World Journal of Surgical Oncology

RESEARCH

Open Access

Evaluating the surgical and oncological outcomes of hepatic artery variations in minimally invasive pancreaticoduodenectomy: insights from 2023 data at a high-volume pancreatic center

Tianyu Li[1†], Liangbo Dong[1†], Dongming Zhang[2], Jiashu Han[1], Menghua Dai[1], Junchao Guo[1], Qiang Xu[1], Weibin Wang[1*], Xianlin Han[1*] and Chen Lin[1*]

Abstract

Background Minimally invasive pancreaticoduodenectomy (MIPD) has seen increased adoption due to advancements in surgical techniques and technology. However, the impact of hepatic artery variations (HAV) and clinically relevant HAV (CR-HAV) on MIPD outcomes remains under-investigated. This study aims to explore the differences in surgical and oncological outcomes of MIPD with or without HAV and CR-HAV.

Methods We enrolled 267 consecutive patients who underwent MIPD at Peking Union Medical College Hospital between January and December 2023. HAV was identified preoperatively through enhanced abdominal CT and three-dimensional reconstruction, and classified according to the Michels and Hiatt systems. Clinically relevant hepatic artery variations (CR-HAV) were defined based on their potential impact on the surgical approach. We collected and analyzed perioperative data and oncological outcomes between patients with and without HAV and CR-HAV. Propensity score matching (PSM) was used to minimize baseline confounding. Survival analysis was performed using the Kaplan-Meier method with log-rank tests.

Results HAV was identified in 26.1% of patients, and CR-HAV in 18.9%. The median operation time was significantly longer in HAV (+) group compared to HAV (-) group (6.72 vs. 5.80 h, $p=0.013$). No significant differences were found

†Tianyu Li and Liangbo Dong contributed equally to this work.

*Correspondence:
Weibin Wang
wwb_xh@163.com
Xianlin Han
hanxianlin@pumch.cn
Chen Lin
linchen0818@sina.com

Full list of author information is available at the end of the article

between HAV/CR-HAV (+) and (-) groups regarding intraoperative blood loss, conversion to laparotomy, postoperative complications, surgical mortality, length of stay, re-operation, and re-admission. Kaplan-Meier survival analysis showed no significant differences in overall survival or progression-free survival between HAV/CR-HAV (+) and (-) groups in the malignant cohort.

Conclusion HAV and CR-HAV do not significantly impact overall or progression-free survival in patients undergoing MIPD. While HAV is associated with longer operation times, other perioperative and oncological outcomes remain comparable between HAV/CR-HAV (+) and (-) groups.

Keywords Hepatic artery variation, Minimally invasive pancreaticoduodenectomy, Robotic surgery, Overall survival, Progression-free survival, Surgical outcomes

Introduction

The pancreaticoduodenal region features a complex anatomy that is intricately connected to the surrounding vasculature. Hepatic artery variation (HAV) is a common event with an incidence of 20–45% [1–7]. Surgical damage to the variant hepatic artery can compromise liver perfusion, resulting in ischemic complications of the liver and bile duct, such as liver abscess, biliary fistula, and even liver failure [2, 8]. The application of minimally invasive techniques to major and complex procedures, such as pancreaticoduodenectomy, presents significant technical challenges for surgeons, particularly in cases involving complex anatomical anomalies, such as hepatic artery variations [9].

The identification of HAV during MIPD presents unique challenges when comparing to open pancreaticoduodenectomy (OPD) [6, 10]. While MIPD is associated with restricted maneuverability of instruments within the abdominal cavity and the inability to palpate the arterial pulse during operation, it offers improved visualization in certain instances. For example, MIPD enables surgeons to get up close to the tissues and provides better angles in specific situations. During kocherization, the duodenum can be visualized more clearly, and when creating the retropancreatic tunnel, surgeons can often look through the tunnel directly. However, these advantages are counterbalanced by challenges such as limited tactile feedback and difficulties in managing unexpected anatomical variations. These factors may complicate the accurate identification and preservation of HAV, potentially increasing the likelihood of inadvertent vascular injury compared to OPD [6]. In contrast, OPD allows for direct and extensive visualization of the surgical field, and provides surgeons with greater flexibility to adapt and modify the surgical approach based on real-time findings, thereby facilitating the preservation of anatomical variations. These challenges of MIPD necessitate reliance on enhanced preoperative imaging and meticulous surgical planning in order to accurately identify HAV [11].

In recent years, MIPD has experienced rapid advancements driven by significant improvements in laparoscopic and robotic surgical technologies [12, 13]. Additionally, increased surgeon expertise and refined surgical techniques have contributed to the growing adoption and success of MIPD [14]. These advancements have collectively resulted in improved patient outcomes, including reduced postoperative pain, shorter hospital stays, and faster recovery times [15–17], making MIPD an increasingly viable and preferred option for complex pancreatic surgeries. To date, there are limited articles investigating the impact of HAV and clinically relevant hepatic artery variation (CR-HAV) on MIPD. Given the rapid advancement of minimally invasive surgical techniques at our center in recent years, particularly in robotic surgery, we selected data from the most recent year to explore the differences in surgical and oncological outcomes of MIPD with or without HAV.

Materials and methods

Study population and design

Two hundred and sixty-seven consecutive patients who underwent MIPD (Laparoscopic or robotic PD) in PUMCH between January 2023 and December 2023 were enrolled from a prospectively maintained database. The research flowchart was shown in Fig. 1. The inclusion and exclusion criteria were as outlined below. Inclusion criteria: Patients with resectable periampullary or pancreatic tumor undergoing MIPD. Exclusion criterion: [1] Immediate conversion to open surgery after laparoscopic or robotic exploration; [2] Important clinical data missing. A total of 238 patients were finally included in the study. This study was approved by the Ethics Committee of Peking Union Medical College Hospital and was conducted in accordance with the Declaration of Helsinki (as revised in 2013). Written informed consent was obtained from all patients participating in the study.

Vascular anatomy was meticulously evaluated using abdominal enhanced computed tomography (CT) and three-dimensional reconstruction. Each HAV was precisely identified preoperatively by experienced surgeons and radiologists, confirmed intraoperatively, and promptly recorded postoperatively at our database based on the Michels classification [18] and Hiatt classification [1]. We defined replaced vascular variations that might

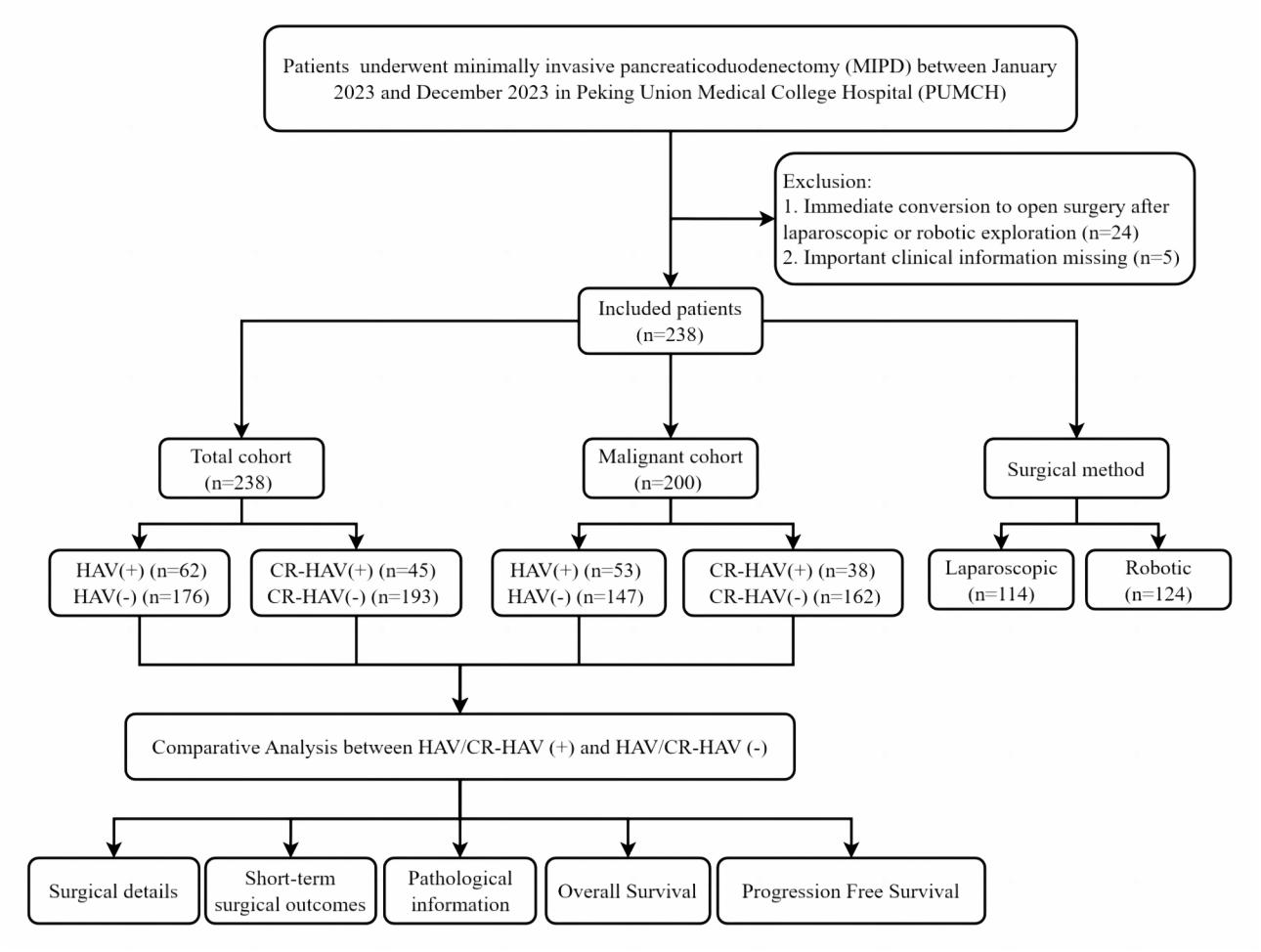

Fig. 1 Research flowchart of this study

influence surgical approach, intraoperative decision-making, and surgical complications as clinically relevant hepatic artery variations (CR-HAV). Specifically, these are classified under Michels classification types II, III, IV, VIII, IX, X. In addition to the total cohort, we created a separate group for patients with malignant pathology. Each cohort was then categorized based on the presence of HAV and CR-HAV. All perioperative information, including patient demographics, surgical details, postoperative complication, pathologic information, and survival outcomes were collected and analyzed between HAV/CR-HAV and non-HAV/CR-HAV groups.

Operative technique

All the robotic pancreaticoduodenectomy (RPD) were carried out with the assistance of da Vinci Robotic Surgical System (Intuitive Surgical, Inc., Sunnyvale, CA, USA). Five small incisions are made for the insertion of robotic trocars, after which the surgical robot is docked. All surgical procedures including tumor resection and gastrointestinal anastomosis were performed using similar techniques. The surgical details of MIPD have been described in detail in our previous study [19].

Study endpoints

The primary endpoints of this study were to assess the safety and feasibility of MIPD in patients with HAV. This involved evaluating surgical parameters such as operation time, blood loss, conversion to open surgery, and postoperative outcomes including complications and hospital stay. Secondary objectives included examining the pathological information, including resection margin, number of lymph nodes sampled, and survival outcomes of MIPD in patients with and without HAV.

Variables and definitions

The Severity grading of postoperative complications were classified according to the Clavien-Dindo classification [20]. Postoperative pancreatic fistula (POPF) was defined based on the 2016 International Study Group of Pancreatic Surgery (ISGPS) classification [21]. Delayed gastric emptying (DGE) [22] and postpancreatectomy

Table 1 Detailed hepatic variations of HAV group and CR-HAV group based on Michels and Hiatt classification

	Total cohort (*n* = 238)	Hepatic artery variation (*n* = 62)	Clinically relevant hepatic artery variation (*n* = 45)
Michels type			
I	176 (73.95%)	0 (0.00%)	0 (0.00%)
II	10 (4.20%)	10 (16.13%)	9 (20.00%)
III	20 (8.40%)	20 (32.26%)	20 (44.44%)
V	10 (4.20%)	10 (16.13%)	5 (11.11%)
VI	2 (0.84%)	2 (3.23%)	0 (0.00%)
VIII	2 (0.84%)	2 (3.23%)	0 (0.00%)
IX	9 (3.78%)	9 (14.52%)	9 (20.00%)
Other	9 (3.78%)	9 (14.52%)	2 (4.44%)
Hiatt type			
I	177 (74.37%)	0 (0.00%)	0 (0.00%)
II	22 (9.24%)	22 (35.48%)	10 (22.22%)
III	24 (10.08%)	25 (40.32%)	21 (46.67%)
IV	5 (2.10%)	5 (8.07%)	4 (8.89%)
V	10 (4.20%)	10 (16.13%)	10 (22.22%)

hemorrhage (PPH) [23] was defined based on the 2007 ISGPS classification. Bile leakage was defined according to the 2011 International Study Group of Liver Surgery classification [24]. Resection radicality was categorized into three groups based on the tumor status of the resection margins: R0, no macroscopic and microscopic evidence of residual tumor at the resection margin; R1, microscopic residual tumor; R2, residual tumor [25].

Statistical analysis

Statistical analysis was performed by R software (version 4.2.1). T test or Mann-Whitney U test was applied for continuous variables, which were presented as mean ± standard deviation (SD) and median (range). Fisher's exact test or chi-square test was applied for categorical variables. Perioperative parameters description and differential analysis were performed by R package comparegroups. We conducted propensity score matching (PSM) to minimize confounding and balance baseline characteristics between the HAV/CR-HAV (-) and HAV/CR-HAV (+) groups. A random seed of 12,345 was used to ensure reproducibility. Variables with a standardized mean difference (SMD) greater than 0.1 were selected as covariates to construct the propensity score model. Matching was performed using the nearest neighbor method, with a caliper width equal to 0.2 times the standard deviation of the propensity score. The matching ratio was set to 2:1. Survival curves were plotted by the Kaplan–Meier method and the log-rank test was applied to compare statistical differences between the survival curves. A two-sided p-value < 0.05 was considered statistically significant.

Table 2 Unclassified variations in the Michels classification

Other (Michel type)	Anatomy	*n* (%)
	Accessory RHA from GDA	2 (22.2%)
	Replaced RHA from CA	2 (22.2%)
	Replaced LHA from LGA and Replaced CHA from SMA	1 (11.1%)
	Replaced RHA from GDA	1 (11.1%)
	Accessory RHA from CA	1 (11.1%)
	Replaced LHA from replaced LGA (LGA from AA)	1 (11.1%)
	Accessory LHA from CHA and Replaced LHA from LGA	1 (11.1%)

Results

Patient cohorts

A total of 238 patients with periampullary lesions undergoing MIPD were enrolled in our study. The incidence of HAV was 26.1% and CR-HAV was 18.9%. Detailed variation information According to the Michels and Hiatt classification. Detailed variation information of total cohort according to the Michels classification and Hiatt classification is given in Table 1. Among them, 9 patients were not defined by Michels classification, as shown in Table 2.

Baseline characteristics

Baseline characteristics of the total cohort (benign and malignant) (*n* = 238) and malignant cohort (*n* = 200) of patients undergoing MIPD were presented in Table S1 and Table 3. Variables such as gender, age, body mass index (BMI), tumor location, American Society of Anesthesiologists (ASA) classification, neoadjuvant therapy, hypertension, diabetes, history of abdominal surgery, history of pancreatitis, preoperative biliary drainage, and surgical method showed no significant differences between HAV (+) and (-) groups, as well as CR-HAV (+) and (-) groups.

Surgical outcomes

As shown in Table S2 and Table 4, in the total cohort, the median operation time was significantly longer by nearly one hour in HAV (+) patients compared to HAV (-), with times of 6.72 and 5.80 h in the two groups, respectively ($p = 0.013$). The median operation time in CR-HAV (+) patients was 6.75 h, which was longer than the 5.90 h observed in CR-HAV (-) patients, but there was no significant difference between the two groups ($p = 0.067$). Similarly, in the malignant cohort, the median operation time was also significantly longer in HAV (+) patients than in the HAV (-) group ($p = 0.014$). However, no significant difference was observed in the CR-HAV (+) and CR-HAV (-) groups ($p = 0.119$). There was no significant difference between the CR-HAV/HAV (+) and (-) patients regarding intraoperative blood transfusion, blood loss, conversion

Table 3 Baseline characteristics of the total cohort (benign and malignant) and malignant cohort of patients with or without clinically relevant hepatic artery variation (CR-HAV)

	Total cohort (Malignant and benign)				Malignant cohort			
		CR-HAV				CR-HAV		
Variables	**Total cohort (*N* = 238)**	**No (*n* = 193)**	**Yes (*n* = 45)**	***p***	**Total cohort (*N* = 200)**	**No (*n* = 162)**	**Yes (*n* = 38)**	***p***
Gender				0.159				0.313
Female	102 (42.86%)	78 (40.41%)	24 (53.33%)		88 (44.00%)	68 (41.98%)	20 (52.63%)	
Male	136 (57.14%)	115 (59.59%)	21 (46.67%)		112 (56.00%)	94 (58.02%)	18 (47.37%)	
Age, years [Median (Q1, Q3)]	60.00 [54.00;68.00]	60.00 [54.00;68.00]	59.00 [56.00;69.00]	0.744	62.00 [56.00;69.00]	61.50 [56.00;69.00]	65.00 [57.00;69.00]	0.629
BMI, kg/m^2 (Mean ± SD)	22.34 ± 3.02	22.44 ± 3.08	21.94 ± 2.76	0.297	22.23 ± 3.01	22.29 ± 3.05	21.96 ± 2.88	0.522
Tumor location				0.597				0.533
Common bile duct	27 (11.34%)	23 (11.92%)	4 (8.89%)		26 (13.00%)	22 (13.58%)	4 (10.53%)	
Duodenum	24 (10.08%)	20 (10.36%)	4 (8.89%)		22 (11.00%)	18 (11.11%)	4 (10.53%)	
Pancreas	141 (59.24%)	116 (60.10%)	25 (55.56%)		107 (53.50%)	89 (54.94%)	18 (47.37%)	
Vater's Ampulla	46 (19.33%)	34 (17.62%)	12 (26.67%)		45 (22.50%)	33 (20.37%)	12 (31.58%)	
ASA classification				0.295				0.125
1	8 (3.36%)	6 (3.11%)	2 (4.44%)		6 (3.00%)	4 (2.47%)	2 (5.26%)	
2	174 (73.11%)	137 (70.98%)	37 (82.22%)		142 (71.00%)	111 (68.52%)	31 (81.58%)	
3	55 (23.11%)	49 (25.39%)	6 (13.33%)		51 (25.50%)	46 (28.40%)	5 (13.16%)	
4	1 (0.42%)	1 (0.52%)	0 (0.00%)		1 (0.50%)	1 (0.62%)	0 (0.00%)	
Neoadjuvant therapy				0.440				0.441
No	227 (95.38%)	185 (95.85%)	42 (93.33%)		189 (94.50%)	154 (95.06%)	35 (92.11%)	
Yes	11 (4.62%)	8 (4.15%)	3 (6.67%)		11 (5.50%)	8 (4.94%)	3 (7.89%)	
Hypertension				1.000				1.000
No	156 (65.55%)	127 (65.80%)	29 (64.44%)		127 (63.50%)	103 (63.58%)	24 (63.16%)	
Yes	82 (34.45%)	66 (34.20%)	16 (35.56%)		73 (36.50%)	59 (36.42%)	14 (36.84%)	
Diabetes				0.749				0.837
No	166 (69.75%)	136 (70.47%)	30 (66.67%)		137 (68.50%)	112 (69.14%)	25 (65.79%)	
Yes	72 (30.25%)	57 (29.53%)	15 (33.33%)		63 (31.50%)	50 (30.86%)	13 (34.21%)	
History of abdominal surgery				1.000				0.926
No	208 (87.39%)	169 (87.56%)	39 (86.67%)		172 (86.00%)	140 (86.42%)	32 (84.21%)	
Yes	30 (12.61%)	24 (12.44%)	6 (13.33%)		28 (14.00%)	22 (13.58%)	6 (15.79%)	
History of pancreatitis				0.596				0.213
No	212 (89.08%)	173 (89.64%)	39 (86.67%)		181 (90.50%)	149 (91.98%)	32 (84.21%)	
Yes	26 (10.92%)	20 (10.36%)	6 (13.33%)		19 (9.50%)	13 (8.02%)	6 (15.79%)	
Biliary Drainage				0.934				0.844
No	152 (63.87%)	124 (64.25%)	28 (62.22%)		116 (58.00%)	95 (58.64%)	21 (55.26%)	
Yes	86 (36.13%)	69 (35.75%)	17 (37.78%)		84 (42.00%)	67 (41.36%)	17 (44.74%)	
Surgical method				0.179				0.291
Laparoscopic	114 (47.90%)	97 (50.26%)	17 (37.78%)		97 (48.50%)	82 (50.62%)	15 (39.47%)	
Robotic	124 (52.10%)	96 (49.74%)	28 (62.22%)		103 (51.50%)	80 (49.38%)	23 (60.53%)	

to laparotomy, lCU stays, postoperative complications, surgical mortality, length of stay, re-operation, re-admission, harvested lymph nodes, and resection margin. Similarly, after PSM, no significant differences were observed between CR-HAV (+) and CR-HAV (-) groups in surgical outcomes (Table S3).

Survival analysis

In the malignant cohort, 172 patients were included in the survival analysis. Among them, 47 patients had HAV and 34 patients had CR-HAV. The mean follow-up period was 10.3 mouths. Only 11 patients were dead by the last follow-up. We illustrated the Kaplan-Meier survival curves comparing overall survival (OS) and progression-free survival (PFS) among patients with and without HAV and CR-HAV. In Fig. 2A, the OS between patients with HAV (+) and HAV (-) groups showed no significant difference (log-rank $P = 0.773$; HR = 1.199, 95% CI: 0.349–4.120). Similarly, Fig. 2B indicated no significant difference in OS between CR-HAV (+) and CR-HAV (-) patients (log-rank $P = 0.200$; HR = 2.188, 95% CI: 0.640–7.481). Figure 2C and D presented the PFS, where

Table 4 Surgical outcomes of the total cohort and malignant cohort of patients with or without clinically relevant hepatic artery variation (CR-HAV)

	Total cohort (Malignant and benign)				Malignant cohort			
		CR-HAV				CR-HAV		
Variables	**Total cohort (*N* = 238)**	**No (*n* = 193)**	**Yes (*n* = 45)**	***p***	**Total cohort (*N* = 200)**	**No (*n* = 162)**	**Yes (*n* = 38)**	***p***
Operative blood loss, ml	200.00 [100.00;500.00]	200.00 [100.00;500.00]	300.00 [150.00;500.00]	0.253	200.00 [100.00;500.00]	200.00 [100.00;500.00]	250.00 [150.00;475.00]	0.431
Operative time, hour	6.00 [4.43;7.30]	5.90 [4.30;7.25]	6.75 [5.40;7.50]	0.067	6.00 [4.30;7.30]	5.80 [4.30;7.30]	6.65 [5.20;7.65]	0.119
Conversion to laparotomy				0.183				0.262
No	212 (89.08%)	169 (87.56%)	43 (95.56%)		178 (89.00%)	142 (87.65%)	36 (94.74%)	
Yes	26 (10.92%)	24 (12.44%)	2 (4.44%)		22 (11.00%)	20 (12.35%)	2 (5.26%)	
Clavien-Dindo ≥ 3a				0.901				0.612
No	205 (86.13%)	167 (86.53%)	38 (84.44%)		171 (85.50%)	140 (86.42%)	31 (81.58%)	
Yes	33 (13.87%)	26 (13.47%)	7 (15.56%)		29 (14.50%)	22 (13.58%)	7 (18.42%)	
Pancreatic fistula (Grades B/C)				0.909				0.618
No	184 (77.31%)	150 (77.72%)	34 (75.56%)		151 (75.50%)	124 (76.54%)	27 (71.05%)	
Yes	54 (22.69%)	43 (22.28%)	11 (24.44%)		49 (24.50%)	38 (23.46%)	11 (28.95%)	
DGE (Grades B/C)				0.494				0.920
No	201 (84.45%)	161 (83.42%)	40 (88.89%)		170 (85.00%)	137 (84.57%)	33 (86.84%)	
Yes	37 (15.55%)	32 (16.58%)	5 (11.11%)		30 (15.00%)	25 (15.43%)	5 (13.16%)	
PPH (Grades B/C)				0.764				0.753
No	219 (92.02%)	178 (92.23%)	41 (91.11%)		182 (91.00%)	148 (91.36%)	34 (89.47%)	
Yes	19 (7.98%)	15 (7.77%)	4 (8.89%)		18 (9.00%)	14 (8.64%)	4 (10.53%)	
Biliary fistula (Grades B/C)				1.000				1.000
No	231 (97.06%)	187 (96.89%)	44 (97.78%)		193 (96.50%)	156 (96.30%)	37 (97.37%)	
Yes	7 (2.94%)	6 (3.11%)	1 (2.22%)		7 (3.50%)	6 (3.70%)	1 (2.63%)	
Length of stay, days	17.00 [14.00;22.75]	17.00 [14.00;24.00]	16.00 [13.00;22.00]	0.385	17.00 [14.00;24.00]	17.00 [14.00;24.00]	17.00 [13.00;22.75]	0.533
In-hospital death								
No	238 (100.00%)	193 (100.00%)	45 (100.00%)	.	200 (100.00%)	162 (100.00%)	38 (100.00%)	.
Re-operation				1.000				1.000
No	235 (98.74%)	190 (98.45%)	45 (100.00%)		197 (98.50%)	159 (98.15%)	38 (100.00%)	
Yes	3 (1.26%)	3 (1.55%)	0 (0.00%)		3 (1.50%)	3 (1.85%)	0 (0.00%)	
Re-admission				0.493				0.276
No	223 (93.70%)	182 (94.30%)	41 (91.11%)		187 (93.50%)	153 (94.44%)	34 (89.47%)	
Yes	15 (6.30%)	11 (5.70%)	4 (8.89%)		13 (6.50%)	9 (5.56%)	4 (10.53%)	
Positive lymph nodes	0.00 [0.00;2.00]	0.00 [0.00;1.00]	0.00 [0.00;2.00]	0.192	0.00 [0.00;2.00]	0.00 [0.00;2.00]	1.00 [0.00;2.75]	0.137
Harvested lymph nodes	19.00 [12.00;26.00]	19.00 [12.00;26.00]	18.00 [13.00;23.00]	0.543	19.00 [13.00;26.00]	19.50 [13.00;26.75]	18.00 [13.00;22.75]	0.419
R1 resection				0.194				0.194
No	222 (93.28%)	182 (94.30%)	40 (88.89%)		184 (92.00%)	151 (93.21%)	33 (86.84%)	
Yes	16 (6.72%)	11 (5.70%)	5 (11.11%)		16 (8.00%)	11 (6.79%)	5 (13.16%)	

no significant differences were observed between HAV (+) and HAV (-) patients (log-rank $P = 0.209$; HR = 0.540, 95% CI: 0.203–1.434) or between CR-HAV (+) and CR-HAV (-) patients (log-rank $P = 0.506$; HR = 0.698, 95% CI: 0.240–2.026).

To further analyze the potential impact of clinically relevant hepatic artery variations (CR-HAV) on survival outcomes, PSM was performed. After PSM, Kaplan-Meier survival analysis still revealed no statistically significant differences in OS or PFS between patients with and without CR-HAV. As shown in Supplementary Figure S1A, the OS analysis indicated no significant difference between CR-HAV (+) and CR-HAV (-) groups (log-rank $P = 0.566$; HR = 1.767, 95% CI: 0.247–12.629). Similarly, Supplementary Figure S1B demonstrated no significant difference in PFS between CR-HAV (+) and CR-HAV (-) groups (log-rank $P = 0.985$; HR = 1.013, 95% CI: 0.261–3.930).

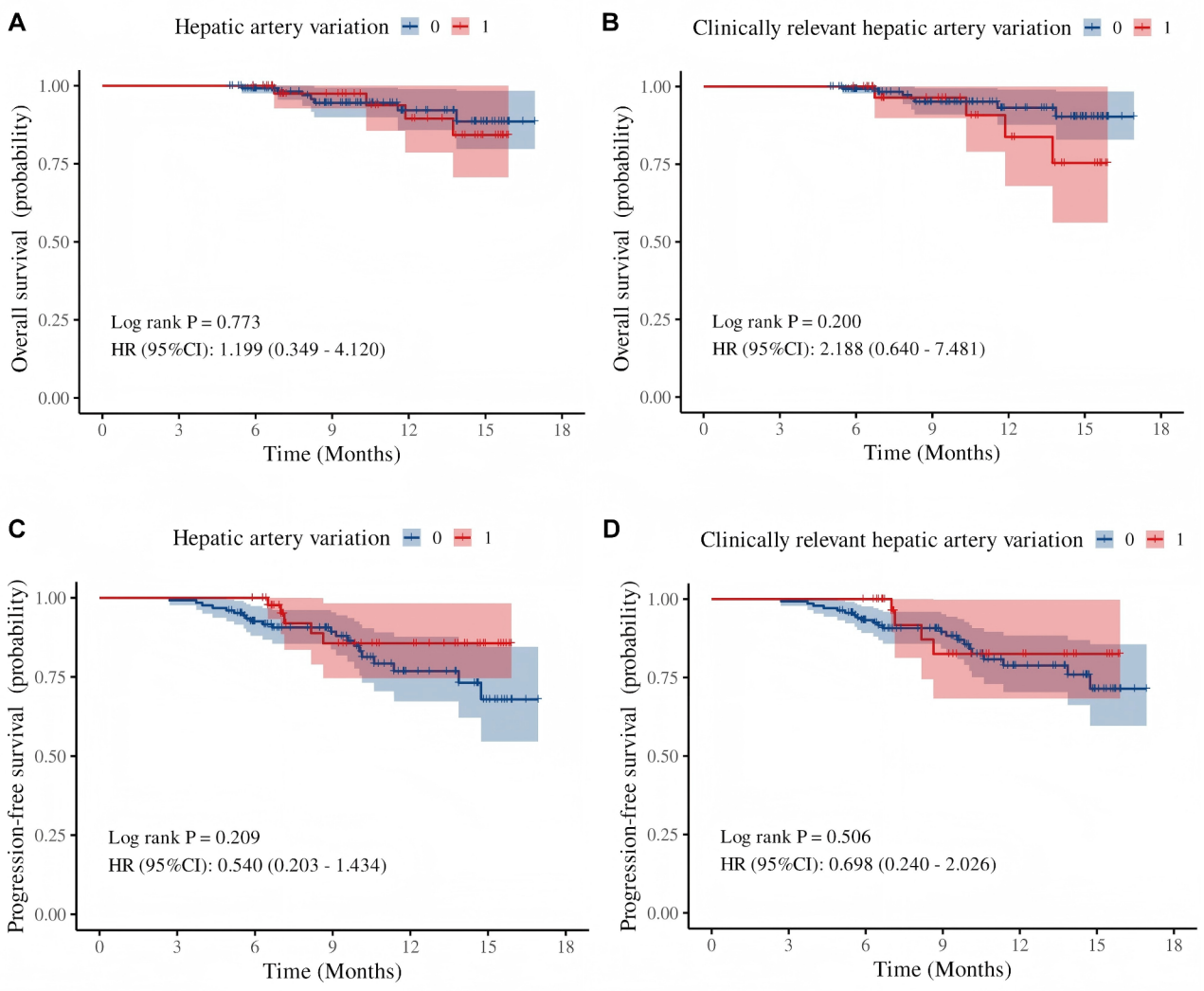

Fig. 2 Kaplan-Meier survival curves that analyze the impact of hepatic artery variation (HAV) and clinically relevant hepatic artery variation (CR-HAV) on both overall survival and progression-free survival among patients in the malignant cohort. (**A**) Overall survival for patients with and without HAV. (**B**) Overall survival for patients with and without CR-HAV. (**C**) Progression-free survival for patients with and without HAV. (**D**) Progression-free survival for patients with and without CR-HAV. The blue line represents patients without HAV/CR-HAV, and the red line represents patients with HAV/CR-HAV. 0, without HAV/CR-HAV; 1, with HAV/CR-HAV

Discussion

Our study underscores the importance of hepatic artery variation (HAV) and clinically relevant hepatic artery variation (CR-HAV) in minimally invasive pancreaticoduodenectomy (MIPD). In our cohort, the incidence of HAV and CR-HAV was 26.1% and 18.9%, respectively, which aligns with previous reports indicating that HAV is relatively common [26]. The presence of HAV poses substantial challenges for surgeons, especially when employing minimally invasive techniques [11, 26]. MIPD is technically demanding due to limited visualization and restricted maneuverability within the abdominal cavity, which complicates the identification and preservation of HAV. This contrasts with open pancreaticoduodenectomy [27], where direct and extensive visualization allows for better adaptability and real-time surgical adjustments. Our study underscores the need for enhanced preoperative imaging and meticulous surgical planning in MIPD to effectively address the risks posed by HAV.

The learning curve for pancreatic surgery varies significantly depending on the type of procedure and the surgeon's prior experience [28]. For robotic pancreaticoduodenectomy (RPD), proficiency generally requires between 20 and 80 case [29–32], with some studies suggesting up to 250 cases for mastery [33]. The learning curve is marked by initial higher estimated blood loss, higher rates of complications and longer operative times, which decrease as experience increases [34, 35]. However, surgeons with substantial prior experience in laparoscopic pancreaticoduodenectomy (LPD) were

shown to safely overcome the RPD learning curve without increasing morbidity during the early phase [36]. The learning curve for LPD also varies significantly, requiring 30 to 70 cases for proficiency [37–40] and mastery often requiring up to 100 cases [38]. Our center has been performing robotic and laparoscopic pancreatic surgeries for over 10 years, with an annual volume exceeding 500 cases in recent 3 years. Having surpassed the learning curve, we selected data from the past year as it represents the period when our surgical techniques are at their best.

The presence of hepatic artery variations often necessitates more complex surgical planning and techniques, which can extend the operation time during robotic pancreaticoduodenectomy [6], hepatectomy [41], and liver transplantation [42, 43]. Similarly, our findings indicate that HAV and CR-HAV significantly extend operation time during MIPD, both in the total cohort and the malignant cohort. This finding reflects the increased complexity and technical challenges posed by HAV, requiring additional time for careful dissection and preservation of the variant arteries. However, other perioperative parameters, including intraoperative blood loss, conversion to laparotomy, postoperative complications, surgical mortality, length of stay, re-operation, re-admission, and pathological indicators such as harvested lymph nodes and resection margin, did not differ significantly between HAV/CR-HAV (+) and (-) groups. Alexakis et al. also reported that HAV does not affect surgical morbidity or resection margin status for patients undergoing pancreatoduodenectomy [44]. Our survival analysis confirms that HAV and CR-HAV have no significant impact on overall or progression-free survival in MIPD patients with malignant periampullary lesions, aligning with findings from previous studies [6, 45]. Despite the increased surgical complexity associated with HAV and CR-HAV, these results suggest that they do not adversely affect other surgical outcomes and oncological outcomes with meticulous preoperative planning and accurately identification of vascular variations.

Although the R1 resection rates in HAV/CR-HAV (+) patients did not reach statistical significance in this study, we observed that the R1 resection rates in these groups were approximately twice as high as those in HAV/CR-HAV (-) groups. This trend may be related to the small sample size and the non-randomized nature of the study, but it remains noteworthy. For patients with HAV/CR-HAV, surgeons should carefully consider the potentially increased risk of R1 resection when deciding whether to perform a minimally invasive Whipple procedure.

To our knowledge, this study is the first to investigate the surgical and oncological impact of HAV/CR-HAV on MIPD. While HAV present significant technical challenges, they do not adversely affect surgical outcomes or long-term survival. The advancements in laparoscopic and robotic surgical technologies, combined with increased surgeon expertise, have made MIPD a viable and preferred option for complex pancreatic surgeries.

One of the limitations of this study is the relatively small sample size, which may restrict the robustness and generalizability of the survival analysis. The results should therefore be considered exploratory, and further research with larger, more diverse cohorts is necessary to validate these findings. Additionally, the follow-up period in this study was relatively short, which limits our ability to assess the long-term outcomes and the full impact of hepatic artery variations (HAV) on patient prognosis. Given the limited sample size and follow-up duration, we caution against overinterpreting the survival outcomes or making broad clinical recommendations based on these results alone. Future studies with larger patient populations and longer follow-up periods will be essential to confirm the long-term impact of HAV on patient outcomes.

Conclusion

In this study, we examined the impact of HAV and CR-HAV on patients with periampullary lesions undergoing MIPD. The incidence rates were 26.1% for HAV and 18.9% for CR-HAV. While HAV (+) patients experienced significantly longer operation times, there were no significant differences in other surgical outcomes or in overall and progression-free survival between HAV/CR-HAV (+) and HAV/CR-HAV (-) patients.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12957-025-03704-6 .

Supplementary Material 1

Author contributions

WWB, HXL, LC designed and guided this study. LTY collected the data, performed statistical analysis, and drafted this manuscript. DLB and LC collected data and revised this manuscript. ZDM collected data on hepatic artery variations. HJS, DMH, GJC and XQ made important data analyzing and revisions to this manuscript. LTY and DLB contributed equally to this work. All authors read and approved the final manuscript.

Funding

This work was supported by the National Natural Science Foundation of China (No. 82173074), Beijing Natural Science Foundation (No. 7232127), the National High Level Hospital Clinical Research Funding (No. 2022-PUMCH-D-001, No. 2022-PUMCH-B-004), the Fundamental Research Funds for Central Universities (No. 3332022114), the CAMS Innovation Fund for Medical Sciences (CIFMS) (No. 2024-I2M-ZD-001), the Nonprofit Central Research Institute Fund of Chinese Academy of Medical Sciences (2018PT32014), and the Peking Union Medical College Hospital Undergraduate Educational Reform Project (No. 2020zlgc0116, No. 2023kcsz004, No. 2024bkjg015).

Data availability

All data analyzed during this study are available from the corresponding author on reasonable request.

Declarations

Ethical approval
This study was approved by the Ethics Committee of Peking Union Medical College Hospital and written informed consent was obtained from all patients. This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). We have obtained consent from all authors and they have agreed to publish the results of this study.

Competing interests
The authors declare no competing interests.

Author details
[1]Department of General Surgery, State Key Laboratory of Complex Severe and Rare Diseases, Peking Union Medical College Hospital, Chinese Academy of Medical Sciences and Peking Union Medical College, Beijing, China
[2]Department of General Surgery, Baotou Central Hospital, Baotou, Inner Mongolia, China

Received: 17 December 2024 / Accepted: 4 February 2025
Published online: 07 February 2025

References

1. Hiatt JR, Gabbay J, Busuttil RW. Surgical anatomy of the hepatic arteries in 1000 cases. Ann Surg. 1994;220(1):50–2.
2. Koops A, Wojciechowski B, Broering DC, Adam G, Krupski-Berdien G. Anatomic variations of the hepatic arteries in 604 selective celiac and superior mesenteric angiographies. Surg Radiol Anat. 2004;26(3):239–44.
3. Noussios G, Dimitriou I, Chatzis I, Katsourakis A. The main anatomic variations of the hepatic artery and their importance in Surgical practice: review of the literature. J Clin Med Res. 2017;9(4):248–52.
4. Nguyen TK, Zenati MS, Boone BA, Steve J, Hogg ME, Bartlett DL, et al. Robotic pancreaticoduodenectomy in the presence of aberrant or anomalous hepatic arterial anatomy: safety and oncologic outcomes. HPB (Oxford). 2015;17(7):594–9.
5. Sayyed R, Baig M, Khan A, Niazi IK, Syed AA, Hanif F. Hepatic arterial system anomalies encountered during pancreaticoduodenectomy - our experience. J Pak Med Assoc. 2020;70(2):337–40.
6. Yu H-H, Wang S-E, Shyr B-S, Chen S-C, Shyr Y-M, Shyr B-U. Impact of hepatic artery variation on surgical and oncological outcomes in robotic pancreaticoduodenectomy. Surg Endosc. 2024.
7. Uraoka M, Funamizu N, Sogabe K, Shine M, Honjo M, Tamura K, et al. Novel embryological classifications of hepatic arteries based on the relationship between aberrant right hepatic arteries and the middle hepatic artery: a retrospective study of contrast-enhanced computed tomography images. PLoS ONE. 2024;19(2):e0299263.
8. Takada S, Uchida H, Hinoki A, Shirota C, Sumida W, Tainaka T, et al. Variations of the hepatic artery and bile duct in patients with pancreaticobiliary maljunction: impact on postoperative outcomes. J Hepatobiliary Pancreat Sci. 2023;30(11):1241–8.
9. Napoli N, Cacace C, Kauffmann EF, Jones L, Ginesini M, Gianfaldoni C, et al. The PD-ROBOSCORE: a difficulty score for robotic pancreatoduodenectomy. Surgery. 2023;173(6):1438–46.
10. Di Meo G, Pontrelli A, Testini M, Boggi U. Intrapancreatic common hepatic artery in pancreatoduodenectomy: a technical note on how to deal with this exceedingly rare arterial variation. Updates Surg. 2024.
11. Xu Y-C, Yang F, Fu D-L. Clinical significance of variant hepatic artery in pancreatic resection: a comprehensive review. World J Gastroenterol. 2022;28(19):2057–75.
12. Kendrick ML, van Hilst J, Boggi U, de Rooij T, Walsh RM, Zeh HJ, et al. Minimally invasive pancreatoduodenectomy. HPB (Oxford). 2017;19(3):215–24.
13. Kim HS, Kim H, Han Y, Lee M, Kang YH, Sohn HJ, et al. ROBOT-assisted pancreatoduodenectomy in 300 consecutive cases: annual trend analysis and propensity score-matched comparison of perioperative and long-term oncologic outcomes with the open method. J Hepatobiliary Pancreat Sci. 2022;29(3):301–10.
14. Fuks D. Minimally invasive pancreatoduodenectomy. Br J Surg. 2020;107(6):630–1.
15. Zhao Z, Yin Z, Hang Z, Ji G, Feng Q, Zhao Q. A systemic review and an updated meta-analysis: minimally invasive vs open pancreaticoduodenectomy. Sci Rep. 2017;7(1):2220.
16. Uijterwijk BA, Wei K, Kasai M, Ielpo B, Hilst Jv, Chinnusamy P, et al. Minimally invasive versus open pancreatoduodenectomy for pancreatic ductal adenocarcinoma: individual patient data meta-analysis of randomized trials. Eur J Surg Oncol. 2023;49(8):1351–61.
17. Kim HS, Kim H, Kwon W, Han Y, Byun Y, Kang JS, et al. Perioperative and oncologic outcome of robot-assisted minimally invasive (hybrid laparoscopic and robotic) pancreatoduodenectomy: based on pancreatic fistula risk score and cancer/staging matched comparison with open pancreatoduodenectomy. Surg Endosc. 2021;35(4):1675–81.
18. Michels NA. Newer anatomy of the liver and its variant blood supply and collateral circulation. Am J Surg. 1966;112(3):337–47.
19. Li T-Y, Qin C, Zhao B-B, Yang X-Y, Li Z-R, Wang Y-Y, et al. Risk stratification of clinically relevant delayed gastric emptying after pancreaticoduodenectomy. BMC Surg. 2023;23(1):222.
20. Clavien PA, Barkun J, de Oliveira ML, Vauthey JN, Dindo D, Schulick RD, et al. The Clavien-Dindo classification of surgical complications: five-year experience. Ann Surg. 2009;250(2):187–96.
21. Bassi C, Marchegiani G, Dervenis C, Sarr M, Abu Hilal M, Adham M, et al. The 2016 update of the International Study Group (ISGPS) definition and grading of postoperative pancreatic fistula: 11 years after. Surgery. 2017;161(3):584–91.
22. Wente MN, Bassi C, Dervenis C, Fingerhut A, Gouma DJ, Izbicki JR, et al. Delayed gastric emptying (DGE) after pancreatic surgery: a suggested definition by the International Study Group of pancreatic surgery (ISGPS). Surgery. 2007;142(5):761–8.
23. Wente MN, Veit JA, Bassi C, Dervenis C, Fingerhut A, Gouma DJ, et al. Postpancreatectomy hemorrhage (PPH): an International Study Group of pancreatic surgery (ISGPS) definition. Surgery. 2007;142(1):20–5.
24. Koch M, Garden OJ, Padbury R, Rahbari NN, Adam R, Capussotti L, et al. Bile leakage after hepatobiliary and pancreatic surgery: a definition and grading of severity by the International Study Group of Liver surgery. Surgery. 2011;149(5):680–8.
25. Hermanek P, Wittekind C. Residual tumor (R) classification and prognosis. Semin Surg Oncol. 1994;10(1):12–20.
26. Wang S, Chen Q, Liu S, Zhang W, Ji B, Liu Y. The impact of aberrant hepatic artery on resection margin and outcomes of laparoscopic pancreatoduodenectomy: a single-Center Report. World J Surg. 2021;45(10):3183–90.
27. de Rooij T, Lu MZ, Steen MW, Gerhards MF, Dijkgraaf MG, Busch OR, et al. Minimally invasive Versus Open Pancreatoduodenectomy: systematic review and Meta-analysis of comparative cohort and Registry studies. Ann Surg. 2016;264(2):257–67.
28. Xu Q, Liu T, Zou X, Li P, Gao R, Dai M, et al. The learning curve for robot-assisted distal pancreatectomy: a single-center experience of 301 cases. J Pancreatology. 2022;5(3):118–24.
29. Boone BA, Zenati M, Hogg ME, Steve J, Moser AJ, Bartlett DL et al. Assessment of quality outcomes for robotic pancreaticoduodenectomy: id entification of the learning curve. JAMA Surg.150(5):416–22.
30. Zhang T, Zhao Z-M, Gao Y-X, Lau WY, Liu R. The learning curve for a surgeon in robot-assisted laparoscopic pancre aticoduodenectomy: a retrospective study in a high-volume pancreatic c enter. Surg Endosc.33(9):2927–33.
31. DeLaura I, Sharib J, Creasy JM, Berchuck SI, Blazer DG 3rd, Lidsky ME et al. Defining the learning curve for robotic pancreaticoduodenectomy for a single surgeon following experience with laparoscopic pancreaticoduode nectomy. J Robot Surg.18(1):126.
32. Yu Y, Changyong E, Lin C, Wang L, Jiang T. Safety and learning curve analysis of robotic-assisted pancreaticoduod enectomy: experience of a single surgeon. J Robot Surg.18(1):92.
33. Shi Y, Wang W, Qiu W, Zhao S, Wang J, Weng Y et al. Learning curve from 450 cases of Robot-assisted pancreaticoduocectomy in a high-volume pancreatic center: optimization of Operative Procedur E and a retrospective study. Ann Surg.274(6):e1277–83.
34. Rice MK, Hodges JC, Bellon J, Borrebach J, Al Abbas AI, Hamad A et al. Association of Mentorship and a Formal Robotic Proficiency Skills Curr iculum With Subsequent Generations' Learning Curve and Safety for Robo tic Pancreaticoduodenectomy. JAMA Surg.155(7):607–15.
35. Napoli N, Kauffmann EF, Palmeri M, Miccoli M, Costa F, Vistoli F et al. The learning curve in robotic pancreaticoduodenectomy. Dig Surg.33(4):299–307.

36. Dai M, Li P, Xu Q, Chen L, Liu W, Han X, et al. Learning curve of robotic pancreatoduodenectomy by a single surgeon with extensive laparoscopic pancreatoduodenectomy experience. J Robot Surg. 2024;18(1):298.
37. Tyutyunnik P, Klompmaker S, Lombardo C, Lapshyn H, Menonna F, Napoli N, et al. Learning curve of three European centers in laparoscopic, hybrid laparoscopic, and robotic pancreatoduodenectomy. Surg Endosc. 2022;36(2):1515–26.
38. Choi M, Hwang HK, Lee WJ, Kang CM. Total laparoscopic pancreaticoduodenectomy in patients with periampullary tumors: a learning curve analysis. Surg Endosc. 2021;35(6):2636–44.
39. Nagakawa Y, Nakamura Y, Honda G, Gotoh Y, Ohtsuka T, Ban D, et al. Learning curve and surgical factors influencing the surgical outcomes during the initial experience with laparoscopic pancreaticoduodenectomy. J Hepatobiliary Pancreat Sci. 2018;25(11):498–507.
40. Wang H, Gao X, Liu M, Kong X, Sun H, Niu Z, et al. The learning curve for laparoscopic pancreaticoduodenectomy by a proficient laparoscopic surgeon: a retrospective study at a single center. BMC Surg. 2024;24(1):14.
41. Ye K, Lin J, Sun Y, Wu Y, Xu J, He S. Variation and treatment of vessels in laparoscopic right hemicolectomy. Surg Endosc. 2018;32(3):1583–4.
42. Karakoyun R, Romano A, Yao M, Dlugosz R, Ericzon B-G, Nowak G. Impact of hepatic artery variations and reconstructions on the outcome of Orthotopic Liver Transplantation. World J Surg. 2020;44(6):1954–65.
43. Zhang R, Zhang H-Z, Han T, Wei Z-G, Shi Z-Y, Xu J. Effect of accessory hepatic artery reconstruction on prognosis in orthotopic liver transplantation: a single center experience. BMC Surg. 2023;23(1):138.
44. Alexakis N, Bramis K, Toutouzas K, Zografos G, Konstadoulakis M. Variant hepatic arterial anatomy encountered during pancreatoduodenectomy does not influence postoperative outcomes or resection margin status: a matched pair analysis of 105 patients. J Surg Oncol. 2019;119(8):1122–7.
45. Petrova E, Mazzella E, Eichler K, Gruber-Rouh T, Schulze F, Bechstein WO, et al. Influence of aberrant right hepatic artery on survival after pancreatic resection for ductal adenocarcinoma of the pancreatic head. Langenbecks Arch Surg. 2024;409(1):111.

Publisher's note