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# Association of low skeletal muscle mass and radiodensity with clinical outcomes in patients undergoing robotic radical gastric cancer surgery: a population-based retrospective cohort study

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## Abstract

**Background** Sarcopenia (defined as low skeletal muscle index - SMI) and myosteatosis (defined as low skeletal muscle radiodensity - SMD) associate with poor outcomes in gastric cancer, but their impact after robotic surgery is unknown.

**Methods** This retrospective cohort study analyzed 381 gastric cancer patients undergoing robotic surgery from December 2019 to October 2022. Sarcopenia and myosteatosis were assessed on preoperative CT scans. Outcomes were postoperative complications, mortality, survival, and recurrence. Multivariable regression and propensity score matching examined associations.

**Results** The mean age at diagnosis was 58.5 ± 10.8 years, and 69.3% (262/381) were male. Low SMI or Low SMD independently associated with more complications (odds ratio[OR] = 3.36, 95%CI: 2.08–5.43; OR = 2.49,95%CI: 1.48–4.19, respectively), unplanned ICU admission (OR = 1.51, 95%CI: 1.22–8.44; OR = 2.00; 95%CI: 1.23–8.89, respectively) or 30-day mortality (OR = 5.89, 95%CI: 1.80-14.23; OR = 7.34; 95%CI: 2.43–18.67, respectively). Concurrent sarcopenia and myosteatosis heightened risks of complications (OR = 7.29, 95%CI: 1.62–42.30), severe complications (OR = 6.67, 95%CI: 2.22–12.68), 30-day mortality (OR = 9.55, 95%CI: 2.67–33.89), and reduced survival (hazard ratio[HR] = 3.09, 95%CI: 1.77–8.60).

**Conclusions** Sarcopenia and myosteatosis independently and additively associate with increased postoperative complications, mortality, and worse prognosis after robotic gastric cancer surgery. Identifying sarcopenia and myosteatosis preoperatively could inform risk assessments and guide management to improve surgical outcomes.

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**Keywords** Gastric cancer, Robotic surgery, Skeletal muscle index, Skeletal muscle radiodensity, Postoperative complications, Long-term prognosis

## Introduction

Research has shown that factors like skeletal muscle mass and radiodensity can affect the prognosis of gastric cancer patients [1–3]. Advances in robotics have improved precision and outcomes in radical gastric cancer surgery [4–5]. However, the impact of preoperative muscle mass and density on the outcomes of robotic surgery is not well understood. To minimize confounding from surgical technique, we included only patients who underwent robotic radical gastrectomy in this study. This allowed us to assess the associations between preoperative skeletal muscle index (SMI) and skeletal muscle radiodensity (SMD) with postoperative outcomes under a standardized surgical context. This study will investigate how low muscle mass and density before surgery affect both short-term and long-term results after robotic radical surgery for gastric cancer. This will help fill an important gap in research on advanced surgical treatments for gastric cancer and the factors that predict their success.

Sarcopenia, or low muscle mass, has been increasingly recognized as a robust, objective marker for risk stratification, particularly in gastric cancer [6–7]. Studies show that sarcopenia increases the risk of complications and death after cancer surgery [8–9]. Measuring SMI using CT scans helps identify sarcopenia, while CT-measured SMD, indicating fat in muscles, is linked to worse outcomes in cancer patients [10–11]. However, previous research hasn't fully explored how SMI and SMD, independent of body fat, relate to various surgical outcomes. This study aims to explore the independent relationships between low SMI and SMD and postoperative indicators in patients undergoing robotic surgery for gastric cancer.

Muscle loss and decreased muscle quality are linked to lower survival rates in late-stage gastric cancer [12]. The impact of muscle decline in early-stage gastric cancer patients undergoing robotic surgery and its potential link to mortality hasn't been studied [13–14]. We conducted a retrospective study to investigate how preoperative muscle characteristics relate to short-term outcomes and long-term prognosis in gastric cancer patients undergoing robotic surgery. Our aim is to enhance understanding and care in this type of surgery.

## Methods and materials

### Patient section

This population-based retrospective cohort study was conducted at the Fourth Hospital of Hebei Medical University, a large comprehensive oncology center in Hebei Province, China. Patients who underwent robotic gastrectomy for gastric cancer between December 2019 and October 2022 were identified from the prospectively collected Hebei Gastric Cancer Collaborative Network (HeB-GCCN) database (http://hbss.suvalue.com/). Preoperative abdominal CT scans performed for clinical staging were collected, and body composition was assessed in 466 patients who underwent robotic gastric cancer surgery. Patients were excluded based on the following criteria: (1) lack of comprehensive clinical treatment and postoperative complication data; (2) suboptimal CT image quality due to metal artifacts at L3, partial exterior abdominal musculature, or severe anatomical aberrations obstructing abdominal muscle groups; (3) neoadjuvant or other preoperative targeted/immunotherapies; (4) CT evidence of concurrent primary malignancies; (5) loss to follow-up or uncooperative during follow-up. The final cohort for analysis comprised 381 patients who underwent robotic resection for gastric cancer. All disease diagnoses, surgical details, and postoperative complication data obtained from the hospital information system were meticulously documented per the International Classification of Diseases, Tenth Revision (ICD-10) standards. This study received ethical approval from the Research Ethics Committee of the Fourth Hospital of Hebei Medical University (approval Number: 2023KY139). Due to the retrospective design, the requirement for informed consent was waived.

### Measures of body composition

A detailed retrospective analysis was performed on preoperative CT images of all patients undergoing robotic radical gastric cancer surgery in this study. Numerous studies have demonstrated a strong correlation between skeletal muscle and adipose tissue cross-sectional areas at the L3 vertebral level in the supine position and overall body composition [15–16]. Given this robust association, we measured skeletal muscle area and adipose tissue area at L3 in patients undergoing robotic surgery for gastric cancer. The skeletal muscle area encompassed the psoas, paraspinal, transversus abdominis, rectus abdominis, and the internal and external obliques.

As with our previous research methods, the 5-mm axial CT scan images were uploaded to the Picture Archiving and Communication System (PACS, SIEMENS SOMATOM) upon acquisition [13–14, 17]. A board-certified radiologist (LY) with over five years of experience led the semi-automatic segmentation process, accurately outlining the L3 vertebral body boundaries along the inner abdominal wall subcutaneous fat edge. A predetermined Hounsfield unit (HU) threshold (-29 to 150 HU) was applied to delineate skeletal muscle [18]. Software

computed average skeletal muscle radiodensity at L3 as SMD. Subcutaneous adipose tissue (SAT) area was difined as fat tissue (-190 to -30 HU) outside muscle. Visceral adipose tissue (VAT) was defined as non-subcutaneous fat (-150 to -50 HU). A sub-sample of 50 randomly selected images was analyzed by two researchers (TZ, XYT) blinded to the outcomes, while a trained researcher (SC), also blinded to the outcomes, analyzed the remaining CT images. Inter-observer coefficients of variation for SMI, SMD, SAT, and VAT in 80 random patients were 1.1%, 1.6%, 1.7%, and 1.1%, respectively. Intra-observer coefficients were 1.1%, 1.5%, 1.5%, and 1.1%, respectively, aligning with literature [2, 19–20]. Body composition measurement demonstrated high reproducibility (Supplementary Figure S1). Skeletal muscle, VAT, and SAT areas were normalized by patient height to calculate skeletal muscle index (SMI), SAT index (SATI), and VAT index (VATI) ($cm^2/m^2$).

As participants were Asian, sarcopenia and low SMD criteria were based on Zhuang et al. [21–22]. Sarcopenia was SMI < 40.8 $cm^2/m^2$ in males and < 34.9 $cm^2/m^2$ in females. Low SMD was < 38.5 HU in males and < 28.6 HU in females.

### Study outcomes

This study categorizes clinical indicators into short-term postoperative outcomes and long-term prognostic outcomes. Short-term postoperative outcomes include incidence and grades (referring to the Clavien-Dindo classification scale) of complications within 30 days post-surgery, identified by ICD-10 codes and medical record visit dates; length of stay (LOS); unplanned ICU admission rates; 30-day readmission; and 30-day mortality. Postoperative complications are defined as one or more conditions occurring within 30 days after surgery, classified into eight major categories by system: gastrointestinal (anastomotic bleeding, leakage, obstruction), incisional (surgical site infection, dehiscence, delayed healing), respiratory (atelectasis, pneumonia, pleural effusion), cardiovascular (myocardial infarction, arrhythmias, arrest), neurological (stroke, delirium), urinary (renal failure, infection), systemic infection (sepsis, septicemia, abdominal), and vascular (pulmonary embolism, deep vein thrombosis, hemorrhage).

Four surgical residents ((JXY, HHG, YT and PGY) reviewed the medical records of patients with the aforementioned conditions, identified by ICD-10 codes, to validate and classify postoperative complications using the Clavien-Dindo system. Severe complications were defined as Clavien-Dindo scores ≥ 3. LOS was calculated by subtracting the surgery date from the initial discharge date post-surgery. The median LOS was 7 days; a prolonged LOS was defined as ≥ 7 days. Readmission referred to hospital admission for inpatient or emergency care within 30 days of discharge. Unplanned ICU admission was characterized by late transfer without early warning or pre-surgery ICU admission plan, as determined intraoperatively or postoperatively. Thirty-day postoperative and overall mortality were obtained through an electronic registry consolidating internal, social security, and cancer registry death data.

Long-term outcomes were overall survival (OS) and disease-free survival (DFS). OS was defined as time from surgery to tumor-related death or last contact; DFS as time from surgery to death from tumor recurrence. Treatment and follow-up of all patients after robotic gastric cancer surgery adhered to recommendations in the Chinese Society of Clinical Oncology (CSCO) Clinical Diagnosis and Treatment Guidelines for Gastric Cancer [23]. Patients were advised to follow-up every 3 months for 2 years, then semiannually or annually. Follow-up comprised phone consultations, clinic visits, and hospitalizations with abdominal/chest CT, endoscopy, and tumor marker assessments. Follow-up ended May 31, 2023.

### Clinicopathological parameters

The clinical parameters assessed included preoperative characteristics such as gender, age, smoking and alcohol consumption history, Charlson Comorbidity Index (CCI), American Society of Anesthesiologists (ASA) classification, and Borrmann type. Intraoperative factors were extent of resection and anastomosis method. Postoperative pathological data included tumor location, size, differentiation, histological type, depth of invasion, lymph node metastasis, vascular and neural invasion, Lauren classification, and TNM staging (referring to the 8th edition AJCC guidelines). All clinical variables and demographic characteristics were extracted from the electronic medical records.

### Statistical analyses

Data normality was assessed using the Kolmogorov-Smirnov test. Normally distributed data were presented as mean ± standard deviation and analyzed by independent t-test, while skewed data were presented as median (interquartile range) and analyzed by Mann-Whitney U test. Categorical variables were analyzed by Chi-square or Fisher's exact test. Potential predictors of outcomes after robotic gastric surgery were identified through literature review and tested for collinearity. Logistic regression models calculated odds ratios (95% CI) for postoperative complications and grade, readmission within 30 days, unplanned ICU transfers, length of stay, and 30-day mortality associated with low SMI or SMD. Models were internally validated by bootstrap procedures (200 repetitions). Likelihood ratio tests evaluated interactions between low SMI, low SMD, and total

**Table 1** Demographic and clinical characteristics of patients undergoing robotic surgical resection for gastric cancer according to muscle characteristics

| Characteristic | Overall (*N* = 381) | | | | Male (*N* = 262) | | | | Female (*N* = 119) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SMD | | SMI | | SMD | | SMI | | SMD | | SMI | |
| | Normal (*N* = 253) | Low (*N* = 128) | Normal (*N* = 203) | Low (*N* = 178) | Normal (*N* = 178) | Low (*N* = 84) | Normal (*N* = 141) | Low (*N* = 121) | Normal (*N* = 75) | Low (*N* = 44) | Normal (*N* = 62) | Low (*N* = 57) |
| **Sex** | | | | | | | | | | | | |
| Male | 178(70.4) | 84(65.6) | 141(69.5) | 121(68.0) | - | - | - | - | - | - | - | - |
| Females | 75(29.6) | 44(34.4) | 62(30.5) | 57(32.0) | - | - | - | - | - | - | - | - |
| **Age, mean (SD), y** | 58.2(10.9) | 59.2(10.6) | 58.8(10.6) | 58.2(11.0) | 59.7(9.4) | 59.5(9.8) | 59.7(9.6) | 59.6(9.4) | 54.6(13.4) | 58.5(12.0) | 56.7(12.5) | 55.3(13.5) |
| **Smoking status**[a] | | | | | | | | | | | | |
| Never | 63(24.9) | 43(33.6) | 62(30.5) | 44(24.7) | 42(23.6) | 31(36.9) | 43(30.5) | 30(24.8) | 21(28.0) | 12(27.3) | 19(30.6) | 14(24.6) |
| Former | 94(37.2) | 53(41.4) | 75(36.9) | 72(40.4) | 65(36.5) | 31(36.9) | 52(36.9) | 44(36.4) | 29(38.7) | 22(50.0) | 23(37.1) | 28(49.1) |
| Current | 66(26.1) | 16(12.5) | 43(21.2) | 39(21.9) | 46(25.8) | 11(13.1) | 28(19.9) | 29(24.0) | 20(26.7) | 5(11.4) | 15(24.2) | 10(17.5) |
| **Alcohol use**[b] | | | | | | | | | | | | |
| Never | 64(25.3) | 37(28.9) | 54(28.1) | 47(26.4) | 45(25.3) | 21(25.0) | 38(27.0) | 28(23.1) | 19(25.3) | 16(36.4) | 16(25.8) | 19(33.3) |
| Former | 101(39.9) | 55(43.0) | 77(37.9) | 79(44.4) | 72(40.4) | 41(48.8) | 56(39.7) | 57(47.1) | 29(38.7) | 14(31.8) | 21(33.9) | 22(38.6) |
| Current | 60(23.7) | 22(17.2) | 49(24.1) | 33(18.5) | 45(25.3) | 13(15.5) | 33(23.4) | 25(20.7) | 15(20.0) | 9(20.5) | 16(25.8) | 8(14.0) |
| **BMI, mean (SD), Kg/m$^2$** | 24.4(3.2) | 24.7(3.7) | 24.9(3.2) | 24.0(3.4) | 24.4(3.2) | 24.9(3.5) | 24.9(3.2) | 24.3(3.4) | 24.0(3.1) | 24.7(3.0) | 24.0(3.4) | 23.4(3.5) |
| **ECOG** | | | | | | | | | | | | |
| 0 | 127(50.2) | 73(57.0) | 107(52.7) | 93(52.2) | 90(50.6) | 49(58.3) | 74(52.5) | 65(53.7) | 37(49.3) | 24(54.5) | 33(53.2) | 28(49.1) |
| 1 | 126(49.8) | 55(43.0) | 96(47.3) | 85(47.8) | 88(49.4) | 35(41.7) | 67(47.5) | 56(46.3) | 38(50.7) | 20(45.5) | 29(46.8) | 29(50.9) |
| **ASA grade**[c] | | | | | | | | | | | | |
| 1 | 130(51.4) | 63(49.2) | 109(53.7) | 84(47.2) | 95(53.4) | 39(46.4) | 80(56.7) | 54(44.6) | 35(46.7) | 24(54.5) | 29(46.8) | 30(52.6) |
| 2 | 123(48.6) | 65(50.8) | 94(46.3) | 94(52.8) | 83(46.6) | 45(53.6) | 61(43.3) | 67(55.4) | 40(53.3) | 20(45.5) | 33(53.2) | 27(47.4) |
| **Tumor size, mean (SD), cm** | 5.0(1.0) | 5.0(1.1) | 4.9(1.0) | 5.1(1.0) | 5.0(1.1) | 5.1(1.1) | 5.0(1.0) | 5.1(1.1) | 5.0(1.0) | 5.1(1.1) | 4.9(1.0) | 5.2(1.0) |
| **Pathological differentiation** | | | | | | | | | | | | |
| Poor | 229(90.5) | 122(95.3) | 185(91.1) | 166(93.3) | 162(91) | 80(95.2) | 130(92.2) | 112(92.6) | 67(89.3) | 42(95.5) | 55(88.7) | 54(94.7) |
| Moderately or well | 24(9.5) | 6(4.7) | 18(8.9) | 12(6.7) | 16(9) | 4(4.8) | 11(7.8) | 9(7.4) | 8(10.7) | 2(4.5) | 7(11.3) | 3(5.3) |
| **Pathological grade** | | | | | | | | | | | | |
| II | 82(32.4) | 40(31.3) | 67(33.0) | 55(30.9) | 58(32.6) | 27(32.1) | 47(33.3) | 38(31.4) | 24(32) | 13(29.5) | 20(32.3) | 17(29.8) |
| III | 171(67.6) | 88(68.7) | 136(67.0) | 123(69.1) | 120(67.4) | 57(67.9) | 94(66.7) | 83(68.6) | 51(68) | 31(70.5) | 42(67.7) | 40(70.2) |
| **Lesion site** | | | | | | | | | | | | |
| Upper 1/2 | 98(38.7) | 44(34.4) | 77(37.9) | 65(36.5) | 75(42.1) | 32(38.1) | 57(40.4) | 50(41.3) | 23(30.7) | 12(27.3) | 20(32.3) | 15(26.3) |
| Lower 1/2 | 155(61.3) | 84(65.6) | 126(62.1) | 113(63.5) | 103(57.9) | 52(61.9) | 84(59.6) | 71(58.7) | 52(69.3) | 32(72.7) | 42(67.7) | 42(73.7) |
| **Vascular tumor thrombus** | | | | | | | | | | | | |
| Yes | 47(18.6) | 37(28.9) | 38(18.7) | 46(25.8) | 33(18.5) | 21(25.0) | 25(17.7) | 29(24) | 14(18.7) | 16(36.4) | 13(21) | 17(29.8) |
| No | 206(81.4) | 91(71.1) | 165(81.3) | 132(74.2) | 145(81.5) | 63(75.0) | 116(82.3) | 92(76) | 61(81.3) | 28(63.6) | 49(79) | 40(70.2) |
| **Nerve invasion** | | | | | | | | | | | | |
| Yes | 68(26.9) | 28(21.9) | 48(23.6) | 48(27) | 52(29.2) | 19(22.6) | 38(27.0) | 33(27.3) | 16(21.3) | 9(20.5) | 10(16.1) | 15(26.3) |
| No | 185(73.1) | 100(78.1) | 155(76.3) | 130(73) | 126(70.8) | 65(77.4) | 103(73.0) | 88(72.7) | 59(78.7) | 35(79.5) | 52(83.9) | 42(73.7) |
| **TNM stage**[d] | | | | | | | | | | | | |

**Table 1** (continued)

| Characteristic | Overall (*N* = 381) | | | | Male (*N* = 262) | | | | Female (*N* = 119) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SMD | | SMI | | SMD | | SMI | | SMD | | SMI | |
| | Normal (*N* = 253) | Low (*N* = 128) | Normal (*N* = 203) | Low (*N* = 178) | Normal (*N* = 178) | Low (*N* = 84) | Normal (*N* = 141) | Low (*N* = 121) | Normal (*N* = 75) | Low (*N* = 44) | Normal (*N* = 62) | Low (*N* = 57) |
| I | 89(35.2) | 11(8.6) | 66(32.5) | 34(19.1) | 61(34.3) | 7(8.3) | 43(30.5) | 25(20.6) | 28(37.3) | 4(9.1) | 23(37.1) | 9(15.8) |
| II | 94(37.2) | 36(28.1) | 71(35.0) | 59(33.1) | 65(36.5) | 26(31) | 51(36.2) | 40(33.1) | 29(38.7) | 10(22.7) | 20(32.3) | 19(33.3) |
| III | 70(27.7) | 81(63.3) | 66(32.5) | 85(47.8) | 52(29.2) | 51(60.7) | 47(33.3) | 56(46.3) | 18(24) | 30(68.2) | 19(30.6) | 29(50.9) |
| **Lauren type** | | | | | | | | | | | | |
| Intestine type | 55(21.7) | 22(17.2) | 44(21.7) | 33(18.5) | 37(20.8) | 14(16.7) | 29(20.6) | 22(18.2) | 18(24.0) | 8(18.2) | 15(24.2) | 11(19.3) |
| Diffuse / mixed | 198(78.3) | 106(82.8) | 159(78.3) | 145(81.5) | 141(79.2) | 70(83.3) | 112(79.4) | 99(81.8) | 57(76.0) | 36(81.8) | 47(75.8) | 46(80.7) |
| **CCI score**[e] | | | | | | | | | | | | |
| 0 | 79(31.2) | 36(28.1) | 58(28.6) | 57(32.0) | 57(32.0) | 27(32.1) | 39(27.6) | 45(37.2) | 22(29.3) | 9(20.5) | 19(30.6) | 12(21.1) |
| 1–2 | 129(51.0) | 67(52.4) | 112(55.2) | 84(47.2) | 93(52.3) | 42(50.0) | 82(58.2) | 53(43.8) | 36(48.0) | 25(56.8) | 30(48.4) | 31(54.4) |
| ≥ 3 | 45(17.8) | 25(19.5) | 33(16.2) | 36(20.8) | 28(15.7) | 15(17.9) | 20(14.2) | 23(19) | 17(22.7) | 10(22.7) | 13(21) | 14(24.5) |
| **Postoperative chemotherapy** | | | | | | | | | | | | |
| Yes | 150(59.3) | 63(49.2) | 118(58.1) | 95(53.4) | 94(52.8) | 61(72.6) | 71(50.4) | 74(61.2) | 36(48) | 32(72.7) | 28(45.2) | 40(70.2) |
| No | 103(40.7) | 65(50.8) | 85(41.9) | 83(46.6) | 84(47.2) | 23(27.4) | 70(49.6) | 47(38.8) | 39(52) | 12(27.3) | 34(54.8) | 17(29.8) |
| **Chemotherapeutic regimen** | | | | | | | | | | | | |
| Oxaliplatin + Capecitabine | 46(18.2) | 29(22.7) | 31(15.3) | 44(24.7) | 33(18.5) | 18(21.4) | 24(17.0) | 27(22.3) | 13(17.3) | 11(25) | 7(11.3) | 17(29.8) |
| Oxaliplatin + S−1 | 74(29.2) | 64(77.3) | 68(33.5) | 70(39.3) | 51(28.7) | 43(51.2) | 47(33.3) | 47(38.8) | 23(30.7) | 21(47.7) | 21(33.9) | 23(40.4) |
| **LOS, mean (SD), d** | 8.0(2.5) | 8.6(2.6) | 7.8(2.4) | 8.4(2.7) | 7.7(2.3) | 8.1(2.8) | 7.9(2.5) | 8.4(2.7) | 8.0(2.5) | 7.6(2.2) | 7.6(2.2) | 8.5(2.7) |
| **30-d Any complications** | | | | | | | | | | | | |
| Yes | 67(26.5) | 61(47.7) | 44(21.7) | 84(47.2) | 48(27.0) | 42(50.0) | 34(24.1) | 56(46.2) | 19(25.3) | 19(43.2) | 52(83.9) | 28(49.1) |
| No | 186(73.5) | 67(52.3) | 159(78.3) | 94(52.8) | 130(73.0) | 42(50.0) | 107(75.9) | 65(53.7) | 56(74.7) | 25(56.8) | 10(16.1) | 29(50.9) |
| **30-d Severe complications**[f] | | | | | | | | | | | | |
| < 3 | 241(95.3) | 108(84.4) | 193(95.1) | 156(87.6) | 169(94.9) | 72(85.7) | 134(95.0) | 107(88.4) | 72(96.0) | 37(84.1) | 59(95.2) | 49(86.0) |
| ≥ 3 | 12(4.7) | 20(15.6) | 10(4.9) | 22(12.4) | 9(5.1) | 12(14.3) | 7(5.0) | 14(11.6) | 3(4.0) | 7(15.9) | 3(4.8) | 8(14.0) |
| **Unplanned ICU transfers** | | | | | | | | | | | | |
| Yes | 1(0.4) | 11(8.6) | 2(1.0) | 10(5.6) | 1(0.6) | 5(6.0) | 2(1.4) | 4(3.3) | 0(0.0) | 6(13.6) | 0(0.0) | 6(10.5) |
| No | 252(99.6) | 117(91.4) | 201(99.0) | 168(94.4) | 177(99.4) | 79(94.0) | 139(98.6) | 117(96.7) | 75(100.0) | 38(86.4) | 62(100.0) | 51(89.5) |
| **30-d Readmission** | | | | | | | | | | | | |
| Yes | 4(1.6) | 16(12.5) | 2(1.0) | 18(10.1) | 5(2.8) | 11(13.1) | 2(1.4) | 107(88.4) | 75(100.0) | 40(90.9) | 61(98.4) | 54(94.7) |
| No | 249(98.4) | 112(87.5) | 201(99.0) | 160(89.9) | 173(97.2) | 73(86.9) | 139(98.6) | 14(11.6) | 0(0.0) | 4(9.1) | 1(1.6) | 3(5.3) |

Abbreviations: [a] Missing value for each variable: 46; [b] Missing value for each variable: 42; [c] ASA, American society of Aneshesiologists; [d] TNM, referring to the 8th edition AJCC guidelines; [e] CCI, Charlson Comorbidity Index; [f] Clavien Dindo score ≥ 3; ECOG, Eastern CooperativeOncology Group; SMD, Skeletal Musclera Diodensity; SMI, Skeletal Muscle Index

adipose tissue. Areas under receiver operating characteristic (ROC) curves were compared using MedCalc software. Model comparisons utilized DeLong tests, net reclassification index (NRI), and integrated discrimination improvement (IDI). Cox regression analyzed overall mortality hazard ratios (95% CI) for low SMI/SMD. Sensitivity analyses using BMI or VATI as obesity covariates verified consistency. To minimize potential bias between the study groups (low SMI vs. normal SMI; low SMD vs. normal SMD; low SMI + low SMD vs. non-low SMI + low SMD), propensity score matching (PSM) without replacement was implemented using a caliper width of 0.1 of the pooled standard deviation of the propensity score logit. The variables considered in propensity score matching include: Age, gender, ECOG score, BMI, VATI, SATI, ASA grade, Tumor size, Pathological differentiation, Pathological grade, Lesion site, Vascular tumor thrombus, Nerve invasion, TNM stage, Lauren type, CCI score, Postoperative chemotherapy, and Chemotherapeutic regimen. This 1:1 matching based on baseline factors ensured comparability between groups. To assess the magnitude of between-group differences in baseline characteristics, covariates with an absolute standardized difference (ASD) < 0.20 were considered well-matched. Analyses were performed in SPSS (IBM Corp, IBM SPSS Statistics for Windows, Armonk, NY, version 25.0), GraphPad Prism (GraphPad Software, San Diego, California, version 8.01), and R software (version 4.0.5, http://www.R-project.org). Two-sided $P \leq 0.05$ defined significance. The data was analyzed from June 1, 2023 to October 1, 2023. This study adheres to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guidelines.

## Results

### Patients characteristics

This study analyzed 381 patients who underwent robotic gastric cancer surgery, sourced from a prospectively registered database and meeting predefined inclusion/exclusion criteria (Supplementary Figure S2). At diagnosis, mean age was 58.5 ± 10.8 years, 69.3% (262/381) were male, and mean BMI was 24.3 ± 3.4 kg/m2. Prevalence of low SMI was 46.7% (178/381) and low SMD was 33.6% (128/381). By gender, low SMI prevalence was 46.2% (121/262) in males and 47.9% (57/119) in females; for low SMD it was 32.1% (84/262) and 37.0% (44/119), respectively. Concurrent low SMI and SMD occurred in 21.0% (55/262) of males and 18.5% (22/119) of females. Patients with low SMI or SMD presented at later disease stages, predominantly stage III, and had higher Charlson Comorbidity Index scores. Regardless of gender, low SMI patients had lower BMI versus normal SMI, while low SMD patients had higher BMI than normal SMD (Table 1).

### Association of low SMI/low SMD with short-term clinical outcomes

Table 1 shows patients with low SMI or SMD had significantly longer hospital stays (8.6 ± 2.6 vs. 8.0 ± 2.5 days, $P = 0.01$; 8.4 ± 2.7 vs. 7.8 ± 2.4 days, $P < 0.001$, respectively). Overall, 128 patients (33.6%) experienced postoperative complications, including 32 (8.4%) with severe complications (Clavien-Dindo score ≥ 3); these patients were more likely to have low SMI or SMD. Furthermore, 12 patients (3.1%) required unplanned ICU transfer, 20 (5.2%) were readmitted within 30 days, and 4 (1.0%) died within 30 days - a greater proportion of these patients had low SMI or SMD. Patients experiencing postoperative complications (38.0 ± 3.9 vs. 39.1 ± 3.9, $P = 0.014$; 35.5 ± 5.1 vs. 36.7 ± 5.4, $P = 0.046$, respectively), 30-day readmissions(37.3 ± 5.0 vs. 38.9 ± 4.0, $P = 0.043$; 33.8 ± 5.4 vs. 36.4 ± 5.3, $P = 0.032$, respectively), LOS ≥ 7 days (38.1 ± 3.9 vs. 39.4 ± 3.9, $P = 0.001$; 35.6 ± 5.2 vs. 37.1 ± 5.3, $P = 0.005$, respectively), unplanned ICU transfers (35.1 ± 5.0 vs. 38.9 ± 3.8, $P = 0.001$; 31.7 ± 6.2 vs. 36.5 ± 5.2, $P = 0.002$, respectively), and 30-day mortality (33.2 ± 5.3 vs. 38.8 ± 3.9, $P = 0.005$; 30.9 ± 6.1 vs. 36.4 ± 5.3, $P = 0.038$, respectively) consistently exhibited lower SMI and SMD values compared to patients without these adverse outcomes, as depicted in Fig. 1A-B. Similarly, this pattern held in gender-stratified analyses, with men and women who experienced adverse outcomes having significantly lower SMI and SMD than those who did not, although this difference was also not significant for severe complications (Fig. 1C-F).

The collinearity analysis unveiled no significant interactions between SMI/SMD and other variables, either overall or by sex (Supplementary Table 1). Moreover, the interaction between low SMI and SMD was not very strong (Supplementary Figure S3), suggesting that low SMI and SMD had some independent associations with the adjusted outcome. Multivariable logistic regression evaluated associations between muscle characteristics and outcomes, adjusting for potential confounders. Table 2 elucidates the association of lower SMI/SMD with higher postoperative complication rates (OR = 3.36; 95%CI: 2.08–5.43, OR = 2.49; 95%CI: 1.48–4.19, respectively) and increased likelihood of unplanned ICU admission (OR = 1.51; 95%CI: 1.22–8.44, OR = 2.00; 95%CI: 1.23–8.89, respectively) or 30-day mortality (OR = 5.89; 95%CI: 1.80-14.23, OR = 7.34; 95%CI: 2.43–18.67, respectively), with gender-stratified patterns remaining consistent. Regarding specific complications, low SMI was associated with higher gastrointestinal complications (OR = 3.44; 95%CI: 1.26–9.34) and low SMD with increased incisional complications (OR = 5.04; 95%CI: 0.82–30.85) (Supplementary Table 2).

Under the independent effect model, patients with lower SMI and SMD values demonstrated a heightened

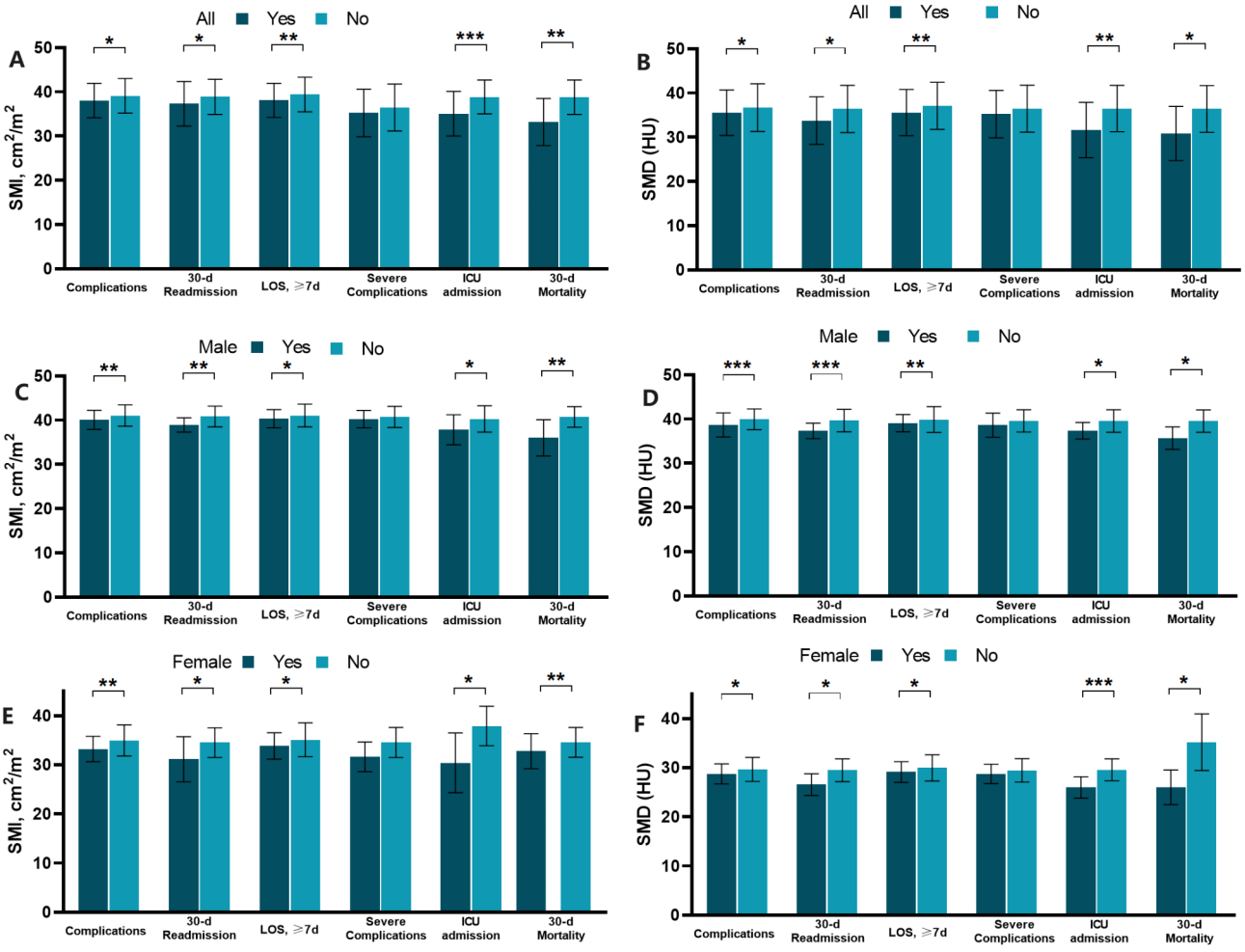


**Fig. 1** Mean SMI and SMD by the presenceor absence of each surgical outcome. **A**, Relationship between SMI and clinical outcomes in all population cohorts; **B**, Relationship between SMD and clinical outcomes in all population cohorts; **C**, Relationship between SMI and clinical outcomes in a male population cohort; **D**, Relationship between SMD and clinical outcomes in a male population cohort; **E**, Relationship between SMI and clinical outcomes in a female population cohort; **F**, Relationship between SMD and clinical outcomes in a female population cohort

risk of adverse surgical outcomes, such as postoperative complications (OR = 7.29; 95%CI: 1.62–42.30), severe complications (OR = 6.67; 95%CI: 2.22–12.68), extended hospital stays (OR = 2.67; 95%CI: 1.71–4.79), unplanned ICU transfers (OR = 2.56; 95%CI: 1.34–9.77), and 30-day readmissions (OR = 8.56; 95%CI: 1.56–33.43). Most notably, these dual-risk patients exhibited a 9.5-fold (OR = 9.55; 95%CI: 2.67–33.89) higher risk of 30-day mortality compared to those without any identified risk factors (Table 2).

Subsequent Receiver Operating Characteristic (ROC) curve analysis revealed that integrating SMI and SMD with clinical variables augmented the discriminative power of clinical outcome stratifications compared to models based on single factors (Fig. 2A-F, I-N, Q-V). Stratified analysis based on sex further corroborated these findings. The robustness of these results was confirmed through internal validation using the bootstrap procedure (200 replicates) (Supplementary Figure S4A-F, I-N, Q-V). Delong test results, alongside IDI and NRI values, attested to the enhanced and stable discriminative ability of the model incorporating SMI and SMD (Supplementary Table 3). Sensitivity analyses independently adjusting for BMI or VATI yielded consistent outcomes across different gender-stratified analyses (Supplementary Table 4).

To further mitigate potential confounding by demographic and clinical characteristics, 1:1 propensity score matching analyses were conducted to evaluate the individual and combined effects of low SMI and low SMD on recent postoperative clinical outcomes. Prior to matching, the groups differed on vascular tumor thrombus, nerve invasion, TNM stage, and postoperative adjuvant chemotherapy administration. Propensity score matching substantially reduced these baseline imbalances, resulting in comparable covariate distributions

**Table 2** Multivariable-adjusted associations between muscle characteristics and clinical outcomes in patients with gastric cancer undergoing robotic surgery

| Independent, mutually adjusted associations | Short-term clinical outcomes, odds ratios(95%CI) | | | | | | Long-term prognosis, hazard ratios (95%CI) | |
|---|---|---|---|---|---|---|---|---|
| | Postoperative complications | Unplanned ICU admission | LOS ≥ 7 d | Severe complications | 30-d Readmission | 30-d Mortality | Overall survival | Disease-free survival |
| **All**[a] | | | | | | | | |
| **Low SMD** | | | | | | | | |
| No (*N* = 253) | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] |
| Yes (*N* = 128) | 2.49(1.48–4.19) | 2.00(1.23–8.89) | 0.95(0.59–1.54) | 4.63(1.84–11.69) | 6.38(1.90–21.49) | 7.43(2.43–18.67) | 2.36(1.08–5.18) | 1.80(1.28–3.33) |
| **Low SMI** | | | | | | | | |
| No (*N* = 203) | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] |
| Yes (*N* = 178) | 3.36(2.08–5.43) | 1.51(1.22–8.44) | 1.63(1.06–2.50) | 2.56(1.08–6.09) | 6.24(1.60–24.36) | 5.89(1.80–14.23) | 2.89(1.34–6.23) | 2.08(1.17–3.70) |
| **Low SMI and low SMD** | | | | | | | | |
| Neither (*N* = 152) | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] |
| Both (*N* = 77) | 7.29(1.62–42.30) | 2.56(1.34–9.77) | 2.67(1.71–4.79) | 6.67(2.22–12.68) | 8.56(1.56–33.43) | 9.55(2.67–33.89) | 3.09(1.77–8.60) | 2.98(1.64–6.34) |
| **Male**[b] | | | | | | | | |
| **Low SMD** | | | | | | | | |
| No (*N* = 178) | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] |
| Yes (*N* = 84) | 3.02(1.64–5.59) | 3.92(1.15–9.37) | 0.89(0.50–1.59) | 2.43(0.84–7.06) | 5.59(1.55–20.13) | 4.67(2.45–13.67) | 2.67(1.07–6.70) | 1.88(0.93–3.79) |
| **Low SMI** | | | | | | | | |
| No (*N* = 141) | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] |
| Yes (*N* = 121) | 2.86(1.64–4.98) | 4.36(1.56–14.44) | 1.58(0.94–2.65) | 2.33(0.81–6.70) | 6.16(1.72–28.09) | 5.22(2.62–17.72) | 3.40(1.36–8.51) | 2.43(1.21–4.89) |
| **Low SMI and low SMD** | | | | | | | | |
| Neither (*N* = 112) | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] |
| Both (*N* = 55) | 4.62(1.82–15.64) | 5.22(1.58–16.80) | 2.67(1.19–5.23) | 2.89(1.40–7.89) | 10.16(2.12–48.67) | 5.88(2.79–19.98) | 4.67(1.82–13.77) | 3.67(1.72–8.80) |
| **Female**[c] | | | | | | | | |
| **Low SMD** | | | | | | | | |
| No (*N* = 75) | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] |
| Yes (*N* = 44) | 2.36(0.88–6.30) | 3.60(1.67–9.58) | 1.42(0.54–3.75) | 4.21(2.35–8.57) | 4.55(2.62–8.52) | 5.63(1.71–13.70) | 4.67(1.85–13.23) | 5.04(1.46–17.38) |
| **Low SMI** | | | | | | | | |
| No (*N* = 62) | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] |
| Yes (*N* = 57) | 3.36(1.28–7.70) | 4.42(1.53–10.40) | 1.22(0.58–2.80) | 5.63(2.57–13.60) | 5.28(2.60–18.89) | 6.38(2.60–18.84) | 7.64(1.54–18.05) | 3.41(1.08–10.76) |
| **Low SMI and low SMD** | | | | | | | | |
| Neither (*N* = 40) | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] | 1 [Reference] |
| Both (*N* = 22) | 4.68(1.52–9.76) | 5.61(1.72–12.64) | 2.87(1.80–7.89) | 6.22(2.73–22.07) | 6.89(2.92–33.64) | 8.98(2.89–23.43) | 8.65(1.72–23.64) | 6.22(1.90–20.69) |

Abbreviations: LOS, length of hospitalstay; SMD, skeletal musclera diodensity; SMI, skeletal muscle index.

a Models adjusted for age at diagnosis, cancer stage, race/ethnicity, smoking history, alcohol intake history, Charlson Comorbidity Inde, total adipose tissue.

b Models adjusted for age at diagnosis, cancer stage, race/ethnicity, smoking history, alcohol intake history, Charlson Comorbidity Inde, total adipose tissue.

c Models adjusted for age at diagnosis, cancer stage, race/ethnicity, smoking history, alcohol intake history, Charlson Comorbidity Inde, total adipose tissue.

(Supplementary Table 5). Patients with low SMI or low SMD, as well as those with concurrent low SMI and low SMD, were more likely to experience poor recent postoperative clinical outcomes. However, an extended length of stay (LOS ≥ 7 days) was predominantly observed among low SMI patients (Supplementary Table 6). Furthermore, multivariate analyses demonstrated increased odds of postoperative complications for patients with low SMI (OR = 3.45; 95% CI: 2.03–5.89) and low SMD (OR = 3.20; 95% CI: 1.80–5.67). The concurrent presence of both low SMI and low SMD conferred a 6-fold higher risk (OR = 6.00; 95% CI: 2.77-13.00) of postoperative complications compared to those with normal SMI/SMD (Supplementary Table 7).

### Association between low SMI/low SMD and long-term prognosis

Following robotic surgery for gastric cancer, 381 patients were monitored for a median follow-up of 23.4 months (interquartile range: 16.0-32.1 months). By the end of follow-up, 42 (11.0%) deaths and 58 (15.2%) disease recurrences were documented. The log-rank test analysis demonstrated that patients with low SMI (HR = 3.77, 95% CI: 2.07–6.90, HR = 2.62, 95% CI: 1.56–4.41, respectively) or low SMD (HR = 3.25, 95% CI: 1.75–6.05, HR = 2.95, 95% CI: 1.71–5.07, respectively) had a significantly higher risk of mortality and recurrence compared to patients with normal SMI or SMD (Fig. 3A-F). Moreover, multivariate Cox regression revealed a 3.09- (HR = 3.09, 95% CI: 1.77–8.60) and 2.98-fold (HR = 2.98, 95% CI: 1.64–6.34) increased risk of mortality and recurrence, respectively, when both low SMI and SMD were present compared to normal SMI/SMD (Table 2, Supplementary Figure S5A-F). Furthermore, incorporating SMI and SMD with clinical variables significantly improved model discrimination for predicting mortality and recurrence risks, evidenced by ROC analysis (Fig. 2G-H). Internal validation through 200 bootstrap resamples demonstrated enhanced predictive performance and stability after integrating SMI and SMD, supported by Delong test, and IDI and NRI values (Supplementary Table 3).

In gender-stratified analysis, male and female patients with low SMI or SMD had higher mortality and recurrence than those with normal SMI or SMD (Fig. 3A-F). Bootstrap validation (200 repetitions) confirmed the robust association between low SMI/SMD and increased risks (Fig. 2O-P and V-X, Supplementary Figure S4O-P, 4V-X). Adjusting for BMI or VAT did not alter the HRs. Comparable results were obtained in gender-stratified analyses (Supplementary Table 4).

Additionally, propensity score-matched analyses revealed reduced overall and disease-free survival for patients with low SMI or low SMD compared to those with normal SMI and SMD. This survival difference was more pronounced in patients with both low SMI and low SMD (Supplementary Figure S6A-F). Furthermore, multivariate analyses demonstrated that patients with concurrent low SMI and low SMD had a 5.1-fold increased risk of postoperative mortality (OR = 5.14; 95% CI: 1.94–13.60) and 2.5-fold increased risk of recurrence (OR = 2.49; 95% CI: 1.22–5.11) compared to those with normal SMI and SMD (Supplementary Table 7).

## Discussion

To our knowledge, this population-based retrospective cohort study is the first to demonstrate that low SMI and density SMD, quantified from routine preoperative CT scans, independently associate with increased postoperative complications, mortality, and reduced survival following robotic surgery for gastric cancer. Furthermore, the concurrent presence of low SMI and SMD heightens the risks of short-term adverse events including 30-day mortality, readmissions, and unplanned ICU transfers, as well as long-term disease recurrence. These associations persisted after adjusting for confounders such as patient demographics characteristics, comorbidities, disease stage, and VATI/BMI. Our study expands on prior evidence linking sarcopenia and myosteatosis to poor surgical outcomes by delineating their distinct and additive contributions, independent of obesity, through comprehensive propensity score-matched analyses. A recent study investigating perioperative changes in skeletal muscle and fat mass reported that greater postoperative loss in body composition was associated with poorer outcomes in patients with gastric cancer [24]. However, that study assessed dynamic changes over time, whereas our research emphasizes the prognostic value of preoperative muscle mass (SMI) and radiodensity (SMD) alone. This distinction highlights the importance of early risk identification before surgery, particularly in a standardized robotic surgical setting.

Our findings demonstrate that low skeletal muscle index (SMI), indicative of sarcopenia, associates with heightened postoperative complications and reduced survival in robotic gastric cancer surgery patients. This aligns with existing evidence linking preoperative sarcopenia to adverse outcomes following gastric cancer resection [25–27]. In contrast, limited studies have examined skeletal muscle density (SMD) in this population, with sparse and conflicting data on the clinical impact of myosteatosis [22, 28]. Unlike prior research focused predominantly on open surgery or assessing SMI and SMD in isolation [22, 29–31], our work provides uniquely granular insights into the prognostic value of these CT-derived body composition parameters in the setting of robotic gastrectomy.

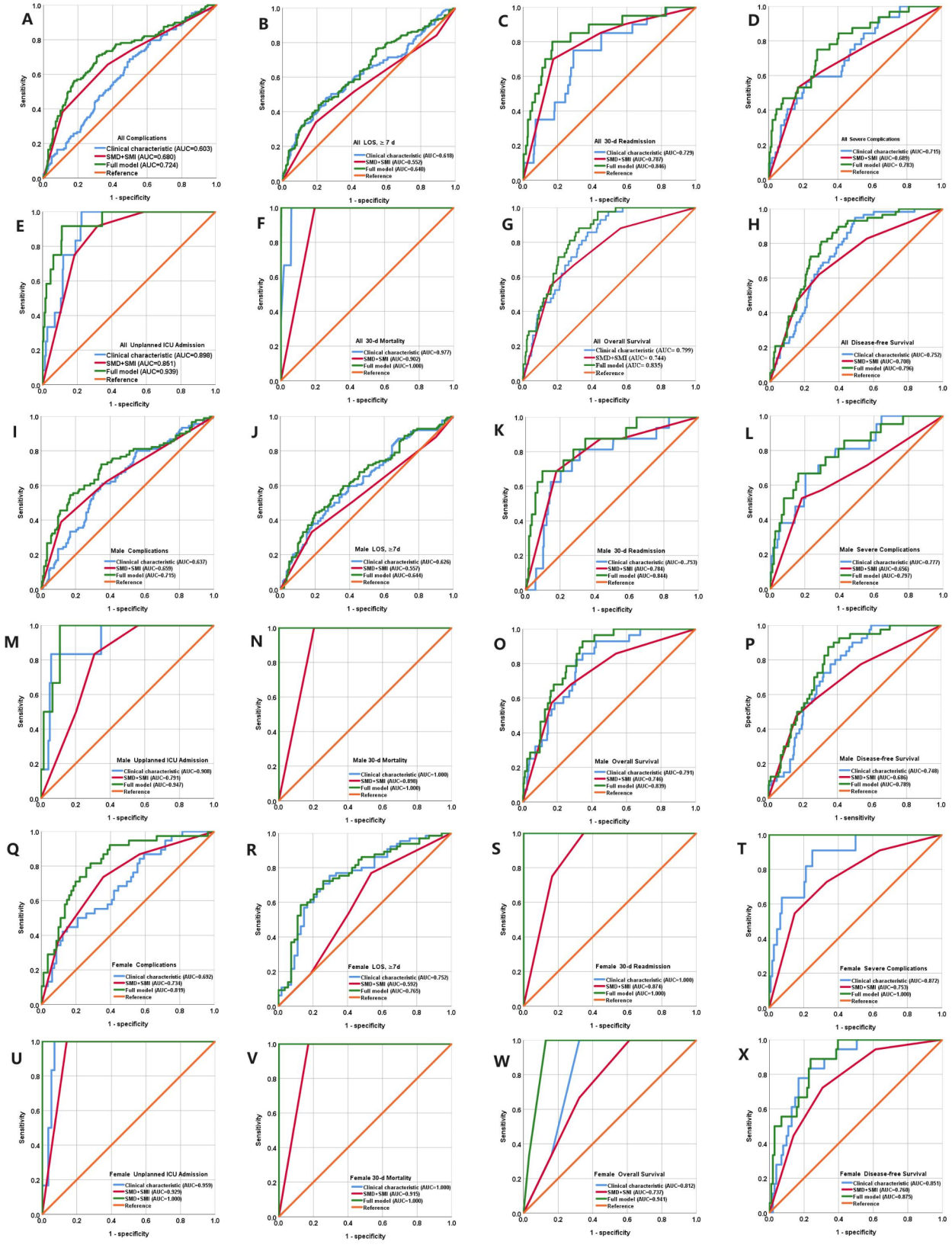


**Fig. 2** (See legend on next page.)

(See figure on previous page.)

**Fig. 2** The area under the receiver operating characteristic curve for different clinical outcomes formed. Area under the receiver operating characteristic curve for any complication (**A**), LOS ≥ 7 days (**B**), readmission within 30 days (**C**), severe complications (**D**), unplanned ICU transfer (**E**), 30-day mortality (**F**), overall survival (**G**), and disease-free survival (**H**) in all population cohorts. Area under the receiver operating characteristic curve for any complication (**I**), LOS ≥ 7 days (**J**), readmission within 30 days (**J**), severe complications (**K**), unplanned ICU transfer (**L**), 30-day mortality (**M**), overall survival (**N**), and disease-free survival (**O**) in a male population cohort. Area under the receiver operating characteristic curve for any complication (**P**), LOS ≥ 7 days (**Q**), readmission within 30 days (**R**), severe complications (**S**), unplanned ICU transfer (**T**), 30-day mortality (**U**), overall survival (**W**), and disease-free survival (**X**) in all population cohorts

By delineating the distinct and synergistic contributions of low SMI and SMD to short- and long-term outcomes, we advance understanding of the muscle prognostic paradigm in the modern era of minimally invasive treatment for gastric cancer. Importantly, all patients included in this study underwent robotic radical gastrectomy, which served as a standardized surgical setting to minimize confounding from procedural variability. Although robotic surgery is known for enhanced precision and reduced trauma, our findings demonstrate that low skeletal muscle mass and radiodensity remain strong predictors of poor outcomes, suggesting that body composition exerts a significant prognostic influence regardless of surgical technique. Therefore, integrating body composition assessment into the perioperative evaluation of gastric cancer patients undergoing robotic surgery remains clinically essential.

The associations between low SMI/SMD and LOS in hospitals have been reported with varying results; certain studies note an extended LOS among patients with low SMI, while others report no significant association [32–33]. In our analysis, neither low SMI nor low SMD independently correlated significantly with an LOS of 7 days or longer; however, a more pronounced correlation emerged under the additive effect when both conditions coexisted. Only one other study has highlighted that the concurrent manifestation of low SMI and low SMD is associated with LOS [34]. The observed extended hospital stay in patients with low SMI correlates with escalated medical costs and potential further muscle loss. Moreover, low SMI was linked with short-term mortality, while the combination of low SMI and low SMD elevated the risk of death, hinting at the likelihood of surgical complications precipitating premature mortality in these patients. These findings align with and extend prior reports on gastric cancer patients with low SMI facing a higher risk of short-term mortality. The ROC curve analysis further substantiated that incorporating both SMI and SMD into the predictive model enhanced the discriminatory power for assessing postoperative mortality risk, as compared to models considering each parameter independently. This underscores the pivotal role of muscle quantity and radiodensity in prognosticating postoperative outcomes.

In their study, Han et al. proposed a combined index, termed SMNI (skeletal muscle index (SMI)-prognostic nutrition index (PNI)), based on nutrition-related PNI and SMI, which showed a significant correlation with the long-term prognosis of advanced gastric cancer (AGC). The results indicated that patients with higher PNI and SMI demonstrated relatively better nutritional status and had a more favorable survival prognosis [35]. Zang et al. found in their study that serum albumin levels are correlated with post-cancer surgery outcomes. Patients with lower preoperative serum albumin levels tend to have poorer survival status and higher mortality rates [36]. One of the nutrition-related indicators, prealbumin, is closely associated with early changes in nutritional status. Researchers have utilized it to predict the prognosis of various malignant tumors, with satisfactory predictive performance [35, 37]. Therefore, the preoperative nutritional optimization for some patients with low SMI / SMD will help to improve the prognosis of such patients.

Few studies have examined the combined association between SMI, SMD, and obesity with adverse short-term postoperative outcomes in gastric cancer patients. Most existing research has not measured or reported BMI or VATI [38]. Our analysis utilized adiposity indices including VATI and BMI. As a metabolic organ, adipose tissue contributes to inflammation by secreting cytokines that may impede healing and promote postoperative infection [39]. Prior studies demonstrate greater abdominal obesity correlates with longer operative times and increased blood loss, elevating complication risk. This heightened risk may lead to complications, readmissions, or prolonged hospital length of stay.

### Limitations

Our findings resonate with existing literature indicating sarcopenia, characterized by low muscle mass, as a robust risk stratification marker in gastric cancer. The delineation of low SMI and low SMD as independent risk factors for adverse outcomes post-robotic surgery dovetails with earlier evidence linking muscle deterioration to reduced survival rates, particularly in advanced-stage gastric cancer. However, as our study is retrospective in nature, we deeply regret not fully considering complications such as respiratory system complications. During the clinical data analysis

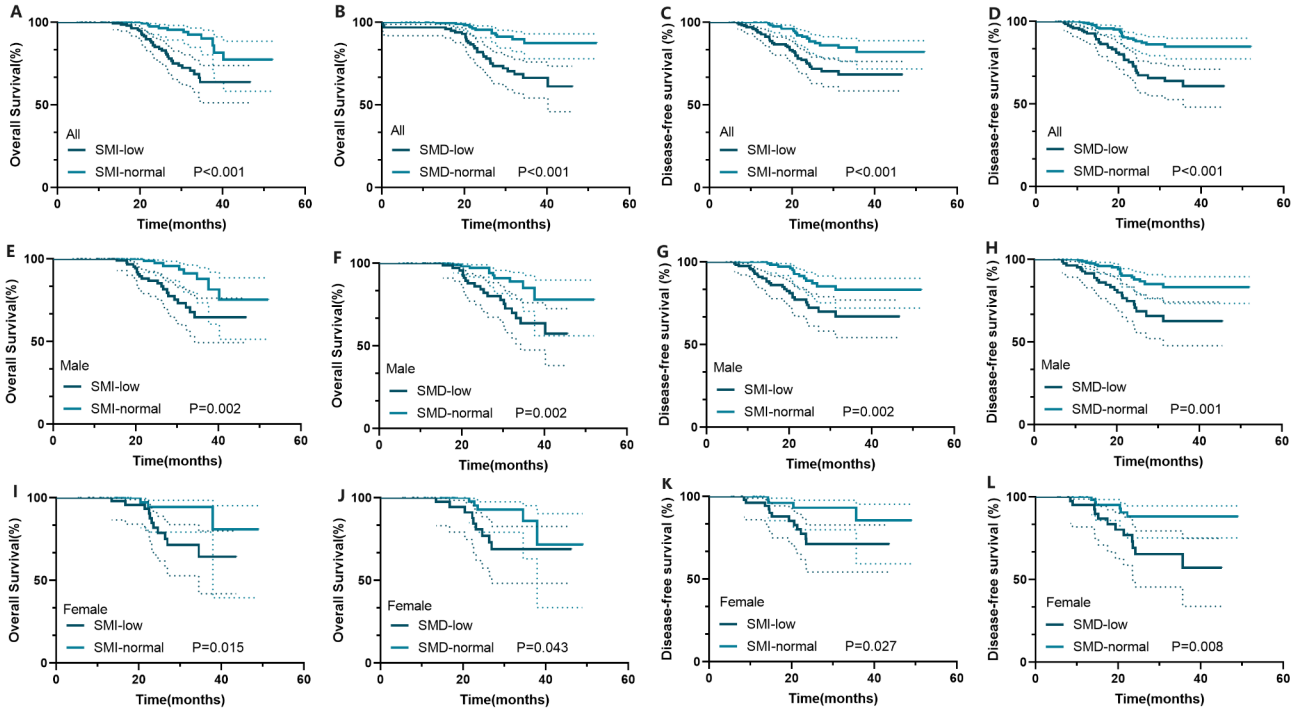


**Fig. 3** Kaplan-Meier curves of overall survival and disease-free survival of gastric cancer patients based on SMI and SMD states. Overall survival curves of low SMI (**A**)/low SMD group (**B**) versus the corresponding normal group in the whole population cohort; disease-free survival curves of low SMI (**C**) /low SMD group (**D**) versus the corresponding normal group in the whole population cohort; overall survival curves of low SMI (**E**)/low SMD group (**F**) versus the corresponding normal group in the male population cohort; disease-free survival curves of low SMI (**G**)/low SMD group (**H**) versus the corresponding normal group in the male population cohort; overall survival curves of low SMI (**I**)/low SMD group (**J**) versus the corresponding normal group in the female population cohort; disease-free survival curves of low SMI (**K**)/low SMD group (**L**) versus the corresponding normal group in the female population cohort

process, more attention was focused on gastrointestinal and incision-related complications, which was also an oversight on our part. Furthermore, we ignored the influence of the type of gastrectomy on our findings when collecting and organizing related data. Therefore, we also hope to comprehensively address these related questions in future studies. We also hope to expand our sample size and include data from multiple research centers in future studies to obtain more conclusive results.

## Conclusions

This study bears meaningful implications for refining risk assessment around the perioperative period. The quantification of SMI and SMD from routine preoperative CT scans offers a convenient, non-invasive means for muscle evaluation. These objective metrics could complement conventional risk factors and staging systems to enhance prognostication accuracy. Patients with sarcopenia may benefit from structured exercise or nutrition programs to improve muscle mass and quality preoperatively. Surgically, a precision approach accounting for sarcopenia may optimize patient selection, technique, and perioperative care to mitigate adverse events. Long term, sarcopenia screening could prompt earlier interventions and more vigilant surveillance in susceptible patients. Overall, this work lays critical groundwork for future research to develop and validate sarcopenia-based clinical tools for prognostication and quality improvement in oncologic surgery.

### Abbreviations

| | |
|---|---|
| AGC | Advanced Gastric Cancer |
| AJCC | American Joint Committee on Cancer |
| ASA | American Society of Anesthesiologists |
| ASD | Absolute Standardized Difference |
| BMI | Body Mass Index |
| CCI | Charlson Comorbidity Index |
| CI | Confidence Interval |
| CSCO | Chinese Society of Clinical Oncology |
| CT | Computed Tomography |
| DFS | Disease-Free Survival |
| HR | Hazard Ratio |
| HU | Hounsfield Unit |
| ICD | 10-International Classification of Diseases, Tenth Revision |
| ICU | Intensive Care Unit |
| IDI | Integrated Discrimination Improvement |
| LOS | Length of Stay |
| NRI | Net Reclassification Index |
| OR | Odds Ratio |
| OS | Overall Survival |
| PACS | Picture Archiving and Communication System |
| PNI | Prognostic Nutrition Index |
| PSM | Propensity Score Matching |

| | |
|---|---|
| ROC | Receiver Operating Characteristic |
| SAT | Subcutaneous Adipose Tissue |
| SATI | Subcutaneous Adipose Tissue Index |
| SMD | Skeletal Muscle radiodensity |
| SMI | Skeletal Muscle Index |
| STROBE | Strengthening the Reporting of Observational Studies in Epidemiology |
| TNM | Tumor, Node, Metastasis |
| VAT | Visceral Adipose Tissue |
| VATI | Visceral Adipose Tissue Index |

## Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12885-025-14156-2.

Supplementary Material 1

Supplementary Material 2

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Not applicable.

**Author contributions**
(I) Conception and design: Q.Z; (II) Administrative support: Q.Z; (III) Provision of study materials or patients: H.H.G, S.C, T.Z, P.A.D, J.X.Y, L.Y, Y.T, P.G.Y, Q.Z; (IV) Collection and assembly of data: S.C, J.X.Y, H.T.W, X.Y.T; (V) Data analysis and interpretation: P.A.D, H.H.G, S.C, J.X.W; (VI) Manuscript writing: H.H.G, S.C, P.A.D, T.Z; (VII) Final approval of manuscript: All authors.

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**Data availability**
The datasets used and/or analyzed during the current study are available from the corresponding authors upon reasonable request.

## Declarations

**Ethical approval and consent to participate**
The study protocol was approved by the Ethics Committee of the Fourth Hospital of Hebei Medical University (approval number: 2023KY139). All procedures were performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. All the authors have followed the applicable ethical standards to maintain the research integrity without any duplication, fraud or plagiarism issues.

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare no competing interests.

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