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Research article

Body composition analysis using convolutional neural network in predicting postoperative pancreatic fistula and survival after pancreatoduodenectomy for pancreatic cancer

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ABSTRACT

Purpose: To evaluate whether body composition measurements acquired using convolutional neural networks (CNNs) from preoperative CT images could predict postoperative pancreatic fistula (POPF) and overall survival (OS) after pancreaticoduodenectomy in patients with pancreatic ductal adenocarcinoma (PDAC).

Methods: 257 patients (160 men; median age [interquartile range], 67 [60–74]) who underwent pancreaticoduodenectomy for PDAC between January 2013 and December 2017 were included in this retrospective study. Body composition measurements were based on a CNN trained to segment CT images into skeletal muscle area, visceral adipose tissue (VAT), and subcutaneous adipose tissue (SAT). Skeletal muscle area, VAT, and SAT were normalized to height square and labeled as skeletal muscle, VAT, and SAT indices, respectively. The independent risk factors for clinically relevant POPF (grade B or C) were determined using a multivariate logistic regression model, and prognostic factors for OS were assessed using Cox proportional hazards regression analyses.

Results: After pancreatioduodenectomy, 27 patients developed POPF grade B or C (10.5 %, 27/257). The VAT index (odds ratio [OR] = 7.43, $p < 0.001$) was the only independent prognostic factor for POPF grade B or C. During the median follow-up period of 23 months, 205 (79.8 % [205/257]) patients died. For prediction of OS, skeletal muscle index (hazard ratio [HR] = 0.58, $p = 0.018$) was a significant factor, along with vascular invasion (HR = 1.85, $p < 0.001$) and neoadjuvant therapy (HR = 0.58, $p = 0.011$).

Conclusions: A high VAT index and a low skeletal muscle index can be utilized in predicting the occurrence of POPF grade B or C and poor OS, respectively.

1. Introduction

Pancreatic cancer is an aggressive and lethal malignancy with a 5-year survival of approximately 12 % [1]. Although surgical resection confers the only curative chance for the treatment of pancreatic cancer, the prognosis following surgery remains poor. Furthermore, despite advances in surgical technique and improvements in postoperative management, postoperative pancreatic fistula (POPF) is still widely considered to be the greatest contributor to major morbidity and mortality after pancreatoduodenectomy [2]. POPF frequently delays the timely delivery of adjuvant therapies and decreases overall survival [3]. The indications for pancreaticoduodenectomy have been widening, and the procedure is offered to an increasing number of elderly patients with multiple comorbidities [4]. Hence, there have been several attempts to predict POPF preoperatively or intraoperatively [2,4,5]; however, its accuracy is questionable.

Recently, there has been increasing interest in the impact of various body compositions on the outcomes of oncology patients. A few studies have shown that preoperative sarcopenia is associated with reduced survival in patients with pancreatic cancer following surgery [6–9].

Abbreviations: AUC, area under the receiver operating characteristic curve; CNN, convolutional neural network; IQR, interquartile range; OS, overall survival; PDAC, pancreatic ductal adenocarcinoma; POPF, postoperative pancreatic fistula; SAT, subcutaneous adipose tissue; VAT, visceral adipose tissue.

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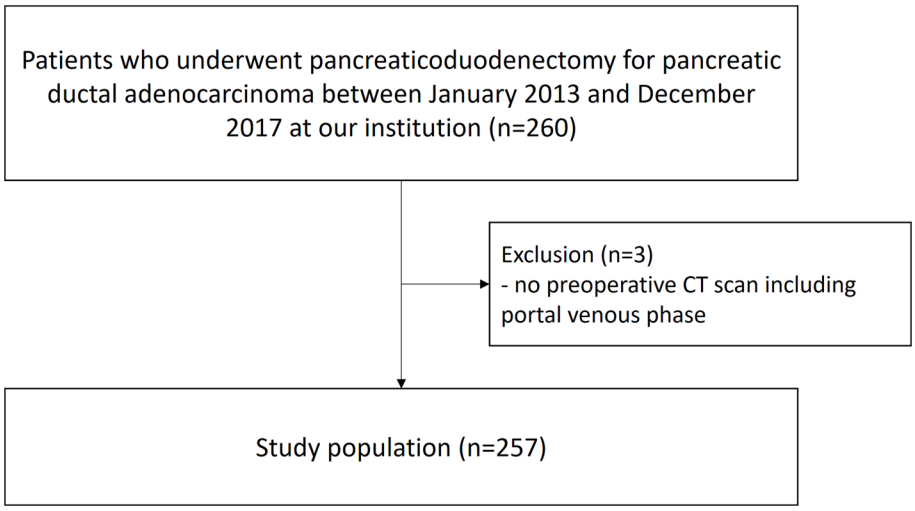

Fig. 1. Patient flowchart for enrollment.

Additionally, visceral obesity [10] or sarcopenic obesity [5] were reported as independent predictors of POPF in patients treated with pancreatic resection for adenocarcinoma. In these studies, measurements of body composition such as skeletal muscle area or visceral or subcutaneous fat area were performed in a semi-automated manner with a manual outlining of muscles [6,7,9]. A deep-learning algorithm, which is being actively used in the medical field, enables the automatic quantification of muscle and fat amount, which traditionally requires extensive time and effort from experienced researchers for manual segmentation. Furthermore, computed tomography (CT), which is performed as the first-line imaging modality in diagnosing pancreatic cancer, is considered a reliable and reproducible tool for quantifying both muscular and adipose tissues within the body [11]. Therefore, in this study, we hypothesized that body composition measurements could be performed using a deep neural network from preoperative CT images to predict clinical outcomes in patients with pancreatic cancer.

This study aimed to evaluate whether body composition acquired using a convolutional neural network (CNN) could predict pancreatic fistula and overall survival (OS) after pancreaticoduodenectomy in patients with pancreatic ductal adenocarcinoma (PDAC).

2. Materials and methods

This retrospective study was approved by our institutional review board (IRB No: 2011–060-1171), and the requirement for signed informed consent was waived due to the retrospective design [12].

2.1. Patients

The pathologic database at our institution between January 2013 and December 2017 was reviewed, and 267 consecutive patients who underwent pancreaticoduodenectomy were identified (Fig. 1). The inclusion criteria were 1) patients who were pathologically diagnosed with PDAC, and 2) patients who underwent preoperative contrast-enhanced CT with an interval of < 4 weeks between CT examination and surgery. Among 260 patients who met the inclusion criteria, patients who did not have portal phase CT images ($n = 3$) were excluded. A total of 257 patients were included in the study. Clinical and pathological information was obtained from the electronic medical records by one board-certified radiologist with 6 years in abdominal imaging who was blinded to body composition data. Resectability status was determined on the initial CT scan by the same radiologist according to National Comprehensive Cancer Network guidelines version 2023. Negative surgical margins were defined as absence of cancer cells within 1 mm of all resection margins.

2.2. CT image acquisition

All patients underwent abdominal CT scans, including the late arterial phase (LAP) and portal venous phase (PVP), using various types of CT scanners owing to the retrospective study design (Supplemental Materials). The median (interquartile range [IQR]) interval between CT scanning and pancreaticoduodenectomy was 9 days (3–17).

CT scanning was performed using the following parameters: tube voltage, 90–120 kVp according to the scanner type; tube current–time products, 100–300 mAs; rotation time, 0.5 s; pitch, 0.6–1.2; and slice thickness, 3 mm. The iobitridol (Xenetix 350; Guerbet) was intravenously injected at a dose of 520 mg/kg body weight using a power injector (Stellent D; Medrad) for 30 s at a rate of 2–5 mL/s according to body weight, followed by a 20–30-mL saline flush. The timing for LAP and PVP scans was determined using the bolus tracking technique; the LAP scan was automatically performed 17 s after the attenuation coefficient of the abdominal aortic blood reached 100 HU. PVP images were acquired 70 s after the initiation of the contrast media administration.

2.3. Body composition using CNN

After uploading PVP CT images to commercially available segmentation software (MEDIP Deep Catch v1.0.0.0, MEDICAL IP Co. Ltd., Seoul, Korea; https://www.medicalip.com/), a three-dimensional U-Net automatically provided volumetric segmentation of body components into seven classes with an average segmentation accuracy of 97 % compared with manual segmentation [13]: skin, bone, muscle, visceral adipose tissue (VAT), subcutaneous adipose tissue (SAT), internal organs with vessels, and central nervous system. The network comprised initial convolutions with an input size of $512 \times 512 \times 8$, three encoders, three decoders, and a final convolution and was developed using 39,286 labeled whole-body CT images and provided the mean segmentation accuracy for VAT and SAT of 92.4–98.9 % and 94.1–99.7 %, respectively, in internal and external test datasets [13]. After segmentation, the software also provided automatic segmentation and labeling of the body composition area at the L3-level cross-sectional image. An experienced radiologist who were blinded to clinicopathologic information of patients confirmed the results of the segmentation. Subsequently, L3 sectional area (cm^2) of the skeletal muscle area, SAT, and VAT were normalized to the height in square meters [4,5,14] and were labeled as skeletal muscle, VAT, and SAT indices, respectively. In addition, measurement of body composition using CNN was performed twice in

Table 1
Baseline characteristics of 257 patients who underwent pancreaticoduodenectomy for ductal adenocarcinoma.

Characteristics	Value
Age (y)	67 (60–74)
Sex	
Male	160 (62.3 %)
Female	97 (37.7 %)
Body mass index (kg/m^2)	23.3 (21.6–24.9)
Preoperative serum albumin (g/dL)	3.9 (3.6–4.1)
Preoperative serum total bilirubin (mg/dL)	1.3 (0.7–3.8)
Preoperative carbohydrate antigen 19–9 (U/mL)	131 (23.1–602)
Preoperative carcinoembryonic antigen (ng/mL)	2.5 (1.7–3.5)
Preoperative biliary drainage	
Yes	93 (36.2 %)
No	164 (63.8 %)
Resectability status determined on initial CT scans*	
Resectable	195 (75.9 %)
Borderline resectable	58 (22.6 %)
Locally advanced	4 (1.6 %)
Neoadjuvant chemotherapy	
Yes	27 (10.5 %)230
No	(89.5 %)
Neoadjuvant radiotherapy	
Yes	10 (3.9 %)
No	247 (96.1 %)
Tumor size (cm)	3 (2.4–3.6)
Main pancreatic duct diameter (mm)	5 (2–6)
Pancreatic texture	
Soft	92 (35.8 %)
Hard	165 (64.2 %)
Vessel resection	
Yes	52 (20.2 %)
SMV/PV†	48 (92.3 %)
CHA†	2 (3.8 %)
SMV and SMA†	1 (1.9 %)
IVC†	1 (1.9 %)
No	205 (79.8 %)
Estimated blood loss (mL)	400 (250–600)
Operation time (min)	345 (279.5–400)
Intensive care unit stay (day)	
0	94 (36.6 %)
1	73 (28.4 %)
2	69 (26.9 %)
3	16 (6.2 %)
>3	5 (1.9 %)
Adjuvant chemotherapy	
Yes	219 (85.2 %)
No	38 (14.8 %)
T staging	
T0 (no residual tumor)	1 (0.4 %)
T1	8 (3.1 %)
T2	6 (2.3 %)
T3	232 (90.3 %)
T4	10 (3.9 %)
N staging	
N0	91 (35.4 %)
N1	166 (64.6 %)
Resection margin	
Negative	216 (84.0 %)
Positive	41 (16.0 %)
Vascular invasion	
Yes	145 (56.4 %)
No	112 (43.6 %)
Tumor grade	
Well differentiated	17 (6.6 %)
Moderately differentiated	209 (81.3 %)
Poorly differentiated or undifferentiated	30 (11.7 %)
No residual tumor	1 (0.4 %)
POPF	
No	178 (69.3 %)
Grade A	52 (20.2 %)
Grade B	26 (10.1 %)
Grade C	1 (0.4 %)
Follow-up period	23 (12–46)

Note.—Values are presented as medians (interquartile range) for continuous variables.

* Resectability status according to National Comprehensive Cancer Network guidelines for pancreatic adenocarcinoma version 2023.
† The percentage values were calculated with 52 as the denominators.

randomly selected 50 patients to evaluate the measurement reproducibility. First, fully automatic segmentation algorithm was used for the body composition measurements. Then, segmentation was manually edited by experience radiologist (S.H.Y. with 12 years' experience in abdominal imaging) to obtain the body composition measurement again. The reproducibility of body composition analysis were assessed between these two measurements (i.e., fully automatic segmentation vs. manually edited segmentation).

2.4. Endpoints

The primary endpoint was development of POPF, which was defined according to the 2016 International Study Group guideline [15] as a drain output of any measurable volume of fluid with an amylase level > three times the upper limit of the normal serum level, associated with a clinically relevant development/condition. The severity of POPF was classified into three grades [15]: grade A, biochemical leak; B, drains either left in place for > 3 weeks or repositioned; and C, which requires reoperation or leads to single/multiple organ failure and/or mortality attributable to POPF.

The secondary endpoint was OS. The survival data of the patients were obtained from national statistical data from the Korean Ministry of Government Administration and Home Affairs. The data cutoff date was November 15, 2021.

2.5. Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics for Windows (version 25.0; IBM Corp., Armonk, NY, USA), SAS version 9.3 (SAS Institute Inc.; Cary, NC, USA), and MedCalc Statistical Software version 18.9.1 (MedCalc Software bvba, Ostend, Belgium; https://www.medcalc.org; 2019). For univariate analysis, continuous variables and categorical variables were compared using the Mann-Whitney *U* test and chi-square test, respectively. Multivariate logistic regression analyses were performed to assess predictors for the development of POPF grade B or C. The area under the receiver operating characteristic curve (AUC) was calculated to estimate the diagnostic performance of body composition measurements for predicting POPF. The Kaplan–Meier method was used to estimate OS after pancreaticoduodenectomy. The prognostic factors for OS were assessed using univariate and multivariate Cox proportional hazards regression analyses. All variables with p-values < 0.05, in univariate analyses, were included in the multivariate analysis using a stepwise selection. The optimal cutoff values of body composition measurements for predicting OS were determined by a statistical consultant at the Medical Research Collaborating Center at our institution using the minimal p-value approach based on log-rank test statistics [16]. Measurement reproducibility was evaluated using intraclass correlation coefficient (ICC). Statistical significance was set at $p < 0.05$.

3. Results

3.1. Patient characteristics

Of the 257 patients, there were 160 men and 97 women, with a median age of 67 years (IQR, 60–74) (Table 1). The median tumor size was 3 cm (IQR, 2.4–3.6). 195 (75.9 %) patients had resectable tumors on initial CT scans. The majority of the pathologic staging of tumors was T3 and N1. Surgical margins were negative in 216 (84.0 %) patients. The median follow-up period was 23 months (IQR, 12–46 months).

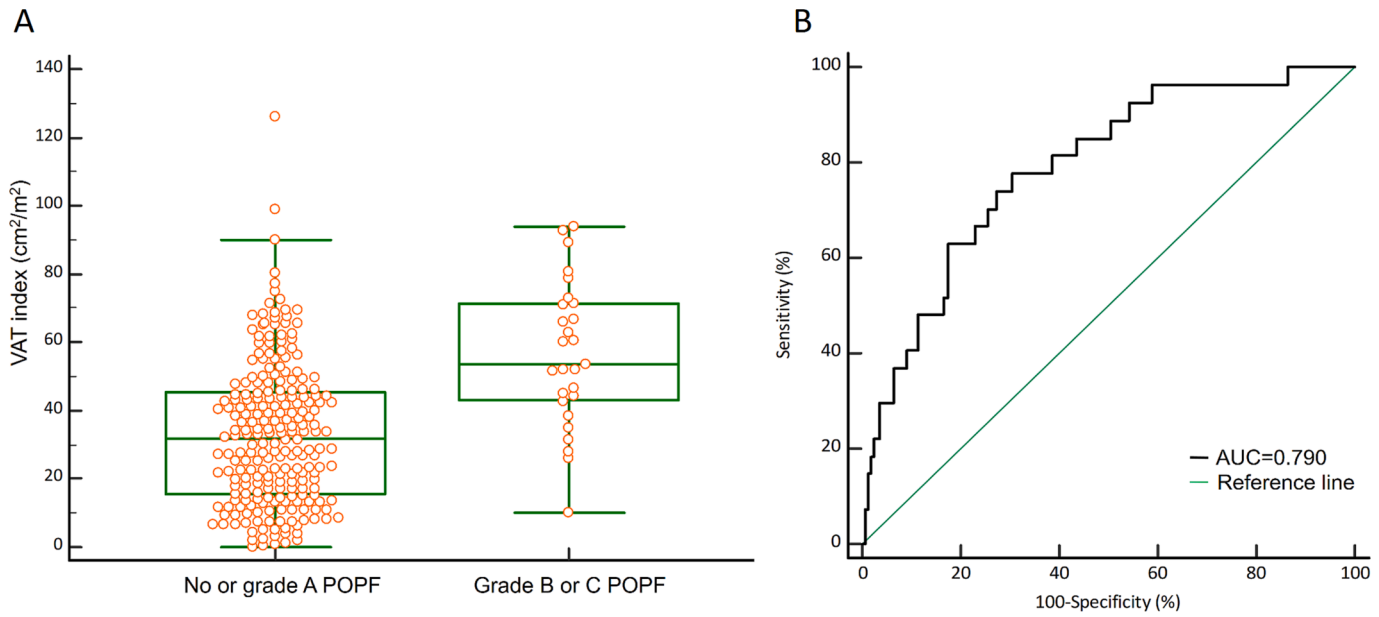

Fig. 2. (A) A box-and-whisker plot showing that the group with grade B or C postoperative pancreatic fistula (POPF) has significantly higher visceral adipose tissue (VAT) index than a group with no or grade A POPF (53.4 [interquartile range, 43.7–71.2] cm^2/m^2 vs. 31.9 [15.4–45.6] cm^2/m^2, $p < 0.001$). (B) A graph showing an area under the receiver operating characteristic curve (AUC) of visceral adipose tissue index for predicting grade B or C postoperative pancreatic fistula.

Table 2
Predictive factors for the development of postoperative pancreatic fistula equal to or more than grade B.

Characteristic	Univariate			Multivariate		
	POPF grade B or C		P-value	Odds radio	95 % CI	P-value
	Yes (n = 27)	No (n = 230)				
Age (age)	69.0 (65.0–76.0)	67.0 (59.0–74.0)	0.111			
Gender (M:F)	22:5	138:92	0.035	2.04	0.69–6.04	0.198
Tumor size (cm)	3.0 (2.4–3.6)	3.0 (2.4–3.6)	0.887			
Main pancreatic duct diameter (mm)	3.0 (2.0–5.0)	4.0 (3.0–6.0)	0.018	0.83	0.68–1.02	0.078
Operation time (hours)	395 (318–425)	341 (277–393)	0.033	1.01	0.99–1.01	0.053
Skeletal muscle index (cm^2/m^2)	46.0 (40.7–50.3)	43.4 (39.1–48.6)	0.211			
Visceral adipose tissue index (cm^2/m^2)	53.4 (43.1–71.2)	31.9 (15.4–45.6)	<0.001	7.43*	2.65–20.8	***<0.001***
Subcutaneous adipose tissue index (cm^2/m^2)	42.8 (29.5–53.8)	40.4 (26.5–54.0)	0.356			
Resection margin (positive:negative)	6:21	35:195	0.402			
Neoadjuvant radiation therapy	0:27	10:220	0.606			
Pancreas texture (soft:hard)	12:15	80:150	0.397			
Body mass index (kg/m^2)	24.2 (23.0–26.2)	23.1 (21.5–24.8)	0.028	0.903	0.75–1.09	0.293

Note.—POPF = postoperative pancreatic fistula; CI = confidence interval.
Values are presented as medians (interquartile range) for continuous variables.
* For the calculation of odds ratio, the cut-off of 42.5 cm^2/m^2 was applied.

3.2. Body composition measurements

Body composition analysis using PVP CT images and CNN was successfully performed for all participants. The median analysis time was 41 s (range, 20–71 s). The median (IQR) skeletal muscle, VAT, and SAT indices (cm^2) of the study population were 114.7 (99.1–133.4), 87.9 (44.8–126.4), and 105.9 (72.8–138.4), respectively. Additionally, the median (IQR) skeletal muscle, VAT, and SAT indices (cm^2/m^2) were 43.8 (39.2–48.9), 33.7 (17.1–49.1), and 41.0 (27.0–54.0), respectively. Regarding the measurement reproducibility, ICC between two measurements was 0.981 (95 % CI, 0.967–0.990) for skeletal muscle indices, 0.978 (95 % CI, 0.959–0.987) for VAT indices, and 0.983 (95 % CI, 0.969–0.992) for SAT indices, indicating excellent measurement reproducibility.

3.3. Predictors for POPF

Among the 257 patients, 178 (69.3 %) did not have POPF, while 79 (30.7 %) had POPF (grade A [n = 52], grade B [n = 26], and grade C [n = 1]). According to univariate analyses, the group with grade B or C POPF had significantly a higher VAT index (53.4 [IQR, 43.1–71.2] cm^2/m^2 vs. 31.9 [15.4–45.6] cm^2/m^2, $p < 0.001$) (Fig. 2a), smaller MPD diameter (3 [2–5] mm vs. 4 [3–6] mm, $p = 0.018$), and a higher proportion of men (M:F, 22 (81.5 %): 5 (18.5 %) vs. 138 (60.0 %): 92 (40.0

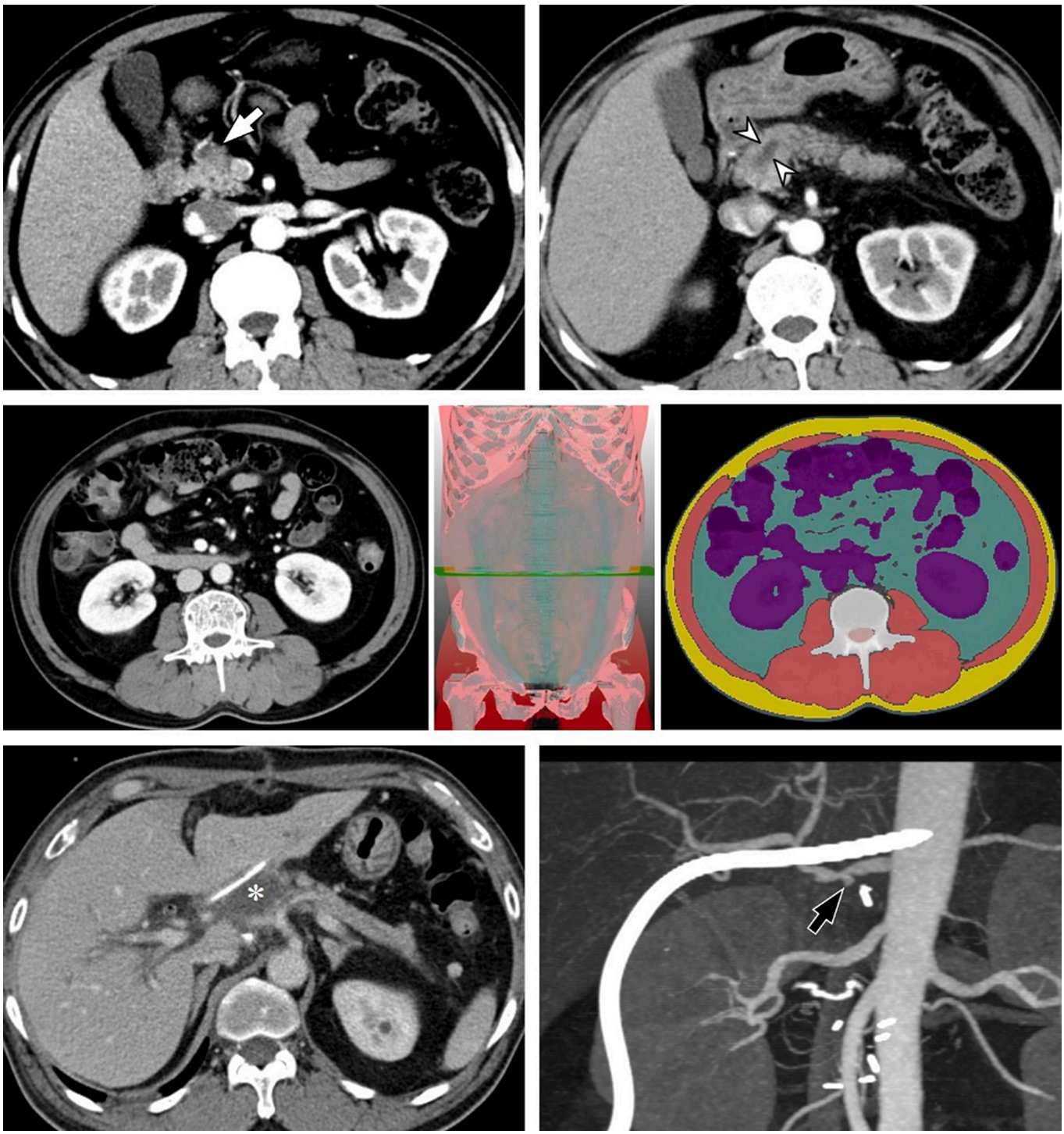

Fig. 3. A 57-year-old man who underwent pancreaticoduodenectomy for pancreatic ductal adenocarcinoma. (A and B) Axial late arterial phase images of preoperative CT scan show a 1.8 cm low-attenuated, ill-defined mass in the pancreas head (white arrow) with upstream main pancreatic duct dilatation measuring 6 mm (arrowheads). (C) A portal venous phase image of preoperative CT scan shows an axial image at the L3 vertebral level. (D) 3D translucent image shows a volumetric segmentation of portal venous phase images of preoperative CT. A green horizontal plane indicate the L3 vertebral level. (E) An axial image show the results of segmentation, which are overlaid on orthogonal cross-sectional images. Red, yellow, green, and purple colors indicate skeletal muscle, subcutaneous adipose tissue (SAT), visceral adipose tissue (VAT), and internal organs, respectively. VAT, SAT, and skeletal muscle indexes of the patient are 66.6 cm^2/m^2, 29.0 cm^2/m^2, 46.6 cm^2/m^2, respectively. (F) Axial CT scan taken on postoperative day 7 shows a small amount of fluid collection (asterisk) around the pancreaticojejunostomy. A surgical drain was repositioned through percutaneous procedures, which indicates postoperative pancreatic fistula grade B. (G) CT angiography taken one month after the surgery shows a 3 mm pseudoaneurysm (black arrow) at the stump of gastroduodenal artery and a stent graft was placed in the hepatic artery.

Table 3
Cox survival analysis of the predictors for overall survival in 257 patients with pancreatic ductal adenocarcinoma after pancreaticoduodenectomy.

Characteristic	Univariate			Multivariate		
	Hazard ratio	95 % CI	P-value	Hazard ratio	95 % CI	P-value
Gender (male)	0.83	0.62–1.10	0.191			
Age (per 1 year)	1.01	0.99–1.02	0.307			
T stage	1.71	1.23–2.38	0.002	1.43	0.98–2.09	0.061
Tumor size (cm)	1.32	1.16–1.51	<0.001	1.09	0.93–1.28	0.280
N stage	1.80	1.33–2.43	<0.001	1.33	0.95–1.86	0.093
Vascular invasion	2.06	1.54–2.76	<0.001	1.85	1.35–2.53	***<0.001***
Resection margin	1.29	0.89–1.87	0.173			
Skeletal muscle index (>49.5 cm^2/m^2)	0.62	0.40–0.95	0.027	0.58	0.37–0.91	***0.018***
Visceral adipose tissue index (>61.8 cm^2/m^2)	0.69	0.40–0.95	0.028	0.74	0.52–1.05	0.094
Subcutaneous adipose tissue index (>40.7 cm^2/m^2)	1.25	0.95–1.65	0.118			
Body mass index	0.99	0.96–1.02	0.351			
Adjuvant therapy	0.58	0.39–0.85	0.005	0.58	0.39–0.88	0.011
Intensive care unit stay (days)	1.07	1.02–1.13	0.008	1.04	0.99–1.11	0.136
Operation time (min)	1.00	0.99–1.00	0.666			

Note.—CI = confidence interval.

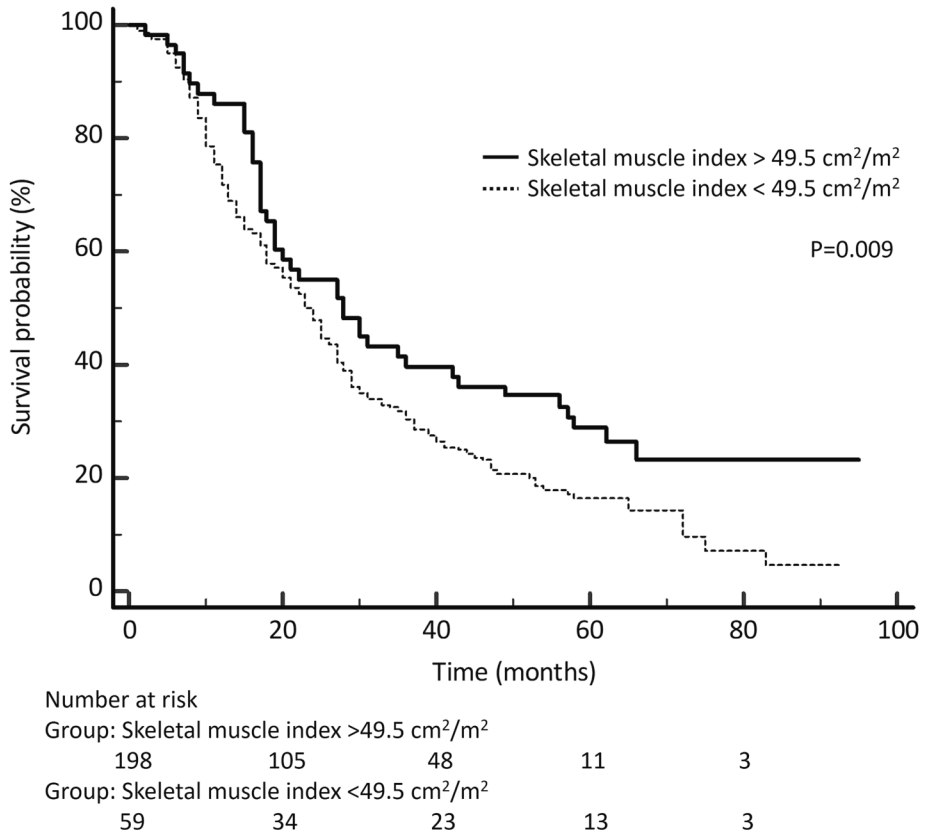

Fig. 4. Kaplan-Meier estimation of overall survival in 59 patients with skeletal muscle index > 49.5 cm^2/m^2 compared with 198 patients with skeletal muscle index < 49.5 cm^2/m^2.

%)) than those in the group with no or grade A POPF (Table 2). However, multivariate analysis revealed that VAT index was the only independent predictive factor for POPF. A representative case is shown in Fig. 3. When the cut-off value of VAT index was set at 42.5 cm^2/m^2, the AUC of VAT index for predicting grade B or C postoperative pancreatic fistula was 0.790 (95 % CI, 0.735–0.838) with sensitivity of 77.8 % (21/27) and specificity of 69.6 % (160/230) (Fig. 2b). The calculated odds ratio of VAT index with cut-off value of 42.5 cm^2/m^2 was 7.43 (95 % CI; 2.65–20.8, $p < 0.001$).

3.4. Predictors for OS

During the follow-up period, 205 (79.8 % [205/257]) patients died. The estimated 1-, 3-, and 5-year OS rates were 75.2 %, 32.5 %, and 19.3 %, respectively. Skeletal muscle index (hazard ratio [HR] = 0.62, $p = 0.010$) was significantly related to OS, along with tumor size (HR = 1.32, $p < 0.001$), T stage (HR = 1.71, $p = 0.002$), N stage (HR = 1.80, $p < 0.001$), and vascular invasion (HR = 2.06, $p < 0.001$) in univariate analyses (Table 3). The optimal cut-off values of skeletal muscle, VAT, and SAT indices (cm^2/m^2) were set at 49.5, 61.8, and 40.7, respectively, using the minimal p-value approach. Multivariate analyses showed that

skeletal muscle index (HR = 0.58, p = 0.018), vascular invasion (HR = 1.85, p < 0.001) and neoadjuvant therapy (HR = 0.58, p = 0.011) were independent predictors of OS. When a cutoff skeletal muscle index of 49.5 was applied, the estimated 1-, 3-, and 5-year OS rates in 59 patients with high skeletal muscle index were 86.2 %, 39.7 %, and 28.8 %, respectively, and significantly higher than 198 patients with low skeletal muscle index of 71.9 %, 30.3 %, and 16.3 %, respectively (p = 0.026) (Fig. 4).

4. Discussion

In our study, automatic measurement of body composition using CT images and CNN was successfully performed for all patients with PDAC, without manual segmentation or measurement. The median analysis time was less than 1 min; thus, body composition analysis was clinically feasible. Additionally, the VAT index was significantly associated with the development of POPF grade B or C, while skeletal muscle index was an independent predictor of OS after pancreaticoduodenectomy for PDAC. These results suggest that radiologic quantification of body composition, such as deficiency of skeletal muscle and excessive visceral fat tissue, might help predict clinical outcomes in patients following pancreaticoduodenectomy. Considering that all patients with pancreatic cancer undergo preoperative CT scans for surgical planning, we suggest that body composition measurement using CNN would be available without additional radiation exposure, cost, or inconvenient manual segmentation and is a useful biomarker in clinical practice.

The POPF rate was 30.0 % in our study, which is similar to reported rates of 16.7 %–27.1 % in previous studies [17–19]. Our study results showed that the VAT index was the only independent prognostic factor for POPF grades B or C, which is in line with previous studies [20,21]. The positive association between visceral obesity and POPF might be elucidated by the fact that excessive adipose tissue may lead to the production and secretion of adipocytokines, such as leptin, tumor necrosis factor-α, interleukin (IL)-1, and IL-6, which are associated with adjustment of the immunity [5]. During the postoperative period, pro-inflammatory adipocytokines can depress the immune system and delay wound healing, thereby increasing the risk of postoperative complications, particularly POPF [5].

Our study results demonstrated that skeletal muscle is a significant predictor of OS, along with vascular invasion and neoadjuvant therapy. Several studies have evaluated the association between sarcopenia and long-term survival in patients with pancreatic cancer following resection. However, the majority of previous studies included heterogeneous patient groups, such as periampullary cancer or pancreatic malignancy of other origin [8] or different types of surgery including pancreaticoduodenectomy, distal pancreatectomy, or total pancreatectomy [9,22,23]. Because various pathologies and surgical methods have significant effects on OS, our study only included patients with adenocarcinoma who underwent pancreaticoduodenectomy. Another strength of our study is that body composition was automatically measured using a deep neural network, in contrast to other previous studies where body composition measurement was performed semi-automatically with a manual outlining of the border of the muscle and adipose tissue on CT [8,9,22,23].

The skeletal muscle is the largest organ in the human body, taking up more than 40 % of the body weight [24]. Accumulating data have shown that muscle cells produce and secrete several hundreds of cytokines and other peptides, termed myokines, which influence various systemic responses [25]. In addition, skeletal muscle contains leukocytes, such as CD8 + T cells, regulatory T cells, and neutrophils, which play important roles in antitumor immunity [26]. Therefore, diminished muscle mass can lead to abnormal energy homeostasis, impaired cell growth, and immune dysfunction in cancer patients, resulting in tumor progression and decreased survival [14]. Another disadvantage of sarcopenia is that chemotherapy may be insufficiently administered due to toxicity. Sarcopenia is significantly associated with anticancer drug toxicity, which can be attributed to overexposure of anticancer drugs and sensitiveness to treatment, and is suggested as more relevant for drug dose calculation than the "classical" body surface area [27]. Considering that the majority of patients with pancreatic cancer are recommended to receive chemotherapy in the adjuvant or palliative setting, these relationships between sarcopenia and drug toxicity may explain the correlation between sarcopenia and poor prognoses in the current study.

Our study has several limitations. First, this was a retrospective study including a Korean population only from a single tertiary referral center. Therefore, a potential selection bias might exist, and further prospective studies with a larger number of participants are warranted to validate the results of our study. Second, we measured skeletal muscle area and adipose tissue at the L3 level and corrected values by the square of body height, which is most commonly performed [28]. However, the methods to estimate muscle mass on CT have not yet been validated or standardized. Last, the CNN was not trained using CT scans of patients with PDAC.

In conclusion, body composition measurements, including skeletal muscle, VAT, and SAT indices, could be automatically acquired from preoperative CT scans using CNN. A high VAT index and a low skeletal muscle index can be utilized to predict the occurrence of POPF grades B or C and poor OS, respectively.

CRediT authorship contribution statement

Jeongin Yoo: Writing – original draft, Formal analysis, Data curation. **Soon Ho Yoon:** Software, Methodology, Investigation, Conceptualization. **Dong Ho Lee:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Jin-Young Jang:** Investigation, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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