Review Article

Resection and reconstruction of the largest abdominal vein system (the inferior vena cava, hepatic, and portal vein): a narrative review

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Background and Objective: As tumors invade major abdominal veins, surgical procedures are transformed from simple and basic to complicated and challenging. In this narrative review, we focus on what is currently known and not known regarding the technical aspects of major abdominal venous resection and its reconstruction, patency, and oncologic benefit in a cross-cutting perspective.

Methods: A systematic literature search was performed in PubMed and Semantic Scholar from inception up to October 18, 2023. We reviewed 106 papers by title, abstract, and full text regarding resection or reconstruction of the inferior vena cava, hepatic vein confluence, portal vein (PV), and middle hepatic vein (MHV) tributaries in living donor liver transplantation (LDLT) in a cross-cutting perspective.

Key Content and Findings: The oncologic benefit of aggressive hepatic vein resection with suitable reconstruction against adenocarcinoma remains unclear, and further studies are required to clarify this point. A superior mesenteric/PV resection is now a universal, indispensable, and effective procedure for pancreatic ductal adenocarcinoma. Although many case series using tailor-made autologous venous grafts have been reported, not only size mismatch but also additional surgical incisions and a longer operation time remain obstacles for venous reconstruction. The use of autologous alternative tissue remains only an alternative procedure because the patency rate of customized tubular conduit type to interpose or replace the resected vein is not known. Unlike arterial replacement, venous replacement using synthetic vascular grafts is still rarely reported and there are several inherent limitations except for reconstruction of tributaries of MHV in LDLT.

Conclusions: Various approaches to abdominal vein resection and replacement or reconstruction are technically feasible with satisfactory results. Synthetic vascular grafts may be appropriate but have a certain rate of complications.

Keywords: Inferior vena cava (IVC); hepatic vein confluence; portal vein (PV); autologous alternative tissue; narrative review

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Introduction

Background

An R0 resection, in which the resection margin is microscopically free of cancer cells, is the only curative treatment for various hepato-pancreato-biliary (HPB) (1) and other malignant tumors following hepatocellular carcinoma, colorectal liver metastasis, biliary tract cancer (2), and pancreatic cancer (3), as well as renal cell carcinoma (4) and rare retroperitoneal tumors (5). When these tumors invade major abdominal veins, surgical procedures are transformed from simple and basic to complicated and challenging (6). Surgeons may hesitate to resect larger hepatic veins with a major confluence, the inferior vena cava (IVC) (1), or portal vein (PV) trunk (7) without more advanced reconstruction because decreased venous flow causes severe congestion all over the liver, intestine, or lower extremity, with sometimes lethal results (8). Thus, surgeons must consider the balance between performing an R0 resection and maintaining venous flow (9). Furthermore, reconstruction of middle hepatic vein (MHV) tributaries requires highly technical skills in living donor liver transplantation (LDLT) (10). The options, however, are limited to extensive venous resection with simple closure to end-to-end or vein graft interposition to maintain venous flow.

Objectives

In this review, we focus on what is currently known and not known regarding the technical aspects of major abdominal venous resection and its reconstruction, patency, and oncologic benefit in a cross-cutting perspective. We present this article in accordance with the Narrative Review reporting checklist (available at https://tgh.amegroups.com/article/view/10.21037/tgh-23-90/rc).

Methods

A systematic literature search was performed in PubMed and Semantic Scholar from inception up to October 18, 2023. We reviewed 106 papers by title, abstract, and full text regarding resection or reconstruction of the IVC, hepatic vein confluence, PV, and MHV tributaries in LDLT in a cross-cutting perspective (*Table 1*).

Discussion

History

Several case series of hepatic vein reconstruction with the aim of maximizing remnant liver function through a trial-and-error basis have been reported. Starzl and colleagues first reported reconstruction of the left hepatic vein with the IVC in 1980. They performed a right trisegmentectomy for a tumor invading the IVC and left hepatic vein and the first replacement of the IVC and left hepatic vein trunk for hepatic venous drainage of the lateral segment using a reversed vena cava and iliac homograft. The patient died of liver failure due to obstruction of the celiac axis (11). In 1988, the same group reported a successful right trisegmentectomy using a synthetic vena cava graft (12). In 1993, Nakamura and colleagues described an 8-case series of main hepatic vein reconstruction using an external iliac vein, superficial femoral vein, or long saphenous vein graft for hepatocellular carcinoma and metastasis (13,14). They reported a reconstructed vein patency rate of 75% at 1 month after surgery (14). Kakazu and colleagues were the first to report successful resection of an MHV tributary and its reconstruction for hepatocellular carcinoma in 1995. They sutured the proximal and distal stumps of the large MHV tributary end-to-side (15).

For pancreatic cancer, there is a long history of resecting the superior mesenteric vein (SMV)/PV because they surround the pancreas head. In 1973, Fortner and colleagues published the first 4-case series of extensive pancreatectomies combined with a major SMV/PV resection and reconstruction for pancreatic cancer (16). These case reports have encouraged surgeons worldwide to perform similar surgeries.

IVC with hepatic venous confluence for hepatic malignancy

In the 2000s, the validity of these challenging techniques was assessed in a small cohort. Aoki and colleagues reported on 9 patients who underwent hepatectomy combined with IVC or hepatic venous confluence reconstruction in 2004. These patients required longer operating times (median 600 *vs.* 320 minutes), suffered greater blood loss (1,034 *vs.* 434 g), underwent more extensive liver parenchyma resection (585 *vs.* 155 g), and had a shorter survival time (25.8 *vs.* 44.0 months) compared with the other 78 patients (1).

Table 1 Search strategy summary

Items	Specifications
Date of search	October 18, 2023
Databases and sources searched	PubMed, Semantic Scholar
Search terms	Resection or reconstruction, repair, replacement of abdominal vein, inferior vena cava, hepatic vein, hepatic vein confluence, portal vein, superior mesenteric vein, tributary of the middle hepatic vein in living donor liver transplantation
Time frame	From inception up to October 18, 2023
Inclusion/exclusion criteria	Inclusion: publication types—review, cohort studies, editorial, case series. English language
	Exclusion: non-English publications
Selection process	J.K. and K.H. conducted the selection

Nuzzo and colleagues reported on 23 patients who underwent hepatectomy with IVC resection (17). The tumors included liver metastases (n=13), hepatocellular carcinoma (n=4), intrahepatic cholangiocarcinoma (n=3), liver hemangioma (n=1), primary hepatic lymphoma (n=1), and recurrent right adrenal gland carcinoma (n=1); R0-resection was successfully achieved in all patients. To date, reports of combined liver and IVC resection for hepatic malignancy remain scarce because of the technical difficulty. Some sporadic case reports of successful combined liver and IVC resection for hepatocellular carcinoma (18) and intrahepatic cholangiocarcinoma (19), however, are found in the literature.

In a 2017 analysis of studies over the last 40 years, a systematic review described 258 patients with IVC repair for colorectal liver metastasis (n=128, 50%), intrahepatic cholangiocarcinoma (n=51, 20%), hepatocellular carcinoma (n=48, 19%), and other pathologies (n=31, 11%) (2). There were 14 (5%) perioperative mortalities. The median survival was 34 months, and the 1-, 3-, and 5-year overall survival rate was 79%, 46%, and 33%, respectively. The 5-year overall survival rate was 26% for colorectal liver metastasis, 37% for intrahepatic cholangiocarcinoma, and 30% for hepatocellular carcinoma (2).

Although on preoperative computed tomography (CT), liver tumors appear to attach to the IVC, direct invasion is not so frequent. Hashimoto and colleagues reported on 157 patients whose tumors appeared to attach to the IVC on preoperative CT (20). They attempted a blunt dissection between the tumor and IVC wall. If the separation was not possible and tumor invasion into the IVC was suspected, combined IVC resection with liver resection was performed (n=18, 12%). These patients were diagnosed with metastatic adenocarcinoma (n=15) and intrahepatic cholangiocarcinoma (n=3). In a logistic multiple regression analysis, the odds ratio of more than a quarter of the IVC circumference being in contact with the tumor in the CT was the biggest predictive factor (odds ratio, 13). The second biggest predictive factor was an irregular appearance of the IVC wall with "peaked tumor" on CT (odds ratio, 5). A "peaked tumor" is one in which the wall of the IVC peaks toward the tumor like a central umbilication. Surgeons should understand that preoperative CT cannot precisely diagnose direct invasion of a tumor into the IVC. To date, no magnetic resonance imaging (MRI) studies have been reported.

Hepatocellular carcinoma has relatively less ability to invade a major vessel. Hashimoto and colleagues reported that, unlike patients with adenocarcinoma, none of their 67 hepatocellular carcinoma patients required IVC resection even if the tumor appeared to attach to the IVC on preoperative CT, excluding existing tumor thrombi of hepatocellular carcinoma (20).

Currently, resection of the IVC with the hepatic venous confluence is feasible to achieve R0 resection, but further studies are required to clarify the oncologic benefits of this difficult procedure in a larger cohort. To our knowledge, no studies to date have compared aggressive major hepatic vein resection combined with suitable reconstruction with comparable tumor backgrounds but distal to the major hepatic veins or confluence.

IVC resection for renal cell carcinoma and leiomyosarcoma

Renal cell carcinoma easily invades the renal vein and IVC as a tumor thrombus. The Mayo Clinic renal cell

carcinoma tumor thrombus classification system, based on reports by Hatakeyama, Neves and colleagues (4,21), divides tumor thrombi into 4 categories ranging from levels 1 to 4. Level 3 thrombi extend above the hepatic vein but below the diaphragm, and level 4 thrombi extend above the diaphragm (22). Complete surgical resection of a tumor may not require complete resection of the IVC in some cases with level 3 to 4 tumor thrombi (23,24). In some rare cases, reconstruction of the resected IVC is not necessary because the collateral circulation is adequate due to chronic complete obstruction (23,25). For other rare retroperitoneal tumors, similar IVC reconstruction procedures have been performed for leiomyosarcoma on a case-by-case basis (5,26,27).

Major hepatic veins

When single-cell cancer invades a major hepatic vein, such as colorectal liver metastasis, surgeons will attempt to resect the tumor with the MHV or perform a right or left liver resection with a right or left hepatic vein with or without the MHV as a conventional hemi liver resection. One interesting study analyzed 300 colorectal liver metastasis patients with a solitary tumor (≤30 mm in size) to identify the role of parenchymal-sparing hepatectomy (9). A total of 156 patients underwent partial hepatectomy as a parenchymal-sparing hepatectomy and 144 patients underwent right hepatectomy, left hepatectomy, or left lateral sectionectomy (non-parenchymal-sparing hepatectomy group). The authors concluded that a parenchymal-sparing hepatectomy did not increase recurrence in the liver remnant and, more importantly, improved salvageability and thus 5-year survival in the case of recurrence (9).

Owing to recent technical advances in liver surgery, hepatic vein reconstruction following minor hepatectomy is proposed as an alternative to major hepatectomy to spare uninvolved liver parenchyma (28). A customized saphenous vein graft is most frequently used as an interposition graft. An external iliac vein graft and left PV extracted from the resected specimen are also used (28). In contrast, in colorectal liver metastasis, Ko and colleagues reported that the cumulative 5-year survival rate for all patients was 54.6%, with no significant difference between those with vascular reconstruction (n=15) and those without vascular reconstruction (n=62, consecutive patients with unknown tumor status) (6). In 2016, Viganò and colleagues reported no significant differences between R1 vascular versus R0 in colorectal liver metastases (29). A similar study reported that although R1 parenchymal resection (margin <1 mm, n=58) was an independent risk factor for disease recurrence, R1 vascular (tumor exposed exclusively along the vessel, n=58) surgery achieved survival outcomes equivalent to R0 (n=167) (30). On the basis of these reports, the oncologic benefit of aggressive hepatic vein resection with suitable reconstruction against adenocarcinoma remains unclear, and further studies are required to clarify this point.

PV

Pancreatic ductal adenocarcinoma adjacent to or invading the PV and SMV can be treated with an R0 resection (31-33); ≤180° contact without vein contour irregularity is considered resectable; contact with the SMV or PV >180° is considered borderline resectable; and locally advanced, unreconstructible SMV/PV due to tumor involvement or occlusion is considered unresectable (34). For diagnosing vascular invasion, CT and MRI had similar high specificities (97–99%), but CT had better sensitivity (77–85%) than MRI (70–74%) (35).

Oba and colleagues suggested that a 20-mm SMV/PV resection could be performed with direct end-to-end anastomosis (33). Dua and colleagues reported that end-to-end anastomosis has better patency than venorrhaphy, patch, or interposition using an autograft and suggested short segment (<30 mm) reconstructions based on an analysis of 90 patients (36). In an analysis of 197 patients, Fujii and colleagues reported that direct end-to-end anastomosis is safe and offers patients improved rates of curative resection (37). They suggested that a PV resection ≥31-mm long required a vein graft to achieve a tension-free anastomosis because of the potential development of severe anastomotic stenosis (37). On the contrary, Wang and colleagues suggested that direct end-to-end anastomosis can be performed safely even when the SMV/PV resection length is ≥4 cm (38). Following analysis of 8 patients, Zhang and colleagues advocated for direct end-to-end anastomosis for a 5–7 cm long-segment SMV/PV resection with tension-reducing liver mobilization and the Cattell-Braasch maneuver without complications (39). Del Chiaro and colleagues similarly reported SMV/PV reconstruction with a Cattell-Braasch maneuver without liver mobilization in a larger (n=144) cohort (40). In their report, the median vein resection length was 4.6 cm (range, 3–7 cm) and all patients underwent direct end-to-end anastomosis. The only case of partial portal thrombosis was detected by surveillance

postoperative ultrasound and could be successfully treated with intravenous heparin administration (40). Fujii and colleagues reported the stenosis rate in 197 patients with SMV/PV resection; 18 (9.1%) had severe stenosis (≥70%). Multivariate analysis showed that an SMV/PV resection length ≥31 mm was among the independent predictors of medium-term, severe anastomotic stenosis (hazard ratio, 5.96; 95% confidence interval, 1.79–22.69; P=0.003) (37). In contrast to direct end-to-end anastomosis, Labori and colleagues produced a systematic review of autologous veins, synthetic grafts, cadaveric allografts, and parietal peritoneum/falciform ligament for SMV/PV resection (41). They reported that the risk rate of thrombosis was higher for synthetic grafts (7.5%) compared with other types of grafts (2.5–6.7%) within 30 days after SMV/PV reconstruction (41).

Oncologically, no studies to date have examined the correlation between the length of SMV/PV invaded by locally advanced pancreatic cancer and long-term outcomes (33). Terasaki and colleagues reported that the survival rate is superior with no PV resection compared with portal resection. On the other hand, with regard to the reconstruction procedure, no significant prognostic difference was detected between pancreaticoduodenectomy with end-to-end anastomosis (n=97) and pancreaticoduodenectomy with an interposition graft (n=25) in patients with pancreatic ductal adenocarcinoma (42). In a multicenter study in the United Kingdom, among 230 PV resection patients, 129 had primary closure (56%), 65 had end-to-end anastomosis (28%), and 36 had interposition grafts (16%) for pancreatic cancer. Perioperative mortality and overall survival were not significantly different compared with 840 standard pancreaticoduodenectomies (32). A recent meta-analysis reported that a Kaplan-Meier curve of venous resection and no-venous resection groups showed comparable overall survival based on 32 studies with 2,216 venous resections and 5,380 no-venous resections (3). An SMV/PV resection is now a universal, indispensable, and effective procedure for malignancy invading the SMV and/or PV.

LDLT

Over the last 20 years, progress in LDLT in particular has highlighted the importance of liver outflow. In general, 2 types of hemi liver grafts, left or right liver, are harvested. An important issue is how to best share the MHV to ensure the safety balance between the living donor and the recipient. A right liver graft without the MHV trunk is commonly used but can lead to severe congestion of the right paramedian sector corresponding to Couinaud segments 5 and 8 (43) because liver outflow of the right paramedian sector drains mostly into the MHV (10). Park and colleagues expressed concern over the threat of congestion leading to liver failure as early as 1999 (44) following the growing demand for right liver grafts after the initial 5 years of adult-to-adult LDLT beginning in 1994 (45). Later, Lee and colleagues reported that 2 of 5 recipients were complicated with severe congestion of the right median sector without MHV reconstruction, followed by prolonged massive ascites, liver dysfunction, and death (8). Currently, the second-order tributaries of the MHV are used for reconstruction (46): V8, which drains the cranial part of the portal trunk of the right paramedian sector and V5, which drains the corresponding caudal part (10,47). Reconstruction of these veins is described in later sections.

Function of the liver venous congestion area (veno-occlusive region)

Few studies have reported on maintaining the function of the hepatic vein congestion area. Sano and colleagues reported that temporary arterial clamping and intraoperative Doppler ultrasonography could be used to assess the venous congestion area from the liver surface (47). The congestion area is easy to visualize following arterial clamping as a discoloration (dark-colored area) and decreasing tissue saturation (74.7–88.7%). Surprisingly, all cases in which an emerging discoloration area was observed (74%) had hepatofugal flow of the portal branches in the veno-occlusive or congestion area. The remaining 24% of cases had reversed flow of an MHV tributary into the right hepatic vein via intrahepatic venous anastomoses, a so-called vein-to-vein shunt, after liver transection in an extended left hepatectomy.

Maema and colleagues reported poor regeneration of the right paramedian sector in donors after left liver harvesting with the MHV (48). Akamatsu and colleagues reported the same phenomenon in recipients (49). Furthermore, Kaneko and colleagues reported the predicted congestion volume of MHV tributaries and liver function in living donor surgery. They showed that alanine transaminase had bimodal peaks at postoperative days 1 and 10 (50) and there was a positive correlation between the predicted congestion volume and total bilirubin level at postoperative day 5 (51).

With regard to vein-to-vein communication between the right hepatic vein and the MHV after left liver procurement with the MHV, postoperative communication developed in 52 (66.7%) of 78 donors, which contributed to a better regeneration rate of the right paramedian sector (52).

Kawaguchi and colleagues provided a more precise report of liver function of the congestion area based on indocyanine green uptake using a dynamic image analysis of a near-infrared camera in a clinical setting. Plateau indocyanine green fluorescence was significantly lower in the veno-occlusive regions of the liver. In fluorescence emission analysis, portal uptake function in veno-occlusive regions was approximately 40% of that in non-veno-occlusive regions (53). Furthermore, Ito and colleagues evaluated a rat model to determine liver function in the congestion area as assessed by mRNA expression [albumin, cytochrome P450 (Cyp) 1a2, Cyp3a1, Cyp7a1, and gamma-glutamylcysteine synthetase] (54). In their report, the mRNA (congestion area)/mRNA (non-congestion area) ratio decreased to approximately 30% at 12 h after the outflow obstruction and increased to approximately 70–80% at 7 days. According to these findings, the estimated liver function of the congestion area decreased 30–40% in the short term, but the long-term results are unknown.

What kinds of grafts should be used for vein reconstruction?

Autologous veins

Many case series using tailor-made autologous venous grafts have been reported, including the external iliac vein for SMV/PV reconstruction (55); great saphenous vein for hepatic vein reconstruction (n=10) (56); short hepatic vein of the harvested liver graft (n=4) (57) and renal vein for HPB surgery (n=14) (58); internal jugular vein (n=4 and 1, respectively) (55,59), umbilical vein patch graft (n=3) (56), and bilateral gonadal vein (ovarian or testicular vein) for HPB surgery (n=1 and 3) (20,60); left internal carotid vein for PV reconstruction (n=1) (61); and superficial femoral vein for hepatic vein reconstruction (14) (n=3).

A larger cohort was reported for evaluation of renal veins. Fogliati and colleagues reported long-term patency outcomes of left renal vein grafts for SMV/PV reconstruction (n=65) (62). The Kaplan-Meier 2-year estimated patency rate of the left renal vein graft was 88%, with no cases of complete occlusion. Six (10%) patients experienced graft stenosis. Impaired renal function was an issue after harvesting the renal vein (58). Of 61 patients, 9 (15%) patients experienced grade II or III acute kidney injury, with 6 of 9 returning to normal renal function before discharge (62).

Smaller graft size of autologous veins is one of the problems. Yamamoto and colleagues reported that they struggled to make SMV/PV size cylindrical grafts from the small pieces of a cut gonadal vein graft (60). Not only size mismatch but also additional surgical incisions and a longer operation time remain challenging obstacles.

Autologous alternative tissues

Recently, peritoneal grafts have been used for PV reconstruction as an autologous alternative tissue (63-65). A systematic review in 2020 analyzed 15 articles, including autologous peritoneofascial grafts (n=30) and autologous non-fascial parietal peritoneum grafts (n=64) (66). The autologous peritoneofascial grafts were harvested from the posterior rectus muscle sheath, while the autologous non-fascial parietal peritoneum type of grafts were harvested from different sites (i.e., diaphragm, hypochondrium, right or left subcostal region, falciform ligament, right parieto-colic gutter, and prerenal area) of the abdominal cavity. Patch-type reconstruction was adopted in 70 patients (74.5%), while a tubular reconstruction was needed in 24 (25.5%). Dokmak and colleagues reported that a good overall patency rate of 96% was observed at 11 months of mean follow-up. Satisfactory results of the overall patency rate were observed in patients who underwent reconstruction with lateral or patch grafts (n=49/49, 100%) compared with the tubular grafts (n=1/3, 33%) (67,68). The use of autologous alternative tissue remains only an alternative procedure because the patency rate of customized tubular conduit type to interpose or replace the resected vein is not known. Further studies are needed to elucidate these points.

Cryopreserved homologous veins

Cryopreserved homologous veins produce better results (69). Homologous grafts, femoral, iliac vein, and vena cava were obtained from non-heart-beating donors within 24 h after cardiac arrest after obtaining appropriate informed consent from relatives, and stored in a qualified human tissue bank (70). In HPB surgery, Yamamoto and colleagues reported pancreatoduodenectomy with homologous vein reconstruction for the SMV/PV (n=18) (71). The 6-month patency rate of the interposed homologous vein was 40%. They also analyzed 28 homologous veins used for hepatic vein reconstruction in another report and the 1-year patency rate was 50% (69).

Frequent use of homologous veins is reported with aggressive reconstruction of the MHV tributaries of a right liver graft for LDLT in 2003 (10,72). Later these groups reported the patency rate and favorable results in a large cohort: right hepatic vein 95% (249/262), V5 36% (40/110), V8 58% (64/111), and inferior right hepatic vein 86% (126/147) (73). Voit and colleagues reported 2 cases of partial IVC reconstruction with a cryopreserved homologous aorta following resection for malignancy (74). Several problems remain to be addressed, however, including the donor shortage, short-staffed human resources for harvesting, and higher preservation costs with special cryogenic storage systems that are limited to those institutions with sufficient resources.

Xenografts

Several studies report the use of bovine or equine pericardial xenografts for IVC reconstruction (74-76). ProxiCor is an extracellular matrix derived from porcine small intestine submucosa that is used for IVC patches in patients with retroperitoneal leiomyosarcoma (77). Surprisingly, 1 case showed evidence of endothelialization of the excised bovine pericardial xenografts graft at a second surgery (78). The first case was already reported in 1994, but there have been few case reports since then. Studies in a larger cohort are needed to determine the clinical efficacy of xenografts.

Synthetic vascular grafts

Unlike arterial replacement, venous replacement using synthetic vascular grafts is still rarely reported and there are several inherent limitations outside of LDLT. In HPB surgery, however, surgeons are reluctant to use synthetic vascular grafts because of their thrombogenicity due to low flow without endothelialization and graft infection as a common concern in contaminated tissue beds under digestive fluid (79). Conventional synthetic vascular grafts permanently remain in the human body and the long-term outcome is unclear. Migration remains a crucial concern as described later. The development of a new tissue-engineered venous graft or scaffold with better endothelialization and a more tolerable risk of infection using absorbable material is anticipated (80).

Expanded polytetrafluoroethylene (ePTFE/PTFE) and polyethylene terephthalate (Dacron)

Reconstruction of the venous system has been attempted with the most popular synthetic vascular grafts, ePTFE/PTFE and Dacron (81). For PVs, polyethylene terephthalate was first used in 1973, but a fungal infection developed on the inner surface of the vascular grafts (16). Ozsay and colleagues reported that the use of Dacron is associated with thrombosis with the median time to detection of thrombosis of 4.3 months (n=26) (82). Takeuchi and colleagues recently reported a case in which ringed ePTFE was used for SMV reconstruction with better results at 2 months (7).

For IVC replacement using ePTFE grafts in 29 patients described in an early report in 2000, a 3.4% mortality rate at 4 months postoperatively resulted from multisystem organ failure leading to graft infection and occlusion. One patient (3.4%) had late graft occlusions at 7.5 months postoperatively (83). Furthermore, PTFE or Dacron vascular grafts were also applied to repair a resected IVC (84). Rare Y-shaped PTFE vascular grafts were also used to reconstruct the IVC hepatic vein confluence for colorectal liver metastasis (85,86). A literature review of 13 studies including 111 cases analyzed in 2018 for IVC resection and reconstruction using Dacron or ePTFE against hepatocellular carcinoma, intrahepatic cholangiocarcinoma, and metastasis mortality revealed an 8.1% operative mortality rate (87). The patency rate during the follow-up period was 98.2% with 2 cases of thrombi. The authors concluded that using the synthetic vascular graft had satisfactory results.

In radical nephrectomy with IVC tumor thrombectomy, Garg and colleagues reported that ePTFE is the most used synthetic graft for IVC reconstruction with better results (88). They warned, however, that synthetic grafts carry a risk of infection and thrombosis. Benkirane and colleagues performed IVC replacement for suspicion of IVC wall invasion (n=26) (89). Histologic invasion of the wall of the IVC was found in 16 (61.5%) cases. Graft thrombosis occurred in 5 patients (19.2%) within the first year. Patency of the graft in the IVC at 6 and 12 months was 88% and 79%, respectively. Several urologic surgeons recommended ePTFE use rather than Dacron (84,90). Other follow-up outcomes of 38 ePTFE synthetic vascular grafts reconstruction for IVC in 114 alveolar echinococcosis patients showed 16.3% Clavien-Dindo Grade IIIa or higher (91), and 11.6% IVC thrombosis, but a favorable survival rate of more than 95% at 2 years (92).

Mainly in Korea, transplant surgeons aggressively use synthetic vascular grafts for LDLT to reconstruct MHV tributaries (93). A recent report indicated that the patency rate of Hemashield (collagen impregnated polyester, n=157) grafts and Gore-Tex (ePTFE, n=157) grafts is less than

Table 2 Summary of the grafts and materials for venous reconstruction

Category	Various types	Advantages	Disadvantages
Autologous veins	Great saphenous vein/short hepatic vein of the harvested liver graft/internal jugular vein/umbilical vein/bilateral gonadal vein/ left internal carotid vein/superficial femoral vein; renal veins	Better patency	Size mismatch with smaller graft/additional surgical incisions/longer operation time; 15% impaired renal function immediately after surgery
Autologous alternative tissues	Peritoneofascial grafts; non-fascial parietal peritoneum type of grafts including diaphragm/hypochondrium/right or left subcostal region/falciform ligament/right parieto-colic gutter/prerenal area	Better patency (patch-type reconstruction)	It is not known yet if patency rate of customized tubular conduit type to interpose or replace the resected vein is better
Cryopreserved homologous veins	–	Favorable results	Donor shortage/short-staffed human resources for harvesting/higher preservation costs with special cryogenic storage system/limited institutions
Xenografts	Bovine or equine pericardial xenograft/an extracellular matrix derived from porcine small intestine submucosa (ProxiCor®)	Endothelialization (a case report, ProxiCor®)	There have been few case reports
Synthetic vascular grafts	Expanded polytetrafluoroethylene/ polyethylene terephthalate	Favorable results/ the second-best solution	Thrombogenicity due to low flow without endothelialization/graft infection/permanently remain in the human body/unclear the long-term outcome/ migration

30% at 24 months after LDLT and less than 50% and 30% at 24 and 42 months after LDLT, respectively (94). In the ringed ePTFE graft group, there were 2 cases of accidental migration of the graft into the gastric wall at 6 months and 3 years after LDLT. Chung and colleagues summarized a total of 42 cases of migration of synthetic vascular grafts that were used for MHV reconstruction in LDLT. They suggested that the migration rate is not negligibly low and lifelong surveillance is necessary (95). Synthetic vascular grafts may still be the second-best solution compared with autologous vein use (*Table 2*).

Development of new synthetic vascular grafts for veins

To overcome the disadvantages of synthetic vascular grafts, Matsumura and colleagues demonstrated favorable results using cell-free 8-mm diameter biodegradable scaffolds consisting of polyglycolide knitted fibers in a canine IVC model (96). In their report, histologic examinations revealed a well-formed vessel-like vasculature without calcification. Kiritani and colleagues reported that the application of silk fibroin for rat vein replacement produced a better short-term outcome than ePTFE/PTFE, with acceptable patency (80). Silk fiber, comprising silk fibroin and silk sericin, is a natural protein fiber and silk thread has long been used in surgery for suturing and ligature (97-99). Silk fibroin biomaterial has biologic advantages such as better biocompatibility, high affinity for cells, and susceptibility to proteolytic degradation *in vivo* without antigenicity (100,101), and its use has been reported for artery replacement in rat and canine models (100,102,103). Kiritani and colleagues also found that CD31-positive endothelial cells covered the luminal surface of the silk fibroin vascular graft walls at 4 weeks after replacement of the rat IVC (80). Furthermore, bioengineered human tissues (104), including a 3-dimensional bioprinted tube of human fibroblasts (105,106), have been developed for future vascular replacement of arteries and may be promising for vein grafts.

Conclusions

Various approaches to abdominal vein resection and replacement or reconstruction are technically feasible with satisfactory results. In hepatic malignancy, further studies in larger cohorts are needed to gain a better understanding of the oncologic benefits. Synthetic vascular grafts may be appropriate but have a certain rate of complications. New tissue-engineered or bioengineered synthetic vascular grafts are expected to enhance the safety of venous replacement.

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Footnote

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