Technical refinement of inferior vena cava replacement using a synthetic vascular graft in living donor liver transplantation

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The native inferior vena cava (IVC) can be resected during living donor liver transplantation (LDLT) in Budd-Chiari syndrome or advanced hepatocellular carcinoma (HCC). The present study aimed to present the technical details of IVC replacement with synthetic vascular graft interposition. Following laparotomy, the recipient liver was mobilized to expose the IVC. Piggyback or classical total hepatectomy including IVC was performed. In patients with Budd-Chiari syndrome, atrio-caval anastomosis with a vascular graft is necessary, in which clamp slippage should be completely prevented. No-touch en bloc isolation of the native liver is necessary for patients with advanced HCC. The wall of a large-caliber vascular graft is pleated to prevent luminal collapse, suggesting the need for tension to stretch it. The length of a vascular graft should be adjusted meticulously. An adequately interposed vascular graft appears to be rather short under IVC cross-clamping, but elongated and expanded after restoration of the IVC flow. A single right or left liver graft, or even dual-graft can be implanted to the interposed IVC vascular graft. An elliptical excision of the graft wall is mandatory for graft hepatic vein implantation, because an incision at the graft does not expand. In conclusion, IVC replacement with interposition of a synthetic vascular graft expands the indications for LDLT, particularly in patients with Budd-Chiari syndrome and advanced HCC, similar to those of deceased donor liver transplantation.

Keywords: Living donor liver transplantation; Budd-Chiari syndrome; Graft outflow vein obstruction; Hepatocellular carcinoma; Synthetic graft

INTRODUCTION

The native inferior vena cava (IVC) can be resected during living donor liver transplantation (LDLT) because of its stenosis or occlusion in Budd-Chiari syndrome or adjacent tumor invasion of advanced hepatocellular carcinoma

(HCC) [1-4]. We performed adult LDLT using IVC replacement with interposition of a large-caliber synthetic vascular graft. One of the most important advantages of deceased donor liver transplantation (DDLT) is that the liver graft contains a retrohepatic IVC, which enables resection of the native recipient IVC. IVC replacement with synthetic vascular

graft interposition is effective in restoring the IVC flow and facilitates implantation of graft outflow hepatic veins, but the details of surgical technique have yet to be reported. The present study presents the technical details of IVC replacement with synthetic vascular graft interposition.

SURGICAL TECHNIQUES FOR IVC REPLACEMENT AND GRAFT HEPATIC VEIN RECONSTRUCTION

Following laparotomy, the recipient liver was mobilized to expose the IVC after isolating the hepatic artery, portal vein, and bile duct. Piggyback total hepatectomy or classical DDLT-style total hepatectomy including the IVC was performed. The use of veno-venous bypass is not always

mandatory if the patient's blood pressure remains stable after IVC test clamping.

In patients with Budd-Chiari syndrome, the nearly completely obliterated native suprahepatic IVC is divided and closed for total hepatectomy before or after atrio-caval anastomosis (Fig. 1A). A large collateral vein should be divided and securely closed. For atrio-caval anastomosis, the tendinous portion of the diaphragm is incised for pericardiotomy (Fig. 1B). A lower median sternotomy and diaphragm split to expose the suprahepatic IVC is helpful if the transdiaphragmatic approach alone cannot provide adequate space and view for clamping the right lateral side of the right atrium. The inferior right-lateral surface of the atrium is securely clamped with a large-sized Satinsky clamp (Fig. 1C), followed by an incision approximately 30 mm in

Fig. 1. Intraoperative photographs of inferior vena cava (IVC) replacement in a patient with Budd-Chiari syndrome. (A) The native suprahepatic IVC is divided and closed after total hepatectomy. (B) Pericardiotomy is performed to expose the atrium. (C) The inferior right-lateral surface of the atrium is clamped with a Satinsky clamp. (D) A 30-mm-long incision is made for anastomosis. (E) A synthetic vascular graft is anastomosed with the atrial opening. (F) A test for hemostasis at the atrio-caval anastomosis is performed. (G) The proximal portion of the vascular graft is clamped after release of the atrial clamping. (H) The outflow vein orifice of a left liver graft is anastomosed with the opening at the vascular graft after elliptical excision of the graft wall. (I, J) The suprahepatic and infrahepatic caval anastomoses are visible.

length to match the size of a large-caliber vascular graft (Fig. 1D). Following completion of atrio-caval anastomosis, atrial clamping is released after complete hemostasis of the anastomosis (Fig. 1E–G). The divided stump of the recipient infrahepatic IVC is anastomosed to the interposed synthetic graft without redundancy. The graft outflow hepatic vein stump is implanted to the interposition vascular graft (Fig. 1H–J).

In patients with advanced HCC, no-touch en bloc isolation of the native liver is necessary. Initially, the hepatic hilum is dissected to reduce tumor cell spread from HCC manipulation before mobilizing the liver. The hepatic artery and bile duct are transected with maintenance of the portal vein flow. The infrahepatic IVC is dissected close to the insertion sites of the renal veins and encircled with a vessel loop. The suprahepatic IVC is also encircled via minimal liver mobilization. A veno-venous bypass using a BioPump is often required because of absence of sizable collateral veins in such patients. After transection of the portal vein, a bypass catheter is inserted to divert the splanchnic blood flow. After cross-clamping the suprahepatic and infrahepatic IVC, the infrahepatic IVC immediately above the renal vein insertion site was transected, followed by transection

of the suprahepatic IVC to remove the native liver. A large-sized vascular graft is anastomosed with the suprahepatic IVC (Fig. 2A). The stump of the infrahepatic IVC can be prepared with a vein patch for secure anastomosis (Fig. 2B, C). The vascular graft is stretched caudally to avoid kinking from redundancy, followed by infrahepatic caval anastomosis (Fig. 2D, E). After the lumen of the vascular graft is filled with heparinized saline, the IVC cross-clamping was temporarily released to identify the configuration of the interposition graft and the status of hemostasis (Fig. 2F). Under cross-clamping of the suprahepatic and infrahepatic IVC, graft hepatic vein anastomosis is performed after creating an elliptical excision of the graft wall (Fig. 2G, H). After portal vein anastomosis, the IVC cross-clamp and portal vein clamp are sequentially released for graft reperfusion. The hepatic artery is reconstructed in an end-to-end manner with a size-matched hepatic artery branch using microvascular techniques, followed by biliary reconstruction.

The wall of a large-caliber vascular graft is pleated to prevent luminal collapse, which requires tension for stretching. The length of a vascular graft should be adjusted meticulously after excising the redundant portion (Fig. 3A, B). An adequately interposed vascular graft appears to

Fig. 2. Intraoperative photographs of inferior vena cava (IVC) replacement in a patient with advanced hepatocellular carcinoma. (A) A large-sized vascular graft is anastomosed with the suprahepatic IVC. (B, C) The stump of the infrahepatic IVC is reinforced with an autologous greater saphenous vein patch. (D, E) The vascular graft is stretched caudally to avoid kinking from redundancy, followed by infrahepatic caval anastomosis. (F) The configuration of the interposition graft is visualized after temporary IVC cross-clamping. (G) The graft right hepatic vein is anastomosed to the vascular conduit after creating an elliptical excision in the graft wall. (H) The graft middle hepatic vein conduit is anastomosed to the vascular conduit after making an elliptical excision of the graft wall.

be rather short under IVC cross-clamping, but will be elongated and expanded after restoration of the IVC flow (Fig. 3C, D).

In HCC patients with intact IVC, the suprahepatic IVC can be transected at the level of the hepatic vein trunk insertion, to divide and unite the hepatic vein openings, similar to DDLT (Fig. 4A). The interposed vascular graft is usually larger than the native IVC, and therefore such enlargement of the suprahepatic IVC stump facilitates wide anastomosis (Fig. 4B). In contrast, the infrahepatic IVC stump is often smaller than that of the suprahepatic IVC, thus a telescoping anastomosis can be used to manage such size mismatch (Fig. 4C, D).

A single right or left liver graft, or even dual-graft can be implanted to the interposed IVC vascular graft. An elliptical excision of the graft wall is mandatory for graft hepatic vein implantation, because an incision in the graft does not expand, unlike the native or homograft IVC (Fig. 1H, 2G).

The inferior right hepatic vein orifice and the middle hepatic vein conduit stump are implanted to the IVC vascular graft under partial side-clamping (Fig. 2F). A preparation

with vein patch venoplasty at the middle hepatic vein conduit insertion site facilitates for its implantation after graft reperfusion (Fig. 5).

Multiple graft outflow veins in a right liver graft can be anastomosed with the vascular graft at the back table in the form of all-in-one anastomosis, which requires only two caval anastomoses during graft implantation, similar to DDLT (Fig. 6).

DISCUSSION

IVC replacement with synthetic vascular graft interposition converts a living donor partial liver graft into deceased donor liver graft including the retrohepatic IVC. This technique resolves the outflow vein complications associated with stenotic IVC and also provides oncological benefits.

Patients with Budd-Chiari syndrome require special care when the pulsating right atrium is partially clamped because the thin and shallow atrial tissue is at high risk of clamp slippage during surgery [3,4]. Ensuring sufficient space and view before clamping the right atrium via lower

Fig. 3. Intraoperative photographs of inferior vena cava (IVC) replacement in a patient with Budd-Chiari syndrome. (A, B) The length of a vascular conduit is adjusted after atrio-caval anastomosis. (C, D) The interposed vascular graft appears to be rather short under IVC cross-clamping, but elongates and expands after the release of the IVC cross-clamping. A modified right liver graft with a middle hepatic vein conduit using a cryopreserved aorta is implanted to the interposed vascular graft.

Fig. 4. Intraoperative photographs of inferior vena cava (IVC) replacement in a patient with advanced hepatocellular carcinoma. (A) The suprahepatic IVC stump is widened after unification of the hepatic vein trunk openings. (B) A size-matched vascular graft is anastomosed with the suprahepatic IVC stump. (C) A telescoping anastomosis is performed with the infrahepatic IVC stump. (D) A modified right liver graft with all-in-one outflow vein venoplasty is implanted to the interposed vascular graft.

Fig. 5. Intraoperative photographs of inferior vena cava replacement in a patient with advanced hepatocellular carcinoma. (A) A saphenous vein patch is attached to create an opening at the interposed vascular graft. (B) A middle hepatic vein conduit of a modified right liver graft is anastomosed with this opening.

hemi-sternotomy and clamping with the Allis tissue forceps at both corners of the already clamped atrium under a Satinsky clamp is a safe strategy to prevent accidental slippage. The atrio-caval anastomosis is an established technique in DDLT [5]. The large-caliber synthetic vascular graft contains multiple vertical pleats which can be stretched, suggesting the need to avoid redundancy through application of adequate tension [6,7].

The indications of LDLT for HCC have been expanded

beyond the Milan criteria [8-11]. A few reports revealed higher rates of posttransplant HCC recurrence following LDLT than DDLT [12,13]. One definite difference between LDLT and DDLT is preservation or resection of the recipient IVC. If advanced HCC is located close to the IVC, piggyback preparation of the recipient IVC may leave microscopic cancer cells at the IVC per se as well as promote micro-metastasis through the draining hepatic veins [1,2]. Thus, concurrent removal of the recipient IVC is associated with

Fig. 6. Intraoperative photographs of inferior vena cava replacement in a patient with advanced hepatocellular carcinoma. (A) The right hepatic vein opening conjoined with a middle hepatic vein conduit is anastomosed with a large-caliber vascular graft. (B) An inferior right hepatic vein opening (arrow) is also anastomosed with the vascular graft. (C, D) This modified right liver graft with all-in-one outflow vein reconstruction is implanted through two caval anastomoses.

theoretical oncological benefit in patients with advanced HCC.

We did not experience any postoperative synthetic IVC graft-related complications in tens of adult LDLT cases who underwent IVC replacement [1,3]. The IVC is a low-velocity high-flow vein, obviating the need for anticoagulation. On the contrary, partial occlusion of a synthetic graft due to redundancy-associated kinking is an indication for endovascular wall stenting to straighten the vascular graft.

There are a few studies reporting IVC replacement with an IVC homograft [4]. A sizable IVC homograft can be recovered only from deceased tissue donors and it is nearly impossible to obtain it from deceased multi-organ donors. The only substitute homograft for IVC is a cryopreserved aorta graft in our institution. However, the diameter of the aorta homograft is often less than 2 cm, thus it is often too small for replacement of the adult IVC [14]. Currently, a large-caliber synthetic vascular graft appears to be most appropriate for IVC replacement.

Dacron woven grafts (Hemashield Platinum, Maquet; San Jose, CA, USA) have been generally used for IVC interposition. Although they do not contain outer rings, the circular pleats (Concentricrimp™, Maquet) of the Hemashield vascular grafts are effective in preventing col-

lapse. Because of the thin-walled flexible structure formed using woven double velour polyester material, it is easy to handle and suture Hemashield grafts. The bellows-like circular pleats facilitates flexible shortening or lengthening of the Hemashield grafts and flexibility of the conduit length during anastomosis to the IVC stumps. The woven structure of these bovine collagen impregnated grafts also prevents needle-hole bleeding. Its longitudinal colored lines (Guideline strip™, Maquet) also enable adjustment of the alignment during anastomosis. In addition, its bovine collagen-impregnated and woven double velour structure facilitates prevention of early luminal thrombus formation and tissue reaction at the anastomotic sites [6].

In conclusion, IVC replacement with interposition of a synthetic vascular graft can facilitate the expansion of the indication for LDLT, particularly in patients with Budd-Chiari syndrome and advanced HCC, similar to those of DDLT.

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CONFLICT OF INTEREST

All authors have no conflicts of interest to declare.

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AUTHORS' CONTRIBUTIONS

Conceptualization: SH. Data curation: All. Formal analysis: All. Investigation: DBM, CSA, TYH, GWS, DHJ, GCP, YIY. Methodology: All. Supervision: SH, SGL. Validation: SH. Visualization: SH, DBM. Writing - original draft: SH, DBM. Writing - review & editing: All.

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