World J Surg (2019) 43:2909–2919
https://doi.org/10.1007/s00268-019-05106-8

World Journal of Surgery

ORIGINAL SCIENTIFIC REPORT

Pancreatectomy with Hepatic Artery Resection for Pancreatic Head Cancer

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Published online: 8 August 2019
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Abstract

Background To report our experiences and outcome of pancreatectomy with hepatic artery resection (PT-HAR) for advanced pancreatic head cancer.

Methods A retrospective study of clinical data from 14 patients with advanced pancreatic ductal adenocarcinoma undergoing PT-HAR in a tertiary academic center between March 2010 and June 2017 was performed. Furthermore, a comparison in a match-pair analysis (1:3) with patients received standard pancreatectomy during the same period was conducted to evaluate the clinical outcome.

Results The PT-HAR cohort included pancreaticoduodenectomy (n = 11) and total pancreatectomy (n = 3). Of them, six underwent portal/superior mesenteric vein resection and reconstruction and three underwent hepatic artery reconstruction. Four patients without arterial reconstruction developed liver perfusion failure. No perioperative mortality occurred, with a median postoperative hospital stay of 10.5 days (range 6–39). The median overall survival was 30 months (95% confidence interval 9.8–50.2 months), with the 1-, 2-, and 3-year survival rates of 81.8%, 63.6%, and 42.4%, respectively. The matched-pair data analysis showed no significant differences between PT-HAR and standard pancreatectomy, except that liver perfusion failure occurred more frequently after PT-HAR.

Conclusions PT-HAR can be performed with acceptable morbidity, mortality, and survival for advanced pancreatic head cancer. Considering the potential risk of liver perfusion failure, only highly selected patients are eligible for PT-HAR without reconstruction.

Introduction

Radical surgery is the only curable method for pancreatic cancer, while less than 20% of patients are considered resectable when detected [1]. Patients have invasion of important peripancreatic blood vessels that belong to unresectable or borderline resectable tumors. R0 resection is an important prognostic factor of patients with locally advanced pancreatic cancer receiving surgical resection. Combined portal vein (PV) resection has been reported to have benefits on prognosis of these patients without increasing surgical morbidity and mortality, especially in high-volume centers [2]. However, in those cases involving main arteries surrounding the pancreas, surgical resection with combined artery resection is usually considered futile due to poor outcome, severe trauma and high risks. Pancreatic cancer involving the hepatic artery is usually assessed as unresectable. Reasons for excluding this type of pancreatic cancer from resection are both technical and oncologic. Aggressive resection is

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technically demanding owing to the presence of arterial invasion, and associated with high morbidity [3, 4]. In addition, the value of pancreatectomy with arterial resection on cancer survival has not been well demonstrated [5].

Although postoperative liver perfusion failure is rare, it is a potentially fatal complication following pancreaticoduodenectomy, especially in those with simultaneous involvement of the hepatic artery and PV [6]. It is important to ensure sufficient reverse perfusion of arterial blood flow to the liver after arterial resection. A few reports have described transposition techniques to restore arterial perfusion of the liver using the gastroduodenal or splenic artery during pancreatectomy [7–9]. There are also studies supporting the use of preoperative hepatic artery embolization to promote development of collateral pathways prior to pancreatectomy with hepatic artery resection (PT-HAR) [10–12]. Previous studies found that 11.8–31% of the patients receiving pancreaticoduodenectomy had anomalies of hepatic arteries [13, 14]. Considering that unilateral reconstruction may be adequate when both the left and right hepatic arteries are divided due to presence of communicating arcades at the hepatic hilum [15], the necessity for arterial reconstruction remains controversial in those with accessory or replaced hepatic artery. Here, we reported our experiences and outcomes of PT-HAR for advanced pancreatic head cancer. In addition, a case-matched comparison with patients receiving standard pancreatectomy was conducted.

Methods

Between March 2010 and June 2017, 14 patients with advanced pancreatic ductal adenocarcinoma (PDAC) in the proximal pancreas underwent PT-HAR. Pre-treatment radiographic imagings were assessed for tumor involvement of the major blood vessels including common hepatic artery (CHA)/celiac axis, superior mesenteric artery (SMA), superior mesenteric vein (SMV), and PV. All patients were classified as borderline resectable according to the NCCN criteria [16]: tumor contact with CHA without extension to hepatic artery bifurcation or celiac axis allowing for complete resection, tumor contact with the SMA of $\leq 180°$, tumor contact with variant hepatic arterial anatomy, and tumor contact with the PV/SMV yet with suitable vessel above and below the involvement site allowing for resection and reconstruction. The presence of hepatic arterial variations was also evaluated [14]. PT-HAR was indicated with the possibility of achieving R0 resection based on preoperative imaging showing free tumor invasion at the origin of celiac trunk, and absence of invasion beyond porta hepatis. As the extent of tumor infiltration was difficult to determine intra-operatively, we usually decided whether to resect the encased hepatic artery or not based on preoperative multidetector computed tomography (MDCT) findings. This study was approved by our hospital Institutional Review Board.

Surgical management

The hepatoduodenal ligament was skeletonized, exploring the whole length of the encased hepatic artery. Then, the hepatic artery proximal and distal to the tumor was dissected and subsequently resected. For patients who had severe arterial infiltration with lumen stenosis or even occlusion, or those who had reduced blood flow detected by intra-operative ultrasound, arterial reconstruction was not routinely performed. If temporarily clamping the affected artery by tumor did not influence arterial flow to the liver, we didn't reconstruct a small accessory or replaced hepatic artery. Additionally, arterial reconstruction was not regularly performed in the early study period due to technical reasons. The arterial blood supply of the common bile/hepatic duct was preserved to avoid ischemic breakdown of the bilioenteric anastomosis. When both arterial and venous resection had to be conducted, we never simultaneously deprived the liver of both portal and arterial inflow. The PV/SMV resection and reconstruction was performed firstly to ensure liver reperfusion quickly and reduce intestinal congestion. Adequate arterial and portal flow was confirmed to prevent postoperative ischemia-related complications. Other surgical procedures and perioperative management have been described previously [17–20].

Postoperative monitoring

Laboratory data such as serum alanine aminotransferase (ALT) and aspartate aminotransferase (AST) levels were examined before operation, and serial changes after surgery were studied until they returned to baseline. Doppler ultrasound was repeated postoperatively to confirm the hepatic arterial flow only if clinically indicated. Drain fluid amylase levels were measured every day until drainage removed. Hepatotoxic drugs were avoided in all patients. Prophylactic anticoagulants were not administered in them postoperatively. CT scans were performed to screen for postoperative complications prior to discharge.

Definition of complications and follow-up

POPF was defined according to the 2016 International Study Group of Pancreatic Surgery (ISGPS) definition and grading system [21]. We used the Clavien–Dindo classification (CDC) for assessing the severity of postoperative complications [22, 23]. Liver perfusion failure was defined by a rise in serum aminotransferase levels (AST or ALT > 200 U/L) that triggered contrast-enhanced CT scan revealing signs of liver perfusion disturbance [4]. Follow-up data were obtained through outpatient records or telephone interviews. Patient status was assessed at date of last follow-up. Overall survival was defined as the time interval between the date of initial treatment and the date of death or last follow-up.

Matched-pair analysis

Patients undergoing PT-HAR were matched in the ratio of 1:3 with those receiving standard pancreatectomy based on sex, age (±5 years), surgery type, venous resection, and lymph node status. Matched controls included only cases with histologically confirmed diagnosis of PDAC and were identified from our prospective database during the same period as the PT-HAR cases.

Statistical analysis

Comparisons were performed using the Chi-square or Fisher's exact test for nominal variables and the independent-samples *t* test or Mann–Whitney *U* test for continuous variables. Survival analysis was performed using the Kaplan–Meier method and compared by log-rank test. A two-sided *P* value of <0.05 was considered statistically significant. Statistical analysis was conducted with the SPSS version 24.0 for Windows (SPSS Inc, Chicago, IL).

Results

Preoperative and surgical data

The PT-HAR cohort included 8 males (57.1%) and 6 females (42.9%), with a median age of 67.5 years (range 42–76). Of the 14 patients, three had a history of diabetes. Ten patients had preoperative serum CA19-9 levels exceeding the upper limit of normal range (≥37 U/ml). Four patients with obstructive jaundice received preoperative biliary drainage. Ten patients were detected to have hepatic artery variants by preoperative MDCT: Michels type III in 3, type V in 1, type VI in 5, and type VIII in 1 [24]. Preoperative hepatic arterial embolization was performed in none of them. The PT-HAR included pancreaticoduodenectomy ($n = 11$) and total pancreatectomy ($n = 3$). Of them, six (42.9%) underwent PV/SMV resection and reconstruction, and three (21.4%) underwent hepatic artery reconstruction. Arterial reconstruction was performed with end-to-end anastomosis ($n = 2$), and anastomosis via the gastroduodenal artery ($n = 1$).

Postoperative complications

Although the resected hepatic arteries were not reconstructed in 11 patients, neither liver abscess nor biliary fistula occurred. Four patients had liver perfusion failure postoperatively. Three of them had no hepatic arterial variants and received CHA resection (A, B, and E in Fig. 1). The other patient with Michels type VI variation underwent accessory right hepatic artery resection during total pancreatectomy with PV resection. Another two of the 14 patients (14.3%) had pulmonary complication and POPF (grade B), respectively, which were labeled as Clavien–Dindo classification I and II. No complications such as arterial thrombosis and bleeding associated with reconstruction were recorded. No perioperative mortality occurred in this series, with a median postoperative hospital stay of 10.5 days (range 6–39). During follow-up, one patient who had postoperative liver perfusion failure developed segmental liver ischemia/infarction. Another two cases without liver perfusion failure were readmitted due to cholangitis and delayed gastric emptying, respectively. Neither segmental atrophy nor cholangitic abscess was observed after discharge.

Liver enzyme alterations after PT-HAR without reconstruction

Among those didn't receive arterial reconstruction, serum ALT levels increased to the maximum levels on postoperative day 1 (POD1), significantly higher than the baseline levels (489.1 ± 660 vs 64.8 ± 63.6, $P < 0.001$), but thereafter decreased and returned to baseline by POD7 (Fig. 1a). AST levels followed a similar course (Fig. 1b). In those without accessory or replaced hepatic arteries, ALT and AST levels remained greatly increased on POD4 whereas returned to normal within the first postoperative week. However, serum liver transaminase levels did not increase significantly in those having accessory or replaced hepatic arteries except one (Fig. 1c, d). The reason may be due to the development of collateral pathways via the hilar plate arterial plexus (Fig. 2), and enlargement of the preserved hepatic artery and increased blood flow through intra-hepatic shunts (Fig. 3). Interestingly, although the median values of postoperative ALT and AST levels were higher in patients without arterial reconstruction than in those with reconstruction, the differences were not statistically significant (Fig. 1e, f). When we compared total bilirubin and serum albumin levels between those with and without liver perfusion failure, no significant differences were detected (Fig. 4).

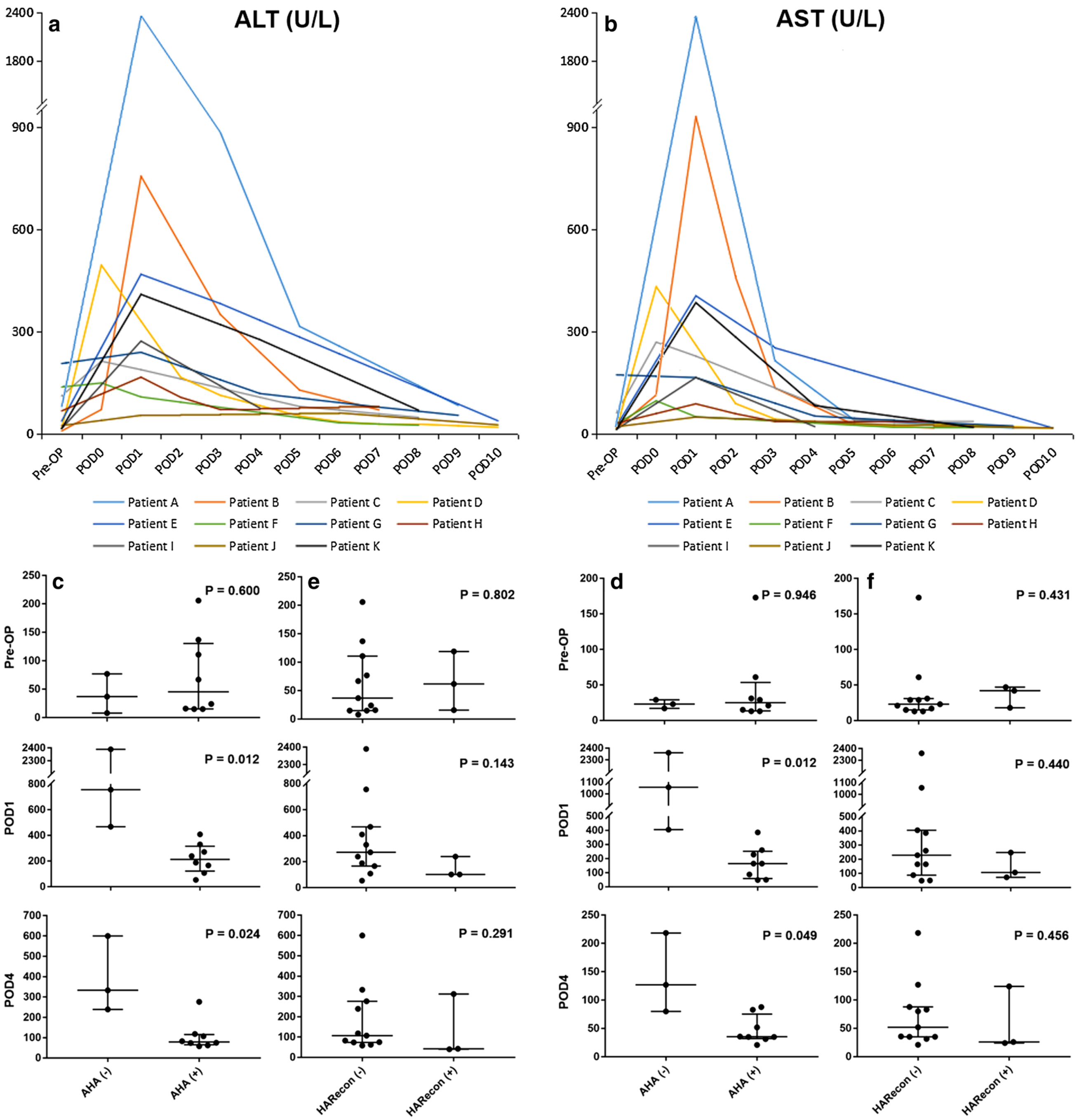

Fig. 1 Postoperative changes in ALT and AST levels after PT-HAR. Postoperative serial changes in ALT (**a**) and AST (**b**) levels after PT-HAR without reconstruction. Three of the patients (A, B, and E) had no hepatic arterial variants. Comparisons of ALT (**c**) and AST (**d**) levels in subgroups of patients with versus without AHA after PT-HAR without reconstruction. Comparisons of ALT (**e**) and AST (**f**) levels in subgroups of PT-HAR with versus without reconstruction. Each dot represents one patient. Solid lines represent the median with interquartile range. Normal ranges of ALT and AST are below 50 and 40 U/L, respectively. *ALT* alanine aminotransferase, *AST* aspartate aminotransferase, *PT-HAR* pancreatectomy with concomitant hepatic artery resection, *Pre-OP* preoperative, *POD* postoperative day, *HARecon* hepatic artery reconstruction, *AHA* aberrant hepatic artery

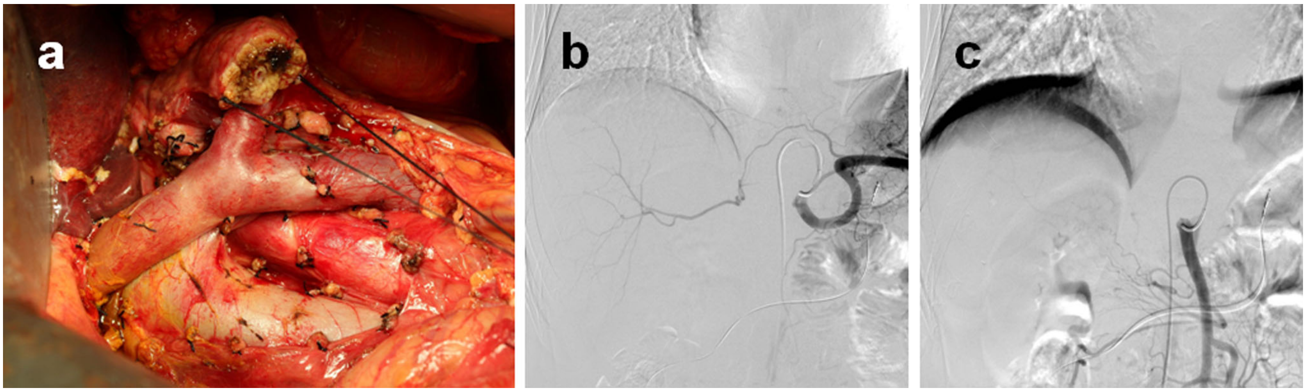

Fig. 2 PT-HAR for Michels type V. A 54-year-old male patient (C in Fig. 1) with Michels type V received PD-CHAR without reconstruction (**a**). The accessory left hepatic artery, which originated from the left gastric artery, facilitated blood flow in the right hepatic artery via the hilar plate arterial plexus (**b**). No collateral pathways from the superior mesenteric artery after surgery were found (**c**). *PT-HAR* pancreatectomy with concomitant hepatic artery resection, *PD-CHAR* pancreaticoduodenectomy with common hepatic artery resection

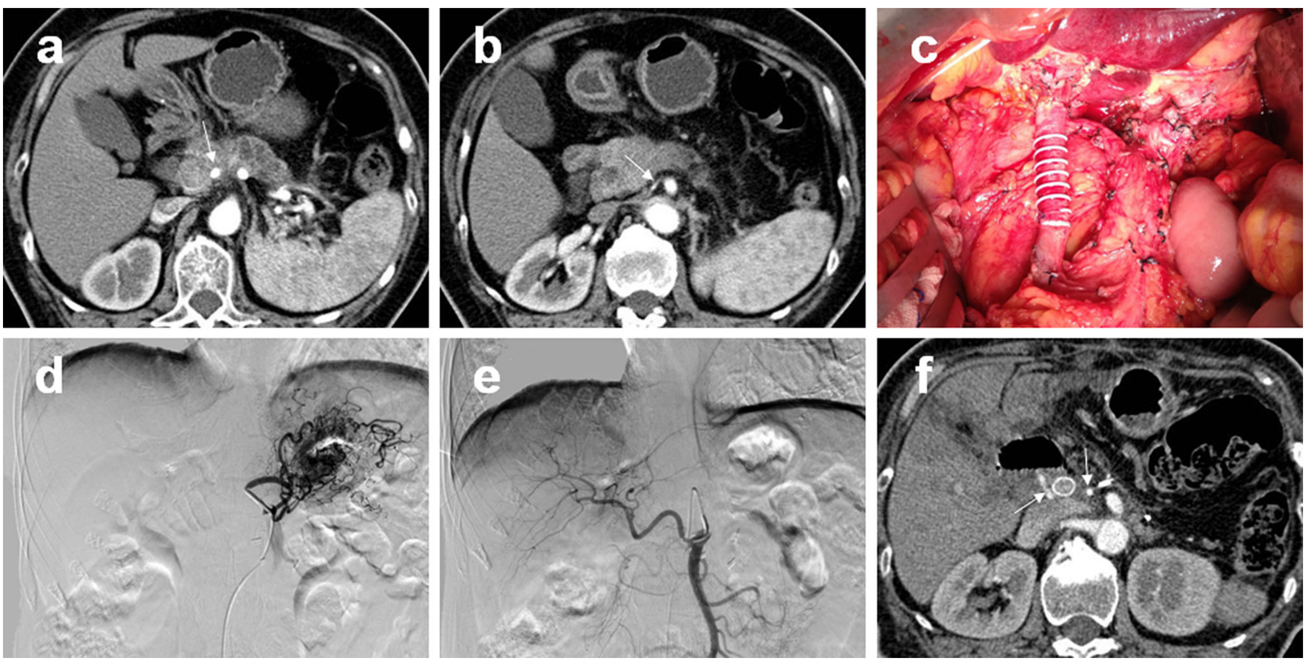

Fig. 3 PT-HAR for Michels type VI. A 67-year-old female patient (D in Fig. 1) with CHA encasement (**a**, arrow) and Michels type VI (**b**, arrow) received TP-CHAR without reconstruction plus PV resection (**c**). The liver was perfused by ARHA after surgery (**d**, **e**). Enlargement of the ARHA was observed (**f**, arrows). *PT-HAR* pancreatectomy with concomitant hepatic artery resection, *TP-CHAR* total pancreatectomy with common hepatic artery resection, *ARHA* accessory right hepatic artery

Histopathologic findings and survival analysis

Pathologic findings showed that 9 patients (64.3%) in the PT-HAR cohort had cancer invasion of the resected hepatic arteries. Nine patients (64.3%) had perineural invasion, 9 (64.3%) lymph node metastases, and 4 of 6 patients who received PV/SMV resection had pathologic venous invasion. Histologically clear surgical margins (R0 resection) were achieved in 13 of 14 patients (92.9%). Adjuvant chemotherapy (gemcitabine-based combination) was administered to all the patients. The median overall survival was 30 months (95% confidence interval 9.8–50.2 months), with the 1-, 2-, and 3-year survival rates of 81.8%, 63.6%, and 42.4%, respectively.

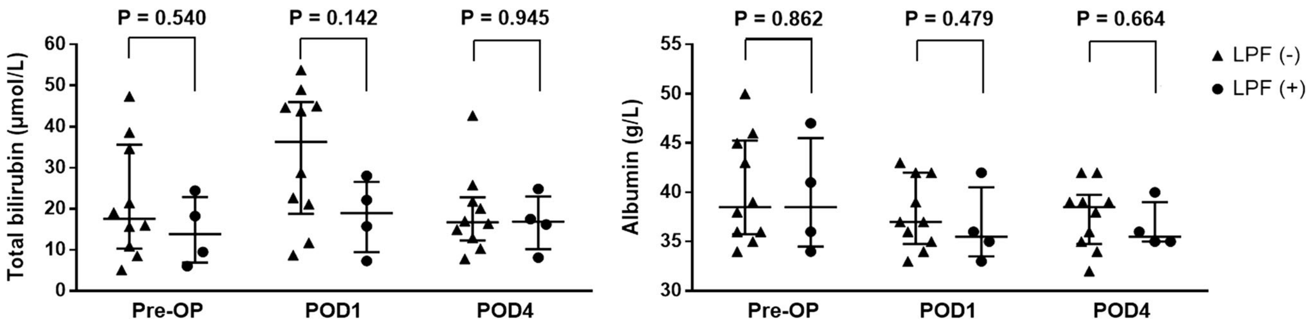

Fig. 4 Comparison of total bilirubin and serum albumin levels between patients with and without liver perfusion failure. *Pre-OP* preoperative, *POD* postoperative day, *LPF* liver perfusion failure

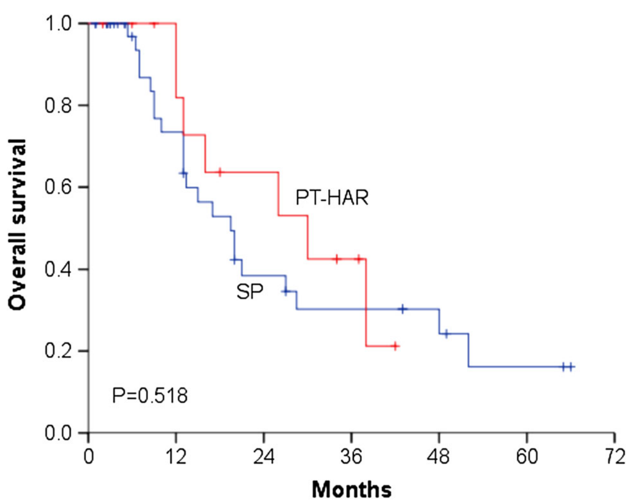

Fig. 5 Overall survival of patients in the PT-HAR and standard pancreatectomy groups. *PT-HAR* pancreatectomy with concomitant hepatic artery resection, *SP* standard pancreatectomy

Matched-pairs analysis

In addition to the matching factors including age and sex, the PT-HAR and standard pancreatectomy groups were similar in terms of comorbidities, symptomology, laboratory test results, biliary drainage, neoadjuvant chemotherapy, and ASA score (Table 1). The surgical data were also comparable between both groups (Table 2). Data on postoperative morbidity and mortality are shown in Table 3. Compared with standard pancreatectomy, no significant increases in incidence of POPF, delayed gastric emptying, hemorrhage, pulmonary and infectious complications were detected in patients receiving PT-HAR. In addition, there were no significant differences in terms of reoperation, mortality, readmission, and duration of postoperative hospital stay. However, liver perfusion failure occurred more frequently after PT-HAR than standard pancreatectomy (28.6% vs 0%, $P = 0.003$). Histologic findings showed no significant differences between the two groups, although the PT-HAR group presented with a little higher incidence of perineural invasion (64.3% vs 38.1%, $P = 0.088$). The rate of adjuvant chemotherapy and overall survival were similar between both groups (Fig. 5).

Discussion

Hepatic artery abutment or encasement has been demonstrated to be associated with poor survival in patients with pancreatic cancer [25]. Studies of hepatic artery resection (HAR) for pancreatic cancer have been sporadically reported in the literature [10, 26, 27]. The indication for combined arterial resection is highly limited because of high incidence of postoperative morbidity and mortality [11]. In view of the facts that distal pancreatectomy with celiac axis resection could achieve favorable outcomes in selected patients with pancreatic body carcinoma involving celiac axis [28, 29], more and more groups reported HAR at the time of pancreatectomy.

Preservation of intact hepatic arteries is critical to avoid complications such as liver ischemia, liver abscess, and breakdown of bilioenteric anastomosis. To prevent ischemic liver damage and risks associated with surgical techniques of vascular reconstruction, preoperative hepatic arterial embolization has been performed to facilitate collateral pathways development prior to pancreaticoduodenectomy with arterial resection. However, although it supports alleviation of hepatic ischemia, some patients still had significantly increased serum transaminases or developed patchy peripheral infarctions in the liver after surgery [10, 12]. Furthermore, this method has not been commonly accepted, as it depends on the radiologist's skill and maybe difficult to embolize small artery with acute angle at the root.

Our series of HAR had absence of high morbidity and mortality. The high incidence of morbidity and mortality

Table 1 Comparison of preoperative characteristics

Variables	PT-HAR (*n* = 14)	SP (*n* = 42)	*P* value
Age (years)	63.8 ± 9.1	63.5 ± 8.5	0.915
Sex (*n* %)			1.000
Male	8 (57.1)	24 (57.1)	
Female	6 (42.9)	18 (42.9)	
BMI	21.7 ± 2.4	22.2 ± 3.1	0.540
Diabetes (*n* %)	3 (21.4)	18 (42.9)	0.151
Symptoms (*n* %)			
Abdominal discomfort	10 (71.4)	33 (78.6)	0.584
Obstructive jaundice	4 (28.6)	19 (45.2)	0.272
Weight loss	3 (21.4)	12 (28.6)	0.601
Back pain	1 (7.1)	8 (19.0)	0.294
Serum albumin (<35 g/L, *n* %)	2 (14.3)	2 (4.8)	0.258
CA19-9 (≥37 U/ml, *n* %)	10 (71.4)	32 (76.2)	0.722
CEA (≥10 ng/ml, *n* %)	2 (14.3)	6 (14.3)	1.000
Preoperative biliary drainage (*n* %)	4 (28.6)	19 (45.2)	0.272
Neoadjuvant chemotherapy (*n* %)	1 (7.1)	8 (19.0)	0.294
ASA score (II–III, *n* %)	9 (64.3)	33 (78.6)	0.285

PT-HAR pancreatectomy with concomitant hepatic artery resection, *SP* standard pancreatectomy, *BMI* body mass index, *TB* total bilirubin, *ASA* American Society of Anesthesiologists

Table 2 Comparison of surgical and pathologic findings

Variables	PT-HAR (*n* = 14)	SP (*n* = 42)	*P* value
Surgery type (*n* %)			1.000
Pancreaticoduodenectomy	11 (78.6)	33 (78.6)	
Total pancreatectomy	3 (21.4)	9 (21.4)	
Venous resection (*n* %)	6 (42.9)	18 (42.9)	1.000
Intra-operative blood loss (ml)	553.6 ± 267.8	616.7 ± 504.6	0.658
Operation time (h)	7.1 ± 1.0	7.1 ± 1.2	0.906
Intra-operative RBC transfusion (*n* %)	7 (50.0)	25 (59.5)	0.533
R0 resection (*n* %)	13 (92.9)	40 (95.2)	0.732
Tumor size (cm)	3.5 ± 1.4	3.4 ± 1.4	0.834
Tumor grade (*n* %)			0.877
G1&2	6 (42.9)	19 (45.2)	
G3	8 (57.1)	23 (54.8)	
Perineural invasion (*n* %)	9 (64.3)	16 (38.1)	0.088
Venous invasion (*n* %)	4 (28.6)	13 (31.0)	0.867
Lymph node metastasis (*n* %)	9 (64.3)	27 (64.3)	1.000
Adjuvant chemotherapy (*n* %)	14 (100)	38 (90.5)	0.562

PT-HAR pancreatectomy with concomitant hepatic artery resection, *SP* standard pancreatectomy, *RBC* red blood cell

following arterial resection reported in the literature may be attributed to an unintended arterial resection where surgeons reached a point of nonreturn [30]. This could be avoided by careful preoperative imaging review and a well-thought-out plan for arterial resection. Our previous study showed that MDCT had a high accuracy in detection of aberrant right hepatic artery preoperatively, and detailed image analysis was critically important [14]. HAR without reconstruction is technically easier to perform. However, concerns remain since it may be challenging to know

Table 3 Comparison of postoperative complications

Variables	PT-HAR (*n* = 14)	SP (*n* = 42)	*P* value
Total complications (*n* %)	6 (42.9)	12 (28.6)	0.322
Clavien–Dindo classification (*n* %)			0.055
I	5 (83.3)	3 (25.0)	
II	1 (16.7)	5 (41.7)	
III a	0 (0)	4 (33.3)	
Liver perfusion failure (*n* %)	4 (28.6)	0 (0)	0.003
Grade B POPF (*n* %)	1 (7.1)	2 (4.8)	0.732
Chyle leak (*n* %)	0 (0)	1 (2.4)	0.560
DGE (all, *n* %)	0 (0)	3 (7.1)	0.304
Grade A	0 (0)	1 (2.4)	
Grade B	0 (0)	1 (2.4)	
Grade C	0 (0)	1 (2.4)	
PPH (*n* %)	0 (0)	1 (2.4)	0.560
Grade A	0 (0)	1 (2.4)	
Intra-abdominal abscess (*n* %)	0 (0)	1 (2.4)	0.560
GI and/or bile leaks (*n* %)	0 (0)	0 (0)	1.000
Pulmonary complications (*n* %)	1 (7.1)	8 (19.0)	0.294
Wound infection (*n* %)	0 (0)	1 (2.4)	0.560
Reoperation (*n* %)	0 (0)	0 (0)	1.000
90-day mortality (*n* %)	0 (0)	0 (0)	1.000
90-day readmission (*n* %)	2 (14.3)*	3 (7.1)[#]	0.590
Postsurgical hospital stay (d)	12.6 ± 8.1	15.3 ± 9.0	0.318

PT-HAR pancreatectomy with concomitant hepatic artery resection, *SP* standard pancreatectomy, *POPF* postoperative pancreatic fistula, *DGE* delayed gastric emptying, *PPH* postpancreatectomy hemorrhage, *GI* gastrointestinal

[*] Reasons for readmission included cholangitis (*n* = 1) and delayed gastric emptying (*n* = 1)

[#] Reasons for readmission included cholangitis (*n* = 2) and delayed gastric emptying (*n* = 1)

Table 4 Reported case series of HAR without reconstruction in pancreaticoduodenectomy or total pancreatectomy

Author	*N*	Aberrant HA	Resected arteries	Preoperative HAE	LI/LA/BF (*n*)	Mortality
Yoshidome [11]	7	NA	7 CHA/3 PHA	All positive	1/0/1	0
Miyazaki [10]	20	6 positive	21 CHA	12 positive	7/2/2	0
Bachellier [35]	8	All positive	a/rHA	All negative	NA	NA
Asano [36]	9	All positive	rRHA	All negative	0/1/0	0
Present series	11	8 positive	6 CHA/5 a/rRHA	All negative	4/0/0	0

HAR hepatic artery resection, *HA* hepatic artery, *HAE* hepatic arterial embolization, *LI* liver infarction, *LA* liver abscess, *BF* biliary fistula, *NA* not available, *CHA* common hepatic artery, *PHA* proper hepatic artery, *a/rHA* accessory/replaced hepatic artery, *rRHA* replaced right hepatic artery, *a/rRHA* accessory/replaced right hepatic artery

whether arterial blood flow to the liver is sufficient. As blood supply to the biliary duct is maintained only by hepatic artery, preservation of hepatic arterial flow is necessary. Careful operation around the hepatic hilar plate is critical to maintain the communicating arteries and confirm the cut line of the biliary duct.

Although reconstruction of the hepatic artery is necessary in most cases, it is sometimes controversial. Someone claims that reconstruction may be refrained from without leading to any issues, as communication is usually maintained between the right and left hepatic arteries at the hepatic hilum [12]. No reconstruction may reduce the risk of postoperative hemorrhage and thrombosis of the reconstructed artery if infectious complications occurred after pancreatectomy. Nevertheless, there is also an opinion that the presence of communication may not be sufficient for the inter-segmental blood flow [6]. It's worth noticing that celiac axis stenosis is a relevant clinical issue that may lead to liver perfusion failure after occlusion of the gastroduodenal artery or aberrant right hepatic artery [3, 31].

Methods for assessing adequate hepatic blood flow include confirming no color change of the liver after test clamping, touching pulsation by fingers, and detecting arterial bleeding at the cut edge of the proximal bile duct. However, evaluation by inspection is subjective and difficult to quantify. Doppler ultrasound measurement of arterial flow and waveform is advocated, but may have limitation in assessment of collateral function. Identification of backflow is an efficient way to test sufficient collateralization after HAR, such as strong bleeding from the cystic artery stump during cholecystectomy. A recent study suggested applying fluorescence imaging by indocyanine green in assessment of liver circulation [32], which needs to be validated in future studies. If liver ischemia or insufficient collateral circulation occurs, hepatic artery reconstruction is required. In addition, the bile duct should be resected near porta hepatis to ensure good blood supply. Simultaneous resection of the PV and hepatic artery remains challenging and should be performed by experienced pancreatic surgeons. Despite immediate rise in postoperative transaminase levels, no mortality occurred in our study. Given the complexity and extent of the procedures, postoperative morbidity seemed reasonable. No liver abscess occurred indicated that hepatic arterial flow to the liver was maintained after arterial resection.

Three of our patients without hepatic arterial variants received no arterial reconstruction and didn't encounter severe complications except for liver perfusion failure. The significantly transient rise in serum transaminases suggested risk of liver damage. The reasons why we did not perform arterial reconstruction for them, all of whom were operated in the early study period, included: collateral arterial blood flow to the liver seemed developed sufficiently due to severe encasement of the artery, size of the affected hepatic artery was small, and no liver ischemia was detected intra-operatively. A recent report showed that the liver could be perfused by the inferior phrenic and retroperitoneal collateral arteries, which occurred rapidly following proper and common hepatic arterial embolization [11, 33]. To assess fine abdominal vessels preoperatively, our patients underwent 64-slice MDCT, which had been reported useful for visualization of the inferior phrenic artery and could replace conventional angiography [14, 34]. Additionally, in order to preserve the collateral vessels to the liver, we minimized isolation of the perihepatic ligaments during operation. HAR without reconstruction has also been found safe by several studies in selected patients (Table 4) [10, 11, 35, 36]. Even if there is liver infarction, it can be treated with medical treatment unless infection or liver failure develops [37]. Nevertheless, considering the occasionally fatal complications of hepatic artery injury during pancreaticoduodenectomy [38], HAR without reconstruction should be done cautiously. Especially for those with normal anatomy of the hepatic artery, arterial reconstruction is required for CHA resection.

The actual rate of microscopic invasion of the resected hepatic arteries in our patients was 64.3%, which was similar to the rate reported by Perinel et al. [30]. The results indicated that preoperative CT scan might overstage arterial encasement and was hard to adequately differentiate between inflammatory and tumor invasion. However, although the artery may not be involved microscopically, the distance between the tumor and artery adventitia is so narrow that curative resection without hepatic artery is unlikely. Generally, macroscopic findings appear to be more important for evaluation of arterial invasion than microscopic findings [39]. Okada et al. [26] divided the replaced right hepatic artery adjacent to pancreatic cancer to improve the rate of R0 resection and achieved encouraging survival time. The expected improvement of prognosis could outweigh the risk of overtreatment in those with only inflammatory adhesions to the artery. Consistent with previous studies [10, 40], our report showed that PT-HAR for advanced pancreatic head cancer was associated with acceptable survival.

Neoadjuvant chemotherapy was administered to few patients in our study. The benefit of neoadjuvant chemotherapy for advanced pancreatic cancer is increasingly being recognized, and it may convert locally advanced or borderline resectable to resectable. However, neoadjuvant chemotherapy has been revealed to be associated with fatty liver and/or sinusoidal obstruction syndrome, which makes the liver more vulnerable to ischemia [5]. Thus, for patients receiving neoadjuvant chemotherapy, more attention should be paid to prevent liver ischemia, especially in those who have already suffered liver damage from biliary obstruction or when both the PV and hepatic artery will be resected. Considering that neoadjuvant treatment is associated with better outcomes than upfront venous resection in patients with suspicion of venous involvement [41], its merit needs further evaluation in those who are going to have HAR.

Our study was limited by its retrospective nature and the fact that surgical treatment was conducted by specialized pancreatic surgeons at a single institution, which led to selection bias. Another limitation was the small number of patients who received HAR, which yielded an insufficient statistic power. However, the matched-pair analysis eliminated potential confounders. Overall, PT-HAR could be performed with acceptable morbidity, mortality, and survival for advanced pancreatic head cancer. Only carefully selected patients with a strong drive for an aggressive surgery at high-volume centers should be considered for this strategy. In highly selected cases, such as those with aberrant hepatic arteries, HAR without reconstruction may be safe following pancreaticoduodenectomy. Nevertheless, considering that there are still risks of liver perfusion failure in the presence of aberrant hepatic artery, arterial reconstruction is recommended if the artery to be resected is a replaced one or a large accessory one, or if PV/SMV resection is required simultaneously.

Acknowledgements Feng Yang: Supported by the National Key R&D Program of China No. 2017YFC1308604.

Author contributions FY contributed to the conception and design of this paper, data acquisition, drafting and revising the article, and final approval of the version to be published; XW, CJ, and HH contributed to the conception and design of this paper, data analysis, and final approval of it; DF contributed to the conception and design of this paper, data analysis, and final approval of it.

Compliance with ethical standards

Conflict of interest We declared no conflict of interest.

Informed consent Informed consent was obtained from all individual participants included in the study.

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