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Prognostic Role of CT-Derived Muscle and Adipose Tissue Parameters After Pancreaticoduodenectomy for Pancreatic Ductal Adenocarcinoma: An Exploratory Analysis

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ABSTRACT

Introduction: Body composition abnormalities, including sarcopenia and adipose tissue alterations, have emerged as potential prognostic biomarkers in pancreatic ductal adenocarcinoma (PDAC). The present study investigated the relationship between preoperative computed tomography (CT)-derived adipose and muscle parameters and survival outcomes in patients undergoing pancreaticoduodenectomy for PDAC.

Methods: This retrospective analysis enrolled 69 patients with histologically confirmed PDAC who underwent pancreaticoduodenectomy between 2018 and 2024. Preoperative contrast-enhanced CT images acquired within 30 days before surgery were assessed at the level of the third lumbar vertebra (L3). Measurements included the area and attenuation of visceral and subcutaneous adipose tissue, as well as the area and attenuation of the psoas muscle. Overall survival (OS) and disease-free survival (DFS) were evaluated using Kaplan-Meier survival curves and Cox proportional hazards models.

Results: Median OS and DFS were 10.0 and 7.0 months, respectively. Kaplan-Meier analyses showed no statistically significant differences in survival across body composition parameters (all $p>0.05$), although several parameters exhibited consistent numerical trends in survival. In multivariable analysis, higher T stage was independently associated with worse OS [hazard ratio (HR): 1.83, 95% confidence interval (CI): 1.12-3.00, $p=0.015$], whereas adjuvant chemotherapy remained independently associated with improved OS (HR: 0.16, 95% CI: 0.07-0.34, $p<0.001$). Because of the limited number of DFS events, multivariable analysis was not performed.

Conclusion: CT-derived body composition analysis may provide complementary prognostic information in patients undergoing pancreaticoduodenectomy for PDAC. Although independent associations were not consistently demonstrated, the observed survival patterns support further investigation of CT-derived muscle and adipose tissue parameters as potential imaging biomarkers. Larger prospective multicenter studies are warranted to clarify their prognostic value.

Keywords: Pancreatic ductal adenocarcinoma, pancreaticoduodenectomy, body composition, sarcopenia, myosteatosis, computed tomography, psoas muscle attenuation, visceral adipose tissue, survival analysis, prognostic biomarkers

Introduction

Pancreatic ductal adenocarcinoma (PDAC) is among the most aggressive and difficult-to-treat malignancies owing to its biological characteristics. According to GLOBOCAN 2020, pancreatic cancer accounted for near 500,000 new cases and over 450,000 deaths worldwide, reflecting its disproportionately high mortality burden (1). Surgical resection remains the primary curative treatment; for tumors located in the pancreatic head, pancreaticoduodenectomy (Whipple procedure) is the only surgical option. Yet, even in patients who undergo resection, outcomes remain disappointing, with a substantial proportion experiencing early recurrence and limited long-term survival (2,3).

In this context, improving preoperative risk stratification has become increasingly important. Conventional prognostic factors such as tumor stage, lymph node involvement, and margin status are typically determined postoperatively, limiting their utility in preoperative decision-making. Therefore, there is growing interest in identifying non-invasive, imaging-based biomarkers that can provide prognostic information before surgery. Computed tomography (CT), routinely performed in the preoperative setting, offers an opportunity to extract such information beyond standard anatomical assessment.

Among CT-derived parameters, body composition analysis at the third lumbar vertebra (L3) level provides a reliable representation of whole-

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body tissue distribution. A single cross-sectional CT image at this level can be used to quantify both adipose and lean tissue compartments with high accuracy (4). This has enabled the use of routine imaging data for quantitative assessment of patient-specific physiological characteristics.

Adipose tissue is increasingly recognized as an active metabolic organ rather than a passive energy reservoir. Both the quantity and quality of adipose tissue—reflected by cross-sectional area and attenuation values measured in Hounsfield units (HUs)—have been associated with systemic inflammation, cachexia, and tumor progression (5). Similarly, skeletal muscle parameters such as psoas muscle area and attenuation may reflect sarcopenia and myosteatosis, both of which have been linked to impaired physiological reserve and adverse oncological outcomes (6). Importantly, these measurements can be easily derived from standard preoperative CT scans without incurring extra costs or imposing an additional burden on patients.

Evidence from gastrointestinal malignancies suggests that both adipose tissue and skeletal muscle characteristics may carry prognostic significance (7,8). Increased visceral adiposity has been associated with adverse oncologic outcomes in colorectal cancer (9), while higher visceral fat attenuation has been linked to worse survival in gastric cancer (10). Likewise, reduced muscle attenuation and myosteatosis have been associated with inferior postoperative and long-term outcomes in several gastrointestinal cancers. Nevertheless, the prognostic significance of these CT-derived body composition parameters in PDAC remains incompletely defined. In particular, the relative contributions of adipose tissue quantity and quality and of muscle-related parameters to survival outcomes remain uncertain in surgically treated PDAC patients.

Therefore, this study was designed to investigate the association between preoperative CT-derived measures at the L3 vertebral level (subcutaneous and visceral adipose tissue area, adipose tissue attenuation values, and psoas muscle area and attenuation) and overall survival (OS) in patients undergoing pancreaticoduodenectomy for PDAC. Secondary objectives included evaluating the relationship between these parameters and disease-free survival (DFS) and 30-day postoperative mortality.

Methods

Study Design and Patient Selection

This retrospective cohort study included patients who underwent pancreaticoduodenectomy (Whipple procedure) at University of Health Sciences Türkiye, Ümraniye Training and Research Hospital between January 2018 and December 2024. Eligible patients were identified using the institutional surgical registry. The study was performed and reported in compliance with the Strengthening the Reporting of Observational Studies in Epidemiology recommendations.

Patients were included if they had histopathologically confirmed PDAC, were aged 18 years or older, had a preoperative abdominal CT scan obtained within 30 days before surgery, and had available OS data.

Patients were excluded if the final histopathology was not consistent with PDAC; if preoperative CT imaging was unavailable or technically inadequate for adipose tissue analysis; if OS data were unknown; if they were younger than 18 years; or if pancreaticoduodenectomy had been performed emergently for hemorrhage. PDAC patients located in the tail of the pancreas were excluded due to differences in the surgical approach and surgical burden.

Data Collection

Demographic, clinical, operative, and pathological data were retrieved retrospectively from electronic medical records. Variables of interest, where available, included age, sex, tumor-related pathological findings, nodal status, resection margin status, and adjuvant treatment status.

Follow-up data were obtained from hospital records and other accessible institutional follow-up sources. OS status, recurrence status, and 30-day postoperative mortality were recorded. Because of the retrospective nature of the study, DFS data were not expected to be available for all patients.

CT Acquisition and Image Analysis

Preoperative contrast-enhanced abdominal CT examinations obtained within 30 days of surgery were retrospectively reviewed. Body composition analysis was performed at the level of the L3 vertebra, which served as the predefined anatomical landmark. Portal venous phase CT images were used for all body composition measurements.

On a single representative axial CT image at the L3 level, subcutaneous adipose tissue, visceral adipose tissue, and bilateral psoas muscles were evaluated. Subcutaneous and visceral adipose tissue areas were segmented using a threshold-based semi-automatic method with a predefined adipose tissue attenuation range of -190 to -30 HUs, followed by manual correction when necessary. During segmentation, bowel contents, vessels, and bone structures were carefully excluded.

For each patient, subcutaneous and visceral adipose tissue areas and their mean attenuations were recorded. All area measurements were expressed in mm^2, whereas attenuation values were expressed in HU. Representative examples of visceral adipose tissue, subcutaneous adipose tissue, and psoas muscle measurements are shown in Figure 1.

Bilateral psoas muscles were segmented on the same axial slice using a semi-automatic method followed by manual correction. The right and left psoas muscle areas were summed to obtain the total psoas muscle area. Psoas muscle attenuation was measured as the mean attenuation of the segmented bilateral psoas muscles.

All CT measurements were performed by two radiologists in consensus: an abdominal radiologist with 12 years of experience and a radiology resident with 4 years of experience. Both readers were blinded to clinical, laboratory, and survival outcome data. For each patient, a single final consensus measurement was recorded for each CT-derived body composition parameter. Total psoas muscle area was used as a pragmatic surrogate marker of skeletal muscle mass because height-normalized skeletal muscle index (SMI) measurements were not consistently available owing to the retrospective study design.

Outcomes

The primary outcome was OS, measured from the date of surgery until death from any cause or the last available follow-up.

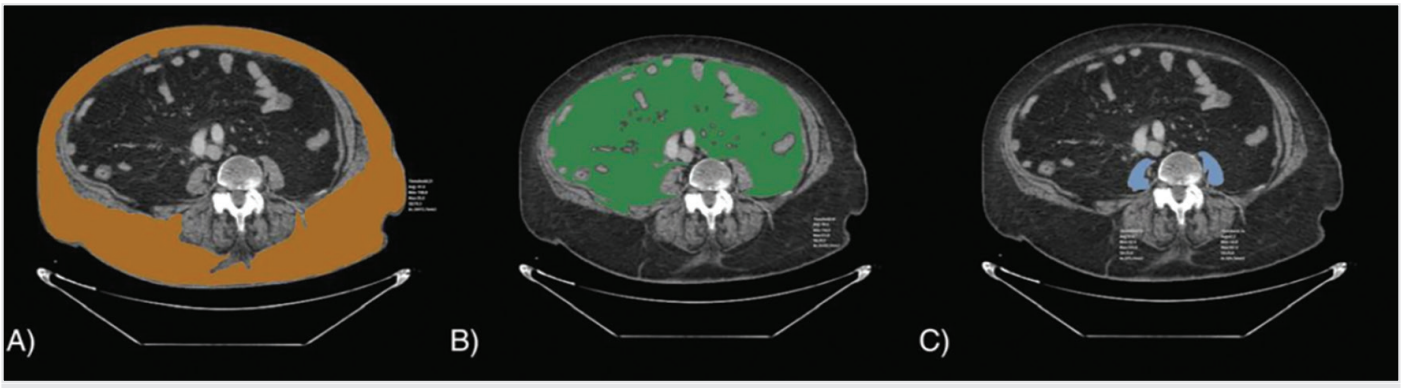

Figure 1. Computed tomography (CT)-based body composition analysis at the L3 vertebral level. Representative axial CT images showing semi-automatic segmentation of A) subcutaneous adipose tissue, B) visceral adipose tissue, and C) bilateral psoas muscles. Subcutaneous and visceral adipose tissue compartments were segmented using a predefined attenuation threshold range of -190 to -30 HU, followed by manual correction. All panels depict different tissue segmentations derived from the same axial CT slice of a single patient

Secondary outcomes included DFS, defined as the interval from surgery to recurrence, death, or last follow-up among patients with documented recurrence status; and early postoperative mortality, defined as mortality occurring within 30 days of surgery.

Ethical Approval

The study adhered to the principles of the Declaration of Helsinki and received approval from the University of Health Sciences Türkiye, Ümraniye Training and Research Hospital (decision number: 146, date: 22.04.2026). Because of the retrospective design and the exclusive use of anonymized patient data, the Institutional Ethics Committee waived the requirement for written informed consent.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics (version 26.0; IBM Corp., Armonk, NY, USA); data visualization and forest-plot generation were performed using RStudio (version 2025.05.1). Continuous variables were summarized as mean ± standard deviation or median with interquartile range (IQR) according to data distribution, whereas categorical variables were expressed as frequencies and percentages.

Radiological body composition parameters were primarily analyzed as continuous variables in Cox proportional hazards regression models to minimize information loss associated with dichotomization. For illustrative Kaplan–Meier analyses, body composition parameters were dichotomized according to median values. Survival curves were estimated using the Kaplan-Meier method and compared using the log-rank test. Additional Kaplan-Meier analysis was performed, stratified by adjuvant chemotherapy status, to provide an unadjusted comparison of OS.

Associations between clinicopathological variables, radiological body composition parameters, and survival outcomes were further evaluated using Cox proportional hazards regression analysis. Imaging parameters were analyzed as continuous variables in Cox models. Univariable Cox regression analyses were initially performed for both OS and DFS. Variables demonstrating statistical or borderline significance in univariable analyses were considered for multivariable Cox regression. T stage was also retained in the final model because of its established prognostic importance in PDAC and its borderline association with OS in the univariable analysis. To minimize the risk of model overfitting, the final multivariable model was restricted to a limited number of covariates. Because of the limited number of DFS events and concerns regarding model stability, multivariable Cox regression analysis was not performed.

The proportional hazards assumption was assessed using both graphical log-minus-log survival plots and formal testing based on Schoenfeld residuals.

Thirty-day postoperative mortality and complications were analyzed descriptively. Because of the limited number of early mortality events, regression analysis was not performed for the 30-day mortality endpoint.

A two-sided p value of less than 0.05 was considered statistically significant.

Results

A total of 231 patients who underwent pancreaticoduodenectomy (Whipple procedure) were screened for eligibility. Among them, 73 patients had histopathologically confirmed PDAC. Three patients were excluded because preoperative CT images were unavailable, and one patient was excluded due to loss to follow-up. Consequently, 69 patients were included in the OS analysis. Eight additional patients were excluded from DFS analysis because postoperative imaging required for recurrence assessment was unavailable, resulting in 61 patients being included in the DFS cohort (Figure 2).

The mean age of the patients was 64.0±7.8 years. Most patients had advanced pathological disease, with T2 and T3 tumors accounting for 49.3% and 36.2% of cases, respectively, while N2 nodal involvement was observed in 46.4% of patients. The mean positive lymph node count was 5.8±4.4, and the majority of tumors were grade 2 (81.2%). Margin positivity was identified in 31.9% of patients, whereas lymphovascular invasion and perineural invasion were present in 72.5% and 98.6% of cases, respectively. Adjuvant therapy was administered to 78.3% of patients, whereas only two patients (2.9%) received neoadjuvant treatment. Additional demographic, clinicopathological, biochemical, and radiological body composition characteristics are summarized in Table 1.

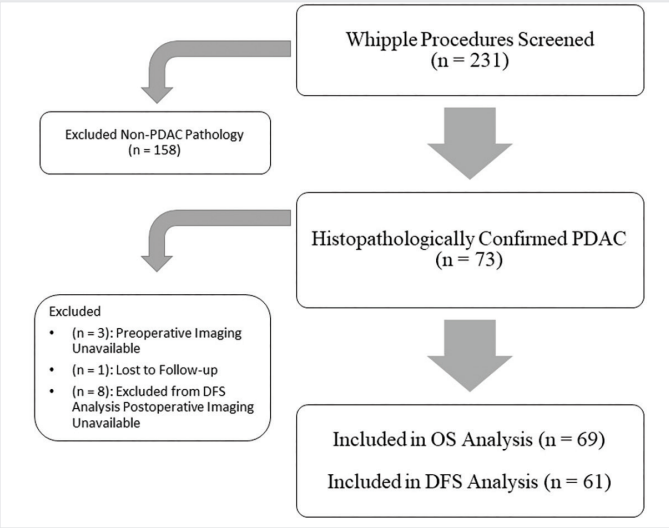

Figure 2. Flow diagram of patient selection and study cohort formation. The eight patients excluded from DFS analysis had available vital status data and were retained in the OS analysis; they were excluded solely due to unavailability of postoperative imaging required for recurrence assessment. OS: Overall survival, DFS: Disease-free survival

Postoperative pancreatic fistula developed in 21 (30.4%) patients, based on the criteria established by the International Study Group on Pancreatic Surgery, irrespective of fistula grade. Grade B/C fistulas occurred in 12 (17.3%) patients. Thirty-day mortality occurred in 5 patients (7.2%). Two deaths were attributed to sepsis secondary to pancreaticojejunostomy (PJ) leakage, while two additional patients died during intensive care follow-up after hemorrhagic complications associated with PJ leakage. One patient died from myocardial infarction on postoperative day 9, unrelated to any surgical morbidity.

Median OS was 10.0 months (IQR: 11.0), while median DFS was 7.0 months (IQR: 5.0). The median follow-up duration was 12.0 months (IQR: 10.0 months). Overall, mortality was observed in 53 patients (76.8%), and recurrence occurred in 35 patients (57.3%). The OS analysis was based on all-cause mortality.

For illustrative Kaplan-Meier analyses, body composition parameters were dichotomized according to median values. Kaplan-Meier analysis demonstrated no significant differences in OS by visceral fat area, visceral fat attenuation, subcutaneous fat area, subcutaneous fat attenuation, psoas muscle area, or psoas muscle attenuation (all $p>0.05$). Nevertheless, patients with higher visceral fat area demonstrated a non-significant trend toward longer OS than those with lower visceral fat area (median: 8.0 vs. 14.0, $p=0.161$). Similarly, a higher psoas muscle area was associated with longer OS (median: 9.0 vs. 13.0 months, $p=0.135$). Detailed OS analyses are summarized in Table 2 and Figure 3.

Likewise, DFS analyses showed no statistically significant differences in survival by visceral fat area, visceral fat attenuation, subcutaneous fat area, subcutaneous fat attenuation, psoas muscle area, or psoas muscle attenuation (all $p>0.05$). However, patients with lower psoas muscle attenuation had a numerically longer DFS (median: 9.0 vs. 7.0) than those with higher attenuation values; this difference was not statistically significant ($p=0.418$). Detailed DFS analyses are presented in Table 2 and Figure 4.

Kaplan-Meier analysis stratified by adjuvant chemotherapy status demonstrated significantly longer OS for patients who received adjuvant chemotherapy than for those who did not (log-rank $p<0.001$; Supplementary Figure 1).

Univariable Cox regression analysis for OS demonstrated borderline associations with T stage [hazard ratio (HR): 1.344, 95% confidence interval (CI): 0.855-2.113, $p=0.200$] and psoas muscle area (HR: 0.946, 95% CI: 0.894-1.000, $p=0.052$), whereas adjuvant therapy emerged as a significant protective factor (HR: 0.198, 95% CI: 0.099-0.396, $p<0.001$). In multivariable analysis, higher T stage was associated with worse OS (HR: 1.83, 95% CI: 1.12-3.00, $p=0.015$), whereas adjuvant chemotherapy was associated with improved OS (HR: 0.16, 95% CI: 0.07-0.34, $p<0.001$). Although higher psoas muscle area showed a protective effect (HR: 0.96 per 100 mm^2 increase), this association was not statistically significant (95% CI: 0.90-1.02, $p=0.200$).

Graphical assessment using log-minus-log survival plots did not demonstrate major violations of the proportional hazards assumption. Formal Schoenfeld residual testing was performed for the revised OS multivariable model. A statistically significant violation was identified for adjuvant chemotherapy ($p=0.003$), suggesting that the effect of adjuvant treatment on OS may not be constant over the entire follow-up period. Therefore, the HR for adjuvant chemotherapy should be regarded as an average effect throughout the follow-up period rather than a fixed treatment effect.

For DFS, univariate Cox regression analysis demonstrated a significant association for neoadjuvant therapy (HR: 11.326, 95% CI: 1.178-108.903, $p=0.036$), although this finding should be interpreted cautiously because only two patients received neoadjuvant therapy. Positive lymph node count ($p=0.134$), psoas muscle attenuation ($p=0.137$), and CA19-9 level ($p=0.092$) demonstrated borderline significance. Because of the limited number of DFS events and concerns regarding model stability, multivariable Cox regression analysis was not performed for DFS. Detailed Cox regression analyses are summarized in Table 3, and the OS multivariable model is visualized in Figure 5.

Table 1. Baseline demographic, clinical, and pathological characteristics of the patients

Age, years	64.0±7.8
Sex (male/female)	37/32 (53.6/46.4%)
T stage (T1/T2/T3/T4)	8/34/25/2 (11.6/49.3/36.2/2.9%)
N stage (N0/N1/N2)	13/24/32 (18.8/34.8/46.4%)
Positive lymph node count	5.8±4.4
Tumor grade (I/II/III)	6/56/7 (8.7/81.2/10.1%)

Table 1. Continued	
Positive resection margin	22 (31.9%)
Lymphovascular invasion	50 (72.5%)
Perineural invasion	68 (98.6%)
ASA score (I/II/III)	4/52/13 (5.8/75.4/18.8%)
Neoadjuvant therapy	2 (2.9%)
Adjuvant therapy	54 (78.3%)
Clavien-Dindo complication grade (0/I/II/III/IV/V)	30/15/14/5/0/5
Biochemical parameters	
CRP (mg/L)	6.7 (IQR: 17.3)
Albumin (g/L)	35.5±4.9
NLR	2.6 (IQR: 4.0)
CA 19.9 (U/mL)	60.7 (IQR: 269.5)
CT-derived body composition parameters	
Visceral adipose tissue area (mm^2)	16196.5±8507.2
Visceral adipose tissue attenuation (HU)	-75.9±15.4
Subcutaneous adipose tissue area (mm^2)	19305.8±10027.7
Subcutaneous adipose tissue attenuation (HU)	-92.0 (IQR: 14.5)
Psoas muscle area (mm^2)	1274.5 (IQR: 815.8)
Psoas muscle attenuation (HU)	45.0 (IQR: 13.0)
Survival outcomes	
Overall mortality	53 (76.8%)
Recurrence	35 (57.3%)
Overall survival, median months	10.0 months (IQR: 11.0)
Disease-free survival, median months	7.0 months (IQR: 5.0)
Median follow-up	12.0 months (IQR: 10.0)

Data are presented as mean ± standard deviation, median [interquartile range (IQR)], or n (%), as appropriate. Normally distributed continuous variables are presented as mean ± standard deviation, whereas non-normally distributed variables are presented as median (IQR). ASA: American Society of Anesthesiologists, CRP: C-reactive protein, NLR: neutrophil-to-lymphocyte ratio, CA: Carbohydrate antigen, CT: Computed tomography, HU: Hounsfield unit

Table 2. Kaplan-Meier overall survival and disease-free survival analyses according to CT-derived body composition parameters

Overall survival			
Parameter	**Cut-off**	**Median OS, months (95% CI) low vs. high**	**Log-rank p**
Visceral adipose tissue area (mm^2)	17825	8.0 (4.3-11.6) vs. 14.0 (9.4-18.5)	0.161
Visceral adipose tissue attenuation (HU)	-89	11.0 (7.8-14.1) vs. 10.0 (5.1-14.8)	0.379
Subcutaneous adipose tissue area (mm^2)	13529	10.0 (5.6-14.3) vs. 11.0 (6.1-15.6)	0.505
Subcutaneous adipose tissue attenuation (HU)	-101.5	11.0 (8.2-13.7) vs. 10.0 (5.5-14.4)	0.423
Psoas muscle area (mm^2)	1056.5	9.0 (6.9-11.1) vs. 13.0 (9.4-16.6)	0.135
Psoas muscle attenuation (HU)	42.5	10.0 (5.9-14.0) vs. 10.0 (7.3-12.7)	0.764
Disease-free survival			
Visceral adipose tissue area (mm^2)	18204.5	8.0 (4.9-11.0) vs. 10.0 (4.7-15.2)	0.249
Visceral adipose tissue attenuation (HU)	-89	8.0 (5.3-10.6) vs. 10.0 (6.1-13.8)	0.797
Subcutaneous adipose tissue area (mm^2)	12129.5	8.0 (4.0-11.9) vs. 8.0 (1.9-14.0)	0.342
Subcutaneous adipose tissue attenuation (HU)	-101.5	7.0 (3.8-10.1) vs. 8.0 (4.0-11.9)	0.968
Psoas muscle area (mm^2)	1127.5	7.0 (3.9-10.0) vs. 10.0 (6.9-13.0)	0.572
Psoas muscle attenuation (HU)	42.5	9.0 (5.8-12.2) vs. 7.0 (4.5-9.5)	0.418

Body composition parameters were dichotomized according to median values for illustrative Kaplan–Meier survival analyses. Survival outcomes are presented as median overall survival (OS) or median disease-free survival (DFS) in months, with 95% confidence intervals. Low and high groups were defined according to the corresponding cut-off values for each parameter. CT: Computed tomography, OS: Overall survival, CI: Confidence interval, HU: Hounsfield unit

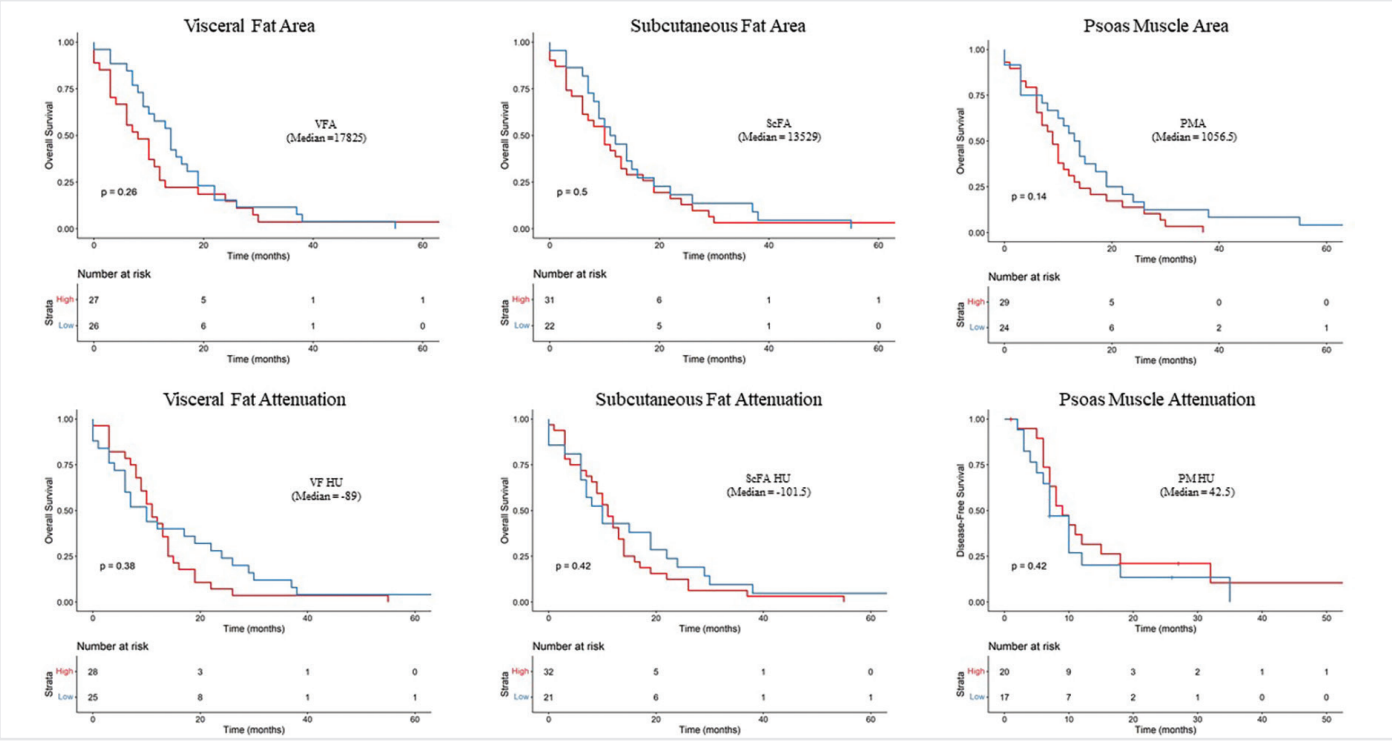

Figure 3. Kaplan-Meier overall survival curves according to computed tomography-derived body composition parameters. Kaplan-Meier overall survival curves stratified according to visceral adipose tissue area, visceral adipose tissue attenuation, subcutaneous adipose tissue area, subcutaneous adipose tissue attenuation, psoas muscle area, and psoas muscle attenuation. Body composition parameters were dichotomized at their median values for illustrative survival analyses. Red curves represent low-value groups, and blue curves represent high-value groups. The x-axis represents time in months. Number-at-risk tables are displayed beneath each survival curve. HU: Hounsfield unit

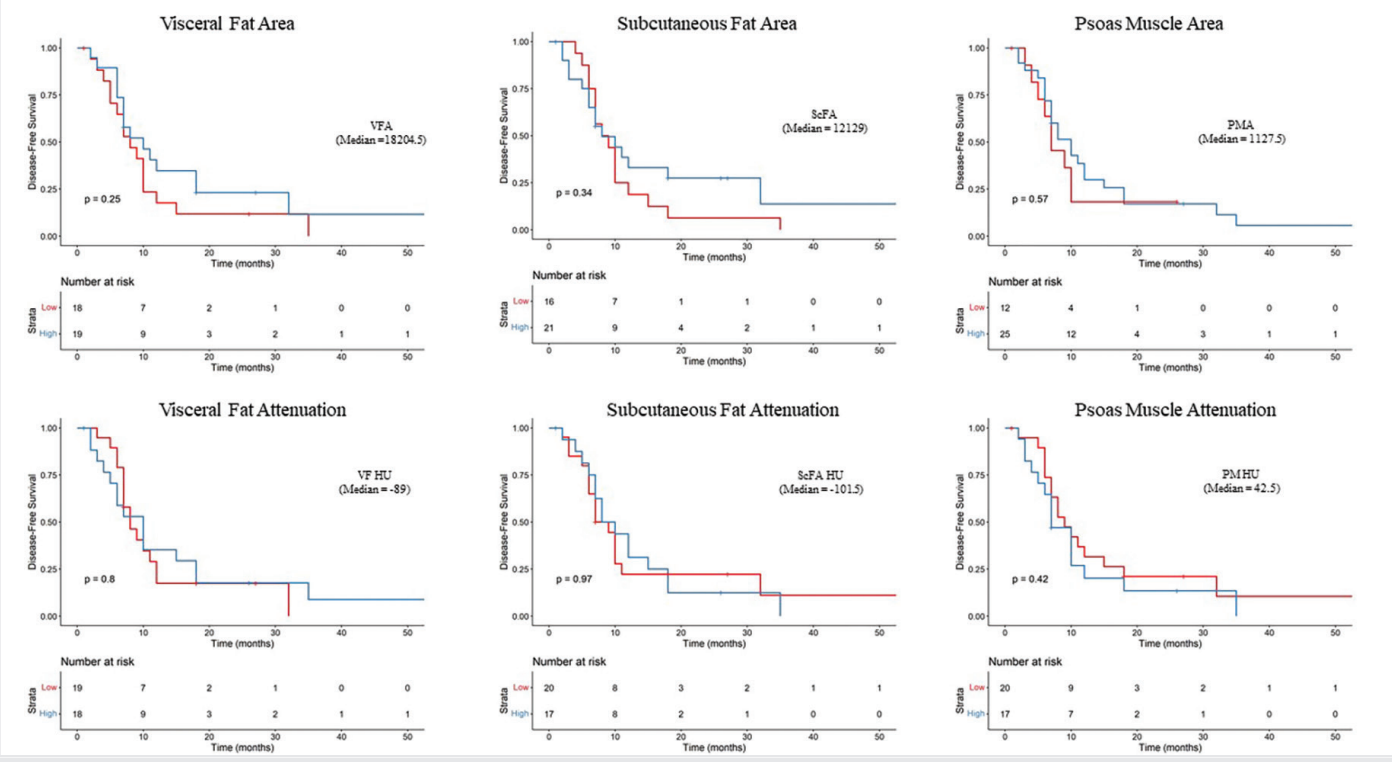

Figure 4. Kaplan-Meier disease-free survival curves according to computed tomography-derived body composition parameters. Kaplan-Meier disease-free survival curves stratified according to visceral adipose tissue area, visceral adipose tissue attenuation, subcutaneous adipose tissue area, subcutaneous adipose tissue attenuation, psoas muscle area, and psoas muscle attenuation. Body composition parameters were dichotomized according to median values for illustrative survival analyses. Red curves represent low-value groups and blue curves represent high-value groups. The x-axis represents time in months. Number-at-risk tables are displayed beneath each survival curve. HU: Hounsfield unit

Table 3. Univariate and multivariable Cox regression analyses of clinicopathological and body composition parameters for overall and disease-free survival

	Overall survival				Disease-free survival	
Variable	**Univariable HR (95% CI)**	**p**	**Multivariable HR (95% CI)**	**p**	**Univariable HR (95% CI)**	**p**
Age	1.01 (0.97-1.04)	0.593			1.01 (0.95-1.07)	0.695
T stage	1.34 (0.85-2.11)	0.200	1.83 (1.12-3.00)	0.015	1.56 (0.82-2.96)	0.166
N stage	0.98 (0.65-1.49)	0.947			1.39 (0.79-2.46)	0.246
Positive lymph node count	1.00 (0.93-1.08)	0.881			1.06 (0.98-1.16)	0.134
Tumor grade	1.04 (0.62-1.76)	0.866			1.15 (0.56-2.38)	0.689
Positive resection margin	1.64 (0.93-2.89)	0.085			0.97 (0.44-2.12)	0.951
Lymphovascular invasion	0.73 (0.37-1.44)	0.378			2.23 (0.51-9.69)	0.284
Visceral adipose tissue area (per 100 mm^2 increase)	0.98 (0.95-1.01)	0.343			0.99 (0.94-1.03)	0.726
Visceral adipose tissue attenuation	0.99 (0.97-1.00)	0.273			1.00 (0.97-1.02)	0.996
Subcutaneous adipose tissue area (per 100 mm^2 increase)	0.99 (0.96-1.02)	0.868			1.00 (0.95-1.05)	0.869
Subcutaneous adipose tissue attenuation	0.99 (0.98-1.01)	0.937			1.00 (0.97-1.02)	0.998
Psoas muscle area (per 100 mm^2 increase)	0.94 (0.89-1.00)	0.052	0.96 (0.90-1.02)	0.200	0.75 (0.35-1.46)	0.362
Psoas muscle attenuation	0.99 (0.97-1.01)	0.394			0.98 (0.95-1.00)	0.137
Adjuvant chemotherapy	0.19 (0.09-0.39)	<0.001	0.16 (0.07-0.34)	<0.001	0.18 (0.02-1.54)	0.119
ASA	1.05 (0.60-1.84)	0.843			1.31 (0.56-3.10)	0.527
CRP	1.00 (0.98-1.01)	0.652			0.99 (0.98-1.01)	0.775
Albumin	1.00 (0.95-1.05)	0.900			1.01 (0.93-1.10)	0.685
NLR	1.00 (0.99-1.01)	0.535			1.00 (0.99-1.01)	0.561
CA 19-9	1.00 (0.99-1.00)	0.472			1.00 (0.99-1.01)	0.092
Postoperative complications	1.20 (0.93-1.55)	0.148	-	-	0.97 (0.68-1.38)	0.889

Variables demonstrating statistical significance or borderline significance in univariable analyses were considered for multivariable Cox regression. The final multivariable model was refined based on clinical relevance and model stability while considering the number of observed events. Hazard ratios (HRs) for radiological body composition parameters were calculated using continuous measurements. HRs for area-based body composition parameters are expressed per 100 mm^2 increase, whereas CA 19-9 is expressed per 100 U/mL increase. Multivariable Cox regression analysis was not performed for disease-free survival because of the limited number of events and concerns regarding model stability. CI: Confidence interval, ASA: American Society of Anesthesiologists, CRP: C-reactive protein, NLR: Neutrophil-to-lymphocyte ratio, CA: Carbohydrate antigen

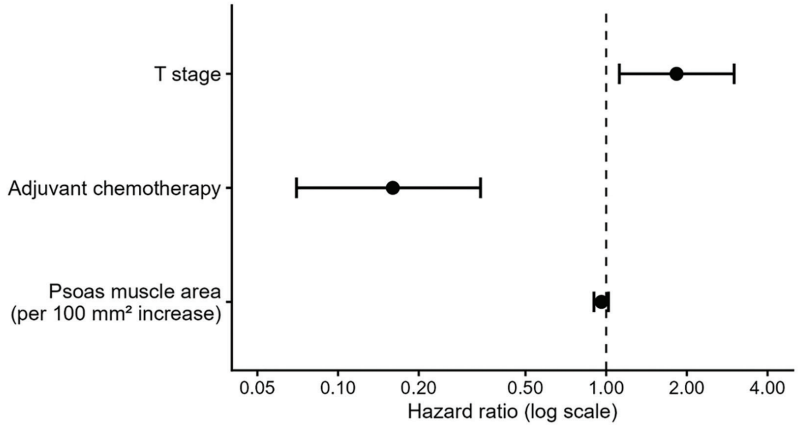

Figure 5. Forest plot of the multivariable Cox regression analysis for overall survival. Adjusted hazard ratios (HRs) and 95% confidence intervals for variables included in the final multivariable model. Psoas muscle area is expressed per 100-mm^2 increase. Hazard ratios are displayed on a logarithmic scale. The dashed vertical line indicates HR: 1.0

Discussion

In this retrospective analysis of patients undergoing pancreaticoduodenectomy for PDAC, CT-derived body composition parameters demonstrated heterogeneous associations with long-term oncological outcomes. Although most Kaplan–Meier comparisons did not reach statistical significance, several radiological markers showed consistent numerical separation of survival curves, suggesting a potential prognostic signal that may become more apparent in larger cohorts. Among the evaluated body composition parameters, psoas muscle area showed a borderline association with OS in univariable analysis and a consistently protective effect in multivariable analysis; however, this association did not remain statistically significant after adjustment. Higher T stage remained independently associated with worse OS, while adjuvant therapy consistently demonstrated a strong protective effect on OS.

Body composition analysis has attracted increasing interest in PDAC because conventional anthropometric measures often fail to capture cancer-related metabolic and muscular alterations. In particular, sarcopenia and myosteatosis have been linked to impaired functional reserve, systemic inflammation, treatment intolerance, and poorer oncological outcomes in several gastrointestinal malignancies (11,12). Recent studies have suggested that muscle quality, reflected by muscle attenuation on CT, may carry greater prognostic relevance than muscle quantity alone (13-16). A recent meta-analysis has also suggested that myosteatosis may outperform traditional sarcopenia measurements as a prognostic biomarker in pancreatic malignancies (17).

Our findings further support the growing interest in skeletal muscle characteristics as potential imaging biomarkers in PDAC. Although higher psoas muscle area showed a numerical association with longer OS in Kaplan-Meier analysis and a protective direction of effect in multivariable analysis, this association did not reach statistical significance after adjustment. Likewise, psoas muscle attenuation demonstrated a borderline association with DFS in univariable analysis but did not reach statistical significance. Overall, these findings indicate that both muscle quantity and quality may warrant further investigation as potential imaging biomarkers. Given the exploratory design and relatively small sample size, these findings should be interpreted with caution.

The relationship between adiposity and pancreatic cancer outcomes remains complex. While visceral obesity has traditionally been linked to adverse oncological biology and postoperative morbidity (18), several recent reports have suggested that severe depletion of adipose tissue may also represent an advanced catabolic state associated with poor survival (19). In our cohort, higher visceral fat area was numerically associated with longer OS and DFS, although these differences did not reach statistical significance. Rather than contradicting prior literature, these findings further support the concept that body composition in PDAC likely reflects a dynamic interaction between nutritional reserve, systemic inflammation, and tumor-related metabolic stress, and warrant further investigation in larger studies specifically designed to evaluate adipose tissue biology and distribution patterns.

Another notable finding of the present study was an independent association between adjuvant therapy and improved survival outcomes. Adjuvant chemotherapy remained independently associated with improved OS in multivariable analysis, underscoring the continued importance of systemic therapy even in surgically treated cohorts. This observation aligns closely with modern PDAC management paradigms and contemporary randomized trials demonstrating substantial survival benefits with adjuvant chemotherapy following resection (2,20). However, formal assessment of the proportional hazards assumption using Schoenfeld residual testing revealed a potential violation for adjuvant therapy in the OS model ($p=0.003$), suggesting that the effect of adjuvant treatment on survival may not be constant over time. Accordingly, the estimated hazard ratio for adjuvant therapy should be interpreted as an average effect over the follow-up period rather than a constant treatment effect.

The present study also provides clinically relevant perioperative context. Postoperative pancreatic fistula occurred in approximately one-third of patients, and early mortality was predominantly related to septic or hemorrhagic complications associated with PJ leakage. These findings reflect the continued technical and physiological complexity of pancreatic surgery, despite ongoing improvements in perioperative care. Although postoperative complications showed no significant association with OS in univariable analysis, larger studies specifically designed to evaluate postoperative morbidities are needed to better define their long-term oncological impact.

This study has several strengths. First, all body composition measurements were derived from routinely obtained preoperative CT imaging, which supports potential real-world applicability without additional cost or invasive assessment. Second, both adipose tissue and muscle-related parameters were evaluated simultaneously, allowing a more integrated assessment of body composition. Third, survival analyses incorporated both Kaplan–Meier and Cox regression approaches, enabling complementary evaluation of categorical survival patterns and continuous imaging parameters.

Study Limitations

This study has several limitations. First, its retrospective single-center design may have introduced selection bias. The relatively limited sample size and event burden may have reduced statistical power, particularly for subgroup analyses and multivariable modeling. Consequently, multivariable analysis was restricted to OS, whereas DFS was evaluated using univariable Cox regression because of concerns regarding model stability. In addition, body composition was measured at a single preoperative time point and therefore could not capture longitudinal changes in muscle or adipose tissue during treatment. Because multiple exploratory statistical comparisons were performed, the possibility of a type I error should be considered when interpreting isolated statistically significant findings.

Furthermore, total psoas muscle area was used as a surrogate for skeletal muscle mass rather than the height-normalized SMI, given the retrospective nature of the study. Although height data are typically available in medical records, SMI-based measurements were not

consistently performed; future studies should adopt standardized SMI to allow cross-study comparisons. Finally, although several radiological parameters demonstrated consistent numerical survival trends, most associations did not reach statistical significance after adjustment. Accordingly, these results should be regarded as preliminary and confirmed in larger, prospective, multicenter studies before being translated into clinical practice.

Conclusion

Overall, the present study suggests that CT-derived body composition parameters may warrant further investigation as potential imaging biomarkers in patients undergoing pancreaticoduodenectomy for PDAC. While most survival differences did not achieve statistical significance, muscle-related CT parameters showed consistent numerical associations with survival outcomes across multiple analyses, supporting their potential biological and clinical relevance. Future multicenter studies with larger cohorts and standardized radiological assessment protocols may help clarify the precise prognostic role of adipose- and muscle-related imaging biomarkers in PDAC.

Ethics

Ethics Committee Approval: The study adhered to the principles of the Declaration of Helsinki and received approval from the University of Health Sciences Türkiye, Ümraniye Training and Research Hospital (decision number: 146, date: 22.04.2026).

Informed Consent: Because of the retrospective design and the exclusive use of anonymized patient data, the Institutional Ethics Committee waived the requirement for written informed consent.

Footnotes

Authorship Contributions: Surgical and Medical Practices - O.E., T.C., A.A., S.N.E., H.T., F.B.; Concept - O.E., T.C., G.K.; Design - O.E., T.C., A.A., F.B.; Data Collection or Processing - A.A., S.N.E., H.T., G.K.; Analysis or Interpretation - O.E., S.N.E., F.B.; Literature Search - O.E.; Writing - O.E.

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References

1. Sung H, Ferlay J, Siegel RL, Laversanne M, Soerjomataram I, Jemal A, et al. Global Cancer Statistics 2020: GLOBOCAN Estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin. 2021; 71: 209-49.
2. Conroy T, Hammel P, Hebbar M, Ben Abdelghani M, Wei AC, Raoul JL, et al. FOLFIRINOX or gemcitabine as adjuvant therapy for pancreatic cancer. N Engl J Med. 2018; 379: 2395-406.
3. Leonhardt CS, Gustorff C, Klaiber U, Le Blanc S, Stamm TA, Verbeke CS, et al. Prognostic factors for early recurrence after resection of pancreatic cancer: a systematic review and meta-analysis. Gastroenterology. 2024; 167: 977-92
4. Babic A, Rosenthal MH, Sundaresan TK, Khalaf N, Lee V, Brais LK, et al. Adipose tissue and skeletal muscle wasting precede clinical diagnosis of pancreatic cancer. Nat Commun. 2023; 14: 4317.
5. Chait A, den Hartigh LJ. Adipose tissue distribution, inflammation and its metabolic consequences, including diabetes and cardiovascular disease. Front Cardiovasc Med. 2020; 7: 22.
6. Kuwabara S, Takeuchi Y, Sato O, Mizota T, Ichinokawa M, Murakawa K, et al. Prognostic value of combined psoas muscle mass and controlling nutritional status in patients with pancreatic ductal adenocarcinoma: a retrospective cohort study. BMC Surg. 2024; 24: 116.
7. Benedek Z, Todor-Boér S, Kocsis L, Bauer O, Suciu N, Coroș MF. Psoas muscle index defined by computer tomography predicts the presence of postoperative complications in colorectal cancer surgery. Medicina (Kaunas). 2021; 57: 472.
8. Taniguchi Y, Kurokawa Y, Takahashi T, Saito T, Yamashita K, Tanaka K, et al. Impacts of preoperative psoas muscle mass and visceral fat area on postoperative short- and long-term outcomes in patients with gastric cancer. World J Surg. 2021; 45: 815-21.
9. Kamada T, Ohdaira H, Takahashi J, Aida T, Nakashima K, Ito E, et al. Effect of low visceral fat area on long-term survival of stage I-III colorectal cancer. Nutrition. 2024; 118: 112302.
10. Lee SM, Song GJ, Son MW, Yun JH, Lee MS, Lee JW. Association of increased CT-attenuation of visceral adipose tissue after surgery with poor survival outcomes in patients with stage II-III gastric cancer: a retrospective cohort study. Cancers (Basel). 2025; 17: 235.
11. Choi MH, Yoon SB. Sarcopenia in pancreatic cancer: effect on patient outcomes. World J Gastrointest Oncol. 2022; 14: 2302-12.
12. Hong S, Kim KW, Park HJ, Ko Y, Yoo C, Park SY, et al. Impact of baseline muscle mass and myosteatosis on the development of early toxicity during first-line chemotherapy in patients with initially metastatic pancreatic cancer. Front Oncol. 2022; 12: 878472.
13. Levolger S, van Vugt JL, de Bruin RW, IJzermans JN. Systematic review of sarcopenia in patients operated on for gastrointestinal and hepatopancreatobiliary malignancies. Br J Surg. 2015; 102: 1448-58.
14. Matsuo N, Yamaguchi T, Yukami H, Kodama H, Ikegami T, Kadono T, et al. Impact of skeletal muscle-related parameters on survival in patients with advanced pancreatic cancer treated with gemcitabine plus nab-paclitaxel as first-line chemotherapy. J Cancer. 2026; 17: 604-13.
15. van Dijk DP, Bakens MJ, Coolsen MM, Rensen SS, van Dam RM, Bours MJ, et al. Low skeletal muscle radiation attenuation and visceral adiposity are associated with overall survival and surgical site infections in patients with pancreatic cancer. J Cachexia Sarcopenia Muscle. 2017; 8: 317-26.
16. Peng P, Hyder O, Firoozmand A, Kneuertz P, Schulick RD, Huang D, et al. Impact of sarcopenia on outcomes following resection of pancreatic adenocarcinoma. J Gastrointest Surg. 2012; 16: 1478-86.
17. Zhang X, Wei L, Li J, Deng Y, Xu W, Chen D, et al. Influence of myosteatosis on survival of patients with pancreatic cancer: a systematic review and meta-analysis. iScience. 2024; 27: 111343.
18. Kim B, Chung MJ, Park SW, Park JY, Bang S, Park SW, et al. Visceral obesity is associated with poor prognosis in pancreatic adenocarcinoma. Nutr Cancer. 2016; 68: 201-7.
19. Yu SY, Luan Y, Dong R, Abazarikia A, Kim SY. Adipose tissue wasting as a determinant of pancreatic cancer-related cachexia. Cancers (Basel). 2022; 14: 4754.
20. Aoyama T, Hara K, Saito A, Cho H. Adjuvant treatment for resectable pancreatic cancer. Anticancer Res. 2025; 45: 1329-41.