

Predictive significance of thoracic skeletal muscle nutritional status for radiotherapy survival in elderly patients with esophageal squamous cell carcinoma

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Abstract. The prognosis of patients with esophageal cancer is associated with nutrition. The aim of the present study was to investigate the effect of thoracic status on the prognosis of elderly patients with esophageal squamous cell carcinoma (ESCC) following radiotherapy. A retrospective analysis was performed of 123 elderly patients who underwent radiotherapy for ESCC and were admitted to The Affiliated Hospital of Xuzhou Medical University (Xuzhou, China) between October 2018 and October 2021. General clinical data and hematological data of the patients were collected before radiotherapy, with CT delineation of the 10-segment thoracic skeletal muscle volume by radiotherapy. The 10th thoracic vertebra level skeletal muscle volume index (T10 SMVI)=T10 skeletal muscle volume (cm³)/height² (m²). By dividing the patients according to the optimal cutoff value (using X-tile 3.6.1) into the T10 sarcopenia group and the T10 non-reduced skeletal muscle group (T10 non-sarcopenia group), intergroup comparisons were performed. The area under the curve was calculated from the receiver operating characteristic curve (ROC) to assess the prediction ability of T10 SMVI, the prognosis nutrition index (PNI) and the geriatric nutrition risk index (GNRI) for survival outcomes. Survival curves were drawn using the Kaplan-Meier method, and risk factors affecting progression-free survival (PFS) and overall survival (OS) were analyzed by a Cox proportional hazards model. The results of the comparisons between the groups showed

significant differences between the two groups in terms of age, body mass index, tumor site, Tumor-Node-Metastasis stage, initial treatment, hemoglobin level, GNRI and albumin level. The T10 sarcopenia group exhibited significantly lower PFS and OS rates compared with the T10 non-sarcopenia group at all time points. The 1- and 3-year PFS rates of the T10 sarcopenia group compared with those of the T10 non-sarcopenia group were 50.8 and 73.4%, and 15.3 and 37.5%, respectively. The median PFS times for the two groups were 12.0 and 24.7 months, respectively. The 1- and 3-year OS rates were 81.4 and 95.3%, and 25.4 and 64.1%, respectively. The median OS time was 22.1 months in the T10 sarcopenia groups and not reached in the T10 non-sarcopenia group. ROC curve analysis showed that T10 SMVI, PNI and GNRI all predicted the long-term survival of elderly patients with ESCC following radiotherapy, and that the predictive efficacy of T10 SMVI was higher than that of the hematological nutritional indicators PNI and GNRI, and was an independent influencing factor of OS. In conclusion, T10 SMVI can quantify the nutritional status of thoracic skeletal muscle and is more efficient than PNI and GNRI for predicting the prognosis of elderly patients with ESCC, providing a reference for clinical evaluation of skeletal muscle dystrophy. The present study pioneers the application of T10 SMVI derived from radiotherapy planning CT, offering a cost-effective, standardized method to assess skeletal muscle nutrition in elderly patients with ESCC.

Introduction

Esophageal cancer (EC) is the seventh most common malignancy worldwide and the sixth leading cause of cancer-related mortality. The incidence and mortality rates of EC in Eastern Asia are significantly higher than the global average (1,2). EC is highly invasive and associated with a poor prognosis. The two major histological subtypes of EC are squamous cell carcinoma and adenocarcinoma, with esophageal squamous cell carcinoma (ESCC) accounting for ~90% of cases in China. Due to the lack of obvious early symptoms, most patients are diagnosed at an advanced stage, leading to a 5-year survival rate of <30% (3), and only 25-35% of patients are eligible for curative surgery. For patients with locally

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advanced disease, poor surgical tolerance or unresectable tumors, radical radiotherapy remains the initial treatment option (4).

Patients with EC frequently experience malnutrition due to dysphagia, and muscle loss worsens with aging (5,6). Elderly patients are particularly susceptible to sarcopenia, and studies have demonstrated that muscle nutritional status is closely associated with the prognosis of various malignancies, including EC (7-9). Therefore, selecting appropriate clinical indicators to quantify muscle nutritional status is crucial for the prognostic evaluation of EC. Imaging modalities such as computed tomography (CT) and magnetic resonance imaging are considered the gold standard for non-invasive muscle mass assessment (10,11). The skeletal muscle index (SMI) (a planar index that describes the area of skeletal muscle) (cm^2/m^2) is a widely accepted parameter for quantifying muscle mass and is calculated as $\text{SMI} = \text{skeletal muscle area (cm}^2\text{)}/\text{height}^2 (\text{m}^2)$. SMI at the third lumbar vertebra (L3) level best reflects overall skeletal muscle status (9). However, as EC is a thoracic malignancy, imaging evaluations primarily involve chest CT scans. Therefore, using radiotherapy planning CT scans to assess thoracic skeletal muscle parameters, such as the skeletal muscle volume index (SMVI) (a three-dimensional index that describes the volume of skeletal muscle), may provide a convenient and standardized method to quantify muscle nutritional status.

The present study utilized CT-based quantification of skeletal muscle volume at the 10th thoracic vertebra (T10) level, combined with hematological nutritional indices, to investigate prognostic factors in elderly patients with ESCC. Additionally, the study proposes a clinically feasible method for quantifying muscle nutritional status to provide a reference for nutritional intervention and prognostic assessment.

Patients and methods

Study participants. The present study was a retrospective analysis of data from 123 elderly patients with ESCC treated with radiotherapy in the Department of Radiotherapy of The Affiliated Hospital of Xuzhou Medical University (Xuzhou, China) between October 2018 and October 2021. The inclusion criteria were as follows: i) Elderly patients aged 60-89 years; ii) a diagnosis of ESCC confirmed through histology or cytology records; iii) stage II-IVa disease [American Joint Committee on Cancer (AJCC) 8th edition] (12); and iv) complete medical records before and after treatment. Exclusion criteria: i) Patients receiving resection; ii) patients with a second primary tumor; iii) patients with serious underlying disease affecting the tumor treatment; iv) patients with distant metastasis; and v) patients missing clinical data or lost to follow-up before and after treatment. Patients were followed up by telephone and by follow-up visits until October 2024. The observed endpoints were overall survival (OS) (defined as the time from the diagnosis to the death due to any cause) and progression-free survival (PFS) (defined as the time from diagnosis to tumor progression or death from any cause). This study was approved by the Ethics Committee of the Affiliated Hospital of Xuzhou Medical University (approval no. XYFY2025-KL215-01).

Collection of clinical data. General clinical data were collected from patient records, including sex, age, height, weight, tumor location, lesion length, gross tumor volume (GTV), Tumor-Node-Metastasis (TNM) stage (AJCC 8th edition), initial treatment, application of immunotherapy (immunotherapy before PFS or OS), radiotherapy dose and ECOG score. Hematological data included routine blood test results and albumin levels in a morning examination within 2 weeks of primary radiotherapy. Imaging data included radiotherapy localization CT.

Research nutrition-related indicators. In the thoracic region, the T10 region is located at the junction of the thoracic and abdominal regions, and contains both thoracic and abdominal skeletal muscles, making it a comprehensive indicator of skeletal muscle status (13). Tissue with a CT attenuation value between -29 and 150 Hounsfield Units (HU) is classified as skeletal muscle (10). In the CT soft-tissue window of the Varian radiotherapy system (Siemens Healthineers), T10 was identified between the upper and lower intervertebral discs, with an automated delineation of tissue within the -29 to 150 HU range, followed by manual layer-by-layer modifications to accurately outline all skeletal muscles in this segment. As shown in Fig. 1, the skeletal muscle volume (cm^3) was measured and normalized by height (m^2) to assess skeletal muscle nutritional status, calculated using the T10 SMVI as follows: $\text{T10 SMVI (cm}^3/\text{m}^2\text{)} = \text{T10 skeletal muscle volume (cm}^3\text{)}/\text{height}^2 (\text{m}^2)$. The Prognostic Nutritional Index (PNI) and the Geriatric Nutritional Risk Index (GNRI) were used as representative hematological nutritional markers (14). PNI has been extensively studied as a prognostic factor for multiple solid tumors, including those of the digestive system (14-17), while GNRI reflects the nutritional status of elderly patients and has been validated in multiple disease studies as an effective predictor of prognosis (18,19). PNI was calculated as $\text{PNI} = \text{serum albumin (g/l)} + 5 \times \text{blood lymphocyte count (/l)}$, while GNRI was calculated as $\text{GNRI} = 1.489 \times \text{serum albumin (g/l)} + 41.7 \times (\text{weight}/\text{ideal weight})$, with ideal weight determined using the Lorentz formula [$22 \times \text{height}^2 (\text{m}^2)$]. GNRI risk classification was divided into four categories: Normal (GNRI >98), low risk ($92 \leq \text{GNRI} \leq 98$), moderate risk ($82 \leq \text{GNRI} < 92$) and high risk (GNRI <82). In this study, a GNRI score of 98 was used as the cutoff to classify patients into a GNRI normal group (GNRI >98; n=84) and a GNRI risk group (GNRI ≤98; n=39) (17).

Statistical analysis. Statistical analysis and data visualization were conducted using SPSS 25.0 (IBM Corp.) and RStudio 4.2.0 (RStudio Inc.). The optimal cutoff values for T10 SMVI, PNI and GTV were determined using X-tile 3.6.1 (Yale University School of Medicine). Quantitative variables following a normal distribution are expressed as the mean \pm standard deviation ($\bar{x} \pm s$) and were compared between groups using an independent sample t-test. Categorical variables are reported as frequencies and percentages, and were analyzed using the χ^2 test for between-group comparisons. Kaplan-Meier survival curves were generated for survival analysis, and the log-rank test was used to assess differences in survival outcomes between subgroups. The receiver operating characteristic (ROC) curve was used to calculate the area under the

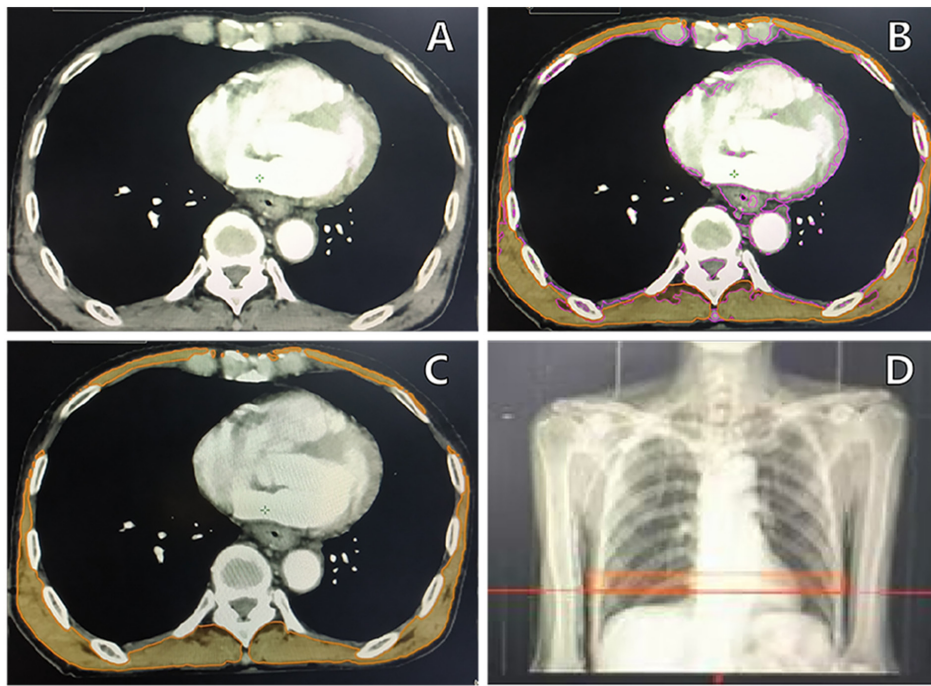


Figure 1. Outlining the T10 level skeletal muscles. (A) Radiotherapy positioning CT at the T10 level of the thorax. (B) The tissues with a CT value of -29-150 Hounsfield units are outlined. (C) Manual revision, layer by layer, to obtain the skeletal muscles. (D) Frontal view of the skeletal muscles at T10. T10, 10th thoracic vertebra; CT, computed tomography.

curve to evaluate the predictive performance of PNI, GNRI and T10 SMVI for survival outcomes in elderly patients with ESCC. Univariate and multivariate analyses were performed using Cox proportional hazards regression models to estimate hazard ratios. $P < 0.05$ was considered to indicate a statistically significant difference.

Results

Comparison of general clinical characteristics in elderly patients with ESCC undergoing radiotherapy. A total of 85 male and 38 female patients were included in this study. The optimal cutoff values for T10 SMVI were determined as $52.1 \text{ cm}^3/\text{m}^2$ for males and $45.5 \text{ cm}^3/\text{m}^2$ for females, and patients were stratified into two groups: The T10 sarcopenia group (below the cutoff value) and the T10 non-sarcopenia group (above the cutoff value). Patients in the T10 sarcopenia group were more likely to be older (≥ 75 years), with a lower BMI, tumors located in the lower thoracic region and advanced TNM stage, and were more likely to have received radiotherapy alone (all $P < 0.05$). Additionally, the T10 sarcopenia group had a significantly lower hemoglobin level, GNRI and serum albumin level compared with the T10 non-sarcopenia group (all $P < 0.05$), as shown in Tables I and II.

Association between T10 SMVI and survival prognosis in elderly patients with ESCC. Kaplan-Meier survival curve analysis (Fig. 2A and B) and the log-rank test demonstrated that OS and PFS times were significantly lower in the T10 sarcopenia group than in the T10 non-sarcopenia group ($P < 0.05$), indicating a worse prognosis in patients with reduced skeletal muscle volume. All patients were followed

up for 36 months, during which 44 patients in the T10 sarcopenia group and 23 patients in the T10 non-sarcopenia group succumbed to the disease. The 1-, 2- and 3-year OS rates were 81.4 vs. 95.3%, 47.5 vs. 76.6% and 25.4 vs. 64.1%, respectively, for the T10 sarcopenia group and T10 non-sarcopenia group. The median OS time in the T10 sarcopenia group was 22.1 months, whereas the median OS time in the T10 non-sarcopenia group was not reached. A significant difference in OS survival curves was observed between the two groups ($P < 0.001$), as shown in Fig. 2, classified by T10 SMVI. The PFS rates in the T10 sarcopenia group compared with those in the T10 non-sarcopenia group were 50.8 vs. 73.4%, 23.7 vs. 51.6% and 15.3 vs. 37.5% at 1, 2, and 3 years, respectively, with a median PFS time of 12.0 vs. 24.7 months. The PFS rate in the T10 sarcopenia group was significantly lower than that in the T10 non-sarcopenia group ($P = 0.0016$), as shown in Fig. 2B.

T10 SMVI and the predictive value of hematological nutritional indicators (PNI and GNRI) for survival prognosis in elderly patients with ESCC. ROC curves were generated for T10 SMVI, PNI and GNRI, as shown in Fig. 3. The results demonstrated that T10 SMVI, PNI and GNRI were all significant predictors of long-term survival in elderly patients with ESCC ($P < 0.05$), with T10 SMVI exhibiting superior predictive value compared with PNI and GNRI, as shown in Table III.

Cox single-and multivariate regression analysis. Univariate Cox proportional hazards regression analysis of the 123 elderly patients with ESCC demonstrated that BMI, TNM stage, GTV, initial treatment, T10 SMVI, PNI, GNRI and immunotherapy were significantly associated with PFS and

Table I. Comparison of general clinical characteristics in elderly patients with esophageal squamous cell carcinoma undergoing radiotherapy [n (%)] classified by the T10 skeletal muscle volume index.

Clinical features	T ₁₀ sarcopenia (n=59)	T ₁₀ non-sarcopenia (n=64)	Total (n=123)	χ^2	P-value
Sex				2.727	0.099
Male	45 (76.3)	40 (62.5)	85 (69.1)		
Female	14 (23.7)	24 (37.5)	38 (30.9)		
Age, years				8.836	0.003
60-74	30 (50.8)	49 (76.6)	79 (64.2)		
75-89	29 (49.2)	15 (23.4)	44 (35.8)		
BMI, kg/m ²				13.063	0.001
<18.5	11 (18.6)	1 (1.6)	12 (9.8)		
18.5-24	39 (66.1)	42 (65.6)	81 (65.9)		
≥24	9 (15.3)	21 (32.8)	30 (24.4)		
Tumor location				7.322	0.026
Upper	13 (22.0)	27 (42.2)	40 (32.5)		
Middle	26 (44.1)	26 (40.6)	52 (42.3)		
Lower	20 (33.9)	11 (17.2)	31 (25.2)		
TNM stage				12.267	0.002
II	2 (3.4)	14 (21.9)	16 (13.0)		
III	37 (62.7)	40 (62.5)	77 (62.6)		
IVa	20 (33.9)	10 (15.6)	30 (24.4)		
Lesion length, cm				0.016	0.898
≤7	39 (66.1)	43 (67.2)	45 (36.6)		
>7	20 (33.9)	21 (32.8)	41 (33.3)		
GTV, cm ³				0.098	0.755
≤22.9	26 (44.1)	30 (46.9)	56 (45.5)		
>22.9	33 (55.9)	34 (53.1)	67 (54.5)		
Initial treatment				8.016	0.018
RT	26 (44.1)	13 (20.3)	39 (31.7)		
CCRT	25 (42.4)	38 (59.4)	63 (51.2)		
RT-AIC	8 (13.6)	13 (20.3)	21 (17.1)		

T10, 10th thoracic vertebra; BMI, body mass index; TNM, Tumor-Node-Metastasis; GTV, gross tumor volume; RT, radiotherapy; CCRT, concurrent chemoradiotherapy; RT-AIC, radiotherapy with adjuvant immuno-chemotherapy.

Table II. Comparison of hematological indicators in elderly patients with esophageal squamous cell carcinoma undergoing radiotherapy (mean ± standard deviation).

Hematological indicator	T ₁₀ sarcopenia (n=59)	T ₁₀ non-sarcopenia (n=64)	T	P-value
HB, g/l	126.47±14.28	131.50±11.61	2.149	0.034
Albumin, g/l	39.63±3.64	40.99±3.46	2.128	0.035
PNI	47.77±4.52	48.91±4.92	1.334	0.185
GNRI	98.99±7.70	105.44±8.11	4.514	<0.001

T10, 10th thoracic vertebra; HB, hemoglobin; PNI, prognosis nutrition index; GNRI, geriatric nutrition risk index.

OS (P<0.05). Further multivariate analysis identified TNM stage, GTV, initial treatment, T10 SMVI and PNI as independent risk factors for OS (P<0.05), while TNM stage, GTV, and initial treatment were independent risk factors for PFS

(P<0.05), as shown in Tables IV and V. Additionally, late-stage radiotherapy alone, advanced TNM stage, high GTV, low T10 SMVI and low PNI were identified as independent risk factors for a shorter survival time.

Table III. Receiver operating characteristic curve analysis of three nutritional indicators for predicting long-term survival (OS and PFS).

Indicator	OS			PFS		
	AUC	95% CI	P-value	AUC	95% CI	P-value
T10 SMVI	0.746	0.659-0.833	<0.001	0.690	0.582-0.798	0.001
PNI	0.629	0.528-0.730	0.014	0.618	0.501-0.736	0.045
GNRI	0.690	0.596-0.784	<0.001	0.624	0.516-0.733	0.035

OS, overall survival; PFS, progression-free survival; AUC, area under the curve; CI, confidence interval; T10, 10th thoracic vertebra; SMVI, skeletal muscle volume index; PNI, prognosis nutrition index; GNRI, geriatric nutrition risk index.

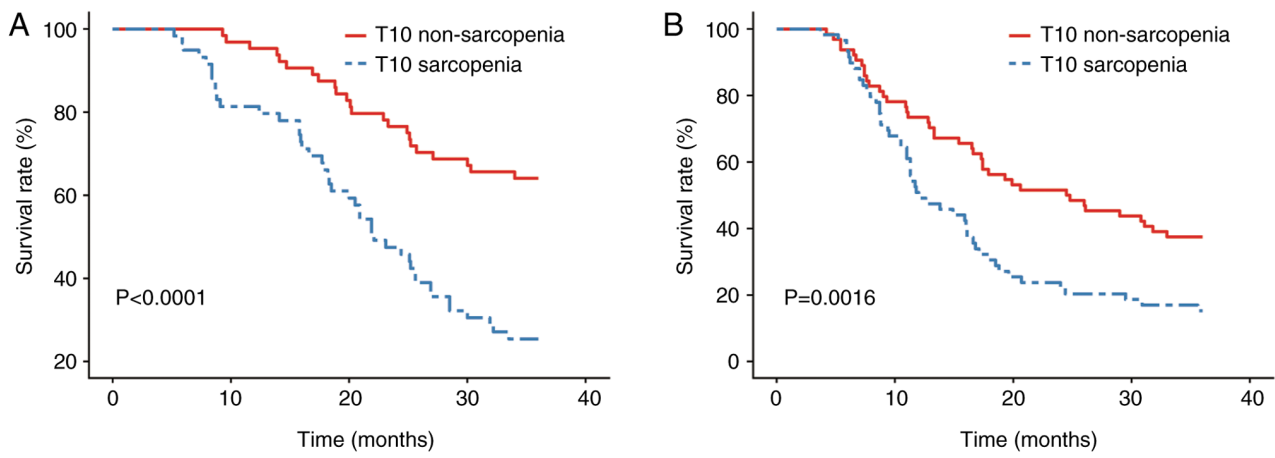


Figure 2. Kaplan-Meier survival plots comparing (A) overall survival and (B) progression-free survival for patients stratified by T10 skeletal muscle volume index. T10, 10th thoracic vertebra.

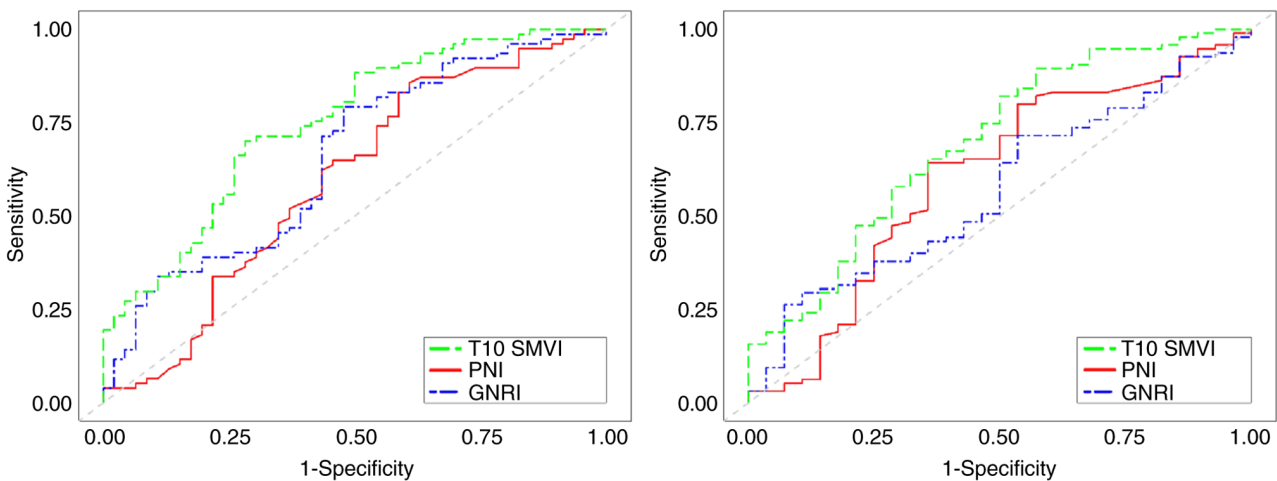


Figure 3. Receiver operating characteristic curves of three nutritional indicators. T10, 10th thoracic vertebra; SMVI, skeletal muscle volume index; PNI, prognosis nutrition index; GNRI, geriatric nutrition risk index.

Discussion

The results of the present study showed that T10 SMVI, as an indicator to quantify the nutritional status of T10 segments, can effectively predict the prognosis of elderly patients with ESCC and has higher predictive efficacy than the hematological

nutritional indicators PNI and GNRI. Specifically, the T10 SMVI threshold value used was 52.1 cm³/m² in men and 45.5 cm³/m² in women. Although there are ethnic, regional and measurement site differences in SMI, there are no uniform criteria or reference values across studies. The samples in the present study are from East China and align with the

Table IV. Univariate and multivariate analyses of overall survival.

Characteristics	Univariate			Multivariate		
	HR	95% CI	P-value	HR	95% CI	P-value
Sex (male vs. female)	0.847	0.512-1.404	0.520			
Age (≥ 75 vs. < 75 years)	1.604	0.991-2.596	0.054			
BMI (≥ 18.5 vs. < 18.5 kg/m ²)	0.307	0.156-0.604	0.001	0.866	0.378-1.980	0.732
Tumor location (upper vs. middle-lower neck)	0.932	0.552-1.574	0.973			
TNM stage (IVa vs. II/III)	3.729	2.246-6.190	< 0.001	2.996	1.692-5.306	< 0.001
Lesion length (> 7 vs. ≤ 7 cm)	0.838	0.500-1.404	0.501			
GTV (> 22.9 vs. ≤ 22.9 cm ³)	1.833	1.116-3.011	0.017	1.943	1.114-3.388	0.019
Initial treatment (non-RT only vs. RT only)	0.388	0.239-0.629	< 0.001	0.527	0.304-0.916	0.023
Immunotherapy (yes vs. no)	0.364	0.190-0.696	0.002	0.595	0.294-1.203	0.148
Radiation dose (≥ 60 vs. < 60 Gy)	1.416	0.875-2.293	0.157			
T10 non-sarcopenia group vs. T10 sarcopenia group	0.332	0.200-0.552	< 0.001	0.467	0.263-0.831	0.010
PNI (> 52.0 vs. ≤ 52.0)	0.357	0.170-0.748	0.006	0.389	0.178-0.848	0.018
GNRI (> 98 vs. ≤ 98)	0.443	0.272-0.720	0.001	0.830	0.458-1.504	0.538

HR, hazard ratio; CI, confidence interval; BMI, body mass index; TNM, Tumor-Node-Metastasis; GTV, gross tumor volume; RT, radiotherapy; T10, 10th thoracic vertebra; PNI, prognosis nutrition index; GNRI, geriatric nutrition risk index.

Table V. Univariate and multivariate analyses of progression-free survival.

Characteristics	Univariate			Multivariate		
	HR	95% CI	P-value	HR	95% CI	P-value
Sex (male vs. female)	0.890	0.572-1.386	0.607			
Age (≥ 75 vs. < 75 years)	1.492	0.981-2.270	0.062			
BMI (≥ 18.5 vs. < 18.5 kg/m ²)	0.478	0.253-0.903	0.023	0.956	0.439-2.081	0.909
Tumor location (upper vs. middle-lower neck)	0.999	0.639-1.564	0.998			
TNM stage (IVa vs. II/III)	2.684	1.685-4.275	< 0.001	2.037	1.240-3.346	0.005
Lesion length (> 7 vs. ≤ 7 cm)	0.739	0.471-1.161	0.190			
GTV (> 22.9 vs. ≤ 22.9 cm ³)	1.624	1.065-2.475	0.024	1.786	1.144-2.790	0.011
Initial treatment (non-RT only vs. RT only)	0.437	0.283-0.673	< 0.001	0.602	0.371-0.979	0.041
Immunotherapy (yes vs. no)	0.410	0.218-0.773	0.006	0.592	0.300-1.168	0.130
Radiation dose (≥ 60 vs. < 60 Gy)	1.156	0.765-1.749	0.491			
T10 non-sarcopenia group vs. T10 sarcopenia group	0.514	0.338-0.783	0.002	0.692	0.433-1.106	0.124
PNI (> 52.0 vs. ≤ 52.0)	0.482	0.277-0.842	0.010	0.559	0.312-1.004	0.051
GNRI (> 98 vs. ≤ 98)	0.559	0.362-0.862	0.008	0.854	0.511-1.427	0.547

HR, hazard ratio; CI, confidence interval; BMI, body mass index; TNM, Tumor-Node-Metastasis; GTV, gross tumor volume; RT, radiotherapy; T10, 10th thoracic vertebra; PNI, prognosis nutrition index; GNRI, geriatric nutrition risk index.

L3 SMI diagnostic reference values [40.8 cm²/m² for men and 34.9 cm²/m² for women, proposed by Zhuang *et al* (20) in Shanghai]. Previous SMI studies have mostly focused on cross-sectional area, but the present study has explored muscle volume in depth (9-11). Compared with plane studies, volume studies are more comprehensive and holistic.

Radiotherapy localized planning CT, as a routine examination method for radiotherapy patients, has the advantages of being simple, non-invasive and economical to operate, so it has high clinical application value. Although the cross-sectional

area of muscles at the lumbar 3 level has a high correlation with the whole body muscle level and has become the common standard for SMI assessment (9), since CT scans in patients with EC do not always contain the third lumbar spine, additional abdominal CT scans not only increase radiation exposure but also increase the economic burden on patients. Unlike prior studies using L3-level muscle index (requiring additional abdominal CT) (9,20), the present study innovatively leveraged routine radiotherapy planning CT to quantify thoracic muscle volume (T10 SMVI), eliminating extra scans

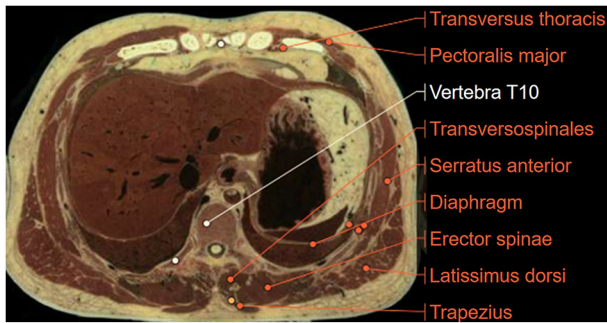


Figure 4. Anatomy map of T10 level skeletal muscle. T10, 10th thoracic vertebra.

and reducing radiation and economic burdens, thus enhancing clinical utility. Therefore, the T10 segment was chosen as the anatomical region for skeletal muscle quality assessment. This segment is located at the thoracoabdominal junction and contains several key skeletal muscle groups such as the erector spinal, latissimus dorsi, trapezius, external abdominis, rectus abdominis and transverse thoracoabdominal muscles (Fig. 4). Among these, the erector spinal muscle is essential for spinal support and serves as an early indicator reflecting whole-body muscle wasting. Therefore, the T10 segment can comprehensively and accurately reflect muscle mass, becoming the ideal region (13,21) for assessing muscle nutritional status in the present study.

EC, as a chronic wasting disease, often leads to sarcopenia in elderly patients, and is more common in male patients >60 years old (22). The causes of skeletal muscular dystrophy in patients with EC include: i) Insufficient nutritional intake due to dysphagia (23). ii) Chronic inflammation promotes protein and energy expenditure through multiple signaling pathways, keeping the body in a negative nitrogen balance (24). iii) Neoadjuvant chemoradiotherapy increases the risk of sarcopenia in patients with EC, which may cause apoptosis during chemoradiotherapy to cause inflammatory response, and activate inflammatory factors to promote muscle breakdown or stress response (25). iv) Patients with EC, after long-term release and chemotherapy, often need long-term bed rest due to physical decline, being easily fatigued, poor spirit and a lack of moderate muscle exercise (26). Therefore, assessing the muscle nutritional status of patients and providing corresponding nutritional intervention and treatment programs are crucial for patient prognosis.

In the present study, the T10 sarcopenia group had a significantly poorer long-term prognosis compared with the T10 non-sarcopenia group. Multivariate analysis showed that T10 SMVI was an independent risk factor for OS in elderly patients with ESCC who underwent radiotherapy. Despite baseline differences, multivariate analysis confirmed the independent prognostic value of T10 SMVI after adjusting for confounders. Further analysis found that T10 sarcopenia group patients were mostly of an advanced prognosis, with low BMI, late TNM stage and undergoing combined radiotherapy rather than antitumor therapy. These characteristics further support the association between skeletal sarcopenia and a poor prognosis, which is consistent with

the association between sarcopenia and tumor prognosis in previous studies (9,20). Patients with sarcopenia often show malnutrition, decreased muscle strength and reduced quality of life, the factors that may influence prognosis by influencing patient tolerance to treatment and tumor biological behavior. The results of the present study suggest that muscle nutritional status not only directly affects the prognosis, but also may indirectly influence the survival benefit of patients by influencing treatment choice and tolerance. Combined treatment of EC can significantly improve OS compared with radiotherapy alone (27). In recent years, the application of immunotherapy in EC has gradually increased, and it has been shown to bring marked survival benefits. The results of the present study also show that either receiving immunotherapy in the initial treatment stage or adding immunotherapy after progression and relapse can improve the long-term prognosis. Although immunotherapy was statistically significant in the univariate analyses of PFS and OS, it did not become an independent influence in the multivariate analysis, which may be related to differences in the sample size and treatment regimen of the patients.

The SMI is related to the toxicity of cancer chemotherapy, and patients with EC and a low SMI are more likely to have acute adverse reactions above grade 3 after chemotherapy (28). Therefore, patients in the T10 sarcopenia group are mostly treated with radiotherapy alone, compared with the non-sarcopenia group with chemoradiotherapy. For patients with EC, the SMI is measured before and during treatment, and the muscle nutritional status is assessed, which can help guide the treatment plan and dosage, and avoid acute adverse reactions. Good nutritional status and muscle reserve help patients better tolerate concurrent chemotherapy and immunotherapy, thus prolonging survival. Clinically, for patients with skeletal muscle dystrophy, personalized nutritional support and skeletal muscle exercise can be provided to enhance treatment tolerance and improve survival benefits (29,30).

In conclusion, the present study quantified the muscle nutrition status of the T10 segment and introduced the T10 SMVI to predict the prognosis of elderly patients with ESCC. The predictive efficacy of the T10 SMVI was higher than that of the hematological nutrition indexes PNI and GNRI. In addition, T10 SMVI has the advantages of being economically viable, rapid to check and standardized, and can provide a new perspective for the prognostic evaluation of elderly patients with ESCC undergoing radiotherapy, with potential clinical application value. Specific values are obtained from this study, which can provide a reference for the clinical prognosis, diagnosis and treatment plan, and nutritional intervention. However, the present study is a single-center study with a limited sample size, and the reference values need to be optimized through a multi-center, large-sample survey. Future multi-center studies should validate T10 SMVI cutoff generalizability and explore integrated models with hematological indices, such as PNI. Investigations on nutrition and exercise interventions to reverse sarcopenia and improve survival outcomes are warranted.

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Availability of data and materials

The data generated in the present study may be requested from the corresponding author.

Authors' contributions

GL was the guarantor of integrity of the entire study. SL and GL were responsible for the study concept and confirm the authenticity of all the raw data. SL and DP performed literature research. SL, QL and DL designed the study and analyzed the data. Data acquisition was performed by SL, QL and DL. Statistical analysis and manuscript preparation were performed by SL, DL, CJ and DP. The manuscript was edited by SL, QL, DL and CJ, and reviewed by SL, QL and DL. All authors have read and approved the manuscript.

Ethics approval and consent to participate

The study was approved by the Clinical Research Ethics Committee of The Affiliated Hospital of Xuzhou Medical University (Xuzhou, China; approval no. XYFY2025-KL215-01). All patients provided written informed consent.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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