear information, attempts were made to contact the study authors for clarification to ensure data accuracy and completeness.

Data synthesis

Across the included studies, several associations were reported between sarcopenia, SO, and frailty, although findings varied depending on study population and assessment criteria. Reduced muscle strength and slower gait speed were strongly associated with the increased prevalence and severity of these conditions. Despite variability in the diagnostic criteria and assessment methods, these functional measures remained reliable indicators across the different populations. Several studies reported associations with inflammatory, hormonal, and metabolic biomarkers. Metabolic dysregulation, particularly insulin resistance and altered glucose and lipid profiles, was more pronounced in individuals with SO. The key contributing factors included advanced age, physical inactivity, and comorbid conditions such as diabetes and cardiovascular disease. Overall, the findings suggest overlapping clinical and biological characteristics among these conditions, although the strength of association was variable across reported studies.

Studies reporting odds ratios (ORs) for the outcome with corresponding 95% confidence intervals (CIs) were included. A random-effects model was applied to account for between-study variability. Statistical heterogeneity was assessed using the I^2 statistic and chi-square test. Meta-analysis was performed using Review Manager (RevMan) version

5.4. A $P < 0.05$ was considered statistically significant. Publication bias was not assessed due to the limited number of studies included ($n = 9$), as funnel plot analysis is considered unreliable with a small number of studies.

PICOS

Critical appraisal was performed to systematically evaluate the quality, relevance, and methodological rigor of the included studies. This process involved examining potential sources of bias, assessing the study design, and determining the credibility of reported findings, particularly for muscle strength, gait speed, and biomarker outcomes. The Population, Intervention, Comparison, Outcomes, and Study Design (PICOS) framework guided this search and selection process. The population included adults assessed for sarcopenia, SO, and frailty. Exposures were defined as the presence or overlap of these conditions, while comparisons involved individuals with varying severity or absence of these conditions. The outcomes of interest included muscle strength, gait speed, functional performance, and the associated biomarkers. Eligible studies comprised observational designs and relevant clinical studies. Screening was performed in stages (title, abstract, and full text) based on the predefined criteria, and the findings were synthesized narratively due to heterogeneity across the studies.

Results

Study selection

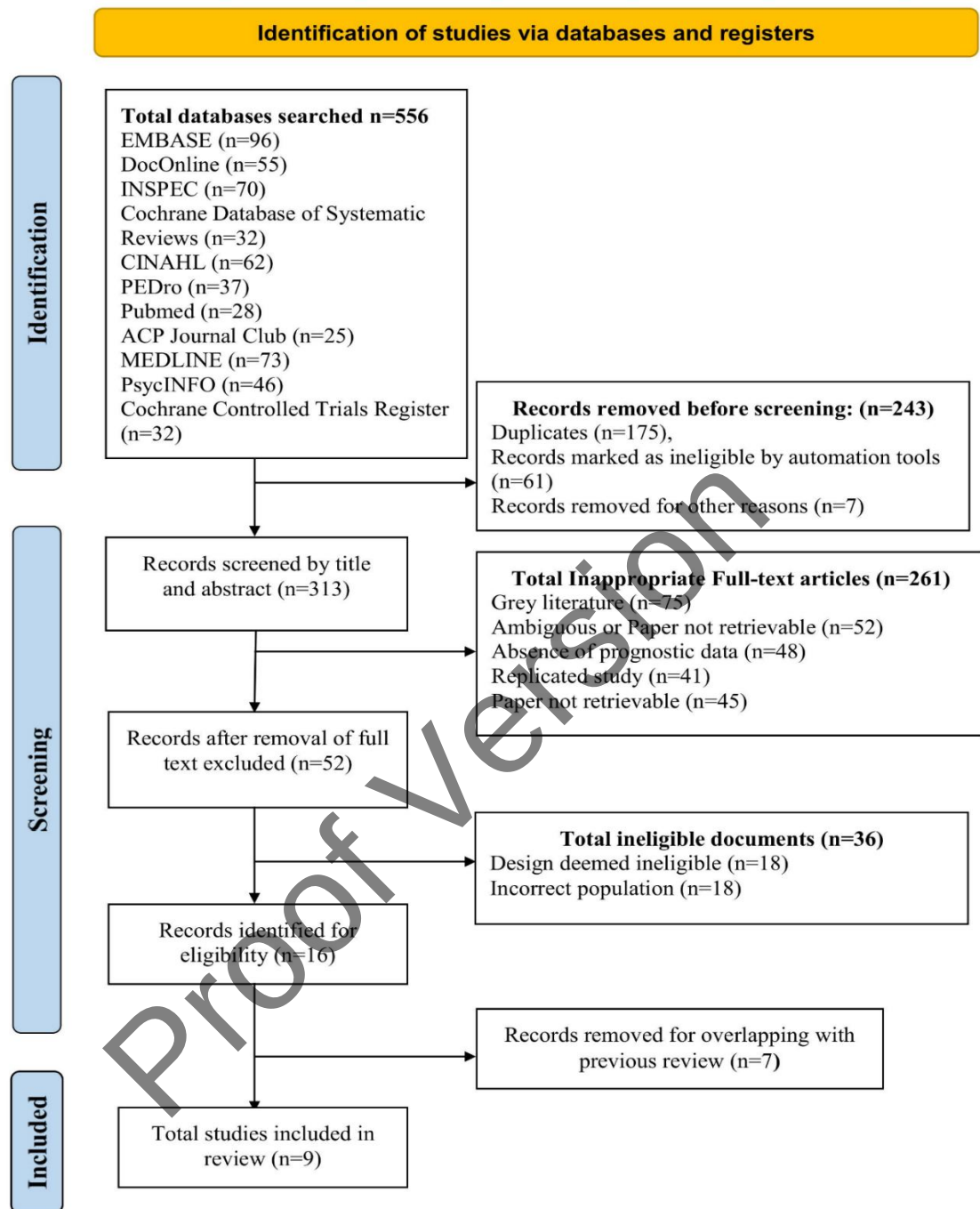
The selection of studies for this systematic review followed the PRISMA 2020 guidelines and was guided by the PICOS framework (**Figure 1**). Observational study designs, including cross-sectional, cohort, and case-control studies, along with relevant clinical studies, were prioritized to determine the association between sarcopenia, SO, and frailty. Only full-text articles published in English in peer-reviewed journals were considered eligible. Studies such as conference abstracts, unpublished data, gray literature, and non-human research were excluded to ensure methodological rigor and data reliability. Eligible studies were required to include adult participants and provide clear and standardized definitions of sarcopenia, SO, and frailty based on recognized criteria or validated assessment tools. Moreover, studies focusing on key outcomes such as muscle strength, gait or walking speed, functional performance, and biomarkers, including inflammatory, metabolic, and hormonal

markers, were included. However, articles were excluded if they lacked clear diagnostic criteria or reported irrelevant outcomes. The study selection process was performed systematically, with duplicate studies removed and titles and abstracts screened before full-text assessment. The risk of bias in the included studies was evaluated using appropriate validated tools based on the study design. To ensure consistency and minimize selection bias, inter-rater agreement between reviewers was assessed using reliability measures such as Cohen's kappa, where applicable. A total of 556 records were identified, but after removal of duplicates, 313 records were screened, and nine studies were included in the final analysis. The characteristics of the included studies are summarized in **Table 1**.

Methodological quality assessment

Risk of bias assessment of the included studies demonstrated an overall moderate methodological quality, with variability observed across specific domains (**Table 2**), and the overall risk-of-bias assessment is presented in **Figure 2**. Bias arising from the randomization or selection process (D1) was generally rated as low or exhibited some concerns, indicating that most studies had reasonably appropriate participant selection. However, a few lacked clarities in sampling procedures. Bias due to deviations from intended exposures or interventions (D2) was predominantly low; however, one study was rated as high risk, which suggests potential issues related to adherence or exposure classification. Bias related to missing outcome data (D3) was largely low across studies, though some studies exhibited concerns, and one study showed high risk, reflecting possible incomplete data or attrition bias. In addition, measurement bias (D4) was mostly low or showed some concerns, revealing generally acceptable methods for assessing outcomes such as muscle strength and gait speed. In contrast, bias in the selection of reported results (D5) demonstrated greater variability, with a few studies rated as high risk, thus suggesting selective reporting of outcomes.

Overall, most studies were categorized as having a low to moderate risk of bias, while only one study was rated as having an overall high risk. These findings indicate that although the included studies provide reasonably reliable evidence, certain domains, particularly missing data and selective reporting, should be interpreted with caution.



Meta-analysis of frailty

A meta-analysis of nine studies (Saito H, *et al.*, 2022; Yang M, *et al.*, 2022; Frisoli A, *et al.*, 2023; Heng MW, *et al.*, 2023; Maheshwari V *et al.*, 2023; Deguchi N, *et al.*, 2024; Güner M, *et al.*, 2024; Bozkurt ME, *et al.*, 2024; and Damanti S, *et al.*, 2024) was conducted using a random-effects model. The pooled meta-analysis results are presented in **Figure 3**. The pooled analysis demonstrated no significant association between SO and frailty, with an overall OR of 1.81 (95% CI: 0.66–4.91, $P = 0.25$). Substantial heterogeneity was observed among the included studies ($I^2 = 97.8\%$), indicating considerable variability in the study results. The substantial heterogeneity likely reflects the major methodological differences

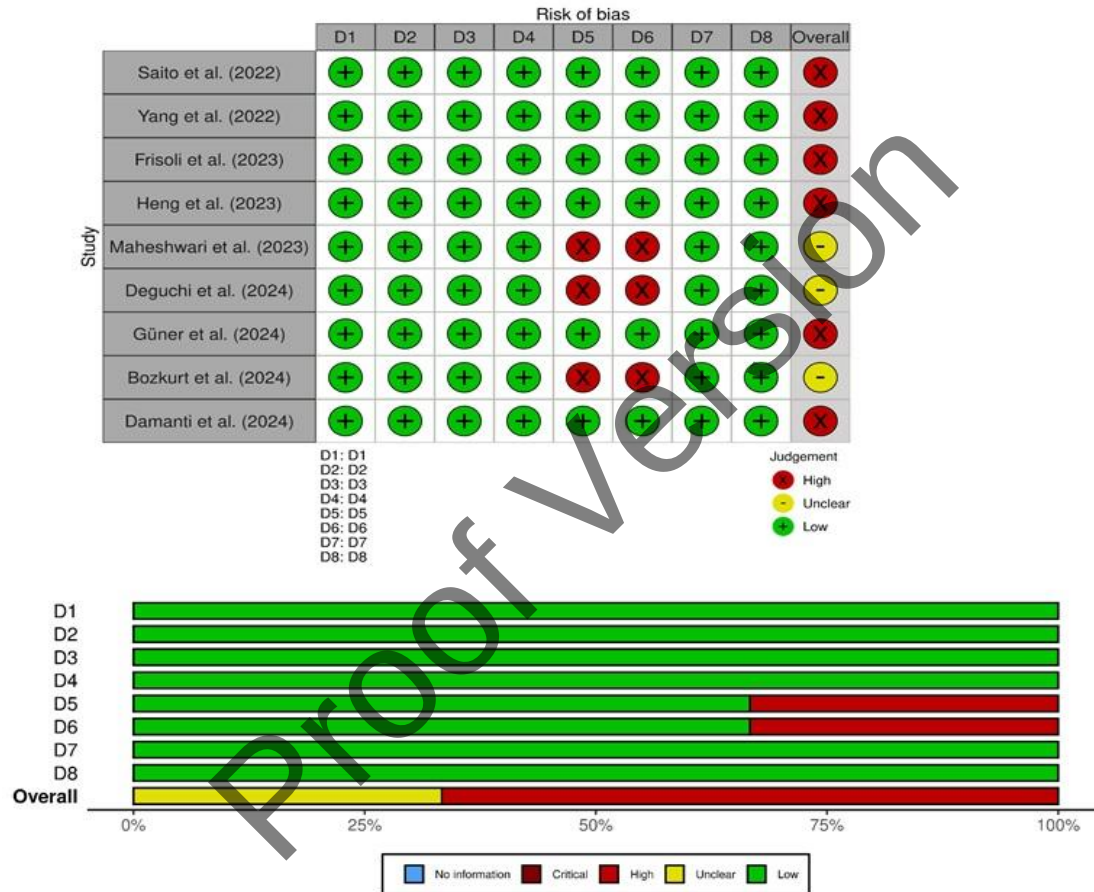
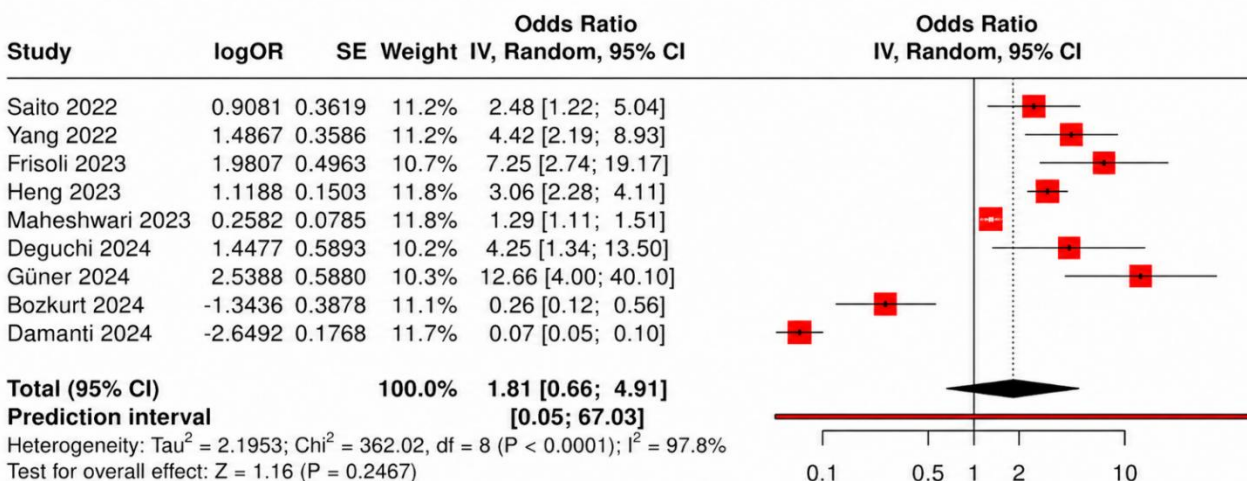
across studies, including variability in diagnostic definitions of SO (AWGS, EWGSOP II, BMI-based criteria, body fat percentage, and waist-calf ratio; WCR), differences in frailty assessment tools (Fried phenotype, Frailty Index, and physical performance criteria), and heterogeneity in the study populations. Because the limited number of studies within each methodological category resulted in insufficient statistical power, formal subgroup meta-analysis was not performed. The wide prediction interval (0.05–67.03) further reflects inconsistency across the studies and suggests uncertainty in the true effect size. Assessment of publication bias using a funnel plot was not performed due to the limited number of studies and high heterogeneity.

Table 1. Summary of included study characteristics.

Study	Study design	Country	Setting	Sample size	Age (years)	Females (%)
Saito H, <i>et al.</i> (2022) ⁽³⁾	Cross-sectional study (post-hoc analysis of prospective cohort)	Japan	Multicenter (15 hospitals; hospitalized heart failure patients)	779 participants	Median 81 (IQR: 74–86)	42.6%
Yang M, <i>et al.</i> (2022) ⁽⁴⁾	Cross-sectional study (retrospective)	China (West)	Community-dwelling older adults (WCHAT study)	2372 participants	Mean 67.6 ± 5.9	60.2%
Frisoli A, <i>et al.</i> (2023) ⁽⁵⁾	Cross-sectional study (from prospective cohort)	Brazil	Geriatric cardiology outpatient clinic (community-dwelling older adults)	371 participants	78.15 ± 7.22	53.2%
Heng MW, <i>et al.</i> (2023) ⁽⁶⁾	Cross-sectional study (population-based)	Singapore	Community-based (PIONEER study – elderly population)	2643 participants	≥ 60 years	54.8%
Maheshwari V, <i>et al.</i> (2023) ⁽⁷⁾	Cross-sectional study	India	Nationally representative dataset from the <i>Longitudinal Aging Study in India (LASI), Wave 1</i>	31,902 participants	≥ 60 years (older adults)	Not reported
Deguchi N, <i>et al.</i> (2024) ⁽⁸⁾	Cross-sectional study	Japan	Community-dwelling older women with locomotive syndrome (measurements conducted in gymnasiums or regional/sports centers)	158 participants	Median = 74.0 years (IQR: 70.0–79.0)	100.0% (all participants were women)
Güner M, <i>et al.</i> (2024) ⁽⁹⁾	Cross-sectional study	Turkey	Geriatric outpatient clinic	234 participants	Mean age = 72.7 ± 5.8 years	175 (78.7%)
Bozkurt ME, <i>et al.</i> (2024) ⁽¹⁰⁾	Cross-sectional study (retrospective observational)	Turkey	Outpatient geriatrics clinic (hospital-based)	367 participants	Median 71 years (range 65–97)	212 (57.8%)
Damanti S, <i>et al.</i> (2024) ⁽¹¹⁾	Cross-sectional study (observational; FRASNET study)	Italy	Community-dwelling older adults	1,114 participants	Median 72 years	60.5%

Table 2. Methodological quality assessment of included studies using the Joanna Briggs Institute (JBI) critical appraisal checklist for analytical cross-sectional studies.

Study	D1	D2	D3	D4	D5	D6	D7	D8	Overall quality
Saito H, <i>et al.</i> (2022)	Low	Low	Low	Low	Low	Low	Low	Low	High
Yang M, <i>et al.</i> (2022)	Low	Low	Low	Low	Low	Low	Low	Low	High
Frisoli A, <i>et al.</i> (2023)	Low	Low	Low	Low	Low	Low	Low	Low	High
Heng MW, <i>et al.</i> (2023)	Low	Low	Low	Low	Low	Low	Low	Low	High
Maheshwari V, <i>et al.</i> (2023)	Low	Low	Low	Low	High	High	Low	Low	Moderate
Deguchi N, <i>et al.</i> (2024)	Low	Low	Low	Low	High	High	Low	Low	Moderate
Güner M, <i>et al.</i> (2024)	Low	Low	Low	Low	Low	Low	Low	Low	High
Bozkurt ME, <i>et al.</i> (2024)	Low	Low	Low	Low	High	High	Low	Low	Moderate
Damanti S, <i>et al.</i> (2024)	Low	Low	Low	Low	Low	Low	Low	Low	High

**Figure 2.** Methodological quality assessment of included studies using the JBI critical appraisal checklist.**Figure 3.** Forest plot showing the association between SO and frailty. CI, confidence interval; OR, odds ratio; SE, standard error of the mean.

Physiological factors associated with sarcopenia and SO

The included studies demonstrated a diverse range of factors associated with sarcopenia and SO. Studies by Saito H, *et al.* and Yang M, *et al.* highlighted the role of glucose-related indicators, including diabetes status, along with lipid profiles such as high- and low-density lipoproteins and triglycerides, and renal markers including creatinine and estimated glomerular filtration rate. These findings suggest a strong link between metabolic dysfunction and muscle deterioration. Frisoli A, *et al.* and Heng MW, *et al.* further highlighted parameters such as body fat, muscle mass, glucose levels, and insulin resistance measured through HOMA-IR, thereby reinforcing the interplay between adiposity and impaired glucose metabolism in SO. Similarly, Maheshwari V, *et al.* reported associations involving insulin resistance, glucose, and lipid abnormalities, indicating metabolic imbalance as a key contributor. Deguchi N, Bozkurt ME, Damanti S, *et al.* did not report specific factors, thus reflecting the variability in study focus or reporting standards. Güner M, *et al.* identified glucose and cholesterol as relevant markers, which supports the importance of glycemic and lipid regulation. Overall, these studies stressed the importance of metabolic markers, particularly glucose metabolism and lipid profiles, in understanding the pathophysiology and clinical assessment of sarcopenia and SO, and associated biomarkers of the included studies are summarized in **Table 3**.

Muscle strength and gait

Across multiple studies, sarcopenia and SO were frequently associated with reduced muscle strength and slower gait speed, thereby contributing to poorer physical performance compared with that of obesity alone.

Individuals with SO often demonstrated greater functional decline, and several studies reported a higher occurrence of frailty, falls, and functional limitations. Reduced muscle strength and slow gait are key sarcopenia indicators, with combined deficits reflecting more severe progression. In contrast, obesity alone exhibits less consistent effects on muscle

function, thus highlighting muscle loss as the primary driver of impairment. Overall, reduced strength and gait speed are reliable markers of decreased mobility and increased health risk.

Obesity and frailty

Across multiple studies, obesity and SO reveal distinct but interrelated effects on health outcomes. Saito H *et al.* reported an obesity prevalence of 26.2% ($\geq 38.0\%$ in women, $\geq 27.0\%$ in men), while SO accounted for 4.0%, with SO significantly associated with poorer physical function and increased mortality risk (OR 2.48). Similarly, Yang M, *et al.* found that obesity alone did not significantly elevate risk (OR ≈ 1.11 – 1.50), whereas SO substantially increased prefrailty (OR 1.74) and frailty (OR 4.42). In line with this, Frisoli A *et al.* demonstrated that total body fat (TBF)-defined obesity (67.7%) was more prevalent than BMI-defined obesity (21.8%), with TBF-based SO strongly associated with frailty (OR ≈ 6.88). Heng MW, *et al.* further reported increased risks for sarcopenia (RR 2.53), SO (RR 2.58), and a negative interaction (RERI -1.00). Among diabetic populations, Maheshwari V, *et al.* observed a 17.7% prevalence of SO, which was associated with greater frailty, fall, and disability risks. Deguchi N, *et al.* defined sarcopenia using SMI < 5.7 kg/m² and SO as its coexistence with body fat $\geq 35.0\%$. Meanwhile, Güner M *et al.* incorporated BMI ≥ 30 kg/m² with low muscle strength (< 27 kg in men, < 16 kg in women), low muscle mass, and high fat percentage thresholds. Bozkurt ME, *et al.* linked SO to increased frailty despite lacking functional measures, while Damanti S, *et al.* confirmed its association with frailty risk with approximately 1.5–2-fold increased frailty risk (OR ≈ 1.75) in obese pre-sarcopenia. Overall, several individual studies have reported stronger associations between SO and adverse outcomes, including frailty, compared with obesity alone. However, the pooled meta-analysis did not demonstrate a significant overall association, and substantial heterogeneity suggests considerable variability in effect estimates across the studies. The overall findings, recommendations, and challenges reported by the included studies are summarized in **Table 4**.

Table 3. Overview of muscle strength, gait speed, SO, frailty, and associated biomarkers in included studies.

Study	Muscle strength and gait /walking speed	Covariate	Data Extraction Summary	SO evaluation	Obesity	Frailty evaluation	Shared factors between Sarcopenia and SO	Metabolic markers in Sarcopenia and SO
Saito H, <i>et al.</i> (2022) ⁽³⁾	SO was associated with reduced muscle function and slower walking capacity, showing the poorest physical performance among groups.	Age, sex, MAGGIC risk score, log-transformed BNP	n=779, age ~81, SO = 4.0%, frailty high (~76.0% in SO), SO ↑ mortality and ↓ physical function	AWGS criteria for sarcopenia; body fat % via BIA (≥ 38.0% women, ≥ 27.0% men)	The prevalence of obesity (≥ 38.0% in women, ≥ 27.0% in men) was 26.2%, while SO was 4.0%. SO was associated with poorer physical function and an increased mortality risk (OR 2.48).	Fried phenotype criteria (gait speed, grip strength, weight loss, exhaustion, physical activity)	BNP, albumin, hemoglobin, lipid profile (cholesterol, triglycerides)	Glucose-related (diabetes status), lipid profile (HDL, LDL, triglycerides), creatinine, eGFR
Yang M, <i>et al.</i> (2022) ⁽⁴⁾	Muscle strength & gait speed both reduced values (weakness and slower gait) are linked to higher frailty risk in sarcopenia and SO.	Age, sex, lifestyle, diseases	N = 2372, age ~67.6, SO = 6.3%, frailty = 6.2%, SO ↑ frailty risk	AWGS + body fat %	It alone showed no significant risk (OR ≈ 1.11–1.50), whereas SO markedly increased prefrailty (OR = 1.74) and frailty (OR = 4.42).	Fried criteria	Inflammation, muscle loss, fat increase	Body fat, muscle mass, metabolic changes
Frisoli A, <i>et al.</i> (2023) ⁽⁵⁾	Both sarcopenia and SO are linked to reduced strength and slower gait, with more severe impairment observed in SO, particularly in the presence of high body fat.	Age, sex	n=371, age=78.1 yrs, SO ↑ frailty risk (OR=6.88)	EWGSOP II + BMI/TBF (DEXA)	TBF obesity (67.7%) was more prevalent than BMI obesity (21.8%), and SO based on TBF showed a strong association with frailty (OR ≈ 6.88), unlike BMI-based obesity.	Fried criteria	Not reported	Not reported
Heng MW, <i>et al.</i> (2023) ⁽⁶⁾	Sarcopenia and SO are characterized by low muscle strength and slow gait speed, contributing to increased frailty risk.	Age, Sex, BMI, lifestyle, diseases	n = 2643, age ~ 60, SO = 7.4%, frailty ≈ 17.5%, SO ↑ frailty risk	Low muscle + high fat	Sarcopenia (RR 2.53), SO (OR 2.58), with a negative interaction between sarcopenia and obesity (RERI -1.00).	Weakness, weight loss, slow	CRP, IL-6, insulin resistance	Glucose, HOMA-IR, lipids
Mareshwari V, <i>et al.</i> (2023) ⁽⁷⁾	Low strength and slow gait indicated possible sarcopenia and SO contribute to increased frailty, falls, and functional impairment.	Age, sex, BMI, activity, smoking, diseases	age ~60+ years, SO & frailty % not reported, SO ↑ frailty risk	Low muscle + high fat	SO, the coexistence of obesity and sarcopenia, has a 17.7% prevalence in diabetics and is linked to higher risks of frailty, falls, and disability.	Weakness, weight loss, slow walking, low activity (frailty criteria)	Inflammation (CRP, IL-6, TNF), Hormones	Insulin resistance, glucose, lipids

Table 3. (Cont.) Overview of muscle strength, gait speed, SO, frailty, and associated biomarkers in included studies.

Study	Muscle strength and gait /walking speed	Covariate	Data Extraction Summary	SO evaluation	Obesity	Frailty evaluation	Shared factors between Sarcopenia and SO	Metabolic markers in Sarcopenia and SO
Deguchi N, <i>et al.</i> (2024) ⁽⁸⁾	Sarcopenia and SO were linked to decreased muscle strength and slower walking speed, increasing frailty risk, whereas obesity alone showed no significant association.	Age, BMI, pain, falls, TUG	Frailty = 32.9%, SO shows highest association with frailty (~4× increased risk)	Muscle mass (SMI) + Obesity (BMI/body fat)	Sarcopenia was identified as skeletal muscle mass index (SMI) < 5.7 kg/m ² , and SO was defined as the coexistence of both conditions (SMI < 5.7 kg/m ² and body fat ≥ 35.0%).	Physical performance tests (TUG, balance)	Not reported	Not reported
Güner M, <i>et al.</i> (2024) ⁽⁹⁾	Sarcopenic obese individuals showed significantly lower muscle strength (14.8 vs. 20.7 kg) and slower gait speed compared to non-sarcopenic obese individuals.	Age, sex, BMI	WCR strongly associated with SO (Unadjusted OR ≈ 13.3; Adjusted OR ≈ 12.7; <i>P</i> < 0.001); ROC analysis performed	Low muscle, High fat	SO included BMI ≥30 kg/m ² with low muscle strength (< 27 kg men, < 16 kg women), low muscle mass (FFMI < 17 men, <15 women), high fat mass (> 31.0% men, > 43.0% women), and WCR ≥ 2.94.	Weakness, Slow walk	CRP, IL-6	Glucose, Cholesterol
Bozkurt ME, <i>et al.</i> (2024) ⁽¹⁰⁾	SO was associated with frailty despite limited functional data, the association of sarcopenia and SO with increased frailty suggests reduced muscle strength and impaired gait performance.	Age, frailty	n = 367, age ≈ 71, SO = 15.3%, frailty = NR, SO ↑ frailty risk	Sarcopenia, obesity combined	Muscle strength and walking speed were not reported, but sarcopenia and SO were linked to increased frailty.	Frailty checked, strong association with SO	Not reported	Not reported
Damanti S, <i>et al.</i> (2024) ⁽¹¹⁾	Reduced strength and gait speed were associated with SO and frailty	Age, sex, health deficits (Frailty Index factors)	n = 1114, age ~72, females = 60.5%, frailty = 21.0%, SO ↑ frailty risk	Muscle loss, high fat mass (body composition based)	SO combined this with low muscle mass (< 32.9% men, < 23.9% women) and associated with approximately 1.5–2-fold increased frailty risk (OR ≈ 1.75) in obese pre-sarcopenia).	Frailty Index (FI) ≥ 0.25 = frailty)	Not reported	Not reported

AWGS, Asian Working Group for Sarcopenia; BIA, bioelectrical impedance analysis; BMI, body mass index; BNP, natriuretic peptide; CRP, C-reactive protein; eGFR, estimated glomerular filtration rate; EWGSOP, European Working Group on Sarcopenia in Older People; FFMI, fat-free mass index; HDL, high-density lipoprotein; IL-6, interleukin-6; LDL, low-density lipoprotein; OR, odds ratio; ROC, receiver operating characteristic curve; RR, relative risk; SMI, skeletal muscle index; SO, sarcopenic obesity; TBG, total body fat; TNF, tumor necrosis factor; TUG, timed up and go; WCR, waist–calf ratio.

Table 4. Overview of studies on SO and frailty in older adults.

Study	Focus area	Methodology	Key findings	Recommendations	Challenges
Saito H, <i>et al.</i> (2022) ⁽³⁾	Impact of sedentary lifestyle on chronic diseases, including obesity, sarcopenia, and mitochondrial dysfunction.	Cross-sectional study using database extraction, study selection criteria, and qualitative synthesis of evidence.	Sedentary behavior increased obesity (30.0% – 50.0%), insulin resistance (25.0% – 40.0%), sarcopenia (15.0% – 25.0%), and inflammation (1.5–2×), contributing to reduced muscle function and metabolic health.	Increase physical activity, reduce sitting time, promote lifestyle interventions, and implement public health strategies.	Limited longitudinal studies, heterogeneity in measurement methods, lack of standardized definitions, and insufficient mechanistic research.
Yang M, <i>et al.</i> (2022) ⁽⁴⁾	Relationship between SO, and frailty in older adults.	Observational study using clinical assessments, body composition measures, and statistical analysis.	SO prevalence was 6.3%, with frailty prevalence of 6.2%. SO significantly increased the risk of prefrailty (OR 1.74) and frailty (OR 4.42; $P < 0.001$).	Early screening and integrated management of sarcopenia and obesity to prevent frailty.	Lack of standardized diagnostic criteria and limited longitudinal data on progression.
Frisoli A, <i>et al.</i> (2023) ⁽⁵⁾	Association between SO and physical frailty in older adults.	Cross-sectional study (SARCOS study); older adults; DXA used for body composition; frailty assessed using Fried criteria.	SO increased frailty risk (OR ~2.5–3.2), with higher frailty prevalence (~20–25.0% vs. ~8.0% – 12.0%). Body fat–based obesity measures predicted frailty better than BMI ($P < 0.05$).	Use appropriate obesity definitions (like total body fat) along with sarcopenia measures for better frailty assessment.	Lack of standardized definition for SO; variability in diagnostic criteria limits comparison across studies.
Heng MW, <i>et al.</i> (2023) ⁽⁶⁾	SO and its association with frailty, metabolic dysfunction, and aging-related health risks.	Observational studies analyzing SO, frailty, and related biomarkers.	SO was strongly associated with inflammation, insulin resistance, and a 2.5–3.2-fold higher risk of frailty compared with individuals without SO.	Screen early and use diet + exercise to improve muscle and reduce inflammation.	Lack of standardized criteria and limited longitudinal studies.
Mareshwari V, <i>et al.</i> (2023) ⁽⁷⁾	SO and frailty using WCR	Cross-sectional study, older adults, WCR measured, regression analysis	WCR was strongly associated with SO (OR ≈ 13.3 ; adjusted OR ≈ 12.7) and was a simple predictor of frailty.	Use WCR for screening, Early detection and management	Cross-sectional design limits causality; standardized cut-off values are needed
Deguchi N, <i>et al.</i> (2024) ⁽⁸⁾	Relationship between sarcopenia, SO, and frailty	Cross-sectional study in older women, measuring muscle and fat using bioelectrical impedance and analyzing data statistically.	Higher WCR increased the risk of SO (OR ~2–3), while SO further increased frailty risk (OR ~2.5–4.0; $P < 0.05$).	Early detection is important can be managed with exercise and proper diet	Lack of standardized SO criteria and longitudinal studies; more research needed

Table 4. (Cont.) Overview of studies on SO and frailty in older adults.

Study	Focus area	Methodology	Key findings	Recommendations	Challenges
Güner M, <i>et al.</i> (2024) ⁽⁹⁾	Study on SO and its link with frailty using body measurements like WCR.	Observational study in older adults using body composition measures and statistical analysis.	supporting WCR as a practical screening tool. WCR was significantly higher in individuals with SO (3.04 vs. 2.82; <i>P</i> < 0.001). A cut-off value of 2.94 showed 72.8% sensitivity and 67.3% specificity for identifying SO.	WCR can be used for early screening; focus on improving muscle mass and reducing fat through lifestyle changes.	Study is cross-sectional, limited population, and more long-term research is needed.
Bozkurt ME, <i>et al.</i> (2024) ⁽¹⁰⁾	Association between SO and frailty	Population-based observational study with statistical analysis	SO significantly increased frailty risk (OR $\approx$ 2.3–2.8; 95% CI: $\sim$ 1.5–4.0; <i>P</i> < 0.05), with frailty prevalence of $\sim$ 30.05 – 40.0% compared with $\sim$ 10.0% – 20.0% in individuals without SO.	Early screening, regular exercise, and balanced diet	Lack of standard definition, limited long-term studies, need for more biomarker research
Damanti S, <i>et al.</i> (2024) ⁽¹¹⁾	SO and its link with frailty in older adults	Observational study with statistical analysis using adjusted variables	SO prevalence ranged from approximately 5.0% – 10.0% and was associated with a 1.5–2.0-fold higher risk of frailty (<i>P</i> < 0.05), likely due to shared metabolic and inflammatory mechanisms.	Early identification of SO, promote physical activity and proper nutrition, Use biomarkers for better assessment	Lack of standardized SO definitions, limited longitudinal studies, and variability in diagnostic methods.

BMI, body mass index; CI, confidence interval; DXA, dual-energy X-ray absorptiometry; OR, odds ratio; SO, sarcopenic obesity; WCR, waist-calf ratio.

Discussion

The findings of this systematic review highlight a strong and consistent interrelationship between sarcopenia, SO, and frailty, underscoring their combined contribution to functional decline and adverse health outcomes in older adults. These conditions share overlapping biological mechanisms and clinical features, which supports the notion of a continuum of age-related deterioration rather than independent disease entities. A key observation across the included studies is the role of muscle strength and gait speed as reliable indicators of physical performance and predictors of frailty. Reduced handgrip strength and slower walking speed were consistently associated with increased sarcopenia severity and SO. These findings align with the revised European Working Group on Sarcopenia in Older People (EWGSOP2), which identifies low muscle strength as a primary determinant of sarcopenia (Sutil DV, *et al.*, 2023).⁽¹²⁾ The consistent use of these measures across studies emphasizes their importance in early identification and clinical assessment.

The evidence also stresses the contribution of underlying biological mechanisms, in particular chronic inflammation and metabolic dysregulation. Elevated inflammatory markers such as C-reactive protein, interleukin-6, and tumor necrosis factor- α were frequently reported, thereby suggesting a state of chronic low-grade inflammation that accelerates muscle degradation. Metabolic dysregulation, such as insulin resistance and abnormal glucose metabolism, has also been linked to muscle wasting in older adults. This is consistent with previous findings by Prado CM, *et al.* (2024)⁽¹³⁾, which link inflammatory processes to sarcopenia progression. Metabolic abnormalities, including insulin resistance and altered lipid profiles, further contribute to the development of SO. These biological mechanisms contribute to the loss of muscle mass and strength and increase the risk of functional decline and disability. Therefore, addressing these underlying factors through targeted interventions may be vital in preventing or slowing the progression of muscle wasting in aging populations.

This dual burden results in greater functional impairment and poorer health outcomes compared to either condition alone, as reported by Murawiak M, *et al.* (2026). Although several of the included studies individually reported that SO was associated with increased frailty risk, the pooled meta-analysis did not

demonstrate a significant overall association. This lack of statistical significance should be interpreted cautiously, as substantial heterogeneity suggests marked variability across the study populations, diagnostic criteria, obesity definitions, and frailty assessment methods. Therefore, while the current evidence supports a possible biological and clinical relationship between SO and frailty, the magnitude and consistency of this association remain uncertain.

From a clinical perspective, these findings emphasize the importance of integrated assessment and management strategies. Moreover, early identification using simple functional measures, combined with targeted interventions such as resistance exercise, nutritional support, and metabolic regulation, may help reduce the risk and progression of these conditions. As noted by Lim WS, *et al.* (2022)⁽¹⁴⁾, early and multidisciplinary interventions are critical for improving functional outcomes and quality of life. Future research should focus on standardizing the diagnostic criteria and conducting longitudinal studies to better understand the causal pathways and optimize intervention strategies.

The extreme heterogeneity observed is likely attributable to methodological inconsistency across the included studies. These studies used diverse diagnostic criteria for SO, including AWGS, EWGSOP II, BMI-based obesity definitions, body fat percentage measurements, DEXA-derived TBF, and WCR. Frailty assessment methods also differed substantially, including Fried phenotype criteria, Frailty Index scoring systems, and physical performance-based measures. These methodological differences likely contributed considerably to variation in the reported effect estimates.

An important source of variability across the included studies is the use of different obesity assessment methods for defining SO. At the same time, several studies relied on conventional measures such as BMI or TBF percentage; others, including Güner M, Maheshwari V, *et al.*, evaluated obesity using the WCR. Unlike BMI, which does not distinguish between fat and lean mass or reflect fat distribution, the WCR integrates central adiposity and peripheral muscle mass into a single anthropometric measure. Consequently, the WCR may identify individuals with relatively preserved BMI but increased abdominal adiposity and reduced calf circumference, thereby improving the detection of SO. This may explain in part the observed differences in

reported prevalence estimates and the strength of the association with frailty across studies. These findings suggest that WCR may represent a practical and sensitive screening tool for identifying older adults at greater risk of frailty. However, further longitudinal studies are required to establish standardized diagnostic thresholds and validate its clinical utility.

This systematic review has several limitations that should be considered when interpreting the findings. Variations in definitions may have affected the comparability of results and consistency. Although a meta-analysis was performed, it only included a small number of studies, which may limit the generalizability of the pooled findings. Publication bias could not be formally assessed, as funnel plot analysis is not considered reliable when fewer than 10 studies are available. Therefore, the possibility of publication bias cannot be excluded. Most of the included studies were cross-sectional, thereby limiting causal inference and restricting the interpretation of temporal relationships. Moreover, inconsistencies in the measurement and reporting of biomarkers posed challenges for synthesis and may have introduced measurement bias. The inclusion of only English-language publications may have led to language bias. Residual confounding remains a concern, as many of the included studies did not adequately control for important variables such as physical activity, nutritional status, comorbidities, and socioeconomic factors. Finally, variations in follow-up duration and the predominance of cross-sectional data restrict our understanding of the temporal relationships and disease progression.

Conclusion

This systematic review highlights the potential clinical and biological overlaps among sarcopenia, SO, and frailty, particularly through shared mechanisms that involve inflammation, metabolic dysfunction, reduced muscle strength, and impaired gait speed. While several individual studies reported positive associations between SO and frailty, the pooled meta-analysis did not demonstrate a significant overall association. This inconsistency is likely influenced by substantial heterogeneity that results from differences in the diagnostic criteria applied, study populations, and assessment methods. Therefore, current evidence suggests a possible relationship, but further standardized longitudinal and interventional studies are required before definitive conclusions can be established. Future research should focus on

establishing causal relationships, refining biomarker profiles, and evaluating the effectiveness of comprehensive treatment strategies. Overall, adopting a holistic and preventive approach is essential to improve functional outcomes, maintain independence, and enhance quality of life in aging populations.

Author contributions

JD, MP, DM, and PMP contributed substantially to the study conception and design; literature search; data acquisition, extraction, synthesis, and analysis; interpretation of the findings; and study supervision. JD, MP, and DM contributed substantially to data acquisition. JD, MRM, and EL contributed to drafting the manuscript. JK, UM, and RKV critically revised and edited the manuscript for important intellectual content. All authors reviewed and approved the final version submitted for publication and take responsibility for the accuracy and integrity of the work and the statements made in the published article.

Acknowledgements

The authors would like to express their gratitude to all participants who were involved in this study.

Conflict of interest statement

The authors declare no conflict of interest.

Data sharing statement

All data generated or analyzed during the present study are included in this published article. Further details are available for non-commercial purposes from the corresponding author on reasonable request.

ORCID

Jagadeesh Dhamodharan  <https://orcid.org/0000-0002-5737-6688>

Mrunal Phatak  <https://orcid.org/0009-0006-2092-2610>

Jacquilyne Kharlukhi  <https://orcid.org/0000-0001-9243-1227>

E. Lakshmi  <https://orcid.org/0000-0001-6042-3759>

Mirra Rajalakshmi. M  <https://orcid.org/0009-0009-2963-2515>

Uthamalingam Mural  <https://orcid.org/0000-0001-9334-9954>

Rajkumar Krishnan Vasanthi  <https://orcid.org/0000-0001-6866-8224>

D. Merriwin  <https://orcid.org/0000-0002-0634-466X>

P. Muthu Prasanna  <https://orcid.org/0000-0001-5907-6649>

References

1. Donini LM, Busetto L, Bischoff SC, Cederholm T, Ballesteros-Pomar MD, Batsis JA, et al. Definition and diagnostic criteria for sarcopenic obesity: ESPEN and EASO consensus statement. *Obes Facts* 2022;15: 321–35.
2. de Souza AF, de Oliveira DC, Ramírez PC, de Oliveira Máximo R, Luiz MM, Delinocente MLB, et al. Low gait speed is better than frailty and sarcopenia at identifying the risk of disability in older adults. *Age Ageing* 2025;54.
3. Saito H, Matsue Y, Kamiya K, Kagiya N, Maeda D, Endo Y, et al. Sarcopenic obesity is associated with impaired physical function and mortality in older patients with heart failure: insight from FRAGILE-HF. *BMC Geriatr* 2022;22:556.
4. Yang M, Hu M, Zhang Y, Jia S, Sun X, Zhao W, et al. Sarcopenic obesity is associated with frailty among community-dwelling older adults: findings from the WCHAT study. *BMC Geriatr* 2022;22:863.
5. Frisoli Jr A, Duque G, Paes AT, Diniz AR, Lima E, Azevedo E, et al. Sarcopenic obesity definitions and their associations with physical frailty in older Brazilian adults: data from the SARCOS study. *Arch Endocrinol Metab* 2023;67:361–71.
6. Heng MW, Chan AW, Man RE, Fenwick EK, Chew ST, Tay L, et al. Individual and combined associations of sarcopenia, osteoporosis and obesity with frailty in a multi-ethnic Asian older adult population. *BMC Geriatr* 2023;23:802.
7. Maheshwari V, Basu S. Sarcopenic obesity burden, determinants, and association with risk of frailty, falls, and functional impairment in older adults with diabetes: a propensity score matching analysis. *Cureus* 2023; 15:e49601.
8. Deguchi N, Tanaka R, Akita T. Association between sarcopenic obesity and frailty risk in community-dwelling older women with locomotive syndrome: a cross-sectional survey. *Cureus* 2024;16:e64612.
9. Güner M, Öztürk Y, Ceylan S, Okyar Ba° A, Koca M, Balci C, et al. Evaluation of waist-to-calf ratio as a diagnostic tool for sarcopenic obesity: a cross-sectional study from a geriatric outpatient clinic. *Eur Geriatr Med* 2024;15:1469–75.
10. Bozkurt ME, Vardal TO. Prevalence of sarcopenic obesity and associated factors in older adults. *Med Bull Haseki* 2024;62:149–53.
11. Damanti S, Citterio L, Zagato L, Brioni E, Magnaghi C, Simonini M, et al. Sarcopenic obesity and pre-sarcopenia contribute to frailty in community-dwelling Italian older people: data from the FRASNET study. *BMC Geriatr* 2024;24:638.
12. Sutil DV, Parentoni AN, Da Costa Teixeira LA, de Souza Moreira B, Leopoldino AA, Mendonça VA, et al. Prevalence of sarcopenia in older women and level of agreement between the diagnostic instruments proposed by the European Working Group on Sarcopenia in Older People 2 (EWGSOP2). *BMC Musculoskelet Disord* 2023; 24:182.
13. Prado CM, Batsis JA, Donini LM, Gonzalez MC, Siervo M. Sarcopenic obesity in older adults: a clinical overview. *Nat Rev Endocrinol* 2024; 20:261–77.
14. Lim WS, Cheong CY, Lim JP, Tan MM, Chia JQ, Malik NA, et al. Singapore clinical practice guidelines for sarcopenia: screening, diagnosis, management and prevention. *J Frailty Aging* 2022;11:348–69.