Impact of Preoperative Muscle Mass Maintenance and Perioperative Muscle Mass Loss Prevention After Pancreatectomy: Association Between Perioperative Muscle Mass and Postoperative Nutritional Status

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Running Title: Muscle Mass Loss and Nutrition in Pancreatectomy

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Abstract:

Objectives: We investigated how preoperative sarcopenia and perioperative muscle mass changes affect postoperative nutritional parameters in patients undergoing pancreatectomy.

Methods: This study included 164 patients undergoing pancreatectomy between January 2011 and October 2018. Skeletal muscle area was measured by computed tomography before and 6-months after surgery. Sarcopenia was defined as the lowest sex-specific quartile, and patients with muscle mass ratios <-10 % were classified into the high reduction group. We examined the relationship between perioperative muscle mass and postoperative nutritional parameters 6-months after pancreatectomy.

Results: There were no significant differences in nutritional parameters between the sarcopenia and non-sarcopenia groups at 6-months after surgery. In contrast, albumin ($P < 0.001$), cholinesterase ($P < 0.001$), and prognostic nutritional index ($P < 0.001$) were lower in the high reduction group. According to each surgical procedure, albumin ($P < 0.001$), cholinesterase ($P = 0.007$) and prognostic nutritional index ($P < 0.001$) were lower in the high reduction group of pancreaticoduodenectomy. In distal pancreatectomy cases, only cholinesterase ($P = 0.005$) was lower.

Conclusions: Postoperative nutritional parameters were correlated with muscle mass ratios but not with preoperative sarcopenia in patients undergoing pancreatectomy. Improvement and maintenance of perioperative muscle mass are important to maintain good nutritional parameters.

Key words: Skeletal muscle mass index, Muscle mass ratio, Nutritional status, Pancreatectomy, Pancreaticoduodenectomy, Sarcopenia

Introduction

Pancreatectomy is the gold standard procedure for both benign and malignant pancreatic diseases. However, pancreatectomy causes pancreatic exocrine insufficiency due to depletion of the pancreatic parenchyma,[1-5] including malnutrition, sarcopenia,[6] and fatty liver.[7,8] Therefore, it is important to manage the nutritional status of the patients after pancreatectomy on a long-term basis.

In recent years, there has been an increasing interest in the influence of sarcopenia on clinical outcomes. Previous reports have suggested that sarcopenia is correlated with survival and complications after pancreatectomy.[9-17] Preoperative sarcopenia has also been observed to be correlated with poor prognosis in patients with pancreatic cancer.[9-12,17] Furthermore, preoperative nutritional and metabolic derangements was associated with postoperative complications and poor survival after pancreatectomy.[18] Therefore, preoperative induction of nutritional and exercise therapies were reported to be important in the management of these patients.[19] Additionally, postoperative sarcopenia was also reported to be a prognostic factor,[11,15] and survival outcomes of pancreatic diseases have been observed to be affected by postoperative malnutrition and the presence of a fatty liver.[7] However, no report has described the association between perioperative muscle mass changes and postoperative nutritional status.

We hypothesized that the preoperative muscle mass and the perioperative muscle mass changes are related to postoperative nutritional parameters in patients undergoing pancreatectomy. The aim of this study was to examine the relationship between perioperative muscle mass and postoperative nutritional parameters after pancreatectomy by using computed tomography (CT) images.

Patients and Methods

Patients' selection

We retrospectively reviewed the medical records of 164 patients who underwent pancreatectomy at the Shiga University of Medical Science (SUMS) Hospital between January 2011 and October 2018. All pancreatectomies were performed by board-certified expert surgeons recognized by the Japanese Society of Hepato-Biliary-Pancreatic Surgery. All patients underwent blood tests and CT scans every 6 months after pancreatectomy. The study protocol was approved by the ethics committee of SUMS (registration number R2017-170) and performed according to the principles of the Declaration of Helsinki. Informed consent was obtained from all patients or their family members on an outpatient basis.

Computed tomography-based image analysis

Computed tomography was performed with 64- and 320-slice devices (Aquilion^{TM} CX Edition and Aquilion^{TM} ONE, respectively; Canon Medical Systems Corporation, Tochigi, Japan). The slice thickness was set at 5 mm in all patients in accordance with our institutional protocol. All CT findings were retrospectively reviewed by two experienced surgeons who were blinded to the laboratory results, surgical findings, postoperative findings, and final diagnosis. The CT attenuation value and the muscle area were determined using a Picture Archiving and Communication System (ShadeQuest/ViewR-DG; Yokogawa Medical Solutions Corporation, Tokyo, Japan). If there was a disagreement with regards to the findings, the scans were reviewed by both surgeons until a consensus was reached.

The skeletal muscle area and CT attenuation value of the multifidus muscle and of the subcutaneous fat were measured at the height of the third lumbar vertebra on the axial view of the unenhanced CT images before and 6 months after surgery. The skeletal muscle was manually outlined using a free-hand region of interest (ROI), and the area of the ROI was automatically calculated. The skeletal muscle mass index (SMI) was calculated as follows (Fig. 1A): [skeletal muscle area, cm^2] / [$height^2$, m^2]. The method for determining the CT attenuation value of the multifidus muscle was as follows (Fig. 1B): the right and left multifidus muscles were manually outlined using free-hand ROIs, and the CT attenuation value of the multifidus muscle was defined as the mean attenuation value of the right and left multifidus muscles. The CT attenuation value of the subcutaneous fat was determined as follows (Fig. 1B): four circle ROIs were set within the subcutaneous fat on unenhanced CT images, and the CT attenuation value of the subcutaneous fat was defined as the mean attenuation value of the four ROIs. The intramuscular adipose tissue content (IMAC) was calculated as follows: [CT attenuation value of the multifidus muscle] / [CT attenuation value of the subcutaneous fat].[20,21]

The method for determining the CT attenuation value of the liver was as follows: four square ROIs were set at different sectors in the liver parenchyma on unenhanced CT images, and the CT attenuation value of the liver was defined as the mean attenuation value of the four ROIs. Nonalcoholic fatty liver disease was defined as a CT attenuation value of the liver <40 Hounsfield units (HU).[7,22]

Sarcopenia was defined as the sex-specific lowest quartile,[9,12,16] and the patients were divided into the sarcopenia and non-sarcopenia groups. The muscle mass ratio (MMR) was measured as follows: ([postoperative muscle mass] - [preoperative muscle mass]) / [preoperative SMI] ×100 (%). Patients with MMR <-10 % were classified into the high reduction group and those with MMR ≥-10 % were classified into the low reduction group.[11]

Clinical data collection and statistical analysis

Patient characteristics, including preoperative laboratory data, postoperative findings, and CT findings, were compared between the sarcopenia and non-sarcopenia groups and between high and low reduction groups. Onodera's prognostic nutritional index (PNI) was based on serum albumin and lymphocyte counts. Onodera's PNI was calculated as 10 × serum albumin (g/dL) + 0.005 × total lymphocyte count (/μL).[23] Controlling nutritional status (CONUT) score was calculated based on serum albumin concentration, total lymphocyte count, and total cholesterol concentration.[24] In the present study, the nutritional status was evaluated using nutritional parameters such as Onodera's PNI [25, 26] and CONUT score [24].

Categorical variables are expressed as numbers and percentages (%), whereas continuous variables are expressed as medians with interquartile ranges. Fisher's exact test (for categorical variables) and the Mann-Whitney U test (for continuous variables) were used to evaluate the significance of differences between two groups. An analysis of covariance (ANCOVA) was used to adjust for covariates. In the two-tailed tests, $P < 0.05$ was considered a statistically significant difference. All statistical calculations were performed using the IBM SPSS Statistics 25 software package (IBM Japan Inc., Tokyo, Japan).

Results

Study population

A total of 164 patients were enrolled in this study. Of these, 104 were men (63.4 %) and 60 were women (36.6 %). Fifty-one patients (31.1 %) had diabetes mellitus, and pancreatic cancer was diagnosed in 78 patients (47.6 %). With regard to the surgical procedures, pancreaticoduodenectomy (PD) was performed in 111 patients (67.7 %), distal pancreatectomy (DP) was performed in 41 patients (25.0 %), and total pancreatectomy (TP) was performed in 12 patients (7.3%). Additionally, neoadjuvant chemotherapy was administered to 14 patients (8.5 %). The median body weight was 59.0 kg (range, 50.8–65.6 kg) in men and 49.7 kg (range, 45.9–56.3 kg) in women. The median body mass index (BMI) was 21.7 kg/m^2 (range, 19.6–23.6 kg/m^2) in men and 21.1 kg/m^2 (range, 18.8–23.8 kg/m^2) in women. The median SMIs were 44.6 cm^2/m^2 (range, 21.9–73.7 cm^2/m^2) in men and 36.8 cm^2/m^2 (range, 29.1–48.8 cm^2/m^2) in women, while the median MMR was -9.5 % (range, -60.2–33.0 %).

Clinical features of the sarcopenia and non-sarcopenia groups

Forty-one patients (25.0 %) were categorized into the sarcopenia group. Baseline characteristics and perioperative nutritional parameters were evaluated between the sarcopenia and non-sarcopenia groups and are summarized in Table 1. Preoperative BMI (19.2 kg/m^2 vs. 22.2 kg/m^2, $P < 0.001$), hemoglobin level (12.2 g/dL vs 12.8 g/dL, $P = 0.023$), and cholinesterase level (240 U/L vs. 278 U/L, $P = 0.002$) were significantly lower in the sarcopenia group than in the non-sarcopenia group. Regarding the postoperative nutritional parameters, there were no significant differences in any nutritional parameters at 6 months after surgery. Furthermore, 45 patients of non-sarcopenia group (36.6 %) became to be diagnosed as sarcopenia 6 months after surgery (Figure 2A). Similarly, 31 patients in the sarcopenia group (75.6 %) could not be diagnosed with non-sarcopenia 6 months after surgery (Figure 2B).

Clinical features of the high and low reduction groups

Table 2 shows the comparison of baseline characteristics and nutritional parameters at 6 months after surgery between the high and low reduction groups, with 80 patients (47.9 %) being categorized into the high reduction group. Preoperative BMI (22.1 kg/m^2 vs. 20.9 kg/m^2, $P = 0.032$) and SMI (45.0 cm^2/m^2 vs. 37.6 cm^2/m^2, $P < 0.001$) were significantly higher in the high reduction group than the low reduction group. There were no significant differences in preoperative nutritional parameters, except BMI, between the two groups. The prevalence of pancreatic cancer was higher in the high reduction group than in the low reduction group (50 cases vs. 28 cases, $P < 0.001$).

At 6 months after surgery, albumin level (3.6 g/dL vs. 4.0 g/dL, $P < 0.001$), cholinesterase level (197 U/L vs. 246 U/L, $P = 0.003$), Onodera's PNI (41.5 vs. 47.2, $P < 0.001$), CONUT score (4 vs 2, $P = 0.047$), CT attenuation value of the liver (53.6 HU vs. 57.5 HU, $P = 0.008$), and IMAC (-0.529 vs. -0.438, $P < 0.001$) were significantly lower in the high reduction group than in the low reduction group. Since preoperative BMI and SMI were significantly higher in the high reduction group, these factors were adjusted as covariates by ANCOVA to compare nutritional parameters at 6-months after surgery between the two groups. In regard to the adjustment by preoperative BMI, albumin level ($P < 0.001$), cholinesterase level ($P < 0.001$), Onodera's PNI ($P < 0.001$), CONUT score ($P = 0.030$), CT attenuation value of the liver ($P = 0.010$), and IMAC ($P < 0.001$) were significantly lower in the high reduction group. As to the adjustment by preoperative SMI, albumin level ($P < 0.001$), cholinesterase level ($P < 0.001$), Onodera's PNI ($P < 0.001$), CONUT score ($P = 0.025$), CT attenuation value of the liver ($P = 0.002$), and IMAC ($P < 0.001$) were significantly lower in the high reduction group.

Clinical features of the high and low reduction groups according to surgical procedures

Table 3 summarizes the comparison of nutritional parameters at 6 months after surgery between the high and low reduction groups according to the surgical procedures. First, of the 111 patients who underwent PD, 57 patients (51.4 %) were categorized into the high reduction group. Preoperative BMI (22.4 kg/m^2 vs. 20.9 kg/m^2, *P* = 0.027) and SMI (45.0 cm^2/m^2 vs. 38.4 cm^2/m^2, *P* = 0.001) were significantly higher in the high reduction group. There were no significant differences in preoperative nutritional parameters, except BMI, between the two groups. At 6 months after surgery, albumin level (3.4 g/dL vs. 3.9 g/dL, *P* < 0.001), cholinesterase level (197 U/L vs. 231 U/L, *P* = 0.007), Onodera's PNI (40.1 vs. 46.3, *P* < 0.001), CT attenuation value of the liver (52.9 HU vs. 56.5 HU, *P* = 0.016), IMAC (-0.541 vs. -0.454, *P* = 0.025), and SMI (35.3 cm2/m2 vs. 39.0 cm2/m2, *P* = 0.008) were significantly lower in the high reduction group.

Of the 41 patients who underwent DP, 15 (36.6 %) were categorized into the high reduction group. The prevalence of pancreatic cancer was significantly higher in the high reduction group (12 cases vs. 8 cases, *P* = 0.010). Further, there were no significant differences in preoperative nutritional parameters between the two groups. At 6 months after surgery, there were no significant differences in other nutritional parameters between the two groups, except for cholinesterase levels (204 U/L vs. 293 U/L, *P* = 0.005).

Discussion:

In this study, we identified two important clinical observations. First, the high reduction in perioperative skeletal muscle mass was correlated with the deterioration of nutritional parameters at 6 months after pancreatectomy, whereas preoperative SMI did not affect postoperative nutritional parameters. Second, there was a correlation between high reduction of perioperative skeletal muscle mass and the deterioration of postoperative nutritional parameters in patients who underwent PD, although DP patients demonstrated little correlation between these factors. Most previous reports have shown the importance of preoperative sarcopenia.[9-12,17,18] However, a few reports have focused on perioperative muscle mass loss.[11,15] Our study suggested an association between perioperative skeletal muscle mass and postoperative nutrition, and these results may be helpful in managing the patient postoperatively after pancreatectomy.

Preoperative sarcopenia was correlated with poor survival in patients with pancreatic cancer.[9-12,17] Similarly, postoperative sarcopenia has also been reported to be a prognostic factor.[11,15] Our results suggested that postoperative nutritional status which was assessed by some nutritional parameters[24-26] was more strongly correlated with perioperative muscle mass loss, despite not having preoperative sarcopenia. In the non-sarcopenia group, SMI decreased in almost all patients, wherein approximately 35% became sarcopenic 6 months after pancreatectomy. Therefore, the postoperative nutritional parameters were not significantly different between the sarcopenia and non-sarcopenia groups. Furthermore, approximately three-quarters of sarcopenia patients could not become non-sarcopenic 6 months after surgery. Thus, it may be difficult to increase muscle mass after pancreatectomy. In contrast, the postoperative nutritional parameters were significantly worse in the high reduction group than in the low reduction group. Namely, both improvement of preoperative muscle mass and maintenance of perioperative nutritional status are important to maintain adequate muscle mass. Therefore, nutritional and exercise therapies may be necessary not only preoperatively but also postoperatively to improve patient prognosis, even if the patients do not have sarcopenia preoperatively.

According to the surgical procedures done, patients who underwent PD had a correlation between MMR and nutritional parameters at 6 months after surgery. On the other hand, patients who underwent DP had few differences in nutritional parameters at 6 months after surgery between the high and low reduction groups. Therefore, patients who underwent PD had a stronger relationship between postoperative muscle mass loss and postoperative nutritional parameters than patients who underwent DP. In previous studies, the incidence of pancreatic exocrine insufficiency (PEI) after PD was higher than that after DP.[2,27-29] Pancreatic head tumors with main pancreatic ductal obstruction cause atrophy of the remnant pancreas due to chronic obstructive damage, subsequently impairing pancreatic exocrine secretion.[1,2,27] Furthermore, PD is necessary for reconstruction, including pancreatic anastomosis, and asynchrony between gastric emptying of nutrients and pancreatic enzyme secretion causes postoperative PEI.[1,30-32] However, DP patients usually have no obstruction of the remnant main pancreatic duct. Moreover, DP does not require reconstruction after resection. These factors, such as the pancreatic exocrine insufficiency and the surgical reconstruction, may strongly affect the postoperative muscle mass loss in PD cases. Therefore, nutritional therapy and pancreatic enzyme replacement therapy may be effective in preventing postoperative muscle mass loss in PD cases. In contrast, more than 10 percent loss of muscle mass caused in 15 patients (36.6 %) after DP although there were no significant differences in nutritional parameters between the high and low reduction groups. This result may be explained by the reason except malnutrition, such as postoperative hypoactivity.

This study had several limitations. First, this was a retrospective study, thus muscle strength could not be measured. Second, the number of enrolled patients was small, and only East Asian (Japanese) individuals from a single institution were enrolled. Finally, given its retrospective nature, we were unable to identify a causal relationship between SMI and nutritional status, and only revealed an association between them. Future prospective studies should focus on investigating the causal association between perioperative muscle mass and the postoperative nutrition.

In conclusion, it was observed that the nutritional status at 6 months after pancreatectomy correlated with MMR, but not with preoperative SMI. Moreover, the postoperative nutritional status of patients that underwent PD was significantly associated with the MMR. Currently, it is difficult to improve the nutritional status and increase the muscle mass of patients after pancreatectomy. Therefore, future studies are needed to clarify the management of the postoperative nutrition and muscle mass.

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Author contributions

Study conception and design: T. Mawkawa and H. Maehira designed and described the manuscript. Acquisition, analysis, and interpretation of data: T. Maekawa and H. Maehira reviewed the computed tomography findings and performed the data analysis and interpretation. H. Iida, H. Mori, N. Nitta, A. Tokuda, K. Takebayashi, S. Kaida, and T. Miyake performed the surgery and postoperative management. Drafting of manuscript: T. Maekawa and H. Maehira. Critical revision of manuscript: M. Tani. All the authors have approved the final manuscript.

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Figure Legends

Figure 1. Imaging analysis by computed tomography at the height of the third lumbar vertebra.

(A) The skeletal muscle area was measured by manual tracing (white lined area). (B) The multifidus muscle areas were measured by manual tracing (white lined area). The CT attenuation value of the subcutaneous fat was measured at the four regions of interest (white circle) which were placed on same cross-section and excluded major vessels.

Figure 2. The change of skeletal muscle mass index before and 6 months after pancreatectomy according to non-sarcopenia and sarcopenia group. (A) Non-sarcopenia group. Thirty-one male patients (39.7%) and 14 female patients (31.1%) were diagnosed with sarcopenia 6 months after surgery. (B) Sarcopenia group. Nineteen male patients (73.1%) and 12 female patients (80.0%) could not become to be diagnosed as non-sarcopenic. The SMI cut-off values for sarcopenia were 38.8 cm^2/m^2 in men and 33.0 cm^2/m^2 in women (dotted line).

Table 1. Clinical Features of the Sarcopenia and Non-sarcopenia Groups			
Findings	Sarcopenia n = 41	Non-sarcopenia n = 123	P
Background, n (%)			
Age, median (IQR), y	71 (64-76)	67 (62-73)	0.075
sex, male/female	26 (63.4)/15 (36.6)	78 (63.4) /45 (36.6)	1.000
Body mass index, median (IQR), kg/m^2	19.2 (17.8-20.8)	22.2 (20.5-24.2)	**<0.001**
Diabetes mellitus	12 (29.3)	39 (31.7)	0.847
Biliary drainage	17 (41.5)	36 (29.3)	0.178
Neoadjuvant therapy	5 (12.2)	9 (7.3)	0.342
Pancreatic cancer	21 (51.2)	57 (46.3)	0.594
Operation			0.768
Pancreaticoduodenectomy	29 (70.7)	82 (66.7)	
Distal pancreatectomy	10 (24.4)	31 (25.2)	
Total pancreatectomy	2 (4.9)	10 (8.1)	
Preoperative nutritional status, median (IQR)			
Hemoglobin, g/dL	12.2 (11.6-13.1)	12.8 (11.9-14.0)	**0.023**
Total lymphocyte count, /μL	1580 (1170-1980)	1526 (1233-2061)	0.757
Platelet count, /μL×10^4	21.0 (18.0-24.6)	20.6 (16.9-25.6)	0.587
Albumin, g/dL	3.6 (3.4-3.9)	3.8 (3.5-4.0)	0.061
Cholinesterase, U/L	240 (196-268)	278 (231-312)	**0.002**
Total cholesterol, mg/dL	179 (144-203)	196 (163-223)	0.092
Triglyceride, mg/dL	110 (73-136)	114 (84-145)	0.192
C-reactive protein, mg/dL	0.16 (0.06-0.46)	0.09 (0.05-0.21)	0.120
Hemoglobin A1c, %	6.1 (5.7-6.6)	6.0 (5.6-6.7)	0.638
Onodera’s PNI	43.8 (41.6-48.3)	46.1 (42.4-49.3)	0.078
CONUT score	2 (1-3)	2 (1-3)	0.102
CT attenuation value of the liver, HU	58.5 (55.4-62.9)	57.8 (53.2-62.4)	0.421
NAFLD, n (%)	0 (0)	3 (2.4)	0.574
IMAC	-0.363 (-0.491--0.283)	-0.395 (-0.482--0.301)	0.462
Postoperative nutritional status, median (IQR)			
Body mass index, kg/m^2	18.0 (16.2-19.1)	19.9 (18.4-22.5)	**<0.001**
Hemoglobin, g/dL	11.7 (9.9-12.4)	11.6 (10.3-12.9)	0.493
Total lymphocyte count, /μL	1315 (1060-1677)	1443 (996-1867)	0.619

Platelet count, /μL×10^4	20.7 (15.3-28.5)	20.7 (16.8-25.8)	0.780
Albumin, g/dL	3.8 (3.5-4.1)	3.8 (3.2-4.1)	0.893
Cholinesterase, U/L	210 (151-271)	210 (166-276)	0.810
Total cholesterol, mg/dL	144 (123-212)	154 (127-183)	0.900
Triglyceride, mg/dL	72 (60-106)	81 (68-115)	0.423
C-reactive protein, mg/dL	0.10 (0.05-0.53)	0.13 (0.05-0.85)	0.508
Hemoglobin A1c, %	5.9 (5.4-6.8)	6.0 (5.5-6.9)	0.545
Onodera's PNI	44.9 (40.1-47.5)	43.8 (38.1-49.1)	0.697
CONUT score	3 (1.5-4)	3 (1-5)	0.582
CT attenuation value of the liver, HU	56.6 (47.5-62.3)	55.3 (48.2-60.3)	0.655
NALFD, n (%)	6 (14.6)	22 (17.9)	0.811
IMAC	-0.470 (-0.604--0.335)	-0.461 (-0.676--0.345)	0.980

Data are expressed as medians with interquartile ranges for continuous data or as numbers and percentages for categorical data. Bold values are statistically significant.

Abbreviations: IQR, interquartile range; PNI, prognostic nutritional index; CONUT, controlling nutritional status; CT, computed tomography; HU, Hounsfield units; NAFLD, nonalcoholic fatty liver disease; IMAC, intramuscular adipose tissue content.

Table 2. Clinical Features of the High and low Reduction Groups			
Findings	High reduction n = 80	Low reduction n = 84	P
Background, n (%)			
Age, median (IQR), y	67 (61-73)	69 (62-74)	0.362
sex, male/female	52 (65.0)/28 (35.0)	51 (60.7) /33 (29.3)	0.747
Body mass index, median (IQR), kg/m^2	22.1 (19.6-22.4)	20.9 (19.2-22.6)	**0.032**
Diabetes mellitus	27 (33.8)	24 (28.6)	0.503
Biliary drainage	26 (32.5)	27 (32.1)	1.000
Neoadjuvant therapy	8 (10.0)	6 (7.1)	0.583
Pancreatic cancer	50 (62.5)	28 (33.3)	**<0.001**
Operation			0.118
Pancreaticoduodenectomy	57 (71.3)	54 (64.3)	
Distal pancreatectomy	15 (18.8)	26 (31.0)	
Total pancreatectomy	8 (10.0)	4 (4.8)	
Preoperative nutritional status, median (IQR)			
Sarcopenia, n (%)	8 (10.0)	33 (39.3)	**<0.001**
Skeletal mass index, cm^2/m^2	44.9 (39.4-49.6)	37.6 (33.3-44.6)	**<0.001**
Hemoglobin, g/dL	12.8 (11.7-13.8)	12.6 (11.7-13.7)	0.777
Total lymphocyte count, /μL	1457 (1165-1965)	1604 (1272-2056)	0.179
Platelet count, /μL×10^4	21.1 (16.5-26.4)	20.4 (17.8-25.5)	0.828
Albumin, g/dL	3.8 (3.5-4.0)	3.6 (3.4-3.9)	0.231
Cholinesterase, U/L	269 (239-302)	263 (212-294)	0.359
Total cholesterol, mg/dL	193 (163-224)	186 (151-209)	0.129
Triglyceride, mg/dL	117 (81-142)	106 (84-139)	0.608
C-reactive protein, mg/dL	0.10 (0.05-0.26)	0.10 (0.05-0.28)	0.876
Hemoglobin A1c, %	6.0 (5.6-6.7)	6.0 (5.6-6.7)	0.622
Onodera's PNI	46.3 (41.7-48.9)	44.9 (42.4-49.0)	0.823
CONUT score	2 (1-3)	2 (1-3)	0.926
CT attenuation value of the liver, HU	57.4 (52.7-62.4)	58.7 (54.5-63.3)	0.235
NAFLD, n (%)	1 (1.3)	2 (2.4)	1.000
IMAC	-0.382 (-0.459--0.303)	-0.395 (-0.497--0.282)	0.808
Postoperative nutritional status, median (IQR)			

Sarcopenia, n (%)	46 (57.5)	30 (35.7)	**0.008**
Skeletal mass index, cm^2/m^2	35.5 (31.5-40.1)	39.0 (34.2-43.3)	**<0.001**
Body mass index, kg/m^2	18.8 (17.1-21.1)	19.6 (18.4-21.6)	0.054
Hemoglobin, g/dL	11.3 (10.1-12.1)	12.0 (10.6-13.1)	**0.010**
Total lymphocyte count, /µL	1221 (857-1784)	1461 (1162-1829)	**0.009**
Platelet count, $/\mu L \times 10^4$	22.4 (17.0-27.0)	19.8 (16.0-24.4)	0.107
Albumin, g/dL	3.6 (3.0-3.8)	4.0 (3.7-4.2)	**<0.001**
Cholinesterase, U/L	197 (136-224)	246 (185-296)	**<0.001**
Total cholesterol, mg/dL	146 (124-177)	161 (130-202)	0.258
Triglyceride, mg/dL	79 (69-102)	76 (61-115)	0.990
C-reactive protein, mg/dL	0.21 (0.05-1.25)	0.10 (0.05-0.29)	0.076
Hemoglobin A1c, %	5.9 (5.5-6.7)	6.0 (5.5-6.8)	0.900
Onodera's PNI	41.5 (34.7-46.4)	47.2 (43.3-49.2)	**<0.001**
CONUT score	4 (2-6)	2 (1-4)	**0.047**
CT attenuation value of the liver, HU	53.5 (44.7-59.8)	57.5 (49.9-62.3)	**0.008**
NALFD, n (%)	18 (22.5)	10 (11.9)	0.096
IMAC	-0.529 (-0.776--0.384)	-0.438 (-0.531--0.318)	**<0.001**

Data are expressed as medians with interquartile ranges for continuous data or as numbers and percentages for categorical data. Bold values are statistically significant.

Abbreviations: IQR, interquartile range; MMR, muscle mass ratio; PNI, prognostic nutritional index; CONUT, controlling nutritional status; CT, computed tomography; HU, Hounsfield units; NAFLD, nonalcoholic fatty liver disease; IMAC, intramuscular adipose tissue content.

Table 3. Postoperative Nutritional Parameters of the High and low Reduction Groups in Terms of Surgical Procedure

Findings	Pancreaticoduodenectomy, median (IQR)			Distal pancreatectomy, median (IQR)		
	High reduction n = 57	Low reduction n = 54	P	High reduction n = 15	Low reduction n = 26	P
MMR, %	-18.9 (-22.7--15.6)	-1.8 (-6.0-3.8)	**<0.001**	-16.7 (-25.1--12.2)	0.6 (-5.1-4.0)	**<0.001**
BMI, kg/m^2	18.8 (16.7-21.4)	19.1 (18.4-21.0)	0.419	19.9 (18.4-21.7)	21.8 (18.5-24.4)	0.103
Hb, g/dL	11.0 (10.0-12.2)	12.1 (10.6-13.0)	0.065	11.4 (10.4-11.9)	12.1 (10.9-13.6)	0.086
TLC, /µL	1099 (784-1731)	1413 (1100-1749)	0.060	1628 (1217-2316)	1822 (1435-2441)	0.512
Platelet count, /µL$\times 10^4$	21.1 (16.8-26.5)	18.8 (14.9-23.1)	0.065	25.0 (20.0-35.3)	21.8 (17.9-29.1)	0.409
Albumin, g/dL	3.4 (2.8-3.8)	3.9 (3.6-4.1)	**<0.001**	4.1 (3.7-4.2)	4.2 (3.8-4.5)	0.139
CHE, U/L	197 (142-225)	231 (183-288)	**0.007**	204 (196-215)	293 (243-339)	**0.005**
T-Chol, mg/dL	130 (124-174)	136 (122-162)	0.884	177 (176-211)	206 (172-224)	0.493
TG, mg/dL	79 (69-111)	72 (60-107)	0.590	79 (71-124)	108 (84-148)	0.671
CRP, mg/dL	0.26 (0.06-1.29)	0.11 (0.05-0.29)	**0.046**	0.08 (0.05-0.25)	0.08 (0.06-0.16)	0.774
Hb A1c, %	5.8 (5.5-6.5)	5.7 (5.2-6.1)	0.565	6.1 (5.6-6.5)	6.2 (6.0-7.2)	0.094
Onodera's PNI	41.0 (33.2-43.7)	46.3 (43.2-48.5)	**<0.001**	48.1 (42.5-51.1)	485. (47.1-51.9)	0.385
CONUT score	4 (2-7.5)	3 (2-4)	0.302	2 (1-2)	1 (0.25-1)	0.249
CT attenuation value of the liver, HU	52.9 (39.7-59.0)	56.5 (50.3-61.9)	**0.016**	58.5 (51.1-62.7)	59.6 (51.7-63.1)	0.766
NALFD, n (%)	15 (26.3)	7 (13.0)	0.097	1 (6.7)	3 (11.5)	1.000
IMAC	-0.541 (-0.755--0.399)	-0.454 (-0.541--0.370)	**0.025**	-0.448 (-0.577--0.360)	-0.365 (-0.515--0.275)	0.093

Data are expressed as medians with interquartile ranges for continuous data or as numbers and percentages for categorical data. Bold values are statistically significant.

Abbreviations: IQR, interquartile range; MMR, muscle mass ratio; BMI, body mass index; Hb, hemoglobin; TLC, total lymphocyte count; CHE, cholinesterase; T-Chol, total cholesterol; TG, triglyceride; CRP, C-reactive protein; PNI, prognostic nutritional index; CONUT, controlling nutritional status; CT, computed tomography; HU, Hounsfield units; NAFLD, nonalcoholic fatty liver disease; IMAC, intramuscular adipose tissue content.

Figure 1.

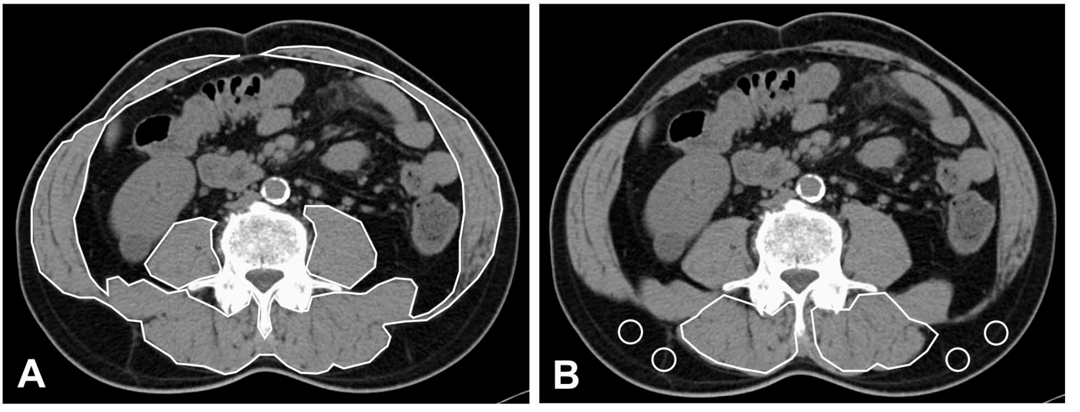
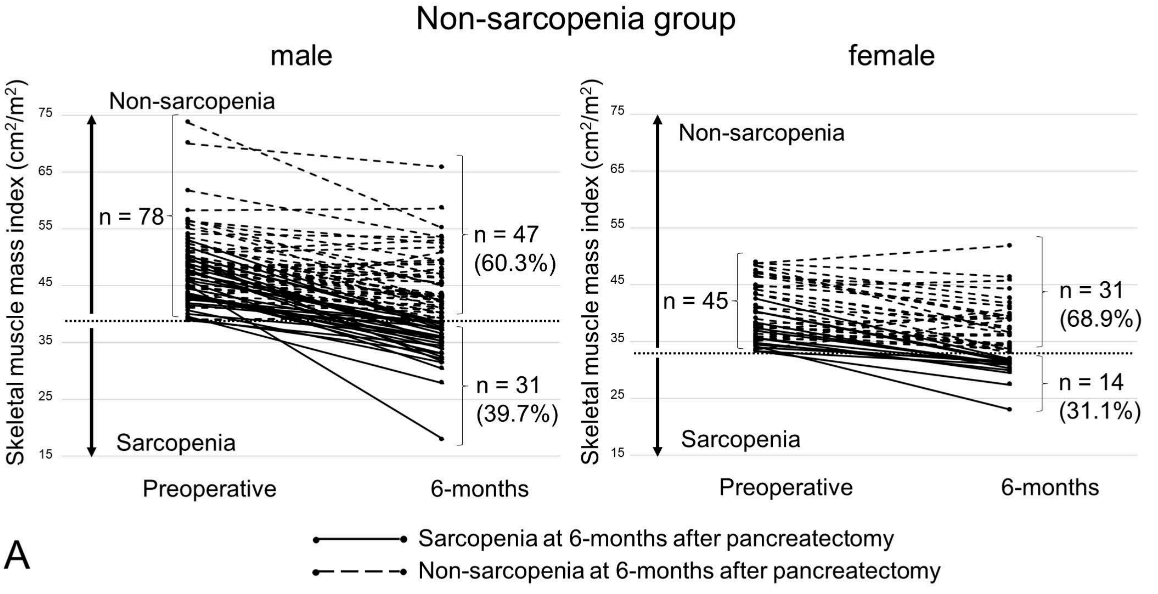
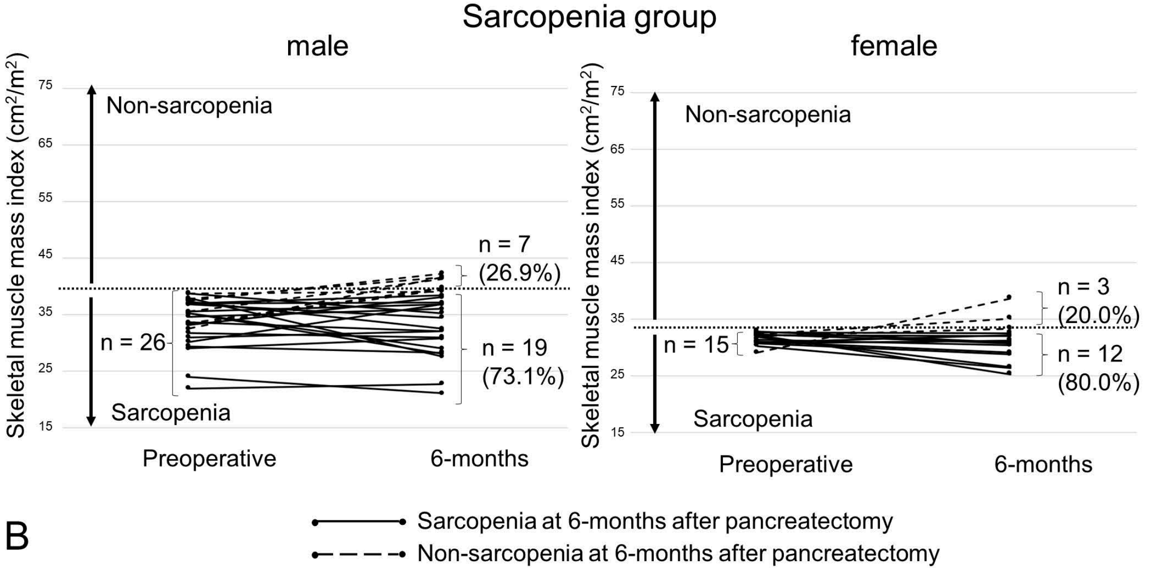


Figure 2.



Non-sarcopenia group
male
female
Skeletal muscle mass index (cm2/m2)
75
65
55
45
35
25
15
Non-sarcopenia
Sarcopenia
n = 78
n = 47
(60.3%)
n = 31
(39.7%)
n = 45
n = 31
(68.9%)
n = 14
(31.1%)
Preoperative
6-months
A
Sarcopenia at 6-months after pancreatectomy
Non-sarcopenia at 6-months after pancreatectomy



Sarcopenia group
male
female
Skeletal muscle mass index (cm2/m2)
75
65
55
45
35
25
15
Non-sarcopenia
Sarcopenia
n = 26
n = 7
(26.9%)
n = 19
(73.1%)
n = 15
n = 3
(20.0%)
n = 12
(80.0%)
Preoperative
6-months
B
Sarcopenia at 6-months after pancreatectomy
Non-sarcopenia at 6-months after pancreatectomy