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Effects of nutritional status on short-term prognosis after minimally invasive pancreaticoduodenectom

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Minimally invasive pancreaticoduodenectomy (MIPD) has been routinely performed in major centers, and its feasibility and efficacy in tumor treatment have been highly recognized. Malnutrition has been associated with higher rates of morbidity, and increased mortality in surgical patients. The effect of the nutritional status on MIPD outcomes still remains unclear and controversial. The clinical data of 207 consecutive patients who had MIPD between June 2017 and December 2022 were retrospectively analyzed. A multidimensional nutrition assessment was performed before surgery. Multivariable analysis and propensity score matching (PSM) was performed to identify the association of preoperative nutritional status on postoperative short-term prognosis(Morbidity–Mortality, Clavien-Dindo classification ≥ IIIa, postoperative pancreatic fistulas and biliary fistula). In the multivariable analysis, sarcopenia (OR 9.74, 95% CI 3.34–43.03) was associated with postoperative morbidity and sarcopenia (OR 6.74, 95% CI 2.24–30.24) was associated with major complications. In the cohort after PSM, sarcopenia remained independently associated with morbidity (OR 12.44, 95% CI 3.72- 59.16) and major complications (OR 8.14, 95% CI 2.13- 43.83). Sarcopenia before MIPD has an impact on postoperative outcomes. Nutritional status assessment, especially sarcopenia, should be part of the routine preoperative procedures to provide early and appropriate nutritional support for MIPD patients.

Keywords Minimally invasive pancreaticoduodenectomy, Nutritional status, Sarcopenia, Weight loss, Morbidity

With the ageing of the population, the incidence of pancreatic head cancer and periampullary cancer has been steadily increasing year by year[1]. Both are highly aggressive malignancies, with a 5-year survival rate of approximately 10%[2]. Pancreatoduodenectomy (PD), as the primary treatment, involves the resection of multiple organs and a wide range of tissues, and has high technical difficulty, and a relatively high incidence of postoperative morbidity with the potential for serious consequences[3]. Over the past decade, with the advent of minimally invasive surgery, minimally invasive pancreatic resections, including both robot-assisted and laparoscopic approaches, have become part of standard surgical practice globally[4]. A Meta-Analysis[5] suggested that minimally invasive pancreatoduodenectomy (MIPD) appears to be relatively safe in elderly patients, a group that may benefit more from this less invasive approach. Nevertheless, despite technological advancements in surgical techniques and perioperative management, postoperative morbidity remains a significant concern. Common morbidities after MIPD include pancreatic fistula, delayed gastric emptying, bleeding, chyle leak, endocrine and exocrine pancreatic insufficiency[6]. Among them, pancreatic fistula has a high prevalence, which can reach 20%[7].

Nutritional status plays a critical role in the outcomes of surgical procedures. Preoperative malnutrition has been linked to increased postoperative morbidities, longer hospital stay, and poor recovery[8]. Specifically, adequate nutritional support can enhance immune function, reduce the risk of infections, and promote wound healing, all of which are essential for successful surgical recovery. Sarcopenia is a systemic malnutrition disease characterized by widespread loss of skeletal muscle mass and function, often associated with aging and

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various diseases[9]. While it can be considered a form of malnutrition due to its impact on muscle health, it is distinct from general malnutrition, which encompasses a broader spectrum of nutritional deficiencies affecting overall health[10]. In cancer patients undergoing pancreatic surgery, preoperative sarcopenia is associated with poorer long-term survival outcomes[3,11–14]. When malnutrition and sarcopenia coexist, this may result in the malnutrition-sarcopenia syndrome (MSS) [15], which has been shown to increase mortality rates even more than sarcopenia alone. Studies have pointed out that MSS increases the risk of multiple postoperative morbidities in cancer patients and prolongs the patient's duration of hospital stay. However, its relationship with the occurrence of postoperative morbidity in MIPD remains unclear[16].

The aim of this study is to analysis the impact of nutritional indices on short-term prognosis following MIPD in terms of survival.

Materials and methods

Patients

This study included patients with pancreatic malignancies who underwent MIPD in the Department of Gastrointestinal and Pancreatic Surgery of Zhejiang Provincial People's Hospital from June 2017 to December 2022. Exclusion criteria are as follows: (1) advanced pancreatic cancer with metastasis; (2) palliative or emergency surgery; (3) prior administration of chemotherapy, radiotherapy, or other oncological treatments before surgery; (4) incomplete data. A multidimensional nutritional assessment was performed preoperatively. This comprehensive evaluation of nutritional status encompasses various interconnected domains. Key components typically include: (1) Anthropometric measurements: These involve assessing body composition, including weight, height, body mass index (BMI). (2) Biochemical indicators such as laboratory tests provide insights into nutrient deficiencies, metabolic status, and organ function. Assessments included serum protein levels and markers of inflammation. (3) Clinical assessment: This involves a thorough physical examination to identify signs of malnutrition. (4) Dietary Evaluation: Analyzing dietary habits through food frequency questionnaires or 24-h dietary recalls helps identify nutrient intake and dietary patterns, allowing for targeted nutritional interventions.

This single-center, retrospective study was approved by the Ethics Committee of Zhejiang Province People's Hospital (QT2024202), and all patients provided written informed consent. Additionally, the study was conducted according to the STROBE reporting guidelines. The research have been performed in accordance with the Declaration of 《Helsinki》.

Sarcopenia definition

Staging computed tomography (CT) scans of patients with pancreatic disease are utilised to evaluate body composition, particularly for the analysis of sarcopenia. Total psoas muscle area (TLA) (cm ^{2}), including paravertebral and abdominal wall muscles at L3 level, was calculated by Sliceomatic 5.0 after manual tracking of ROI, which includes psoas, paravertebral muscles (erectus, quadrate, multifidus) and parietal muscles (transversals, internal and external obliques, rectus abdominis). The skeletal muscle index (SMI) was derived as the ratio of TLA to height squared (cm^2/m^2). The CT attenuation values for muscle tissue were set between -29 and 150 Hounsfield units (HU). Sarcopenia was defined as an SMI < 53.00 cm^2/m^2 for males with a BMI ≥ 25 kg/m^2, < 43.00 cm^2/m^2 for males with a BMI < 25 kg/m^2, and < 41.00 cm^2/m^2 for females[17]. Diagnostic images of sarcopenia are shown in Fig. 1, 2.

1. The L3 level of the lumbar spine was selected for the analysis;
2. Sliceomatic 5.0 (https://www.tomovision.com) was applied to manually delineate L3 plane skeletal muscle boundaries, including rectus abdominis and internal obliquus abdominis Muscle, external oblique muscle, transverse muscle, vertical spine muscle, psoas major muscle, quadratus psoas muscle, by applying the threshold -29/ + 150 HU.

Data collection

Before surgery, a CT scan was assessed sarcopenia. The diagnosis of cancer-related malnutrition (CRM) adhered to the Global Leadership Initiative on Malnutrition (GLIM) criteria[18]. Preoperative patient characteristics, retrieved from hospital databases, included age, sex, American Society of Anesthesiologists (ASA) scores, preoperative albumin and hemoglobin levels, history of prior abdominal surgery, anti-jaundice therapy, percentage weight loss, body mass index (BMI), Nutritional Risk Screening 2002 (NRS2002) score, Charlson Comorbidity Index (CCI), and third lumbar vertebra (L3) skeletal muscle index (SMI, cm^2/m^2). Surgical variables included type of MIPD and operation time. Postoperative outcomes included length of hospital stay, morbidity, 30-day readmission, pancreatic fistula, biliary fistula, delayed gastric emptying, abdominal infection and gastrointestinal bleeding, and associated postoperative morbidities (the grades of postoperative morbidities were recorded according to the Clavien–Dindo classification), as well as patients' pathology results.

According to the definition and grading system of postoperative pancreatic fistulas (POPFs) published by the 2016 revised International Classification of Pancreatic Surgery Study Group[19]. To diagnose of nutritional risk and malnutrition, a questionnaire about weight loss, reduced food intake, and general condition were conducted at the time of admission[18]. We define "major complications" as Clavien-Dindo classification ≥ III[20].

Operative procedure

Standard radical MIPD was performed in accordance with established guidelines[21]. Two surgeons with extensive experience in MIPD, who had successfully completed a series of robotic hepatobiliary and pancreatic surgeries to better appreciate the learning curve associated with these procedures, and who were from the same department performed the operations.



Fig. 1. Sarcopenia is diagnosed at the L3 level.

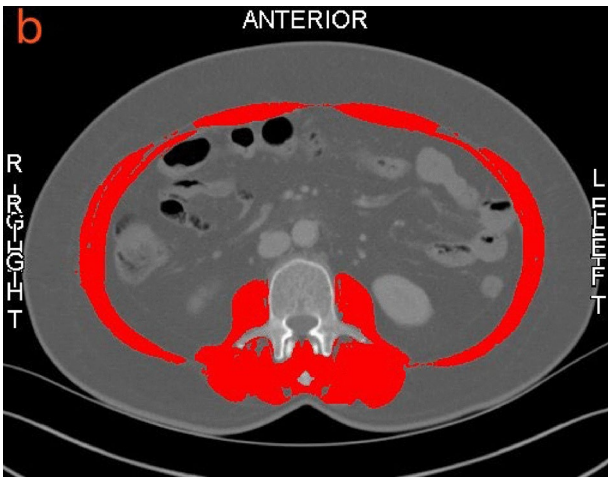


Fig. 2. Diagnostic image of sarcopenia.

Outcomes

The primary outcome was the analysis of the risk factors of nutrition status for the short-term prognosis after MIPD. The secondary outcome was preoperative nutritional status analysis of MIPD patients.

Statistical analysis

Continuous variables were expressed as mean and standard deviation (SD), or median and interquartile range (IQR). Categorical variables were expressed as counts and percentages. Logistic regression models were used to investigate the relationship with the primary and secondary outcome. Firstly, for each outcome, we perform a univariate analysis. Secondly, variables which $P < 0.05$ were included into multivariable analyses. The propensity score-matched (PSM) procedure was conducted using the MatchIt package in RStudio. PSM was performed to identify the association of preoperative nutritional status with postoperative short-term prognosis. Statistical significance was determined at a two-tailed $P < 0.05$. Analyses were performed using RStudio 4.2.1 statistical software (http://www.Rproject.org).

Results

Patients' cohort

Ultimately, 207 patients who met the specified inclusion and exclusion criteria were selected for this study, as depicted in Fig. 3. A total of 207 patients participated in this study (82 women, 125 men) with a median age of 65 (range: 33–79) years. Of these, 69 patients (33.3%) had morbidities, and there were no deaths within 90 days postoperatively. The median preoperative plasma albumin concentration was 36.9 g/L (range: 28.6–49). And the median preoperative hemoglobin (Hb) concentration was 124 g/L (range: 71–182). A total of 107 patients (51.7%) had an NRS2002 score ≥ 3. The ASA score was II in 82.1% of patients. The median operation time was approximately 370 min. The most common tumor location was the head of the pancreas (49.8%), followed by the duodenum (24.2%). The majority of tumors were moderately differentiated (49.8%). Laparoscopic PD(LPD) was performed in 111 (53.6%) patients, robotic PD (RPD) was performed in 96 (46.4%) patients. The demographic characteristics of the patients are summarized in Table 1.

Nutritional status before surgery

Regarding preoperative nutritional status, the mean BMI was 22.6 kg/m^2 (SD $\pm$ 3), with weight loss observed in 39.1% of the cohort. Notably, 9.7% of patients exhibited weight loss exceeding 10%. Furthermore, 19.3% of patients reported reduced oral intake. The mean SMI was 35.4 cm^2/m^2 (SD $\pm$ 9.3), with females having a mean SMI of 29.8 cm^2/m^2 (SD $\pm$ 9.1) and males 39.2 cm^2/m^2 (SD $\pm$ 9.3). Sarcopenia was present in 32.9% of patients. Cancer-related malnutrition (CRM), as defined by the GLIM criteria, was identified in 84.1% of the population. A detailed summary of the nutritional parameters is presented in Table 2.

Multivariable analysis for the risk of adverse clinical outcomes

In the multivariable analysis, sarcopenia was found to be significantly associated with postoperative morbidity (OR 9.74, 95% CI 3.34–43.03) and with major complications (OR 6.74, 95% CI 2.24–30.24). Furthermore, in the cohort after propensity score matching (PSM), sarcopenia remained independently associated with morbidity (OR 12.44, 95% CI 3.72–59.16) and with major complications (OR 8.14, 95% CI 2.13–43.83). A detailed multivariable analysis of risk factors for adverse clinical outcomes is provided in Table 3.

Multivariable analysis with propensity scores for the risk of adverse clinical outcomes

The patients were stratified into two groups based on the presence or absence of sarcopenia, matched in a 1:3 ratio. To explore the association between sarcopenia and short-term morbidity and prognosis following minimally invasive pancreatoduodenectomy (MIPD), we excluded covariates with high collinearity to prevent multicollinearity issues, and performed PSM. After head-to-head PSM, no significant differences were observed between the groups in terms of sex, age, diabetes status, body mass index (BMI), percentage weight loss, reduced oral intake, hypoalbuminemia, anemia, prior abdominal surgery, Charlson Comorbidity Index (CCI), anti-jaundice therapy, type of MIPD, or operative time. A multivariable logistic regression model was subsequently employed, incorporating variables potentially associated with sarcopenia into the propensity score model. Sarcopenia was identified as an independent, prognostic factor for Morbidity (OR 12.44, 95% CI 3.72–59.16) and for complications Clavien-Dindo grade $\geq$ IIIa (OR 8.14, 95% CI 2.13- 43.83). Moreover, following PSM, sarcopenia remained an independent risk factor for POPFs (OR 8.50, 95% CI 2.56–40.18), although no statistical significance was observed between sarcopenia and POPFs prior to PSM. See Table 4.for details.

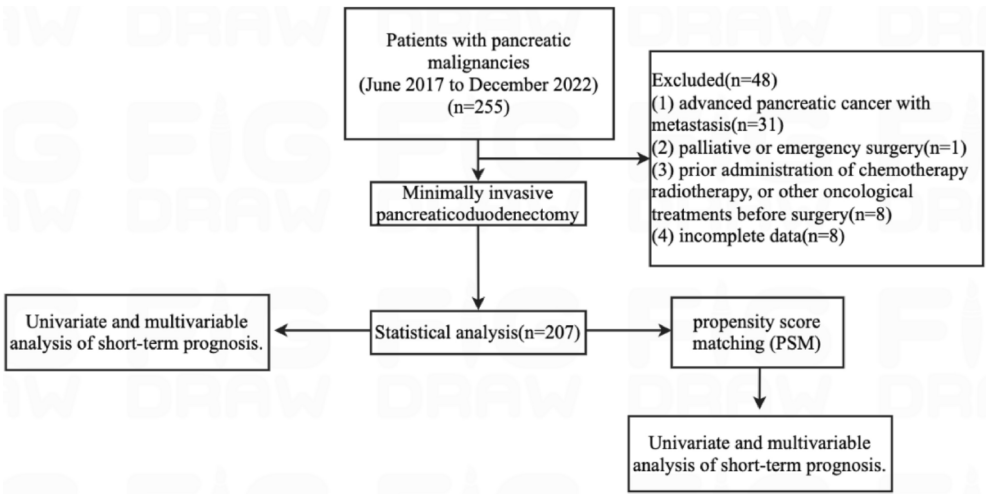


Fig. 3. Flow chart of patient inclusion and exclusion.

Factors	Number	Percentage	IQR	Range
Age, median (IQR), years			65.0	33–79
Gender				
Male	125	60.4		
Female	82	39.6		
Albumin, median (IQR), g/L			36.9	28.6–49.0
Hemoglobin, median (IQR), g/L			124.0	71.0–182.0
ASA grade				
I	28	13.5		
II	142	68.6		
III	37	17.9		
NRS 2002 scores (≥ 3)	107	51.7		
Charlson Comorbidity Index				
0	14	6.7		
1	27	13.0		
≥ 2	166	80.2		
Previous abdominal surgery	54	26.1		
Operation time, median (IQR), min			370.0	150.0–490.0
Tumor location				
Head of pancreas	103	49.8		
Ampulla	38	18.4		
Common bile duct	16	7.5		
Duodenum	50	24.3		
Differentiation of tumor				
Well-differentiated	19	9.2		
Moderately-differentiated	108	52.2		
Poorly differentiated	80	38.6		
Type of MIPD				
RPD	96	46.4		
LPD	111	53.6		

Table 1. Comparison of demographic and clinical characteristic of patients. Missing values were excluded from calculations. ASA: American Society of Anesthesiologists; MIPD: Minimally invasive pancreaticoduodenectomy; LPD: Laparoscopic pancreaticoduodenectomy; RPD: Robotic pancreaticoduodenectomy; IQR: Interquartile Range.

		Number	Percentage	Mean	± SD
BMI	kg/m2			22.7	3.0
Weight Loss %	No weight Loss	126	60.9		
	< 5%	31	15.0		
	5–10%	30	15.5		
	≥ 10%	20	9.8		
Reduced Oral Intake	Yes	40	19.3		
SMI	Total—cm2/m2			37.1	8.5
	Female—cm2/m2			29.8	9.1
	Male—cm2/m2			39.2	9.3
Sarcopenia	Yes	68	32.9		
Diagnosis of Malnutrition (GLIM)	Yes	174	84.1		

Table 2. Nutritional parameters before surgery. Missing values were excluded from calculations. BMI: body mass index; SMI: skeletal muscle index; GLIM: Global Leadership Initiative on Malnutrition.

Discussion

In our study, we found that sarcopenia had a significant impact on major complications and postoperative morbidity, which were considered short-term outcomes in patients undergoing MIPD. In addition, sarcopenia was identified as an independent predictor of POPFs.

Factors	Morbidity				Major complications			
	Univariate analysis		Multivariable analysis		Univariate analysis		Multivariable analysis	
	OR (95% CI)	p	OR (95% CI)	p	OR (95% CI)	p	OR (95% CI)	p
Age	1.04(1.01; 1.07)	0.022*	1.03(1.01; 1.06)	0.060	1.03(0.99; 1.08)	0.177		
BMI	1.03(0.94; 1.14)	0.517			1.07(0.96; 1.20)	0.209		
Weight Loss %	1.07(1.01; 1.14)	0.039*	1.05(0.99; 1.10)	0.181	1.08(1.01; 1.15)	0.025*	1.06(0.99; 1.12)	0.119
ASA								
1–2/ 3	0.71(0.31; 1.53)	0.401			0.53(0.17; 1.34)	0.215		
Hypoalbuminemia								
Yes/no	1.39(0.73; 2.62)	0.312			0.72(0.32; 1.53)	0.411		
Anemia								
Yes/no	1.07(0.57; 1.99)	0.824			1.35(0.66; 2.69)	0.399		
Oral Intake Reduced								
Yes/no	1.81(0.89; 3.66)	0.097			1.26(0.54; 2.75)	0.578		
Sarcopenia								
Yes/no	11.22(3.27; 70.58)	0.001*	9.74(3.34; 43.03)	0.002*	5.71(1.64; 36.10)	0.019*	6.74(2.24; 30.24)	0.012*
Charlson Comorbidity Index								
1/0	2.10(0.42; 15.67)	0.399			4.55(0.69; 90.28)	0.179		
≥ 2/0	3.49(0.91; 22.88)	0.110			3.73(0.71; 68.84)	0.212		
Previous abdominal surgery								
Yes/no	1.09(0.56; 2.07)	0.805			1.04(0.48; 2.15)	0.920		
Preoperative biliary drainage								
Yes/no	1.09(0.60; 1.94)	0.784			0.92(0.46; 1.80)	0.812		
Type of MIPD								
LPD/RPD	0.68(0.38; 1.21)	0.189			0.64(0.32; 1.24)	0.193		

Table 3. Univariate and multivariable analysis for risk factors of short-term prognosis. *Statistically significant ($P < 0.05$). CI: Confidence Interval; BMI: Body mass index; ASA: American Society of Anesthesiologists. LPD: Laparoscopic pancreaticoduodenectomy; RPD: Robotic pancreaticoduodenectomy.

		Sarcopenia			
		OR	95% CI		p-Value
Morbidity–Mortality	Unmatch	9.74	3.34	43.03	0.002*
	PSM	12.44	3.72	59.16	0.002*
Major complications	Unmatch	6.74	2.24	30.24	0.012*
	PSM	8.14	2.13	43.83	0.019*
POPFs	Unmatch	3.76	1.06	23.96	0.079
	PSM	8.50	2.56	40.18	0.008*
Biliary Fistula	Unmatch	1.72	0.30	32.38	0.615
	PSM	3.18	0.54	35.38	0.327

Table 4. Multivariable analysis with propensity scores for the risk of adverse clinical outcomes. *Statistically significant ($P < 0.05$). OR: odds ratio; CI: confidence interval.

In our cohort, malnutrition and sarcopenia were prevalent and were associated with higher rates of postoperative morbidities, including POPFs. These observations align with existing literature[22], which has demonstrated that patients with pancreatic cancer are at increased risk of malnutrition due to the tumor's metabolic demands and the malabsorption resulting from pancreatic exocrine insufficiency. For example, Pellegrinelli et al.[22] reported that malnourished patients had significantly higher morbidity and longer hospital stays after pancreatoduodenectomy.

Although pancreatic malignancy patients can be treated with chemotherapy, radiation, immunotherapy, and other, pancreaticoduodenectomy still represents the only chance of radical cure for pancreatic head malignancies[23]. With the advent of minimally invasive techniques, both robot-assisted and laparoscopic pancreatic resections have become an integral part of standard surgical practice worldwide over the past decade[24–26]. As the global population ages, the number of elderly patients requiring surgical intervention is increasing, and MIPD is being performed more frequently in this demographic. However, elderly patients face a higher risk of postoperative mortality, with approximately half of the survivors experiencing a significant decline in functional capacity[27]. From this, MIPD is difficult and still has many morbidities. While much of the existing literature has focused

on open pancreatic surgery, our study is among the few that specifically investigate the impact of nutritional status in patients undergoing MIPD. Although the minimally invasive approach is associated with reduced intraoperative blood loss and shorter hospital stays, it does not mitigate the increased risks associated with malnutrition. Indeed, our findings indicate that patients with poor nutritional status continue to experience significant postoperative complications, highlighting the importance of preoperative nutritional optimization, irrespective of the surgical technique used.

Although prior research[28] has evaluated the impact of nutritional interventions in other types of surgery, there is limited data specifically addressing how malnutrition and sarcopenia affect outcomes in patients undergoing MIPD. The concept of sarcopenia was first proposed by Irwin H. Roth of Tufts University in 1989[29], and sarcopenia might be predictive for postoperative pancreatic fistula after MIPD[30–34]. POPFs, delayed gastric emptying, bile leak and postoperative hemorrhage were reported in 20.9%, 5.5%, 3.5% and 6.0% of patients respectively[7,35]. POPFs were generally associated with pancreatic thickness, duct diameter, and patient factors[36], among which the management of patients' nutritional status is an important factor affecting POPFs.

Currently, there are numerous preoperative nutritional assessment methods; however, selecting an appropriate and effective approach is crucial for optimizing preoperative preparation[37]. Given that all patients undergoing MIPD routinely undergo abdominal imaging, including CT and magnetic resonance imaging (MRI), sarcopenia can be readily assessed during these procedures.

In this study, the incidence of malnutrition in MIPD patients was 84.1%, compared with other studies[8], the incidence of malnutrition before pancreatic malignant tumors was 75.7%. Moreover, the incidence of malnutrition was notably higher in patients with tumors located in the pancreatic head. In addition, despite the average body mass index (BMI) of patients being 22.7, indicating no apparent underweight status, the sarcopenia diagnosis rate reached 32.9%. This finding suggests that sarcopenia is not confined to underweight individuals, a significant number of Chinese patients may present with sarcopenic obesity (SO)[38]. Sarcopenia was strongly associated with postoperative morbidity/mortality ($P = 0.002$), which is consistent with the findings of Menozzi et al. We recommend preoperative sarcopenia assessments for patients with pancreaticoduodenal disease. Patients at nutritional risk or diagnosed with sarcopenia should receive preoperative nutritional support and exercise interventions[39,40]. Relevant studies[41] have shown that exercise can increase muscle mass and function and reduce systemic inflammation, thereby reducing the symptoms of cachexia and sarcopenia.

The strength of this study lies in its novel description of how the co-existence of malnutrition, particularly sarcopenia, influences short-term outcomes in patients undergoing MIPD. However, there are some potential limitations to the study. First, this is a single-center study, and the small sample size may contribute to the broad confidence intervals, potentially affecting the accuracy. Given potential ethnic and physiological differences between Eastern and Western populations, future multicenter studies are essential to validate these findings. Moreover, concurrent screening for both conditions was not conducted. Further research should prioritise the development of simple and accessible screening tools. Finally, prospective studies are necessary to specifically target the optimisation of preoperative nutritional status.

Conclusions

The results of this study suggest that preoperative sarcopenia in patients with MIPD affects postoperative morbidity and major complications. Therefore, sarcopenia and nutritional status assessment should be part of routine preoperative procedures. Strengthening nutritional therapy for MIPD patients maybe can reduce the incidence of postoperative morbidities. Furthermore, in patients with MIPD, proper and appropriate identification and management of CRM is a key clinical concern, and in particular, assessment of sarcopenia with CT should also be performed.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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References

1. Staerkle RF, Vuille-Dit-Bille RN, Soll C, Troller R, Samra J, Puhan MA, Breitenstein S: Extended lymph node resection versus standard resection for pancreatic and periampullary adenocarcinoma. *Cochrane Database Syst Rev* 2021, **1**(1):CD011490.
2. Mizrahi, J. D., Surana, R., Valle, J. W. & Shroff, R. T. Pancreatic cancer. *Lancet* **395**(10242), 2008–2020 (2020).
3. Tazeoglu, D., Benli, S., Colak, T. & Apaydin, F. D. Comparative analysis of the sarcopenia and HALP score on postoperative outcomes in pancreatic cancer patients after pancreatoduodenectomy. *Pancreatology* **23**(5), 530–536 (2023).
4. Fuks, D. Minimally invasive pancreatoduodenectomy. *Br J Surg* **107**(6), 630–631 (2020).
5. Zhu, J., Wang, G., Du, P., He, J. & Li, Y. Minimally Invasive Pancreaticoduodenectomy in Elderly Patients: Systematic Review and Meta-Analysis. *World J Surg* **45**(4), 1186–1201 (2021).
6. Zhang, Q.-H. et al. Sarcopenia adversely impacts clinical outcomes in patients undergoing pancreaticoduodenectomy: A systematic review and meta-analysis. *World J Gastrointest Surg* **16**(6), 1857–1870 (2024).
7. Ding, J., Zhang, C., Huang, D. & Zhang, Y. The state of minimally invasive pancreaticoduodenectomy in Chinese mainland: A systematic literature review. *Biosci Trends* **13**(6), 488–501 (2020).
8. Menozzi R, Valoriani F, Ballarin R, Alemanno L, Vinciguerra M, Barbieri R, Cuoghi Costantini R, D'Amico R, Torricelli P, Pecchi A: Impact of Nutritional Status on Postoperative Outcomes in Cancer Patients following Elective Pancreatic Surgery. *Nutrients* 2023, **15**(8).
9. Cruz-Jentoft, A. J. et al. Sarcopenia: revised European consensus on definition and diagnosis. *Age Ageing* **48**(1), 16–31 (2019).
10. Kiss, N. et al. Low muscle mass, malnutrition, sarcopenia, and associations with survival in adults with cancer in the UK Biobank cohort. *J Cachexia Sarcopenia Muscle* **14**(4), 1775–1788 (2023).

11. Aoki, Y. et al. Influence of sarcopenia as defined by EWGSOP2 on complications after pancreaticoduodenectomy and on the prognosis of pancreatic head cancer: A prospective cohort study. *Nutrition* **99–100**, 111660 (2022).
12. Peng, Y.-C. et al. Preoperative sarcopenia is associated with poor overall survival in pancreatic cancer patients following pancreaticoduodenectomy. *Eur Radiol* **31**(4), 2472–2481 (2021).
13. Ryu, Y. et al. The effects of sarcopenia and sarcopenic obesity after pancreaticoduodenectomy in patients with pancreatic head cancer. *HPB (Oxford)* **22**(12), 1782–1792 (2020).
14. Utsumi, M. et al. Combination of sarcopenia and systemic inflammation-based markers for predicting the prognosis of patients undergoing pancreaticoduodenectomy for pancreatic cancer. *PLoS One* **19**(6), e0305844 (2024).
15. Juby AG, Mager DR: A review of nutrition screening tools used to assess the malnutrition-sarcopenia syndrome (MSS) in the older adult. *Clin Nutr ESPEN* 2019, **32**.
16. Gümüşsoy, M. et al. Malnutrition-sarcopenia syndrome and all-cause mortality in hospitalized older people. *Clin Nutr* **40**(11), 5475–5481 (2021).
17. Martin, L. et al. Cancer cachexia in the age of obesity: skeletal muscle depletion is a powerful prognostic factor, independent of body mass index. *J Clin Oncol* **31**(12), 1539–1547 (2013).
18. Cederholm, T. et al. GLIM criteria for the diagnosis of malnutrition - A consensus report from the global clinical nutrition community. *Clin Nutr* **38**(1), 1–9 (2019).
19. Bassi, C. et al. The 2016 update of the International Study Group (ISGPS) definition and grading of postoperative pancreatic fistula: 11 Years After. *Surgery* **161**(3), 584–591 (2017).
20. Clavien, P. A. et al. The Clavien-Dindo classification of surgical complications: five-year experience. *Ann Surg* **250**(2), 187–196 (2009).
21. Asbun HJ, Moekotte AL, Vissers FL, Kunzler F, Cipriani F, Alseidi A, D'Angelica MI, Balduzzi A, Bassi C, Björnsson B *et al*: The Miami International Evidence-based Guidelines on Minimally Invasive Pancreas Resection. *Ann Surg* 2020, **271**(1).
22. Pellegrinelli A, Mancin S, Brolese A, Marcucci S, Roat O, Morenghi E, Morales Palomares S, Cattani D, Lopane D, Dacomi A *et al*: Impact of Preoperative Malnutrition on Patients with Pancreatic Neoplasms Post-Duodenopancreatectomy: A Retrospective Cohort Study. *Nutrients* 2024, **16**(12).
23. Kelliher, L. J. S. & Krige, A. Anaesthesia for Pancreatic Surgery. *Anesthesiology Clinics* **40**(1), 107–117 (2022).
24. Rodríguez-Sanjuán, J. C. et al. Laparoscopic and robot-assisted laparoscopic digestive surgery: Present and future directions. *World J Gastroenterol* **22**(6), 1975–2004 (2016).
25. Sheetz, K. H., Claflin, J. & Dimick, J. B. Trends in the Adoption of Robotic Surgery for Common Surgical Procedures. *JAMA Network Open* **3**(1), e1918911–e1918911 (2020).
26. Guni, A., Varma, P., Zhang, J., Fehervari, M. & Ashrafian, H. Artificial Intelligence in Surgery: The Future Is Now. *European Surgical Research* **65**(1), 22–39 (2024).
27. Suwanabol, P. A. et al. Functional and Cognitive Decline Among Older Adults After High-risk Surgery. *Ann Surg* **275**(1), e132–e139 (2022).
28. Jing, W. et al. Early oral feeding versus nasojejunal early enteral nutrition in patients following pancreaticoduodenectomy: a propensity score-weighted analysis of 428 consecutive patients. *Int J Surg* **110**(1), 229–237 (2024).
29. Rolland Y, Czerwinski S, Abellan Van Kan G, Morley JE, Cesari M, Onder G, Woo J, Baumgartner R, Pillard F, Boirie Y *et al*: Sarcopenia: its assessment, etiology, pathogenesis, consequences and future perspectives. *J Nutr Health Aging* 2008, **12**(7):433–450.
30. Cai, Z., Yang, Y., Fu, X., Mao, L. & Qiu, Y. Predictive Value of Body Composition Parameters for Postoperative Complications in Patients Who Received Pancreaticoduodenectomy. *Eur Surg Res* **64**(2), 252–260 (2023).
31. Hayashi, H. et al. A new fistula risk score using sarcopenic obesity and subcutaneous fat area for predicting postoperative pancreatic fistula after pancreaticoduodenectomy. *J Hepatobiliary Pancreat Sci* **30**(6), 792–801 (2023).
32. Jang, M. et al. Predictive value of sarcopenia and visceral obesity for postoperative pancreatic fistula after pancreaticoduodenectomy analyzed on clinically acquired CT and MRI. *Eur Radiol* **29**(5), 2417–2425 (2019).
33. La Vaccara, V. et al. Role of preoperative sarcopenia in predicting postoperative complications and survival after pancreatoduodenectomy for pancreatic cancer. *Ann Ital Chir* **94**, 45–51 (2023).
34. Linder, N. et al. Power of computed-tomography-defined sarcopenia for prediction of morbidity after pancreaticoduodenectomy. *BMC Med Imaging* **19**(1), 32 (2019).
35. Fahlbusch, T. et al. Impact of pylorus preservation on delayed gastric emptying after pancreaticoduodenectomy—analysis of 5,000 patients based on the German StuDoQ|Pancreas-Registry. *Gland Surgery* **11**(1), 67–76 (2022).
36. Ecker, B. L. et al. Risk Factors and Mitigation Strategies for Pancreatic Fistula After Distal Pancreatectomy: Analysis of 2026 Resections From the International, Multi-institutional Distal Pancreatectomy Study Group. *Ann Surg* **269**(1), 143–149 (2019).
37. Probst, P. et al. Prospective trial to evaluate the prognostic value of different nutritional assessment scores in pancreatic surgery (NURIMAS Pancreas). *Br J Surg* **104**(8), 1053–1062 (2017).
38. Anand, A. C. Nutrition and Muscle in Cirrhosis. *Journal of Clinical and Experimental Hepatology* **7**(4), 340–357 (2017).
39. Rovesti G, Valoriani F, Rimini M, Bardasi C, Ballarin R, Di Benedetto F, Menozzi R, Dominici M, Spallanzani A: Clinical Implications of Malnutrition in the Management of Patients with Pancreatic Cancer: Introducing the Concept of the Nutritional Oncology Board. *Nutrients* 2021, **13**(10).
40. Gianotti, L. et al. Nutritional support and therapy in pancreatic surgery: A position paper of the International Study Group on Pancreatic Surgery (ISGPS). *Surgery* **164**(5), 1035–1048 (2018).
41. Tsukagoshi, M. et al. Impact of preoperative nutritional support and rehabilitation therapy in patients undergoing pancreaticoduodenectomy. *International Journal of Clinical Oncology* **26**(9), 1698–1706 (2021).

Author contributions

ZYX and CJT conceived and designed the experiment. ZYX ran the analysis and verified the underlying data. ZYX, CJT and LO wrote the original manuscript. ZYC and MYP involved in data interpretation. All authors have read and approved the final version of the manuscript.

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Declarations

Competing interests

The authors declare no competing interests.

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