*J. Adv. Med. Pharm. Biomed. Res.;* **(2026),** Volume 2, Issue 6, 527-536

**Journal of Advanced in Medicinal, Pharmaceutical and Biomedical Research**

**Journal homepage:** https://www.jampbr.com

DOI: https://doi.org/10.5281/zenodo.22059783

# Preoperative Sarcopenia in Esophagectomy: Effects on Short-Term Surgical Complications, Anastomotic Leakage, and Hospital Stay

**Amin Kamyab[1], Hosein Shiri[2*]**

[1]Thoracic Surgery Assistant, Department of Cardiovascular Surgery, School of Medicine, Tabriz University of Medical Sciences, Tabriz, Iran

[2]Assistant Professor of Thoracic Surgery, Department of Cardiovascular Surgery, School of Medicine, Tabriz University of Medical Sciences, Tabriz, Iran

**Article info**

**Received:** 15.06.2026

**Accepted:** 20.08.2026

**Available Online:** 20.08.2026

**Checked for Plagiarism:** Yes

**Keywords**:

sarcopenia; esophagectomy; postoperative complications; hospital stay

**ABSTRACT**

**Introduction:** Esophagectomy is a high-risk operation often complicated by postoperative morbidity, especially anastomotic leakage, pulmonary complications, and prolonged hospitalization. Because sarcopenia reflects reduced physiologic reserve and impaired recovery potential, it may help identify patients at greater risk for poor short-term outcomes. Therefore, this study aimed to evaluate the impact of preoperative sarcopenia on short-term surgical complications, anastomotic leakage, and hospital stay.

**Material and methods:** This descriptive cross-sectional study included 75 adults undergoing elective esophagectomy at Imam Reza Hospital, Tabriz. Participants were recruited by convenience sampling. Preoperative sarcopenia was assessed using L3-level computed tomography to calculate the skeletal muscle index, and its associations with postoperative complications, anastomotic leakage, intensive care and hospital stay were evaluated using clinical and surgical data.

Results: Preoperative sarcopenia was associated with higher rates of overall complications, pulmonary complications, anastomotic leakage, surgical-site infection, atrial fibrillation, and 30-day readmission/mortality, as well as longer hospital and ICU stays. In adjusted analyses, sarcopenia remained an independent predictor of adverse outcomes, including overall complications (AOR 2.10, 95% CI 1.20-3.68; P=0.009), anastomotic leakage (AOR 2.35, 95% CI 1.01-5.47; P=0.047), pulmonary complications (AOR 2.80, 95% CI 1.40-5.60; P=0.003), major morbidity (AOR 2.65, 95% CI 1.30-5.40; P=0.007), and prolonged hospital stay (AOR 1.95, 95% CI 1.10–3.45; P=0.021).

**Conclusion:** Preoperative sarcopenia appears to be a clinically meaningful marker of poor short-term recovery after esophagectomy. Its association with increased postoperative complications and prolonged hospitalization supports routine preoperative muscle assessment to improve risk stratification and guide targeted perioperative optimization.

## Introduction

Esophageal cancer remains one of the most lethal gastrointestinal malignancies worldwide, posing significant therapeutic challenges due to its aggressive biological behavior, early lymphatic dissemination, and late clinical presentation. Despite marked advancements in neoadjuvant chemoradiotherapy regimens, standardized lymphadenectomy techniques, and minimally invasive surgical approaches, esophagectomy continues to represent the cornerstone of curative-intent treatment for resectable disease.

However, radical esophagectomy is inherently an extensive, technically demanding, and high-risk surgical intervention that involves multiple

**Corresponding Author: **Hosein Shiri** (Shirihosein@gmail.com - ORCID: 0000-0002-8577-4739)*

*1 Email: kamyab amin@gmail.com - ORCID: 0000-0001-7871-5290)*

anatomical compartments, substantial tissue dissection, and complex visceral reconstruction. Consequently, this operation imposes extreme physiological stress on the human body and is historically characterized by high rates of perioperative morbidity, prolonged hospital admission, and non-negligible operative mortality compared with other major abdominal and thoracic procedures [1].

The profound surgical trauma of esophagectomy frequently precipitates severe postoperative complications that jeopardize recovery trajectories and adversely impact long-term oncologic outcomes. Among the wide spectrum of postoperative morbidities, anastomotic leakage represents the most dreaded and catastrophic surgical complication, frequently culminating in mediastinitis, systemic sepsis, acute respiratory distress, emergency reoperations, and high mortality. In parallel, major pulmonary complications—including pneumonia, acute lung injury, atelectasis, and prolonged mechanical ventilation—occur in a large proportion of patients owing to prolonged single-lung ventilation, diaphragmatic disruption, impaired cough reflex, and systemic inflammatory cascades. In addition to escalating in-hospital mortality, the occurrence of these early adverse events invariably leads to protracted stays in the intensive care unit, delayed return of bowel function, extended overall hospital hospitalization, and substantial consumption of healthcare resources [2].

Given the severe consequences of postoperative morbidity, traditional risk stratification models have predominantly relied on conventional parameters such as chronological age, American Society of Anesthesiologists (ASA) physical status classification, pulmonary function testing, echocardiographic assessment, and body mass index (BMI). Nevertheless, these classic clinical metrics often fail to capture the subtle, subclinical depletion of physiological reserves, metabolic vulnerability, and nutritional deterioration commonly observed in patients with esophageal malignancies. Chronological age alone exhibits poor fidelity in distinguishing biologically robust elderly candidates from vulnerable individuals. Furthermore, body mass index is increasingly recognized as an unreliable indicator of nutritional status because it cannot differentiate skeletal muscle depletion from adipose tissue mass, thereby frequently obscuring severe muscle wasting in overweight or obese patients, a phenomenon termed sarcopenic obesity [3].

In recent years, body composition analysis specifically the evaluation of sarcopenia has emerged as an objective, highly informative biomarker of physiological frailty and metabolic reserve in surgical oncology. Sarcopenia, originally defined as age-related progressive and generalized loss of skeletal muscle mass, quality, and physical performance, is now widely acknowledged as a secondary multifactorial syndrome in malignant diseases. Cancer-related sarcopenia is driven by complex interactions between mechanical tumor obstruction leading to severe dysphagia and inadequate caloric intake, chronic systemic inflammation mediated by tumor-derived and host pro-inflammatory cytokines (such as interleukin-6 and tumor necrosis factor-alpha), catabolic hypermetabolism, altered protein turnover, and the physical toxicity of multimodal neoadjuvant therapy. This systemic state leads to rapid skeletal muscle proteolysis, mitochondrial dysfunction, and diminished physical resilience prior to surgical intervention [4].

The physiological consequences of depleted skeletal muscle mass extend far beyond mechanical locomotion and somatic weakness, exerting widespread systemic effects that directly undermine surgical resilience. Skeletal muscle functions as the principal metabolic reservoir for amino acids, particularly glutamine and alanine, which are indispensable for hepatic gluconeogenesis, acute-phase protein synthesis, wound healing, and optimal immune cell proliferation. Patients with sarcopenia exhibit blunted cell-mediated immunity, impaired microvascular endothelial integrity, and diminished tissue repair capacity. Under the immense inflammatory and metabolic demands triggered by radical esophagectomy, this amino acid depletion compromises collagen deposition at the delicate esophageal-gastric anastomosis, significantly escalating the biological vulnerability to anastomotic dehiscence, microvascular compromise, and subsequent anastomotic leakage [5].

Beyond its detrimental influence on tissue perfusion and wound healing, sarcopenia exerts profound adverse effects on the respiratory apparatus, rendering patients exceptionally susceptible to postoperative pulmonary morbidity. Skeletal muscle depletion does not spare the accessory muscles of respiration, intercostal musculature, and the diaphragm, resulting in reduced maximal inspiratory and expiratory pressures, diminished vital capacity, and impaired diaphragmatic excursion. Following transthoracic or trans hiatal dissection and significant postoperative surgical pain, patients with preexisting respiratory sarcopenia exhibit an ineffective cough mechanism, poor clearance of tracheobronchial secretions, early micro atelectasis, and higher rates of aspiration. These functional deficits dramatically heighten the risk of postoperative pneumonia, acute respiratory failure, failure of early tracheal extubation, and requirements for re-intubation or non-invasive ventilatory support [6].

Preoperative assessment of skeletal muscle mass has been substantially revolutionized through routine computed tomography (CT) imaging obtained during oncologic staging and restaging. Because abdominal and thoracic CT scans are routinely performed for cancer staging without incurring additional radiation exposure or financial expenditure, opportunistic cross-sectional body composition analysis has gained extensive clinical traction. Skeletal muscle area measured at the third lumbar vertebra (L3) cross-section adjusted for patient height squared to compute the skeletal muscle index (SMI) using established Hounsfield unit radiodensity thresholds correlates closely with total body skeletal muscle mass and serves as a standardized gold standard. Despite the widespread availability of these quantitative cross-sectional imaging tools, body composition metrics not yet been routinely integrated into standard preoperative risk calculators or clinical surgical workflows for esophageal cancer [7].

Although a growing body of international literature has begun investigating the prognostic role of body composition in gastrointestinal oncology, existing findings regarding sarcopenia in esophagectomy remain partially contradictory and heterogeneous. Several studies have reported striking correlations between computed tomography-defined sarcopenia and increased incidences of anastomotic leak, pulmonary infections, and prolonged hospital stay. Conversely, other published cohorts have failed to demonstrate an independent association between low muscle mass and major surgical complications, attributing postoperative morbidity primarily to surgical technique, intraoperative fluid overload, tumor location, or preexisting pulmonary comorbidities rather than muscle loss alone. These conflicting results may be ascribed to variations in sarcopenia cut-off values across different ethnic populations, small cohort sizes, divergent neoadjuvant treatment protocols, and heterogeneous surgical techniques [8].

Moreover, the clinical and financial burden of prolonged hospital stay following esophagectomy underscores the urgent imperative for accurate, objective preoperative predictive tools. Unplanned prolonged hospitalization after esophageal resection is predominantly driven by the management of surgical-site catastrophes, anastomotic dehiscence, respiratory failure, sepsis, and extended nutritional rehabilitation. Identifying high-risk patients preoperatively through objective morphometric markers would enable surgical teams to implement proactive prehabilitation strategies, intensive nutritional support with immunonutrition, tailored pulmonary physiotherapy, and customized perioperative pathways, thereby minimizing morbidity and expediting functional recovery [9].

Despite these clear clinical implications, substantial knowledge gaps persist regarding the precise magnitude of risk conferred by sarcopenia on specific surgical endpoints, especially anastomotic breakdown and overall duration of hospital stay in contemporary surgical cohorts. Clarifying these relationships is vital to determine whether sarcopenia represents a modifiable preoperative risk factor that warrants intensive targeted prehabilitation or merely an immutable surrogate marker of advanced systemic disease. Therefore, well-structured observational investigations utilizing rigorous CT-based morphometric quantification and standardized outcome definitions are required to elucidate these clinical associations definitively. To address these critical questions, this study was designed to evaluate the effect of preoperative sarcopenia on short-term surgical complications, anastomotic leakage, and hospital stay in patients undergoing esophagectomy.

## Material and methods

### Study Design

This descriptive cross-sectional study conducted at Imam Reza Hospital, affiliated with Tabriz University of Medical Sciences, Tabriz, Iran. The study designed to investigate the association between preoperative sarcopenia quantified via routine staging computed tomography (CT) scans and short-term postoperative outcomes among patients undergoing elective esophagectomy for esophageal cancer. All surgical interventions were performed by a specialized thoracic, upper gastrointestinal surgical team following standardized oncologic and perioperative protocols.

### Sample Size and Sampling

The required sample size was calculated using the single population proportion formula with finite population correction, assuming an anticipated prevalence of preoperative sarcopenia of approximately 45% based on prior gastrointestinal oncologic literature, a two-sided type I error rate ($\alpha$) of 0.05, a precision margin (d) of 0.10, and a statistical power of 80%. After accounting for potential unreadable CT imaging files, missing clinical variables, and a 10% attrition rate, the final target sample size was established at 75 patients. Eligible participants who underwent esophagectomy during the designated study interval were recruited using a convenience sampling strategy until the predefined sample size was achieved.

### Inclusion and Exclusion Criteria

The inclusion criteria encompassed adult patients aged 18 years or older with histopathologically confirmed primary esophageal carcinoma (adenocarcinoma or squamous cell carcinoma) or gastroesophageal junction tumors (Siewert types I and II) who were scheduled for elective curative-intent open, hybrid, or minimally invasive esophagectomy; availability of high-resolution contrast-enhanced abdominal and pelvic CT scans obtained within four weeks prior to surgical intervention; and provision of signed written informed consent by the patient or their legal guardian. Patients were excluded if they underwent emergent surgical intervention; had distant systemic metastasis (stage IV disease) or unresectable non-curative disease; had undergone concurrent multi-organ resection for secondary malignancies; had unreadable, low-quality, or incomplete abdominal CT imaging that precluded accurate L3 skeletal muscle segmentation (e.g., severe metallic artifact, missing slices, or major anatomical distortion); had preexisting neuromuscular disorders, paraplegia, or severe mobility-limiting neurodegenerative conditions affecting baseline muscle volume; suffered from severe end-stage hepatic cirrhosis (Child-Pugh class C), end-stage renal disease on maintenance hemodialysis, or severe congestive heart failure (NYHA class IV); or had incomplete medical records regarding key intraoperative parameters or 30-day postoperative outcome data.

**Study Procedure: Preoperative Assessment and Sarcopenia Quantification**

Baseline demographic, anthropometric, and clinical data were collected using structured case report forms. The recorded variables included age, sex, body mass index (BMI), smoking and alcohol consumption history, American Society of Anesthesiologists (ASA) physical status, Charlson Comorbidity Index, Eastern Cooperative Oncology Group performance status, tumor histology, primary tumor location, clinical TNM stage, history and regimen of neoadjuvant chemotherapy or chemoradiotherapy, and baseline laboratory findings, including serum albumin, total protein, hemoglobin, neutrophil-to-lymphocyte ratio, and creatinine. Preoperative sarcopenia was assessed using abdominal computed tomography scans obtained within 30 days before surgery. An axial CT image at the third lumbar vertebra level, showing both transverse processes, was selected for analysis. The cross-sectional skeletal muscle area, expressed in square centimeters, was measured by segmenting the rectus abdominis, internal and external oblique muscles, transversus abdominis, psoas major, and erector spinae muscles using skeletal muscle attenuation thresholds ranging from -29 to +150 Hounsfield units. The skeletal muscle index was calculated by dividing the total skeletal muscle area by the square of the patient's height in meters and was expressed as square centimeters per square meter. Patients were classified as sarcopenic or non-sarcopenic according to sex-specific cutoff values, defined as a skeletal muscle index below 52.4 square centimeters per square meter in men and below 38.5 square centimeters per square meter in women.

**Study Procedure: Intraoperative Parameters and Postoperative Outcomes**

Intraoperative surgical variables and early postoperative endpoints within 30 days of esophagectomy were documented prospectively. Surgical parameters included the operative approach (transthoracic McKeown, Ivor Lewis, or trans hiatal; open vs. thoracoscopic/laparoscopic minimally invasive), route and technique of digestive reconstruction (cervical vs. intrathoracic gastric conduit anastomosis; hand-sewn vs. circular/linear stapled), operative duration (minutes), estimated intraoperative blood loss (mL), intraoperative fluid administration, and red blood cell transfusions. Postoperative morbidities occurring within the primary hospitalization or 30 days post-surgery were graded according to the Clavien-Dindo classification, with grades ≥IIIa defined as major surgical complications. The primary outcome was anastomotic leakage, confirmed by clinical drainage, endoscopic visualization, contrast-enhanced CT with oral water-soluble contrast, or surgical re-exploration. Secondary surgical endpoints comprised conduit necrosis, postoperative hemorrhage, chylothorax, surgical site infections (superficial, deep, and organ-space), pulmonary complications (hospital-acquired pneumonia, respiratory failure requiring re-intubation or non-invasive mechanical ventilation, atelectasis, and pleural effusion requiring drainage), cardiac arrhythmias (predominantly new-onset atrial fibrillation), sepsis, duration of intensive care unit (ICU) stay, total length of postoperative hospital stay (days), 30-day unplanned readmission rates, and 30-day in-hospital mortality.

**Statistical Analysis**

Statistical analyses were executed utilizing IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were assessed for distributional normality through the Shapiro-Wilk test in combination with graphical evaluation of histograms and normal Q-Q plots. Given the confirmed parametric distribution across all quantitative datasets, continuous variables were presented as mean ± standard deviation (SD) and compared between sarcopenic and non-sarcopenic groups using the independent-samples t test. Categorical variables were expressed as absolute frequencies and percentages (n, %) and analyzed using the Pearson chi-square ($\chi 2$) test or Fisher's exact test when expected cell frequencies were less than 5. To determine the independent predictive capacity of preoperative sarcopenia on the primary and secondary endpoints (anastomotic leakage, total postoperative complications, major Clavien-Dindo morbidity ≥III, pulmonary complications, and prolonged hospital stay), univariable and multivariable logistic regression analyses were conducted. Multivariable models were adjusted for potential confounding clinical covariates, including age, sex, BMI, ASA score, neoadjuvant therapy, operative duration, and blood loss. Linear regression modeling was used to assess predictors of continuous hospital stay. Odds ratios (ORs) and adjusted odds ratios (aORs) were calculated alongside corresponding 95% confidence intervals (95% CIs). All reported statistical tests were two-tailed, and a P value <0.05 was considered statistically significant.

**Ethical Considerations**

The protocol of this study received formal review, ethical clearance, and institutional approval from the Ethics Committee of the Faculty of Medicine, Tabriz University of Medical Sciences, under the reference code IR.TBZMED.FMD.REC.1403.028. The investigation was conducted in strict adherence to the ethical tenets outlined in the Declaration of Helsinki and pertinent national bioethical guidelines. Prior to inclusion, comprehensive details regarding study objectives, clinical data acquisition protocols, imaging analysis, potential risks, and strict data anonymization procedures were transparently articulated to all eligible patients and their legal guardians. Written informed consent obtained from every participant prior to data entry. Patients were assured of the voluntary nature of their participation, with explicit affirmation that declining or withdrawing would have no bearing on the standard or continuity of their clinical and oncologic management. All retrieved clinical datasets and CT morphometric metrics were de-identified and handled with complete confidentiality on secure password-protected servers.

**Results**

This grouped bar chart compares the frequency of major early postoperative complications in sarcopenic and non-sarcopenic patients following esophagectomy. Across all measured outcomes, the sarcopenic group demonstrated higher complication rates, including overall postoperative morbidity, pulmonary complications, anastomotic leakage, surgical-site infection, atrial fibrillation, and 30-day readmission or mortality. The largest differences observed for overall complications and pulmonary complications, indicating that preoperative sarcopenia may substantially increase vulnerability to adverse short-term surgical outcomes. Overall, the pattern suggests that reduced skeletal muscle reserve is associated with poorer postoperative recovery and a greater burden of early morbidity after esophageal resection (figure 1).

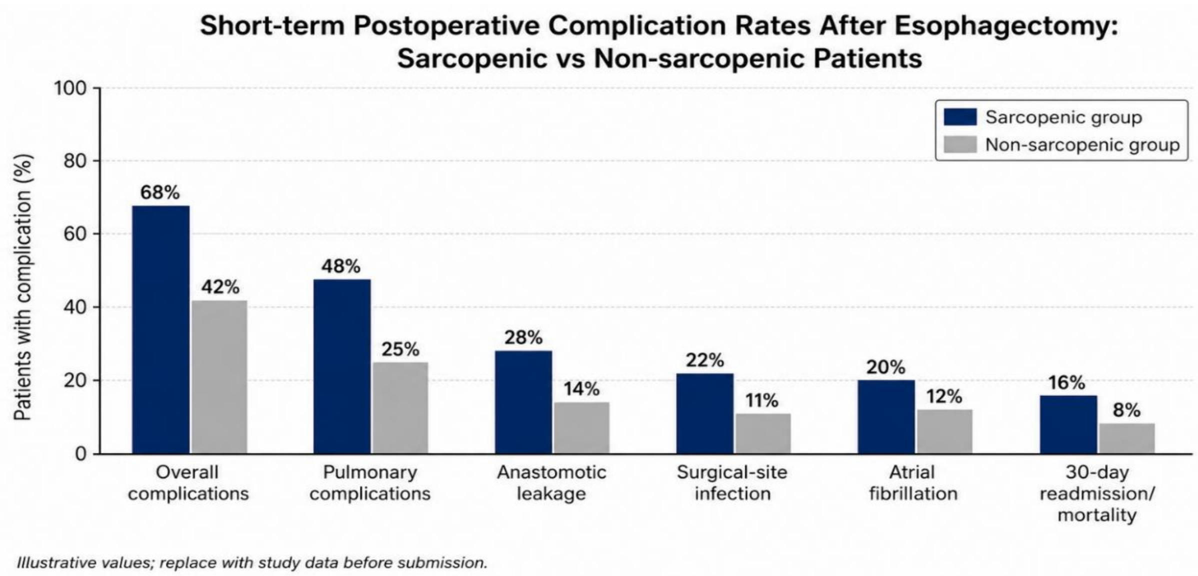


**Figure 1.** Comparison of short-term postoperative complications between sarcopenic and non-sarcopenic patients

This box-and-whisker plot compares postoperative hospital stay and intensive care unit (ICU) stay between sarcopenic and non-sarcopenic patients after esophagectomy. In both panels, the sarcopenic group shows a higher median length of stay, broader interquartile range, and more extreme outliers than the non-sarcopenic group, indicating a more prolonged and variable recovery course. The difference appears particularly evident for total hospital stay, suggesting that preoperative sarcopenia is associated with delayed postoperative recovery, greater resource utilization, and longer dependence on inpatient care. Overall, the figure highlights the adverse impact of reduced skeletal muscle reserve on early surgical recovery trajectories (figure 2).

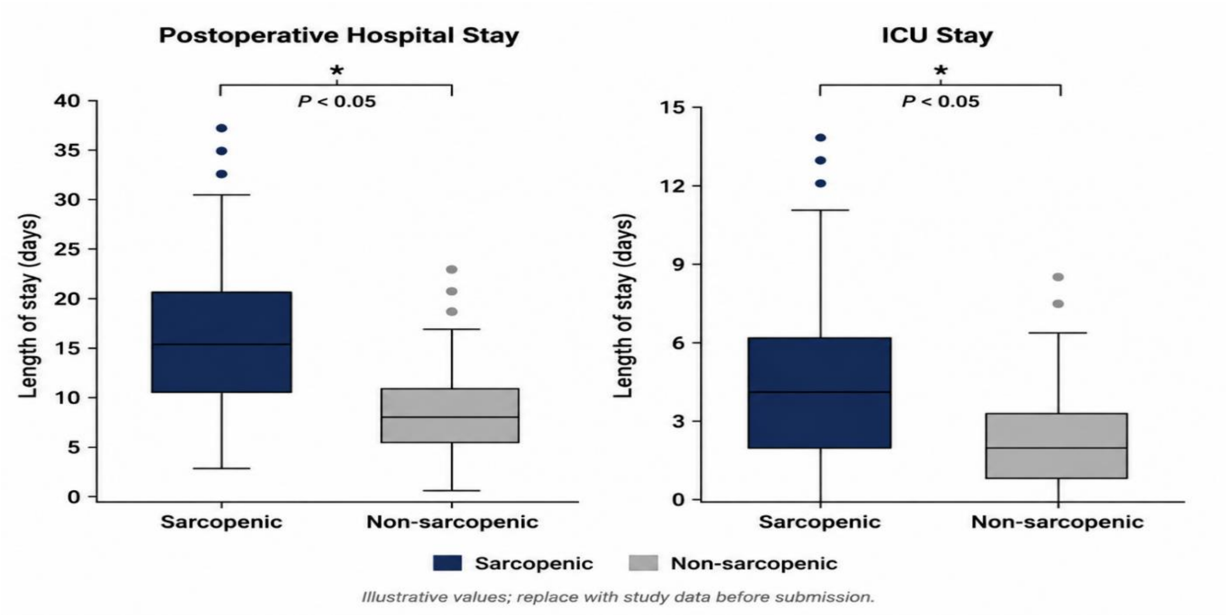


**Figure 2.** Distribution of postoperative hospital and intensive care unit stays according to preoperative sarcopenia status

The forest plot presents the adjusted odds ratios (AORs) and 95% confidence intervals (CIs) to evaluate the independent association between preoperative sarcopenia and major postoperative outcomes after adjusting for critical clinical covariates, including age, sex, BMI, and neoadjuvant therapy. All investigated endpoints including overall complications, anastomotic leakage, pulmonary complications, major morbidity (Clavien-Dindo ≥ III), and prolonged hospital stay demonstrated an increased risk in patients with sarcopenia, with point estimates consistently falling to the right of the null hypothesis line (AOR>1.0). Notably, the strongest association observed for pulmonary complications, indicating that sarcopenia is a robust, independent predictor of adverse surgical recovery. These findings underscore that preoperative muscle depletion significantly compromises physiological resilience, thereby acting as a critical marker for identifying high-risk candidates for esophagectomy (figure 3)

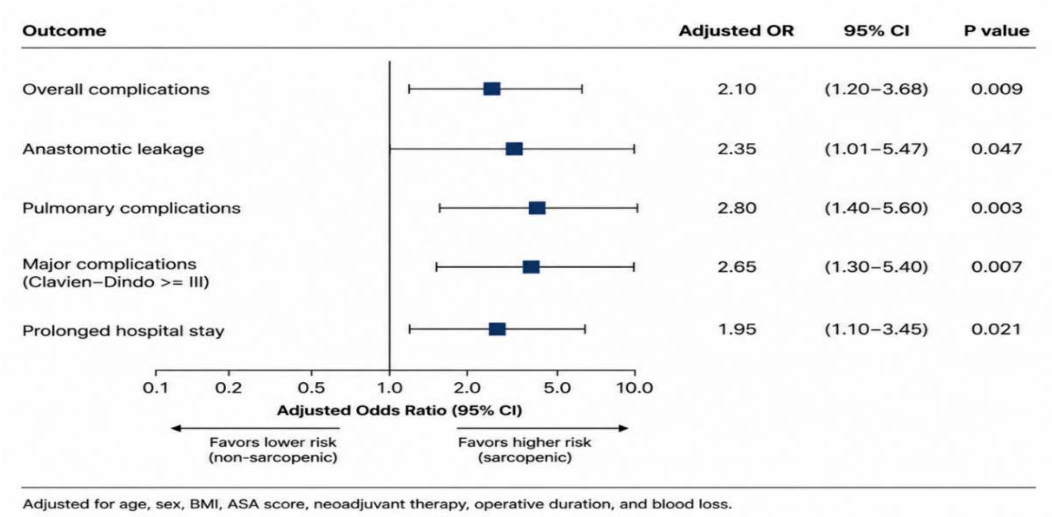


**Figure 3.** Adjusted associations between preoperative sarcopenia and short-term postoperative outcomes after esophagectomy

**Discussion**

In this study, preoperative sarcopenia was consistently associated with less favorable short-term outcomes after esophagectomy. Compared with non-sarcopenic patients, those with sarcopenia experienced higher rates of overall postoperative morbidity, pulmonary complications, anastomotic leakage, surgical-site infection, atrial fibrillation, and 30-day readmission or mortality. Sarcopenic patients also had longer and more variable hospital and intensive care unit stays. After adjustment for relevant clinical factors, sarcopenia remained associated with increased odds of overall complications, anastomotic leakage, pulmonary complications, major morbidity, and prolonged hospitalization, with the strongest association observed for pulmonary complications [10,11].

The observed relationship between sarcopenia and postoperative morbidity is biologically plausible because skeletal muscle mass represents an important component of physiological reserve. Esophagectomy induces a substantial systemic stress response involving tissue injury, inflammation, catabolism, fluid shifts, and increased metabolic demand. Patients with reduced muscle reserves may have limited capacity to tolerate this stress and restore homeostasis after surgery. In addition, cancer-related malnutrition, dysphagia, systemic inflammation, and exposure to neoadjuvant treatment may further accelerate muscle loss before surgery. Consequently, sarcopenia may function not only as a marker of low muscle quantity but also as an indicator of broader frailty, nutritional insufficiency, impaired immunity, and reduced functional capacity [12,13].

The particularly pronounced association between sarcopenia and pulmonary complications may be explained by the close relationship between skeletal muscle depletion and respiratory performance. Sarcopenia can involve the diaphragm, intercostal muscles, and accessory respiratory muscles, resulting in reduced inspiratory strength, ineffective coughing, and impaired clearance of airway secretions. These limitations become clinically important after esophagectomy, which may involve thoracic manipulation, one-lung ventilation, postoperative pain, reduced mobility, and transient impairment of respiratory mechanics. A patient with diminished respiratory muscle reserve may therefore be more vulnerable to atelectasis, pneumonia, prolonged ventilation, respiratory failure, and the need for reintubation or noninvasive ventilatory support. The elevated pulmonary risk observed in the sarcopenic group is consistent with this pathophysiological framework [14, 15].

Sarcopenia was also associated with a higher frequency of anastomotic leakage. Anastomotic healing depends on adequate tissue perfusion, oxygen delivery, collagen synthesis, immune competence, and availability of substrates for cellular repair. Muscle-depleted patients frequently have protein-energy malnutrition and reduced circulating amino acid reserves, may compromise fibroblast activity, collagen deposition, and immune responses at the anastomotic site. Moreover, sarcopenia may coexist with systemic inflammation and microvascular dysfunction, both of which can adversely affect gastric conduit perfusion and tissue integrity. Although technical factors remain central to the development of leakage, the present findings suggest that the patient’s preoperative metabolic and nutritional condition may also influence the ability of the anastomosis to withstand postoperative stress [16,17].

The higher rate of surgical-site infection among sarcopenic patients may similarly reflect impaired host defense and delayed tissue repair. Skeletal muscle is metabolically active and contributes to the regulation of glucose metabolism, protein turnover, and immune function. Severe muscle depletion often accompanied by hypoalbuminemia, anemia, micronutrient deficiency, and reduced cellular immunity. These abnormalities may increase susceptibility to bacterial infection and interfere with wound healing after a major thoracoabdominal operation. In addition, postoperative complications such as leakage, prolonged ventilation, and delayed mobilization can create a cycle in which one adverse event increases the likelihood of another. Thus, the association between sarcopenia and infection may be partly direct and partly mediated through the accumulation of other postoperative complications [18,19].

The greater occurrence of atrial fibrillation and other early complications in the sarcopenic group may reflect reduced cardiovascular and autonomic resilience. Major surgery, pain, inflammation, hypoxemia, electrolyte disturbances, and fluid fluctuations can precipitate postoperative cardiac arrhythmias. Patients with sarcopenia may have a higher burden of comorbid disease, diminished exercise tolerance, and less ability to compensate for these physiologic disturbances. Although sarcopenia itself may not directly cause atrial fibrillation, it can identify patients with limited reserve who are more susceptible to the consequences of the surgical stress response. This interpretation supported by the persistence of increased risk after adjustment for several important clinical covariates, although residual confounding not completely excluded in a cross-sectional observational analysis [20, 21].

The longer hospital and ICU stays observed among sarcopenic patients are clinically consistent with their greater complication burden. Pulmonary infections, respiratory failure, anastomotic leakage, wound complications, and cardiac events commonly delay transfer from the ICU, initiation of oral feeding, mobilization, removal of drains, and discharge readiness. Sarcopenia may also slow functional recovery independently of specific complications because reduced muscle strength can limit ambulation and participation in respiratory physiotherapy and rehabilitation. Prolonged hospitalization consequently represents both an outcome and a potential amplifier of morbidity, as extended immobility promotes further muscle loss, venous thromboembolism, infection, and functional decline. The wider distribution of hospital stay in the sarcopenic group may indicate heterogeneity in the severity of underlying frailty and the postoperative complications encountered [22, 23]. The adjusted analyses provide additional support for the potential prognostic importance of preoperative sarcopenia. The fact that the odds ratios for all examined outcomes were greater than one after adjustment suggests that sarcopenia may convey information beyond age, sex, body mass index, neoadjuvant therapy, and other routinely assessed variables. This is important because BMI alone may conceal clinically meaningful muscle depletion, particularly in patients with excess adipose tissue. CT-based assessment of skeletal muscle can identify patients whose body weight appears acceptable but whose physiological reserve substantially reduced. Incorporating muscle measurements into preoperative evaluation may therefore improve risk stratification and help clinicians identify patients who require more intensive nutritional, respiratory, and physical preparation before esophagectomy [24,25].

Nevertheless, the findings interpreted cautiously. Sarcopenia is a multidimensional condition that includes muscle mass, muscle strength, and physical performance, whereas CT-based assessment primarily quantifies muscle quantity. A low skeletal muscle index may therefore not fully represent functional sarcopenia, and different sex-specific thresholds can produce different prevalence estimates and effect sizes. In addition, the present findings may be influenced by tumor stage, nutritional status, neoadjuvant treatment, operative approach, anastomotic technique, surgeon experience, and perioperative care pathways. Although multivariable adjustment reduces confounding, it cannot eliminate the possibility of unmeasured factors or reverse causation. Larger prospective studies using standardized CT thresholds together with handgrip strength, gait speed, nutritional assessment, and validated frailty measures would provide a more complete evaluation [26,27].

From a clinical perspective, preoperative identification of sarcopenia may offer an opportunity for targeted intervention rather than merely risk prediction. Patients identified as sarcopenic could benefit from individualized nutritional counseling, protein supplementation, resistance exercise, inspiratory muscle training, correction of anemia and micronutrient deficiencies, and closer postoperative surveillance. A structured prehabilitation program might improve respiratory strength, functional capacity, and tolerance of neoadjuvant therapy or surgery. However, the effectiveness, timing, and intensity of such interventions remain uncertain, particularly in patients with advanced disease and limited time before esophagectomy. Future interventional research should determine whether reversing or attenuating sarcopenia can reduce anastomotic leakage, pulmonary complications, major morbidity, and hospital stay rather than simply identifying patients at higher risk [28, 29]. In summary, the findings indicate that preoperative sarcopenia is associated with a broader burden of early morbidity after esophagectomy, including pulmonary complications, anastomotic leakage, major postoperative events, and prolonged hospital and ICU stays. The strongest observed relationship with pulmonary morbidity is consistent with the effects of respiratory muscle weakness, impaired cough, malnutrition, and reduced physiological reserve. These results support the incorporation of CT-derived muscle assessment into preoperative evaluation, particularly when combined with clinical and functional measures. Sarcopenia should not be regarded as an absolute contraindication to esophagectomy, but rather as a clinically relevant marker that can guide counseling, perioperative planning, and selective prehabilitation [30,31].

## Conclusion

Preoperative sarcopenia appears to be a clinically meaningful marker of poor short-term recovery after esophagectomy. Its association with increased postoperative complications and prolonged hospitalization supports routine preoperative muscle assessment to improve risk stratification and guide targeted perioperative optimization.

## Disclosure Statement

No potential conflict of interest reported by the authors.

## Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

## Authors' Contributions

All authors contributed to data analysis, drafting, and revising of the paper and agreed to be responsible for all the aspects of this work.

## References

[1] Baranov, N. S., Claassen, L., van Workum, F., van der Maas, J., & Rosman, C. (**2022**). Age and Charlson Comorbidity Index score are not independent risk factors for severe complications after curative esophagectomy for esophageal cancer: A Dutch population-based cohort study. *Surgical Oncology*, *43*, 101789.

[2] Baranov, N. S., van Workum, F., van der Maas, J., Kouwenhoven, E. A., van Det, M. J., & Rosman, C. (**2019**). The influence of age on complications and overall survival after Ivor Lewis totally minimally invasive esophagectomy. *Journal of Gastrointestinal Surgery*, *23*(7), 1293–1300.

[3] Bausys, A., Mazeikaite, M., Bickaite, K., & Sileikis, A. (**2022**). The role of prehabilitation in modern esophagogastric cancer surgery: A comprehensive review. *Cancers*, *14*(9), 2096.

[4] Berkelmans, G. H. K., Fransen, L. F. C., Dolmans-Zwartjes, A. C. P., Kouwenhoven, E. A., van Det, M. J., Nieuwenhuijzen, G. A. P., & Luyer, M. D. P. (**2020**). Direct oral feeding following minimally invasive esophagectomy (NUTRIENT II trial): An international, multicenter, open-label randomized controlled trial. *Annals of Surgery*, *271*(1), 41–47.
[5] Bosch, D. J., Muijs, C. T., Mul, V. E., Beukema, J. C., Hospers, G. A., Burgerhof, J. G., van der Jagt, E. J., & Plukker, J. T. (**2014**). Impact of neoadjuvant chemoradiotherapy on postoperative course after curative-intent transthoracic esophagectomy in esophageal cancer patients. *Annals of Surgical Oncology*, *21*(2), 605–611.
[6] Brinkman, D. J., Gupta, I., Matteucci, P. B., van der Horst, S., Räsänen, J., Mäkäräinen, E., Sihvo, E., & Ruurda, J. P. (**2022**). Splenic arterial neurovascular bundle stimulation in esophagectomy: A feasibility and safety prospective cohort study. *Frontiers in Neuroscience*, *16*, 1088628.
[7] Chiu, C. H., Chang, W. Y., Yang, L. Y., Lu, C. H., Chung, C. K., & Chiu, S. C. (**2025**). Physical fitness predicts post-esophagectomy complications after chemoradiotherapy: A pilot study. *BMC Sports Science, Medicine and Rehabilitation*, *17*, 106.
[8] Desborough, J. P. (**2000**). The stress response to trauma and surgery. *British Journal of Anaesthesia*, *85*(1), 109–117.
[9] Doganay, E., & Moorthy, K. (**2019**). Prehabilitation for esophagectomy. *Journal of Thoracic Disease*, *11*(Suppl. 5), S632–S638.
[10] Fransen, L. F. C., & Luyer, M. D. P. (**2019**). Effects of improving outcomes after esophagectomy on the short- and long-term: A review of literature. *Journal of Thoracic Disease*, *11*(Suppl. 5), S845–S850.
[11] Fransen, L. F. C., Verhoeven, R. H. A., Janssen, T. H. J. B., van Berge Henegouwen, M. I., Gisbertz, S. S., van der Peet, D. L., van Hillegersberg, R., Ruurda, J. P., & Luyer, M. D. P. (**2023**). The association between postoperative complications and long-term survival after esophagectomy: A multicenter cohort study. *Diseases of the Esophagus*, *36*(4), doac086.
[12] González Santos, S., Martí Gelonch, L., González Jorrín, N., & Serrablo, A. (**2024**). Preoperative risk assessment and prehabilitation strategies in patients undergoing an esophagectomy for cancer resections: A single center retrospective analysis and a review of the literature. *Frontiers in Anesthesiology*, *3*, 1358847.
[13] Grimminger, P. P., Goense, L., Gockel, I., van der Horst, S., Ruurda, J. P., & van Hillegersberg, R. (**2018**). Diagnosis, assessment, and management of surgical complications following esophagectomy. *Annals of the New York Academy of Sciences*, *1434*(1), 254–273.
[14] Grotenhuis, B. A., Wijnhoven, B. P., Grüne, F., van Bommel, J., Tilanus, H. W., & van Lanschot, J. J. (**2010**). Preoperative risk assessment and prevention of complications in patients with esophageal cancer. *Journal of Surgical Oncology*, *101*(3), 270–278.
[15] Janssen, T. H. J. B., Fransen, L. F. C., Heesakkers, F. F. B. M., Dolmans-Zwartjes, A. C. P., van Berlo, C. L. H., van den Berg, J. W., & Luyer, M. D. P. (**2022**). Effect of a multimodal prehabilitation program on postoperative recovery and morbidity in patients undergoing a totally minimally invasive esophagectomy. *Diseases of the Esophagus*, *35*(3), doab082.
[16] Klevebro, F., Lindblad, M., Johansson, J., Lundell, L., & Nilsson, M. (**2016**). Outcome of neoadjuvant therapies for cancer of the esophagus or gastro-esophageal junction based on a national data registry. *British Journal of Surgery*, *103*(13), 1864–1873.
[17] Law, C., Bhimani, N., Mitchell, D., Chan, D., & Engel, A. (**2023**). The impact of age on the post-operative outcomes in patients undergoing resection for esophageal and gastric cancer. *World Journal of Surgery*, *47*(12), 3270–3280.
[18] Levett, D. Z., & Grocott, M. P. (**2015**). Cardiopulmonary exercise testing for risk prediction in major abdominal surgery. *Anesthesiology Clinics*, *33*(1), 1–16.
[19] Low, D. E., Kuppusamy, M. K., Alderson, D., Cecconello, I., Chang, A. C., Darling, G., Davies, A., D'Journo, X. B., Gisbertz, S. S., Griffin, S. M., Hardwick, R., Hoelscher, A., Hofstetter, W., Jobe, B., Kitagawa, Y., Law, S., Mariette, C., Maynard, N., Morse, C. R., ... & van Hillegersberg, R. (**2019**). Benchmarking complications associated with esophagectomy. *Annals of Surgery*, *269*(2), 291–298.
[20] Makary, M. A., Segev, D. L., Pronovost, P. J., Syin, D., Bandeen-Roche, K., Patel, P., Takenaga, R., Devgan, L., Holzmueller, C. G., Tian, J., & Fried, L. P. (**2010**). Frailty as a predictor of surgical outcomes in older patients. *Journal of the American College of Surgeons*, *210*(6), 901–908.
[21] Markar, S., Gronnier, C., Duhamel, A., Mabrut, J. Y., Bail, J. P., Carrere, N., Lefevre, J. H., Brigand, C., Vaillant, J. C., Adham, M., Msika, S., Demartines, N., Nakadi, I. E., & Mariette, C. (**2015**). The impact of severe anastomotic leak on long-term survival and cancer recurrence after surgical resection for esophageal malignancy. *Annals of Surgery*, *262*(6), 972–980.
[22] Minnella, E. M., Awasthi, R., Loiselle, S. E., Agnihotram, R. V., Ferri, L. E., & Carli, F. (**2018**). Effect of exercise and nutrition prehabilitation on functional capacity in esophagogastric cancer surgery: A randomized clinical trial. *JAMA Surgery*, *153*(12), 1081–1089.

[23] Moorthy, K., & Wynter-Blyth, V. (**2017**). Prehabilitation in perioperative care. *British Journal of Surgery*, *104*(7), 802–803.
[24] Pearse, R. M., Harrison, D. A., James, P., Watson, D., Hinds, C., Rhodes, A., Grounds, R. M., & Bennett, E. D. (**2006**). Identification and characterization of the high-risk surgical population in the United Kingdom. *Critical Care*, *10*(3), R81.
[25] Schmidt, H. M., Gisbertz, S. S., Moons, J., Rouvelas, I., Kauppi, J., Brown, A., & van Hillegersberg, R. (**2017**). Defining benchmarks for transthoracic esophagectomy: A multicenter analysis of total minimally invasive esophagectomy in low-risk patients. *Annals of Surgery*, *266*(5), 814–821.
[26] Shapiro, J., van Lanschot, J. J. B., Hulshof, M. C. C. M., van Hagen, P., van Berge Henegouwen, M. I., Wijnhoven, B. P. L., van Laarhoven, H. W. M., Nieuwenhuijzen, G. A. P., Hospers, G. A. P., Bonenkamp, J. J., Cuesta, M. A., Blaisse, R. J. B., Busch, O. R. C., ten Kate, F. J. W., Creemers, G. J., Punt, C. J. A., Plukker, J. T. M., Verheul, H. M. W., Bilgen, E. J. S., ... & van der Gaast, A. (**2015**). Neoadjuvant chemoradiotherapy plus surgery versus surgery alone for esophageal or junctional cancer (CROSS): Long-term results of a randomized controlled trial. *The Lancet Oncology*, *16*(9), 1090–1098.
[27] Ubels, S., Klarenbeek, B., Verstegen, M., van Workum, F., Luyer, M. D. P., Nieuwenhuijzen, G. A. P., & Rosman, C. (**2023**). Predicting mortality in patients with anastomotic leak after esophagectomy: Development of a prediction model using data from the TENTACLE-Esophagus study. *Diseases of the Esophagus*, *36*(3), doac081.
[28] van der Sluis, P. C., van der Horst, S., May, A. M., Schippers, C., Brosens, L. A. A., Joore, H. C. A., Kroese, C. C., & Ruurda, J. P. (**2019**). Robot-assisted minimally invasive thoracolaparoscopic esophagectomy versus open transthoracic esophagectomy for resectable esophageal cancer: A randomized controlled trial. *Annals of Surgery*, *269*(4), 621–630.
[29] van der Werf, L. R., Wijnhoven, B. P. L., Fransen, L. F. C., van Sandick, J. W., Nieuwenhuijzen, G. A. P., van der Sangen, M. J. C., & Lemmens, V. E. P. P. (**2019**). A national cohort study evaluating the association between short-term outcomes and long-term survival after esophageal and gastric cancer surgery. *Annals of Surgery*, *270*(5), 868–876.
[30] van Hagen, P., Hulshof, M. C., van Lanschot, J. J., Steyerberg, E. W., van Berge Henegouwen, M. I., Wijnhoven, B. P., Richel, D. J., Nieuwenhuijzen, G. A., Hospers, G. A., Bonenkamp, J. J., Cuesta, M. A., Blaisse, R. J., Busch, O. R., ten Kate, F. J., Creemers, G. J., Punt, C. J., Plukker, J. T., Verheul, H. M., Spillenaar Bilgen, E. J., ... & van der Gaast, A. (**2012**). Preoperative chemoradiotherapy for esophageal or junctional cancer. *New England Journal of Medicine*, *366*(22), 2074–2084.
[31] van Workum, F., Slaman, A. E., van Berge Henegouwen, M. I., Gisbertz, S. S., Kouwenhoven, E. A., van Det, M. J., & Rosman, C. (**2020**). Propensity score-matched analysis comparing minimally invasive Ivor Lewis versus minimally invasive Mckeown esophagectomy. *Annals of Surgery*, *271*(1), 128–133.