A single-center clinical study of hepatic artery variations in laparoscopic pancreaticoduodenectomy
A retrospective analysis of data from 218 cases

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Abstract

Hepatic artery variations increase the difficulty of laparoscopic pancreaticoduodenectomy (LPD). The safety and efficacy of LPD in the presence of aberrant hepatic arteries (AHA) must be further verified.

Patients with normal and variant hepatic arteries who underwent LPD and preoperative arterial angiography were retrospectively analyzed. Variation type, intraoperative management, and clinical treatment outcomes were compared.

There were 54 cases (24.8%) of AHA. The most common hepatic artery variation was accessory right hepatic artery (RHA) from the superior mesenteric artery (SMA, n = 12, 5.5%), followed by replaced RHA from the SMA (n = 10, 4.6%), accessory left hepatic artery from the SMA (n = 10, 4.6%), and replaced common hepatic artery from the SMA (n = 6, 2.8%). Each type of arterial variation was successfully preserved in all cases, and there were no significant effects on the evaluated surgical indices, conversion rate, incidence of postoperative complications, or follow-up results.

Our findings indicated that preservation of AHAs during total LPD is feasible. There were no significant effects on surgical indices, incidence of postoperative complications, or follow-up outcomes.

The influence of AHA on the safety and efficacy of LPD must be further verified. Patients with normal and variant hepatic arteries who underwent LPD and preoperative arterial angiography were retrospectively analyzed. There were 54 cases (24.8%) of AHA. There were no significant effects of AHAs on surgical indices, incidence of postoperative complications, or follow-up outcomes.

Abbreviations: AHA = aberrant hepatic arteries, aLHA = accessory left hepatic artery, aRHA = accessory right hepatic artery, CA = celiac artery, CHA = common hepatic artery, DSA = digital subtraction angiography, LPD = laparoscopic pancreaticoduodenectomy, MDCTA = multidetector computed tomography angiography, RHA = right hepatic artery, rRHA = replaced right hepatic artery, SMA = superior mesenteric artery, SMV = superior mesenteric vein.

Keywords: hepatic artery variation, laparoscopy, pancreaticoduodenectomy

1. Introduction

Pancreaticoduodenectomy is the standard procedure for the treatment of various benign and malignant tumors in the distal

bile duct, pancreatic head, and duodenal papilla. It is characterized by high surgical difficulty, high risk, and high incidence of postoperative complications. Intraoperative injury is highly likely due to the complex anatomical structure of the pancreatic head and the hepatoduodenal ligament involved in the operation; the difficulty and risk of surgery are increased if an anatomical variation is present. Aberrant hepatic arteries (AHAs) are particularly important and common and have recently been the focus of attention in pancreaticoduodenectomy.[1,2] Laparoscopic pancreaticoduodenectomy (LPD) has been performed for over 20 years.[3] Laparoscopic techniques have rapidly developed in the past decade and complex pancreaticoduodenectomies have been completed laparoscopically.[4–7] However, the demands for surgical skill and experience are greater in LPD than in traditional open surgery; moreover, encountering hepatic artery variations during LPD can make the surgery exceptionally difficult.

In 1966, Michels[8] developed a detailed classification of hepatic artery variations by compiling 200 cases. In 1994, Hiatt et al[9] developed a new classification based on a compilation of 1000 cases (Table 1). The Michels classification is more specific, whereas the Hiatt classification is simpler. The most common abnormal variation in both the Michels and Hiatt classifications is type III—specifically, Hiatt type III replaced or accessory right hepatic artery (RHA) originating from the superior mesenteric artery (SMA). This variation must be given particular attention

Table 1

Michels and Hiatt hepatic artery types.

Michels	Anatomy	Hiatt
I	Normal (RHA and LHA arise from the proper hepatic artery)	I
II	Replaced LHA from the LGA	II
III	Replaced RHA from the SMA	III
IV	Replaced LHA from the LGA and replaced RHA from the SMA	IV
V	Accessory LHA from the LGA	II
VI	Accessory RHA from the SMA	III
VII	Accessory LHA and accessory RHA	IV
VIII	Replaced RHA and accessory LHA or replaced LHA and accessory RHA	IV
IX	Replaced CHA from the SMA	V
X	Replaced CHA from the LGA	
	Replaced CHA from the aorta	VI

CHA = common hepatic artery, LGA = left gastric artery, LHA = left hepatic artery, RHA = right hepatic artery.

Table 2

Hepatic artery variations.

Michels	Anatomy	n (%)
I	Normal (RHA and LHA arise from the proper hepatic artery)	164 (75.2%)
II	Replaced LHA from the LGA	2 (0.9%)
III	Replaced RHA from the SMA	10 (4.6%)
IV	Replaced LHA from the LGA and replaced RHA from the SMA	1 (0.5%)
V	Accessory LHA from the LGA	10 (4.6%)
VI	Accessory RHA from the SMA	12 (5.5%)
VII	Accessory LHA and accessory RHA	1 (0.5%)
VIII	Replaced RHA and accessory LHA or replaced LHA and accessory RHA	0 (0%)
IX	Replaced CHA from the SMA	6 (2.8%)
X	Replaced CHA from the LGA	0 (0%)
Others		12 (5.5%)

CHA = common hepatic artery, LGA = left gastric artery, LHA = left hepatic artery, RHA = right hepatic artery.

during dissection of the uncinate process of the pancreas in LPD, as the variant arteries may be adjacent to or penetrate the pancreatic head or uncinate process and run along the right or dorsal side of the common bile duct, reaching the hepatic hilum. Similarly, in the less common Michels type IX (Hiatt type V) variation, the common hepatic artery (CHA) originates from the SMA, which is highly susceptible to vascular damage during dissection of the uncinate process. The RHA provides the main blood supply to the common bile duct; therefore, both CHA and RHA damage can lead to hepatic ischemia, resulting in abnormal liver function or biliary ischemia, which can affect biliary anastomosis healing.

With advancements in technology, LPD has gradually been accepted as an alternative to open pancreaticoduodenectomy for most indications. Nonetheless, in the presence of abnormal hepatic arteries, the safety and therapeutic effects of LPD must be further verified as they remain unclear. Hence, the present study aimed to confirm whether laparoscopic pancreatoduodenectomy is safe and effective in patients with hepatic artery variation.

2. Methods

This study was performed following approval from the Institutional Review Board of the First Hospital of Jilin University, Changchun, Jilin, China (approval number: 19K046-001; date of approval: XXXX XX XXXX). The requirement for acquisition of informed consent from patients was waived owing to the retrospective nature of the study.

A retrospective analysis of the complete preoperative data of patients who underwent LPD at the Department of Hepatobiliary and Pancreatic Surgery, First Hospital of Jilin University, between February 2017 and March 2019 was conducted. Cases in which patients did not complete preoperative three-dimensional multidetector computed tomography angiography (MDCTA) for various reasons were excluded from the study, which led to a total of 218 cases being included in the study. Patients with and without AHA were included in the AHA (−) and AHA (+) groups, respectively. All surgeries were performed by the same surgical team.

The planned surgical method was total LPD with a posterior, uncinate process-first approach. Surgery was performed under

general anesthesia using the conventional 5-port method. This posterior, uncinate process-first, gradual, and total removal of the uncinate process from the bottom to the top can expose abnormal hepatic arteries behind the uncinate process originating from the SMA, which helps prevent arterial damage due to the unclear anatomy.

All surgical outcomes were followed up for over 90 days. The preoperative, intraoperative, and postoperative data of the two groups were analyzed. Pancreatic fistulae and bleeding were graded according to the International Study Group for Pancreatic Fistula criteria,[10,11] and postoperative complications were scored according to the Clavien-Dindo classification system.[12]

2.1. Statistical analysis

SPSS software version 23.0 (IBM Corp., Armonk, NY) was used for statistical analysis. Normally distributed data are presented as mean ± standard deviation, and t test was used for comparisons between groups. Discrete data are presented as frequencies and percentages, and χ^2 test was used for comparisons between groups. Differences with $P < .05$ were considered statistically significant.

3. Results

Of the 218 patients who underwent LPD, there were 54 cases of AHA. No hepatic artery variations were detected in 164 cases (Table 2). No significant differences in preoperative indices were observed between both groups (Tables 3 and 4). The most common variation was accessory RHA (aRHA) from the SMA (Fig. 1), followed by replaced RHA (rRHA) from the SMA (Fig. 2), accessory left hepatic artery (aLHA) from the SMA (Fig. 3), and replaced CHA from the SMA (Fig. 4). Furthermore, there were multiple hepatic artery variations in addition to the common types (Table 5), most of which were special variants of rRHA arising directly from the celiac artery (CA, Figs. 5 and 6). In the AHA (+) group, LPD was successfully performed on 52 patients and 2 cases were converted to open pancreaticoduodenectomy. In the AHA (−) group, LPD was successfully performed on 161 patients and 3 cases were converted to open pancreaticoduodenectomy. No significant difference in conver-

Table 3

Preoperative variables.

		AHA (−) (N=164)	AHA (+) (N=54)	t/X^2	P
Sex	Male	91 (55.5%)	31 (57.4%)	0.061	.805
	Female	73 (44.5%)	23 (42.6%)		
Age (years)		59.20±9.879	57.16±11.071	−1.208	.228
BMI (kg/m²)		23.0302±2.4064	23.1426±2.9664	0.252	.801
ASA score	I	1 (0.6%)	0 (0.0%)	1.020	.796
	II	147 (90.2%)	46 (88.5%)		
	III	14 (8.6%)	6 (11.5%)		
	IV	1 (0.6%)	0 (0.0%)		
Drainage method	None	112 (68.3%)	36 (66.7%)	1.849	.763
	PTGBD	43 (26.2%)	16 (29.6%)		
	PTCD	7 (4.3%)	1 (1.9%)		
	ERCP	1 (0.6%)	0		
	T-tube drainage	1 (0.6%)	1 (1.9%)		
Preoperative CA199 (U/mL)		165.3330±214.6934	195.591±32.0504	0.846	.398
Preoperative CA125 (U/mL)		16.2794±12.4873	21.5759±22.5351	1.644	.102
Preoperative total bilirubin (mg/dL)		142.3338±118.2059	126.4279±132.8118	−0.778	.438
Symptoms at admission	Jaundice with abdominal pain	45 (27.4%)	19 (35.2%)	1.517	.678
	Jaundice	75 (45.7%)	24 (44.4%)		
	Findings on physical examination	40 (24.4%)	10 (18.5%)		
	Fever	4 (2.4%)	1 (1.9%)		
Comorbidity		44 (26.8%)	11 (20.4%)	0.898	.343
Cardiovascular disease		27 (16.5%)	6 (11.1%)	0.906	.341
Diabetes		18 (11.0%)	4 (7.4%)	0.570	.450
Chronic pancreatitis		5 (3.0%)	0 (0.0%)	1.685	.194
Hepatitis		3 (1.8%)	1 (1.9%)	0.000	.991
History of upper abdominal surgery		9 (5.5%)	3 (5.6%)	0.000	.992

ASA = American Society of Anesthesiology, BMI = body mass index, ERCP = endoscopic retrograde cholangiopancreatography, PTCD = percutaneous transhepatic cholangial drainage, PTGBD = percutaneous transhepatic gallbladder drainage.

sion rate was noted between the two groups. Each type of arterial variation was successfully preserved in all cases (Figs. 7 and 8), and there were no significant effects on the evaluated surgical indices (Table 6), conversion rate, incidence of postoperative complications, or follow-up results (Table 7). However, additional arterial dissection and isolation led to a significant increase in surgical duration, unlike the increases in surgical duration and intraoperative blood loss, which were not significant. Moreover, there were no significant differences in the postoperative pathological indices (Table 8). There was one case in the AHA (+) group in which the CHA originated from the SMA and the artery was partially ruptured during the isolation process. The damaged site of the CHA was partially resected under laparoscopy and reconstructed with end-to-end anastomosis. Postoperative recovery was uneventful, and there were no obvious abnormalities in any indices.

4. Discussion

Our findings indicate that preservation of abnormal hepatic arteries during LPD is feasible. There were no significant effects on surgical resection and postoperative complication rates. Additional dissection and reconstruction of the arteries can lead to a slight increase in surgical duration; nonetheless, concomitant AHA did not affect surgical safety or postoperative outcomes. With respect to the curative effect, we concluded that total laparoscopic tumor resection did not have a negative effect on tumor outcomes, which was similar to the results reported in the literature with open surgery.[13] Some researchers[14,15] have reviewed whether preserving abnormal rRHAs during open pancreaticoduodenectomy in patients with malignant tumors affects curative effects and concluded that, even when the rRHAs were preserved, pathological findings did not indicate an increased incidence of positive margins, which is consistent with

Table 4

Preoperative diagnosis.

		AHA (−) (N=164)	AHA (+) (N=54)	X^2	P
Diagnosis	Pancreatic ductal adenocarcinoma	44 (26.8%)	17 (31.5%)	4.616	.707
	Ampullary adenocarcinoma	28 (17.1%)	13 (24.1%)		
	Cholangiocarcinoma	50 (30.5%)	11 (20.4%)		
	IPMN	9 (5.5%)	2 (3.7%)		
	Neuroendocrine tumor	7 (4.3%)	1 (1.9%)		
	Duodenal cancer	7 (4.3%)	2 (3.7%)		
	GIST	1 (0.6%)	1 (1.9%)		
	Others	18 (11.0%)	7 (13.0%)		

AHA = aberrant hepatic arteries, GIST = gastrointestinal stromal tumor, IPMN = intraductal papillary mucinous neoplasm.
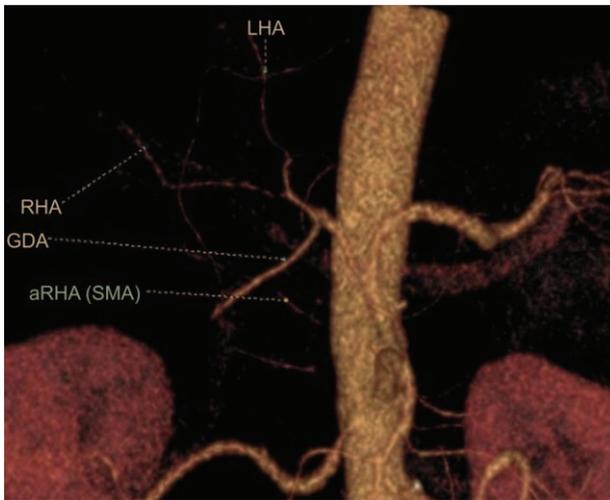
Figure 1. aRHA from the SMA. aRHA=accessory right hepatic artery, GDA= gastroduodenal artery, LHA=left hepatic artery, RHA=right hepatic artery, SMA=superior mesenteric artery.

Figure 3. aLHA from the LGA. aLHA=accessory left hepatic artery, CA= celiac artery, LGA=left gastric artery.

our findings under laparoscopy. However, these researchers believe that there seems to be some effect on the prognosis of patients with rRHA. Therefore, they recommend that patients with the rRHA variation be considered for neoadjuvant chemo-radiotherapy. Some researchers[16] advocate attention when resecting tumors <1 cm from an aRHA; we will also conduct long-term follow-up studies for confirmation. In addition, Japanese researchers[17] analyzed the prognosis of intraoperative resection in patients with the rRHA variation and found that the variant blood vessel could not be preserved or reconstructed and was directly resected without reconstruction, which can serve as an alternative treatment method.

Can laparoscopic surgery clearly reveal the variation of hepatic artery? A large evidence base indicates that AHAs are very common. In the past 40 years, the rate of hepatic artery variations has been found to be ~20% to 45% through autopsy and various imaging methods. These variations increase the difficulty of some
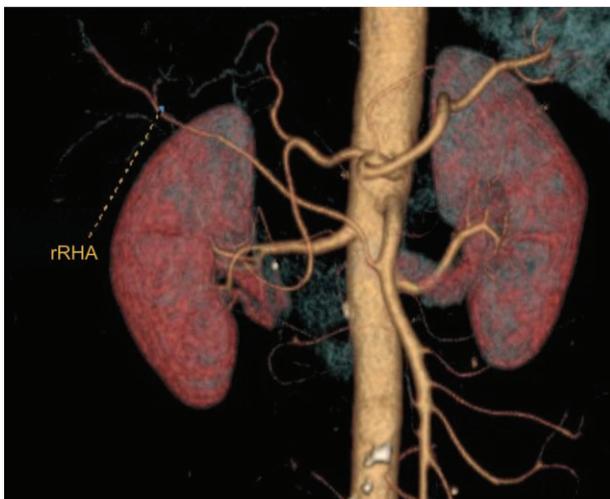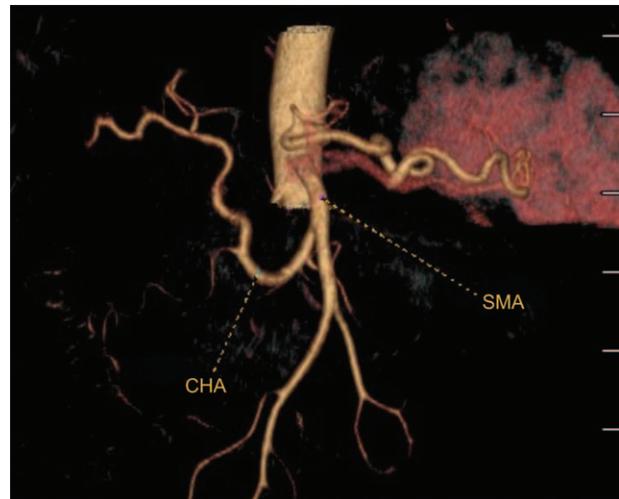

Figure 4. CHA from the SMA. CHA=common hepatic artery, SMA=superior mesenteric artery.

Figure 2. rRHA from the superior mesenteric artery. rRHA=replaced right hepatic artery.

Table 5

Unclassified variations.

Other	Anatomy	n (%)
	Replaced RHA from the CA	4 (1.8%)
	Replaced LHA from the GDA	2 (0.9%)
	Replaced LHA from the CHA	2 (0.9%)
	Replaced CHA from the AA	1 (0.5%)
	Accessory LHA from the CHA	1 (0.5%)
	Replaced LHA from the CA	1 (0.5%)
	Accessory RHA from the GDA	1 (0.5%)

AA=abdominal aorta, CA=celiac artery, CHA=common hepatic artery, GDA=gastroduodenal artery, LGA=left gastric artery, LHA=left hepatic artery, RHA=right hepatic artery.
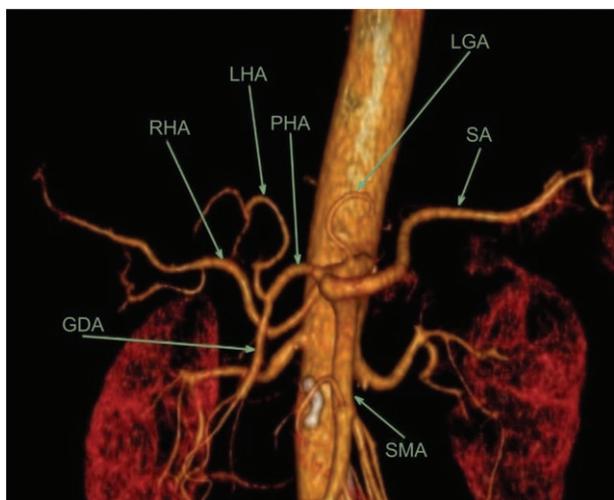
Figure 5. Replaced right hepatic artery from the celiac artery. GDA= gastroduodenal artery, LGA=left gastric artery, LHA=left hepatic artery, PHA=proper hepatic artery, RHA=right hepatic artery, SA=splenic artery, SMA=superior mesenteric artery.

Figure 7. Preserved accessory right hepatic artery (aRHA).

high-risk surgical procedures.[18–22] The source of the variant blood supply is divided into two types—namely, accessory hepatic arteries and replaced hepatic arteries. The former refers to the presence of an additional hepatic artery of abnormal origin supplying the same hepatic lobe at the site of the existing hepatic artery blood supply, whereas the latter refers to blood supply of a hepatic lobe completely from an abnormally derived hepatic artery. Hepatic artery variations, especially the relatively common rRHA or aRHA from the SMA and CHA originating from the SMA, are particularly relevant to LPD. They have a great impact on the intraoperative dissection of the hepatoduo-denal ligament, especially when dissecting the pancreatic head and uncinate process, and can be crucial to determine surgical success or failure. Thus, surgeons must reach a consensus on the status of any abnormalities of major blood vessels before surgery. Currently, the most widely used classifications of hepatic artery
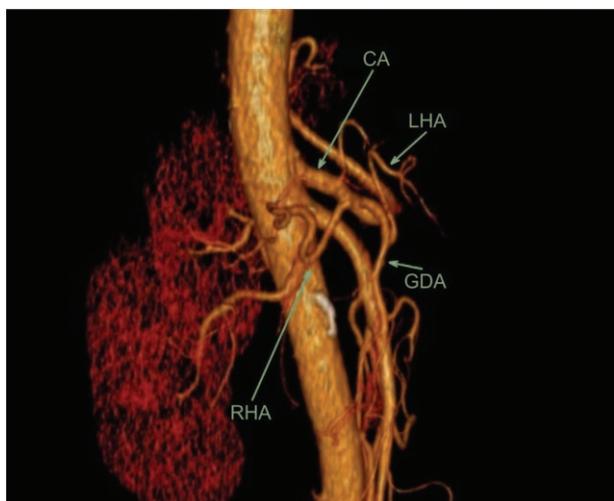
variation are the Michels and Hiatt classification systems. However, some variations are not included in either of these two classification systems, such as LHA or RHA originating from the gastroduodenal artery, RHA originating directly from the CA, and other variations that were classified in the AHA (+) group in the present study. It is necessary to be aware of the presence of these variations if an arterial approach is used during surgery.

Preoperative angiography is essential; there are several major methods to determine vascular variations, the simplest of which is vascular ultrasound. Due to the complexity of arterial variations and the subjectivity of ultrasound diagnosis, vascular ultrasound cannot be used as a reliable basis for preoperative determination of arterial variations. In the past, digital subtraction angiography (DSA) was considered to be the most common method. For some time, DSA was the major angiographic method for patients undergoing pancreaticoduodenectomy, but it is an invasive examination, and its effectiveness is also affected by human

Figure 6. Replaced right hepatic artery from the celiac artery. CA=celiac artery, GDA=gastroduodenal artery, LHA=left hepatic artery, RHA=right hepatic artery.

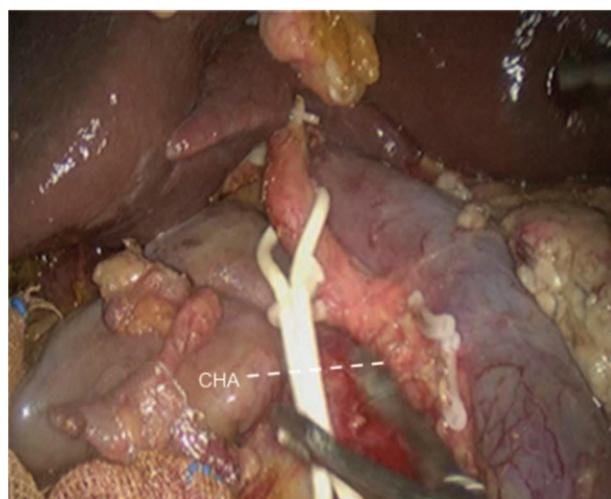**Figure 8.** Preserved common hepatic artery (CHA) originating from the superior mesenteric artery.

Table 6

Intraoperative conditions.

		AHA (−) (N=164)	AHA (+) (N=54)	Test statistic	P
Pancreatic texture	Soft	71 (32.6%)	2 (10.1%)	2.027	.363
	Moderate	62 (28.4%)	17 (7.8%)		
	Hard	31 (14.2%)	15 (6.9%)		
Pancreatic duct diameter (mm)	≤3	86 (39.4%)	20 (9.2%)	3.858	.050
	>3	78 (35.8%)	34 (15.6%)		
Duration of surgery (min)		260.02±52.067	276.87±51.940	−2.064	.040
Duration of sample resection (min)		105.64±26.614	121.46±23.840	−3.885	.000
Time of pancreatic-enteric anastomosis (min)		30.02±7.419	30.65±7.021	−0.543	.588
Conversion to open surgery		3 (1.8%)	1 (1.9%)	0.000	.991
Intraoperative blood loss (mL)		76.31±81.233	101.02±97.198	−1.843	.067
Cases of intraoperative blood transfusion		26 (15.9%)	10 (18.5%)	0.209	.647

Table 7

Postoperative conditions.

		AHA (−) (N=164)	AHA (+) (N=54)	Test statistic	P
Pancreatic fistula	None	143 (65.6%)	49 (22.5%)	0.848	.654
	Grade B	19 (8.7%)	4 (1.8%)		
	Grade C	2 (0.9%)	1 (0.5%)		
Gastroparesis		3 (1.4%)	1 (0.5%)	0.000	.991
Postoperative bleeding		15 (6.9%)	5 (2.3%)	0.004	.950
Biliary fistula		4 (1.8%)	3 (1.4%)	1.270	.260
Gastrointestinal fistula		4 (1.8%)	0 (0.0%)	1.342	.247
Intra-abdominal infection		15 (6.9%)	4 (1.8%)	0.154	.694
Pneumonia		8 (3.7%)	4 (1.8%)	0.500	.480
Clavien-Dindo grade (≥III)		15 (9.1%)	5 (9.3%)	0.001	.980
Time to gas expulsion (days)		2.73±0.917	2.65±1.031	0.551	.582
Time to feeding (days)		5.70±3.943	5.31±1.921	0.689	.491
Postoperative hospitalization time (days)		18.90±10.509	16.70±6.359	1.447	.149
Re-operation		14 (6.4%)	1 (0.5%)	2.833	.092
Re-hospitalization within 30 days		10 (6.1%)	3 (5.6%)	0.021	.884
Death within 90 days		7 (4.3%)	2 (3.7%)	0.033	.856

AHA=aberrant hepatic arteries.

factors. Takahashi and Sahani et al[23,24] conducted comparative studies of the anatomical structure of the hepatic artery using computed tomography angiography and DSA and found that it showed 94% sensitivity, 100% specificity, and 97% accuracy. The method used in the present study was MDCTA. Since, it can clearly indicate the route of arteries as well as abnormal conditions, MDCTA has been used to determine the respectability of pancreatic cancer at earlier time points,[25] and it also allows the route and variation of blood vessels to be determined prior to pancreaticoduodenectomy. Studies have shown[26,27] that MDCTA is able to provide information about hepatic artery abnormalities.[28]

The surgical approach for LPD differs from that for traditional open surgery. Although several surgical approaches currently exist, the posterior approach is the most common for LPD. This approach was used in all patients irrespective of whether a hepatic artery variation was present. In the AHA (+) group, there was one case of localized rupture of the CHA, which occurred during dissection of an aberrant CHA originating from the SMA that runs through the uncinate process. Bleeding was controlled immediately by performing a laparoscopic end-to-end anastomosis of ~1 cm after resection of the damaged segment. The patient recovered uneventfully and there were no vascular complications. Next, the stomach, pancreatic neck, and bile duct

Table 8

Postoperative pathology.

	AHA (−) (N=164)	AHA (+) (N=54)	Test statistic	P
Tumor size (cm)	2.73±1.335	3.14±2.532	−1.531	.127
Number of lymph nodes	18.26±6.081	18.59±6.317	−0.343	.732
Number of positive lymph nodes	4.55±2.443	4.89±3.172	−0.806	.421
Positive margin	1 (0.6%)	0 (0.0%)	0.331	.565

AHA=aberrant hepatic arteries.

were divided to complete the resection. In all cases, the Child method was used for the reconstruction of the digestive tract and pancreatojejunostomy was performed using "Hong's single-stitch duct-to-mucosa pancreaticojejunostomy."[29] The biliary anastomosis was continuously sutured using 4-0 absorbable barbed suture. The gastrointestinal anastomosis was performed with a side-to-side anastomosis using an occlusion device, and routine abdominal drainage was performed.

In conclusion, the aberrant hepatic artery does not affect the outcome of the LPD. It is currently considered that hepatic artery variations, particularly replaced hepatic artery, should be preserved during surgery as much as possible. The present study showed that preservation of variant arteries can be feasibly completed by laparoscopy. Aside from a slight increase in the duration of surgical resection, there were no other obvious complications. Therefore, LPD is safe and feasible in patients with hepatic artery variations, who do not have to choose a more traumatic open abdominal surgery. This study also has some limitations and we did not analyze the long-term prognosis of LPD patients. In future studies, we will increase our follow-up period of treatment efficacy to determine long-term prognosis.

Author contributions

Yahui Liu and Wei Zhang proposed the idea and conceptualization. Wei Zhang and Kun Wang performed data analysis, experimentation and scientific discussions, and prepared the original draft. Songyang Liu, Yingchao Wang and Kai Liu Yahui Liu and Wei Zhang proposed the idea and conceptualization. Wei Zhang and Kun Wang performed data analysis, experimentation and scientific discussions, and prepared the original draft. Songyang Liu, Yingchao Wang and Kai Liu performed data analysis and scientific discussions. Lingyu Meng, Qingmin Chen and Baoxing Jia validated the findings and helped in revision and organization of the paper.

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