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***Retrospective Study***

**Surgical management of** **liver diseases invading the hapatocaval confluence based on IH classification: the surgical guideline in our center**

Wei Li, Jun Han, Zhao-ping Wu, Hong Wu

Li W *et al*. Hepatectomy and IVC reconstruction

**Wei Li, Hong Wu,** Department of Liver Surgery and Liver Transplantation Centre, West China Hospital, Sichuan University, Chengdu 610041, Sichuan Province, China

**Zhao-ping Wu,** Department of hepatobiliary surgery, Jiujiang NO.1 People’s Hospital, Jiujiang 332000, Jiangxi Province, China

**Jun Han,** Department of Critical Care Medicine, Sichuan Provincial Hospital for Women and Children, Chengdu 610041, Sichuan Province, China

**Author contributions:** Wu H proposed the study; Li W, Wu ZP, and Han J performed research and wrote the first draft; Li W collected and analyzed the data; Wu H is the guarantor; all authors contributed to the design and interpretation of the study and to further drafts, and have read and approved the final version to be published. Jean T revised the language.

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**Correspondence to:** **Hong Wu, MD, PhD,** Department of Liver Surgery and Liver Transplantation Center, West China Hospital, Sichuan University, Chengdu 610041, Sichuan Province, China. wuhong7801@163.com

**Telephone:** +86-18980601958

**Fax:** +86-28-85422474

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**Abstract**

***Aim***

to investigate the short-term outcomes and risk factors indicating postoperative death of patients with lesions adjacent to the hapatocaval confluence.

***Methods***

We retrospectively analyzed 54 consecutive patients who underwent hepatectomy combined with inferior vena cava (IVC) and/or hepatic vein reconstruction (HVR) from January 2012 to January 2016 at our liver surgery center. The patients were divided into 5 groups according to the range of IVC and hepatic vein involvement. The patient detail, indications for surgery, operative techniques, intra- and postoperative outcomes were compared among the 5 groups. Univariate and multivariate analyses were performed to explore factors predictive of overall operative death.

***Results***

IVC replacement was done in 37 (68.5%) patients and HVR in 17 (31.5%) patients. Type I2H2 had the longest operative blood loss, operative duration and overall liver ischemic time (all; *P* < 0.05). Three patients of Type I3H1 with totally occluded IVC did not need IVC reconstruction. Total postoperative morbidity rate was 40.7% (22 patients) and the operative mortality rate was 16.7 % (9 patients). Factors predictive of operative death included IVC replacement (*P* = 0.048), duration of liver ischemia (*P* = 0.005) and preoperative liver function being Child-Pugh B (*P* = 0.025).

***Conclusion***

IVC replacement, duration of liver ischemia and preoperative poor liver function were risk factors predictive of postoperative death. We should be cautious about IVC replacement especially in Type I2H2. For Type I3H1, it was unnecessary to replace IVC when the collateral circulation was established.

**Key words:**Hepatectomy; Inferior vena cava; Hepatic vein; Reconstruction

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**C****ore tip:** The proposed IH classification, which divided the patients into five groups according to the range of vascular invasion, may be meaningful in selecting procedures for patients with hepatocaval confluence infiltration. inferior vena cava replacement, duration of liver ischemia and preoperative poor liver function were risk factors predictive of postoperative death for patients with lesions adjacent to the hapatocaval confluence.

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**Introduction**

Liver malignancies including hepatocellular carcinoma (HCC), intro-hepatic cholangiocarcinoma (ICC) and colorectal liver metastases, combined with liver parasitic disease like alveolar echinococcosis (AE), often showed an infiltrative growth pattern. If major vessels such as inferior vena cava (IVC) and hepatic vein adjacent to its caval confluence were invaded by these lesions, combined liver and IVC resection followed by IVC and/or hepatic outflow reconstruction with other materials is necessary to achieve R0 resection[1-3]. As a consequence of recent advances in perioperative management and surgical technique, liver and IVC resection combined with major vascular reconstruction becomes a reasonably safe treatment option with acceptable short- and long-term survival. Preoperative portal vein embolism (PVE), ALPPS (associating liver partition with portal vein ligation for staged hepatectomy), systemic chemotherapy (mainly for colorectal liver metastases) and other innovative treatments increase the tumor resectability[4-6]. Total vascular exclusion (TVE) and other vascular exclusion techniques offer chances of resection for tumor with major vascular involvement. In situ perfusion technique can be applied in patients with TVE longer than 60 min. Moreover, the utilization of anti-situm and *ex vivo* technique makes it easier to acquire a better operative filed and obtain tumor-free surgical margins[7-9]. Venovenous bypass (VVB) is necessary in some patients under TVE with drastic hemodynamic fluctuations[7].

Though technically challenging, hepatectomy combined with major vascular resection and reconstruction was performed in many centers[7-10]. Due to the lack of surgical protocols, different standards were used in different centers. In this study, we presented our surgical guideline and outcomes about the combined liver and IVC resection in 54 patients with different kinds of liver lesions invading the hapatocaval confluence. The IH classification was established based on our experience, which was the surgical guideline in our center.

**Materials and methods**

We retrospectively analyzed 54 consecutive patients who underwent liver resection combined with IVC resection and reconstruction from January 2012 to January 2016 at our liver surgery center at the West China Hospital, Sichuan University. The Cases with IVC involvement that could be detached primarily without reconstruction were not included in this study. Patients with tumor thrombus in the IVC or hepatic veins were excluded. The final diagnoses were confirmed by histopathological examinations after surgery. We have established classifications for this challenging situation based on our experience and the patients were divided into 5 groups according to the classifications (Figure 1). The indications for surgery of these patients were summarized in Table 1. All procedures described in this study were approved by the Ethics Committee of West China Hospital, Sichuan University.

***Classifications for liver diseases invading the hapatocaval confluence***

**The classification based on varying degrees of IVC infiltration:** I1: Less than 50% of IVC circumference is involved and the IVC is not totally occluded; I2: More than 50% of IVC circumference is involved and the IVC is not totally occluded; and I3: The encroached IVC is totally occluded.

**The classification based on hepatic outflow conditions:** H1:The hepatic outflow of the residual liver is not involved; and H2: The hepatic outflow of the residual liver is involved (three hepatic veins are all infiltrated).

***Preoperative management***

The ultrasonography and contrast computed tomography (CT) scan or magnetic resonance imaging (MRI) of the abdomen were performed to evaluate the number and extent of lesions, gross type, liver volume, presence of major vascular infiltration, and regional or distant metastasis. Our standard indication for hepatectomy was Child–Pugh grade A or B, or indocyanine green retention rate at 15 min (ICG-R15) below 10 percent. Some patients with metastatic colorectal cancer received systemic chemotherapy after evaluation in the cancer center of our hospital, and all of them underwent colonoscopy before surgery. Our policy for indication of PVE is when the predicted future liver remnant is less than 40% of the total non-tumorous functional liver volume[11].

***Surgical procedures***

The procedures for hepatectomy were reported elsewhere[11,12]. Our preferred abdominal incision was J-shaped thoracoabdominal incision. After mobilization, the intraoperative ultrasound was performed routinely to confirm the number and location of lesions as well as to evaluate the relation of tumor to major vessels. The other major procedures before hepatectomy included: portal pedicle division and ligation, exposing and encircling the infra- and supra-hepatic IVC (the supradiaphragmatic IVC was encircled if the diaphragm was invaded), and dividing and ligating the short hepatic veins if possible. Liver parenchyma transaction (Pringle’s maneuver was used if necessary) was carried out with the Kelly crush technique or other instruments including (CUSA, Valleylab Corp. Somerville, NJ, United States) or Harmonic scalpel (Johnson & Johnson Corp. Princeton, NJ, United States). The anterior approach was used if bulky lesions reside in the right lobe of the liver.

When the critical remaining parenchyma and vascular structures were exposed, various vascular control techniques were applied. For type I1H1, we clamped the IVC tangentially without IVC exclusion or clamped IVC below the hepatic vein (CIBH) of the remnant liver without hepatic outflow exclusion. In our experience, if IVC involvement was less than 30% of the IVC circumference and 2 centimeters of the length, the defect was usually sutured transversely after removing the invaded IVC wall. If IVC involvement was 30% to 50% of IVC circumference and longer than 2 cm, we used autogenous veins like great saphenous vein patches or expanded polytetrafluoroethylene [ePTFE; (Gore-Tex, Flagstaff, AZ)] patches for IVC repair. As for type I1H2, IVC reconstruction was similar to type I1H1. TVE (clamping the infra-hepatic IVC, portal triad and supra-hepatic IVC sequentially) was utilized for IVC and hepatic vein reconstruction. In this type, three hepatic veins were involved, and the remaining stump of hepatic vein was reimplanted directly into the vena cava, or an interposed reinforced ePTFE graft. With respect to type I2H1, we used TVE or CIBH (if there was enough room below the hepatic vein) for blood control. And if longitudinal infiltration was longer than 3 cm, IVC replacement was performed. Regarding type I2H2, TVE was necessary to complete tumor resection and vascular reconstruction. In this type, vascular reconstruction included hepatic outflow and IVC reconstruction. IVC was replaced with ePTFE tube graft and the hepatic vein was reimplanted into the ePTFE tube graft if it was totally invaded. Otherwise, if hepatic vein of the residual liver was partially involved, we used autogenous vein patches or ePTFE patches for hepatic vein plasty. With respect to I3H1, if collateral circulation including ascending lumbar veins, hemiazygos vein, and azygos vein were dilated and compensated portal hypertension and caval flow effectively, we only performed liver and IVC resection without IVC replacement (Figure 2).

***Ex vivo,*** ***in situ perfusion and*** ***anti-situm technique***

*Ex vivo*, *in situ* perfusion and anti-situm technique were predominately used in type I2H2. In situ hypothermic perfusion as described by DuBay*et al*[13] can be performed when TVE lasting longer than 60 min. When TVE was utilized, the patient’s hemodynamic condition was carefully monitored and VVB (installed from the inferior mesenteric vein, and the right femoral vein to the left internal jugular vein) was applied when the patient could not tolerate the hemodynamic fluctuation. *Ex vivo* technique which we have reported elsewhere is easier to obtain tumor-free surgical margins and reconstruct the vessels[14]. However, given the higher complications (including bile leakage, bile duct stricture and prosthetic graft infection caused by bile leakage) associated with biliary tract anastomosis[15,16], *ex vivo* was done only on patients with the IVC, hepatic vein confluence, and/or portal structures infiltrated extensively. VVB was needed for most of the patients who underwent ex vivo. Anti-situm technique, first introduced by Pichlmayr *et al*. twenty years ago[17], did not need to divide the portal structures. After cutting off the supra-hepatic IVC, the liver together with the IVC was rotated to the anterior position, away from their anatomic location. Then hepatectomy could be achieved rather easily with infra-hepatic IVC and the portal triad exclusion, hypothermic hepatic perfusion and percutaneous VVB.

***Postoperative management***

All patients were treated with low-molecular-weight heparin sodium anticoagulation solution (1 mg per kg bodyweight) from 2 d after surgery with close monitoring. After discharge from hospital, the patients were given warfarin (2.5 mg, qd, po) for 3 months. Enhanced abdominal CT or ultrasonography was done every 7 days in the first month postoperatively to detect the patency of reconstructed vessels. For hepatitis-B-virus infected patients, anti-viral drugs were applied.

Postoperative mortality was defined as death within 90 days of operation. Clavien–Dindo classification was used to classify all general complications occurring at any time during the hospital stay[18]. Liver failure was defined as peak bilirubin concentration > 7 mg/dl, peak international normalized ratio > 2.0, refractory ascites, or encephalopathy[19]. Bile leakage was defined as a drain fluid-to-serum total bilirubin concentration ratio ≥ 3.0[20]. Renal insufficiency was defined as increase of serum urea and/or creatinine level (50% above the baseline). Clinically significant ascites was defined when abdominal drainage was more than 500 ml/d for longer than 3 d.

***Statistical*** ***analysis***

The clinicopathologic characteristics and short-term surgical outcomes of these patients were compared among the 5 groups. Categorical variables were expressed as number and tested by chi-square test or Fisher’s exact test. Continuous variables were presented as mean (range) and tested by one-way ANOVA (Student-Newman-Keuls test was used when ANOVA was significant) or Kruskal–Wallis H rank test when necessary. The prognostic significance of the variables in predicting operative death was performed by univariate and multivariate binary logistic regression analysis. All statistical analyses were 2-tailed and p values < 0.05 were regarded as statistically significant. All analyses were performed by SPSS 19.0 statistical software (SPSS Company, Chicago, IL, United States).

**Results**

Fifty-fourpatients (34 male, 20 female)underwent hepatectomy combined with vascular resection and reconstruction with a mean (range) age of 49.7 (39-72) years. The indications for surgery were: ICC (*n* = 26), HCC (*n* = 13), colorectal metastases (*n* = 8), AE (*n* = 9) (Table 1). The intra- and postoperative data for the different types of liver lesions treated by hepatectomy combined with IVC and/or HVR were summarized in Table 2. The resection concerned 4.7 liver segments medially (range, 1-6 segments). IVC replacement was done in 37 (68.5%) patients and HVR in 17 (31.5%) patients. Type I2H2 had the longest operative blood loss, operation duration and overall liver ischemic time than the other 4 types (all; *P* < 0.05). The other clinical characteristics of the 5 types including tumor size, postoperative liver function, and hospital stay were listed in Table 2 in detail. Type I2H2 had the most complex procedure, which needed IVC replacement and hepatic vein plasty (*n* = 3; with autogenous vein patches in 2, ePTFE patches in 1) or reimplantation (*n* = 9; reimplant to ePTFE graft in 5, to residual IVC in 4). Anti-situm (*n* = 2), *ex vivo* (*n* = 6) and in-situ perfusion (*n* = 5) were mainly utilized in I2H2. Three patients of type I3H1 with totally occluded IVC did not need IVC reconstruction. The other 2 patients underwent IVC resection and replacement due to the uncompensated collateral circulation. The surgical procedures for the other 3 types were described in Table 2.

Total postoperative morbidity rate was 40.7% (22 patients) and the operative mortality rate 16.7% (9 patients) (Table 3). Total morbidity and mortality rate of type I2H2 were higher than type I1H1 (both; *P* < 0.05). Artificial graft infection (*n* = 4; two in type I2H2, two in type I2H1), liver failure (*n* = 4; two in type I2H1, two in type I2H2) and thrombosis of reconstructed vessels (*n* = 1; one in type I2H2) were the main reasons leading to postoperative death. Univariable analysis of factors predictive of death were Child-Pugh B (*P* = 0.004), IVC replacement (*P* = 0.044), duration of ischemia (*P* < 0.001) and duration of operation (*P* < 0.001) (Table 4). Factors predictive of operative death in multivariable analysis included IVC replacement (*P* = 0.048), duration of liver ischemia (*P* = 0.005) and preoperative liver function being Child-Pugh B (*P* = 0.025) (Table 5).

The median follow-up time was 20 mo (range, 2-48 mo). No patient was lost during follow-up. Eight patients (three in type I2H2, two in type I2H1, two in type I1H2, and one in type I1H1) died from tumor recurrence within 6 months after the operations. Overall 1- and 3-year actuarial survival rates for HCC were 60% and 45% and for ICC were 55% and 38%. Twenty-five patients developed recurrence. Local recurrence in the liver was in 16 patients, brain in three, lung in four, and abdominal cavity metastasis in two. Disease-free 1- and 3-year survival rates for patients with HCC were 18 and 8% respectively, and for patients with ICC were 16 and 9%. All AE patients were alive without recurrence and metastasis at the last follow-up.

**Discussion**

In the present study, 54 patients underwent liver resection combined with IVC and/or HVR were included. ICC, HCC, AE, colorectal metastasis were the main causes leading to IVC encroach. Undoubtedly, when liver diseases have involved the hepatocaval confluence, resection and reconstruction of the vascular structures remain technically difficult. A variety of vascular exclusion techniques, IVC reconstruction strategies, and other innovative surgical methods have brought hope for patients in this late stage[21,22].

Due to the high postoperative morbidity and mortality rate, though technically feasible, it is controversial about whether we should perform radical resection with vascular reconstruction for lesions invading IVC and other major vessels. However, prognosis of malignant tumor involved IVC is unfavorable when performing hepatectomy without IVC reconstruction[10]. R0 resection combined with IVC reconstruction may have a better short- and long-term prognosis than cases only underwent hepatectomy or conservative treatment, but further prospective studies are needed to investigate it. In table 6, we summarized the morbidity and mortality rates of the patients underwent liver resection and IVC reconstruction in previous reports. In the present study, total postoperative morbidity rate was 40.7% (22 patients) and the operative mortality rate was 16.7% (9 patients, Table 3). Artificial vascular graft was the most commonly used material due to the shortage of xenogenous vessels and a larger surgery injury when utilizing autogenous vein[23]. Though graft infection was a life-threatening complication of artificial tube graft, many studies including ours showed that graft infection rate after artificial graft replacement was lower than 10%[15,24,25]. For type I2H2, postoperative mortality rate was higher than the other types, which may be related to the longer operation time, longer ischemic time, more blood loss and higher postoperative morbidity rate. Consequently, for patients in type I2H2, it was still controversial about whether we should perform such an extensive operation.

Most of the previous studies demonstrated that it was difficult to assess IVC involvement preoperatively relying on imaging technique[15,24,25]. Though intraoperative ultrasonography and cavography were performed to help confirm the IVC invasion, the true IVC invasion rate confirmed by pathological examinations after surgery was only 60% in our study (data not shown). For malignant infiltrative-growth diseases including ICC and AE (characterized by tumor-like growth), R0 resection was a primary goal of treatment. IVC resection was necessary when it was infiltrated or embraced by the lesions which cannot be divided totally. For HCC and colorectal liver metastases (the tumor usually compress rather than encroach the vessels), sometimes we also could not achieve R0 resection when the IVC was surrounded by the tumor, thus IVC replacement was performed in some of these patients. Multi-organ infiltration was not a surgical contraindication for AE. Given the lack of alternative curative approaches, a radical operation with complete removal of the parasitic lesions was the best beneficial way to achieve radical treatment[26-28]. However, IVC resection combined with reconstruction in AE patients was still controversial considering the severe complications related to the IVC replacement.

Moreover, multivariable analysis in the present study showed that IVC replacement was a prognostic factor predictive of operative death (*P* = 0.048), thus indications of IVC replacement should be controlled strictly. In our experience, we have established IH classification according to the range of tumor invasion. According to the extent of caval involvement, the IVC was reconstructed using a tube graft (I2), direct suture or with patches (I1). For I3 (IVC was totally occluded), if there were no symptoms and life-threatening complications associated with caval obstruction and portal hypertension (Figure 2), the IVC was removed without replacement (empirically, when renal vein pressure was < 40 mmHg, the kidney function was not affected). Once the collateral circulation could not compensate the IVC stricture or occlusion, IVC replacement was necessary. In our study, three patients with AE were performed IVC resection without reconstruction and had good short- and long-term survival. As for H1, we protected the hepatic vein of the residual liver during the operation and HVR was unnecessary. If three hepatic veins were involved (H2), hepatic vein plasty (with autogenous vein graft or ePTFE patches) or reimplantation (to the tube graft or residual IVC) was done to recover hepatic outflow. However, the criteria of IVC reconstruction in different centers are not identical due to the small sample size and patient heterogeneity (Table 7).

Vascular exclusion methods, including intermittent pringle manoeuvre, TVE, and CIBH, are all widely utilized in different centers[24,25,29-31]. Multivariable analysis showed duration of liver ischemia was a factor predictive of operative death (*P* = 0.005). When the duration of anticipated TVE was longer than 60 min, hypothermic hepatic perfusion (University of Wisconsin solution, chilled to 4 °C) was applied to acquire an extended period of time (the longest was 102 min in our study) and protect the remnant liver. Kim et al. used a new technique of extracorporeal hepatic venous bypass to avoid hypothermic perfusion successfully. They sutured a part of cryopreserved iliac vein to the hepatic vein stump of the remnant liver and a cannula for hepatic venous bypass was placed in it to drain the blood to the internal jugular vein[32]. When *ex vivo* and anti-situm were carried out, consistent with some of the previous reports[10,21,29], we used VVB if hemodynamic intolerance and splanchnic congestion happened. Our criterion was: a decrease in mean arterial pressure > 30% and/or a decrease in cardiac index > 50%. However, Zhang *et al*[33] have performed *ex vivo* liver resection and liver autotransplantation without VVB in order to shorten anhepatic time. After removing en bloc liver and IVC, they replaced the IVC transiently with a tube graft before reconstructing the IVC with autogenous veins. In one of our patient, we also utilized synthetic caval graft to replace the resected part of IVC combined with transient portacaval shunt reconstruction. A vena cava vessel made by autogenous veins was applied to replace the IVC eventually. This technique is feasible and it could take place of VVB in selected patients.

If the lesions involved three hepatic veins at the hepatic vein confluence (H2), then *ex vivo*, in situ perfusion and anti-situm technique were applied. In these cases, hepatic vein reconstruction of the remnant liver should be done[17]. *In situ* perfusion and anti-situm technique were preferable for protection of the portal structures. However, if the portal triads were also be involved, *ex vivo* technique had to be used. We have performed *ex vivo* liver resection followed by autotransplantation to several patients with advanced AE. The IVC were replaced using autogenous vein graft or artificial graft. We propose that AE may be a specific indication for *ex vivo* technique with better prognosis than in malignant cancers.

In conclusion, liver resection combined with IVC and/or HVR is technically feasible with acceptable short-term survival. However, IVC replacement should be prudent as it was a risk factor related to postoperative death. In addition, preoperative liver function should be placed on special attention and intraoperative liver ischemia time should be shortened to reduce postoperative mortality. The proposed IH classification, which divided the patients into five groups according to the range of vascular invasion, may be meaningful in selecting procedures for patients with hepatocaval confluence infiltration. However, due to the small sample size and patient heterogeneity in the present study, this classification still needs to be investigated in more studies. For example, IVC replacement and HVR must be applied in type I2H2 patients to achieve R0 resection. Nevertheless, such an aggressive treatment is controversial for colorectal liver metastasis and HCC because alternative treatment approaches with lower morbidity and mortality could be applied. Consequently, the proposed IH classification describes anatomic issues but may not have identical significance in guiding surgical approach and indicating postoperative prognosis in different liver diseases.

**COMMENTS**

***Background***

Though technically challenging, hepatectomy combined with major vascular resection and reconstruction was performed in many centers because it was the only way to achieve R0 resection. However, the surgical indications and protocols were different and controversial in different centers.

***Research frontiers***

The authors investigated the short-term outcomes and risk factors predictive of postoperative death for patients with lesions adjacent to the hapatocaval confluence.

***Innovations and breakthrough***

The authors established the IH classification dividing the patients into five groups according to the range of vascular invasion, which was meaningful in selecting procedures for patients with hepatocaval confluence infiltration.

***Applications***

In this study, the authors presented our surgical guideline and outcomes about the combined liver and inferior vena cava (IVC) resection in 54 patients with different kinds of liver lesions invading the hapatocaval confluence. The IH classification was established based on our experience, which can be a reference for other surgeons.

***Peer-review***

This is an interesting paper reviewing the center’s experience with a very challenging group of patients with liver malignancies and IVC or hepatic vein involvement.

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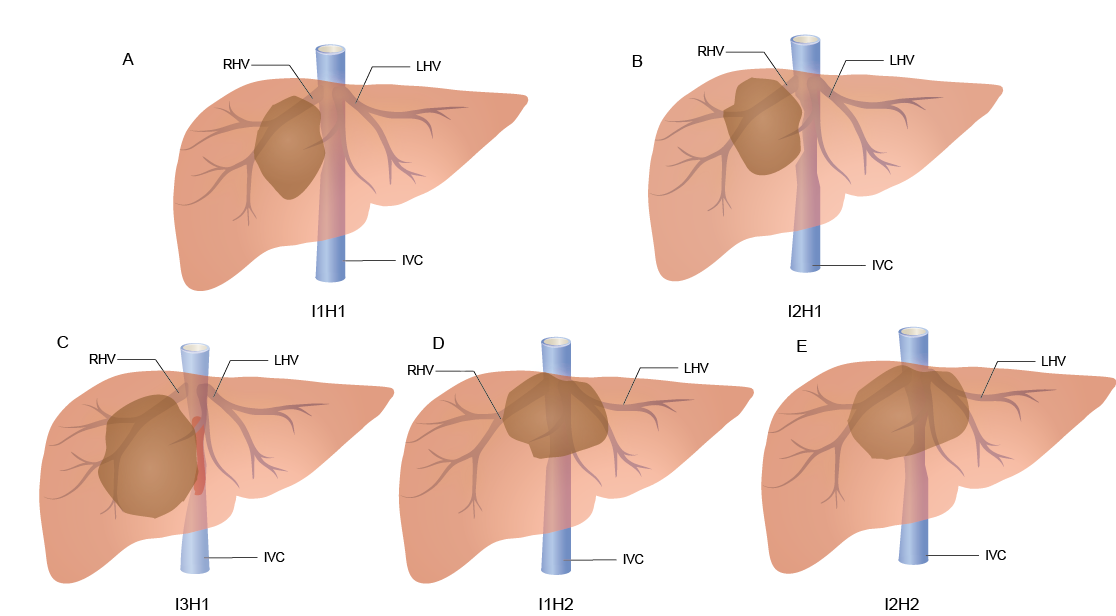
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Grade B (Very good): 0

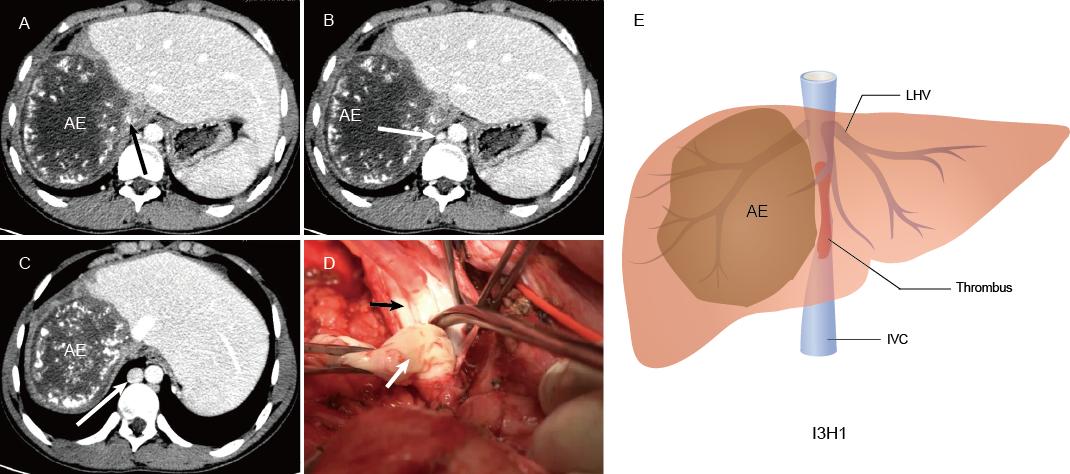
Grade C (Good): C

Grade D (Fair): 0

Grade E (Poor): 0



**Figure 1 Classifications of liver lesions.** A: type I1H1; B: I2H1; C: I3H1; D: I1H2; E: I2H2. RHV: right hepatic vein; LHV: left hepatic vein; IVC: inferior vena cava.



**Figure 2 One patient with alveolar echinococcosis in the right lobe of liver.** A: The IVC wall was totally occluded (longer black arrow). B and C: The azygos vein was dilated gradually (longer white arrows). D: The retrohepatic IVC was totally occluded, filled with organized thrombus (shorter white arrow). The shorter black arrow: IVC. E: The classification of this patient (I3H1). LHV: left hepatic vein; IVC: inferior vena cava; AE: alveolar echinococcosis.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Indications for surgery** | ***n*** | **Sex (M:F), *n*** | **Classifications** | | | | |
| **I1H1** | **I2H1** | **I1H2** | **I2H2** | **I3H1** |
| Hepatocellular carcinoma | 11 | 6:5 | 2 | 5 | 1 | 3 | 0 |
| Cholangiocarcinoma | 26 | 18:8 | 3 | 10 | 4 | 6 | 3 |
| Colorectal metastases | 8 | 5:3 | 1 | 5 | 0 | 1 | 1 |
| alveolar echinococcosis | 9 | 5:4 | 3 | 3 | 0 | 2 | 1 |

**Table 1 Patients undergoing combined liver and inferior vena cava resection**

**Table 2 Intra- and postoperative results**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Variables** | **I1H1 (*n* = 9)** | **I2H1 (*n* = 23)** | **I1H2 (*n* = 5)** | **I2H2 (*n* = 12)** | **I3H1 (*n* = 5)** | |
| **IVC resection and replacement (*n* = 2)** | **Only IVC resection (*n* = 3)** |
| RL:REL:RT:LEL:LT | 3:2:2:1:1 | 4:6:8:2:3 | 0:1:2:2:0 | 2:4:3:2:1 | 1:0:1:0:0 | 1:2:0:0:0 |
| Tumour size (cm) | 7.2 (2.9-14.3) | 8.7 (7.1-15.4) | 9.2 (3.9-9.9) | 9.6 (7.2-16.1) | 9.4 (6.6,12.2) | 8.3 (7.1-10.2) |
| Operative blood loss (mL) | 460 (310-950) | 740 (450-1250) | 570 (450-1050) | 1020 (550-1700)a | 680 (550-810) | 450 (350-560) |
| Need for blood transfusion | 1 | 8 | 0 | 7 | 1 | 0 |
| Transfusion volume (mL) | 400 | 550 (200-950) | 0 | 600 (300-850)c | 400 | 0 |
| Operation duration (min) | 290 (210-420) | 592 (480-800) | 520 (250-860) | 750 (310-1150)a | 580 (490-670) | 320 (240-440) |
| No. of patients using TVE | 2 | 23 | 3 | 12 | 2 | 0 |
| No. of patients using PM | 5 | 17 | 2 | 8 | 2 | 2 |
| Duration of TVE (min) | 50 (40,60) | 62 (46-90) | 48 (35-68) | 73 (37-89)a | 49 (39-57) | 0 |
| Duration of PM (min) | 25 (10-35) | 36 (15-45) | 22.5(20-25) | 38 (10-50) | 30 (15-15) | 30 (15-15) |
| Reconstrction detail | IVCR: direct suture in 4, with a patch in 5; HVR: no | IVCR: replacement; HVR: no | IVCR: with a patch in 5; HVR: reimplant to ePTFE in 1, to residual IVC in 4 | IVCR: replacement; HVR: with a patch in 3, reimplant to ePTFE in 5, to residual IVC in 4 | IVCR: replacement; HVR: no | IVCR: no; HVR: no |
| Surgical technique |  |  |  |  |  |  |
| anti-situm | 0 | 0 | 0 | 2 | 1 | 0 |
| *ex vivo* | 0 | 0 | 0 | 6 | 0 | 0 |
| *in situ* perfusion | 0 | 2 | 1 | 5 | 0 | 0 |
| Postoperative liver function |  |  |  |  |  |  |
| Serum maximum AST (IU/L) | 460 (220-870) | 557 (240-1240) | 490 (230-590) | 630 (330-1350) | 520 (370,670) | 665 (265-768) |
| Serum maximum ALT (IU/L) | 565 (345-1350) | 695 (230-1510) | 520 (280-1020) | 710 (340-1405) | 610 (410-810) | 685 (210-830) |
| Serum maximum PT (s) | 14.1 (12.2-16.3) | 15.4 (13.3-16.9) | 14.8 (12.8-15.9) | 15.4 (13.4-17.5) | 16.4 (15.5-17.3) | 15.5 (13.7-16.7) |
| Serum maximum TB (mmol/L) | 33.4 (28.5-44.7) | 36.8 (29.4-56.9) | 33.7 (31.2-47.7) | 45.0 (34.1-55.6) | 35.0 (27.0-43.0) | 33.1 (28.0-56.1) |
| Hospital stay (d) | 11 (7-17) | 15 (9-24) | 12 (8-22) | 19 (13-28) | 14 (11-17) | 16 (13-19) |

Data are shown as median (range) or *n*. a*P* < 0·05 *vs* each other type; c*P* < 0·05 *vs* each other type except for I2H1. RL: right lobectomy; REL: right extended lobectomy; RT: right tri-segmentectomy; LEL: left extended lobectomy; LT: left tri-segmentectomy; TVE: total vessel exclusion; PM: Pringle maneuver; IVCR: inferior vena cava reconstruction; HVR: hepatic vein reconstruction; ALT: alanine transaminase; AST: aspartate transaminase; PT: prothrombin time; TB: total bilirubin.

**Table 3 Postoperative complications**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Variables** | **I1H1 (*n* = 9)** | **I2H1 (*n* = 23)** | **I1H2 (*n* = 5)** | **I2H2 (*n* = 12)** | **I3H1 (*n* = 5)** | |
| **IVC resection and replacement (*n* = 2)** | **Only IVC resection (*n* = 3)** |
| Total numbers | 1 | 8 | 2 | 8a | 2 | 1 |
| Biliary leak | 1 | 1 |  | 1 |  |  |
| Liver failure |  | 2 |  | 2 |  |  |
| Ascites | 1 | 4 | 1 | 2 | 1 | 1 |
| Jaundice |  |  |  | 1 |  |  |
| Haemorrhage requiring reoperation |  |  | 1 |  |  |  |
| Thrombosis of reconstructed vessels |  |  |  |  |  |  |
| Hepatic vein |  |  |  | 1 |  |  |
| Inferior vena cava |  | 1 |  |  |  |  |
| Intraabdominal abscess |  |  |  | 1 |  |  |
| Reconstructed vessel infection |  | 2 |  | 2 | 1 |  |
| Wound infection |  |  |  |  |  |  |
| Respiratory complication |  | 1 |  | 1 |  |  |
| Clavien–Dindo classification |  |  |  |  |  |  |
| Grade I–II | 3 | 7 | 2 | 5 | 1 | 1 |
| Grade III–IV | 1 | 3 | 0 | 4 | 1 | 0 |
| Grade V | 0 | 1 | 0 | 0 | 0 | 0 |
| 90-d mortality | 0 | 4 | 0 | 5a | 0 | 0 |

Data are shown as n. a*P* < 0·05 *vs* I1H1; liver failure: peak bilirubin concentration > 7 mg/dl, peak international normalized ratio > 2.0, refractory ascites, encephalopathy. Ascites: more than 500 ml/d lasting longer than 3 days. IVC: inferior vena cava.

**Table 4 Univariable analysis of factors predictive of death**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **All patients (*n* = 54)** | **Operative death** | | ***P* value** |
| **Yes (*n* = 9)** | **No (*n* = 45)** |
| Age (years) | 49.7 (39-72) | 53(45-72) | 49 (39-67) | 0.249 |
| Sex ratio (M : F) | 34:20 | 6:3 | 28:17 | 0.801 |
| Preoperative chemotherapy | 4 | 1 | 3 | 1.000 |
| Preoperative PVE | 9 | 2 | 7 | 1.000 |
| Tumour type |  |  |  |  |
| Colorectal metastases | 8 | 2 | 6 | 0.864 |
| Hepatocellular carcinoma | 11 | 2 | 9 | 1.000 |
| Cholangiocarcinoma | 26 | 4 | 22 | 1.000 |
| Alveolar echinococcosis | 9 | 1 | 8 | 1.000 |
| Preoperative TB *>* 34μmol/l | 6 | 1 | 5 | 1.000 |
| ICG-R15 over 10% | 9 | 3 | 6 | 0.327 |
| Child-Pugh B | 6 | 4 | 2 | 0.004 |
| No. of segments resected | 4.7 (3-6) | 5.1 (4-6) | 4.6 (4-6) | 0.189 |
| Classifications |  |  |  | 0.157 |
| I1H1 | 9 | 0 | 9 | 0.328 |
| I2H1 | 23 | 5 | 18 | 0.623 |
| I1H2 | 5 | 0 | 5 | 0.576 |
| I2H2 | 12 | 4 | 8 | 0.188 |
| I3H1 | 5 | 0 | 5 | 0.576 |
| IVC replacement |  |  |  |  |
| Yes (I2 + 2 cases in I3) | 37 | 9 | 28 | 0.044 |
| No (I1 + 3 cases in I3) | 17 | 0 | 17 |
| Hepatic vein reconsrection |  |  |  |  |
| Yes (H2) | 17 | 4 | 13 | 0.600 |
| No (H1) | 37 | 5 | 32 |
| Duration of ischaemia (min) | 68.7 (0-112) | 87.7 (62-112) | 64.9 (0-106) | < 0.001 |
| Operative blood loss (mL) | 721.5 (310-1250) | 769.0 (550-1250) | 712.3 (310-780) | 0.389 |
| Blood transfused amount (mL) | 174.1 (0-950) | 219.4 (0-950) | 165.8 (0-850) | 0.501 |
| Duration of operation (min) | 554.8 (210-1150) | 709.6 (310-1150) | 523.7 (210-860) | < 0.001 |
| R0 resection | 49 | 7 | 42 | 0.401 |
| Tumor size | 8.7 (2.9-16.1) | 9.5 (8.8-16.1) | 8.6 (2.9-15.4) | 0.062 |

Data are shown as median (range) or *n*. PVE: portal vein embolization; TB: total bilirubin; ICG-R15: indocyanine green retention rate at 15 min; IVC: inferior vena cava.

**Table 5 Multivariable binary logistic regression analysis of factors predictive of death**

|  |  |  |  |
| --- | --- | --- | --- |
|  |  | **OR (95%CI)** | ***P* value** |
| IVC Replacement | | 37.56 (1.46-945.32) | 0.048 |
| Duration of ischaemia | | 1.65 (1.02-2.58) | 0.005 |
| Child B or C |  | 1.82 (1.14-2.89) | 0.025 |

IVC: inferior vena cava.

**Table 6 Literature review of the reported series of hepatectomies combined with inferior vena cava resection**

|  |  |  |  |
| --- | --- | --- | --- |
| **Ref.** | **Hospital Mortality** | **Hospital morbidity** | **No. of the allive/total (follow-up time)** |
| DuBay *et al*[13] | 11.1% (one of gastrointestinal bleeding and multiple organ failure) | 22.2% | 6/9 (2-33 mo) |
| Malde *et al*[15] | 11.4% (four of multiple organ failure) | 40.0% | 16/35 (1-140 mo) |
| Azoulay *et al*[28] | 4.5% (one of sepsis and multiple organ failure) | 64.0% | 11/22 (7-84 mo) |
| Madariaga *et al*[21] | 11.0% (one of liver failure) | 22.2% | 6/9 (3-156 mo) |
| Giordano *et al*[27] | 4.0% (one of liver failure) | 39.1% | 16/23 (1-33 mo) |
| Hemming *et al*[26] | 8.3% (liver of liver failure and multiple organ failure) | 43.0% | 46/60 (median 31 mo) |
| Yamamoto[24] | 28.6% (one of sepsis, one of liver failure) | 28.6% | 2/7 (2-72 mo) |
| Lodge *et al*[10] | 25% (one of sepsis and multiple organ failure, one of respiratory and renal failure) | 87.5% | 7/8 (0.5-30 mo) |

**Table 7 The surgical technique of reported series of hepatectomies combined with inferior vena cava reconstruction**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Ref.** | **Year** | **No. of cases** | **Indication** | **IVC repair type** | | | **Hepatic vein reconstruction** | **VVB** | **Perfusion** | **Technique** | **IVC reconstruction criteria** |
| **Tube** | **Patch** | **suture** |
| DuBay *et al*[13] | 2009 | 9 | IVC leiomyosarcoma = 4 ICC = 2; PCC = 1; Metastases = 1; Malignant schwannoma = 1 | 7 | 0 | 0 | Into the native IVC = 1, Into the graft = 5, Primary repair = 1 | Not described | 9 | *In situ* perfusion | Not described |
| Malde *et al*[15] | 2011 | 35 | metastasis = 21; HCC = 6; ICC = 3 Other conditions = 5 | 11 | 2 | 22 | Not described | Not described | 12 | *In situ* perfusion = 13, Anti situm = 3, *Ex vivo* = 6 | < 2 cm: direct suture, > 2 cm: with patches, > 50% of the circumference and longitudinally infiltration: replacement |
| Azoulay *et al*[18] | 2006 | 22 | Metastasis = 9; ICC =8; HCC = 2; Other cancers = 3 | 10 | 4 | 8 | Into the native IVC = 4, Into the graft =2 | 12 | 9 | *In situ* perfusion = 9; Anti situm and *ex vivo* = 0, TVE only = 12; Others = 1 | < 30% circumference: longitudinally suture, 30% to 50% circumference: transversely suture, > 50% circumference: replacement |
| Madariaga *et al*[21] | 2000 | 9 | Metastasis = 1 IVC leiomyosarcoma = 3; ICC = 3; other cancers = 2 | 8 | 0 | 1 | Into the graft = 1, Primary repair = 1 | 1 | 0 | *In situ* perfusion, Anti situm and *ex vivo* = 0, TVE only = 3 | Not described |
| Giordano *et al*[27] | 2011 | 23 | Metastases = 11; ICC = 3; HCC = 4; Others = 2 | 7 | 0 | 16 | Into the graft = 1 | 4 | 4 | *In situ* perfusion = 4; Anti situm = 0; *Ex vivo* = 0 | < 30% of the circumference: suture, > 50% of the circumference: replacement |
| Hemming *et al*[26] | 2012 | 60 | ICC = 26; HCC = 16; Metastases = 13; Others = 5 | 38 | 14 | 8 | Into the graft = 4 | 6 (*ex vivo*) | 8 | *In situ* perfusion = 8; *Ex vivo* = 6; Anti situm = 0 | < 3 cm longitudinally: end-to-end anastomosis, > 5 cm sections of the anterolateral wall: with patches, 3 to 8 cm longitudinally : replacement |
| Yamamoto[24] | 2012 | 7 | ICC = 2; HCC = 5 | 4 | 1 | 2 | Into the graft = 4 | 0 | 7 | Anti-situm = 7 | > 50% of the circumference: replacement |
| Lodge *et al*[10] | 1999 | 8 | Metastasis = 8 | 3 | 4 | 1 | Into the native IVC = 1, Into the graft =3 | 6 (4 *ex vivo* and 2 TVE) | Not described | *Ex vivo* = 4; TVE only = 4; Anti situm = 0 | <60° circumferentially and < 2 cm longitudinally: Clamp tangentialy |

PCC: Perihilar cholangiocarcinoma; IVC: inferior vena cava; HCC: hepatocellular carcinoma; ICC: cholangiocarcinoma.