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# A systematic review and meta-analysis of the association between sarcopenia and myocardial infarction

Feika Li<sup>†</sup>, Tingting Bai<sup>†</sup>, Yan Ren<sup>†</sup>, Qiqi Xue, Jiaan Hu and Jiumei Cao<sup>\*</sup>

## Abstract

**Background:** Systematic review and meta-analysis of the association between sarcopenia and the development of myocardial infarction.

**Methods:** PubMed, Cochrane Library, and Embase were searched for studies on the association between sarcopenia and myocardial infarction from their inception until November 26, 2022. The fixed-effects model was used to calculate the combined risk ratio (RR) of sarcopenia in patients with myocardial infarction. Sensitivity analysis was used to test the robustness of the combined result, and funnel plot were used to test publication bias.

**Results:** Five studies were included finally. There was no significant association between sarcopenia and risk of developing myocardial infarction [RR = 1.01; 95% CI = 0.94, 1.08;  $P = 0.317$ ]. The sensitivity analysis showed robustness of the combined result. The funnel plot showed no significant publication bias.

**Conclusion:** Limited evidence suggests no definitive association between sarcopenia and risk of myocardial infarction.

## Highlights

- First meta-analysis on the correlation between sarcopenia and myocardial infarction
- A certain relationship exists between sarcopenia and myocardial infarction
- Provides a clinical basis for sarcopenia patients with myocardial infarction

**Keywords:** Sarcopenia, Myocardial infarction, Systematic review, Meta-analysis

## Background

Sarcopenia is defined as a clinical syndrome with symptoms, such as age-related decrease of skeletal muscle mass, loss of muscular strength, and dysfunction [1]. Sarcopenia has an estimated prevalence rate of 5% to 15%,

affecting the population above 65 years [2]. According to epidemiological research, the prevalence of sarcopenia in elderly Asian patients is high variable, ranging from 7.8% to 35.3% [3, 4], displaying a lower rate compared to the Western population [5]. Notably, sarcopenia is strongly associated with impaired physical function [6], poor quality of life (QoL) [7], and higher risk of adverse events (AEs) [8], even death [2]. Studies further showed that sarcopenia increases the likelihood for elderly people to use hospital care, raising the expense of health service [9, 10].

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Besides the adverse effects described above, studies reported that sarcopenia is closely related to a higher risk of cardiovascular mortality [11], which is a world-wide disease that causes disability and death. Specifically, studies revealed that patients with myocardial infarction faced a greater probability of developing sarcopenia than those without the condition [12]. Another study also reported that early myocardial contractility impairment raises the risk of mortality in patients with coronary heart diseases by affecting functions related to skeletal muscle strength like grip strength and walking speed [13].

The relationship between sarcopenia and chronic heart failure (CHF), and their common pathophysiological mechanisms and treatments have been recent research focus in studies [14]. Studies found that malnutrition, oxidative stress, systemic inflammatory response, and endocrine imbalance appear to be related with sarcopenia and CHF. However, the underlying mechanisms remains elusive and thus needs to be explored [15, 16]. Sarcopenia and CHF both affect the ubiquitin–proteasome system, myogenic inhibitor signaling, and apoptosis in the muscle [17], which may cause decrease in muscle mass and muscle dysfunction. Moreover, patients sarcopenic CHF patients are at higher risk of suffering from left ventricular ejection fraction, frailty, cachexia, mortality and other aggressive diseases [14].

As mentioned above, although the understanding of the association between sarcopenia and cardiovascular diseases is only in the initial phase, it is reasonable to speculate that there is a close association between them. Notably, an in-depth study on this topic may allow early detection of key risk factors for cardiovascular diseases in older patients with sarcopenia, and could also help effectively organize prevention and treatment strategies associated with particular vulnerabilities. Therefore, by clarifying the association between sarcopenia and myocardial infarction, the current systematic review and meta-analysis attempted to determine whether sarcopenia is associated with a higher risk of occurrence of cardiovascular diseases.

## Methods

### Study design

We conducted and then reported the current systematic review and meta-analysis according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [18]. However, we did not publicly register a formal protocol for the current systematic review and meta-analysis.

### Eligibility criteria

Inclusion criteria: (1) clinical studies included sarcopenia patients with myocardial infarction; (2) the results of the

literature summary can be expressed in terms of the corresponding statistical indicators; (3) the control group was patients with sarcopenia without myocardial infarction; (4) relationship between sarcopenia and myocardial infarction was used as an outcome indicator; and (5) only studies published in English were considered to meet our inclusion criteria.

Exclusion criteria: (1) animal experiments, review literature, conference reports, case reports, reviews; (2) studies with an unclear diagnosis of sarcopenia or myocardial infarction; (3) the control group combined with other cardiac diseases; (4) studies that could not provide disease correlation.

### Literature search

We performed systematic literature search in PubMed, the Cochrane library, and EMBASE to retrieve potentially eligible studies published before February 7, 2022. In addition, we updated literature search weekly to include the latest studies and the search was last updated on 26 November, 2022. Based on the PICO framework, we construct search strategy by combining ‘myocardial infarction,’ ‘sarcopenia,’ and their synonyms using Boolean operators. Details of the search strategy are documented in Supplementary Table 1. Furthermore, we also manually checked the reference lists of included studies to identify studies missed by the electronic search.

### Study selection

We used the EndNote X9 software to manage literature. Duplicate studies were first removed by using this software, and then ineligible studies were excluded based on the title and abstract screening. Finally, we determine eligible studies that met our eligibility criteria based on full-text screening of the remaining studies.

### Data extraction

Duplicate studies were removed. Two researchers (FKL and JMC) independently read the titles and abstracts of the remaining records, excluding those that did not meet the inclusion criteria, and the reasons for exclusion were recorded. Finally, two investigators checked with each other to decide whether to include the reports in the study. Differences in study inclusion were resolved through discussion. If they could not be resolved through discussion, a third researcher (TTB) intervened to decide whether to include the study or not. Data extraction for the included studies was performed independently by two researchers according to a pre-designed table. The extracted contents included: (1) general information: first author, year of publication, nationality, and study type; (2) source of study subjects, diagnostic criteria for sarcopenia and myocardial

infarction, myocardial measurements, and infarction grade; (3) outcome indicators: the total number of subjects, the total number of subjects in the “sarcopenia group” and the “non-sarcopenia group”, and the number of subjects complicated by myocardial infarction; (4) the quality evaluation of the literature included in the study was completed by two investigators independently, and the results were checked. If there was any disagreement, it was resolved through consultation and discussion. For studies without data, we contacted the authors by email to obtain the necessary data.

### Quality evaluation

The Quality evaluation for Newcastle–Ottawa Scale (NOS) was used to assess the quality of the included studies [19]. In this tool, seven items were covered, with a total score ranging from 0 to 9. A study was considered to be of high methodological quality if the total score was  $\geq 5$  stars.

### Statistical analysis

Meta-analysis was performed using STATA 14.0. Statistical heterogeneity among the included studies was evaluated using the Cochrane’s  $Q$  statistic [20] and  $I^2$  index [21]. If  $P > 0.1$  and  $I^2 < 50.0\%$ , statistical heterogeneity between studies were considered significant, so the fixed-effects model was used for meta-analysis. On the contrary, statistical heterogeneity was considered insignificant if  $P < 0.1$  and  $I^2 \geq 50.0\%$ , so the random-effects model was used for meta-analysis. The risk ratio (RR) with corresponding 95% confidence interval (CI) was used to express the combined result. When the RR was greater than 1 or the lower limit of the 95% CI was greater than 1 and the diamond box was on the right side of the equivalence line, indicating that the risk of myocardial infarction was higher in the sarcopenic group than in the non-sarcopenic group.

### Sensitivity analysis and publication bias

We performed sensitivity analysis using the leave-one-out strategy to test the robustness of the pooled result. The risk of publication bias was tested by visually inspecting whether the funnel plot was symmetrical, and if both sides of the funnel plot were symmetrical, it indicated that there was no publication bias, while the opposite suggested that there might be some degree of publication bias [22]. When the number of included studies was  $\geq 10$ , Begg’s and Egger’s tests were introduced to quantitatively test whether the funnel plot was symmetrical [23].

## Results

### Literature search

The literature search was last updated on 26 November, 2022. A total of 294 studies on sarcopenia and myocardial infarction were retrieved, including 59 studies in PubMed, 17 in the Cochrane library, and 218 studies in Embase. A total of 44 duplicate studies were first removed. Furthermore, 14 registered protocols were also removed. After reading titles and abstracts of the remaining studies, we excluded 227 studies that did not meet our eligibility criteria. After screening full texts of the remaining 9 studies, we further excluded 4 ineligible studies according to the following two reasons: unrelated to the topic ( $n = 1$ ) [24] and lack of grouping myocardial infarction ( $n = 3$ ) [25–27] (Supplementary Table 2). Finally, five studies [28–32] were included in the final data analysis. Following the PRISMA flowchart [18], we showed the study screening process in Fig. 1.

### Basic characteristics of the included studies

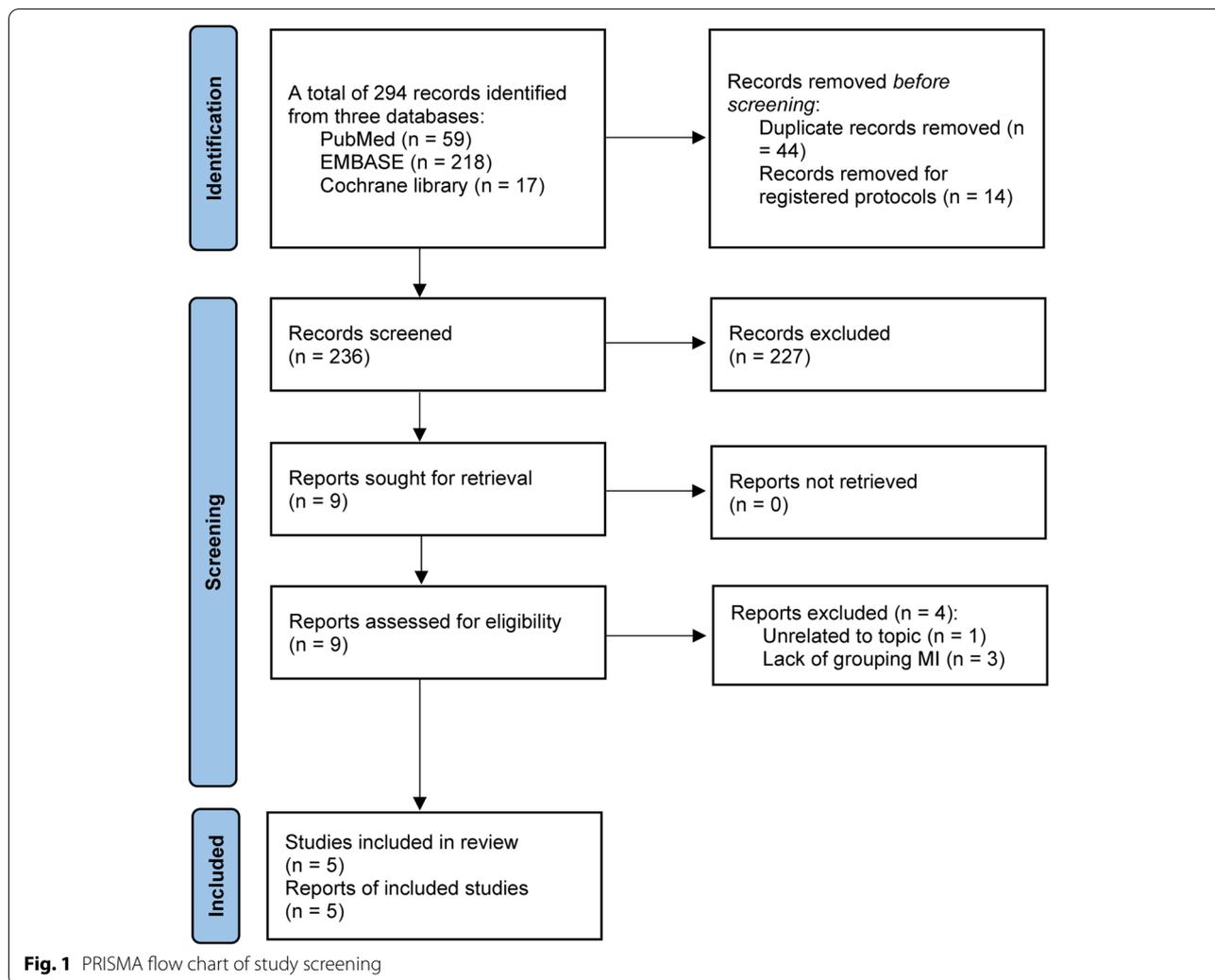
The detailed basic characteristics of these five studies are summarized in Table 1. Of these five included studies, two [28, 32] were from China, one [29] was from Brazil, and two [30, 31] were from Japan. Three studies [30–32] used Asian Working Group for Sarcopenia (AWGS) as a diagnostic criterion for sarcopenia [33], which was assessed by dual-energy X-ray absorptiometry and appendicular skeletal muscle mass index (ASMI). However, another two studies [28, 29] made a diagnosis of sarcopenia based on muscle mass, muscle strength and physical performance. For the diagnosis of heart attack, five studies used a comprehensive clinical diagnosis, including serum, electrocardiogram (ECG), and clinical presentation.

### Quality evaluation

According to the NOS tool, the total NOS score of 3 studies [30–32] was 7 stars and the total NOS score of two studies [28, 29] was 5 stars, indicating that the overall quality of all studies was high in terms of methodological quality. The results of methodological quality assessment based on the NOS tool are shown in Table 2.

### Correlation between sarcopenia and myocardial infarction

A total of five studies with a total sample size of 783,626 were included. Heterogeneity assessment showed no significantly statistical heterogeneity among the five studies ( $I^2 = 15.3\%$ ,  $P = 0.317$ ), so we selected the fixed-effects model to perform meta-analysis. Pooled result from meta-analysis showed that there was no significantly statistical association between sarcopenia



and the risk of myocardial infarction [RR=1.01; 95% CI=0.94, 1.08; z=0.661, P=0.509). The results of individual studies and pooled results are shown in Fig. 2. Furthermore, as shown in Fig. 3, the results of sensitivity analysis using the leave-one-out strategy showed that the pooled result of the current meta-analysis was robust.

**Publication bias**

A funnel plot was evaluated for all five studies, and the results are shown in Fig. 4. The two sides of the funnel are symmetrical, and no significant publication bias was found in this study.

**Discussion**

As far as we know, this is the first study to investigate the association between sarcopenia and myocardial infarction using the meta-analytical technique. In the

current systematic review and meta-analysis, a total of 783,626 patients from 5 eligible studies were included in the final analysis. All five studies were high quality in methodological quality, while pooled result showed no significant association between sarcopenia and myocardial infarction.

Healthcare systems are under great stress with an increasing demand resulting from the ageing of the population [34], because various potential physiological changes and a higher risk of diseases emerge with ageing [35]. Sarcopenia and weakness are two common geriatric syndromes [2] and these two conditions are closely related [36]. Despite the fact that these two diseases were commonly confused, they are two distinct diseases [37]. It should be highlighted that sarcopenia and frailty are reported to be associated with chronic diseases [38] (e.g., chronic obstructive pulmonary disease [COPD] [39] and osteoporosis [40]), a

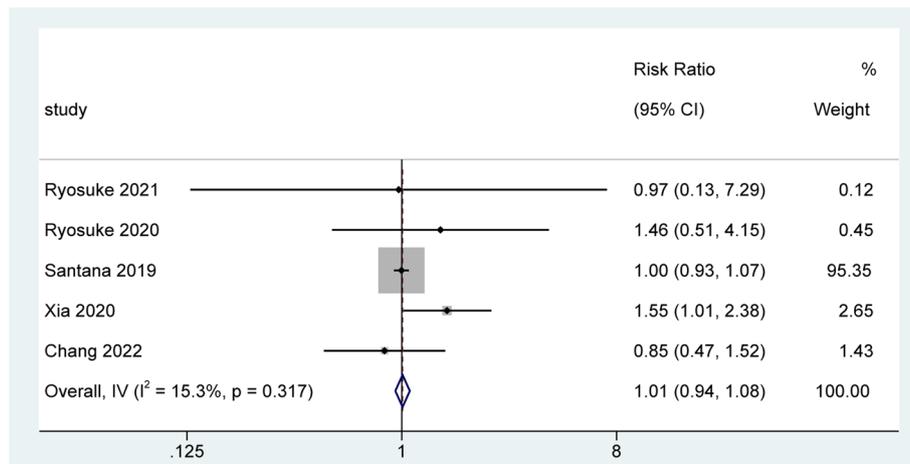
**Table 1** The basic characteristic of the included studies

Author	Country	Age	Study design	Sample	Muscle measurement method	Diagnosis of sarcopenia	Diagnosis criteria for sarcopenia	Diagnostic criteria for heart attack	Heart Attack Classification
Sato 2021 [31]	Japan	72 ± 1 / 65 ± 13	Retrospective case-control study	303	DXA	ASMI	AWGS	Comprehensive clinical diagnosis	Not mentioned
Sato 2020 [30]	Japan	66 ± 13	Observational cohort study	387	DXA	ASMI	AWGS	Comprehensive clinical diagnosis	Not mentioned
Santana 2019 [29]	Brazil	71.6 ± 7.4	Cross-sectional study	99	Muscle mass, HGS measurements made using a digital dynamometer, and the gait speed test	Muscle mass, muscle strength and physical performance	Based on muscle mass, muscle strength and physical performance	Comprehensive clinical diagnosis	Not mentioned
Xia 2021 [32]	China	62.2 ± 8.4	Prospective cohort study	2432	DXA	ASMI	AWGS	Comprehensive clinical diagnosis	Not mentioned
Chang 2022 [28]	China	≥ 20	Cross-sectional study	780,405	Muscle mass, HGS made using a digital dynamometer, the gait speed test	Muscle mass, muscle strength and physical performance	Based on muscle mass, muscle strength and physical performance	Comprehensive clinical diagnosis	Not mentioned

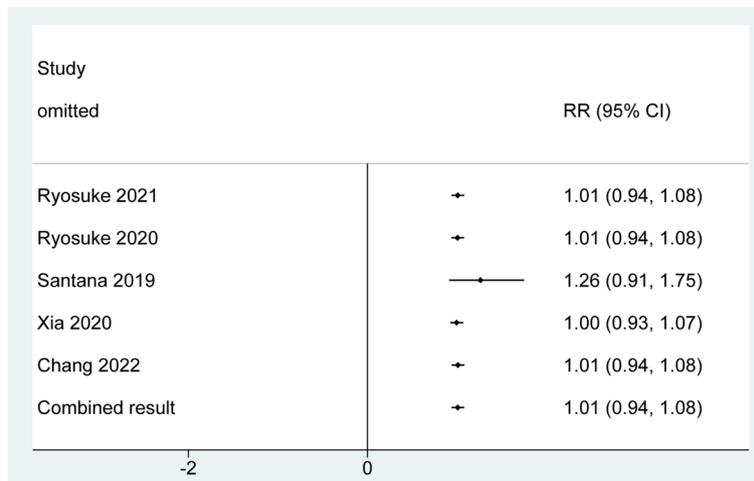
DXA Dual energy X-ray absorptiometry, HGS Hand grip strength, ASMI Appendicular skeletal muscle mass index, AWGS Asian working group for sarcopenia

**Table 2** Newcastle Ottawa scale to assess the quality of the included studies

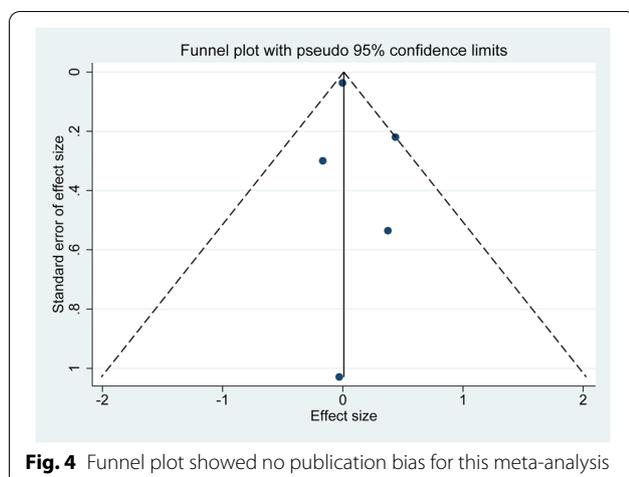
Study	Selection				Comparability	Outcome			NOS score
	Representative of the cases	Selection of controls	Ascertainment of exposure	Outcome of interest		Comparability of the design or analysis	Assessment of outcome	Sufficient follow-up	
Sato 2021 [31]	1	1	1	1	2	1	0	0	7
Sato 2020 [30]	1	1	1	1	2	1	0	0	7
Santana 2019 [29]	0	0	1	1	2	1	0	0	5
Xia 2021 [32]	1	1	1	1	2	1	0	0	7
Chang 2022 [28]	0	0	1	1	2	1	0	0	5



**Fig. 2** Forest plot of the association between sarcopenia and myocardial infarction, showing a significant association between sarcopenia and risk of myocardial infarction



**Fig. 3** Sensitivity analysis based on the leave-one-out strategy showed that the exclusion of individual study did not significantly affect the result



high occurrence of polypharmacy [41, 42] and adverse events as falls and poor QoL [7, 8, 43].

Fortunately, sarcopenia and frailty are both curable, and their expenses can be avoided, eliminating pressing social needs in the future [44–47]. Clarifying how these two factors relate to chronic diseases is therefore essential [38]. Studies attempted to investigate the correlation between cardiovascular mortality and sarcopenia and frailty given that cardiovascular illnesses are a major worldwide disease causing disability and death [11–13], but the results have been inconsistent. Sarcopenia, however, is not significantly linked to the occurrence of myocardial infarction, according to the current systematic review and meta-analysis. In fact, among the five studies included in the current systematic review and meta-analysis, only one study [32] found that sarcopenia increased the risk of myocardial infarction, while the remaining four studies [28–31] did not reveal a significant association between sarcopenia and myocardial infarction. Age, the presence of a disease, dietary status, and lifestyle choices are all thought to have an impact on the development of sarcopenia. So far, sedentary and inactive lifestyles are known risk factors for the condition [2]. In these eligible studies included in the current systematic review and meta-analysis, patients with different diseases were involved, which will inevitably confuse the association between sarcopenia and myocardial infarction. Therefore, we also suggest to interpret our finding with caution before more studies with large-scale validate it.

This study has some limitations. There is a lack of research literature on the association between sarcopenia and myocardial infarction, which might contribute to the low confidence of the findings. In addition, it was not possible to perform subgroup analyses. The association of body mass and nutritional indicators with myocardial infarction in patients with sarcopenia should be explored in greater depth. Furthermore,

we did not have strong confidence in whether publication bias influenced the pooled result as only 4 studies were included in the final analysis. Finally, there was no formal protocol for current systematic review and meta-analysis, thus inevitably compromising the transparency of the current study despite being conducted strictly in accordance with the PRISMA statement.

## Conclusions

Based on the limited evidence, we conclude that there is no significantly statistical association between sarcopenia and the occurrence of myocardial infarction. However, considering the extremely limited number of included studies, more in-depth studies are needed.

## Abbreviations

RR: Risk ratio; QoL: Quality of life; PRISMA: Preferred reporting items for systematic reviews and meta-analyses; CI: Confidence interval; AWGS: Asian working group for Sarcopenia; ASMI: Appendicular skeletal muscle mass index; ECG: Electrocardiogram; COPD: Chronic obstructive pulmonary disease; NOS: Newcastle Ottawa scale.

## Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12877-022-03712-1>.

**Additional file 1: Supplementary Table 1.** Details of search strategy of three target databases. **Supplementary Table 2.** The list of excluded studies during the full text screening phase.

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Not applicable.

## Authors' contributions

JMC and FKL designed and conducted the research; FKL, JMC, TTB, YR and QXQ collected and assembled data; FKL, JAH and JMC executed data analysis and interpretation; All authors wrote the manuscript and approved the final manuscript.

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## Availability of data and materials

All data generated or analysed during this study are included in this article.

## Declarations

### Ethics approval and consent to participate

Not applicable.

### Consent for publication

Not applicable.

### Competing interests

The authors declare that they have no competing interests.

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## References

- Fielding RA, Vellas B, Evans WJ, et al. Sarcopenia: an undiagnosed condition in older adults. Current consensus definition: prevalence, etiology, and consequences international working group on sarcopenia. *J Am Med Dir Assoc*. 2011;12:249–56.
- Cruz-Jentoft AJ, Baeyens JP, Bauer JM, et al. Sarcopenia: European consensus on definition and diagnosis: report of the European working group on sarcopenia in older people. *Age Ageing*. 2010;39:412–23.
- Lau EM, Lynn HS, Woo JW, et al. Prevalence of and risk factors for sarcopenia in elderly Chinese men and women. *J Gerontol A Biol Sci Med Sci*. 2005;60:213–6.
- Ryu M, Jo J, Lee Y, et al. Association of physical activity with sarcopenia and sarcopenic obesity in community-dwelling older adults: the Fourth Korea National Health and Nutrition Examination Survey. *Age Ageing*. 2013;42:734–40.
- von Haehling S, Morley JE, Anker SD. An overview of sarcopenia: facts and numbers on prevalence and clinical impact. *J Cachexia Sarcopenia Muscle*. 2010;1:129–33.
- Cesari M, Landi F, Vellas B, et al. Sarcopenia and physical frailty: two sides of the same coin. *Front Aging Neurosci*. 2014;6:192.
- Kojima G, Iliffe S, Jivraj S, et al. Association between frailty and quality of life among community-dwelling older people: a systematic review and meta-analysis. *J Epidemiol Community Health*. 2016;70:716–21.
- Öztürk ZA, Türkbeyler İH, Abiyev A, et al. Health-related quality of life and fall risk associated with age-related body composition changes; sarcopenia, obesity and sarcopenic obesity. *Intern Med J*. 2018;48:973–81.
- Sirven N, Rapp T. The Dynamics of Hospital Use among Older People Evidence for Europe Using SHARE Data. *Health Serv Res*. 2017;52:1168–84.
- Antunes AC, Araújo DA, Veríssimo MT, et al. Sarcopenia and hospitalisation costs in older adults: a cross-sectional study. *Nutr Diet*. 2017;74:46–50.
- Goodpaster BH, Carlson CL, Visser M, et al. Attenuation of skeletal muscle and strength in the elderly: The Health ABC Study. *J Appl Physiol*. 1985;2001(90):2157–65.
- Fülster S, Tacke M, Sandek A, et al. Muscle wasting in patients with chronic heart failure: results from the studies investigating co-morbidities aggravating heart failure (SICA-HF). *Eur Heart J*. 2013;34:512–9.
- Nichols S, O'Doherty AF, Taylor C, et al. Low skeletal muscle mass is associated with low aerobic capacity and increased mortality risk in patients with coronary heart disease - a CARE CR study. *Clin Physiol Funct Imaging*. 2019;39:93–102.
- Curcio F, Testa G, Liguori I, Papillo M, Flocco V, Panicara V, et al. Sarcopenia and Heart Failure. *Nutrients*. 2020;12(1):211.
- Carbone S, Billingsley HE, Rodriguez-Miguel P, et al. Lean Mass Abnormalities in Heart Failure: The Role of Sarcopenia, Sarcopenic Obesity, and Cachexia. *Curr Probl Cardiol*. 2020;45:100417.
- Yin J, Lu X, Qian Z, et al. New insights into the pathogenesis and treatment of sarcopenia in chronic heart failure. *Theranostics*. 2019;9:4019–29.
- Dos Santos MR, Saitoh M, Ebner N, et al. Sarcopenia and Endothelial Function in Patients With Chronic Heart Failure: Results From the Studies Investigating Comorbidities Aggravating Heart Failure (SICA-HF). *J Am Med Dir Assoc*. 2017;18:240–5.
- Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*. 2021;372:n71.
- Cook DA, Reed DA. Appraising the quality of medical education research methods: the Medical Education Research Study Quality Instrument and the Newcastle-Ottawa Scale-Education. *Acad Med*. 2015;90:1067–76.
- Bowden J, Tierney JF, Copas AJ, et al. Quantifying, displaying and accounting for heterogeneity in the meta-analysis of RCTs using standard and generalised Qstatistics. *BMC Med Res Methodol*. 2011;11:41.
- Higgins JP, Thompson SG, Deeks JJ, et al. Measuring inconsistency in meta-analyses. *Bmj*. 2003;327:557–60.
- Begg CB, Berlin JA. Publication Bias: A Problem in Interpreting Medical Data. *J R Stat Soc A Stat Soc*. 1988;151:419–45.
- Page MJ, McKenzie JE, Higgins JPT. Tools for assessing risk of reporting biases in studies and syntheses of studies: a systematic review. *BMJ Open*. 2018;8:e019703.
- Qiao YS, Tang X, Chai YH, et al. Association of Sarcopenia and A Body Shape Index With Overall and Cause-Specific Mortality. *Front Endocrinol*. 2022;13:839074.
- Kobayashi H, Takahashi M, Fukutomi M, et al. The long-term prognostic factors in hemodialysis patients with acute coronary syndrome: perspectives from sarcopenia and malnutrition. *Heart Vessels*. 2021;36:1275–82.
- Nilsson G, Hedberg P, Leppert J, Ohrvik J. Basic Anthropometric Measures in Acute Myocardial Infarction Patients and Individually Sex- and Age-Matched Controls from the General Population. *J Obes*. 2018;2018:3839482.
- Zhang N, Zhu W, Liu X, et al. Related factors of sarcopenia in hospitalized elderly patients with coronary heart disease. *Chinese J Cardiology*. 2019;47:979–84.
- Chang CM, Lin JR, Fu TC. Associations Between Sarcopenia, Heart Failure and Myocardial Infarction in Patients With Systemic Lupus Erythematosus and Rheumatoid Arthritis. *Front Med*. 2022;9:882911.
- Santana NM, Mendes RML, Silva NFD, et al. Sarcopenia and sarcopenic obesity as prognostic predictors in hospitalized elderly patients with acute myocardial infarction. *Einstein (Sao Paulo)*. 2019;17:eAO4632.
- Sato R, Akiyama E, Konishi M, et al. Decreased appendicular skeletal muscle mass is associated with poor outcomes after st-segment elevation myocardial infarction. *J Atheroscler Thromb*. 2020;27:1278–87.
- Sato R, Okada K, Akiyama E, et al. Impact of sarcopenic obesity on long-term clinical outcomes after ST-segment elevation myocardial infarction. *Atherosclerosis*. 2021;335:135–41.
- Xia MF, Chen LY, Wu L, et al. Sarcopenia, sarcopenic overweight/obesity and risk of cardiovascular disease and cardiac arrhythmia: A cross-sectional study. *Clin Nutr*. 2021;40:571–80.
- Chen LK, Liu LK, Woo J, et al. Sarcopenia in Asia: consensus report of the Asian Working Group for Sarcopenia. *J Am Med Dir Assoc*. 2014;15:95–101.
- Álvarez-Bustos A, Rodríguez-Sánchez B, Carnicero-Carreño JA, et al. Healthcare cost expenditures associated to frailty and sarcopenia. *BMC Geriatr*. 2022;22:747.
- Sousa-Santos AR, Amaral TF. Differences in handgrip strength protocols to identify sarcopenia and frailty - a systematic review. *BMC Geriatr*. 2017;17:238.
- Landi F, Calvani R, Cesari M, et al. Sarcopenia as the Biological Substrate of Physical Frailty. *Clin Geriatr Med*. 2015;31:367–74.
- Davies B, García F, Ara I, et al. Relationship Between Sarcopenia and Frailty in the Toledo Study of Healthy Aging: A Population Based Cross-Sectional Study. *J Am Med Dir Assoc*. 2018;19:282–6.
- de Sire A, Lippi L, Aprile V, et al. Pharmacological, Nutritional, and Rehabilitative Interventions to Improve the Complex Management of Osteoporosis in Patients with Chronic Obstructive Pulmonary Disease: A Narrative Review. *J Pers Med*. 2022;12.
- Gao J, Deng M, Li Y, et al. Resistin as a Systemic Inflammation-Related Biomarker for Sarcopenia in Patients With Chronic Obstructive Pulmonary Disease. *Front Nutr*. 2022;9:921399.
- Yeung SSY, Reijnierse EM, Pham VK, et al. Sarcopenia and its association with falls and fractures in older adults: A systematic review and meta-analysis. *J Cachexia Sarcopenia Muscle*. 2019;10:485–500.
- Gnjidic D, Hilmer SN, Blyth FM, et al. High-risk prescribing and incidence of frailty among older community-dwelling men. *Clin Pharmacol Ther*. 2012;91:521–8.
- König M, Spira D, Demuth I, et al. Polypharmacy as a Risk Factor for Clinically Relevant Sarcopenia: Results From the Berlin Aging Study II. *J Gerontol A Biol Sci Med Sci*. 2017;73:117–22.
- Fried LP, Tangen CM, Walston J, et al. Frailty in older adults: evidence for a phenotype. *J Gerontol A Biol Sci Med Sci*. 2001;56:M146–56.
- Puts MTE, Toubasi S, Andrew MK, et al. Interventions to prevent or reduce the level of frailty in community-dwelling older adults: a scoping review of the literature and international policies. *Age Ageing*. 2017;46:383–92.
- Gill TM, Gahbauer EA, Allore HG, et al. Transitions between frailty states among community-living older persons. *Arch Intern Med*. 2006;166:418–23.
- Dent E, Morley JE, Cruz-Jentoft AJ, et al. Physical Frailty: ICFSR International Clinical Practice Guidelines for Identification and Management. *J Nutr Health Aging*. 2019;23:771–87.
- Mareschal J, Genton L, Collet TH, et al. Nutritional Intervention to Prevent the Functional Decline in Community-Dwelling Older Adults: A Systematic Review. *Nutrients*. 2020;12.

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