Systematic review and/or Meta-analysis

INTERNATIONAL JOURNAL OF SURGERY

OPEN

Impact of sarcopenia on outcomes in surgical patients: a systematic review and meta-analysis

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Background: Surgeons have historically used age as a preoperative predictor of postoperative outcomes. Sarcopenia, the loss of skeletal muscle mass due to disease or biological age, has been proposed as a more accurate risk predictor. The prognostic value of sarcopenia assessment in surgical patients remains poorly understood. Therefore, the authors aimed to synthesize the available literature and investigate the impact of sarcopenia on perioperative and postoperative outcomes across all surgical specialties.

Methods: The authors systematically assessed the prognostic value of sarcopenia on postoperative outcomes by conducting a systematic review and meta-analysis according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, searching the PubMed/MEDLINE and EMBASE databases from inception to 1st October 2022. Their primary outcomes were complication occurrence, mortality, length of operation and hospital stay, discharge to home, and postdischarge survival rate at 1, 3, and 5 years. Subgroup analysis was performed by stratifying complications according to the Clavien–Dindo classification system. Sensitivity analysis was performed by focusing on studies with an oncological, cardiovascular, emergency, or transplant surgery population and on those of higher quality or prospective study design.

Results: A total of 294 studies comprising 97 643 patients, of which 33 070 had sarcopenia, were included in our analysis. Sarcopenia was associated with significantly poorer postoperative outcomes, including greater mortality, complication occurrence, length of hospital stay, and lower rates of discharge to home (all $P < 0.00001$). A significantly lower survival rate in patients with sarcopenia was noted at 1, 3, and 5 years (all $P < 0.00001$) after surgery. Subgroup analysis confirmed higher rates of complications and mortality in oncological (both $P < 0.00001$), cardiovascular (both $P < 0.00001$), and emergency ($P = 0.03$ and $P = 0.04$, respectively) patients with sarcopenia. In the transplant surgery cohort, mortality was significantly higher in patients with sarcopenia ($P < 0.00001$). Among all patients undergoing surgery for inflammatory bowel disease, the frequency of complications was significantly increased among sarcopenic patients ($P = 0.007$). Sensitivity analysis based on higher quality studies and prospective studies showed that sarcopenia remained a significant predictor of mortality and complication occurrence (all $P < 0.00001$).

Conclusion: Sarcopenia is a significant predictor of poorer outcomes in surgical patients. Preoperative assessment of sarcopenia can help surgeons identify patients at risk, critically balance eligibility, and refine perioperative management. Large-scale studies are required to further validate the importance of sarcopenia as a prognostic indicator of perioperative risk, especially in surgical subspecialties.

Keywords: aging, muscle, muscle loss, sarcopenia, surgery, surgical outcomes

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Sponsorships or competing interests that may be relevant to content are disclosed at the end of this article.

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International Journal of Surgery (2023) 109:4238–4262

Received 15 April 2023; Accepted 4 August 2023

Supplemental Digital Content is available for this article. Direct URL citations are provided in the HTML and PDF versions of this article on the journal's website, www.lww.com/international-journal-of-surgery.

Published online 7 September 2023

http://dx.doi.org/10.1097/JS9.0000000000000688

Introduction

The population is aging, median ages are rising, and the age pyramid is, thus, widening at the top[1,2]. Research has shown that up to a third of Medicare beneficiaries in the United States undergo one or more surgical procedures in their final year of life[3]. As most patients age, cardiovascular stability, immune system competence, and wound healing capacity decrease. This age-related decline in health exacerbates surgical vulnerability and predisposes to postoperative complications. Accordingly, the preemptive identification of vulnerable patients and the anticipation of postoperative adverse events will become even more relevant.

Traditionally, surgeons have correlated chronological age as a predictor of postoperative outcomes, but this may be outdated. In fact, patients' chronological and physiological ages rarely match[4–10]. To reconcile this discrepancy, the concept of frailty has been successfully introduced. Frailty is broadly understood as an increased vulnerability to external and internal stressors. Frailty is, therefore, not limited to physicality but also accounts for psychological and social aspects[11]. Recent studies have highlighted the predictive value of frailty indices, such as the modified frailty index (mFI), the Rockwood Frailty Index, or the Clinical Frailty Index (CFI)[12–15]. However, the heterogeneity in frailty scores inevitably leads to variability in clinical practice and documentation. As a result, to date, frailty prevalence and its predictive validity strongly vary by the scale applied[16,17]. Therefore, standardization and objectification of frailty measurement are urgently needed.

Sarcopenia is considered the key component of physical frailty (Fig. 1)[18,19]. More specifically, sarcopenia refers to the progressive loss of muscle mass and strength typically seen with age and the associated functional limitations[19]. Computed tomography and magnetic resonance imaging are considered the gold standard for muscle quantification in sarcopenic patients[20–22]. Specifically for the diagnosis of sarcopenia, a wide array of muscle metrics such as the Skeletal Muscle Index, the Psoas Muscle Index, and the Pectoralis Muscle Index have been proposed[23,24]. Age-related muscle atrophy can begin as early as in the third decade of life, with the process accelerating after age 60[25]. Studies suggest that one in ten people suffers from sarcopenia, and the prevalence may be as high as 50% in people over 80 years of age[26,27]. According to the European Working Group on Sarcopenia in Older People, more than 50 million people are currently affected by sarcopenia and, with the increasing percentage of elderly people, more than 200 million people worldwide will suffer from this condition and its consequences in the next 40 years[28]. Yet, the manifestations of sarcopenia are often concealed by age-related changes in body composition, such as malnutrition and weight loss. These symptoms can be trivialized as normal aging processes, thereby hampering and delaying accurate diagnosis[19,29–31]. This diagnostic dilemma is also mirrored by the fact that sarcopenia was not officially recognized as a disease entity until 2016 (ICD-10-CM M62.84)[32].

As a quantifiable variable, muscle mass (and, therefore, sarcopenia) can be accurately and objectively determined, with internationally defined cut-off values indicating pathological conditions. As a clear-cut entity, sarcopenia may help quantify frailty and holds the potential to accurately predict a patient's perioperative risk. Given its quantifiability as well as worldwide and rising prevalence, sarcopenia is of increasing importance in the field of surgery. Previous studies that investigated the impact of sarcopenia on postoperative outcomes were largely based on single-institution experience and procedure/pathology-specific analyses. In addition, the findings seem to conflict and, therefore, suggest discordant conclusions. As a result, the research transferability and significance remain limited, with scarce evidence on the true effects of sarcopenia in the far-reaching field of surgery.

Pooling data with geographic, institutional, and procedural variance can help fill this knowledge gap. We, therefore, conducted a systematic review and meta-analysis, aiming to determine the impact of sarcopenia on surgical outcomes. Specifically, we compared the postoperative morbidity and mortality between surgical patients with sarcopenia and those without sarcopenia. Ultimately, these insights regarding the prognostic value of sarcopenia diagnosis can help surgeons refine preoperative risk stratification and critically balance patient eligibility.

HIGHLIGHTS

- Sarcopenia was found to be a significant predictor of poorer outcomes in surgical patients.
- Sarcopenia was associated with significantly increased mortality in surgical patients.
- Patients with sarcopenia experienced significantly more complications, including all grades of the Clavien–Dindo classification.
- Sarcopenic patients showed significantly lower survival rates at 1, 3, and 5 years after surgery.
- Sarcopenia was associated with a significantly prolonged length of hospital stay and a lower rate of home discharge.

Patients and methods

Search strategy

This study followed the recommendations of the Assessing the Methodological Quality of Systematic Reviews (AMSTAR) guidelines (Supplemental Digital Content 1, http://links.lww.com/JS9/A965) and was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[33,34] (Supplemental Digital Content 2, http://links.lww.com/JS9/A966 and Supplemental Digital Content 3, http://links.lww.com/JS9/A967). The systematic review was registered a priori at the International Prospective Register of Systematic Reviews (PROSPERO) database. A comprehensive and systematic literature review was performed by the authors of this review on PubMed/MEDLINE and EMBASE databases from database inception to 1st October 2022 for studies published in the English, Spanish, German, and French languages. The search terms were (i) "sarcopenia" OR "sarcopenic" OR "loss of skeletal muscle" OR "muscular atrophy" OR "muscle wasting" OR "muscle depletion" AND (ii) "operation" OR "operative" OR "operated" OR "post-operative" OR "postoperative" OR "peri-operative" OR "perioperative" OR "surgical" OR "surgery" OR "surgeries". The search format was tailored to the appropriate syntax of each database. In addition, the reference list of each retrieved article, systematic review, and meta-analysis was manually searched for relevant literature ("other sources").

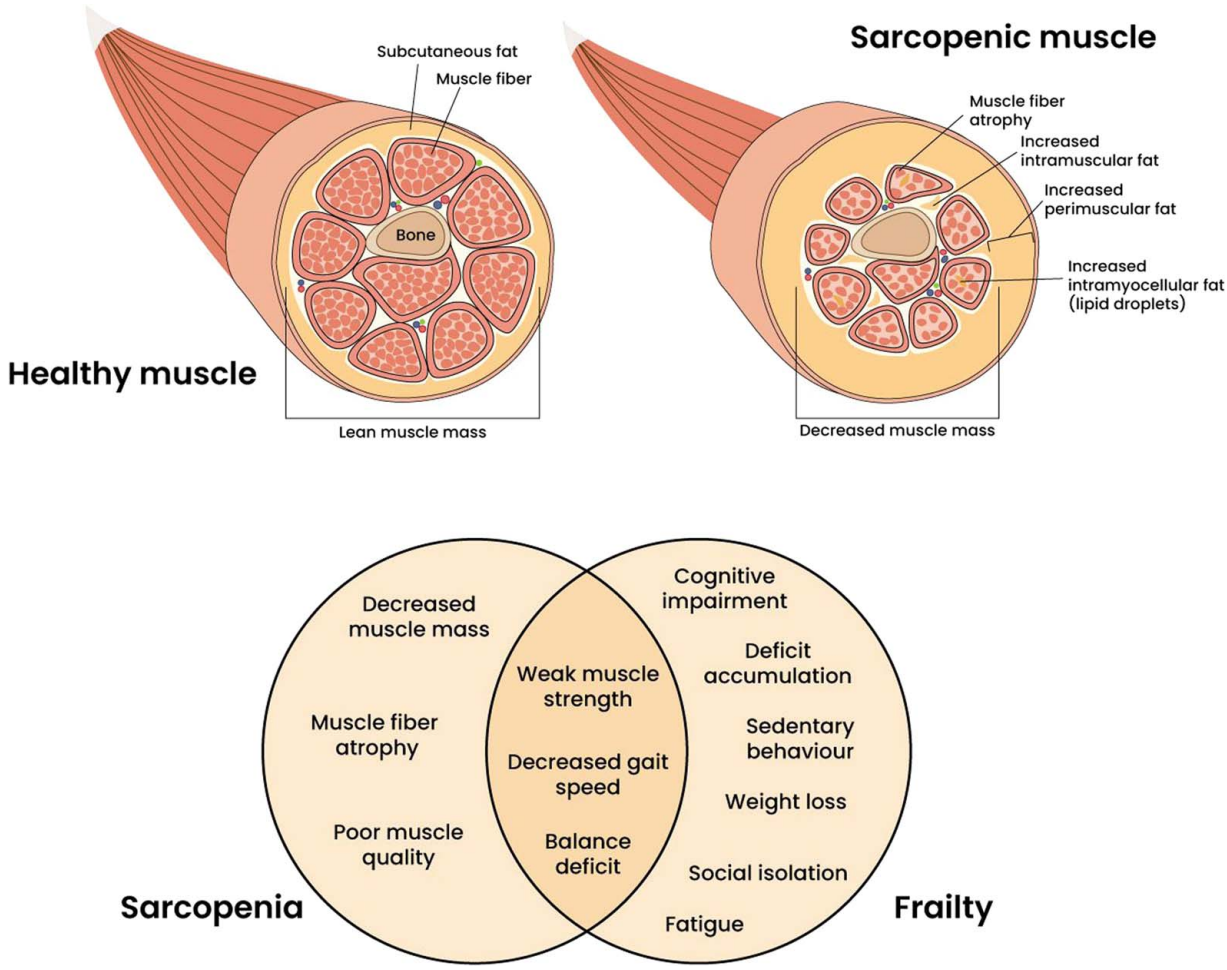

Figure 1. Sarcopenia is the age-related loss of skeletal muscle mass, muscle strength, and muscle function. From a pathophysiological perspective, this disorder may be associated with muscle fiber and motor unit atrophy and a concomitant increase in intramuscular and perimuscular and intramyocellular fat. As such, sarcopenia is closely interwoven with the multifaceted frailty syndrome and is considered the key component of physical frailty. Accordingly, frailty and sarcopenia share similar characteristics, such as weak muscle strength and decreased gait speed. However, the concept of frailty reaches beyond physicality and also encompasses psychological and social dimensions.

Study identification and selection

Three authors (S.K., R.S., and A.C.P.) identified articles via a three-stage process. As a first step, these three investigators independently reviewed all titles and abstracts (or summaries), presorting potentially eligible studies. These preselected articles were then assessed in detail, with the abstracts being checked for the presence of any exclusion criteria. Finally, the full texts of the generated study pool were thoroughly analyzed, and their compliance with the inclusion criteria or absence of any exclusion criteria was verified. Any vagueness or discrepancies during the screening process were discussed by the three reviewers after each stage in order to reach a consensus. A fourth independent reviewer (F.J.H.) was consulted to resolve any further disagreement.

Inclusion and exclusion criteria

Eligible studies had to fulfill outcome and study design inclusion criteria:

Only surgical studies reporting at least one of our primary outcomes of interest (with extractable, numerical data) were included in the final analysis. The nine outcomes of interest included (i) mortality, (ii) any postoperative complication (not further specified), (iii) surgical complications (Clavien–Dindo grade), (iv) duration of surgery, (v) length of hospital stay, (vi) discharge to home, and (vii) 1-year, (viii) 3-year, and (ix) 5-year survival rates. Studies in which none of the aforementioned parameters were reported and in which not all participants underwent surgery were excluded. Of note, only robust data were extracted. Metrics based on probability calculations (such as Kaplan–Meier curves) were, therefore, not included in any analyses.

Skeletal muscle mass was quantified by computed tomography and/or magnetic resonance imaging. Accordingly, the diagnosis "sarcopenia" was defined based on the two gold standards for non-invasive assessment of muscle quantity recommended by consensus statements, with validated cut-off levels. Studies in which sarcopenia was not determined radiographically were excluded from the analysis. The use of other diagnostic tools

complementing/supplementing the anthropometric measures, such as gait speed and grip strength, did not contradict our study's inclusion criteria. Sarcopenia was exclusively evaluated as a dichotomic variable. As such, non-dichotomous recording of sarcopenia (in tertials or quartiles) was considered an exclusion criterion.

In terms of study design, we included both prospective and retrospective studies such as case series, randomized control trials, cohort studies, and case–control studies. Descriptive studies not reporting original data, such as reviews and meta-analyses were excluded. Studies specifying the increase and/or decrease of muscle quantity only during chemotherapy were ineligible. We also did not include unpublished studies, books, cost-effectiveness studies, case reports, animal studies, and cadaver studies. Articles published in languages other than English, Spanish, German, and French were excluded.

Data extraction

Two investigators (S.K. and F.J.H.) independently extracted the following data from the included articles: first author name, publication year, type of study, total number of patients, number of patients with sarcopenia, type of surgery, type of radiographic measurement, type of sarcopenia assessment method, and outcomes of interest. All metrics were extracted into Microsoft Excel 2020 (Microsoft, Redmond, Washington, USA). Data were collected and saved in an electronic laboratory notebook (LabArchives, LLC, San Marcos, California, USA).

Subgroup analysis

Complications were divided into subgroups according to the Clavien–Dindo classification system, whereby Grade II are complications requiring pharmacological treatment beyond analgesics, antipyretics, antiemetics, diuretics, and electrolytes; Grade III are complications requiring endoscopic, radiologic, or surgical intervention; and Grade IV are life-threatening complications requiring intensive care management, including single and multi-organ dysfunction[35]. Subgroup analysis assessing the mortality and complication rates was performed by dividing the papers based on the type of surgery they assessed. Specifically, we sub-analyzed the following cohorts: (i) transplant surgery, (ii) surgical oncology, (iii) surgery for inflammatory bowel disease, (iv) cardiovascular surgery, and (v) emergency surgery. We focused on these five cohorts since they were found to be the most frequently represented among all included studies.

Sensitivity analysis

In addition, two investigators (S.K. and D.Y.M.) assessed the methodological quality of the studies by applying the Newcastle–Ottawa Scale (NOS)[36]. The NOS tool is commonly used to assess non-randomized studies based on eight items, which are categorized into three clusters: (i) selection of study cohorts, (ii) comparability of the cohorts, and (iii) ascertainment of exposure or outcome of interest (for case–control and cohort studies, respectively). With each quality item being marked with an asterisk, the NOS enables a concise evaluation of the assessed studies (Supplementary Table 1, Supplemental Digital Content 4, http://links.lww.com/JS9/A968). The criterion of comparability may be rated twice, meaning that the highest quality studies can achieve a maximum of nine asterisks. In case of discrepant assessments, a third investigator (L.K.) was consulted.

Based on the results of this assessment, a sensitivity analysis was performed to verify whether the results in terms of mortality and complication rates were valid – when the analysis was restricted to high-quality studies with an NOS score of ≥ 8. Furthermore, the design of all included studies was specified, separating between retrospective and prospective data collection. Subsequently, all prospective studies were integrated into a further sensitivity analysis.

Meta-regression analyses

Mixed-effect linear meta-regression analyses were conducted in OpenMeta[Analyst] (Brown School of Public Health, Providence, Rhode Island; V1.15) to investigate the correlation between age, body mass index (BMI), and American Society of Anesthesiologists (ASA) physical status classification system with patients' postoperative morbidity and mortality – in both sarcopenic and non-sarcopenic cohorts[37].

Statistical analysis

Data analysis was performed using RevMan 5.4 software (Cochrane, London, UK). For dichotomous variables, a random-effects model with the Mantel–Haenszel method was used to combine the data from the included studies to calculate the Odds Ratios (OR). For continuous variables, a random-effects model with the Inverse Variance method was used to calculate the Mean Differences (MD). Heterogeneity was quantified with the χ^2 and I^2 score and given high heterogeneity ($I^2 \geq 25\%$), a random-effects model was employed. When the heterogeneity was low ($I^2 < 25\%$), the fixed model was applied[38–40]. Pooled effect sizes were calculated with 95% confidence intervals (95% CI). Statistical significance was set at $P < 0.05$.

Results

Studies included in the meta-analysis

A total of 76 617 articles were identified upon initial literature search (Fig. 2). 75 512 articles were excluded after title and abstract evaluation, leaving 1105 articles for detailed assessment. A total of 811 studies were excluded for the following reasons: irrelevance or lack of original data, inability to extract data due to missing numbers for certain variables, ineligible sarcopenia diagnostic methods, nonquantitative muscle assessment, non-surgical interventions, sarcopenia sub-diagnoses (e.g. sarcopenic obesity or sarcopenic underweight), and non-dichotomized sarcopenia records. Finally, 294 studies were included, accounting for a total of 97 643 patients with 33 070 diagnosed sarcopenia cases. Three studies were identified that provided data on two distinct and separate surgical patient populations[41–43]. These studies were included in the evidence synthesis of this meta-analysis as sub-studies. Table 1 summarizes the characteristics of the 294 included studies.

Patient characteristics

On average, patients diagnosed with sarcopenia were significantly older (65.0 ± 11.8 years) and had a lower BMI (23.0 ± 3.0 kg/m^2) than the non-sarcopenic patient population (61.6 ± 10.9 years and 25.4 ± 3.0 kg/m^2, respectively) (both

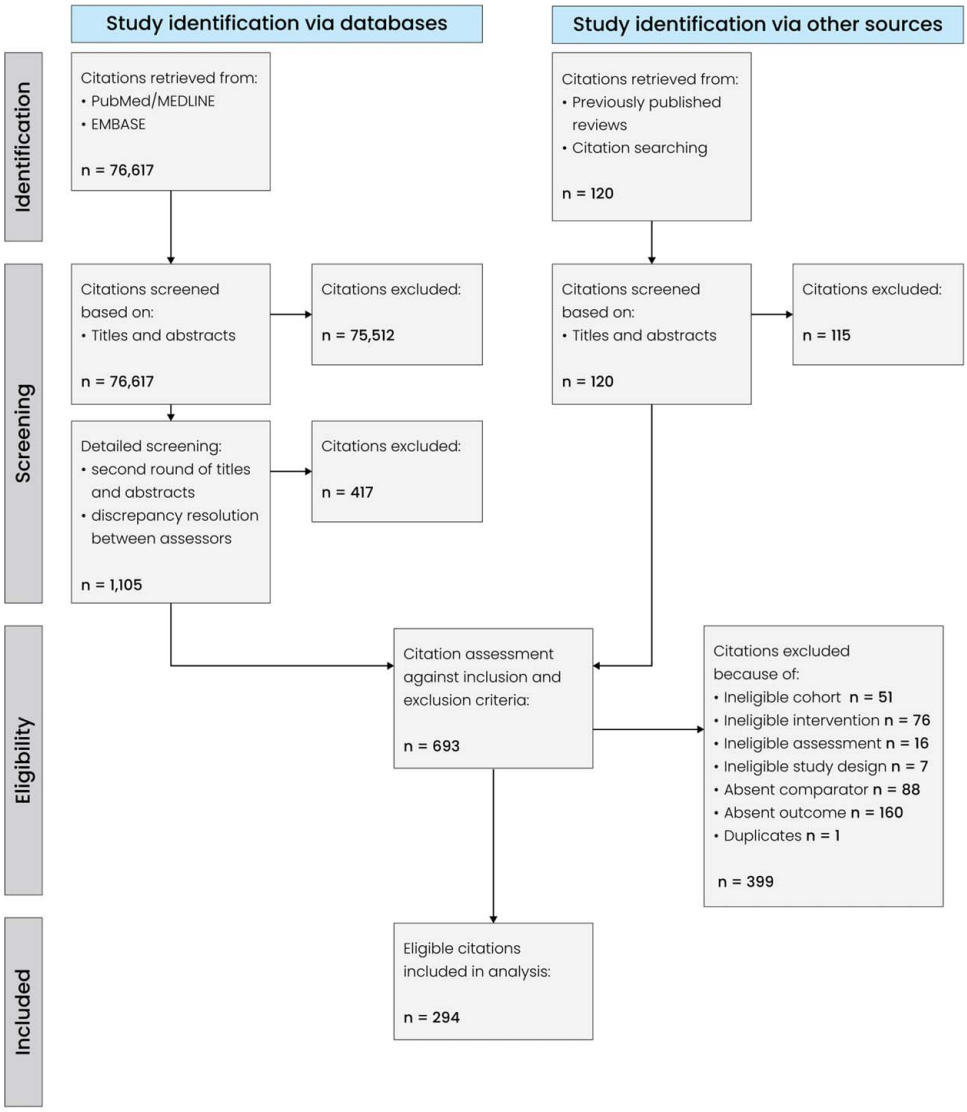

Figure 2. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram of the search and selection process. Supplementary Table 3 (Supplemental Digital Content 7, http://links.lww.com/JS9/A971) lists all potentially relevant studies ($n = 399$) that were assessed in full-text form but excluded from any further analysis due to noncompliance with inclusion criteria and/or the presence of exclusion criteria.

$P < 0.001$). Mean ASA scores were comparable in both cohorts (2.32 ± 0.47 in sarcopenic patients versus 2.22 ± 0.44 in non-sarcopenic patients; $P = 0.12$).

Mortality

A total of 154 studies provided data on mortality (Table 1). The rate of mortality in patients with sarcopenia and patients without sarcopenia was 26.6% and 20.2%, respectively. Pooled analysis showed a significant increase in mortality in patients with sarcopenia (OR 2.69; 95% CI: 2.31–3.12; $P < 0.00001$; Table 2, Fig. 3).

Overall complications

A total of 160 studies provided data on any complications (Table 1). The overall complication rate of patients with sarcopenia and patients without sarcopenia was 39.5% and 26.8%, respectively. Pooled analysis showed a significant increase in overall complications in patients with sarcopenia (OR 1.68; 95% CI: 1.51–1.87; $P < 0.00001$; Table 2, Fig. 3).

Length of hospital stay

A total of 64 studies provided data on the length of hospital stay (Table 1). Pooled analysis showed a significant increase in the length of hospital stay in patients with sarcopenia (MD: 1.68; 95% CI: 1.18–2.17; $P < 0.00001$; Table 2, Fig. 3).

Length of operative time

A total of 40 studies provided data on the operative time (Table 1). Pooled analysis showed no significant difference in operative time between patients with and without sarcopenia (MD: 1.68; 95% CI: – 5.62 to 8.98; $P = 0.65$; Table 2, Fig. 3).

Table 1

Characteristics of all included studies.

Study	Year	R/P	Patients [with sarcopenia] (*n*)	Surgery type	Category	Imaging	Assessment Method	Outcomes	Survival (years)	Complications (C-D Grade)
Peng *et al.*[44]	2011	R	259 [41]	Hepatic Metastases Surgery	2	CT	TPA	M, LOS		≥ III
Lieffers *et al.*[45]	2012	R	234 [91]	Colorectal Cancer Surgery	2	CT	SMI	LOS		
Peng *et al.*[46]	2012	R	557 [139]	Pancreatic Cancer Surgery	2	CT	TPA	C	1, 3	≥ III
van Vledder *et al.*[47]	2012	R	196 [38]	Hepatic Metastases Surgery	2	CT	SMI		1	
Harimoto *et al.*[48]	2013	R	186 [75]	Hepatic Cancer Surgery	2	CT	PMI	C		
Smith *et al.*[49]	2014	R	191 [77]	Bladder Cancer Surgery	2	CT	TPA	C		
Du *et al.*[50]	2014	R	100 [73]	Emergency General Surgery	5	CT	SMI	M, C, HD		
Montano-Loza *et al.*[51]	2014	R	248 [112]	Liver Transplant	1	CT	SMI	M	1	
Psutka *et al.*[52]	2014	R	205 [141]	Bladder Cancer Surgery	2	CT	SMI	M	5	
Jones *et al.*[53]	2015	P	100 [15]	Colorectal Cancer Surgery	2	CT	TPA	LOS		II, ≥ III
Amini *et al.*[54]	2015	R	763 [192]	Pancreatic Cancer Surgery	2	CT	TPA	M	1, 3	≥ III
Huang *et al.*[55]	2015	P	142 [17]	Colorectal Cancer Surgery	2	CT	SMI	C		II, III, IV
Kuroki *et al.*[56]	2015	R	122 [61]	Endometrial Cancer Surgery	2	CT	PMA	C, LOS		
Levolger *et al.*[57]	2015	R	90 [52]	Hepatic Cancer Surgery	2	CT	SMI	M, C		≥ III
Lodewick *et al.*[58]	2015	R	171 [80]	Hepatic Metastases Surgery	2	CT	SMI	C		
Matsubara *et al.*[59]	2015	R	64 [28]	Limb Ischemia Revascularization	4	CT	SMA	C		
Okumura *et al.*[60]	2015	R	230 [64]	Pancreatic Cancer Surgery	2	CT	PMI	M		≥ III
Otsuji *et al.*[61]	2015	R	256 [85]	Hepatic Cancer Surgery	2	CT	PMA	M, LOS, OT		≥ III
Sharma *et al.*[62]	2015	R	93 [27]	Renal Metastases Surgery	2	CT	SMI			≥ III
Tegels *et al.*[63]	2015	R	152 [86]	Gastric Cancer Surgery	2	CT	SMI	M, LOS		≥ III
Valero *et al.*[64]	2015	R	96 [47]	Hepatic Surgery	6	CT	TPV	M, C, LOS	1, 3, 5	≥ III
Voron *et al.*[65]	2015	R	109 [59]	Hepatic Cancer Surgery	2	CT	SMI	M, C		II, III, IV
Zhou *et al.*[66]	2015	R	67 [33]	Hepatic Cancer Surgery	2	CT	SMI			≥ III
Jaap *et al.*[67]	2016	R	180 [44]	Pancreatic Resection	6	CT	PMA	C, HD		
Higashi *et al.*[68]	2016	P	144 [72]	Hepatic Cancer Surgery	2	CT	SMI	M, OT		
Bokshan *et al.*[69]	2016	R	46 [16]	Thoracolumbar Spine Surgery	6	CT	TPA	LOS		
Buettner *et al.*[70]	2016	R	1326 [398]	Gastrointestinal Cancer Surgery	2	CT	TPA	M, C	1	II, III, IV
Chemama *et al.*[71]	2016	R	97 [39]	Cytoreductive Surgery	2	CT	SMM	M, C		
Gani *et al.*[72]	2016	P	1169 [293]	Major Abdominal Surgery	6	CT	TPV	M, C, HD		
Grotenhuis *et al.*[73]	2016	R	120 [54]	Esophageal Cancer Surgery	2	CT	SMI	M		II, III, ≥ III, IV
Hale *et al.*[74]	2016	R	200 [25]	Endovascular Aneurysm Repair	4	CT	SMA	M		
Heberton *et al.*[75]	2016	R	100 [32]	LVADI	4	CT	PMA	M		
Hirasawa *et al.*[76]	2016	R	136 [65]	Bladder Cancer Surgery	2	CT	SMI	M		
Izumi *et al.*[77]	2016	P	47 [30]	Liver Transplant	1	CT	PMI	M		≥ III
Kelm *et al.*[78]	2016	R	36 [10]	Lung Transplant	1	CT	SMI	M		
Malietzis *et al.*[79]	2016	R	805 [320]	Colorectal Cancer Surgery	2	CT	SMI	M		≥ III
Nishida *et al.*[80]	2016	R	266 [132]	Pancreatic Resection	6	CT	SMI	M, C		
Nishigori *et al.*[81]	2016	R	199 [149]	Esophageal Cancer Surgery	2	CT	SMI	M, C		II, III, ≥ III, IV
Okumura *et al.*[82]	2016	R	207 [71]	Biliary Cancer Surgery	2	CT	PMI	M, LOS, OT	1	≥ III
Ouchi *et al.*[83]	2016	R	60 [20]	Colorectal Cancer Surgery	2	CT	PMA	C		≥ III
Pecorelli *et al.*[84]	2016	P	202 [132]	Pancreatic Cancer Surgery	2	CT	SMA	M, C		II, III, IV
Pedziwiatr *et al.*[85]	2016	R	124 [34]	Colorectal Cancer Surgery	2	CT	SMI	C, LOS		II, III, IV
Peyton *et al.*[86]	2016	R	128 [32]	Renal Cancer Surgery	2	CT	TPA	M, LOS		≥ III
Suzuki *et al.*[87]	2016	R	100 [38]	Lung Cancer Surgery	2	CT	SMI	C		
Takagi *et al.*[88]	2016	R	254 [118]	Hepatic Cancer Surgery	2	CT	SMA	M, OT	1	≥ III

Table 1

(*Continued*)

Study	Year	R/P	Patients [with sarcopenia] (*n*)	Surgery type	Category	Imaging	Assessment Method	Outcomes	Survival (years)	Complications (C-D Grade)
Wagner *et al.*[89]	2016	R	445 [112]	Hepatopancreaticobiliary Surgery	6	CT	TPA	M	1	
Wang *et al.*[90]	2016	P	255 [32]	Gastric Cancer Surgery	2	CT	SMI	C, OT		II, III, IV
Zhuang *et al.*[91]	2016	R	937 [389]	Gastric Cancer Surgery	2	CT	SMI	M, C		II, III, IV
Fujikawa *et al.*[92]	2017	R	69 [18]	IBD Surgery	3	CT	TPA	OT		
Rutten *et al.*[93]	2017	R	216 [70]	Ovarian Cancer Surgery	2	CT	SMI	M, LOS		II, III, ≥III, IV
Achim *et al.*[94]	2017	R	70 [54]	Laryngeal Cancer Surgery	2	CT	SMI	C		
Black *et al.* (a)[41]	2017	R	108 [23]	Esophagogastric Cancer Surgery	2	CT	SMI	M		
Black *et al.* (b)[41]	2017	R	331 [81]	Colorectal Cancer Surgery	2	CT	SMI	M		
Elliott *et al.*[95]	2017	P	207 [49]	Esophageal Cancer Surgery	2	CT	SMI	M		II, III, ≥III, IV
Hamaguchi *et al.*[96]	2017	R	250 [53]	Liver Transplant	1	CT	SMI	M		
Harimoto *et al.*[97]	2017	P	102 [24]	Liver Transplant	1	CT	SMA	M, C, LOS, OT		
Ikeno *et al.*[98]	2017	R	266 [81]	Aortic Arch Replacement	4	CT	PAI	M, HD		
Ishihara *et al.*[99]	2017	R	137 [90]	Urinary Tract Cancer Surgery	2	CT	SMI	M, C		II, III, IV
Kudou *et al.*[100]	2017	R	148 [42]	Esophagogastric Cancer Surgery	2	CT	SMI	M, C		≥III
Matsubara *et al.*[101]	2017	R	114 [53]	Limb Ischemia Revascularization	2	CT	SMA	M		
Matsushima *et al.*[102]	2017	R	89 [32]	Emergency Surgery	4	CT	PMA	C		
Mirkin *et al.*[103]	2017	R	36 [12]	Gastric Cancer Surgery	5	CT	PMI	C		
Ninomiya *et al.*[104]	2017	R	265 [170]	Pancreatic Cancer Surgery	2	CT	SMI	C, OT		
Okumura *et al.*[105]	2017	R	109 [69]	Hepatic Cancer Surgery	2	CT	SMI	M		≥III
Paireder *et al.*[106]	2017	P	130 [80]	Esophageal Cancer Surgery	2	CT	SMI	C		
Rangel *et al.*[107]	2017	R	297 [75]	Emergency Abdominal Surgery	2	CT	TPI	M		
Saitoh-Maeda *et al.*[108]	2017	R	63 [34]	Bladder Cancer Surgery	5	CT	PMI	M		II, ≥III
Sakurai *et al.*[109]	2017	R	569 [142]	Gastric Cancer Surgery	2	CT	SMI	M, LOS		II, III, IV
Takagi *et al.*[110]	2017	R	219 [55]	Pancreatic Resection	2	CT	SMA	M, OT		≥III
Tsukioka *et al.*[111]	2017	R	215 [30]	Lung Cancer Surgery	6	CT	SMA	M, C		
van Dijk *et al.*[112]	2017	P	186 [62]	Pancreatic Cancer Surgery	2	CT	SMA	M		
Zhang *et al.*[113]	2017	R	114 [70]	IBD Surgery	2	CT	SMA			≥III
Zhou *et al.*[114]	2017	P	240 [69]	Gastric Cancer Surgery	3	CT	SMI	M, C		≥III
Choi *et al.*[115]	2018	R	188 [74]	Rectal Cancer Surgery	2	CT	SMI	M, C, LOS		
Nakanishi *et al.*[116]	2018	R	494 [298]	Colorectal Cancer Surgery	2	CT	SMI	C, LOS, OT		
Umetsu *et al.*[117]	2018	R	65 [48]	Bile Duct Cancer Surgery	2	CT	PMI	M		≥III
Aby *et al.*[118]	2019	R	146 [90]	Liver Transplant	2	CT	PMA	M		
Banaste *et al.*[119]	2018	R	214 [90]	Cytoreductive Surgery	1	CT	SMM	C		
Barnes *et al.*[120]	2018	R	58 [21]	Ventral Hernia Repair	2	CT	PMA	C		
Chakedis *et al.*[121]	2018	R	78 [30]	Biliary Tract Cancer Surgery	6	CT	PMI	C	1	II, III, ≥III, IV
Choi *et al.*[122]	2018	R	180 [60]	Pancreatic Cancer Surgery	2	CT	SMI	C, LOS, OT		≥III
El Amrani *et al.*[123]	2018	R	107 [50]	Pancreatic Resection	2	CT	SMI	LOS, OT		III
Francomacaro *et al.*[124]	2018	R	967 [241]	Emergency Laparotomy	6	CT	TPA	C, HD		≥III
Hamidi *et al.*[125]	2019	R	452 [113]	Emergency General Surgery	5	CT	TPA	M		
Harimoto *et al.*[126]	2018	R	146 [39]	Hepatic Cancer Surgery	5	CT	SMA	LOS, OT		≥III
Hawkins *et al.*[127]	2018	R	240 [60]	Aortic Valve Replacement	2	CT	PMI	M, C, HD	1	
Heard *et al.*[128]	2018	P	314 [129]	Vascular Surgery	4	CT	SMI	M, HD		

Järvinen *et al.*[129]	2018	R	115 [92]	Esophageal Cancer Surgery	4	CT	SMI	M, C		II, III, ≥ III
Kays *et al.*[130]	2018	R	505 [294]	Aortic Aneurysm Repair	2	CT	SMI	M, C		
Kim, Lee *et al.*[131]	2018	R	272 [61]	Lung Cancer Surgery	4	CT	PMI	C		
Kim, Yi *et al.*[132]	2018	P	91 [45]	Hip Fracture Surgery	6	CT	SMI		1, 5	
Kobayashi *et al.*[133]	2018	R	124 [24]	Hepatic Metastases Surgery	2	CT	SMI			≥ III
Kocher *et al.*[134]	2018	R	100 [42]	Urinary Tract Cancer Surgery	2	CT	SMI	M, C, LOS, OT		
Kuwada *et al.*[135]	2018	R	491 [123]	Gastric Cancer Surgery	2	CT	SMA			≥ III
Mason *et al.*[136]	2018	R	698 [388]	Prostate Cancer Surgery	2	CT	SMI	C, LOS		≥ III
Mayr *et al.*[137]	2018	P	327 [108]	Bladder Cancer Surgery	2	CT	SMI	M		II, III, ≥ III, IV
Mosk *et al.*[138]	2018	R	251 [61]	Colorectal Cancer Surgery	2	CT	SMI	M, C		II, ≥ III
Nakamura *et al.*[139]	2018	R	328 [183]	Lung Cancer Surgery	2	CT	PMI			≥ III
Nakashima *et al.*[140]	2018	R	341 [171]	Esophageal Cancer Surgery	2	CT	SMI	M		
Newton *et al.*[141]	2018	R	135 [45]	Aortic Aneurysm Repair	4	CT	TPA	C		
O'Brien, Kavanagh *et al.*[142]	2018	R	77 [30]	IBD Surgery	3	CT	SMI			≥ III
O'Brien, Twomey *et al.*[143]	2018	R	56 [20]	Gastric Cancer Surgery	2	CT	SMI	M		≥ III
Siegal *et al.*[144]	2018	R	193 [127]	Esophageal Cancer Surgery	2	CT	SMI	M, C, LOS		
Silva de Paula *et al.*[145]	2018	R	249 [90]	Gynecological Cancer Surgery	2	CT	SMI	M, C		≥ III
Sui *et al.*[146]	2018	P	354 [87]	Pancreatic Cancer Surgery	2	CT	SMI	M, OT		III, IV
Tamagawa *et al.*[147]	2018	R	82 [40]	Colorectal Cancer Surgery	2	CT	TPA	C, LOS		
Tanaka *et al.* (a)[43]	2018	R	71 [34]	Aortic Aneurysm Repair	4	CT	PMI	M, C, HD		
Tanaka *et al.* (b)[43]	2018	R	211 [120]	Open Aortic Aneurysm Repair	4	CT	PMI	M, C, HD		
Thurston *et al.*[148]	2018	R	191 [30]	Endovascular Aneurysm Repair	4	CT	TPA	C		
van der Kroft *et al.*[149]	2018	P	63 [33]	Colorectal Cancer Surgery	2	CT	SMI	C		
van Vugt *et al.*[150]	2018	P	816 [411]	Colorectal Cancer Surgery	2	CT	SMI	M, C, HD	1, 3, 5	≥ III
Wakabayash *et al.*[151]	2018	R	100 [47]	Liver Transplant	1	CT	SMI	C, LOS, OT		
Zhang *et al.*[152]	2018	P	156 [24]	Gastric Cancer Surgery	2	CT	SMI			II, III, IV
Cheng *et al.*[153]	2019	R	272 [50]	Endovascular Aneurysm Repair	4	CT	TPA	M, C		
Ma *et al.*[154]	2019	R	545 [40]	Gastric Cancer Surgery	2	CT	SMI	M, C		II, III, IV
Babu *et al.*[155]	2019	R	86 [39]	Hip/Knee Arthroplasty	6	CT	PMI	HD		
Brandt *et al.*[156]	2019	R	150 [38]	Emergency Abdominal Surgery	5	CT	TPA	M		
Bril *et al.*[157]	2019	R	235 [109]	Total Laryngectomy	6	CT	SMM	M, C		
Chen *et al.*[158]	2019	P	313 [37]	Gastric Cancer Surgery	2	CT	SMI	M, C		II, III, IV
Cho *et al.*[159]	2019	R	45 [18]	Lung Transplant	1	CT	SMA	M, LOS		
Dolan *et al.*[160]	2019	R	163 [32]	Colorectal Cancer Surgery	2	CT	TPI	C	1	
Gruber *et al.*[161]	2019	R	133 [78]	Pancreatic Cancer Surgery	2	CT	SMI			≥ III
Herrod *et al.*[162]	2019	R	169 [51]	Colorectal Cancer Surgery	2	CT	SMI			≥ III
Hsu *et al.*[163]	2019	R	95 [39]	Lung Transplant	1	CT	PMA	M	1	
Hwang *et al.*[164]	2019	R	230 [73]	Trauma Surgery	6	CT	SMI	M, HD		
Ishida *et al.*[165]	2019	R	165 [51]	Esophageal Cancer Surgery	2	CT	PMI	C		
Jochum *et al.*[166]	2019	R	48 [24]	Rectal Cancer Surgery	2	CT	SMI	C		
Kitano *et al.*[167]	2019	P	110 [31]	Hepatic Cancer Surgery	2	CT	SMI		1, 3	≥ III
Koch *et al.*[168]	2019	R	83 [30]	Esophagogastric Cancer Surgery	2	CT	SMI			≥ III
Kroh *et al.*[169]	2019	R	70 [33]	Hepatic Cancer Surgery	2	CT	PMI	M, C, LOS		II, III, IV
Kubo *et al.*[170]	2019	R	103 [50]	Emergency Surgery	5	CT	SMI	M, LOS		≥ III
Kurumisawa and Kawahito[171]	2019	R	138 [35]	Cardiac Surgery	6	CT	PMI	M, LOS, OT		
Makiguchi *et al.*[172]	2019	R	122 [31]	Oral Cancer Surgery	2	CT	SMI	OT		
Miller *et al.*[173]	2019	R	178 [45]	Abdominoperineal Resection	6	CT	TPA	C		
Nakada *et al.*[174]	2019	R	173 [59]	Lung Cancer Surgery	2	CT	PMI	C		

Table 1

(*Continued*)

Study	Year	R/P	Patients [with sarcopenia] (*n*)	Surgery type	Category	Imaging	Assessment Method	Outcomes	Survival (years)	Complications (C-D Grade)
Nakayama *et al.*[175]	2019	R	94 [21]	Ovarian Cancer Surgery	2	CT	SMI	C, LOS		
Oguma *et al.*[176]	2019	R	194 [28]	Esophageal Cancer Surgery	2	CT	SMI	C		
Oh *et al.*[177]	2019	R	74 [31]	Fontan Surgery	4	CT	SMI	OT		≥ III
Okabe, Hayashi *et al.*[178]	2019	P	143 [80]	Hepatic Metastases Surgery	2	CT	SMA			≥ III
Okabe, Ohsaki *et al.*[179]	2019	P	268 [159]	Colorectal Cancer Surgery	2	CT	SMI			≥ III
Okamura *et al.*[180]	2019	R	428 [107]	Heart Valve Surgery	4	CT	PMA	M, HD		
Olmez *et al.*[181]	2021	R	160 [73]	Colon Cancer Surgery	2	CT	SMI	M, LOS, OT		≥ III
Shi *et al.*[182]	2019	R	279 [68]	Gastric Cancer Surgery	2	CT	TPA	C		II, III, IV
Sierzega *et al.*[183]	2019	R	138 [60]	Gastric Cancer Surgery	2	CT	SMI	M, C	1	≥ III
Soma *et al.*[184]	2019	R	102 [45]	Esophageal Cancer Surgery	2	CT	SMI	C, OT		
Stone *et al.*[185]	2019	R	260 [144]	Head and Neck Cancer Surgery	2	CT	SMI		5	
Suh *et al.*[186]	2019	R	107 [35]	Lung Transplant	1	CT	PMM	M, LOS, OT	1, 3	
Xu *et al.*[187]	2019	R	141 [73]	Esophageal Cancer Surgery	2	CT	SMI	M, C, LOS, OT	1	
Yoon *et al.*[188]	2019	R	371 [185]	Biliary Tract Cancer Surgery	2	CT	SMI	M, LOS, OT		≥ III
Zhang *et al.*[189]	2019	P	6447 [1638]	Digestive Tract Cancer Surgery	2	CT	PMA	C, LOS		
Pittelkow *et al.*[190]	2020	R	108 [8]	Breast Reconstruction	6	CT	SMI	LOS		
Agalar *et al.*[191]	2020	P	65 [20]	Cytoreductive Surgery	2	CT	SMI	M		
Alwani *et al.*[192]	2020	R	168 [47]	Head and Neck Cancer Surgery	2	CT	SMI	C, OT		≥ III
Ansari *et al.*[193]	2020	R	78 [48]	Oral Cancer Surgery	2	CT	SMI	C	1	≥ III
Aro *et al.*[194]	2020	R	348 [208]	Colorectal Cancer Surgery	2	CT	SMI	M, C, HD	5	≥ III
Bailey *et al.*[195]	2020	R	86 [23]	Abdominal Wall Reconstruction	6	CT	TPI	C		
Broyles *et al.*[196]	2020	R	208 [30]	Breast Reconstruction	6	CT	SMI	LOS, C		
Chen *et al.*[197]	2020	P	360 [133]	Colorectal Cancer Surgery	2	CT	SMI	C		
de Cabo *et al.*[198]	2020	R	97 [43]	Liver Transplant	1	CT	PMI			≥ III
Giani *et al.*[199]	2020	R	173 [43]	Rectal Cancer Surgery	2	CT	SMI	C		
Halpern *et al.*[200]	2020	R	132 [95]	Lung Transplant	1	CT	SMI	HD		
Hendrickson *et al.*[201]	2020	R	145 [38]	Sarcoma Surgery	2	CT	TPI	M, C		II, III, IV
Huang *et al.*[202]	2020	P	880 [167]	Gastric Cancer Surgery	2	CT	SMI	C		
Kärkkäinen *et al.*[203]	2020	P	244 [165]	Endovascular Aortic Repair	4	CT	PMM	M, C, LOS		
Kim *et al.*[204]	2020	R	305 [115]	Gastric Cancer Surgery	2	CT	SMI	C, LOS, OT		
Lee, Moon *et al.*[205]	2020	R	236 [59]	Lung Cancer Surgery	2	CT	PMI	C, LOS, OT		
Lee, Park *et al.*[206]	2020	R	158 [88]	Gallbladder Cancer Surgery	2	CT	SMI	M		III, ≥ III, IV
Lee, Won *et al.*[207]	2020	R	216 [72]	Colorectal Cancer Surgery	2	CT	SMI	M, C		≥ III
Madariaga *et al.*[208]	2020	R	130 [33]	Lung Cancer Surgery	2	CT	SMA	C, HD		≥ III
Mao *et al.*[209]	2020	R	200 [67]	Bladder Cancer Surgery	2	CT	TPI	M, LOS	3, 5	
Meier *et al.*[210]	2020	R	107 [23]	Pancreas and Kidney Transplant	1	CT	PMI	C, LOS		II, III, IV
Menezes *et al.*[211]	2020	P	77 [26]	Esophagogastric Cancer Surgery	2	CT	SMI	C		
Morisaki *et al.*[212]	2020	R	117 [34]	Infrainguinal Revascularization	4	CT	PMA	M, C	1	
Oh, Ko *et al.*[213]	2020	R	423 [54]	Colon Cancer Surgery	2	CT	SMI	C		≥ III
Oh, Song *et al.*[214]	2020	R	144 [73]	Tricuspid Valve Surgery	4	CT	SMI	M, C		
Okamura *et al.*[215]	2020	R	304 [76]	Coronary Artery Bypass Surgery	4	CT	PMI	M		
Olmez *et al.*[216]	2020	R	209 [97]	Colorectal Cancer Surgery	2	CT	SMI	C, LOS		
Olson *et al.*[217]	2020	P	200 [75]	Aortic Repair	4	CT	SMA	M, C	5	
Richards *et al.*[218]	2020	R	350 [115]	Colorectal Cancer Surgery	2	CT	TPI	M, C, HD	1	≥ III

Ryu *et al.*[219]	2020	R	548 [252]	Pancreatic Cancer Surgery	2	CT	SMI	M		≥ III
Shinohara *et al.*[220]	2020	R	391 [198]	Lung Cancer Surgery	2	CT	PMA	M, C		
Srpcic *et al.*[221]	2020	P	139 [23]	Esophageal Cancer Surgery	2	CT	SMI	M, C		
Sun *et al.*[222]	2020	R	347 [69]	Lung Cancer Surgery	2	CT	PeMI	C		
Tokuda *et al.*[223]	2020	R	1375 [802]	Aortic Valve Replacement	4	CT	PMA	M		
Tokunaga *et al.*[224]	2020	R	328 [117]	Colorectal Cancer Surgery	2	CT	SMI	M		
Trikudanathan *et al.*[225]	2020	R	138 [46]	Pancreatic Resection	6	CT	SMI	M		≥ III
Wang *et al.*[226]	2020	R	138 [59]	Gastric Cancer Surgery	2	CT	SMI	C		
Xiao *et al.*[227]	2020	R	1630 [704]	Colon Cancer Surgery	2	CT	SMI	M, C, LOS		≥ III
Xie *et al.*[228]	2020	R	298 [132]	Colorectal Cancer Surgery	2	CT	SMI	C, LOS		II, III, IV
Xu *et al.*[229]	2020	R	152 [59]	Pancreatic Resection	6	CT	TPI	M, LOS		
Zhuang *et al.*[230]	2020	P	883 [167]	Gastric Cancer Surgery	2	CT	SMI	M, C	3	II, III, IV
Fang *et al.*[231]	2021	R	409 [265]	Gastric Cancer Surgery	2	CT	PMI	C		
Peng *et al.*[232]	2021	R	116 [20]	Pancreatic Cancer Surgery	2	CT	SMA	LOS		≥ III
Yabe *et al.*[233]	2021	R	88 [43]	Breast Cancer Patients	2	CT	PMI	C, LOS		
Bang *et al.*[234]	2021	R	379 [104]	Aortic Aneurysm Repair	4	CT	SMI	M		
Carvalho *et al.*[235]	2021	P	84 [15]	Gastrointestinal Cancer Surgery	2	CT	SMI	C		
Celentano *et al.*[236]	2021	R	31 [8]	IBD Surgery	3	MRI	TPA	C		
Chae *et al.*[237]	2021	R	82 [17]	Ovarian Cancer Surgery	2	CT	SMI	M		
Chai *et al.*[238]	2021	P	228 [36]	Colorectal Cancer Surgery	2	CT	SMI	M	1	≥ III
Chatterjee *et al.*[239]	2021	R	392 [131]	Aortic Aneurysm Repair	4	CT	TPI	M, C		
Che *et al.*[240]	2021	R	167 [86]	Major Gynecologic Surgery	6	CT	SMA	C		II
Choi *et al.*[241]	2021	R	440 [246]	Lung Cancer Surgery	2	CT	SMI	M	5	
Çınar *et al.*[242]	2021	R	120 [60]	Lung Cancer Surgery	2	CT	SMI	M, C, LOS, OT		≥ III
Doolittle *et al.*[243]	2021	R	78 [21]	Rib Fracture Surgery	6	CT	SMI	LOS		
Fehrenbach *et al.*[244]	2021	R	85 [58]	Esophageal Cancer Surgery	2	CT	SMI	C		
Hirase *et al.*[245]	2021	R	114 [49]	Thoracolumbar Spine Surgery	6	CT/MRI	PMI	M, C, HD, OT		
Ilic *et al.*[246]	2021	P	141 [79]	Brain Metastases Surgery	2	MRI	TMT	M		
Ishida *et al.*[247]	2021	P	333 [37]	Esophageal Cancer Surgery	2	CT	PMA	C		
Jang *et al.*[248]	2021	R	160 [28]	Hepatic Cancer Surgery	2	CT	PMI	M	5	
Jitwongwai *et al.*[249]	2021	R	77 [36]	Pediatric Liver Transplant	1	CT	PMI	M		
Jung *et al.*[250]	2021	P	190 [64]	Head and Neck Cancer Surgery	2	CT	SMI	M		
Katsui *et al.*[251]	2021	P	99 [59]	Lung Cancer Surgery	2	CT	PMM	M, C		
Lee *et al.*[252]	2021	R	1801 [593]	Gastric Cancer Surgery	2	CT	SMI	C, LOS, OT		≥ III
Lim *et al.*[253]	2021	R	367 [92]	Cardiac Surgery	6	CT	PMA	M		
Maddox *et al.*[254]	2021	R	50 [12]	Lower Extremity Reconstruction	6	CT	TPA	C		
Mazzola *et al.*[255]	2021	R	43 [31]	Liver and Kidney Transplant	1	CT	TPA	M, C		
Mercan *et al.*[256]	2021	R	40 [11]	Cytoreductive Surgery	2	CT	TPI			≥ III
Nakayama *et al.*[257]	2021	R	63 [34]	Esophageal Cancer Surgery	2	CT	PMI			≥ III
Olmez *et al.*[258]	2021	R	149 [57]	Gastric Cancer Surgery	2	CT	SMI	C, LOS, OT		
Pessia, Giuliani *et al.*[259]	2021	R	76 [32]	Pancreatic Cancer Surgery	2	CT	SMI			≥ III
Pessia, Romano *et al.*[260]	2021	R	74 [48]	Hepatic Metastases Surgery	2	CT	SMI			IV
Regnier *et al.*[261]	2021	R	82 [47]	Bladder Cancer Surgery	2	CT	SMI	C		II, IV
Ritz, Froeba-Pohl *et al.*[262]	2021	R	80 [50]	Neuroblastoma Cancer Surgery	2	CT	PMA		5	
Ritz, Kolorz *et al.*[263]	2021	R	33 [17]	Hepatic Cancer Surgery	2	CT/MRI	PMA	M, C		
Sakurai *et al.* (a)[42]	2021	R	691 [117]	Gastric Cancer Surgery	2	CT	SMI	M, LOS		≥ III
Sakurai *et al.* (b)[42]	2021	R	363 [76]	Gastric Cancer Surgery	2	CT	SMI	M, LOS		≥ III
Sim *et al.*[264]	2021	R	615 [309]	Hip Fracture Surgery	6	CT	PMI	M	1	
Sinduja *et al.*[265]	2021	P	100 [62]	Gastric Cancer Surgery	2	CT	SMI	M, C, LOS, OT		II, III, ≥ III
Sivaharan *et al.*[266]	2021	R	116 [12]	Infrainguinal Bypass Surgery	4	CT	SMA	M, LOS	1	

Table 1

(Continued)

Study	Year	R/P	Patients [with sarcopenia] (*n*)	Surgery type	Category	Imaging	Assessment Method	Outcomes	Survival (years)	Complications (C-D Grade)
Sun *et al.*[267]	2021	P	267 [49]	Gastric Cancer Surgery	2	CT	SMI	C, OT		II, III, IV
Takahashi *et al.*[268]	2021	R	315 [79]	Lung Cancer Surgery	2	CT	PMA	C		
Taniguchi *et al.*[269]	2021	R	567 [88]	Gastric Cancer Surgery	2	CT	PMI	C		
Tuncer *et al.*[270]	2021	R	107 [51]	Gastric Cancer Surgery	2	CT	SMA	M, C, LOS		II, III, IV
Uemura *et al.*[271]	2021	R	121 [78]	Esophageal Cancer Surgery	2	CT	PMI		3	≥ III
Wakefield *et al.*[272]	2021	R	52 [39]	Esophageal Cancer Surgery	2	CT	SMI	C		
Watanabe, Osaki *et al.*[273]	2021	R	242 [154]	Gastric Cancer Surgery	2	CT	PMI	M		
Watanabe, Ishihara *et al.*[274]	2021	R	83 [54]	Renal Cancer Surgery	2	CT	SMI			≥ III
Wittmann *et al.*[275]	2021	R	106 [20]	LVADI	4	CT	PMI	M		
Wu *et al.*[276]	2021	R	122 [14]	Liver Transplant	1	CT	PMI	M	1,3,5	
Zhang *et al.*[277]	2021	R	124 [34]	IBD Surgery	3	CT	SMI	M, C, LOS		
Zou *et al.*[278]	2021	R	135 [27]	Gastric Cancer Surgery	2	CT	SMI	C, LOS, OT		II, III, IV
Trinder *et al.*[279]	2022	R	147 [53]	IBD Surgery	3	CT	SMA	M, C, LOS		III, IV
Uehara *et al.*[280]	2022	R	262 [49]	Rectal Cancer Surgery	2	CT	PMI	M, C		≥ III
Aoki *et al.*[281]	2022	P	180 [19]	Pancreatic Cancer Surgery	2	CT	SMI	C		II, III, ≥ III, IV
Asai *et al.*[282]	2022	R	456 [152]	Hepatic Cancer Surgery	2	CT	PMI	M		≥ III
Barazanchi *et al.*[283]	2022	R	167 [84]	Emergency Laparotomy	5	CT	SMI	M, C, LOS, OT	1	II, IV
Body *et al.*[284]	2022	P	609 [179]	Emergency Laparotomy	5	CT	SMI	M, C, HD	1	II, III, IV
Brinkmann *et al.*[285]	2022	R	48 [24]	Sacral Cancer Surgery	2	CT	PMI	OT		
Chang *et al.*[286]	2022	R	1174 [288]	Colorectal Resection	6	CT	TPI	M, C, HD		
Chargi *et al.*[287]	2022	R	554 [209]	Head and Neck Cancer Surgery	2	CT	SMM	LOS		
Chen *et al.*[288]	2022	R	921 [233]	Colorectal Cancer Surgery	2	CT	SMI	C		≥ III
de Jong *et al.*[289]	2022	R	35 [17]	Adrenocortical Cancer Surgery	2	CT	SMI	C		≥ III
D'Oria *et al.*[290]	2022	R	338 [154]	Endovascular Aortic Repair	4	CT	PMA	M, C, LOS, OT		
Erkul *et al.*[291]	2022	P	146 [31]	Gastric Cancer Surgery	2	CT	SMI	M, C		II, III, IV
Gallone *et al.*[292]	2022	R	391 [117]	Aortic Valve Replacement	4	CT	PMA	M, OT		
Gao *et al.*[293]	2022	R	252 [85]	Bladder Cancer Surgery	2	CT	SMI	M		≥ III
Groot *et al.*[294]	2022	R	205 [79]	Bone Metastases Surgery	2	CT	SMA	M, C	1	
Hayashi *et al.*[295]	2022	R	303 [106]	Hepatic Cancer Surgery	2	CT	SMI	M		≥ III
Heil *et al.*[296]	2022	R	306 [194]	Portal Vein Embolization	4	CT	SMI	M		≥ III
Hisada *et al.*[297]	2022	R	700 [239]	Gastric Cancer Surgery	2	CT	SMI	C		
Hogenbirk *et al.*[298]	2022	P	123 [23]	Carotid Endarterectomy	2	CT	MMA	C	5	
Hong *et al.*[299]	2022	R	76 [48]	IBD Surgery	3	CT/MRI	SMI	M, C		
Horie *et al.*[300]	2022	P	46 [22]	Rectal Cancer Surgery	2	CT	PMA	M, C		≥ III
Huang *et al.*[301]	2022	R	592 [318]	Oral Cavity Cancer Surgery	2	CT	SMI	M, C		II, III, IV
Ito *et al.*[302]	2022	R	88 [64]	Gastric Cancer Surgery	2	CT	PMI	M	3, 5	
Jensen *et al.*[303]	2022	R	329 [82]	Emergency Laparotomy	5	CT	TPA	M		
Kamada *et al.*[304]	2022	R	70 [36]	Esophageal Cancer Surgery	2	CT	MMA	M		
Kim, Lee *et al.*[305]	2022	R	557 [154]	Breast Reconstruction	6	CT	SMI	C		
Kim, Choi *et al.*[306]	2022	R	159 [74]	Hepatic Cancer Surgery	2	CT	SMI			≥ III
Kondo *et al.*[307]	2022	R	140 [29]	Aortic Valve Replacement	4	CT	PMI	M, C, OT	1	
Krenzlin *et al.*[308]	2022	R	68 [28]	Vertebral Fracture Surgery	6	CT	SMA	C		
Lee *et al.*[309]	2022	R	1270 [323]	Colorectal Cancer Surgery	2	CT	SMI	C		
Liu *et al.*[310]	2022	R	224 [145]	TIPS	4	CT	SMA		1	
Martin *et al.*[311]	2022	R	355 [212]	Hepatic Resections	6	CT	SMI	M, C		≥ III

Meister *et al.*[312]	2022	R	100 [54]	Hepatic Cancer Surgery	2	CT	SMI	LOS		≥ III
Pernik *et al.*[313]	2022	R	196 [48]	Spine Surgery	6	CT/MRI	PMI	M, HD, LOS, OT	1	
Rizzo *et al.*[314]	2022	R	107 [58]	Lung Cancer Surgery	2	CT	SMI	M		
Rom *et al.*[315]	2022	R	111 [30]	Pancreatic Cancer Surgery	2	CT	SMI	C		≥ III
Sadok *et al.*[316]	2022	R	103 [50]	Breast Reconstruction	6	CT	SMI	C		
Selçuk *et al.*[317]	2022	R	217 [82]	Limb Ischemia Revascularization	4	CT	PMI	M		
Shen *et al.*[318]	2022	R	338 [44]	Coronary Artery Bypass Surgery	4	CT	SMA	M, C		II, III, IV
Sim *et al.*[319]	2022	R	2816 [309]	Liver Transplant	1	CT	SMI	M	1	
Simpson *et al.*[320]	2022	P	944 [235]	Emergency Laparotomy	5	CT	PMA	M		
Song *et al.*[321]	2022	R	107 [28]	Gastric Cancer Surgery	2	CT	SMI	M, C		II, III, IV
Springer *et al.*[322]	2022	R	85 [29]	Rectal Cancer Surgery	2	CT	PMI	C		
Sun *et al.*[323]	2022	R	346 [98]	Lung Cancer Surgery	2	CT	PeMI	C		
Takenami *et al.*[324]	2022	R	209 [86]	Colorectal Cancer Surgery	2	CT	SMI	M, C		≥ III
Tan *et al.*[325]	2022	R	70 [38]	Liver Transplant	1	CT	PMI	M, C		
Tsai *et al.*[326]	2022	R	16 294 [5439]	Oral Cavity Cancer Surgery	2	CT/MRI	SMI	M		
Ushitani *et al.*[327]	2022	R	443 [209]	Lung Cancer Surgery	2	CT	PMI	C		
Wackenthaler *et al.*[328]	2022	R	82 [49]	Liver Transplant	1	CT	PMA		1	
Wu *et al.*[329]	2022	R	148 [89]	Emergency Laparotomy	5	CT	PMI	M		
Yoshino *et al.*[330]	2022	R	128 [57]	Breast Reconstruction	6	CT	PMI	C		
Zhang *et al.*[331]	2022	P	507 [73]	Gastric Cancer Surgery	2	CT	SMI	C	1	

Category: 1 = Transplant Surgery; 2 = Surgical Oncology; 3 = IBD Surgery; 4 = Cardiovascular Surgery; 5 = Emergency Surgery; 6 = Other.
C, Complications; C–D, Clavien–Dindo; CT, computed tomography; G ≥ III, Grade ≥ III Complications; GII, Grade II Complications; GIII, Grade III Complications; GIV, Grade IV Complications; HD, home discharge; IBD, inflammatory bowel disease; LOS, length of hospital stay; LVAD, left ventricular assist device implantation; M, mortality; MMA, masseter muscle area; MRI, magnetic resonance imaging; OT, operative time; P, prospective study; PeMI, pectoralis muscle index; PMA, psoas muscle area; PMI, psoas muscle index; PMM, psoas muscle mass; R, retrospective study; S1, 1-year survival; S3, 3-year survival; S5, 5-year survival; SMA, skeletal muscle area; SMI, skeletal muscle index; SMM, skeletal muscle mass; TIPS, transjugular intrahepatic portosystemic shunt; TMT, temporal muscle thickness; TPA, total psoas area; TPI, total psoas index; TPV, total psoas volume.

Discharge to home

A total of 21 studies provided data on the discharge destination (Table 1). The overall rate of home discharge in patients with sarcopenia and patients without sarcopenia was 67.3% and 79.7%, respectively. Pooled analysis showed a significant decrease in home discharge in patients with sarcopenia (OR 0.50; 95% CI: 0.40–0.63; $P < 0.00001$; Table 2, Fig. 3).

Survival rate

Thirty-four studies provided data on 1-year survival, 11 studies provided data on 3-year survival, and 14 studies provided data on 5-year survival (Table 1). Patients with sarcopenia were significantly less likely to survive 1 year postsurgery (78.2 vs. 90.0%; OR 0.45; 95% CI: 0.38–0.53; $P < 0.00001$; Table 2, Fig. 3), 3 years postsurgery (57.9 vs. 70.2%; OR 0.44; 95% CI: 0.31–0.61; $P < 0.00001$; Table 2, Fig. 3), and 5 years postsurgery (63.5 vs. 75.9%; OR 0.55; 95% CI: 0.46–0.65; $P < 0.00001$; Table 2, Fig. 3).

Subgroup analysis

Subgroup analysis of the complications was performed based on 41 studies that provided specific data on grade II complications, 40 studies that provided data on Clavien–Dindo (C–D) grade III complications, 92 that provided data on C–D grade ≥ III complications, and 38 that provided data on C–D grade IV complications (Table 1). Patients with sarcopenia were significantly more likely to experience C–D grade II (21.9 vs. 15.8%; OR 1.60; 95% CI: 1.33–1.91; $P < 0.00001$; Table 3, Fig. 3), C–D grade III (13.2 vs. 10.7%; OR 1.22; 95% CI: 1.06–1.40; $P = 0.005$; Table 3, Fig. 3), C–D grade ≥ III (19.6 vs. 14.9%; OR 1.59; 95% CI: 1.40–1.81; $P < 0.00001$; Table 3, Fig. 3), and C–D grade IV complications (5.9% vs. 2.8%; OR 2.09; 95% CI: 1.70–2.57; $P < 0.00001$; Table 3, Fig. 3).

When restricting the analysis to studies analyzing patients undergoing oncological surgery, mortality (88 studies; OR 2.69; 95% CI: 2.21–3.28; $P < 0.00001$) and complication occurrence (114 studies; OR 1.68; 95% CI: 1.47–1.92; $P < 0.00001$) were significantly higher in patients diagnosed with sarcopenia (Table 4, Fig. 3). Similar effects were seen in the cardiovascular surgery cohort (mortality: 27 studies; OR 2.18; 95% CI: 1.76–2.70; $P < 0.00001$; complication occurrence: 16 studies; OR 1.51; 95% CI: 1.25–1.82; $P < 0.0001$) and the emergency surgery cohort (mortality: 10 studies; OR 2.64; 95% CI: 1.04–6.72; $P = 0.04$; complication occurrence: 5 studies; OR 1.68; 95% CI: 1.06–2.67; $P = 0.03$; Table 3, Fig. 3). In the transplant surgery cohort, mortality was significantly higher in patients with sarcopenia (14 studies; OR 3.46; 95% CI: 2.00–5.99; $P < 0.00001$), however, complication occurrence was not different (7 studies; OR 1.52; 95% CI: 0.81–2.84; $P = 0.19$; Table 3, Fig. 3). Among all patients undergoing surgery for inflammatory bowel disease, the frequency of complications was significantly increased among sarcopenic patients (4 studies; OR 1.92; 95% CI: 1.20–3.07; $P = 0.007$; Table 4, Fig. 3).

Sensitivity analysis

When restricting the analysis to studies with a NOS quality score of ≥ 8 (Supplementary Table 1, Supplemental Digital Content 4, http://links.lww.com/JS9/A968), the mortality (21 studies; OR 3.39; 95% CI: 2.28–5.04; $P < 0.00001$) and complication rates

Table 2

Analysis of primary outcomes.

Outcome	Studies	Patients (events)		OR (95% CI)	P	I^2% (P)
		With sarcopenia	Without sarcopenia			
Mortality	154	21 122 (5599)	40 236 (8119)	2.69 (2.31–3.12)	< 0.00001	79 (< 0.00001)
Any complications	160	16 859 (6660)	33 534 (8993)	1.68 (1.51–1.87)	< 0.00001	79 (< 0.00001)
Home discharge	21	2720 (1833)	5338 (4257)	0.50 (0.40–0.63)	< 0.00001	67 (< 0.00001)
1-Year	34	3560 (2785)	8814 (7935)	0.45 (0.38–0.53)	< 0.00001	39 (0.01)
3-Year	11	1245 (721)	2618 (1839)	0.44 (0.31–0.61)	< 0.00001	69 (0.0003)
5-Year	14	1563 (993)	1666 (1260)	0.55 (0.46–0.65)	< 0.00001	18 (0.25)
		Patients		MD (95% CI)		
LOHS	64	7377	14 385	1.68 (1.18–2.17)	< 0.00001	90 (< 0.00001)
Operative time	40	3350	5792	1.68 (– 5.62 to 8.98)	0.65	79 (< 0.00001)

Odds ratio estimates (OR) and mean differences (MD) with 95% confidence intervals (CI). Patients with sarcopenia were more likely to experience complications and mortality, had longer hospital stays, and were less likely to be discharged home. Operative time did not differ between the two cohorts. A direct significant correlation between the presence of sarcopenia and lower survival rates at 1, 3, and 5 years was noted.

(20 studies; OR 1.82; 95% CI: 1.48–2.25; $P < 0.00001$) remained significantly higher in the sarcopenia cohort (Table 3). Analyzing the outcome of all prospective studies, sarcopenic patients again showed significantly higher mortality (26 studies; OR 3.79; 95% CI: 2.23–6.46; $P < 0.00001$) and complication rates (29 studies; OR 1.94; 95% CI: 1.47–2.55; $P < 0.00001$; Table 4).

Forest plots and funnel plots for all aforementioned analyses are available as Supplementary Figures 1–27 (Supplemental Digital Content 5, http://links.lww.com/JS9/A969).

Meta-regression analyses

Specifically in the cohort of patients with radiographically diagnosed sarcopenia, meta-regressions revealed nonsignificant correlations between age (coefficient: – 0.001, $P = 0.684$ and coefficient: – 0.001, $P = 0.491$, respectively), BMI (coefficient: 0.004, $P = 0.591$ and coefficient: – 0.014, $P = 0.098$, respectively) and ASA scores (coefficient: 0.122, $P = 0.051$ and coefficient: 0.008, $P = 0.891$, respectively) with patient complication occurrence and mortality, respectively. In other words, neither age nor BMI and ASA significantly influenced the prognostic value of sarcopenia with regard to postoperative morbidity and mortality. Similarly, among all patients without sarcopenia, age (coefficient: – 0.002, $P = 0.320$ and coefficient: 0.001, $P = 0.711$, respectively) and BMI (coefficient: 0.008, $P = 0.123$ and coefficient: 0.001, $P = 0.906$, respectively) had no significant impact on the incidence of postoperative adverse events and mortality. In the absence of sarcopenia, the risk for complications increased significantly with higher ASA scores (coefficient: 0.191; $P = 0.002$). As for patient mortality, we found a similar correlation, albeit not statistically significant (coefficient: 0.030; $P = 0.509$) (Supplementary Figure 28, Supplemental Digital Content 5, http://links.lww.com/JS9/A969 and Supplementary Figure 29, Supplemental Digital Content 5, http://links.lww.com/JS9/A969).

Discussion

Implications for clinical management

This meta-analysis, which is the largest to date, pools data from 294 studies and almost 100 000 patients to compare the surgical outcomes of patients with and without sarcopenia. The clinical impact of this study is that it provides indisputable evidence that sarcopenia is a risk factor for poor outcomes across all surgical specialties. Our findings clearly demonstrate patients with sarcopenia are more likely to experience complications and mortality, as well as longer hospital stays during postoperative recovery. Higher rates of complications and longer hospital stays possibly underlie the higher rates of non-home discharge seen in patients with sarcopenia. At the same time, the necessity for discharge to specialized care may be delaying discharge from the hospital and, thus, prolonging the hospital stay. Furthermore, sarcopenia continues to impact patient outcomes in the long term, with sarcopenic patients having lower 1-year, 3-year, and 5-year survival rates.

Our findings highlight the significance of the impact of sarcopenia in the field of surgery and call for a re-assessment of the operative routine. More specifically, we propose a three-stage optimization plan:

Preoperative care

We advocate the preoperative and early diagnosis of sarcopenia. Identifying sarcopenic patients at an early stage will allow surgeons to critically balance patients' eligibility and optimally plan for more individualized surgical care, including the selection of the most appropriate anesthesia regimen. Although reports vary, in recent years, the general consensus that regional anesthesia is associated with better outcomes in frail patients has arisen[332,333]. In addition, early sarcopenic diagnostics may aid in refining preoperative counseling. The sarcopenia-related predisposition to adverse events should be thoroughly discussed, and when possible, patients may wish to consider alternative, more appropriate treatment modalities given their increased risk. Furthermore, with sarcopenia being diagnosed preoperatively, the operative plan can be refined, and proactive prehabilitation via nutrition and exercise can be promptly initiated. Multiple studies have supported that the implementation of a multidisciplinary prehabilitation regimen, which includes physical, nutritional, and psychological programs, has the potential to drastically enhance patient physiological reserve and functional capacity, enabling patients to withstand the incoming stressor of surgery and accelerating their postoperative recovery[334–336]. Also important during the preoperative planning stage is the preemptive mobilization of the correct multidisciplinary team required for the postoperative period, including physiotherapy, psychology, and social work. This may decrease hospital stay, as patients who

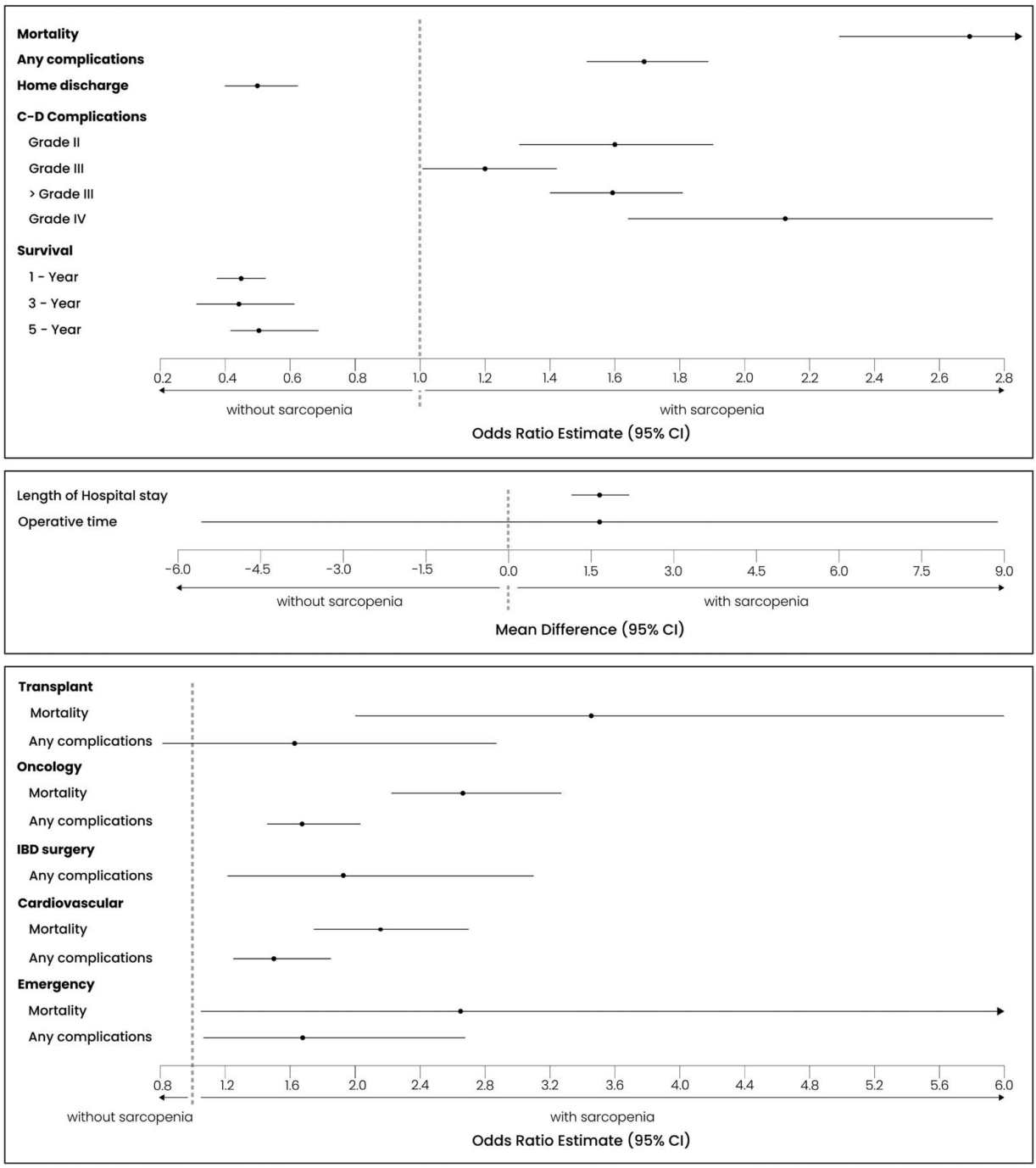

Figure 3. Odds ratio estimates and mean differences with 95% confidence intervals (CI). Mortality and any complications, including all grades of the Clavien–Dindo (C–D) classification, were more likely to occur in patients with sarcopenia. Furthermore, patients with sarcopenia were less likely to be discharged home and had lower 1-year, 3-year and 5-year survival rates. The length of hospital stay was also prolonged in patients with sarcopenia. Focusing on surgical specialties, patients with sarcopenia undergoing transplant surgery had the highest correlation with mortality, while any complications were most likely to occur in patients with sarcopenia undergoing surgery for inflammatory bowel disease (IBD).

are unfit to be discharged home are often kept in the hospital for nonmedical reasons, including delayed involvement of social care or posthospitalization specialized care facilities. It should be noted that this first stage of optimal preoperative planning is more applicable to elective surgeries, with emergency and nonelective surgeries rarely allowing time for physical optimization prior to surgery. Preemptive mobilization of the appropriate postoperative care team is, however, equally applicable to elective and nonelective surgery.

Perioperative hospitalization

Owing to the herein presented prognostic value of sarcopenia, surgeons should be aware of the increased risk of complications in patients with sarcopenia, and as such, throughout the

Table 3

Subgroup analysis of Clavien–Dindo (C–D) complications and based on surgical specialty.

		Patients (events)				
	Studies	With sarcopenia	Without sarcopenia	Estimate (95% CI)	*P*	I^2% (*P*)
C–D grade						
II	41	3542 (776)	7655 (1207)	1.60 (1.33–1.91)	< 0.00001	55 (< 0.00001)
III	40	3541 (469)	7668 (822)	1.22 (1.06–1.40)	0.005	23 (0.10)
> III	92	9025 (1768)	15 275 (2275)	1.59 (1.40–1.81)	< 0.00001	52 (< 0.00001)
IV	38	3426 (203)	7405 (210)	2.09 (1.70–2.57)	< 0.00001	17 (0.18)
Surgical specialty – Mortality						
Transplant	14	893 (267)	3365 (493)	3.46 (2.00–5.99)	< 0.00001	56 (< 0.00001)
Oncology	88	14 385 (4246)	26 163 (6654)	2.69 (2.21–3.28)	< 0.00001	75 (< 0.00001)
Cardiovasc	27	3099 (470)	4729 (446)	2.18 (1.76–2.70)	< 0.00001	21 (0.17)
Emergency	10	1018 (333)	2208 (270)	2.64 (1.04–6.72)	< 0.00001	94 (< 0.00001)
Surgical specialty – Any complication						
Transplant	7	236 (121)	330 (138)	1.52 (0.81–2.84)	0.19	61 (0.02)
Oncology	114	12 966 (5038)	26 150 (6437)	1.68 (1.47–1.92)	< 0.00001	83 (< 0.00001)
IBD surgery	4	143 (60)	235 (76)	1.92 (1.20–3.07)	0.007	0 (0.50)
Cardiovasc	16	1366 (386)	622 (2236)	1.51 (1.25–1.82)	< 0.00001	0 (0.46)
Emergency	5	609 (392)	1250 (742)	1.68 (1.06–2.67)	0.03	68 (0.01)

A direct significant correlation between the presence of sarcopenia and the occurrence of all C–D grades of complications was identified. The strongest correlation was seen with the occurrence of grade IV complications, which were seen to be more than twice likely to occur in patients with sarcopenia. The meta-analysis was repeated with studies classified according to surgical specialty. In terms of mortality, the direct significant correlation with the presence of sarcopenia was maintained across specialties, with transplant surgery showing the strongest correlation. In terms of any complication occurrence, the direct significant correlation with the presence of sarcopenia was maintained across specialties, with the exception of transplant surgery which although there was a direct correlation, it was no longer significant. Cardiovasc., cardiovascular; IBD, inflammatory bowel disease.

hospitalization period, particular attention should be paid to these patients. The diagnosis of sarcopenia should also trigger close-knit postoperative monitoring, aiming to decrease adverse events. In anticipation of complications, multimodal monitoring may enable the early detection of any adverse events and offer the possibility for timely intervention. By optimizing patients' care, such a surveillance strategy will also help to shorten the length of hospital stay. In this context, we also suggest concomitant supplementary therapies which can help to further dampen the sarcopenia-related risk. Given the multifactorial etiology of sarcopenia, a series of nutritional, physical, and pharmacological interventions have the potential to improve the sarcopenic status, ultimately leading to better surgical outcomes. In-hospital physiotherapy, particularly for patients with predicted longer hospital stays, would be of benefit to patients with sarcopenia. The oral consumption of branched-chain amino acids has been shown to decrease lipid oxidation and improve nitrogen balance, contributing to both energy metabolism and protein synthesis in muscle[337,338]. When combined with moderate physical activity, studies indicated improved tight muscle mass in patients with sarcopenia[339,340]. Ammonia-lowering therapy, combined with rifaximin and L-ornithine L-aspartate, has been reported to reduce plasma and muscle ammonia concentrations and improve muscle mass, which provides a potential avenue for stimulating muscle growth in sarcopenic patients[341]. Further studies highlight the anabolic effects of intramuscular testosterone administration in male patients[342]. Another therapeutic lever may be the supplementation of pharmaceutics/agents such as vitamin D, ghrelin, and myostatin inhibitors[343,344]. Thus, we suggest implementing an in-hospital strategy of physical optimization to reduce the perioperative risk of sarcopenic patients.

Posthospitalization care

Appropriate and adequate postdischarge analgesic control is of relevance for all patients, but particular care should be paid to

Table 4

Sensitivity analysis based on publication quality.

		Patients (events)				
Publication quality	Studies	With sarcopenia	Without sarcopenia	Estimate (95% CI)	*P*	I^2% (*P*)
NOS						
Mortality	21	1993 (318)	3590 (251)	3.39 (2.28–5.04)	< 0.00001	56 (0.0009)
Complications	20	2390 (753)	4566 (991)	1.82 (1.48–2.25)	< 0.00001	55 (0.001)
Prospective studies						
Mortality	26	2698 (420)	5711 (229)	3.79 (2.23–6.46)	< 0.00001	80 (< 0.00001)
Complications	29	4091 (1709)	11 065 (2250)	1.94 (1.47–2.55)	< 0.00001	87 (< 0.00001)

The meta-analysis was restricted to higher quality studies, either based on NOS Quality Score (> 8) or prospective methodology with the predictability of sarcopenia remaining significant.
NOS, Newcastle–Ottawa Scale.

patients with sarcopenia. Research has highlighted that frail patients are significantly more prone to experiencing adverse reactions to opioid analgesia, with the risk of opioid-associated respiratory depression increasing with age[345]. At the same time, caution should be paid with regard to the use of nonsteroidal anti-inflammatory drugs due to their accepted renal, gastrointestinal, and cardiovascular side effects. Therefore, in all appropriate cases, and as recommended by the American Geriatrics Society, acetaminophen, with its favorable safety profile, should be the first-line agent for pain management in patients with sarcopenia[346]. Posthospitalization care is also tightly associated with preoperative planning. Prior research has highlighted the importance of a clear, preoperative discussion with patients regarding their postoperative timeline. This consultation should outline all immediate, short-term, and long-term events that the patient should anticipate, as well as all potential and predictable postoperative interactions. Such preoperative planning, which would include a clear diagnosis and prognosis, can assist in better management of patients' expectations. Early involvement of the patient's family or circle of care would allow preemptive education with regard to the days, months, and years postsurgery. Particularly important for long-term survival is a holistic patient care plan that includes psychosocial support. Given our results that the long-term survival of patients with sarcopenia is significantly decreased, care should be paid to the postoperative factors that can increase mortality in such patients. One such modifiable factor that has been identified as a substantial concern is the vulnerability that patients with sarcopenia have to falling after surgical procedures. Effective fall prevention requires a multicomponent intervention approach, including re-assessment and modification of patients' pharmacological regimens and occupational therapy home visits for assessment of home safety and hazard removal to counteract polypharmacy and home environment hazards, respectively, two of the major identified causes of falls[347].

Ultimately, we emphasize that the presence of sarcopenia is not an absolute contraindication for surgery, and patients should in no way be screened out of undergoing surgery. Rather, through the outlined three-stage optimization plan, we recommend individualized perioperative care for such patients. Overall, this has the potential to improve surgical and healthcare provision for an increasing proportion of the population.

Diagnosis of sarcopenia

A wide array of methods has been proposed to measure muscularity, ranging from laboratory chemical tests through plethysmography and bioelectrical impedance to radiological scanning, that is, computed tomography (CT) and magnetic resonance imaging (MRI). While the majority of these available tools lack clinical applicability and/or provide limited accuracy and reproducibility, CT and MRI are considered the gold standard for muscle quantification[20–22]. Recent studies confirm the reliability and precision of CT and MRI, thereby highlighting their suitability in sarcopenia diagnostics: Zopfs *et al*.[348] concluded that single-slice axial CT measurements allow for the accurate assessment of sarcopenia, Zwart *et al*.[349] and Faron *et al*.[350] indicated the applicability of MRI in muscle quantification–. Therefore, in our analysis, we have concentrated on studies using CT and/or MRI as sarcopenia assessment tools.

Despite their wide-spread acceptance, these cross-sectional forms of functional imaging also have limitations: while CT is criticized for the lack of standardized imaging protocols and patient exposure to radiation, the operational complexity, long imaging acquisition time, and high costs hamper the ubiquitous utilization of MRI in sarcopenia assessment[351–354]. These drawbacks of MRI are also reflected numerically in our analysis: Only seven studies (2.4%) reported the (complimentary) usage of MRI in sarcopenia diagnostics. In contrast, CT-scan images are commonly acquired during the preoperative planning stage and can, thus, be readily used to derive muscle metrics from staging, follow-up, or routine CT scans without the need to re-radiate the patient. When evaluating the muscle mass on CT and MRI images, a broad spectrum of indices has been proposed, such as the Skeletal Muscle Index, Psoas Muscle Index, or Pectoralis Muscle Index. These metrics are interpreted differently, with varying sex-specific cut-off values[351,355]. We, therefore, suggest consulting an experienced radiologist when determining patients' sarcopenic status and selecting the appropriate metric.

Further implications for future research

Our findings highlight the need to further describe the role of sarcopenia as a predictor of poor postoperative outcomes. Large-scale studies are needed to investigate the feasibility of routine sarcopenia testing and validate the prognostic value of sarcopenia. Discrepancies in the postoperative outcomes of the different specialties suggest the need for further research in individual specialties to further decipher the relationship between sarcopenia and short-term and long-term outcomes in surgical patients. In addition, research on the use and validity of muscle metrics, as well as the need for standardization of scoring and reporting is required. This is critical to best define the relationships across studies and to improve the validity of risk predictions and potential clinical guidelines.

Strengths and limitations

Although this meta-analysis represents the largest study to pool data assessing the effect of sarcopenia on surgical outcomes, utilizes research methodology that follows the PRISMA guidelines, and was registered a priori, it carries some limitations. The quality of a meta-analysis is a reflection of the quality of the studies which it analyzes. While most studies analyzed in this meta-analysis are retrospective and single-center, no randomized-controlled trial was included. As pointed out in previous meta-analyses, such studies carry inherent biases, including selection bias[356,357]. Consequently, this may affect the validity of this study, which may reduce the power of the evidence found. High heterogeneity was seen among the included studies, likely due to variance in the eligible study design (retro vs. prospective methodology), the broad nature of the surgical field with its multifaceted procedures, and differences in patients' characteristics and general health status. Yet, sensitivity, subgroup, and meta-regression analyses validated and substantiated our findings, thereby highlighting the prognostic value of sarcopenia diagnosis with regard to postoperative outcomes. Funnel plots are included in the supplementary file, demonstrating the risk of publication bias. In addition, when analyzing the quality of the studies using the NOS criteria for risk of bias, only 32 of the 294 studies included in this meta-analysis were of high quality (i.e. NOS score ≥ 8), which may affect the transferability of the findings

synthesized and presented herein. It is worth mentioning that, particularly in the field of surgical research, this phenomenon is well-described and mainly due to the discipline-inherent scarcity of high-quality evidence (including randomized-controlled trials and placebo interventions) and methodological hurdles[358]. However, in order to investigate the validity of our findings, we conducted two types of sensitivity analyses: (i) we restricted the analyses to exclusively high-quality studies, wherein the mortality and complication rates remained significantly higher in the sarcopenia cohort and (ii) we included only studies with prospective data collection in the analyses, which, again, found sarcopenic patients to have a significantly higher mortality and complication occurrence. In other words, our sensitivity analyses conclusively substantiated our study's findings and their validity, robustness, and plausibility. While 76 of the studies declared financial support, the majority of the study pool (218/296) received no funding. Supplementary Table 2 (Supplemental Digital Content 6, http://links.lww.com/JS9/A970) provides a detailed overview of the funding sources for the studies included in the quantitative synthesis. Lastly, the study is subject to publication bias as 190 of 294 studies assessed oncological surgery cohorts. We sought to overcome this limitation by running a sensitivity analysis focusing on different surgical specialties. Regarding our methodology, it should be noted that articles in languages other than English, Spanish, German, and French were not considered eligible. Since a lot of research on sarcopenia comes from Asia, the noninclusion of Japanese and/or Chinese studies may withhold valuable evidence. In addition, as with every meta-analysis, the search strategy can be further expanded by including additional search terms.

Conclusion

Our findings suggest that the presence of sarcopenia is a strong predictor for poor postoperative outcomes. Identification of patients most at risk prior to surgery can assist surgeons in optimizing their perioperative plan, including preoperative patient identification, surgical plan optimization, and prehabilitation. Prospective actions can improve the status of the patients by optimizing postoperative outcomes. Postoperative hospitalization, support, rehabilitation, and discharge planning should also be optimized for patients with sarcopenia. Formal incorporation of preoperative assessment of sarcopenia through imaging can improve surgical risk stratification, which has the potential to decrease postoperative complications, shorten the length of hospital stay, and have long-lasting benefits for patients, including better survival outcomes.

Ethical approval

Not applicable.

Consent

Not applicable.

Sources of funding

No funding was received for this study.

Author contribution

S.K.: conceptualization, investigation, data curation, methodology, formal analysis, and writing Author Disclosure Form 2 – original draft; R.S.: investigation, data curation, and formal analysis; L.K.: investigation and data curation; M.W.: conceptualization and writing – review and editing; F.J.H. and D.Y.M.: data curation; D.O., D.V., A.P., and M.K.N.: writing – review and editing; V.H. and G.H.: writing – review and editing and methodology; U.K. and B.P.: writing – review and editing and supervision; D.P.O.: conceptualization, writing – review and editing, and supervision; A.C. P.: conceptualization, investigation, data curation, methodology, formal analysis, project administration, visualization, and writing – original draft. All authors read and approved the final manuscript.

Conflicts of interest disclosure

None of the authors have a financial interest in any of the products, devices, or drugs mentioned in this manuscript.

Research registration unique identifying number (UIN)

1. Name of the registry: International Prospective Register of Systematic Reviews (PROSPERO).
2. Unique identifying registration number: CRD42020221984.
3. Hyperlink to the registration: https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=221984

Guarantor

Samuel Knoedler and Adriana C. Panayi.

Data availability statement

All data generated or analyzed during this study are included in this published article (and its supplementary information files). Raw data are available from the corresponding author on reasonable request.

Provenance and peer review

Not commissioned, externally peer-reviewed.

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