Journal of Anesthesia (2025) 39:607–619
https://doi.org/10.1007/s00540-025-03512-y

ORIGINAL ARTICLE

Sarcopenia and adverse surgical outcomes following cholecystectomy

Mingyang Sun[1] · Wan-Ming Chen[2,3] · Szu-Yuan Wu[2,3,4,5,6,7,8,9,10] · Jiaqiang Zhang[1,11]

Received: 18 January 2025 / Accepted: 27 April 2025 / Published online: 16 May 2025

Abstract

Purpose Postoperative complications and mortality following cholecystectomy persist despite the procedural simplicity. We utilized a nationwide administrative database from Taiwan and conducted propensity score matching (PSM) to investigate the association between sarcopenia and major postoperative complications.

Patients and methods This retrospective cohort study analyzed data from the Taiwan National Health Insurance Research Database from 2016 to 2020. Patients who underwent elective cholecystectomy under general anesthesia for gallstone disease were included. They were categorized into two groups: those with sarcopenia and those without. The cohorts were matched at a 1:4 ratio using PSM.

Results PSM yielded a final cohort of 13,330 surgical patients (10,664 without sarcopenia and 2666 with sarcopenia). Multivariate logistic regression demonstrated that sarcopenia was significantly associated with higher 30 day mortality (adjusted odds ratio [aOR] = 2.26, 95% confidence interval [CI] 1.61–3.18) and major complications, including acute renal failure (aOR = 1.71, 95% CI 1.02–2.84), pneumonia (aOR = 1.68, 95% CI 1.22–2.31), stroke (aOR = 1.13, 95% CI 1.06–1.57), and overall complications (aOR = 1.23, 95% CI 1.07–1.41). Sarcopenia also increased the risk of 90-day mortality (aOR = 2.09, 95% CI 1.58–2.76) and 90-day major complications, including acute renal failure (aOR = 1.61, 95% CI 1.01–2.56), pneumonia (aOR = 1.70, 95% CI 1.30–2.21), stroke (aOR = 1.28, 95% CI 1.04–1.58), and overall complications (aOR = 1.24, 95% CI 1.09–1.41).

Conclusions We found that sarcopenia is an independent risk factor for increased postoperative complications and mortality following cholecystectomy. These findings highlight the importance of preoperative sarcopenia assessment to improve surgical outcomes.

Keywords Sarcopenia · Cholecystectomy · Complications · Mortality · Postoperative

Abbreviations

OR	Odds ratio
aOR	Adjusted odds ratio
CI	Confidence interval
ICD-9-CM	*International Classification of Diseases, Ninth Revision, Clinical Modification*
ICD-10-CM	*International Classification of Diseases, Tenth Revision, Clinical Modification*
PSM	Propensity score matching; NHIRD, National Health Insurance Research Database
ASA	American Society of Anesthesiology
SD	Standard deviation
SMD	Standardized mean difference
IQR	Interquartile range
y	Years old
NHI	National Health Insurance
SMI	Skeletal muscle mass index

Introduction

Sarcopenia is a complex syndrome defined by progressive and generalized loss of skeletal muscle mass and strength [1, 2]. Sarcopenia is a multifactorial disease caused by low levels of physical activity and calorie intake, a progressive increase in fibrosis, altered muscle metabolism, chronic inflammation, oxidative stress, and the degeneration of neuromuscular junctions [3–6]. Preexisting sarcopenia is

Mingyang Sun and Wan-Ming Chen have contributed equally to this study (joint primary authors).

Szu-Yuan Wu and Jiaqiang Zhang have contributed equally to this study (joint Correspondence authors).

Extended author information available on the last page of the article

an independent risk factor for mortality, nephropathy, and cancer following treatment [7–10]. Results from a meta-analysis indicated that sarcopenia significantly increased the risk of major complications, 30-day mortality, and length of hospital stay following gastrointestinal oncological surgery [11]. However, the association between sarcopenia and postoperative adverse outcomes remains controversial [11–14], especially in cases of cholecystectomy for gallstone disease.

Gallstone disease is a very common disease of the digestive system that affects up to 20% of adults, 20% of whom develop complications and need surgery [15–17]. Cholecystectomy is one of the most common general surgical procedures performed worldwide [15–17]. Postoperative complications and mortality following cholecystectomy persist despite the straightforwardness of the procedure. In population-based studies, the risk of mortality following cholecystectomy for gallstone disease was estimated to be 0.1%–0.7% [18]. Mortality rates were not substantially affected by the conversion of laparoscopic to open cholecystectomy [18]. Major postoperative complications following cholecystectomy can be life threatening [17, 19–26]. Postoperative complications of cholecystectomy include bile duct injury, biliary leak, strictures, bleeding, deep wound infection, septicemia, retained gallstones, postcholecystectomy syndrome, stroke, and acute kidney injury [17, 25, 26]. Dudanov et al. found that the incidence rates of postoperative complications and mortality in elderly patients undergoing cholecystectomy were 5.2% and 4.1%, respectively [27]. Nevertheless, the association between sarcopenia and major postoperative complications following cholecystectomy remains unclear. Cholecystectomy has a 30-day mortality rate of less than 1% in the general population and is not considered to be a high-risk surgical procedure [18, 28, 29]. Previous studies have noted relatively high incidences of major postoperative complications following cholecystectomy in patients with sarcopenia [11–14].

To adequately evaluate the risk–benefit ratio of elective cholecystectomy for gallstone disease for patients with sarcopenia, the association between sarcopenia and major postoperative complications following cholecystectomy must be understood.

Patients and methods

Data sources

Data were obtained from the National Health Insurance Research Database (NHIRD) of Taiwan from January 2016 to December 2019. The follow-up period was from the index date (the date of surgery) to December 31, 2020 [7, 9, 10, 30, 31]. All datasets can be interlinked through patient identification numbers. The study protocols were reviewed and approved by the Institutional Review Board of Tzu-Chi Medical Foundation (IRB109-015-B).

Participant selection

In total, 57,659 patients aged ≥ 20 years who underwent elective cholecystectomy with general anesthesia for gallstone disease in Taiwan between 2016 and 2019 were included in our study. Among these, 2666 patients had a diagnosis of sarcopenia, and 54,993 patients did not have a diagnosis of sarcopenia (Supplementary Table 1). To ensure a homogeneous study population and minimize confounding, we applied the following exclusion criteria: patients who had concurrent major surgeries, had a history of malignancies (ICD-10-CM: C00-C97), had missing key medical data (e.g., ASA score or hospital type), had previously undergone cholecystectomy, had end-stage renal disease requiring dialysis (ICD-10-CM: N18.6, Z99.2), or died intraoperatively. A detailed depiction of the patient selection process is provided in Supplementary Fig. 1.

In 2016, the US Centers for Disease Control and Prevention formally recognized sarcopenia as a disease, coding it as M62.84 in *ICD-10-CM*.[32] In our study, sarcopenia was defined according to the 2016 and later versions of *ICD-10-CM*.[7] Patients had sarcopenia if they had at least two claims with a principal diagnosis of sarcopenia within the 12-month period prior to surgery. In Taiwan, sarcopenia (ICD-10-CM M62.84) is typically diagnosed by specialists in geriatrics, rehabilitation medicine, or endocrinology based on muscle mass, strength, and function. Perioperative assessment often includes Skeletal Muscle Mass Index (SMI) via computed tomography (CT) at the L3 vertebral level, dual-energy X-ray absorptiometry (DXA), bioelectrical impedance analysis (BIA), handgrip strength, and gait speed, following Asian Working Group for Sarcopenia (AWGS) guidelines [33–35]. Preoperative frailty screening also aids in identifying sarcopenia to assess surgical risk. However, systematic screening is not universally implemented, and coding accuracy depends on physician awareness and hospital documentation practices.

Propensity score matching and covariate analysis

To reduce the effects of potential confounders when comparing postoperative adverse outcomes between patients with sarcopenia and patients without sarcopenia, all patients were matched using propensity scores based on the following variables: age, sex, surgical procedure (laparoscopic cholecystectomy or open cholecystectomy), comorbidities, hospital type, and American Society of Anesthesiologists (ASA) physical status score

(Table 1). In Taiwan, hospitals are classified as medical centers, regional hospitals, and district hospitals/clinics. Medical centers offer the highest level of care, while non-medical centers (regional/district hospitals, clinics) provide essential services with fewer resources for complex surgeries. Given these differences, hospital classification was included as a covariate to account for its impact on surgical outcomes. Comorbidities were determined according to the *ICD-9-CM* or *ICD-10-CM* codes used in the main diagnosis for an inpatient visit or for an outpatient visit if the number of visits was ≥ 2 within 1 year. Comorbidities that presented up to 2 years before the index date were recorded. Given the relatively low prevalence of sarcopenia in our surgical cohort and the low incidence of postoperative complications and mortality, a 1:4 matching ratio is generally recommended to minimize bias while maximizing sample size [36]. Prior studies have demonstrated that one-to-k matching (k > 1) enhances efficiency without introducing substantial bias in large observational datasets [36, 37]. We matched the cohorts at a ratio of 1:4 using the greedy matching method, and covariates were matched using propensity scores within a caliper width of 0.2 [38]. To reduce potential confounding, we adjusted for clinically relevant variables associated with both sarcopenia and surgical outcomes. These included demographic characteristics (age, sex), comorbidities (diabetes, chronic kidney disease, hypertension, cardiovascular diseases, COPD, and stroke), surgical factors (laparoscopic vs. open cholecystectomy), hospital type (medical center vs. nonmedical center), and ASA physical status score. These factors were selected based on established literature and their impact on postoperative morbidity and mortality (Table 1). To ensure model robustness, variance inflation factor (VIF) analysis was performed to assess collinearity [39]. However, recognizing that VIF does not address confounding, covariates were chosen based on clinical significance rather than automated statistical selection alone. After adjustment for confounders, a multivariate logistic regression model was used to compare 30 day and 90 day postoperative complications between patients with and without sarcopenia.

In this study, continuous variables are presented as mean ± standard deviation, where appropriate. Matching is a common technique used for selecting controls with identical background covariates as study participants so as to minimize differences among study participants that prior research has indicated are necessary to control [19–24]. A multivariate logistic regression model was used to regress postoperative complication-related variables in surgical patients with and without sarcopenia [40]. Multivariate logistic regression analysis was performed to calculate odds ratios (ORs) with 95% confidence intervals (CIs) to determine whether sarcopenia is a potential independent predictor for 30-day or 90-day postoperative complications.

Table 1 Characteristics of propensity score-matched patients with and without sarcopenia undergoing cholecystectomy

	Without Sarcopenia		With Sarcopenia		
	N = 10,664		*N* = 2,666		*SMD*
	N	%	*N*	%	
Age groups					0.000
20 y < Age ≤ 30 y	692	6.49%	173	6.49%	
30 y < Age ≤ 40 y	1208	11.33%	302	11.33%	
40 y < Age ≤ 50 y	1916	17.97%	479	17.97%	
50 y < Age ≤ 60 y	2508	23.52%	627	23.52%	
60 y < Age ≤ 70 y	2028	19.02%	507	19.02%	
Age > 70 y	2312	21.68%	578	21.68%	
Sex					0.000
Female	5176	48.54%	1294	48.54%	
Male	5488	51.46%	1372	51.46%	
Surgical procedure					0.000
Laparoscopic cholecystectomy	9280	87.02%	2320	87.02%	
Open cholecystectomy	1384	12.98%	346	12.98%	
Comorbidities					
Hypertension	3101	29.08%	954	35.78%	0.144
COPD	1249	11.71%	436	16.35%	0.134
Rheumatoid arthritis	169	1.58%	68	2.55%	0.068
Diabetes	1526	14.31%	468	17.55%	0.089
Hyperlipidemia	1816	17.03%	660	24.76%	0.191
Osteoporosis	517	4.85%	165	6.19%	0.059
Stroke	744	6.98%	250	9.38%	0.088
Dementia	119	1.11%	30	1.12%	0.001
Congestive heart failure	299	2.8%	109	4.09%	0.070
Peripheral vascular disease	112	1.05%	60	2.25%	0.094
Hypothyroidism	82	0.77%	36	1.35%	0.057
Myocardial infarction	55	0.52%	11	0.41%	0.015
Acute renal failure	42	0.39%	16	0.60%	0.029
Hospital type					0.000
Medical center	6532	61.25%	1633	61.25%	
Nonmedical center	4132	38.75%	1033	38.75%	
ASA physical status score					0.000
I	3524	33.05%	881	33.05%	
II	1764	16.54%	441	16.54%	
III	4732	44.37%	1183	44.37%	
IV	644	6.04%	161	6.04%	

ASA American Society of Anesthesiology, *SD* standard deviation, *y* years, *N* Number, *COPD* chronic obstructive pulmonary disease, *SMD* standardized mean difference

Outcome measures

Patients were monitored for the following eight major postoperative complications: acute myocardial infarction, acute renal failure, deep wound infection, pneumonia, bleeding, pulmonary embolism, septicemia, and stroke [19–24]. These complications and institutional mortality within 30 days of surgery were the primary outcomes of the study [19–24]. All ICD-10-CM codes used for defining sarcopenia, comorbidities, and postoperative complications are provided in Supplementary Table 2 to ensure reproducibility. Ninety-day mortality has been suggested to be a more appropriate indicator of quality than 30-day mortality, particularly after digestive surgery [41–45]. Therefore, 90 day postoperative complications and institutional mortality were the secondary outcomes in our study. Patients who died after the 90th day of hospitalization were counted as alive, and patients who died within 90 days but outside of the hospital were not included in the mortality outcome.

Data analysis

We used Chi-square tests to analyze demographic parameters and comorbidities in a comparison of postoperative complications and mortality following cholecystectomy among patients with and without sarcopenia. Continuous variables were analyzed using t tests to compare the differences between patients with and without sarcopenia. The adjusted ORs (aOR) with 95% CIs for 30 day and 90 day postoperative complications and mortality following cholecystectomy between patients with and without sarcopenia were analyzed through multivariate logistic regression by adjusting for covariates in Table 1.

Kaplan–Meier survival curves were constructed to estimate cumulative postoperative mortality, and the log-rank test was performed to compare survival distributions between the sarcopenia and non-sarcopenia groups. This time-to-event analysis accounted for differences in postoperative survival while incorporating censoring.

Data analyses were performed using SAS software V 9.4 (SAS Institute, Cary, NC, USA). Differences between groups were considered significant if two-sided P values were < 0.05.

Results

Study cohort

We included a final cohort of 13,330 surgical patients (10,664 patients without sarcopenia and 2666 patients with sarcopenia) who were eligible for further analysis; their characteristics are shown in Table 1. Furthermore, after PSM, the between-group differences in all covariates were nonsignificant. The confounding factors (before matching) in patients with sarcopenia significantly differed from those in the patients without sarcopenia ($P < 0.001$; Supplementary Table 1). Patients with sarcopenia tended to be older, were more likely to be female, were more likely to undergo laparoscopic cholecystectomy, had more comorbidities, were more likely to have their cholecystectomy performed in a medical center, and were more likely to have an ASA physical status score of III–IV than patients without sarcopenia (Supplementary Table 1).

30 day or 90 day postoperative adverse outcomes

As shown in Table 2, patients with sarcopenia had higher incidence rates of 30-day postoperative complications, including acute renal failure (0.86% vs. 0.46%, $P = 0.011$), pneumonia (2.18% vs. 1.22%, $P < 0.001$), stroke (3.90% vs. 2.80%, $P = 0.003$), and overall complications (12.60% vs. 10.02%, $P < 0.001$). The 30-day mortality rates for patients with and without sarcopenia were 2.14% and 0.74%, respectively ($P < 0.001$). Moreover, patients with sarcopenia had higher incidence rates of 90-day postoperative complications, including acute renal failure (1.01% vs. 0.57%, $P = 0.012$), pneumonia (3.23% vs. 1.81%, $P < 0.001$), stroke (5.18% vs. 3.66%, $P < 0.001$), and overall complications (15.00% vs. 11.90%, $P < 0.001$). The 90-day mortality rates for patients with and without sarcopenia were 3.11% and 1.12%, respectively ($P < 0.0001$).

Adjusted ORs and 95% CIs for 30-day or 90-day postoperative adverse outcomes

As shown in Table 3, after adjusting for age, sex, surgical procedure, comorbidities, hospital type, and ASA physical status score, our multivariate logistic regression analyses demonstrated that patients with sarcopenia had a significantly higher risk of 30-day mortality (aOR = 2.26, 95% CI: 1.61–3.18) and 30-day major postoperative complications, including acute renal failure (aOR = 1.71, 95% CI: 1.02–2.84), pneumonia (aOR = 1.68, 95% CI: 1.22–2.31), stroke (aOR = 1.13, 95% CI: 1.06–1.57), and overall complications (aOR = 1.23, 95% CI: 1.07–1.41). In addition, patients with sarcopenia had a significantly higher risk of 90-day mortality (aOR = 2.09, 95% CI: 1.58–2.76) and 90-day major postoperative complications, including acute renal failure (aOR = 1.61, 95% CI: 1.01–2.56), pneumonia (aOR = 1.70, 95% CI: 1.30–2.21), stroke (aOR = 1.28, 95% CI: 1.04–1.58), and overall complications (aOR = 1.24, 95% CI: 1.09–1.41).

Table 2 Postcholecystectomy adverse outcomes for propensity score–match patients with or without sarcopenia

Outcome	Without Sarcopenia N = 10,664		With Sarcopenia N = 2,666		P value
Postoperative complications (within 30 days)	*N*	*%*	*N*	*%*	
Acute myocardial infarction	17	0.16%	3	0.11%	0.575
Acute renal failure	49	0.46%	23	0.86%	0.011
Deep wound infection	56	0.53%	17	0.64%	0.481
Pneumonia	130	1.22%	58	2.18%	< 0.001
Pulmonary embolism	6	0.06%	2	0.08%	0.7236
Bleeding	85	0.80%	29	1.09%	0.1449
Septicemia	567	5.32%	160	6.00%	0.1639
Stroke	299	2.80%	104	3.90%	0.003
Any of the above	1068	10.02%	336	12.60%	< 0.001
30 day mortality	79	0.74%	57	2.14%	< 0.001
Postoperative complications (within 90 days)					
Acute myocardial infarction	27	0.25%	7	0.26%	0.931
Acute renal failure	61	0.57%	27	1.01%	0.012
Deep wound infection	69	0.65%	19	0.71%	0.708
Pneumonia	193	1.81%	86	3.23%	< 0.001
Pulmonary embolism	8	0.08%	2	0.08%	1.0000
Bleeding	87	0.82%	29	1.09%	0.176
Septicemia	631	5.92%	183	6.86%	0.067
Stroke	390	3.66%	138	5.18%	< 0.001
Any of the above	1269	11.90%	400	15.00%	< 0.001
90 day mortality	119	1.12%	83	3.11%	< 0.001

N number

Kaplan–Meier 30 day or 90 day mortality and postoperative complications

Figures 1 and 2 present the cumulative risks of 30-day or 90-day mortality and postoperative complications between propensity score-matched patients with and without sarcopenia. As shown in Fig. 1, the cumulative incidence of 30-day mortality was significantly higher in patients with sarcopenia than in patients without sarcopenia ($P < 0.001$, Fig. 1A), and the cumulative incidence of 30-day postoperative overall complications was significantly higher in patients with sarcopenia than in patients without sarcopenia ($P < 0.0001$, Fig. 1B). Moreover, the Kaplan–Meier curves indicated that the cumulative incidence rates of 90-day mortality and overall complications were significantly higher in patients with sarcopenia than in those without ($P < 0.0001$; Fig. 2). As shown in Supplementary Figs. 2 and 3, the cumulative incidence rates of acute renal failure, pneumonia, and stroke within 30 and 90 days of surgery were significantly higher in patients with sarcopenia than in patients without sarcopenia (all P values < 0.001).

Discussion

Although cholecystectomy for gallstone disease is a relatively straightforward procedure [18, 28, 29], major postoperative complications may persist. Higher levels of morbidity are a heavy economic burden for patients, especially for older patients with comorbidities.[19–24] Sarcopenia is a multifactorial syndrome that is often associated with a higher prevalence of adverse outcomes, including functional decline, frailty, and mortality [46], but its association with major postoperative complications following cholecystectomy is unknown. Until now, no study has compared major postoperative complications in patients with sarcopenia with those in patients in the general population following elective cholecystectomy for gallstone disease, although studies have shown a link between higher incidence rates of postoperative complications and mortality in patients with sarcopenia [11–14, 47–55]. In our study, the prevalence of sarcopenia among patients undergoing elective cholecystectomy was 4.6% (2666/57,659) before matching and 20.0% (2666/13,330) after matching. This prevalence is lower than that reported in other high-risk surgical populations, likely

Table 3 Adjusted ORs and 95% CIs for postcholecystectomy adverse outcomes associated with sarcopenia

	Control	Sarcopenia			
Outcomes	*N* = 10,664	*N* = 2,666	aOR*	(95% CI)	*P* value
Postoperative complications (within 30 days)					
Acute myocardial infarction	0.16%	0.11%	0.66	(0.17, 2.54)	0.547
Acute renal failure	0.46%	0.86%	1.71	(1.02, 2.84)	0.040
Deep wound infection	0.53%	0.64%	1.22	(0.7, 2.11)	0.476
Pneumonia	1.22%	2.18%	1.68	(1.22, 2.31)	0.001
Pulmonary embolism	0.06%	0.08%	1.75	(0.34, 8.98)	0.503
Bleeding	0.80%	1.09%	1.34	(0.87, 2.05)	0.180
Septicemia	5.32%	6.00%	1.11	(0.93, 1.34)	0.252
Stroke	2.80%	3.90%	1.13	(1.06, 1.57)	0.013
Any of the above	10.02%	12.60%	1.23	(1.07, 1.41)	0.002
30-day mortality	0.74%	2.14%	2.26	(1.61, 3.18)	< 0.001
Postoperative complications (within 90 days)					
Acute myocardial infarction	0.25%	0.26%	1.06	(0.44, 2.59)	0.893
Acute renal failure	0.57%	1.01%	1.61	(1.01, 2.56)	0.047
Deep wound infection	0.65%	0.71%	1.10	(0.66, 1.84)	0.709
Pneumonia	1.81%	3.23%	1.70	(1.30, 2.21)	< 0.001
Pulmonary embolism	0.08%	0.08%	1.20	(0.25, 5.77)	0.820
Bleeding	0.82%	1.09%	1.31	(0.86, 2.01)	0.211
Septicemia	5.92%	6.86%	1.15	(0.96, 1.36)	0.121
Stroke	3.66%	5.18%	1.28	(1.04, 1.58)	0.020
Any of the above	11.90%	15.00%	1.24	(1.09, 1.41)	< 0.001
90 day mortality	1.12%	3.11%	2.09	(1.58, 2.76)	< 0.001

OR odds ratio, *aOR* adjusted odds ratio, *CI* confidence interval, *N* number

*All covariates mentioned in Table 1 were adjusted

due to differences in age distribution, surgical complexity, and baseline comorbidities. Prior studies have documented sarcopenia prevalence ranging from 26.9% preoperatively to 46.4% postoperatively in open-heart surgery patients [56], 25.7–44.1% in orthopedic surgery patients [57], and an average of 42.8% in lung cancer surgery patients [58]. These surgical populations typically involve older patients with greater frailty and more advanced comorbidities, contributing to their higher sarcopenia prevalence. In Taiwan, sarcopenia prevalence varies by setting, with rates reported at 50.9% in daycare centers [59], 50.4% in geriatric hip fracture patients [60], and 22% among healthcare professionals, mostly in the pre-sarcopenia stage [61]. Given that our study population consisted of predominantly younger patients undergoing elective cholecystectomy, with 87.0% undergoing laparoscopic cholecystectomy, a minimally invasive procedure, the lower prevalence of sarcopenia observed is expected. These factors should be considered when interpreting our findings, as they may limit the generalizability of our results to higher-risk surgical populations. Despite the relatively smaller difference in postoperative complication rates, sarcopenia was strongly associated with higher mortality. This suggests that sarcopenia may impair physiological resilience and recovery, contributing to increased vulnerability to surgical stress [62]. Mechanistically, sarcopenia is linked to immune dysfunction, chronic inflammation, and metabolic dysregulation, which may exacerbate surgical stress responses and increase mortality risk [62, 63]. Prior studies have consistently identified sarcopenia as an independent predictor of mortality across various surgical populations [64], reinforcing the biological plausibility of our findings. Given that this is the first study to examine sarcopenia in cholecystectomy patients, further research is needed to explore perioperative interventions, such as prehabilitation and nutritional optimization, to mitigate its impact on surgical outcomes. Our results indicate that sarcopenia is associated with significantly higher rates of 30-day and 90-day major postoperative complications, including acute renal failure, pneumonia, stroke, and overall complications (Tables 2 and 3, Figs. 1 and 2). These findings underscore the need for early identification and management of sarcopenia to improve perioperative outcomes.

In addition, the higher incidence of choking or aspiration pneumonia in patients with sarcopenia is likely due to respiratory muscle weakness, impaired cough reflex, and decreased immune function [34, 65, 66]. Sarcopenia has been linked to dysphagia and impaired swallowing coordination, contributing to a higher risk of pulmonary

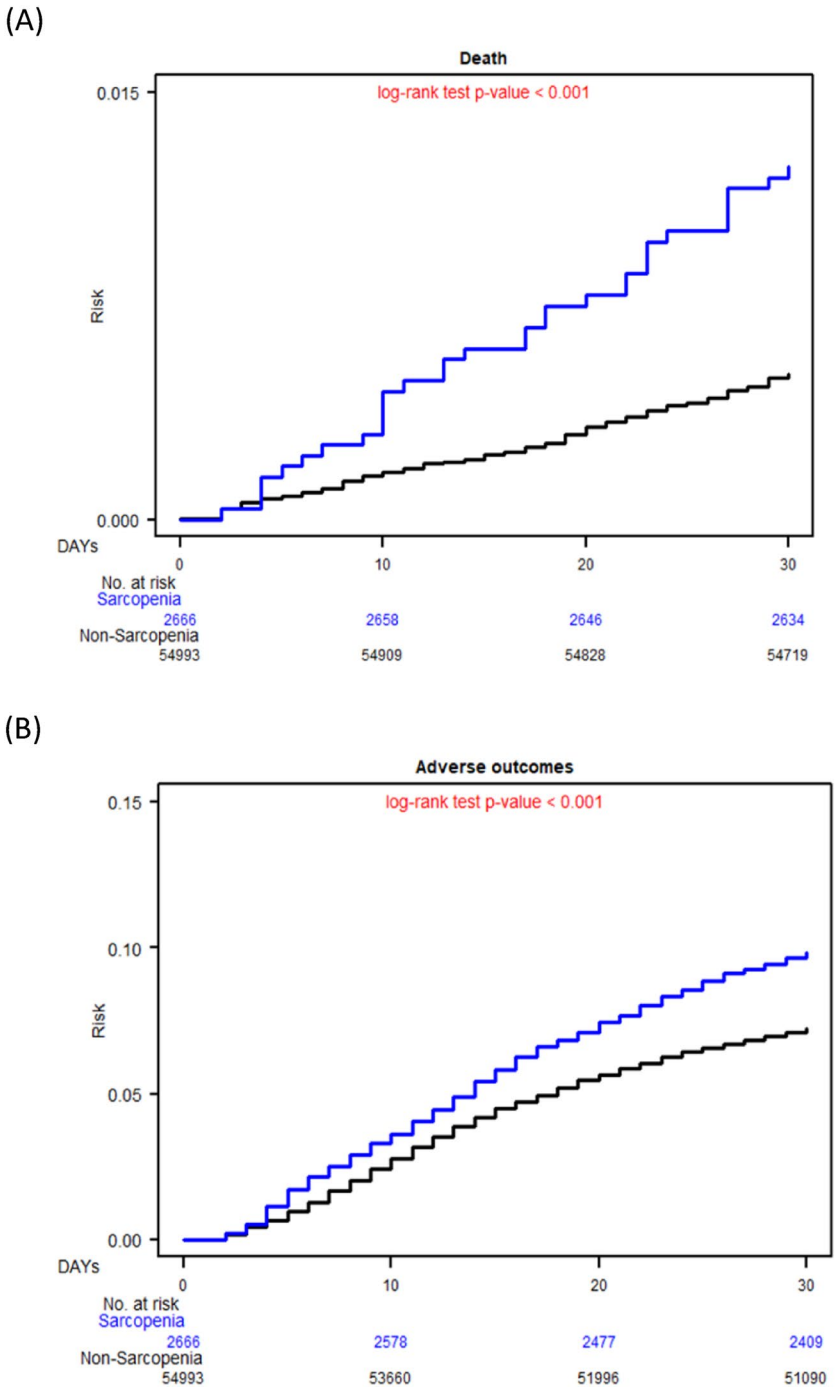

Fig. 1 Kaplan–Meier 30 day postcholecystectomy mortality and complications for patients with and without sarcopenia. **A** 30 day postcholecystectomy mortality; **B** 30 day postcholecystectomy overall complications

aspiration and pneumonia [66]. A study by Soma et al. found that sarcopenia was a risk factor for postoperative respiratory complications in patients undergoing esophageal cancer surgery [67], which aligns with our findings in the context of cholecystectomy (Tables 2 and 3). Although the prevalence of COPD was comparable between the two groups after propensity score matching (Table 1, SMD < 0.2), pneumonia incidence remained significantly higher in the sarcopenia group. This suggests that the increased pneumonia risk in sarcopenia patients is independent of COPD prevalence and is likely driven by compromised respiratory mechanics, dysregulated immune response, and impaired mucociliary clearance [63, 65, 68, 69]. Further research is needed to evaluate whether preoperative interventions, such as pulmonary rehabilitation, targeted nutrition, or early mobilization strategies, can mitigate this increased pneumonia risk in sarcopenia patients undergoing elective surgery.

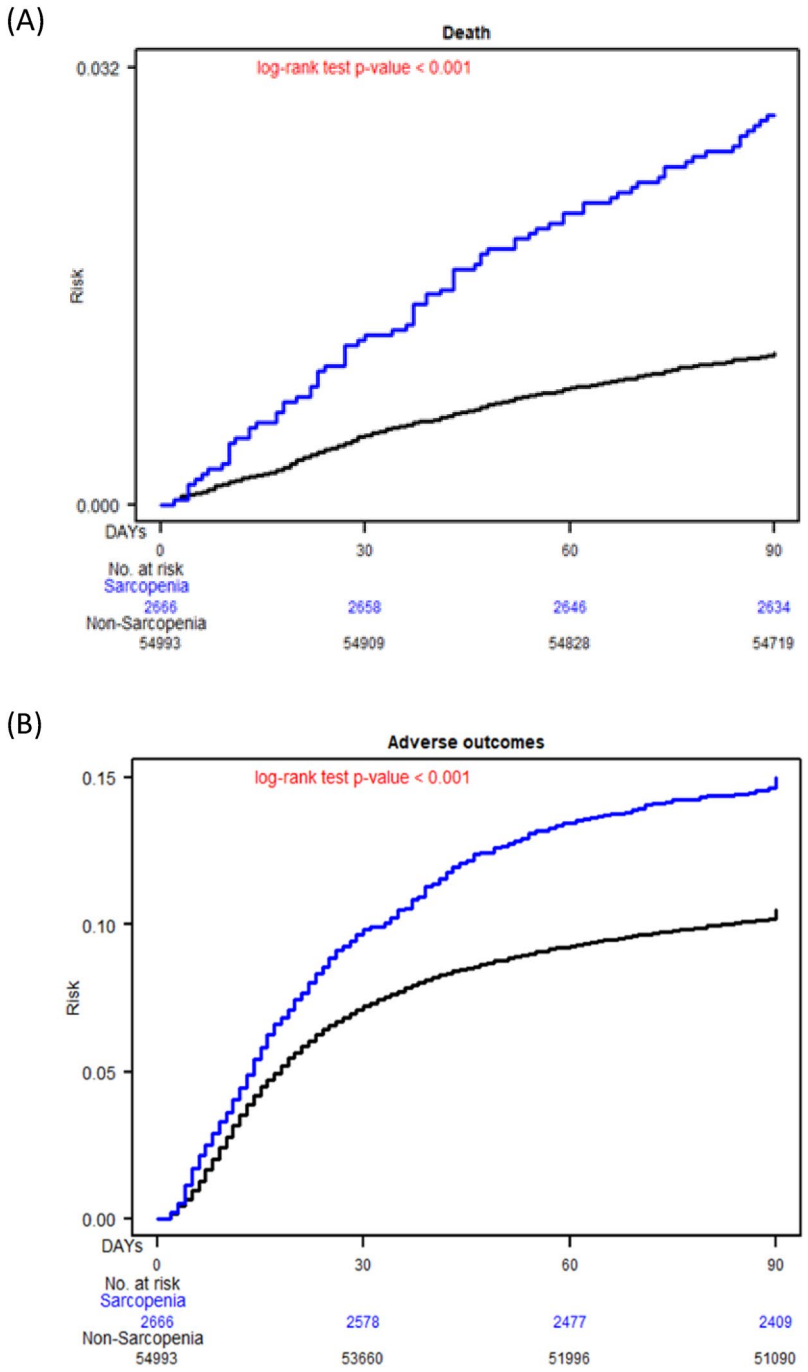

Fig. 2 Kaplan–Meier 90 day postcholecystectomy mortality and complications for patients with and without sarcopenia. **A** 90 day postcholecystectomy mortality; **B** 90 day postcholecystectomy overall complications

The pathological mechanisms of sarcopenia mainly include cellular senescence, protein imbalance, oxidative stress, metabolic abnormalities, hyperinsulinemia, insulin resistance, and inflammation [70–72], which increase the burden on the kidney and are more likely to cause acute renal failure in patients with sarcopenia than in patients without sarcopenia when combined with the surgical stress induced by cholecystectomy (Tables 2 and 3). Ultimately, alterations in glomerular hemodynamics, inflammation, and fibrosis are the possible primary mediators of kidney tissue damage under surgical stress, although the relative contributions of these mechanisms likely vary among patients with and without sarcopenia [73]. Moreover, Huang et al. found that patients with sarcopenia were at a higher risk of severe nephropathy than were patients without sarcopenia, similar to our finding that sarcopenia is a risk factor for acute renal failure following cholecystectomy (Tables 2 and 3) [10]. In addition, the higher incidence of choking or aspiration pneumonia in patients with sarcopenia is likely due to muscle weakness [65, 74].

A study by Soma et al. found that sarcopenia was a risk factor for postoperative respiratory disease in patients with esophageal cancer [67], similar to our findings (Tables 2 and 3). The higher incidence of postoperative pneumonia in patients with sarcopenia may be related to decreased skeletal muscle and weakened respiratory and swallowing-related muscles [65, 74]. The incidence rates of 30-day and 90-day mortality were consistent with the incidence of pneumonia following cholecystectomy. Sarcopenia is associated with insulin resistance and metabolic syndrome, with an attendant increased risk of cardiovascular disease and stroke [7, 75–78], especially under surgical stress. Because insulin resistance and sarcopenia have similar pathogenetic mechanisms [71, 72, 75, 79], exercise to correct sarcopenia may help attenuate the progression of major postoperative complications [80]. Therefore, early detection and the correction of sarcopenia may be associated with lower incidence rates of major postoperative complications; this hypothesis must be verified. Sarcopenia might be an independent risk factor for major postoperative complications following cholecystectomy (Tables 2 and 3 and Figs. 1 and 2). Solutions such as exercise, nutrition, and medication and hypotheses should be developed to address this problem. This study may serve as a valuable reference for governmental authorities creating health policies that promote the early detection and correction of sarcopenia to prevent major postoperative complications.

Thirty-day mortality rates greater than 1% have been used to identify high-risk procedures [28, 29]. In our study, the cumulative 30-day mortality rate in patients with sarcopenia was 2.14% (Table 2), which was significantly higher than in patients without sarcopenia (0.74%). Gallstone disease is one of the most common digestive diseases; therefore, investigating the association between sarcopenia and major postoperative complications following cholecystectomy would yield useful information for physicians and patients. Although measures of perioperative mortality have conventionally been limited to 30-day institutional mortality, 90-day mortality has been suggested as a more appropriate indicator of surgical quality, particularly after digestive surgery [41–45, 81]. In our study, the cumulative 90-day mortality in patients with sarcopenia was 3.11% (Table 2), which was significantly higher than in patients without sarcopenia (1.12%). Our study demonstrated that sarcopenia was an independent risk factor for subacute (90-day) mortality following cholecystectomy, and the mortality rate did not plateau in that period (Figs. 1 and 2). In addition, 90 day major postoperative complications are also a valid indicator of surgical quality, and incidence rates of major complications were higher in patients with sarcopenia (Fig. 2). Early detection and correction of sarcopenia may help prevent major postoperative complications and mortality.

This study has several limitations. First, misclassification bias may exist as sarcopenia and postoperative complications were identified using ICD-10-CM codes rather than direct clinical adjudication. Although prior studies report moderate-to-high sensitivity (70–85%) and specificity (> 90%) for administrative coding in hospitalized patients [82, 83], residual misclassification remains possible. Given that postoperative complications such as pneumonia and stroke require ICD coding for appropriate treatment and reimbursement, coding accuracy in inpatient settings is expected to be relatively high. However, some complications may be underreported or misclassified, particularly in cases of milder severity. Second, cognitive and swallowing function data were unavailable, which may contribute to residual confounding in postoperative pneumonia risk. We used pre-existing stroke and dementia as proxies in propensity score matching, but this does not fully account for undiagnosed impairments. Future studies should include standardized assessments to better evaluate their impact. Third, selection bias may limit generalizability, as our cohort consisted of relatively younger and healthier patients undergoing elective cholecystectomy, with a lower sarcopenia prevalence than that reported in orthopedic, cardiovascular, and oncologic surgical populations. Finally, causality cannot be established due to the observational nature of this study, and residual confounding cannot be fully excluded despite propensity score matching and multivariate adjustment. Future prospective studies are needed to validate these findings and evaluate whether targeted perioperative interventions can mitigate sarcopenia-related surgical risks.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00540-025-03512-y.

Author contributions Conception and design: Mingyang Sun; Wan-Ming Chen; Szu-Yuan Wu; Jiaqiang Zhang. Collection and assembly of data: Szu-Yuan Wu; Jiaqiang Zhang. Data analysis and interpretation: Jiaqiang Zhang; Szu-Yuan Wu. Administrative support: Szu-Yuan Wu*. Manuscript writing: Mingyang Sun; Wan-Ming Chen; Szu-Yuan Wu; Jiaqiang Zhang. Final approval of manuscript: All authors.

Funding The National Key Research and Development Program of China (Funding Number: 2023YFC25069003), Special training program for clinical research doctors in Henan Province (HNCRD20240), supported Zhang's work. Lo-Hsu Medical Foundation, LotungPoh-Ai Hospital, supported Szu-Yuan Wu's work (Funding Number: 11001, 11010, 11013 and 11103).

Data availability The datasets supporting the study conclusions are included within this manuscript and its additional files.

Declarations

Conflict of interests The authors have no potential conflicts of interest to declare. The datasets supporting the study conclusions are included within the manuscript.

Ethical approval and consent

The study protocols were reviewed and approved by the Institutional Review Board of Tzu-Chi Medical Foundation (IRB109-015-B).

Consent for publication Not applicable.

References

1. Janssen I. The epidemiology of sarcopenia. Clin Geriatr Med. 2011;27(3):355–63. https://doi.org/10.1016/j.cger.2011.03.004.
2. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F, Martin FC, Michel JP, Rolland Y, Schneider SM, Topinkova E, Vandewoude M, Zamboni M, European Working Group on Sarcopenia in Older P. Sarcopenia. European consensus on definition and diagnosis: report of the European Working Group on Sarcopenia in Older People. Age Ageing. 2010;39(4):412–23. https://doi.org/10.1093/ageing/afq034.
3. Papadopoulou SK. Sarcopenia: a contemporary health problem among older adult populations. Nutrients. 2020. https://doi.org/10.3390/nu12051293.
4. Choe HJ, Cho BL, Park YS, Roh E, Kim HJ, Lee SG, Kim BJ, Kim M, Won CW, Park KS, Jang HC. Gender differences in risk factors for the 2 year development of sarcopenia in community-dwelling older adults. J Cachexia Sarcopenia Muscle. 2022;13(3):1908–18. https://doi.org/10.1002/jcsm.12993.
5. Chen X, Hou L, Zhang Y, Dong B. Analysis of the prevalence of sarcopenia and its risk factors in the elderly in the Chengdu Community. J Nutr Health Aging. 2021;25(5):600–5. https://doi.org/10.1007/s12603-020-1559-1.
6. Hwang J, Park S. Gender-specific risk factors and prevalence for sarcopenia among community-dwelling young-old adults. Int J Environ Res Public Health. 2022. https://doi.org/10.3390/ijerph19127232.
7. Sun MY, Chang CL, Lu CY, Wu SY, Zhang JQ. Sarcopenia as an independent risk factor for specific cancers: a propensity score-matched Asian population-based cohort study. Nutrients. 2022. https://doi.org/10.3390/nu14091910.
8. Lin JA, Hou JD, Wu SY. Effect of sarcopenia on mortality in type 2 diabetes: a long-term follow-up propensity score-matched diabetes cohort study. J Clin Med. 2022. https://doi.org/10.3390/jcm11154424.
9. Tsai YH, Chen WM, Chen MC, Shia BC, Wu SY, Huang CC. Effect of pre-existing sarcopenia on oncological outcomes for oral cavity squamous cell carcinoma undergoing curative surgery: a propensity score-matched, nationwide, population-based cohort study. Cancers (Basel). 2022. https://doi.org/10.3390/cancers14133246.
10. Huang YM, Chen WM, Chen M, Shia BC, Wu SY. Sarcopenia is an independent risk factor for severe diabetic nephropathy in type 2 diabetes: a long-term follow-up propensity score-matched diabetes cohort study. J Clin Med. 2022. https://doi.org/10.3390/jcm11112992.
11. Wang H, Yang R, Xu J, Fang K, Abdelrahim M, Chang L. Sarcopenia as a predictor of postoperative risk of complications, mortality and length of stay following gastrointestinal oncological surgery. Ann R Coll Surg Engl. 2021;103(9):630–7. https://doi.org/10.1308/rcsann.2021.0082.
12. Hendrickson NR, Mayo Z, Shamrock A, Kesler K, Glass N, Nau P, Miller BJ. Sarcopenia is associated with increased mortality but not complications following resection and reconstruction of sarcoma of the extremities. J Surg Oncol. 2020;121(8):1241–8. https://doi.org/10.1002/jso.25898.
13. Kim EY, Lee HY, Kim KW, Lee JI, Kim YS, Choi WJ, Kim JH. Preoperative computed tomography-determined sarcopenia and postoperative outcome after surgery for non-small cell lung cancer. Scand J Surg. 2018;107(3):244–51. https://doi.org/10.1177/1457496917748221.
14. Siegal SR, Dolan JP, Dewey EN, Guimaraes AR, Tieu BH, Schipper PH, Hunter JG. Sarcopenia is not associated with morbidity, mortality, or recurrence after esophagectomy for cancer. Am J Surg. 2018;215(5):813–7. https://doi.org/10.1016/j.amjsurg.2017.12.017.
15. Lammert F, Gurusamy K, Ko CW, Miquel JF, Mendez-Sanchez N, Portincasa P, van Erpecum KJ, van Laarhoven CJ, Wang DQ. Gallstones. Nat Rev Dis Primers. 2016;2:16024. https://doi.org/10.1038/nrdp.2016.24.
16. Gutt C, Schlafer S, Lammert F. The treatment of gallstone disease. Dtsch Arztebl Int. 2020;117(9):148–58. https://doi.org/10.3238/arztebl.2020.0148.
17. Feng XC, Phillips E, Shouhed D. Management of postcholecystectomy complications. Surg Clin North Am. 2021;101(5):889–910. https://doi.org/10.1016/j.suc.2021.06.012.
18. Sandblom G, Videhult P, Crona Guterstam Y, Svenner A, Sadr-Azodi O. Mortality after a cholecystectomy: a population-based study. HPB (Oxford). 2015;17(3):239–43. https://doi.org/10.1111/hpb.12356.
19. Lin JA, Liao CC, Lee YJ, Wu CH, Huang WQ, Chen TL. Adverse outcomes after major surgery in patients with systemic lupus erythematosus: a nationwide population-based study. Ann Rheum Dis. 2014;73(9):1646–51. https://doi.org/10.1136/annrheumdis-2012-202758.
20. Lin JA, Liao CC, Chang CC, Chang H, Chen TL. Postoperative adverse outcomes in intellectually disabled surgical patients: a nationwide population-based study. PLoS ONE. 2011;6(10):e26977. https://doi.org/10.1371/journal.pone.0026977.
21. Liao CC, Shen WW, Chang CC, Chang H, Chen TL. Surgical adverse outcomes in patients with schizophrenia: a population-based study. Ann Surg. 2013;257(3):433–8. https://doi.org/10.1097/SLA.0b013e31827b9b25.
22. Ghaferi AA, Birkmeyer JD, Dimick JB. Variation in hospital mortality associated with inpatient surgery. N Engl J Med. 2009;361(14):1368–75. https://doi.org/10.1056/NEJMsa0903048.
23. Khuri SF, Henderson WG, DePalma RG, Mosca C, Healey NA, Kumbhani DJ, Participants in the VANSQIP. Determinants of long-term survival after major surgery and the adverse effect of postoperative complications. Ann Surg. 2005;242(3):326–41. https://doi.org/10.1097/01.sla.0000179621.33268.83.
24. Chang CC, Hu CJ, Lam F, Chang H, Liao CC, Chen TL. Postoperative adverse outcomes in surgical patients with epilepsy: a population-based study. Epilepsia. 2012;53(6):987–94. https://doi.org/10.1111/j.1528-1167.2012.03448.x.
25. Weng X, Fu F, Ling Y, Sun J, Chen W. Gallstone disease is an independent predictor for poststroke cognitive impairment in young patients with acute ischemic stroke. Eur Neurol. 2019;82(1–3):15–22. https://doi.org/10.1159/000504343.
26. Liu Z, Li C. A predictive model for the risk of cognitive impairment in patients with gallstones. Biomed Res Int. 2021;2021:3792407. https://doi.org/10.1155/2021/3792407.
27. Dudanov IP, Andreev IuV, Sobolev VE, Mezhenin DA, Smirnov DB, Kozlov KL. Postoperative complications of gallstone disease in elderly and aged patients. Adv Gerontol. 2007;20(4):79–82.
28. Shah R, Attwood K, Arya S, Hall DE, Johanning JM, Gabriel E, Visioni A, Nurkin S, Kukar M, Hochwald S, Massarweh NN.

Association of frailty with failure to rescue after low-risk and high-risk inpatient surgery. JAMA Surg. 2018;153(5): e180214. https://doi.org/10.1001/jamasurg.2018.0214.
29. Schwarze ML, Barnato AE, Rathouz PJ, Zhao Q, Neuman HB, Winslow ER, Kennedy GD, Hu YY, Dodgion CM, Kwok AC, Greenberg CC. Development of a list of high-risk operations for patients 65 years and older. JAMA Surg. 2015;150(4):325–31. https://doi.org/10.1001/jamasurg.2014.1819.
30. Sun M, Chang CL, Lu CY, Zhang J, Wu SY. Effect of opioids on cancer survival in patients with chronic pain: a propensity score-matched population-based cohort study. Br J Anaesth. 2022;128(4):708–17. https://doi.org/10.1016/j.bja.2021.12.051.
31. Sun M, Lin JA, Chang CL, Wu SY, Zhang J. Association between long-term opioid use and cancer risk in patients with chronic pain: a propensity score-matched cohort study. Br J Anaesth. 2022;129(1):84–91. https://doi.org/10.1016/j.bja.2022.04.014.
32. Anker SD, Morley JE, von Haehling S. Welcome to the ICD-10 code for sarcopenia. J Cachexia Sarcopenia Muscle. 2016;7(5):512–4. https://doi.org/10.1002/jcsm.12147.
33. Ishii S, Tanaka T, Akishita M, Iijima K. Re: growing research on sarcopenia in Asia. Geriatr Gerontol Int. 2015;15(2):238–9. https://doi.org/10.1111/ggi.12304.
34. Ohashi K, Ishikawa T, Hoshii A, Hokari T, Noguchi H, Suzuki M, Hirosawa H, Imai M, Mitobe Y, Yoshida T. Optimal skeletal muscle mass index cut-off values for presarcopenia evaluated by computed tomography against dual-energy X-ray absorptiometry in patients with chronic liver disease. J Clin Med. 2021. https://doi.org/10.3390/jcm10071419.
35. Yamada Y, Yamada M, Yoshida T, Miyachi M, Arai H. Validating muscle mass cutoffs of four international sarcopenia-working groups in Japanese people using DXA and BIA. J Cachexia Sarcopenia Muscle. 2021;12(4):1000–10. https://doi.org/10.1002/jcsm.12732.
36. Linden A, Samuels SJ. Using balance statistics to determine the optimal number of controls in matching studies. J Eval Clin Pract. 2013;19(5):968–75. https://doi.org/10.1111/jep.12072.
37. Ury HK. Efficiency of case-control studies with multiple controls per case: continuous or dichotomous data. Biometrics. 1975;31(3):643–9.
38. Austin PC. Optimal caliper widths for propensity-score matching when estimating differences in means and differences in proportions in observational studies. Pharm Stat. 2011;10(2):150–61. https://doi.org/10.1002/pst.433.
39. Salmerón Gómez R, García Pérez J, López Martín MDM, García CG. Collinearity diagnostic applied in ridge estimation through the variance inflation factor. J Appl Stat. 2016;43(10):1831–49.
40. Austin PC. The performance of different propensity score methods for estimating marginal hazard ratios. Stat Med. 2013;32(16):2837–49. https://doi.org/10.1002/sim.5705.
41. Qin L, Chen TM, Kao YW, Lin KC, Yuan KS, Wu ATH, Shia BC, Wu SY. Predicting 90-day mortality in locoregionally advanced head and neck squamous cell carcinoma after curative surgery. Cancers (Basel). 2018;10(10):392. https://doi.org/10.3390/cancers10100392.
42. Lin KC, Chen TM, Yuan KS, Wu ATH, Wu SY. Assessment of predictive scoring system for 90-day mortality among patients with locally advanced head and neck squamous cell carcinoma who have completed concurrent chemoradiotherapy. JAMA Netw Open. 2020;3(3): e1920671. https://doi.org/10.1001/jamanetworkopen.2019.20671.
43. Shia BC, Qin L, Lin KC, Fang CY, Tsai LL, Kao YW, Wu SY. Age comorbidity scores as risk factors for 90-day mortality in patients with a pancreatic head adenocarcinoma receiving a pancreaticoduodenectomy: a national population-based study. Cancer Med. 2020;9(2):562–74. https://doi.org/10.1002/cam4.2730.
44. Pugalenthi A, Protic M, Gonen M, Kingham TP, Angelica MI, Dematteo RP, Fong Y, Jarnagin WR, Allen PJ. Postoperative complications and overall survival after pancreaticoduodenectomy for pancreatic ductal adenocarcinoma. J Surg Oncol. 2016;113(2):188–93. https://doi.org/10.1002/jso.24125.
45. Mise Y, Vauthey JN, Zimmitti G, Parker NH, Conrad C, Aloia TA, Lee JE, Fleming JB, Katz MH. Ninety-day postoperative mortality is a legitimate measure of hepatopancreatobiliary surgical quality. Ann Surg. 2015;262(6):1071–8. https://doi.org/10.1097/SLA.0000000000001048.
46. Cruz-Jentoft AJ, Sayer AA. Sarcopenia. Lancet. 2019;393(10191):2636–46. https://doi.org/10.1016/S0140-6736(19)31138-9.
47. Hirase T, Haghshenas V, Bratescu R, Dong D, Kuo PH, Rashid A, Kavuri V, Hanson DS, Meyer BC, Marco RAW. Sarcopenia predicts perioperative adverse events following complex revision surgery for the thoracolumbar spine. Spine J. 2021;21(6):1001–9. https://doi.org/10.1016/j.spinee.2021.02.001.
48. Flexman AM, Street J, Charest-Morin R. The impact of frailty and sarcopenia on patient outcomes after complex spine surgery. Curr Opin Anaesthesiol. 2019;32(5):609–15. https://doi.org/10.1097/ACO.0000000000000759.
49. Charest-Morin R, Street J, Zhang H, Roughead T, Ailon T, Boyd M, Dvorak M, Kwon B, Paquette S, Dea N, Fisher CG, Flexman AM. Frailty and sarcopenia do not predict adverse events in an elderly population undergoing non-complex primary elective surgery for degenerative conditions of the lumbar spine. Spine J. 2018;18(2):245–54. https://doi.org/10.1016/j.spinee.2017.07.003.
50. Sandini M, Patino M, Ferrone CR, Alvarez-Perez CA, Honselmann KC, Paiella S, Catania M, Riva L, Tedesco G, Casolino R, Auriemma A, Salandini MC, Carrara G, Cristel G, Damascelli A, Ippolito D, D'Onofrio M, Lillemoe KD, Bassi C, Fernandez-Del CC. Association between changes in body composition and neoadjuvant treatment for pancreatic cancer. JAMA Surg. 2018;153(9):809–15. https://doi.org/10.1001/jamasurg.2018.0979.
51. Feliciano EMC, Kroenke CH, Meyerhardt JA, Prado CM, Bradshaw PT, Kwan ML, Xiao J, Alexeeff S, Corley D, Weltzien E, Castillo AL, Caan BJ. Association of systemic inflammation and sarcopenia with survival in nonmetastatic colorectal cancer: results from the C SCANS study. JAMA Oncol. 2017;3(12): e172319. https://doi.org/10.1001/jamaoncol.2017.2319.
52. Yamashita S, Iguchi T, Koike H, Wakamiya T, Kikkawa K, Kohjimoto Y, Hara I. Impact of preoperative sarcopenia and myosteatosis on prognosis after radical cystectomy in patients with bladder cancer. Int J Urol. 2021;28(7):757–62. https://doi.org/10.1111/iju.14569.
53. Kobayashi A, Kaido T, Hamaguchi Y, Okumura S, Shirai H, Yao S, Kamo N, Yagi S, Taura K, Okajima H, Uemoto S. Impact of sarcopenic obesity on outcomes in patients undergoing hepatectomy for hepatocellular carcinoma. Ann Surg. 2019;269(5):924–31. https://doi.org/10.1097/SLA.0000000000002555.
54. Antoniou GA, Rojoa D, Antoniou SA, Alfahad A, Torella F, Juszczak MT. Effect of low skeletal muscle mass on post-operative survival of patients with abdominal aortic aneurysm: a prognostic factor review and meta-analysis of time-to-event data. Eur J Vasc Endovasc Surg. 2019;58(2):190–8. https://doi.org/10.1016/j.ejvs.2019.03.020.
55. Stone L, Olson B, Mowery A, Krasnow S, Jiang A, Li R, Schindler J, Wax MK, Andersen P, Marks D, Achim V, Clayburgh D. Association between sarcopenia and mortality in patients undergoing surgical excision of head and neck cancer. JAMA Otolaryngol Head Neck Surg. 2019;145(7):647–54. https://doi.org/10.1001/jamaoto.2019.1185.
56. Yuenyongchaiwat K, Kulchanarat C, Satdhabudha O. Sarcopenia in open heart surgery patients: a cohort study. Heliyon.

2020;6(12): e05759. https://doi.org/10.1016/j.heliyon.2020.e05759.
57. Ji HM, Han J, Jin DS, Suh H, Chung YS, Won YY. Sarcopenia and sarcopenic obesity in patients undergoing orthopedic surgery. Clin Orthop Surg. 2016;8(2):194–202. https://doi.org/10.4055/cios.2016.8.2.194.
58. Nishimura JM, Ansari AZ, D'Souza DM, Moffatt-Bruce SD, Merritt RE, Kneuertz PJ. Computed tomography-assessed skeletal muscle mass as a predictor of outcomes in lung cancer surgery. Ann Thorac Surg. 2019;108(5):1555–64. https://doi.org/10.1016/j.athoracsur.2019.04.090.
59. Chang CF, Yeh YL, Chang HY, Tsai SH, Wang JY. Prevalence and risk factors of sarcopenia among older adults aged >/=65 years admitted to daycare centers of Taiwan: using AWGS 2019 guidelines. Int J Environ Res Public Health. 2021. https://doi.org/10.3390/ijerph18168299.
60. Chen YP, Wong PK, Tsai MJ, Chang WC, Hsieh TS, Leu TH, Jeff Lin CF, Lee CH, Kuo YJ, Lin CY. The high prevalence of sarcopenia and its associated outcomes following hip surgery in Taiwanese geriatric patients with a hip fracture. J Formos Med Assoc. 2020;119(12):1807–16. https://doi.org/10.1016/j.jfma.2020.02.004.
61. Chen Y-S, Yin T-H, Huang H-YI, Huang T-H, Lai M-C, Chang C-M, Huang C-W. Prevalence of and risk factors for pre-sarcopenia among healthcare professionals. Clin Nutr Open Sci. 2023;52:179–92.
62. Wagner D, DeMarco MM, Amini N, Buttner S, Segev D, Gani F, Pawlik TM. Role of frailty and sarcopenia in predicting outcomes among patients undergoing gastrointestinal surgery. World J Gastrointest Surg. 2016;8(1):27–40. https://doi.org/10.4240/wjgs.v8.i1.27.
63. Nelke C, Dziewas R, Minnerup J, Meuth SG, Ruck T. Skeletal muscle as potential central link between sarcopenia and immune senescence. EBioMedicine. 2019;49:381–8. https://doi.org/10.1016/j.ebiom.2019.10.034.
64. Hajibandeh S, Hajibandeh S, Jarvis R, Bhogal T, Dalmia S. Meta-analysis of the effect of sarcopenia in predicting postoperative mortality in emergency and elective abdominal surgery. Surgeon. 2019;17(6):370–80. https://doi.org/10.1016/j.surge.2018.09.003.
65. Okazaki T, Ebihara S, Mori T, Izumi S, Ebihara T. Association between sarcopenia and pneumonia in older people. Geriatr Gerontol Int. 2020;20(1):7–13. https://doi.org/10.1111/ggi.13839.
66. Nagai T, Wakabayashi H, Nishioka S, Momosaki R. Importance of early assessment and multioccupational interventions in sarcopenic dysphagia and aspiration pneumonia. Geriatr Gerontol Int. 2023;23(2):153–4. https://doi.org/10.1111/ggi.14527.
67. Soma D, Kawamura YI, Yamashita S, Wake H, Nohara K, Yamada K, Kokudo N. Sarcopenia, the depletion of muscle mass, an independent predictor of respiratory complications after oncological esophagectomy. Dis Esophagus. 2019. https://doi.org/10.1093/dote/doy092.
68. Shiozu H, Higashijima M, Koga T. Association of sarcopenia with swallowing problems, related to nutrition and activities of daily living of elderly individuals. J Phys Ther Sci. 2015;27(2):393–6. https://doi.org/10.1589/jpts.27.393.
69. Okazaki T, Suzukamo Y, Miyatake M, Komatsu R, Yaekashiwa M, Nihei M, Izumi S, Ebihara T. Respiratory muscle weakness as a risk factor for pneumonia in older people. Gerontology. 2021;67(5):581–90. https://doi.org/10.1159/000514007.
70. Mankhong S, Kim S, Moon S, Kwak HB, Park DH, Kang JH. Experimental models of sarcopenia: bridging molecular mechanism and therapeutic strategy. Cells. 2020. https://doi.org/10.3390/cells9061385.
71. Charpentier G, Riveline JP, Varroud-Vial M. Management of drugs affecting blood glucose in diabetic patients with renal failure. Diabetes Metab. 2000;26(Suppl 4):73–85.
72. Snyder RW, Berns JS. Use of insulin and oral hypoglycemic medications in patients with diabetes mellitus and advanced kidney disease. Semin Dial. 2004;17(5):365–70. https://doi.org/10.1111/j.0894-0959.2004.17346.x.
73. Tonneijck L, Muskiet MH, Smits MM, van Bommel EJ, Heerspink HJ, van Raalte DH, Joles JA. Glomerular hyperfiltration in diabetes: mechanisms, clinical significance, and treatment. J Am Soc Nephrol. 2017;28(4):1023–39. https://doi.org/10.1681/ASN.2016060666.
74. Ebihara S, Sekiya H, Miyagi M, Ebihara T, Okazaki T. Dysphagia, dystussia, and aspiration pneumonia in elderly people. J Thorac Dis. 2016;8(3):632–9. https://doi.org/10.21037/jtd.2016.02.60.
75. Cleasby ME, Jamieson PM, Atherton PJ. Insulin resistance and sarcopenia: mechanistic links between common co-morbidities. J Endocrinol. 2016;229(2):R67-81. https://doi.org/10.1530/JOE-15-0533.
76. Wang T, Feng X, Zhou J, Gong H, Xia S, Wei Q, Hu X, Tao R, Li L, Qian F, Yu L. Type 2 diabetes mellitus is associated with increased risks of sarcopenia and pre-sarcopenia in Chinese elderly. Sci Rep. 2016;6:38937. https://doi.org/10.1038/srep38937.
77. Lu CW, Yang KC, Chang HH, Lee LT, Chen CY, Huang KC. Sarcopenic obesity is closely associated with metabolic syndrome. Obes Res Clin Pract. 2013;7(4):e301–7. https://doi.org/10.1016/j.orcp.2012.02.003.
78. Atkins JL, Whincup PH, Morris RW, Lennon LT, Papacosta O, Wannamethee SG. Sarcopenic obesity and risk of cardiovascular disease and mortality: a population-based cohort study of older men. J Am Geriatr Soc. 2014;62(2):253–60. https://doi.org/10.1111/jgs.12652.
79. Srikanthan P, Hevener AL, Karlamangla AS. Sarcopenia exacerbates obesity-associated insulin resistance and dysglycemia: findings from the National Health and Nutrition Examination Survey III. PLoS ONE. 2010;5(5): e10805. https://doi.org/10.1371/journal.pone.0010805.
80. Yoo SZ, No MH, Heo JW, Park DH, Kang JH, Kim SH, Kwak HB. Role of exercise in age-related sarcopenia. J Exerc Rehabil. 2018;14(4):551–8. https://doi.org/10.12965/jer.1836268.134.
81. Taylor M, Grant SW, West D, Shackcloth M, Woolley S, Naidu B, Shah R. Ninety-day mortality: redefining the perioperative period after lung resection. Clin Lung Cancer. 2021;22(4):e642–5. https://doi.org/10.1016/j.cllc.2020.12.011.
82. Tseng TG, Lu CK, Hsiao YH, Pan SC, Tai CJ, Lee MC. Development of Taiwan Risk Score for Sarcopenia (TRSS) for sarcopenia screening among community-dwelling older adults. Int J Environ Res Public Health. 2020. https://doi.org/10.3390/ijerph17082859.
83. Falcon LJ, Harris-Love MO. Sarcopenia and the new ICD-10-CM code: screening, staging, and diagnosis considerations. Fed Pract. 2017;34(7):24–32.

Authors and Affiliations

Mingyang Sun[1] · Wan-Ming Chen[2,3] · Szu-Yuan Wu[2,3,4,5,6,7,8,9,10] · Jiaqiang Zhang[1,11]

✉ Szu-Yuan Wu
szuyuanwu5399@gmail.com

Mingyang Sun
mingyagnsun1986@163.com

Jiaqiang Zhang
zhangjiq@zzu.edu.cn

1 Department of Anesthesiology and Perioperative Medicine, Henan Provincial People's Hospital, People's Hospital of Zhengzhou University, Zhengzhou, China

2 Graduate Institute of Business Administration, College of Management, Fu Jen Catholic University, Taipei, Taiwan

3 Artificial Intelligence Development Center, Fu Jen Catholic University, Taipei, Taiwan

4 Department of Food Nutrition and Health Biotechnology, College of Medical and Health Science, Asia University, Taichung, Taiwan

5 Big Data Center, Lo-Hsu Medical Foundation, Lotung Poh-Ai Hospital, No. 83, Nanchang St., Luodong Township, Yilan 265, Taiwan

6 Division of Radiation Oncology, Department of Medicine, Lo-Hsu Medical Foundation, Lotung Poh-Ai Hospital, Yilan 265, Taiwan

7 Department of Healthcare Administration, College of Medical and Health Science, Asia University, Taichung, Taiwan

8 Cancer Center, Lo-Hsu Medical Foundation, Lotung Poh-Ai Hospital, Yilan, Taiwan

9 Centers for Regional Anesthesia and Pain Medicine, Taipei Municipal Wan Fang Hospital, Taipei Medical University, Taipei, Taiwan

10 Department of Management, College of Management, Fo Guang University, Yilan, Taiwan

11 Institute of Electrophysiology, Henan Academy of Innovations in Medical Science, Zhenzhou, China