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Initial experience of parenchyma-sparing liver resection with systematic selective hepatic vein reconstruction for colorectal metastases

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ABSTRACT

Objectives This study aims to assess the feasibility and short-term and intermediate-term technical success rate of the concept of systematic selective hepatic vein (HV) reconstruction for parenchyma-sparing hepatectomies (PSHs) in patients with colorectal liver metastases (CRLM) in accordance with stage 2a of the IDEAL framework.

Design The prospective case series of patients deemed eligible and operated on according to the concept.

Setting All patients were treated by a single surgical team in three hospitals in Ukraine from June 2022 to November 2023.

Participants The study included nine cases of resectable CRLM with at least one lesion located in the hepatocaval confluence with HV(s) invasion, for whom reconstruction of the HV(s) allowed for additional parenchyma preservation, being an alternative to major or extended hepatectomy.

Interventions Liver resections with different types of HVs reconstruction (primary closure, patching, end-to-end anastomosis with or without grafting) were performed after a thorough evaluation of the future liver remnant volume, volume of potentially additionally preserved parenchyma and possibility of future repeat hepatectomies.

Main outcome measures Postoperative morbidity, short-term and long-term patency of the reconstructed vessels, and the volume of additionally preserved parenchyma were the focus.

Results Segmental resection was performed in four cases, two with graft interposition. Patch reconstruction was performed for three HVs and two inferior vena cava resections. Two cases required primary closure. No mortality was observed, while the major morbidity rate was 33%. The short-term and long-term patency of the reconstructed HVs was 88.9% and 66.7%, respectively. HV reconstructions allowed the preservation of additional parenchyma (mean 495.4 mL, 95% CI 350.2 to 640.7). A decision-making algorithm to be used within the described approach is proposed.

Conclusions Selective HV reconstruction is a feasible approach for PSH for CRLM. Further studies are needed to compare this approach to convenient major hepatectomies.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Parenchyma-sparing liver resection is a practical approach in patients with colorectal liver metastases that may improve salvageability and survival in case of intrahepatic recurrence.

WHAT THIS STUDY ADDS

⇒ Preserving additional liver parenchyma by selective hepatic vein (HV) reconstruction may be an effective alternative to extended hepatectomies. It would improve the current concept of parenchyma-sparing resection by excluding congested areas and the necessity of margin compromise and potentially preserve more options for repeat hepatectomies.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Systematic selective HV reconstruction is a ready-to-use approach that offers a predictable postoperative course and acceptable morbidity.

⇒ Further research has to assess the long-term oncological outcomes of the parenchyma-sparing resections with HV reconstruction and directly compare this approach to conventional hepatectomies.

INTRODUCTION

A free resection margin is considered the optimal result of any liver resection. The technical criteria of resectability are not clearly defined, and practice depends on the surgeon's expertise and preference. In general, resectability consists of the possibility of removing the entire disease with an adequate margin while preserving a sufficient volume of the future liver remnant (FLR) with the preserved portal and arterial inflow and venous and biliary outflow.[1]

An effective way to increase resectability may be to preserve the 'vascular skeleton of the liver by removing tumors near large vascular structures with minimal margins, known as the R1 vascular (R1vasc) concept.

This technique, as independently demonstrated by Torzilli *et al*[2] and Umeda *et al*,[3] allows the preservation of portal triads and venous outflow of the liver remnant. This parenchyma-sparing approach allows for the reduction of the risk of posthepatectomy liver failure (PHLF) and preserves the possibility of repeated liver resections.[4 5]

Resection of tumors in contact with the hepatocaval confluence may require resection of the hepatic veins (HVs) with or without reconstruction. The R1vasc approach may be used in selected cases of tumor contact but not where the vein is invaded. This technique could be appropriate for multiple otherwise unresectable lesions,[6 7] while it is more controversial with resectable oligometastases, especially if features of locally-but-not-systemically aggressive biology are present.[8]

PHLF is one of the most dangerous complications of major liver surgery.[9] Along with the preservation of sufficient liver parenchyma and excluding prolonged liver ischemia and blood loss, ensuring adequate venous outflow is essential to prevent the risk of PHLF.[10] Large areas of postresection congestion are associated with an increased risk of major complications.[11] Moreover, preserving large areas of the liver without adequate venous outflow may lead to persistent haemorrhage from the congested parenchyma.[12]

If venous resection is needed, the outflow can be ensured either by reconstructing the HV or by ensuring accessory HVs or venous collaterals draining the affected parenchyma.[13] The latter is most relevant for patients with previous chronic HV occlusion, when collaterals can be detected on preoperative radiology or intraoperative ultrasound (IOUS). Accessory inferior right HVs (IRHVs) may allow resection of the right HV without reconstruction since the IRHV provides adequate outflow from segments 5d, 6, and part of the 7[14] while the middle HV drains segments 5v and 8.

The decision-making algorithm for HV resection and reconstruction is not standardized. Mise *et al* propose to reconstruct the venous outflow in the case when the volume of non-congested parenchyma in the FLR is less than 40% of the total liver volume (TLV) for healthy liver (or 50% if parenchyma is of low quality).[10] Kawano *et al* defined two scenarios for the need for reconstruction of the HVs: definitive resection of the vein, in which the need for its reconstruction is absolute, and parenchyma-preserving resection of the vein, in which reconstruction of the venous outflow ensures the preservation of a larger amount of liver parenchyma, but is not an absolute necessity.[15] The principle of parenchyma preservation is of paramount importance for liver resection for colorectal cancer (CRC) metastases, as it keeps more possibilities open for repeat hepatectomies in the event of intrahepatic recurrence, potentially leading to improved overall survival.[16 17] This principle can be embodied by preserving the ‘liver vascular skeleton’ and selectively reconstructing the HVs.

This paper summarizes the current status of the systematic selective HV reconstruction approach for parenchyma-preserving liver resection for CRC metastases, which is developed and used by our surgical team.

This manuscript is written following the IDEAL Framework and Recommendations.[18]

METHODS

Study design

This study analyses prospectively collected data of all consecutive cases from June 2022 to November 2023 operated on by a single surgical team at three centers: the high-volume hepato-pancreato-biliary (HPB) department in the academic center and two community hospitals. The study included patients with CRC liver metastases who underwent any type of liver resection with HV reconstruction. The study did not include patients who underwent resection of only the distal parts of the HV (outside the zone of hepatocaval confluence, ie, central 4 cm from the vein orifice)[19] and vein resection without reconstruction.

The present manuscript summarizes the IDEAL Stage 2a development of the concept of parenchyma-sparing liver resection with systematic selective HV reconstruction for colorectal liver metastases (CRLM).

The main measured outcomes were perioperative adverse effects, namely morbidity, mortality, blood loss and the number of transfusions, and short- and long-term patency of the reconstructed HVs.

Statistical analyses were made with GraphPad Prism V.9.3.0 software. Mean scores with SD and 95% CIs are provided for variabilities with a normal distribution; otherwise, median values with IQR and 95% CIs are given.

Patient and public involvement

The concept and core differences of the approach were extensively discussed with patients. The main outcome measures were discussed and agreed on as valuable by the participants. Only those who gave fully informed consent operated with the studied approach, meaning that patients were consciously involved in the recruitment process.

Terminology

The terminology for liver anatomy and resections is based on the Brisbane classification[20] and ‘The New World’ classification.[21] Hepatic resections are considered major when at least three adjacent liver segments are removed.

Short-term patency of the reconstructed vein was defined as a patent vein at discharge from the hospital after liver resection.

Long-term patency of the reconstructed vein was defined as a patent vein after a 90-day follow-up period.

Potentially congested area (PCa)—an area of FLR parenchyma drained by the vein being considered for reconstruction. The volume of the potentially congested area related to the volume of the FLR is referred to as PCa/FLR.

Preoperative assessment and selection

All cases were discussed by a multidisciplinary team and consulted by an experienced hepatobiliary surgeon. In general, we consider liver resection for CRLM where complete resection of the primary tumor, liver lesions and extrahepatic metastases (if present) is possible. Neoadjuvant chemotherapy is proposed for patients with extrahepatic metastases, or if reducing the volume of surgery by hepatic lesions' downsizing is possible. The type of surgery and perioperative risks were thoroughly discussed with patients, and written consent for the procedure was obtained in each case.

The decision on the possibility of liver resection was based on an assessment of liver function according to local protocol, similar to those proposed by Inssbruck consensus guidelines.[22] Liver volumetry with calculation of individual HVs drainage areas was performed for each case. We assess liver function based on biochemical indices (ALBI, APRI scores) in each patient and functional MRI with hepatobiliary-specific contrast agents in most cases of major liver resection and/or impaired parenchyma. Liver elastography is performed in cases where liver fibrosis is suspected by radiology or biochemical indices. We do not use the ICG retention test and LIMAX in routine practice.

The patients' selection criteria for parenchyma-sparing liver resection with systematic selective HV reconstruction were:

1. CRC liver oligometastases, deemed resectable by one-stage hepatectomy.
2. A tumor involving HV(s) in the hepatocaval confluence.
3. The absence of visible collaterals between involved and non-involved HVs on preoperative radiology
4. Volume of parenchyma drained by a non-involved HV(s) >30% of TLV.
5. The absence of unresectable extrahepatic disease
6. Preserved liver function.

An algorithm of decision-making regarding the HV management is depicted in figure 1.

In each case, we determined the extent of liver resection for three scenarios: (1) a conventional major hepatectomy without the HV reconstruction; (2) parenchyma-sparing hepatectomy (PSH) without HV reconstruction, which requires either occlusive HV resection or the R1v approach; (3) PSH with HV reconstruction using the principles described in this article. Alternative scenarios for each patient are depicted in figure 2 to demonstrate the core differences.

The volume of residual liver parenchyma drained by the involved HV was calculated individually and defined as the potentially congested area.

Intervention

All patients received thromboprophylaxis and antibiotic prophylaxis according to local protocols based on Enhanced Recovery After Surgery (ERAS) guidelines.[23]

Surgery was performed through an 'inverted-L' incision. After excluding unresectable peritoneal lesions, complete mobilization of the left and right lobes of the liver and liver IOUS is performed according to the technique described by Torzilli[24] to confirm resectability and the extent of the tumor's contact with the HVs, as well as the to detect venous collaterals. If new lesions are detected, resectability is reassessed, considering the findings. After this, the nature of the contact of the lesions with the vascular structures is assessed: for HVs—the degree of contact to the circumference (ie, ¼, 1/3, 2/3, etc), distortion of the contour of the vein wall, the presence of vessel narrowing and intraluminal thrombus; for Glissonean pedicles—the degree of contact to the circumference

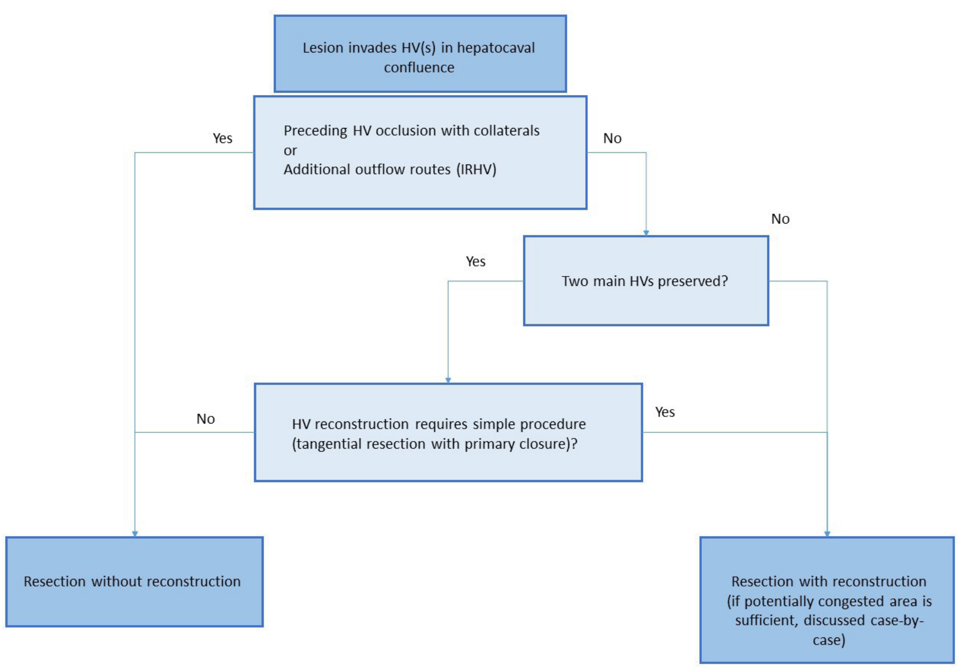

Figure 1 An institutional decision-making algorithm for HV reconstruction in colorectal liver metastases patients. HV, hepatic vein; IRHV, inferior right hepatic vein.

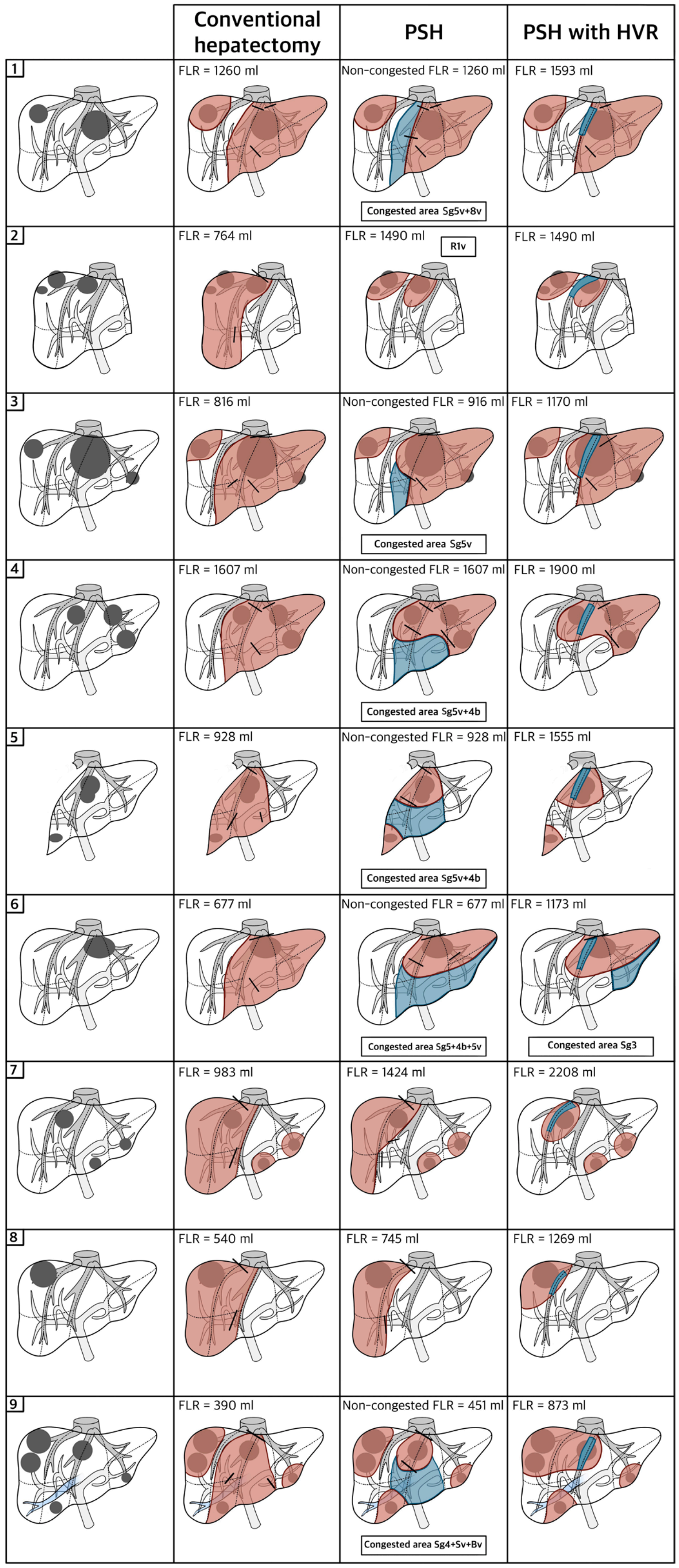

Figure 2 A schematic representation of potential scenarios that could be applied in each case from the series. Conventional hepatectomy consists of major anatomical resections and offers straightforward solutions but less FLR and potentially fewer possibilities for repeat hepatectomies. Classic PSH either preserves congested areas in FLR, or requires the R1v approach. PSH with HVR offers preservation of much FLR without sufficient congested areas, and does not compromise the margin. FLR, future liver remnant; HVR, hepatic vein reconstruction; PSH, parenchyma-sparing hepatectomy; R1v, R1 vascular.

(similar to the HVs), the presence of dilation of the bile ducts proximal to the contact zone and an intraluminal thrombus in the branch of the portal vein. After isolation and clamping of the involved HV in the orifice, a Doppler ultrasound of its drainage area is performed to detect distal venous collaterals and determine the direction of blood flow in the corresponding branches of the portal vein. If the hepatofugal portal blood flow is identified, the absence of adequate venous outflow in the corresponding segment is confirmed.

If invasion of the inferior vena cava (IVC) is suspected, its retrohepatic and suprahepatic segments are completely mobilized to ensure the possibility of cross-clamping.

Parenchyma transection is performed by kellyclasia or with a CUSA device under the intermittent Pringle manoeuvre in sets of 15 min and breaks of 5 min, without ischaemic preconditioning.[25] A complete transection of the parenchyma is performed so that the involved segment of the vessel remains the last point of fixation. If more than one involved vein requires reconstruction, the repair is performed sequentially without the need for long-term total vascular exclusion (TVE). In this case, when one HV is clamped for reconstruction, hepatic blood outflow does not stop in the others.

The HV is isolated distally and proximally to the invasion zone. In general, for tumor contact of more than ½ of the vessel circumference, segmental resection with or without graft interposition is performed; for a contact of ½–1/3 of the circumference, we perform tangential resection with patch; for less than 1/3 tangential resection with primary closure is performed. A technique described by Langella *et al*[26] is used for tangential resection requiring patch reconstruction. When segmental resection was needed, it was performed similarly to the description of Ahuja *et al*.[27] We do not use synthetic material for vessel repair in liver resections.

We do not routinely use the R1vasc tumor detachment technique proposed by Torzilli *et al*[6] for oligometastatic disease, except in cases where it is possible to detach the Laennec fascia[28] near the orifice of the HV. This is performed in the absence of convincing IOUS data of invasion into the vein wall,[24] using the technique described by Monden *et al*.[28] Resection of the HV without reconstruction is performed if the remaining two main HVs are preserved, significant additional drainage routes are present (eg, IRHV in case of RHV resection), active collateral blood flow is stated or a volume of potentially congested area is deemed too small (decided on a case-by-case basis). Perioperative care is performed according to the ERAS guidelines.[23]

Screening Doppler ultrasound of the liver vessels is performed routinely on the first postoperative day and the day of discharge. After completion of treatment, patients are monitored by performing multiphase CT with IV contrast and monitoring the levels of carcinoembryonic antigen and CA-19-9 every 3 months for 2 years and every 6 months thereafter. Recurrence is determined as a lesion detected on CT, MRI or PET/CT (assigned as additional studies in case of ambiguous CT results or serial increase in tumor markers without a substrate on CT).

RESULTS

During the period 2022–2023, 62 liver resections for colorectal metastases were performed (44 minor, 18 major resections); in 12 (19.3%) cases, an HV was resected with preservation of the corresponding parenchyma, 3 of which were performed without vein reconstruction.

The study included 9 (14.5%) patients with CRC liver metastases who underwent hepatectomy with resection and reconstruction of an HV. The mean age was 57.9 years (SD 9.5, 95% CI 50.6 to 65.2 years); 6 patients were female. Data regarding patients' characteristics are presented in table 1.

Surgery

Data regarding surgical details and short-term and long-term outcomes are depicted in table 2 and figure 2.

Four cases required major liver resection. Resection of Sg1 was not required in four cases where the tumor was located mainly cranial to HVs. Segmental resection of the HV was performed in four cases, two of them with graft interposition (figures 3 and 4). Patch reconstruction was performed for three HVs and two IVC resections. The mean operation time was 496.7 min (SD 172.9, 95% CI 363.8 to 629.6 min), and the mean blood loss was 511.1 mL (SD 247.2, 95% CI 321.1 to 701.1 mL).

The mean volume of the potentially congested area was 495.4 mL (SD 188.9, 95% CI 350.2 to 640.7 mL); the mean PCa/FLR was 34.9% (12.5, 95% CI 25.4 to 44.5%); no correlation was observed between these variabilities (p=0.148).

Short-term results

The median postoperative length of stay was 7 days (IQR 7–10, 95% CI 6 to 10). We did not observe postoperative mortality in our series. Major postoperative complications (CD IIIa or higher) occurred in 33% of cases: Patient 2, who had a history of right hemicolectomy with pancreaticoduodenectomy with cholecystojejunostomy for biliary reconstruction, developed severe cholangitis and biliary fistula, which resolved after biloma drainage and antibacterial therapy. Patient 6 experienced postoperative intra-abdominal bleeding from a branch of the supraduodenal artery on the first postoperative day, which required relaparotomy; in the same case, early thrombosis of the reconstructed HV occurred (probably due to hypotension and reduced hepatic blood flow) without clinical consequences (figure 5). In patient 9 (figure 4), a subdiaphragmatic fluid collection was drained, which turned out to be a collection of ascites.

The short-term patency of the reconstructed HVs was 88.9%.

We did not observe clinically significant (ie, grade B or C) PHLF. Two patients, both of whom had altered

Table 1 Data of disease features, preoperative treatment and postoperative follow-up

No	Primary tumor	Pathologic stage	Time of metastases occurrence	Surgery for primary tumor	BMI	Neoadj before hepatectomy, response	Adjuvant chemotherapy	Previous hepatectomy	CEA (before neaodj/ before resection)	CA-19-9 (before neaodj/ before resection	Number of lesions	Max lesion diameter, cm	TBS	Follow-up, months	Status at follow-up
1	Sigmoid	pT3N0M1(hep)	synch	Hartman procedure (simultaneous)	23.8	3 cs CapOX (PR)	3 cs CapOX	–	–/2.69	9.62	2	2.5	3.2	10	Alive
2	Right colon	pT4bN0M0	metachron	Right colecromy with pancreaticoduodenectomy	20.8	–	3 cs CapOX	–	8.06	–	4	3.7	5.4	15	Alive
3	Sigmoid	pT3N2aM1(hep)	synch	Laparoscopic sigmoidectomy (liver first)	24.7	4 cs FOLFOX (PR)	4 cs FOLFOX	–	28.5/2.8	565/44	3	2.7	4.0	13	Alive with recurrence
4	Rectum	pM1(hep)*	synch	non (liver first)	27.3	6 cs FOLFOX (PR)	2 cs FOLFOX	–	507/60	2.5/1.5	5	3.6	6.2	4	Alive with recurrence
5	Sigmoid	pT3N0M1(hep)	metachron	Sigmoidectomy	36	–	4 cs CapOX	H678/2'-RHV 2. H5'	–	–	3	4	5.0	11	Alive with recurrence
6	Rectum	pT2N1M1(hep)	synch	Anterior resection (colon-first)	24	9 cs CapOX+bev (SD)	–	–	–/9.67	590	1	5.2	5.3	6	Alive
7	Rectum	pT4aN2aM1(hep)	synch	APE (liver first)	26.1	5 cs FOLFOX (PD) 4 cs FOLFIRI+bev (SD)	3 cs FOLFIRI	–	108/19	9.62	3	7.5	8.1	2	Alive
8	Sigmoid	pT4aN1M0	metachron	Sigmoidectomy	27.7	–	–	–	34.19	–	1	7	7.1	20	Alive
9	Sigmoid	pT3N0M1(hep)	synch	Sigmoidectomy (liver first)	23.9	4 cs FOLFOX (PR)	3 cs CapOX	–	–	–	4	4.5	6.0	6	Alive

*The patient underwent liver first resection and have not proceeded to a colon resection.
BMI, body mass index; CEA, carcinoembryonic antigen; cs, cycles; f, female; PD, progressive disease; PR, partial response; SD, stable disease; TBS, tumor burden score.

Table 2 Data of surgical details, postoperative morbidity and reconstructed veins patency

No	Vessels involved	Type of hepatectomy	Type of venous plasty	Potentially congested area, mL (PCa/FLR)	Pringle maneuvre time, min	TVE time, min	Morbidity, Clavien-Dindo	Duration of procedure, min	Blood loss, mL	Blood transfusion units	Short-term vein patency	Long-term vein patency
1	MHV, left GP	Left hepatectomy+Sg1, wedge Sg7 (H1234/7'-MHV)	MHV— tangential with primary closure	333 (20.9%)	0		–	540	400	0	+	+
2	RHV, IVC	Liver tunnel, wedge Sg6, 7 (H18'/7'/6'-RHV,IVC)	RHV, IVC—tangential with bovine pericardium patch	726 (48.7%)	75		Cholangitis, biliary fistula Grade B, sepsis. CD IIIa	660	400	n.a.	+	+
3	MHV, LHV, IVC, left GP	Left hepatectomy+Sg1 (H1234-MHV)	MHV— segmental with ext. ileal venous allograft interposition. IVC—tangential with venous allograft patch	254 (21.7%)	36	23		720	700	6	+	–
4	MHV	Left upper transversal hepatectomy (H234a'8-MHV)	MHV— tangential with peritoneal patch	293 (15.5%)	83		PHLF grade A. CD I	360	500	1	+	–
5	MHV	H14a/5'-MHV	MHV— segmental with primary anastomosis	627 (40.3%)	50		–	630	300	2	+	+
6	LHV, MHV	Left upper transversal hepatectomy (H24a-LHV, MHV)	MHV— segmental with primary anastomosis; LHV—without reconstruction	496 (42.3%)	45		Intra-abdominal bleeding, MHV thrombosis. CD IIIb	260	200	6	–	–
7	RHV	H3'/4b'/8-RHV	RHV— tangential with peritoneal patch	784 (35.5%)	76		–	520	400	2	+	+
8	RHV	H1'7-RHV	RHV— tangential with primary closure	524 (41.3%)	40		–	240	1000	n.a.	+	+
9	MHV	Right upper tranversal hepatectomy, wedge Sg3, 5 (H3'/5'/784a-MHV, RHV)	RHV—without reconstruction MHV— segmental with RHV autograft interposition	422 (48.3%)	104		PHLF grade A. Fluid collection (ascitis). CD IIIa	540	700	1	+	+

CD, Clavien-Dindo; IVC, inferior vena cava; MHV, middle hepatic vein; PCa/FLR, potentially congested area related to future liver remnant volume; PHLF, posthepatectomy liver failure; RHV, right hepatic vein; TVE, total vascular exclusion.

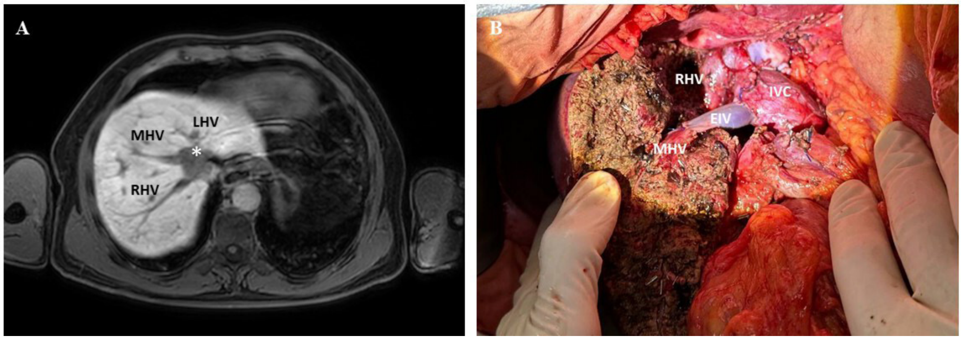

Figure 3 (A) The MRI scan of patient 3 shows a tumor in Sg1 (asterisk) involving LHV, MHV, RHV and IVC. (B) The operative field after left hepatectomy with caudal lobectomy and wedge Sg8 resection. MHV is resected and reconstructed with an interposed allogenic external iliac vein graft. RHV appeared not involved after intraoperative US revision (resection required inter-Laennec resection). IVC, inferior vena cava; LHV, left hepatic vein; MHV, middle hepatic vein; RHV, right hepatic vein.

liver quality due to chemotherapy-associated injury, had a transient increase in bilirubin and INR, which resolved without intervention up to day 5.

Long-term patency

The median follow-up time was 10.4 months.

All patients are alive at the time of final follow-up. Data on the long-term patency of the reconstructed vessels are available in all patients, of whom 66.7% (6 patients) had a patent reconstructed HV. After reconstructions, we did not observe stenosis or thrombosis of the IVC. The type of reconstruction (primary closure, patch augmentation or segmental resection with anastomosis) did not affect the risk of delayed occlusion (p=0.472).

Among patients with HV occlusion, one had an early thrombosis (patient 6) that had no clinical consequences; in another case, occlusion of the interposed iliac vein allograft developed gradually 4 months after resection (patient 3); in another case, occlusion occurred 1 month after resection during the first cycle of postoperative chemotherapy and manifested itself with an increase in transaminases and was initially misconstrued as chemotherapy-induced liver toxicity (patient 4).

The volume of potentially congested area in patients who developed occlusion of the reconstructed HV did not differ significantly from that in patients without occlusion (mean volume 347.7 mL (SD 129.9, 95% CI 24.9 to 670.4 mL) vs 569.3 mL (SD 175.3, 95% CI 385.4

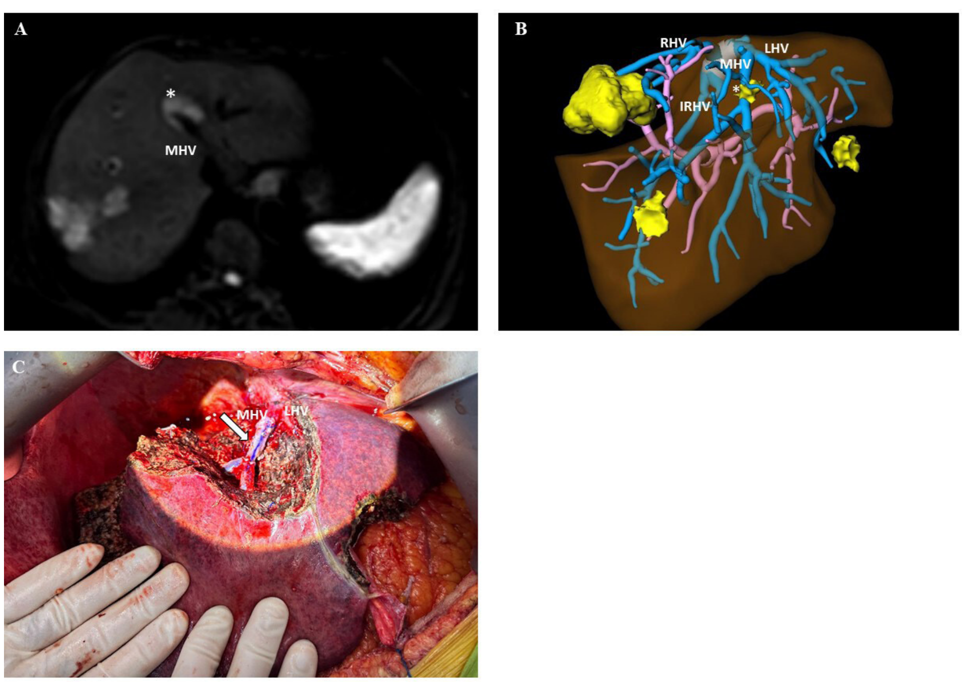

Figure 4 (A) The MRI scan (DWI) of patient 9 shows a tumor in Sg4a/8 (asterisk) enveloping MHV. (B) The 3D reconstruction of the FLR with a planned resection. MHV is invaded by a lesion in Sg4a/8 (asterisk); the main trunk of RHV is intact. (C) An operative field after right upper transversal hepatectomy (Sg4a+8+7 resection) with MHV segmental resection and reconstruction using an autologous RHV graft extracted from the specimen. White arrow: RHV graft. IRHV, inferior right hepatic vein; LHV, left hepatic vein; MHV, middle hepatic vein; RHV, right hepatic vein.

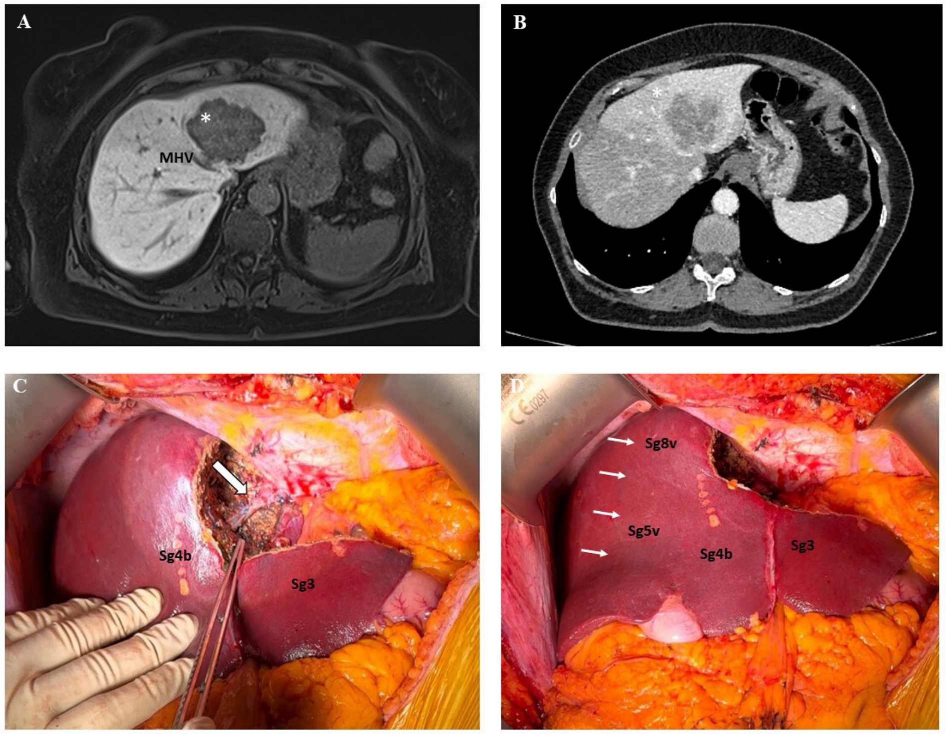

Figure 5 (A) The MRI scan of patient 6 shows a tumor in Sg2/4a (asterisk) involving MHV and LHV (not shown). (B) The arterial phase of the CT shows hyperattenuation of the left lobe due to the hepatic artery buffering response in the setting of chronic HVOO leading to portal hypoperfusion. (C, D) An operative field after the left upper transversal hepatectomy—Sg2, 4a en-bloc resection with MHV segmental resection and end-to-end reconstruction. White arrow: venous anastomosis. Thin white arrows: a demarcation line between chronic HVOO area (LHV and MHV drainage area) and parenchyma with preserved outflow (RHV area), which remained even after successful restoration of MHV flow. HVOO, hepatic vein outflow obstruction; LHV, left hepatic vein; MHV. middle hepatic vein; RHV, right hepatic vein.

to 753.2 mL), p=0.08 (A); mean PCa/FLR 26.5% (SD 14, 95% CI −8.4–61.4%) vs 39.2% (SD 10.3, 95% CI 28.4 to 49.9%), p=0.26). On multiple logistic regression analysis, no factor that influences the risk of graft occlusion could be identified.

Of the four patients with the liver-first approach, the treatment plan was completed in three. Patient 4 progressed with new liver and lung metastases following postoperative chemotherapy after hepatectomy and is receiving second-line chemotherapy.

DISCUSSION

This study demonstrated our experience with the concept of selective HV reconstruction for parenchyma-preserving resection for CRLM, accumulated over 1.5 years.

Tumors involving the hepatocaval confluence structures are considered a technical challenge and may be deemed unresectable. Different techniques have been proposed to solve the problem of this complex localization. Torzilli proposes the liberal use of tumor detachment techniques to reduce the need for vein reconstruction.[29] We believe that this approach is justified in patients with multiple liver metastases,[6] pushing or desmoplastic, but not replacement histological growth pattern,[7] aggressive tumor biology[8] (eg, RAS or BRAF mutants, whose risk of death from systemic progression prevails over the risk of clinical deterioration due to relapse in the resection plane). It is worth noting that when the metastasis is large, R1vasc may be accompanied by a higher risk of R1 parenchymal at the point where the resection plane approaches the vessel. Urbani *et al*, on the contrary, predominantly resort to segmental vein resections in case of tumor contact and widely use PTFE grafts to replace the vein defect.[30] The authors postulate the concept of using PTFE grafts for HV reconstructions as a 'bridge' to the formation of communicating veins.[31 32]

A more technically demanding approach is in situ or ante-situm liver resection with cold perfusion. This allows hepatocaval confluence reconstruction to be performed in conditions of a bloodless field and virtually unlimited liver ischemia time without the risks associated with warm ischemia.[33 34] In centers with extensive experience, these procedures are associated with low mortality[35] and are safer than prolonged (more than 60 min) continuous warm ischemia. Our series, as well as those by Torzilli and Urbani, demonstrates that most hepatocaval confluence resections for CRC metastases can be performed without TVE with cold perfusion and ante-situm.

Resection of the HVs without reconstruction appears to be a useful approach in specific cases. Intraoperative assessment of the sufficiency of collateral blood flow can be made on the basis of IOUS Doppler findings, namely the presence of preserved hepatopetal blood flow in the portal branches or the presence of blood flow in the distal parts of the interested HV after it is clamped at the orifice. Another simple method is assessing the discoloration zone of the occluded HV's basin when clamping the hepatic artery.[13]

However, collateral outflow may be insufficient in the absence of preceding chronic vein occlusion, as has been shown for donor FLR in living donor liver transplantation when the MHV has been allocated to the graft.[36] Nevertheless, the absence of MHV in the donor's FLR does not affect the donor's postoperative risks in right lobe transplantation.[37–39] The same is shown in liver resections—resection of MHV without reconstruction during right or left hepatectomy does not increase postoperative risks if the volume of the remnant is sufficient.[40] However, a study of the function of the congested but not deportalized area of the liver (Sg4) using hepatoscintigraphy in patients after extended liver venous deprivation (portal vein embolization (PVE) of the right branch and occlusion of the RHV and MHV) demonstrated a decrease in the function of this area on the 7th day after the procedure and an increase in function on the 21st day, probably due to the formation of venous collaterals.[41] This is important to consider in patients with borderline FLR volume, for whom it is critical to ensure maximum function of the entire remnant parenchyma in the early postoperative period. In such cases, preservation or reconstruction of venous outflow will help reduce the risk of PHLF.[42]

On the other hand, resection of MHV without reconstruction leads to a change in the regeneration pattern: areas of the liver drained by an unreconstructed vein regenerate less than those with preserved MHV, which is compensated by increased hypertrophy in the area with preserved outflow. However, in the long term, remnants without MHV demonstrate a lower degree of general hypertrophy than remnants with preserved MHV.[42–44] This phenomenon is most relevant for situations in which repeated hepatic resections are possible, such as CRC liver metastases. In this case, parenchymal preservation, as well as the presence of more than one venous drainage route, leaves more room for repeat resections, which potentially improves overall survival according to Mise *et al* (5 year OS 72.4% vs 47.2% in a non-parenchyma-sparing group)[16] and Okumura *et al* (79.4 vs 64.3%).[17]

We observed two cases of asymptomatic reconstructed MHV occlusion. In patient 3, the interposed venous allograft was patent at 3 months but occluded with developed communicants at 6 months after surgery. In patient 6, early MHV thrombosis was possibly associated with the presence of chronic vessel subocclusion and formed (although not visualized in preoperative radiology) collaterals. In this case, the volume of parenchyma drained by RHV (Sg5d, 6, 7, 8d) was 38% of the TLV, which could also contribute to the absence of clinical consequences of MHV thrombosis.

Thus, synthesizing our observations and data obtained from studies on MHV allocation in living donor liver transplantation,[37–39] the question arises: considering that the postoperative period is not aggravated in patients with resected but not reconstructed MHV with a sufficient volume of FLR with preserved outflow, when does the MHV (and other HVs) need reconstruction?

We strive to reconstruct the HVs so that at least two veins provide the outflow from the FLR and rely on the reconstructed vein's long-term patency to ensure maximum salvageability in the event of intrahepatic relapse. The question remains whether the small volume of parenchyma drained by the reconstructed vein (and, accordingly, low blood flow velocity in the vein) is a predictor of an increased risk of thrombosis at the reconstruction site. Tani *et al* demonstrated that the drainage area of RHV is 45% of TLV, MHV is 33% and LHV is 21%.[45] A decrease in the drainage area due to resection of the parenchyma may lead to a decrease in the blood volume flow rate through the draining HVs and, consequently, the linear blood flow velocity because the HV has a constant cross-sectional area. In the presence of a reconstructed vein wall, this may cause thrombosis (extrapolating from data on the effect of low linear blood flow velocity on the risk of HV thrombosis in conditions of thermal injury).[46] We observed a trend that patients who did develop HV thrombosis had lower volumes of parenchyma drained by that vein. Conceivably, the trend may be confirmed in a larger sample, but it is too early to draw conclusions.

The variant anatomy of the HVs deserves special attention, particularly the presence of IRHV, which makes RHV reconstruction unnecessary after segments 7 and 8 resection (H78-RHV). This feature is demonstrated by the example of surgical planning in patient 9 (figure 4): the RHV was resected without reconstruction with segment 7 while preserving segments 5 and 6 due to the functioning IRHV and then used as a graft for interposition during resection of MHV with segments 4a and 8. This made it possible to perform a right upper transversal hepatectomy with resection of two main HVs and preserve segments 4b, 5, and 6 with adequate venous outflow.

Our study demonstrates that CRC metastases invading the hepatocaval confluence are accessible to resection with good postoperative results, and proficiency can be obtained in a short time, provided there is a sufficient concentration of cases.

Several studies reported on a similar concept of HV reconstruction for parenchyma preservation. Apers *et al*, in their series of 10 cases, describe their experience of parenchyma preservation by HV reconstruction as an alternative approach to major hepatectomy with preceding PVE for different liver malignancies with acceptable short-term results.[47] Panaro *et al* used RHV reconstruction with arterial allografts for parenchyma preservation in five patients in cases when PCa/FLR was >20%.[48] Ko *et al* reported six cases of parenchyma-sparing liver resection with HV reconstruction for CRLM, although did not specify the selection criteria.[49] These studies introduced similar concepts of parenchyma preservation in terms of short-term benefits, although they did not focus on either well-defined selection criteria and decision-making or the long-term potential of salvageability.

To summarize, we believe it is important to highlight several different scenarios regarding HV resection for colorectal metastases:

1. Patients with the definite invasion of all major HVs in the hepatocaval confluence, for whom the need for resection and reconstruction of at least one HV is absolute (definitive vein resection, according to Kawano *et al*)[15]. The majority of these patients will require reconstruction under TVE with cold perfusion to allow high-quality HV reconstruction in a bloodless field with virtually unlimited liver ischemia time.
2. Potentially resectable patients with an initially small FLR, for whom preservation of additional parenchyma through HV reconstruction would be an alternative to FLR augmentation techniques (such as PVE or ALPPS)[50], and R1vasc is considered not feasible. In these patients, the short-term patency of the reconstructed vein is critical for PHLF prevention, and the decision to reconstruct the vein must be made carefully based on the risks associated with the type of reconstruction, the center's experience and the patient's features, and opposed to the well-established risks and benefits of augmentation techniques on an individual basis.
3. Resectable cases with sufficient FLR in whom HV reconstruction will preserve more healthy parenchyma for possible repeat resections in the event of intrahepatic recurrence (parenchyma-sparing vein resection, according to Kawano *et al*)[15]. In these cases, the feasibility of vein reconstruction should be assessed based on the volume of potentially preserved parenchyma (potentially congested area).
4. Patients with sufficient additional outflow tracts (eg, IRHV) developed collaterals due to chronic vein occlusion or a very small volume of potentially congested area (eg, preserved Sg3 with resected LHV). In these cases, reconstruction of the HV is not required.

Among our study's limitations that warrant attention is the short period of postoperative observation, which does not allow for evaluating long-term oncological results. This was not the objective of the work, however. Another weakness is the small number of observations, which limits the possibility of drawing conclusions regarding the best reconstruction methods.

This study presents the IDEAL stage 2a development of the parenchyma-sparing HVs reconstruction approach.[18] We demonstrated this concept's feasibility and short-term and intermediate-term safety for thoroughly selected patients. We aimed not to outline the most efficient techniques of HV reconstruction for different scenarios but rather to develop definitions and preliminary selection criteria for patients who would fit this approach. Although we could not find a significant difference in potentially congested areas between those who did and did not develop HV occlusion, we believe this must be an important factor to consider when planning these procedures.

In prospect, the larger cohort of patients operated on with the parenchyma-sparing HVs reconstruction approach will be compared with patients who underwent convenient vessel-sacrificing major hepatectomy in terms of postoperative outcomes. Finally, long-term outcomes, namely the salvageability of liver recurrences and overall survival, will be studied prospectively.

CONCLUSIONS

HV reconstruction is a safe approach for PSHs for CRLM invading elements of hepatocaval confluence, which may be a feasible alternative to extended liver resections. Further studies may reveal the most appropriate patient selection criteria and the real effect of this approach on salvageabillity in case of intrahepatic recurrence.

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