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RESEARCH ARTICLE

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Prevalence and prognosis of sarcopenia in acute COVID-19 and long COVID: a systematic review and meta-analysis

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ABSTRACT

Background: A comprehensive investigation delineating the prevalence of sarcopenia across different infection phases, from acute COVID-19 to long COVID, is lacking. Meanwhile, the relationship between sarcopenia and adverse outcomes among COVID-19 patients remains inconsistent.

Materials and methods: A systematic search of MEDLINE/PubMed, Embase, Cochrane Library, Web of Science, and Scopus, before 22nd February 2025, was conducted to identify studies assessing sarcopenia prevalence in acute COVID-19 and long COVID. Random effects meta-analyses were performed to estimate the pooled prevalence of sarcopenia for acute COVID-19 and long COVID patients. Subgroup analyses stratified by assessment tool, region, income, hospitalization status, and age were performed. The associations between sarcopenia and COVID-19-related clinical outcomes were further quantified.

Results: A total of 39 studies with 6,982 individuals were included. The pooled prevalence of sarcopenia was 48.7% (95% confidence interval (CI): 39.6–57.9%) in acute COVID-19 and 23.5% (95% CI: 12.7–39.4%) in long COVID. In acute COVID-19 patients, sarcopenia was not significantly associated with length of stay (mean difference = 2.215, 95% CI: −0.004 to 4.433), mechanical ventilation (Odds ratio (OR) = 1.80, 95% CI: 0.84–3.85), admission to the intensive care unit (OR = 1.05, 95% CI: 0.63–1.77), or mortality (OR = 1.41, 95% CI: 0.86–2.32), but was significantly associated with tracheostomy (OR = 2.48, 95% CI: 1.28–4.82).

Conclusion: In conclusion, our findings indicate that sarcopenia is highly prevalent in acute COVID-19 and persists in a substantial proportion of long COVID patients, suggesting prolonged muscle loss beyond the acute phase. Future well-designed studies are needed to further investigate the association between sarcopenia and short-term and long-term prognostic outcomes in both acute and long COVID patients.

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Sarcopenia; COVID-19; long COVID; prevalence; prognosis; systematic review; meta-analysis

Introduction

The outbreak of coronavirus disease 2019 (COVID-19) has profoundly shaped the healthcare system and the entire world. Millions of people continue to suffer long-term sequelae of COVID-19 infection, a condition recognized as long COVID (LC) [1]. LC is a multisystemic condition generally defined as symptoms persisting for three months or more after acute COVID-19 infection, with incidence rates ranging from 10 to 70% depending on the studied cohorts and the time of screening [2]. LC can occur in individuals of all ages, regardless of the severity of the initial infection or the presence of comorbidities [3]. LC patients experience a wide range of persistent signs and symptoms, such as cardiovascular and thrombotic diseases, cerebrovascular disease, myalgic encephalomyelitis/chronic fatigue syndrome (ME/CFS), dysautonomia, autoimmune conditions, and cognitive impairment [4]. Beyond its health implications, LC also imposes a substantial

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socioeconomic burden, contributing to increased healthcare costs and reduced workforce productivity [5].

Sarcopenia, a condition characterized by progressive and generalized deterioration of skeletal muscle, including changes in muscle strength and function [6], has been widely recognized as a predictor of adverse outcomes among general older adults, such as frailty [7], falls [8], functional impairment [9], increased vulnerability [10], and mortality [11]. Although traditionally considered as a condition of the elderly, emerging evidence suggests that sarcopenia can develop at any age [11]. The European Working Group on Sarcopenia in Older People (EWGSOP) defines acute sarcopenia as incidental sarcopenia occurring within 6 months after stressful events, which is particularly prevalent among hospitalized patients [6]. Although multiple factors are associated with sarcopenia [12], COVID-19 infection has emerged as a potent trigger for its onset and progression [13]. COVID-19 patients frequently exhibit immune dysregulation that is mediated by an exaggerated inflammation response associated with cytokine storm or release syndrome [14]. This phenomenon has been linked to the development of sarcopenia, as reported in previous studies [15,16]. A study by Quaisar et al. [17] demonstrated that 26% of previously non-sarcopenic individuals developed sarcopenia following COVID-19 infection. Furthermore, our prior meta-analysis estimated that 48.0% of COVID-19 patients exhibited sarcopenia [18].

While previous findings highlight the high prevalence of sarcopenia among COVID-19 patients, two important knowledge gaps remain. First, the prevalence of sarcopenia specifically in LC patients has not been systematically synthesized, despite increasing concerns about its persistence and progression beyond the acute phase. Understanding this prevalence is essential for identifying at-risk populations and guiding post-acute rehabilitation strategies. Second, while sarcopenia has been linked to mortality in critically ill patients in the intensive care unit (ICU) [19], its prognosis on COVID-19-related clinical outcomes remains unclear, with inconsistent results [20]. Investigating the value of sarcopenia in predicting the prognosis of COVID patients is crucial for prognostication and clinical decision-making. Therefore, in this meta-analysis, we aimed (1) to estimate the prevalence of sarcopenia among COVID-19 patients with different infection phases, and (2) to examine its association with clinical outcomes across these phases.

Materials and methods

This systematic review was performed following the 24-step guide [21] and Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines [22] (Table S1). The review protocol was registered with PROSPERS (CRD42022339508).

Search strategy

Two independent investigators conducted a literature search in MEDLINE/PubMed, Embase, Cochrane Library, Web of Science, and Scopus without language restriction up to February 22nd, 2025. Relevant key terms were combined in the search strategy, which included 'coronavirus infections', 'coronavirus', 'COVID-19', 'SARS-CoV-2', 'severe acute respiratory syndrome', '2019-nCoV', 'sarcopenia', 'muscular atrophy', 'muscle weakness', 'muscle loss', 'muscle depletion', 'muscle reduction', 'muscle wasting', 'reduced muscle', 'loss of muscle', 'low muscle mass' and 'body composition'. The full search strategy is presented in the (Supplementary Materials Table S2).

Study selection

After the initial search and removal of duplicate literature, two independent reviewers conducted a screening for eligibility on the title and abstract of the literature, and the full text of potentially relevant studies was further evaluated if they satisfied the inclusion criteria. Conflicts were resolved by a third researcher.

Inclusion and exclusion criteria

Studies were included in our systematic review if they met the following criteria: (1) population: patients with acute COVID-19 or LC, (2) exposure: Covid-19 patients with sarcopenia, (3) control: Covid-19 patients without sarcopenia, (4) outcome: sarcopenia or risk of sarcopenia identified by validated assessment tools as the primary outcome, and (5) study designs: observational studies including both cross-sectional and longitudinal cohort studies. No restrictions were placed on language, country of origin, patient age, or gender. Conference abstracts, letters, comments, editorials, case reports, systematic reviews, and meta-analyses were excluded. Discrepancies during the screening process were resolved through consensus with a senior investigator.

Outcomes

The primary outcome of this meta-analysis was the pooled prevalence of sarcopenia among patients with COVID-19 across different infection phases, from acute COVID-19 to LC. The secondary outcomes were the length of stay (LOS), the need for mechanical

ventilation (MV) or tracheostomy, ICU admission, and mortality. These outcomes were selected based on their clinical relevance in assessing sarcopenia status and prognosis in COVID-19 patients.

Data extraction

Data were extracted by two independent authors using a standardized data extraction form. The following items of studies were extracted: first author, publication date, study location (country and World Health Organization [WHO] region), income level, study type, COVID confirmation, population setting, hospitalization status, sarcopenia assessment tools, total sample size, number of sarcopenia cases, infection phase, mean of age (if applicable, otherwise, the median of age was extracted), and clinical outcomes (if available in each included studies). Following independent data extraction, two researchers cross-checked all extracted data and resolved disagreements by consultation until a consensus was reached. Disagreements were resolved by recruiting a third author to review the data.

Quality assessment

All included studies were independently evaluated by two authors for the risk of bias, assessed separately for the primary outcome (prevalence of sarcopenia) and secondary outcomes (clinical outcomes) in line with previous meta-analyses [23]. For studies reporting sarcopenia prevalence among COVID-19 patients, we used an adapted Newcastle-Ottawa Quality Assessment Scale (NOS), as previously adapted by Modesti et al. [24]. Since most included studies were single-arm observational studies, we excluded non-applicable NOS sections (e.g. comparability and outcome assessment), to our needs (Table S3). This modified NOS has been previously applied in meta-analysis evaluating disease prevalence [25,26]. Studies scoring ≥3 points were considered to have a low risk of bias, while those scoring <3 points were classified as having a high risk of bias. For studies assessing clinical outcomes based on the presence of sarcopenia, we used an adapted NOS for cross-sectional studies (Table S4) and the standard NOS for cohort studies (Table S5). In cross-sectional studies, a score of ≥7 indicated a low risk of bias, while scores <7 indicated a high risk of bias. In cohort studies, a total score of 8 or 9 was considered low risk, while scores of 6 or 7 indicated moderate risk. Any disagreements in risk assessment were resolved through consensus and review by an experienced methodologist.

Statistical analysis

The estimate of sarcopenia was expressed as proportions (%) with corresponding 95% confidence intervals (CI). The prevalence of sarcopenia reported in the studies was pooled using the 'metaprop' programs as it allows the inclusion of studies with proportions equal to zero or 100% and avoids confidence intervals beyond the 0 to 1 range. As for investigating the impact of sarcopenia on clinical outcomes, we used the random effect generic inverse variance model to calculate Odds Ratios (OR) and 95% CI for dichotomous variables, and the mean difference (MD) and 95% CI were used for continuous variables. We evaluated heterogeneity between study-specific estimates using two methods [27]. First, the presence of heterogeneity was assessed using Cochran's Q-test. As this test is underpowered to detect moderate degrees of heterogeneity [28], a significance level of $p < 0.10$ was considered suggestive of heterogeneity. Second, we calculated the I^2 statistic to estimate what proportion of total variation across studies was due to heterogeneity rather than chance. Heterogeneity can be quantified as low, moderate, and high, with upper limits of 25%, 50%, and 75% for the I^2 value, respectively [29]. After completing the heterogeneity analysis, we chose the appropriate effects summary model to analyze according to the I^2 value. Given the I^2 value ≥ 50%, the random effects model was used to pool the effect size. Otherwise, it would be replaced by a fixed effects model. According to the prevalence of sarcopenia in patients with COVID-19, to find out the source of heterogeneity in the data, we performed subgroup analyses stratified by assessment tool, WHO region, income level, hospitalization status, and age. For the primary outcome, a sensitivity analysis was performed with a 'leave-one-out' approach, in which all studies are removed one at a time to identify studies that may influence the primary analysis. We also evaluated the publication bias for primary outcome using both visual inspection of a funnel plot and the Egger regression test [30]. The threshold for statistical significance was 2-sided $p < 0.05$. All statistical analyses were performed using R software (version 4.3.3, R Foundation for Statistical Computing, Vienna, Austria).

Results

Selection process

A total of 7,208 references were initially identified through electronic databases, of which 1,037 were from MEDLINE/PubMed, 1,875 were from Embase, 963 were from Web of Science, 297 were from the Cochrane Library, and 3,036 were from Scopus. After removing

duplicates, 4,753 records remained and were screened. Title and abstract screening excluded 4,430 studies; the full texts of the remaining 311 studies were reviewed. Finally, 39 observational studies which met the eligibility criteria were included into the meta-analysis [31–69] (Figure 1).

Study characteristics

All the studies included in the present study were published between March 2021 and March 2024 (Table 1). A total of 6,982 COVID-19 patients were included in these studies with median/mean age ranging from 44.5 to 86.1 years. Twenty-six studies were conducted in the European Region (EURO); 8 in the Region of the Americas (AMRO); 4 in the Western Pacific Region (WPRO); and one in the Eastern Mediterranean Region (EMRO). Eighteen studies were retrospective cohort studies; 12 studies were prospective cohort studies; and nine studies were cross-sectional studies. 36 studies were conducted in a hospital-based setting; 2 in a rehabilitation unit setting; and one in mixed settings. Regarding the infection phase of COVID-19, 30 studies included 5,123 patients with acute COVID-19 while 9 studies included 1,859 patients with LC. As for the type of sarcopenia assessment tool, 7 used abdominal computed tomography (CT) body composition parameters; 7 used chest CT body composition parameters; 12 were based on Strength, Assistance with Walking, Rising from a Chair, Climbing Stairs, and Falls (SARC-F) questionnaire; 5 on HGS measured using a digital hand dynamometer; and 8 on other methods such as bioelectrical impedance analysis (BIA), dual-energy X-ray absorptiometry (DXA), and short physical performance battery (SPPB); Table 2 provides a summary of the assessment methods, parameters, and cut-off values applied to all included studies.

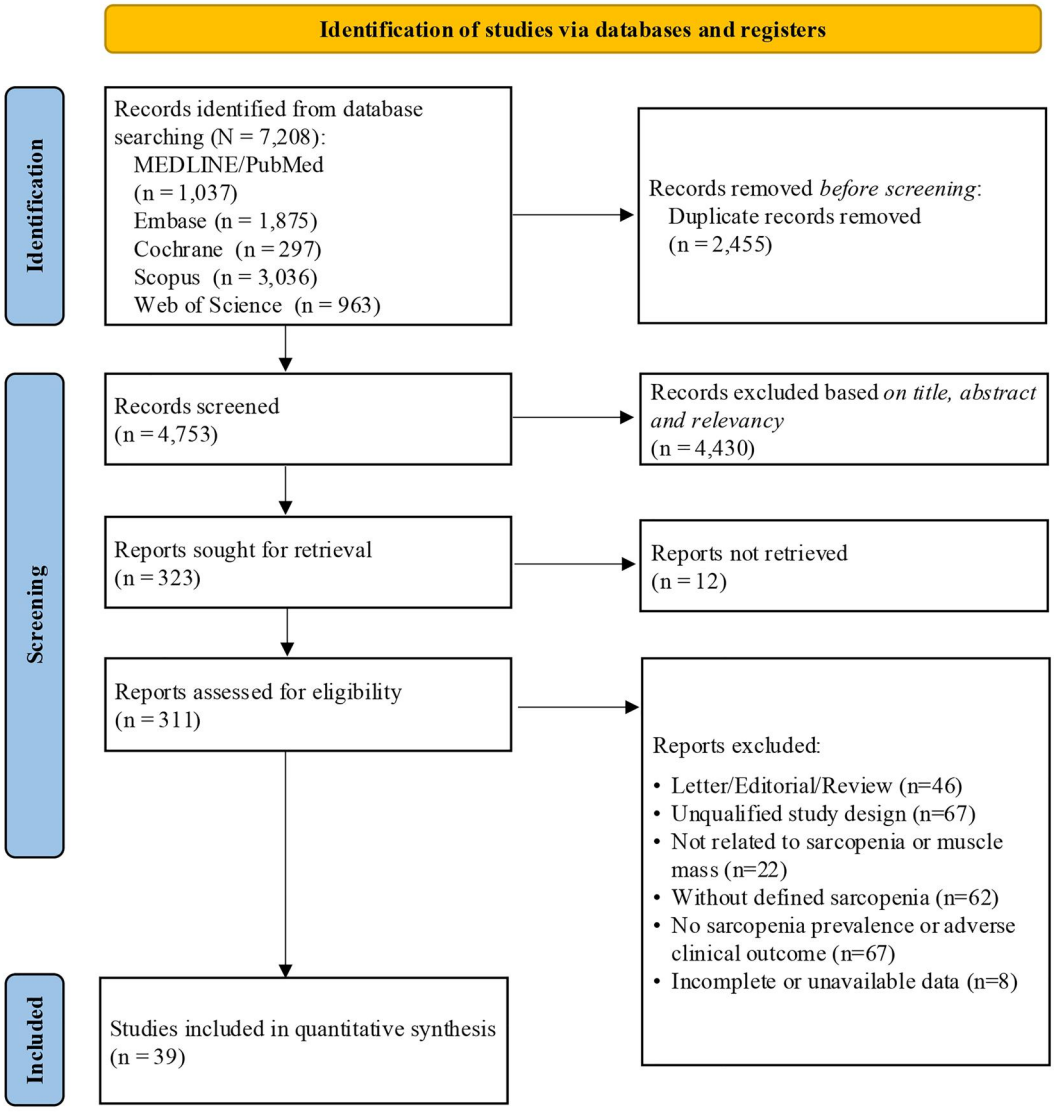

Figure 1. PRISMA (2020) diagram of study screening and selection.

Table 1. Basic information of included studies.

Study	Country	WHO region	Income	Study type	COVID Confirmation	Setting	Hospitalization status	Assessment tool	N	SP	Infection phase	Age	Male	Outcome
Ufuk et al. (2020) [63]	Turkey	EURO	UMIC	PCS	RT-PCR	Hospital	Mixed wards	Chest CT-scan	130	44	Acute COVID-19	48	0.58	Intubation, Prolonged Hospital stay, Mortality, Severity[f]
Moctezuma-Velázquez et al. (2021) [55]	Mexico	AMRO	UMIC	RCS	RT-PCR	Hospital	Mixed wards	Chest CT-scan	519	115	Acute COVID-19	51	0.64	Mortality, ICU admission, MV, Severity[f]
Gil et al. (2021) [37]	Brazil	AMRO	UMIC	PCS	PCR	Hospital	Mixed wards	Dynamometer	174	58	Acute COVID-19	NR	0.49	Hospital stay
McGovern et al. (2021) [53]	UK	EURO	HIC	RCS	PCR or chest X-ray or CT thorax	Hospital	Mixed wards	Abdominal CT-scan	63	39	Acute COVID-19	NR	0.48	ICU admission, Mortality, Severity[f]
Damanti et al. (2021) [36]	Italy	EURO	HIC	RCS	RT-PCR	Hospital	ICU	Abdominal CT-scan	81	53	Acute COVID-19	59.3	0.88	Extubation, Complications, Mortality
Giraudo et al. (2021) [38]	Italy	EURO	HIC	RCS	RT-PCR	Hospital	Mixed wards	Chest CT-scan	150	43	Acute COVID-19	61.3	0.69	ICU admission, Mortality, Severity[f]
Kara et al. (2021) [45]	Turkey	EURO	UMIC	CSS	PCR	Hospital	Nursing ward	Dynamometer	312	40	Acute COVID-19	46.1	0.55	Severity[f]
Gobbi et al. (2021) [39]	Italy	EURO	HIC	PCS	RT-PCR	RC	NR	BIA	34	20	Long COVID	NR	0.47	Rehabilitation outcomes
Wierdsma et al. (2021) [64]	NL	EURO	HIC	PCS	NR	Hospital	Mixed wards	SARC-F	219	159	Acute COVID-19	NR	NR	Nutritional status, risk of SP and nutrition related complaints
Cuerda et al. (2021) [33]	Spain	EURO	HIC	RCS	NR	Hospital	ICU	SARC-F	176	153	Acute COVID-19	60.3	0.72	Hospital stay, ICU stay, Tracheostomy, MV, Mortality
Riesgo et al. (2021) [60]	Spain	EURO	HIC	CSS	RT-PCR	Hospital	NR	SARC-F	337	304	Acute COVID-19	86.1	0.5	Mortality, Hospital stay
Yi et al. (2021) [66]	China	WPRO	UMIC	RCS	RT-PCR	Hospital	Mixed wards	Chest CT-scan	234	78	Acute COVID-19	44.5	0.57	Severity[f]
Kim et al. (2021) [46]	Korea	WPRO	HIC	RCS	RT-PCR	Hospital	Mixed wards	Chest CT-scan	121	29	Acute COVID-19	62	0.36	Hospital stay, Mortality, ICU admission, Severity[f]
Ma et al. (2021) [50]	China	WPRO	UMIC	PCS	RT-PCR	Hospital	NR	SARC-F	114	38	Acute COVID-19	69.5	0.5	Severity[f]
Ramos et al. (2022) [58]	Spain	EURO	HIC	PCS	NR	Hospital	Mixed wards	SARC-F	62	31	Long COVID	NR	NR	The prevalence of DRM and the risk of SP
Osuna-Padilla et al. (2022) [57]	Mexico	AMRO	UMIC	PCS	RT-PCR and suggestive tomographic findings	Hospital	ICU	Abdominal CT-scan	86	41	Acute COVID-19	48.6	0.73	MV, ICU stay, Tracheostomy, Hospital stay
González-Islas et al. (2022) [41]	Mexico	AMRO	UMIC	CSS	PCR	Hospital	NR	Dynamometer and BIA	530	98	Long COVID	53.8	0.61	MV
Silva et al. (2022) [61]	Brazil	AMRO	UMIC	CSS	NR	Hospital	Mixed wards	SARC-F	68	50	Acute COVID-19	NR	NR	Risk of SP
Aguiar et al. (2022) [31]	Brazil	AMRO	UMIC	CSS	RT-PCR or laboratory serology	Hospital	Mixed wards	SARC-F	214	87	Acute COVID-19	61.8	0.48	Risk of SP
da Silva et al. (2022) [34]	Brazil	AMRO	UMIC	RCS	RT-PCR	Hospital	Nursing ward	SARC-F	102	75	Acute COVID-19	NR	NR	Mortality
Ahmadiani et al. (2022) [32]	Iran	EMRO	LMIC	PCS	RT-PCR	Hospital	NR	SARC-F	165	34	Acute COVID-19	69	0.56	Oxygen therapy, Hospital stay
McGovern J et al. (2022) [52]	UK	EURO	HIC	RCS	PCR or chest X-ray or CT thorax	Hospital	NR	Abdominal CT-scan	106	85	Acute COVID-19	NR	0.53	Systemic inflammation
Molwitz et al. (2022) [56]	Germany	EURO	HIC	RCS	RT-PCR and CT scan of the thorax and abdomen	Hospital	ICU	Abdominal CT-scan	32	24	Acute COVID-19	64.4	0.63	MV, Mortality
Koehler at al. (2022) [47]	France	EURO	HIC	RCS	RT-PCR	Hospital	Mixed wards	Abdominal CT-scan	162	83	Acute COVID-19	64.6	0.57	Hospitalization in intensive care
Menozzi et al. (2022) [54]	Italy	EURO	HIC	RCS	Positive SARS CoV-2 molecular test and chest CT	Hospital	Mixed wards	Chest CT-scan	272	113	Acute COVID-19	71	0.63	ICU admission, Mortality, Severity[f]
Martone et al. (2022) [51]	Italy	EURO	HIC	PCS	NR	Hospital	Mixed wards	Dynamometer	541	106	Long COVID	53.1	0.49	Severity[f], MV, Hospital stay
Levy et al. (2022) [48]	France	EURO	HIC	RCS	RT- PCR or radiological findings	Hospital	Mixed wards	Dynamometer and DXA	139	6	Long COVID	62	0.68	Hospital stay, ICU admission, ICU stay, Tracheostomy, Severity[f]
Damanti et al. (2022) [35]	Italy	EURO	HIC	CSS	NR	Hospital	Mixed wards	Dynamometer	255	121	Acute COVID-19	67	0.6	Muscle ultrasound characteristics, measures of muscle function and nutritional status

(*Continued*)

Table 1. Continued.

Study	Country	WHO region	Income	Study type	COVID Confirmation	Setting	Hospitalization status	Assessment tool	N	SP	Infection phase	Age	Male	Outcome
Baptista et al. (2022) [59]	France	EURO	HIC	PCS	PCR or serology	Hospital	Mixed wards	DXA	105	21	Long COVID	59.2	0.75	The frequency of long-term exercise capacity limitation and their factors
Graziano et al. (2022) [42]	Italy	EURO	HIC	PCS	RT-PCR	Hospital	Mixed wards	BIA	151	104	Acute COVID-19	71	0.65	ICU admission, Hospital stay, Mortality
Gómez-Uranga et al. (2022) [40]	Spain	EURO	HIC	CSS	PCR	Hospital	Mixed wards	SARC-F	101	33	Acute COVID-19	66.3	0.67	Hospital stay, Severity[f], ICU admission
Yamamoto et al. (2022) [65]	Japan	WPRO	HIC	RCS	PCR	Hospital	Mixed wards	SPPB	23	11	Acute COVID-19	59	0.74	Physical functions and ADLs
Surov et al. (2023) [62]	Germany	EURO	HIC	RCS	PCR	Hospital	Mixed wards	Abdominal CT-scan	173	110	Acute COVID-19	61	0.54	Mortality, Intubation, Severity[f], ICU admission
Grigioni et al. (2023) [43]	France	EURO	HIC	RCS	Positive nasopharyngal swab	Hospital	Mixed wards	Chest CT-scan	244	102	Acute COVID-19	62.2	0.55	In-Hospital Mortality, Length of stay > 23 days, Acquired Infection, ICU admission
Iannaccone et al. (2023) [44]	Italy	EURO	HIC	CSS	Positive swab for SARS-CoV-2	RC	Nursing ward	Dynamometer and BIA	126	52	Acute COVID-19	69.5	0.6	Risk of SP
López-Sampalo et al. (2023) [49]	Spain	EURO	HIC	PCS	RT-PCR or laboratory serology	Mixed	NR	Dynamometer	106	61	Long COVID	76.8	0.52	Risk of SP
Álvarez-Hernández et al. (2023) [67]	Spain	EURO	HIC	RCS	NR	Hospital	ICU	SARC-F	186[g]	25	Long COVID	60.7	0.7	weight, risk of malnutrition and SP, MNT, functional status, and HRQoL
Aykanat Yurtsever et al. (2024) [68]	Turkey	EURO	UMIC	RCS	NR	Hospital	Mixed wards	SARC-F	156	17	Long COVID	55	0.59	Risk of SP
Silva et al. (2024) [69]	Brazil	AMRO	UMIC	CSS	PCR	Hospital	Nursing ward	SARC-F and other tools	213	34	Acute COVID-19	57.4	0.64	Risk of SP

Abbreviations: SP, Sarcopenia; NL, Netherlands; the UK, The United Kingdom; WHO, World Health Organization; EURO, European Region; AMRO, Region of the Americas; WPRO, Western Pacific Region; EMRO, Eastern Mediterranean Region; LMIC, Lower-Middle Income Country; UMIC, Upper-Middle Income Country; HIC, High Income Country; PCS, Prospective Cohort Study; RCS, Retrospective Cohort Study; CSS, Cross-Sectional Study; PCR, Polymerase Chain Reaction; RT-PCR, Reverse Transcription Polymerase Chain Reaction; RC, Rehabilitation Unit; ICU, Intensive Care Unit; CT, Computed Tomography; SARC-F, Strength, Assistance in walking, Rise from a chair, Climb stairs, and Falls; BIA, Bioelectrical Impedance Analysis; DXA, Dual-energy X-ray Absorptiometry; SPPB, Short Physical Performance Battery; SARS CoV-2, Severe Acute Respiratory Syndrome Coronavirus 2; COVID, Coronavirus Disease 2019; MV, Mechanical Ventilation; DRM, Disease Related Malnutrition; ADLs, Activities of Daily Living; MNT, Medical Nutrition Therapy; HRQoL, Health-Related Quality of Life; NR, Not Reported.

[a]WHO region and Income level were classified by the location (country) of the study, according to the criteria of WHO and the World Bank.

[b]Among 106 participants, 80 were hospitalized during an infection and 26 were not hospitalized during an infection.

[c]Mixed wards refer to ICU wards and nursing wards.

[d]Data are given as mean or median.

[e]Data are given as the percentage of male in the total sample size.

[f]Any of the following were considered severe COVID-19 symptoms: (1) respiratory distress (≥30 breaths per min); (2) oxygen saturation at rest ≤93%; (3) ratio of the partial pressure of arterial oxygen (PaO_2) to a fractional concentration of oxygen-inspired air (fiO2) ≤300 mmHg; (4) critical complications; (5) Admission into ICU; (6) The use of MV.

[g]The initial number of patients was 199, but only 186 patients was assessed for the status after the 12 months post-discharge.

Table 2. Assessment tools, measurement parameters, and cut-off values of sarcopenia of the included studies.

First author, Year	Sarcopenia assessment tool	The investigated level/muscles	Sarcopenia parameters	Cut-off used
Ufuk et al. (2020) [63]	Chest CT-scan	Pectoralis muscle	PMI	First tertile of PMI values, Men: < 12.73 cm^2/m^2 Women: < 9 cm^2/m^2
Moctezuma-Velázquez et al. (2021) [55]	Chest CT-scan	Every muscle on T12 level	SMI	Men: < 42.6 cm^2/m^2 Women: < 30.6 cm^2/m^2
Gil et al. (2021) [37]	Dynamometer	NR	HGS and vastus lateralis	Sex-specific tertiles as threshold
McGovern et al. (2021) [53]	Abdominal CT-scan	Every muscle on L3 level	BMI and SMI	Men: BMI < 25 kg/m^2 and SMI < 43 cm^2/m^2, or BMI > 25 and SMI < 53 cm^2/m^2 Women: BMI < 25 and SMI < 41 cm^2/m^2, or BMI > 25 and SMI < 41 cm^2/m^2
Damanti et al. (2021) [36]	Abdominal CT-scan	Every muscle on L1, L2 or L3 level; L3 were preferentially chosen when available	SMI	According to vertebra levels and literature data
Giraudo et al. (2021) [38]	Chest CT-scan	The right paravertebral muscle at T12 level	The mean Hu value	Hu values < 30
Kara et al. (2021) [45]	Dynamometer	NR	HGS	Men: < 32 kg Women: < 19 kg
Gobbi et al. (2021) [39]	BIA	NR	ASM	According to EWGSOP2 criteria, Men: ASM < 20 kg Women: ASM < 15 kg
Wierdsma et al. (2021) [64]	SARC-F	NR	SARC-F scale	Total score ≥ 4
Cuerda et al. (2021) [33]	SARC-F	NR	SARC-F scale	Total score ≥ 4
Riesgo et al. (2021) [60]	SARC-F	NR	SARC-F scale	Total score ≥ 4
Yi et al. (2021) [66]	Chest CT-scan	Every muscle at T12 level	SMI	NR
Kim et al. (2021) [46]	Chest CT-scan	Every muscle on T12 level	SMI	Men: ≤ 24 cm^2/m^2 Women: ≤ 20 cm^2/m^2
Ma et al. (2021) [50]	SARC-F	NR	SARC-F scale	Total score ≥ 4
Ramos et al. (2022) [58]	SARC-F	NR	SARC-F scale	Total score ≥ 4
Osuna-Padilla et al. (2022) [57]	Abdominal CT-scan	Every muscle on L3 level	SMI	Men: BMI < 30 kg/m^2 and SMI ≤ 52.3 cm^2/m^2, or BMI ≥ 30 and SMI ≤ 54.3 cm^2/m^2 Women: BMI < 30 kg/m^2 and SMI ≤ 38.6 cm^2/m^2, or BMI ≥ 30 and SMI ≤ 46.6 cm^2/m^2
González-Islas et al. (2022) [41]	Dynamometer and BIA	NR	ASMM and HGS	(1) ASMM Me): < 20 kg Women: < 15 kg (2) HGS Men: < 27 kg Women: < 16 kg
Silva et al. (2022) [61]	SARC-F	NR	SARC-F scale	Total score ≥ 4
Aguiar et al. (2022) [31]	SARC-F	NR	SARC-F scale	Total score ≥ 4
da Silva et al. (2022) [34]	SARC-F	NR	SARC-F scale	Total score ≥ 4
Ahmadiani et al. (2022) [32]	SARC-F	NR	SARC-F scale	Total score ≥ 4
McGovern J et al. (2022) [52]	Abdominal CT-scan	Every muscle on L3 level	SMI	According to literature data
Molwitz et al. (2022) [56]	Abdominal CT-scan	Every muscle on L3 level	SMI	Men: < 52.4 cm^2/m^2 Women: < 38.5 cm^2/m^2
Koehler at al. (2022) [47]	Abdominal CT-scan	Every muscle on L3 level	SMI	Men: BMI < 30 kg/m^2 and SMI <52.3 cm^2/m^2, or BMI > 30 and SMI < 54.3 cm^2/m^2 Women: BMI < 30 and SMI < 38.6 cm^2/m^2, or BMI > 30 and SMI < 46.6 cm^2/m^2
Menozzi et al. (2022) [54]	Chest CT-scan	Every muscle on T12 level	SMA	Men: < 92.3 cm^2 Women: 56.1 cm^2
Martone et al. (2022) [51]	Dynamometer	NR	HGS	Men: < 16 kg Women: < 27 kg
Levy et al. (2022) [48]	Dynamometer and DXA	NR	HGS and ALM	(1) HGS Men: < 27 kg Women: < 16 kg (2) ALM/Height Men: < 7.0 kg/m^2 Women: < 5.5 kg/m^2
Damanti et al. (2022) [35]	Dynamometer	NR	HGS	Men: < 27 kg Women: < 16 kg
Baptista et al. (2022) [59]	DXA	NR	ASMMI	Men: < 7.26 Women: < 5.45
Graziano et al. (2022) [42]	BIA	NR	SMM and BMI	Men: < 1.05 kg/kg/m^2 Women: < 0.71 kg/kg/m^2

(*Continued*)

Table 2. Continued.

First author, Year	Sarcopenia assessment tool	The investigated level/muscles	Sarcopenia parameters	Cut-off used
Gómez-Uranga et al. (2022) [40]	SARC-F	NR	SARC-F scale	Total score ≥ 4
Yamamoto et al. (2022) [65]	SPPB	NA	SPPB score	SPPB score of ≤ 9
Surov et al. (2023) [62]	Abdominal CT-scan	Measurements of paraspinal, abdominal wall, and psoas muscles are usually performed at the L3 level.	SMI	Men: < 52.4 cm^2/m^2 Women: < 38.5 cm^2/m^2
Grigioni et al. (2023) [43]	Chest CT-scan	Rectus abdominis, external oblique, internal oblique, latissimus dorsi, intercostal and erector spinae muscles on T12 level	SMI	Men: < 28.9 cm^2/m^2 Women: < 20.8 cm^2/m^2
Iannaccone et al. (2023) [44]	Dynamometer and BIA	NR	ASMMI and HGS	(1) ASMMI Men: < 20 kg Women: < 15 kg (2) HGS Men: < 27 kg Women: < 16 kg
López-Sampalo et al. (2023) [49]	Dynamometer	NR	HGS	Men: < 27 kg Women: < 16 kg
Álvarez-Hernández et al. (2023) [67]	SARC-F	NR	SARC-F scale	Total score ≥ 4
Aykanat Yurtsever et al. (2024) [68]	SARC-F	NR	SARC-F scale	Total score ≥ 4
Silva et al. (2024) [69]	SARC-F and other tools	NR	SARC-F, HGS and CP	Men: Total score ≥ 4 and HGS < 35 kg and CP < 34 cm Women: Total score ≥ 4 and HGS < 20 kg and CP < 33 cm

Abbreviations: L3, The 3rd Lumbar Vertebra; T12, The 12th Thoracic Vertebra; EWGSOP, The European Working Group on Sarcopenia in Older People; PMI, Pectoralis Muscle Index; SMI, Skeletal Muscle Index; HGS, Handgrip Strength; BMI, Body Mass Index; Hu, Hounsfield Unit; ASM, Appendicular Skeletal Muscle Mass; SARC-F, Strength, Assistance in Walking, Rise from a Chair, Climb Stairs, and Falls; SMA, Skeletal Muscle Area; SMM, Skeletal Muscle Mass; ALM, Appendicular Lean Mass; ASMMI, Appendicular Skeletal Muscle Mass Index; SPPB, Short Physical Performance Battery; CP, Calf Circumference.

Quality of included studies

For the primary outcome, 36 studies had a low risk of bias (quality score > 3), while three studies had a high risk of bias (quality score ≤ 3), primarily due to selection bias. Most studies had low non-respondent rates, employed validated assessment tools, and used proper statistical methods; However, few studies justified their sample size selection or used random sampling (Figure S1); For the secondary outcome, among the four included cross-sectional studies assessing clinical outcomes by sarcopenia status in COVID-19, three were considered to have a low risk of bias (quality score ≥ 7), while one was considered to have a medium risk of bias (quality score < 7) (Figure S2). Among the 17 included cohort studies reporting clinical outcomes by sarcopenia status, 11 studies had a low risk of bias (quality score ≥ 8), while six studies had a medium risk of bias (quality score < 8) (Figure S3).

Meta-analysis results

Pooled sarcopenia prevalence in acute COVID-19 and LC

Our meta-analysis of 30 studies assessing sarcopenia prevalence in acute COVID-19 patients estimated a pooled prevalence of 48.7% (95% CI: 39.6–57.9%; I^2 = 96.71%, $p<0.05$), indicating substantial heterogeneity among studies (Figure 2). Similarly, our meta-analysis of 9 studies evaluating sarcopenia prevalence in LC patients estimated a pooled prevalence of 23.5% (95% CI: 12.7–39.4%; I^2 = 94.79%, $p<0.05$), also demonstrating high heterogeneity (Figure 2). A significant subgroup difference was observed between the acute COVID-19 and LC groups ($p<0.05$).

Subgroup analyses

Separate subgroup analyses were conducted for sarcopenia prevalence in acute COVID-19 and LC patients, stratified by assessment tool, WHO region, income level, hospitalization status, and age.

In acute COVID-19 patients, significant subgroup differences were observed when stratified by assessment tool ($p<0.05$), WHO region ($p<0.05$), income level ($p<0.05$), and hospitalization status ($p=0.04$), while no significant difference was found for age ($p=0.06$) (Table S6).

In LC patients, no significant subgroup differences were observed across any stratification variables, including assessment tool ($p=0.72$), WHO region ($p=0.44$), income level ($p=0.19$), hospitalization status ($p=0.59$), and age ($p=1.00$) (Table S7).

Publication bias and sensitivity analysis

Separate evaluation of publication bias was conducted for sarcopenia prevalence in acute COVID-19 and LC

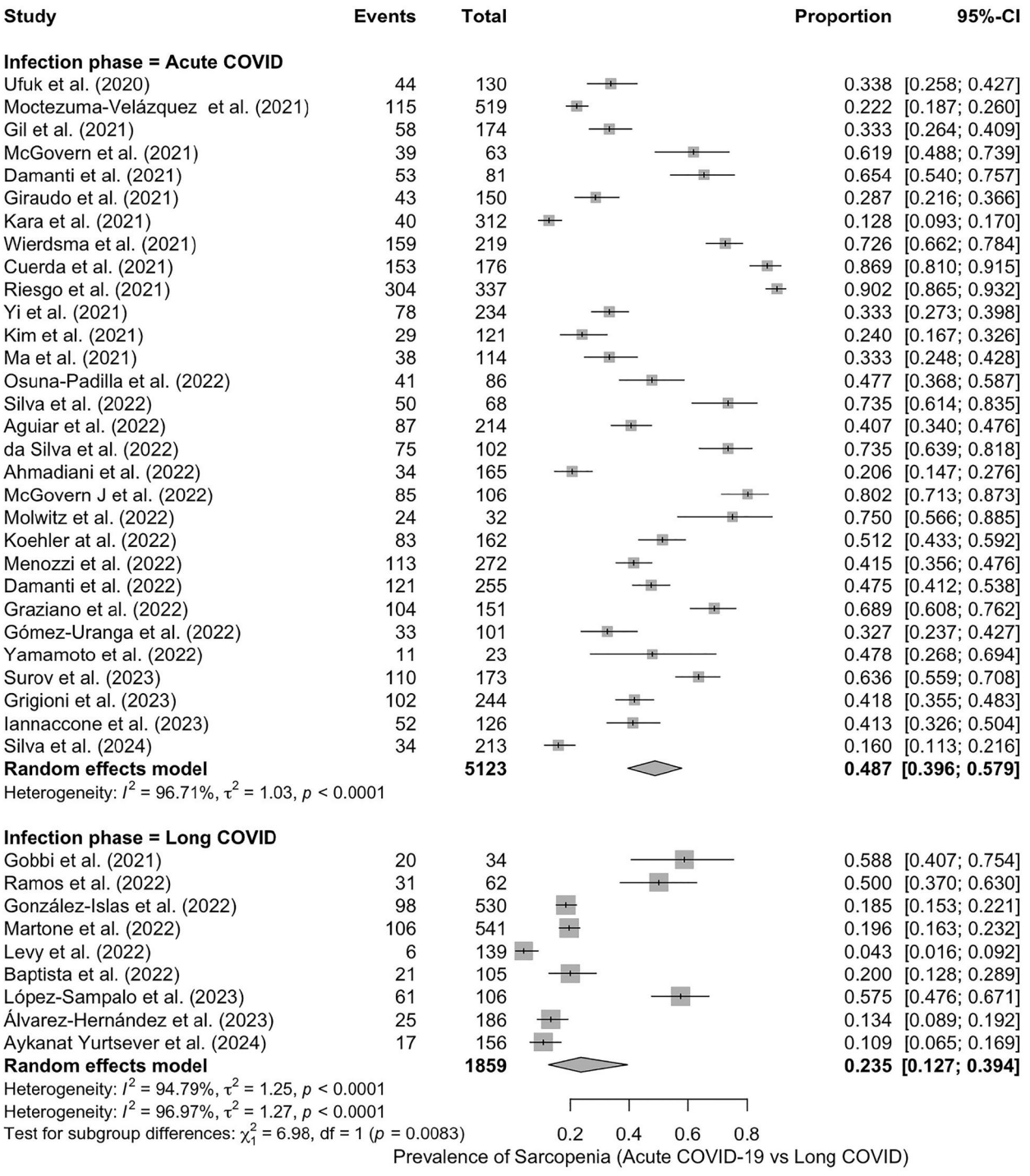

Figure 2. Prevalence of sarcopenia among acute COVID-19 and long COVID patients. (A) Prevalence of sarcopenia in acute COVID-19 patients. (B) Prevalence of sarcopenia in long COVID patients.

patients. There was no evidence of publication bias either in acute COVID-19 (Egger's test, $p = 0.07$) or LC (Egger's test, $p = 0.68$) (Figure 3). We also performed separate sensitivity analysis for sarcopenia prevalence in acute COVID-19 and LC patients. Sensitivity analyses by omitting each included study separately were largely consistent with the main analysis (Figures S4 and S5).

Association between sarcopenia and clinical outcomes

The following five comparisons were performed for the meta-analysis of investigating the association between sarcopenia and clinical outcomes, including LOS, MV, tracheostomy, ICU admission, and mortality.

Six studies on patients with acute COVID-19 provided available information regarding the association

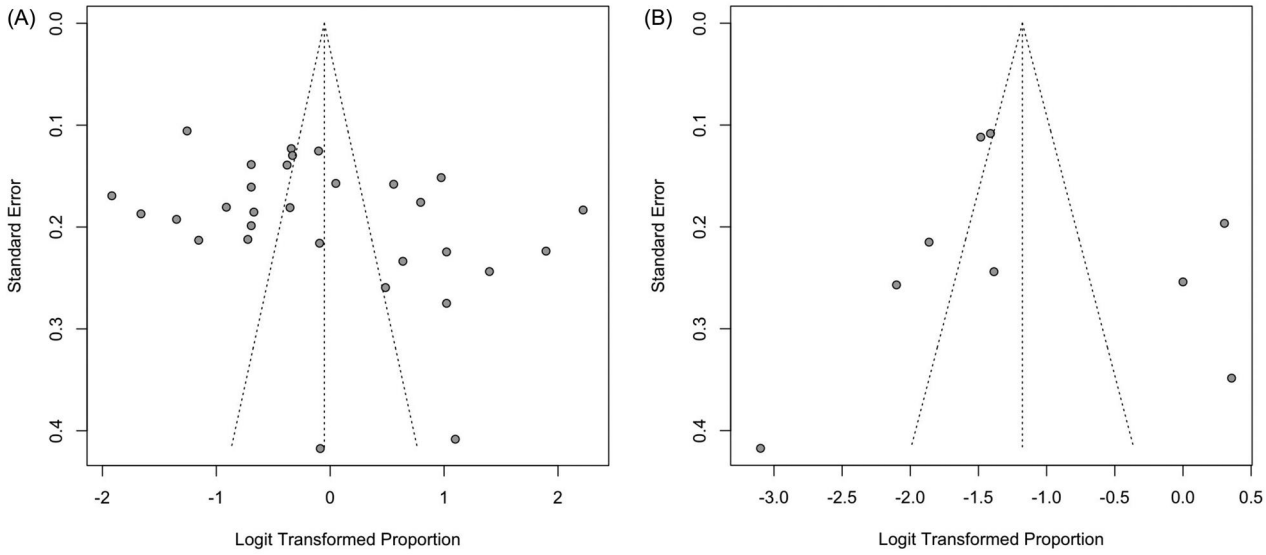

Figure 3. Funnel plots among acute COVID-19 and long COVID patients, classified by (A) acute COVID-19, and (B) long COVID.

between sarcopenia and LOS. The meta-analysis showed that sarcopenia was not significantly associated with a prolonged LOS in patients with acute COVID-19 (MD = 2.215; 95% CI: −0.004 to 4.433; $p = 0.05$). According to the I^2 statistic, moderate heterogeneity existed among the studies (I^2 = 67.48%, $p = 0.01$, random-effect modeling) (Figure 4A).

Four studies on patients with acute COVID-19 and two studies on patients with LC provided data on the association between sarcopenia and MV. Our pooled analysis indicated that sarcopenia was not significantly associated with an increased risk of MV requirement in patients with acute COVID-19 (OR = 1.80, 95% CI: 0.84–3.85). According to the I^2 statistic, moderate heterogeneity was observed among the studies (I^2 = 61.3%, $p = 0.05$, random-effects model) (Figure 4B). In contrast, our pooled analysis revealed that sarcopenia was significantly associated with a higher risk of MV requirement in patients with LC (OR = 2.63, 95% CI: 1.74–3.97). Low heterogeneity was observed among these studies (I^2 = 24.9%, $p = 0.25$, random-effects model) (Figure 4B).

Two studies on patients with acute COVID-19 provided available information regarding the association between sarcopenia and the need for tracheostomy. Our pooled analysis indicated that sarcopenia was significantly associated with an increased risk of tracheostomy requirement in patients with acute COVID-19 (OR = 2.48, 95% CI: 1.28–4.82). According to the I^2 statistic, no heterogeneity was observed among the studies (I^2 = 0%, $p = 0.93$, fixed-effects model) (Figure 4C).

Eight studies on patients with acute COVID-19 provided available information regarding the association between sarcopenia and risk of admission to the ICU. The pooled analysis showed sarcopenia was not associated with an increased risk of admission to the ICU in patients with acute COVID-19 (OR = 1.05, 95% CI: 0.63–1.77). According to the I^2 statistic, moderate heterogeneity existed among the studies (I^2 = 58.8%, $p = 0.02$, random-effect modeling) (Figure 4D).

Ten studies on patients with acute COVID-19 provided available information regarding the association between sarcopenia and mortality. The meta-analysis showed that sarcopenia was not associated with an increased risk of death in patients with acute COVID-19 (OR = 1.41, 95% CI: 0.86–2.32; $p = 0.17$). According to the I^2 statistic, moderate heterogeneity existed among the studies (I^2 = 67.6%, $p < 0.05$, random-effect modeling) (Figure 4E).

Discussion

The present study provides an up-to-date estimate by integrating the latest evidence on the prevalence of sarcopenia among COVID-19 patients with different infection phases, and its association with clinical outcomes. In this systematic review and meta-analysis of 6,982 patients with COVID-19, our results showed that the prevalence of sarcopenia among acute COVID-19 and LC patients is 48.7%, and 23.5%, respectively.

Skeletal muscle-related symptoms, including ME/CFS, muscle pain, muscle weakness, fatigue, and exercise intolerance, have been reported in both acute Covid-19 and LC, including ME/CFS, muscle pain, muscle weakness, fatigue, and exercise intolerance [70,71].

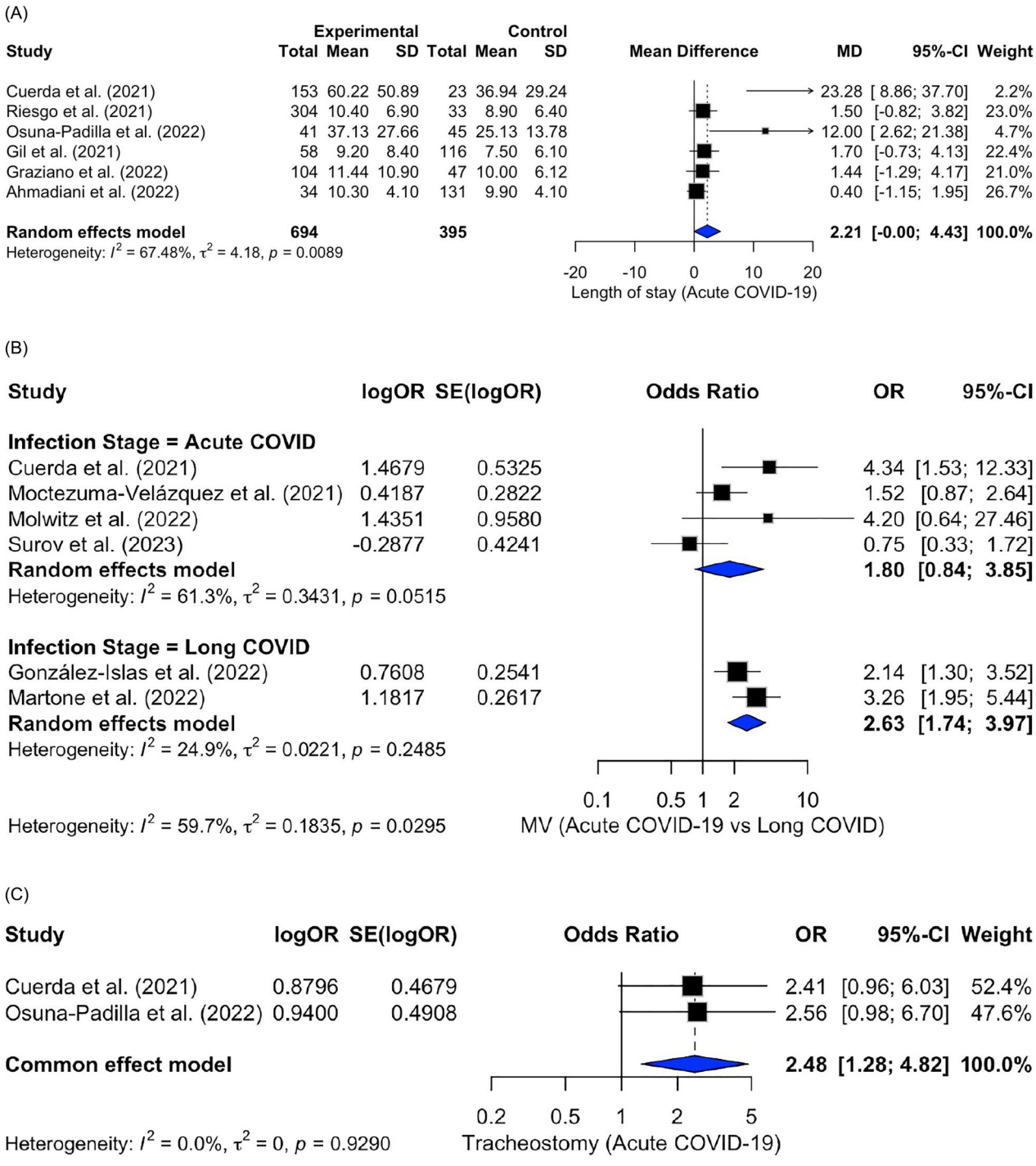

Figure 4. Forest Plot that demonstrates the association between sarcopenia and prognosis outcomes, classified by (A) length of stay; (B) Mechanical ventilation; (C) Tracheostomy; (D) Intensive care units' admission, and (E) Mortality.

Sarcopenia, characterized by loss of muscle mass, strength, and function, involves systematic skeletal muscle changes and is increasingly recognized as a consequence of COVID-19, rather than just an age-related condition. Most previous meta-analysis have focused on the overall prevalence of sarcopenia in COVID-19 patients [18,72], with limited attention to how prevalence varies across different infection phases. Identifying the distinct prevalence in each infection phase is crucial, as the pathophysiology of skeletal muscle alterations in acute COVID-19 and long COVID shares some similarities but also may differ in key mechanisms [73]. Our pooled results reveal a significant difference in sarcopenia prevalence between acute COVID (48.7%) and LC (23.5%) patients, suggesting a potential decline in prevalence over time. This may reflect partial muscle recovery or improvements in post-acute care interventions [73]. However, the

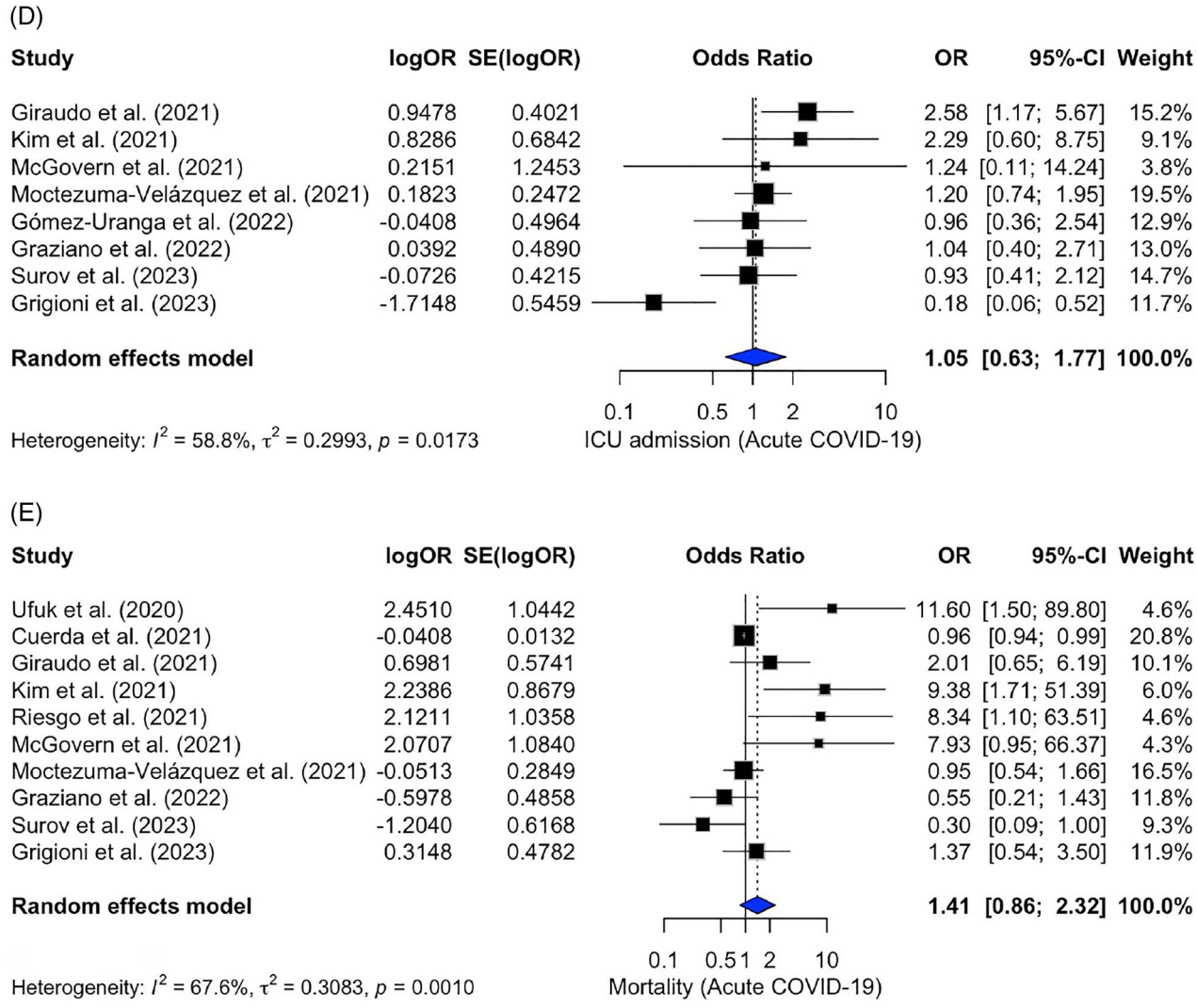

Figure 4. Continued.

persistence of sarcopenia in nearly a quarter of LC patients highlights the long-term musculoskeletal burden of COVID-19, indicating that muscle deterioration may extend well beyond the acute phase and contribute to prolonged functional impairment and reduced quality of life [74].

Our subgroup analyses revealed significant variations in sarcopenia prevalence among acute COVID-19 patients, suggesting that assessment tool, WHO region, income level, and hospitalization status may contribute to the heterogeneity observed in sarcopenia prevalence. Interestingly, no significant difference was observed between age groups, suggesting that multifactorial factors beyond ageing may contribute to sarcopenia [15]. However, the limited sample size may have reduced the statistical power to detect a true subgroup difference. Future research with larger sample size is needed to determine potential age-related effects. In contrast, no significant subgroup differences were observed in LC patients, suggesting that the prevalence of sarcopenia in post-acute care settings may follow a similar trajectory across different demographic and clinical subgroups. This aligns with previous research suggesting that, aside from the loss of smell and taste, the prevalence and progression of long COVID symptoms were similar between individuals with confirmed and suspected COVID-19 [75]. In addition, our findings indicate that sarcopenia was not significantly associated with most clinical outcomes, suggesting that sarcopenia alone may not be a primary determinant of COVID-19 prognosis. However, this should not be considered conclusive, as the results may be influenced by inconsistencies in outcome definitions, variations in assessment tools, and the limited sample size within each group. Besides, due to the paucity of short-term clinical outcomes in LC patients, we were unable to pool outcome data in that group, except for MV. This is not surprising, as these

outcomes are more common during the acute phase of COVID-19, whereas LC patients are more likely to experience long-term health complications and quality-of-life impairments [76].

Several meta-analyses have examined sarcopenia in COVID-19 patients, but limitations remain. Our earlier meta-analysis estimated a 48.0% pooled prevalence, but could not distinguish between acute and LC or assess prognosis due to limited studies at that time [18]. Sumbal et al. focused on CT-derived sarcopenia, aligning with our subgroup analysis in acute COVID-19 patients, but included only 14 CT-based studies, limiting generalizability [72]. Pinto et al. found muscle quality and function, rather than muscle mass, predicted COVID-19 severity, but they assessed these separately, whereas we considered sarcopenia as an overall indicator of muscle health [77]. Siahaan et al. linked sarcopenia to COVID-19 severity and mortality [20], but their findings were based on only 9 studies before 2021, whereas our meta-analysis included more recent studies with larger sample size.

Clinical implications

Our findings reveal a high prevalence of sarcopenia in both acute COVID-19 and LC, emphasizing the need for early identification and long-term management. In acute COVID-19, where sarcopenia is most prevalent, immediate ambulation and neuromuscular electrical stimulation should be prioritized [78–80], particularly in ICU patients who are at the highest risk. Although sarcopenia prevalence declines over time, its persistence in nearly a quarter of LC patients suggests prolonged muscle loss, necessitating continued rehabilitation beyond hospital discharge. Given the challenge of post-exertional malaise in LC [81], rehabilitation should be gradual and individualized, integrating nutrition (e.g. nutritional supplements and dietary food supplements), functional mobility exercises, and resistance training [13]. In resource-limited settings, where structured rehabilitation may not be feasible, emphasis should be placed on low-cost, accessible interventions, such as dietary support [82], bodyweight exercises [83] and community-based programs [84]. Future research should explore scalable rehabilitation strategies to mitigate the long-term impact of sarcopenia across diverse healthcare settings.

Strengths and limitations

This meta-analysis provides the most comprehensive and up-to-date evidence on the prevalence of sarcopenia in COVID-19 patients with different infection phases and its impact on prognosis. Key strengths include: (1) an updated meta-analysis and systematic review with the largest number of studies and sample size to date on this topic, (2) inclusion of diverse assessment tools, diagnostic criteria, parameters, and cut-off values, (3) a broad evaluation of the association between sarcopenia and COVID-19-related clinical outcomes. However, it still has certain limitations. Firstly, as all included studies were observational, selection and information bias were inevitable, potentially limiting the generalizability of our findings and contributing to the high observed heterogeneity. Second, only a small number of studies examined sarcopenia prevalence and its association with COVID-19-related clinical outcomes in long COVID patients, which may have led to insufficient statistical power to detect true associations. The lack of long COVID data also limits insights into the chronic effects of sarcopenia beyond the acute phase. Future research with larger representative sample sizes is needed to validate our findings in LC populations. Third, inconsistencies in outcome definitions and variations in sarcopenia assessment tools may also have caused bias in the analyses and contributed to the high heterogeneity. However, these methodological inconsistencies were largely unavoidable due to COVID-19 restrictions, which limited the use of standard diagnostic tools for sarcopenia. Future research should prioritize standardizing assessment tools and diagnostic criteria in post-acute care settings to improve the identification of high-risk patients. Fourth, while no significant associations were found for most outcomes in acute COVID-19, these results should not be considered conclusive. Given the observational nature of the included studies, causality cannot be determined, and residual confounding may exist due to unmeasured factors (e.g. medication use, lifestyle behaviors, and pre-existing comorbidities) may have influenced the observed estimates. Additionally, reverse causation cannot be ruled out, as severe COVID-19 itself may contribute to sarcopenia through prolonged hospitalization, systemic inflammation, and immobility [85]. Future longitudinal studies are needed to better establish the temporal relationship between sarcopenia and COVID-19 outcomes. Fifth, although we did not detect significant publication bias, restricting our analysis to published studies may still introduce reporting bias. The absence of grey literature and preprints may have led to an overrepresentation of significant findings. Lastly, data from Africa and other low- and middle-income countries (LMICs) remain scarce, with only one included study from an LMIC and none from Africa. This highlights a critical gap in global sarcopenia research, and future studies should

prioritize these regions to improve our understanding of sarcopenia burden and support global health equity.

Conclusions

In conclusion, our findings indicate that sarcopenia is highly prevalent in acute COVID-19 and persists in a substantial proportion of LC patients, suggesting prolonged muscle loss beyond the acute phase. Future well-designed studies are needed to further investigate the association between sarcopenia and short-term and long-term prognostic outcomes in both acute and LC patients.

Authors contributions

CRediT: **Ying Xu**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing; **Jia-Wen Xu**: Data curation, Investigation, Visualization, Writing – review & editing; **You Wu**: Writing – review & editing; **Li-Juan Rong**: Data curation, Investigation, Writing – review & editing; **Li Ye**: Data curation, Investigation, Writing – review & editing; **Oscar H. Franco**: Writing – review & editing; **Ching-Wen Chien**: Writing – review & editing; **Xiao-Ru Feng**: Writing – review & editing; **Jia-Yu Chen**: Writing – review & editing; **Tao-Hsin Tung**: Methodology, Project administration, Supervision, Writing – review & editing.

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Data availability statement

The data will be made available on request from the corresponding author.

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