SURGICAL REPAIR FOR LATE-ONSET HEPATIC VENOUS OUTFLOW BLOCK AFTER LIVING-DONOR LIVER TRANSPLANTATION

Nobuhisa Akamatsu, Yasuhiko Sugawara, Junichi Kaneko, Yoji Kishi, Takashi Niiya, Norihiro Kokudo, and Masatoshi Makuuchi

The incidence of hepatic venous complications in partial liver transplantation is more frequent than that in whole liver transplantation. There are no reports of a surgical strategy for hepatic venous outflow block (HVOB) after living-donor liver transplantation. HVOB was diagnosed when the pull-through pressure gradient across the anastomotic site was over 5 mm Hg. Reoperation for venous anastomosis was performed if the angioplasty was unsuccessful. After dissection around the hepatic venous anastomotic site, a patch venoplasty of the anastomosis was performed. When the inferior vena cava was constricted, venoatrial anastomosis was performed. In 6 years, 5 of 223 patients experienced HVOB. Balloon angioplasty was successfully performed in two patients, a patch venoplasty of the anastomosis in two, and venoatrial anastomosis in one. In all patients, the ascites stopped. HVOB must be diagnosed as soon as possible with Doppler ultrasound and venography. Prompt surgical revision can salvage the grafts.

The limited supply of cadaveric donor organs for liver transplantation has fostered the use of segmental liver graft with reduced-size grafts, split-liver transplantation, and living-donor liver transplantation (LDLT). The overall survival rates of recipients using these technical innovations is equivalent to those achieved with whole liver grafts. Nonetheless, the use of a partial liver graft demands more meticulous surgical procedures, resulting in an increase in various vascular complications. The incidence of hepatic venous complication in partial liver transplantation is more frequent (2%–13%) (*1, 2*) than that in whole liver transplantation (1%–2%) (*2, 3*).

The occurrence of hepatic venous outflow block (HVOB) can be divided into two categories on the basis of the timing of onset (*3*): early, in the immediate postoperative period; and late, thereafter. The cause of early-onset HVOB often includes technical problems, and late-onset HVOB might be caused by subsequent fibrosis with inflammatory processes such as bile leakage, abscess formation, and compression or twisting of the anastomosis caused by the graft growth (*4*). Graft salvage is difficult without prompt revision in both types of HVOB. Our surgical techniques for HVOB are presented in this article.

From January 1996 to April 2003, 223 patients underwent LDLT at our hospital (153 adults and 70 children). The mean follow-up period was 603 days. The indications for LDLT in these patients included biliary atresia (n=69), primary biliary cirrhosis (n=43), hepatitis C virus cirrhosis (n=33), hepatitis B virus cirrhosis (n=22), fulminant hepatic failure (n=18), cryptogenic cirrhosis (n=13), metabolic disorder (n=13), primary sclerosing cholangitis (n=6), and autoimmune hepatitis (n=6). The most commonly used type of graft was the left liver with or without the caudate lobe (n=84), followed by right liver (n=73), segments II and III (n=51), and right lateral sector (segments VI and VII, n=15). The transplantation procedure and donor selection criteria are described elsewhere (*5*).

HVOB was suspected with massive pleural effusion and ascites and one of the following Doppler ultrasound (US) findings: (1) a decrease in hepatic vein flow velocity; (2) a flat waveform of the hepatic vein, especially in cases with a previously multiphasic pattern (*6*); (3) mild dilatation of the distal venous tributaries; and (4) a decrease in portal flow. When HVOB was suspected on the basis of US findings, venography was performed. Patients can be diagnosed with HVOB when the pull-through pressure gradient across the anastomotic site is over 5 mm Hg (*7*). Balloon angioplasty was performed first, followed by 1 week of intravenous administration of heparin (200 U/kg/day). Reoperation for venous anastomosis was performed when the angioplasty was unsuccessful.

When dissection around the hepatic venous anastomotic site was possible, a patch venoplasty of the anastomosis was performed. After vascular exclusion, the right wall of the suprahepatic inferior vena cava (IVC) above the anastomosis was incised longitudinally and passed through the anastomosis and extended to the left and middle hepatic veins (Fig. 1). The IVC defect was covered by a triangle-shaped cryopreserved venous patch, allowing the patch to expand outside. Sutures were continuous using 6-0 monofilament. The vein grafts were provided by the University of Tokyo Tissue Bank. They were obtained from cadavers or non–heart-beating donors within 24 hr after cardiac arrest after obtaining informed consent. When inflammatory changes around the IVC were severe and the IVC was constricted, a venoatrial anastomosis was performed. The pericardium was incised. The bottom of the right atrium was then side-clamped and anastomosed with the hepatic veins of the graft (Fig. 2).

Five patients (2%) experienced HVOB. HVOB was not suspected in any other patients in the series. The demo-

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Artificial Organ and Transplantation Division, Department of Surgery, Graduate School of Medicine, University of Tokyo, Tokyo, Japan.

Address correspondence to: Yasuhiko Sugawara, M.D., Artificial Organ and Transplantation Division, Department of Surgery, Graduate School of Medicine, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8655, Japan. Email: yasusuga-tky@umin.ac.jp.

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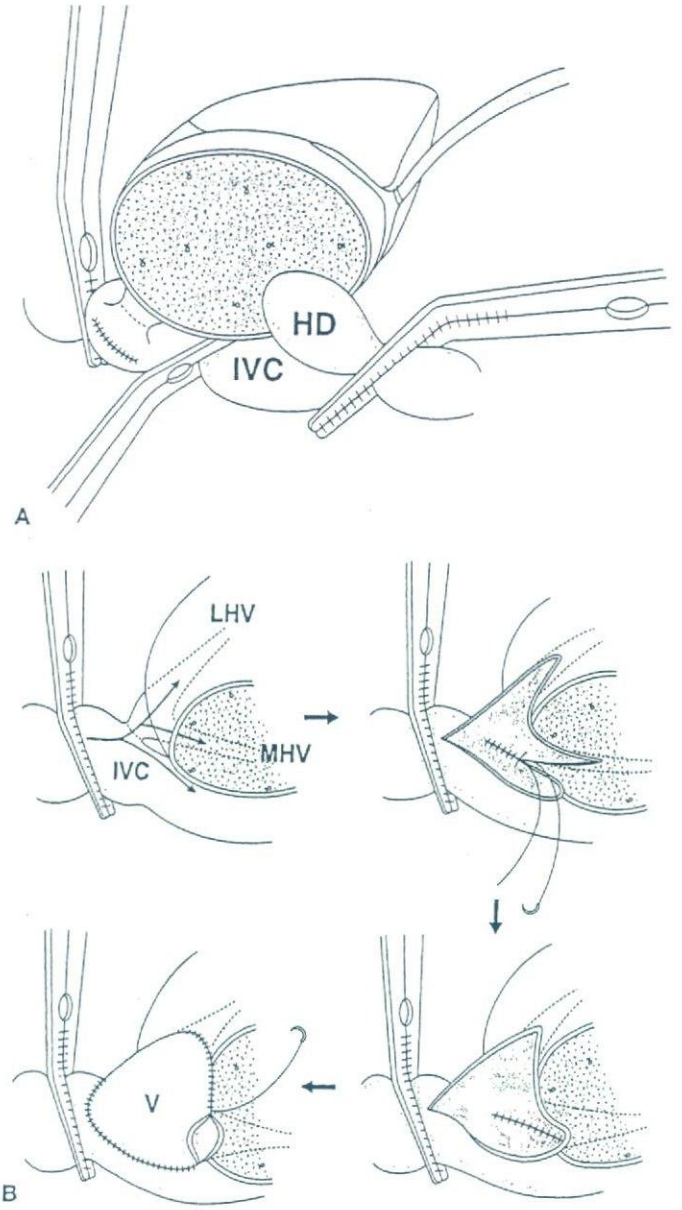

FIGURE 1. A patch plasty for hepatic venous reconstruction. (A) Total vascular occlusion and cold perfusion of the graft. (B) Venoplasty of the stenotic anastomosis using a venous patch. HD, Hepatic artery, portal vein, and common bile duct; LHV, left hepatic vein; MHV, middle hepatic vein; IVC, inferior vena cava; V, venous patch.

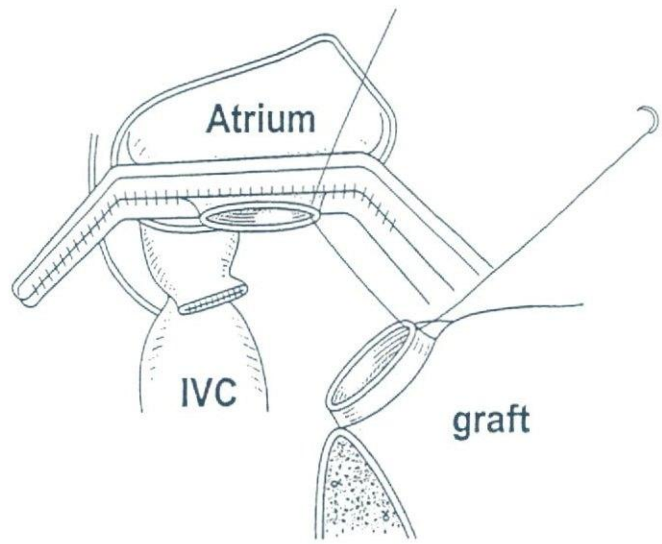

FIGURE 2. A venoatrial anastomosis. The pericardium was incised. The bottom of the right atrium was then side-clamped and anastomosed with the hepatic veins of the graft. IVC, Inferior vena cava.

graphics of the five HVOB patients are shown in Table 1. In two patients, balloon angioplasty was successfully performed. The profile of the other three patients in whom a revision operation was necessitated is described in detail.

In patient 2, during LDLT, a fresh femoral venous graft from a cadaver was used as a conduit from the superior mesenteric vein of the recipient to the graft portal vein because the native portal vein was completely thrombosed. Hepatic venous reconstruction was performed using the technique described previously (*8*). The patient's postoperative course was uneventful, and the patient was symptom-free for 4 years after LDLT. Ascites retention occurred and was first managed with diuretics and periodic abdominocentesis but increased beyond conservative treatment 5 years after LDLT. Doppler US indicated that hepatic venous flow was still biphasic in its waveform and maintained its velocity (30 cm/sec). The portal flow was slow, down to 5 cm/sec. Celiac angiography revealed that the jumping graft was stenotic, probably because of thrombosis. The venogram indicated hepatic venous stenosis with a 7-mm Hg pull-through pressure gradient. The patient underwent surgical venoplasty with the technique shown in Figure 1. After thrombectomy near the anastomotic site of the superior mesenteric vein, portal inflow was reinstated using a cryopreserved femoral vein from a cadaver between the superior mesenteric vein (end-to-side) and umbilical portion of the graft (end-to-side). The ascites completely stopped within 2 weeks after the revision.

In patient 4, who weighed 13 kg, ascites and pleural effusion increased over 700 mL/day, 5% of the patient's body weight, 1 month after the LDLT. On postoperative day (POD) 54, a venogram was obtained using a percutaneous transhepatic approach that revealed hepatic venous obstruction and an 18-mm Hg pull-through pressure gradient. Successive angioplasty using a 12-mm-diameter balloon catheter was performed. The amount of ascites and pleural effusion transiently decreased just after the angioplasty. The hepatic vein, however, thrombosed 1 month after the angioplasty. Retransplantation using the left liver graft from the child's mother was performed 8 months after the first LDLT. The ABO blood-type was incompatible. Because severe fibrosis was observed around the previous venous anastomotic site and suprahepatic IVC, a venoatrial anastomosis was performed. The patient was discharged from the hospital 104 days after the operation; however, the child died because of chronic rejection 28 months after the first LDLT.

In patient 5, on POD 47, open drainage was performed for biloma formation in the right subphrenic space. After the operation, the amount of ascites and right pleural effusion gradually increased. On POD 110, total fluid was over 5,000 mL/day, which was 12% of the body weight. Doppler US

TABLE 1. Profile of the patients with hepatic venous outflow block

Patient	Age (yr)	Gender	Indication	Graft type	Onset (mo after LDLT)	Angioplasty (times)	LDLT to reoperation	Results
1	1	F	BA	SII+III	3	2	—	Alive 74 mo
2	48	F	PBC	Left liver	48	1	Patch plasty	Alive 65 mo
3	12	M	BA	LL+CL	5	3	—	Died 11 mo for biliary infection
4	2	M	BA	SII+III	2	1	Venoatrial anastomosis	Died 28 mo for chronic rejection
5	14	F	FH	LL+CL	2	3	Patch plasty	Alive 9 mo

BA, Biliary atresia; PBC, primary biliary cirrhosis; FH, fulminant failure; LDLT, living-donor liver transplantation; LL+CL, left liver with caudate lobe; SII+III, segments II and III; mo, months after transplantation.

revealed that the hepatic vein waveform was monophasic and the flow speed was 7.6 cm/sec. Venography revealed severe stenosis of the hepatic venous anastomosis, and the patient was diagnosed with HVOB. The pull-through pressure gradient was 19 mm Hg. Balloon angioplasty was performed three times at 14-day intervals with transjugular or transsubclavian catheterization. Even after the angioplasty, the amount of ascites did not decrease. The preoperative splenic volume was 240 mL, which increased to 880 mL in the post-LDLT period. On POD 160, patch venoplasty was performed as shown in Figure 1. Doppler US after the revision revealed a biphasic sharp waveform with the peak flow speed of 120 cm/sec. The amount of ascites dramatically decreased within 10 days after the revision.

Balloon angioplasty might be the first line of treatment for HVOB. Buell and colleagues (*2*) reported a 75% success rate (six of eight). In spite of their successful results, generally balloon angioplasty alone might yield unsatisfactory results as in our cases because of the fibrotic nature of the lesions. Stenosis refractory to angioplasty might be an indication for stent placement. Recent studies on the results of stenting for HVOB (*2*) reported a 72% success rate (18 of 25). In partial liver transplantation, as in whole liver transplantation using piggyback techniques, stenting is not always secure. Double stents might be necessary—one in the IVC and the other across the venous anastomotic site—which can slip off. In our patients, we chose surgical revision instead of stent placement because in patients with partial liver grafts, stent dislocation might occur along with graft regeneration and patient growth in pediatrics.

There are few reports of successful surgical treatment for late-onset HVOB. Lerut and associates (*9*) reported that one patient with a whole liver graft died during the revision operation for HVOB. Eid and colleagues reported successful whole liver graft salvage by retrohepatic cavoatrial shunt using a 16-mm, ring-enforced polytetrafluoroethylene graft (*10*). A French group (*3*) reported a 2% incidence of venous complications (21 of 1,361). Of these, four patients experienced late-onset HVOB. Details of the therapy and the results, however, were not reported. In pediatric LDLT cases, HVOB is treated with angioplasty (*4*) and stenting. There are no reports of a surgical strategy for HVOB, especially in LDLT. The severe liver graft shortage in Japan has made retransplantation extremely difficult, which forces us to choose the most reliable treatment for HVOB.

In an LDLT series of 223 patients, there were 5 cases of late-onset HVOB. It is important to diagnose HVOB as soon as possible with Doppler US and venography before irreversible congestive changes occur in the grafts. Prompt surgical revision could salvage the grafts, although it requires meticulous surgical technique.

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Duct-to-Duct Biliary Reconstruction in Adult Living-Donor Liver Transplantation

Ender Dulundu,[1,2] Yasuhiko Sugawara,[2,3] Keiji Sano,[2] Yoji Kishi,[2] Nobuhisa Akamatsu,[2] Junichi Kaneko,[2] Hiroshi Imamura,[2] Norihiro Kokudo,[2] and Masatoshi Makuuchi[2]

Background. Bile duct-to-duct reconstruction is now used in living-donor liver transplantation (LDLT) for adult patients.

Methods. The results of duct-to-duct reconstruction were retrospectively analyzed. The subjects were 81 adult patients who underwent LDLT at the University of Tokyo Hospital with a follow-up period of at least 1 year. The hilar plate of the recipient was dissected to at least the second-order branch of the bile ducts. Duct-to-duct anastomosis was performed with interrupted sutures, and an external stent tube was inserted from the orifice opposite the hilar plate.

Results. During the observation period (median, 664 days), biliary complications were observed in 26 cases (32%). The complications included bile juice leakage at the anastomosis or dissection plane of the graft in 12 patients, anastomotic stenosis in 10 patients, and tube trouble in 6 patients. Two patients had bile juice leakage followed by stenosis. Of the 26 patients, 21 required surgical revision.

Conclusions. The current technique did not reduce morbidity as expected. Further technical advancement and refinement are needed for better results.

Keywords: Bile leakage, Anastomotic stricture, Standard liver volume.

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Various refinements in surgical techniques, organ preservation, and immunosuppressive management have reduced the incidence of complications after liver transplantation. Biliary tract complications, however, continue to be a significant cause of morbidity after liver transplantation (*1, 2*).

Living-donor liver transplantation (LDLT) was initially performed for pediatric patients with biliary atresia. Therefore, the type of biliary anastomosis was limited to hepaticojejunostomy. Now, LDLT is widely performed for adults, and duct-to-duct direct biliary reconstruction is enthusiastically presented in some institutions (*3–7*). These reports advocate the advantages of duct-to-duct biliary reconstruction over hepaticojejunostomy (i.e., it could preserve physiologic bilioenteric and bowel continuity, thus preventing delayed bowel movement). Duct-to-duct reconstruction is described as allowing easy endoscopic access to the biliary tree for diagnostic and therapeutic instrumentation and management and to prevent ascending cholangitis (*3, 7, 8*).

These advantages are optimistically described but are not clearly established as beneficial. The number of patients who underwent LDLT and received duct-to-duct reconstruction is small, and the length of the follow-up periods is thus far limited. To confirm the feasibility of biliary reconstruction in LDLT, the results of duct-to-duct reconstruction were retrospectively analyzed in our series. The subjects were limited to those with a follow-up of at least 1 year.

PATIENTS AND METHODS

At the University of Tokyo Hospital, duct-to-duct biliary reconstruction was started in May 2000. By the end of 2002, 86 patients received LDLT with the reconstruction. Of these, five patients died within 1 year after LDLT and were excluded from the study. The remaining 81 patients were the subjects of the present study. They were 42 men and 39 women (average age, 50±10 years).

The most common indication for LDLT was viral hepatitis and cirrhosis with or without hepatocellular carcinoma (n=39), followed by cholestatic disease (n=27), including primary biliary cirrhosis, autoimmune hepatitis, primary sclerosing cholangitis, fulminant hepatic failure (n=9), metabolic diseases (n=4), and cryptogenic cirrhosis (n=2). The most commonly used graft type was the right liver in 46 patients, followed by the left liver with or without the caudate lobe in 29 patients, and the right lateral sector in 6. The donors were 56 men and 25 women (average age, 35±11 years). Their relation to the patients was child (n=41), sibling (n=14), spouse (n=12), nephew (n=7), parent (n=4), or other (n=3).

Donor Operation

Standard techniques were previously described (*9*). In brief, after cholecystectomy, a Phycon cholangiocatheter (Fuji Systems Corp., Tokyo, Japan) was inserted through the cystic duct stump for intraoperative cholangiography to ver-

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[1] Foundation for Promotion of Cancer Research, Tokyo, Artificial Organ and Transplantation Division, Department of Surgery, Graduate School of Medicine, University of Tokyo, Tokyo, Japan.

[2] Artificial Organ and Transplantation Division, Department of Surgery, Graduate School of Medicine, University of Tokyo, Tokyo, Japan.

[3] Address correspondence to: Yasuhiko Sugawara, M.D., Artificial Organ and Transplantation Division, Department of Surgery, Graduate School of Medicine, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8655, Japan. E-mail: yasusuga-tky@umin.ac.jp.

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ify the transection point of the hepatic duct. The hepatic duct was sharply severed near the confluence and the remnant stump was carefully sutured closed with 4-0 Vicryl (Ethicon, Inc., Somerville, NJ). After harvesting, completion cholangiography was performed to confirm that there was no bile juice leakage or stricture.

Recipient Operation

The technique was described previously (*4*). In brief, in total hepatectomy of the patients, the hilar plate was dissected sharply at or distal to the second-order branch of the bile ducts. In dissection, careful attention was paid to preserve as much as possible of the surrounding tissues with an adequate blood supply to the bile duct. To maintain the blood supply from the right hepatic artery to the bile duct, dissection between the right hepatic artery and the bile duct was avoided.

An end-to-end anastomosis between graft and patient bile duct was performed using an interrupted 4-0 Vicryl suture. When the bile duct of the graft was larger than the recipient's duct, bile duct plasty of the hilar plate was performed (Fig. 1). Then, on the patient's hilar plate, an external stent tube was inserted into the bile duct from the orifice opposite the duct for which anastomosis was planned. When there were multiple bile duct orifices in the graft, stent tubes were used separately for each of them. When two bile ducts in the graft were located close to each other, they were joined into one. If they were widely separated, they were anastomosed independently. A stent tube was fixed not at the anastomotic site but rather at the orifice site opposite the hilar plate. The anastomosis was begun at the posterior wall. The needle was inserted into the bile duct of the graft from outside to inside, and then to the orifice of the hilar plate from inside to outside. The knots were always outside of the bile duct. The anastomotic site can be turned around for better access. Thereafter, anastomosis of the anterior wall was started. For feeding or injection of the drained bile juice, a 4-French polyethylene tube was inserted from the stump of the cystic duct and introduced into the duodenum. The tubes for bile duct stenting and feeding were removed 3 months after LDLT.

The postoperative care and our immunosuppression regimen have been described previously (*10*). Biliary complications were classified into three categories: bile juice leakage, bile duct stenosis, and tube trouble. Bile juice leakage was diagnosed when the total bilirubin level of the discharge around the dissection plane of the graft was over 5 mg/dL. Bile duct stenosis was suspected on the basis of laboratory data,

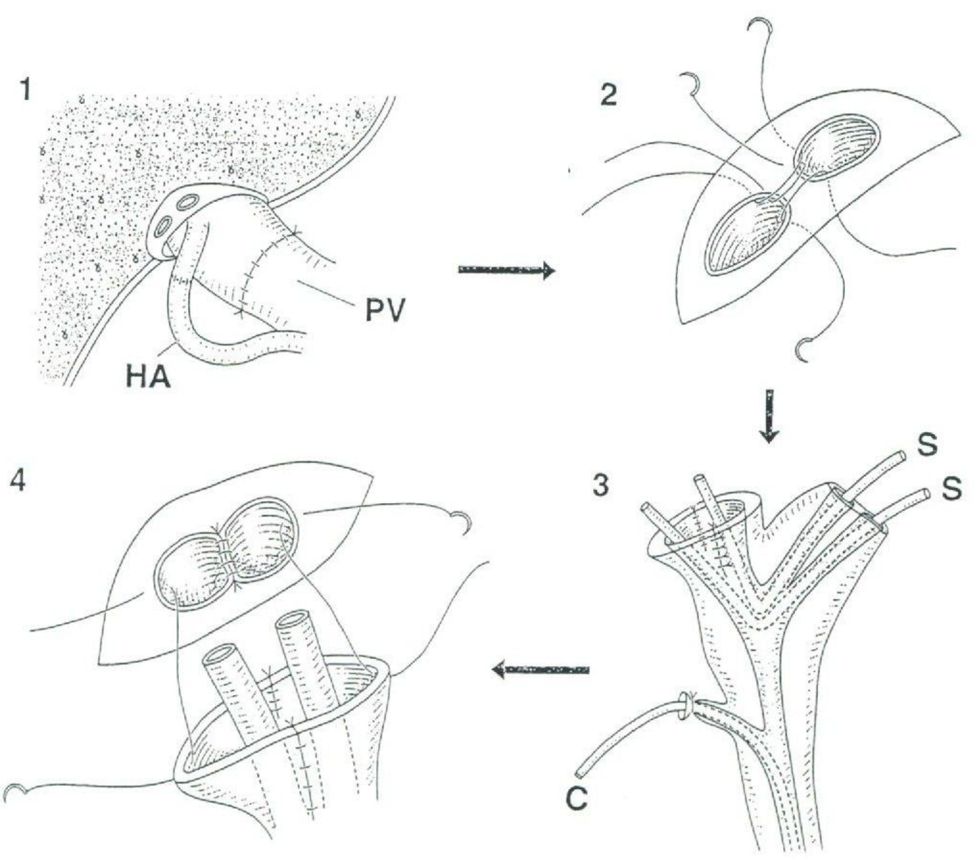

FIGURE 1. When there are two closely located bile duct orifices in the graft, the bile ducts in the hilar plate and graft were sutured into one. A stent tube (*S*) is introduced from the orifice opposite the hilar plate where the tube will be fixed to the plate. For nutrition or bile juice feeding, a 4-French polyethylene tube (*C*) was inserted from the stump of the cystic duct and introduced into the duodenum. The anastomosis was begun at the posterior wall and the needle was inserted into the bile duct in the graft from outside to inside; then, the orifice of the hilar plate was inserted from inside to outside. The knots were always outside of the bile duct. HA, Hepatic artery; PV, portal vein.

including a significant increase of γ-glutamyl transpeptidase and alkaline phosphatase, and was diagnosed radiologically by ultrasound, computed tomography, and cholangiography, showing slight dilatation of the graft bile duct.

A multivariate analysis was performed to find a predictor of bile juice leakage or bile duct stenosis. The independent factors consisted of seven intraoperative and two postoperative factors. Intraoperative factors included graft weight-to-standard liver volume ratio, duration of biliary reconstruction, blood loss per patient body weight, cold ischemic time of liver graft, warm ischemia time, number of bile duct orifices of the graft, and number of sutures used for biliary reconstruction. Two postoperative factors were acute rejection and cytomegalovirus infection. Differences were considered significant at a value of $P<0.05$. Data were shown as mean±SD or median and range.

RESULTS

Donors

The average duration of operation for the donors was 567±93 min. The average blood loss volume was 536±281 mL, which was replaced by 385±351 mL of autologous blood. The most common type of procedure was right liver resection (n=46), followed by left liver resection (n=29) and right lateral sectorectomy (n=6). There were no significant complications in the postoperative period. The mean postoperative hospitalization was 15±2 days. The donors have all returned to their normal daily activity.

Recipients

The average duration of operation for the recipients was 887±184 min. The duration for biliary reconstruction was 66±16 min. The average blood loss volume per body weight was 109±50 mL/kg. The mean graft weight was 577±177 g, which corresponded to 50±11% of the recipient's standard liver volume. Cold and warm ischemic times of the grafts were 99±37 and 71±10 min, respectively. The number of bile duct orifices was one (n=39), two (n=34), or three (n=8), with an average of 1.6±0.7 (Table 1). The number of sutures used for anastomosis was 12±4, ranging from 6 to 23.

During the observation period, biliary complications were observed in 26 patients (32%). The complications included bile juice leakage (n=12), anastomotic stenosis (n=10), and tube trouble (n=6). Two patients experienced complications with leakage followed by stenosis. Of the 26 patients, 21 complications necessitated surgery. For leakage, percutaneous drainage under ultrasound guidance was possible in five patients. The other patients underwent reoperation for drainage. The onset of leakage ranged between 4 and 65 days after LDLT. All of the patients with anastomotic stenosis underwent surgical revision. The procedure included a T-tube insertion from the common bile duct into the intrahepatic bile duct through stenosis (n=5), conversion to hepaticojejunostomy (n=3), dilation of anastomosis using a Kelly clamp under radiographic guidance (n=1), and transhepatic bile duct drainage (n=1). Nine of the 10 events occurred within 1 year after LDLT. The details of the anastomotic stenosis and outcome of the patients after each procedure are shown in Table 2. Briefly, three of the five patients with T-tubes are waiting for T-tube removal, one patient underwent retransplantation for refractory cholangitis, and one was cured. All of the patients with conversion to hepaticojejunostomy were cured and the patient with transhepatic bile duct drainage died as a result of sepsis. Because of the severe adhesion of the hepatic hilum, safe dissection of the bile duct and conversion to hepaticojejunostomy was not possible in one patient. Intraoperative cholangiography of this patient showed an anastomotic stricture and sludge formation on the graft side of the bile duct. A Kelly clamp was inserted into the hepatic hilum from the opposite side of the anastomosis, and all of the sludge was removed. Then, under radiographic guidance, dilatation of the anastomosis was performed and the external tube was changed with a new one. This patient was cured after the procedure.

A common cause of tube trouble was mislocation of the external drainage tube in three patients. The location was corrected in these patients to allow the tube to adequately drain bile juice 1, 3, and 5 days after LDLT. Complications in the other two patients included bile peritonitis after removal of external tubes. One patient was treated conservatively and the other underwent reoperation for irrigation and drainage. In another patient, 13 days after LDLT, there was bile juice leakage around a 4-French polyethylene tube introduced into the duodenum for feeding. Contrast medium injection through the tube revealed leakage from the stump of the cystic duct. The 4-French polyethylene tube was retracted until the tip was in the common bile duct for drainage. The peritonitis subsided thereafter.

Multivariate analyses failed to detect any significant predictors for bile juice leakage or bile duct stenosis (Table 3). The incidence of acute rejection was 27%. Portal vein thrombosis occurred in one patient and was successfully treated with anticoagulants, and none of the patients had hepatic arterial thrombosis. Cytomegalovirus infection occurred in 17% of the patients.

All but two patients are alive with normal liver function at a median follow-up period of 664 days. The patient with autoimmune hepatitis died 13 months after LDLT because of thrombocytopenic purpura. Bile duct stenosis occurred in the other patient, who underwent transhepatic bile duct drainage. The cholangitis was resistant to conservative therapy, however, and the patient died as a result of sepsis 13 months after LDLT.

TABLE 1. Number of bile duct orifices

Graft	1	2	3	Total
Left liver	14	12	3	29
Right liver	20	21	5	46
Right lateral sector	5	1	0	6
Total	39	34	8	81

DISCUSSION

The morbidity rate was 32% during the 1-year observation period, and the results are comparable among other series of right liver transplantation (Table 4). The rate might be higher, however, than that after whole liver transplanta-

TABLE 2. Detail of bile duct stenosis

Patient	Age/Gender	Onset (day)	Treatment	Result
1	57/F	89	Hepaticojejunostomy	Cured
2	20/M	214	Hepaticojejunostomy	Cured
3	54/F	810	T-tube drainage	Waiting for T-tube removal
4	52/F	334	Hepaticojejunostomy	Cured
5	50/M	73	T-tube drainage	Retransplantation for refractory cholangitis
6	34/F	44	Dilation of anastomosis by Kelly clamp and reinsertion of the external tube under radiographic guidance	Cured
7	67/M	18	T-tube drainage	Cured
8	59/M	310	T-tube drainage	Waiting for T-tube removal
9	43/M	69	Transhepatic bile duct drainage	Died as a result of sepsis
10	53/M	300	T-tube drainage	Waiting for T-tube removal

TABLE 3. Multivariate analysis for detecting predictors of biliary complications

	Leakage		Stenosis	
	Regression index	*P* value	Regression index	*P* value
GW/SLV	−0.366	0.31	0.007	0.10
Duration	−0.001	0.39	0.0005	0.97
Blood loss/BW	−0.001	0.19	−0.0005	0.49
CIT	−0.0004	0.64	−0.0002	0.77
WIT	−0.001	0.40	0.002	0.11
No. of ducts	−0.077	0.30	0.06	0.40
No. of threads	0.01	0.52	−0.01	0.36
Acute rejection	—	—	0.073	0.41
CMV infection	—	—	−0.0005	0.97

GW, Graft weight; SLV, standard liver volume; BW, body weight of the patients; CIT, cold ischemic time of liver graft; WIT, warm ischemic time of liver graft; CMV, cytomegalovirus.

TABLE 4. Comparison with the previous references

	No.	DDR (%)	Median FUT	Morbidity (%)
Icoz et al., 2003[15]	50	72	15	30
Settmacher 2003[26]	50	76	ND	40
Nakamura 2002[27]	120	34	13	24
Testa, 2000[1]	30	ND	ND	27
Marcos, 1999[28]	25	0	5	24
Present study	81	100	22	32

DDR, Rate of duct-to-duct biliary reconstruction to the whole series; FUT, follow-up term (mo).

tion (2%–24%) (*11–14*). This difference might be because of anatomic variations in bile ducts rather than surgical experience. In cadaveric transplantation, the anastomosis is performed on the intact hepatic duct of the donor and the recipient common bile duct so that only one anastomosis with well-vascularized tissue can be performed (*15*). This is not the case for LDLT, which often necessitates multiple and thin bile duct anastomoses.

In our series, 52% of all the grafts and 57% of the right liver grafts had multiple bile duct orifices. The incidence was comparable to the others (*1*). The poorer outcome might be related to the complicated procedure. Some surgeons performed duct-to-duct anastomosis in selected grafts that would secure a single bile duct anastomosis (*8, 16*). The results of the present multivariate analysis, however, contradicted this presumption. Takatsuki and colleagues (*6*) reported that multiple hepatic ducts were not a significant risk factor for biliary reconstruction. In our technique, the hilar plate was dissected distal to the second-order branch of the bile ducts. The extensive dissection enabled us to overcome the technical difficulty of multiple and widely separated graft bile ducts because the corresponding orifices in the recipient hilar plate could be freely selected.

Wide dissection of the hilar plate might be advantageous for tension-free anastomosis but disadvantageous because of decreased arterial supply to the duct (*17*). The common bile duct, if properly dissected, has its own axial blood supply that is provided mainly by branches of the superior posterior pancreaticoduodenal artery or the right hepatic artery (*18–20*). As in the recipient operation, the bile duct was inevitably dissected from the right hepatic artery, and the arterial supply was provided through connective tissues around the bile duct and the bile duct itself. Meticulous attention must be paid to dissection of the hepatoduodenal ligament, and preservation of axial periductal microcirculation is mandatory for successful biliary reconstruction (*15*). Similarly, the ability to preserve the blood supply to the donor's bile duct requires sharp dissection around the duct (*21*). The use of electrocautery should be avoided. The viability of the bile ducts for donor and recipient should be confirmed by the presence of pulsatile arterial bleeding from the cut ends. The venous drainage system of the duct might be more important. Venous blood enters into the portal venous branch, and the direction of the blood flow is from the caudal to the cranial direction in the upper part of the bile duct. It is unclear whether venous drainage can be maintained after anastomosis.

Transanastomotic external drainage or a T-tube is another concern of LDLT (*15*). Marcos and associates (*22*) reported that the biliary complication rate after routine use of an external drainage tube decreased from 24.% to 13%. A transanastomotic external tube could theoretically help to decrease the intrahepatic biliary pressure caused by edema and consequent partial obstruction of the anastomosis (*1*). The tube can also facilitate a postoperative imaging study; however, its advantage over no stenting and relation with the anastomotic biliary complication has not been clearly shown. In our series, six patients had tube complications, including mislocation and leakage, and one of them underwent reoperation. The complications caused by tubes should not be neglected. In the series of Testa and associates (*1*), stenting of the anastomosis was not routinely performed. Some institutions used a T-tube for decompression (*3, 7*). The randomized, controlled trial of biliary reconstruction in whole liver transplantation (*12*) revealed an increase in the biliary complication rate in the T-tube group. In LDLT, a T-tube will help decompress the bile duct but it will not help prevent stenosis at the anastomotic site. Because in LDLT there are often multiple duct orifices in the graft and a size difference between common bile duct and duct orifice in the graft, it is difficult to put the tip of a T-tube across the anastomotic site.

For surgical repair of stenosis, some authors converted duct-to-duct anastomosis directly to the hepaticojejunostomy for biliary complications (*1, 5, 8, 23*). Another strategy was T-tube insertion in the common bile duct with one arm in the stenotic portion. The surgical revision is technically demanding. The hilar plate of the patient often severely adheres to the hepatic artery or portal vein, and it is difficult to isolate the bile duct safely. In repairs using a T-tube, careful attention must be paid to the appropriate localization of the T-tube under intraoperative cholangiography, allowing for appropriate bile juice drainage. The Kyoto group (*24*) recently reported that 13 of 14 patients were successfully treated with an inside stent. The endoscopic approach is a therapeutic alternative to reoperation (*25*).

CONCLUSION

The results of duct-to-duct anastomosis in 81 patients with at least a 1-year follow-up were reviewed. Long dissection of the recipient hilar plate makes our technique unique and enables a tension-free biliary anastomosis and the ability to overcome the size and number discrepancy between graft and recipient bile ducts. In spite of these advantages, the morbidity rate was 32%, which was not as satisfactory as expected. The present results reveal the necessity for technical modifications to reduce the morbidity rates.

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Prediction of hepatic artery thrombosis by protocol Doppler ultrasonography in pediatric living donor liver transplantation

J. Kaneko,[1,2] Y. Sugawara,[1,2] N. Akamatsu,[1,2] Y. Kishi,[1,2] T. Niiya,[1,2] N. Kokudo,[1,2] M. Makuuchi,[1,2] K. Mizuta[1,2]

[1]Artificial Organ and Transplantation Division, Department of Surgery, Graduate School of Medicine, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8655, Japan
[2]Department of Transplantation Surgery, Jichi Medical School, 3311-1 Yakushiji, Minamikawachi-machi, Kawac-gun Tochigi, Japan

Abstract

Hepatic arterial thrombosis (HAT) after liver transplantation is a life-threatening event. Previous reports have suggested that the resistive index (RI) of the hepatic artery predicts HAT. Doppler ultrasonography (US) to measure RI, however, is not routinely performed. The subjects were 70 pediatric patients who underwent living donor liver transplantation (LDLT). Protocol Doppler US was performed once or twice a day for 2 weeks postoperatively and 692 records were examined. Changes in RI values were examined separately in patients with and without HAT complications. The incidence of HAT was 10% (seven of 70). HAT was diagnosed an average of 6.2 days after LDLT. In patients without HAT complications (n = 63), average RI levels at 14 days after LDLT were 0.71 ± 0.1 (records, n = 625). In patients with HAT complications, RI decreased gradually within 2 days before the onset of HAT. RI values of less than 0.6 predicted HAT within 2 days before onset, with 83% sensitivity and 85% specificity. RI during the first 2 weeks after LDLT is a sensitive predictor for HAT. Thrombectomy and reanastomosis should be considered when RI values are less than 0.6 in Doppler US.

Key words: Hepatic artery thrombosis—Living donor—Liver transplantation—Doppler ultrasonography—Resistive index

Hepatic arterial thrombosis (HAT) after liver transplantation is a life-threatening event associated with a high rate of graft loss or death [1]. The incidence of HAT during the first 30 days has been reduced to approximately 5% by recent technical advances [2]. HAT is more common, however, in split or living donor liver transplantation (LDLT) [3].

Although arteriography remains a standard of reference for the diagnosis of HAT, Doppler ultrasonography (US) is a useful diagnostic tool for detecting HAT and the need for urgent revascularization. Rescue of liver graft from HAT depends on its early detection [4]. Protocol postoperative Doppler US appears to be mandatory for early detection [5]. Some studies [6–8] have proposed that decreases in the resistive index (RI) of the hepatic artery might predict HAT. Doppler US is not routinely performed, however, and the indication for Doppler US remains unclear from previous reports. The purpose of our study was to evaluate the significance of RI as a predictor of HAT in protocol Doppler US after pediatric LDLT.

Materials and methods

Seventy-two patients younger than 18 years underwent LDLT procedures at the University of Tokyo from January 1996 to December 2002. Of these, two patients were excluded from the analysis because they died due to simultaneous HAT and portal vein thrombosis. The remaining 70 patients (33 male, 37 female; mean age, 4.6 years) comprised the subjects of this study. The most common indication for LDLT was biliary atresia (n = 61), followed by Wilson disease (n = 2), fulminant hepatic failure (n = 2), cryptogenic cirrhosis (n = 2), and metabolic diseases (n = 1). The remaining two patients had indications for retransplantation. The most commonly used graft was the left lateral sector (n = 50), followed by the left liver (n = 15), right liver (n = 3), and right lateral sector (n = 2).

The operative procedure and postoperative management have been described elsewhere [3]. In brief, the donor and patient hepatic arteries were anastomosed end to end with an

Correspondence to: Y. Sugawara; *email:* yasusuga-tky@umin.ac.jp

interrupted suture using 9-0 monofilament under a microscope. Anticoagulant therapy with prostaglandin E1 (0.01 μg/kg per hour) and a protease inhibitor (mesylate gabexate; 1 mg/kg per hour) was administered intravenously just after the operation for 14 days. Antithrombin III concentrates and low-molecular-weight heparin were also used.

Protocol Doppler US was performed once or twice a day for 2 weeks postoperatively with an SSD 2000 or SSD 6500 (Aloka Co. Ltd., Tokyo, Japan). The patencies of the hepatic artery, portal vein, and hepatic vein were assessed. Hepatic artery flow was determined near the porta hepatis. If intrahepatic artery flow was absent, then emergent laparotomy was performed without a confirmatory angiogram. RI ([systolic velocity − diastolic velocity]/systolic velocity) was calculated during each examination.

A total of 692 Doppler US records was collected. Changes in RI values were examined for 2 weeks after LDLT in patients without HAT complications. In patients with HAT complications, changes in RI values were analyzed for 1 week before the onset of HAT. The RI values in patients without HAT, those in patients with HAT within 2 days before the onset, and those in patients with HAT 7 to 2 days before the onset were compared with an unpaired t test. $P < 0.05$ was considered statistically significant. Values were recorded as average ± standard deviation.

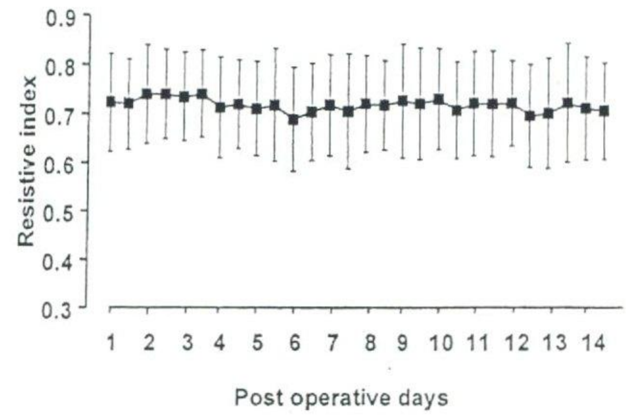

Fig. 1. Changes in RI values in patients without HAT (n = 63). RI was constant around 0.7 during the observation period.

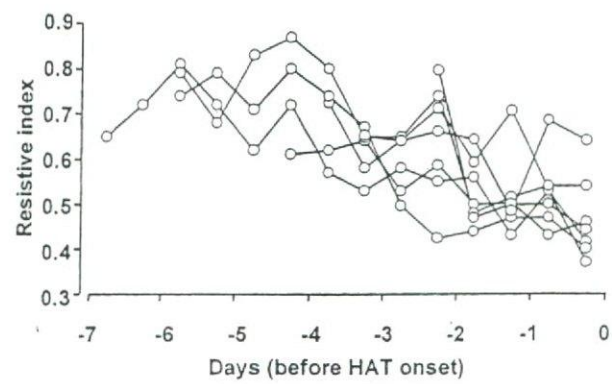

Fig. 2. Changes of RI values in patients with HAT complications (n = 7). RI decreased gradually 2 days before the onset of HAT.

Results

Clinical results

The incidence of HAT was 10% (seven in 70). HAT was diagnosed an average of 6.2 days after LDLT. Laparotomy was performed immediately after the diagnosis in each patient. In one patient, thrombus was not apparent but reanastomosis was performed because of anastomotic kinking. In the remaining six patients, a thrombus was detected at the anastomotic site and extended a few millimeters proximally into the reconstructed hepatic artery and was successfully removed. All patients survived the reoperation without retransplantation. One patient died 47 days after LDLT despite successful thrombectomy.

RI levels

In patients without HAT complications (n = 63), RI levels for 14 days after LDLT were 0.71 ± 0.1 (record n = 625; Fig. 1). In patients with HAT complications (n = 7), RI decreased gradually within 2 days before the onset of HAT. RI levels within 2 days before the onset (record n = 28) and those 7 to 2 days before the onset (record n = 39) were 0.52 ± 0.08 and 0.66 ± 0.09, respectively (Fig. 2). There was a significant difference between the two values ($p < 0.001$; Fig. 3).

Ten records in four patients without HAT showed an RI of less than 0.5, recorded on the fourth, fifth, sixth, and ninth days after LDLT. In each patient, the RI level spontaneously recovered within 12 h. When the threshold was set at 0.6, the sensitivity and specificity of RI for HAT detection were 83% and 85%, respectively (Table 1).

Discussion

RI is a popular parameter that reflects vascular resistance and compliance [9] and is used to characterize the arterial waveform of Doppler US. Dodd and associates [7] emphasized that RI provides excellent screening for the detection of liver graft arterial stenosis or thrombosis. Of the 72 transplant recipients, 42 had normal arteries, 27 had substantial stenoses, and six had thromboses at angiography. Arterial flow was detected using Doppler US in 26 of 27 patients with stenosis, three of six patients with thrombosis, and in all patients with normal angiograms. In patients with HAT and flow detected by Doppler US, only RI was statistically significantly different from that in patients with normal angiograms. Another report [10] concluded that duplex Doppler US is useful for the diagnosis of HAT. In these reports [7,

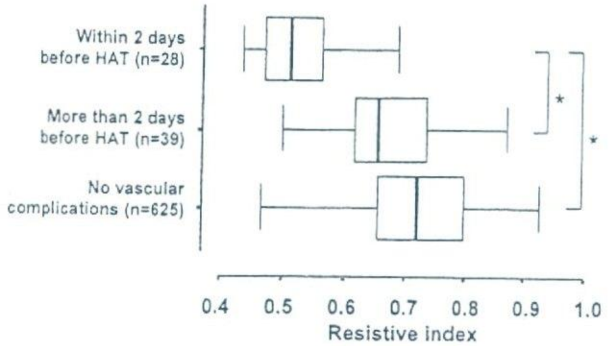

Fig. 3. Distribution of RI values in box-and-whisker plots. In patients with HAT, the RI values 2 days before the onset of HAT were significantly lower than those 2 to 7 days before the onset of HAT or those in patients without HAT. $^{*}p < 0.001$. n indicates the number of the US records.

Table 1. Sensitivity and specificity for HAT diagnosis for multiple discriminatory thresholds of RI

Threshold	TN	TP	FN	FP	Sensitivity (%)	Specificity (%)
< 0.4	660	1	29	2	3	100
< 0.5	652	13	17	10	43	99
< 0.6	564	25	5	98	83	85

FN, false negative; FP, false positive; HAT, hepatic artery thrombosis; RI, resistive index; TN, true negative; TP, true positive

10], however, Doppler US was not performed routinely and the indications for Doppler US were not clarified.

Recent studies [58] have indicated that protocol Doppler US is useful for early HAT detection. Urgent thrombectomy and revascularization based on the findings of protocol study significantly reduced the rate of late biliary complications and graft loss subsequently complicated by HAT. The present study differed from previous studies in which RI data were consecutively and prospectively collected. Nolten and colleagues [11] reported a qualitative change in the Doppler waveform over time. Although the waveform was initially normal in appearance, it progressed to an absent diastolic flow, dampening of the systolic peak, and, finally, loss of the hepatic arterial signal. The present study confirmed their findings, indicating that RI values of less than 0.6 predict HAT onset within 2 days with 83% sensitivity and 85% specificity.

In summary, we reviewed 692 Doppler US records in 70 pediatric patients. RI was a sensitive predictor for HAT during the first 2 weeks after LDLT. Thrombectomy and reanastomosis should be considered when RI values are less than 0.6 in protocol Doppler US.

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Revolution and Refinement of Surgical Techniques for Living Donor Partial Liver Transplantation

Ender Dulundu, Yasuhiko Sugawara, and Masatoshi Makuuchi

Department of Surgery, Graduate School of Medicine, University of Tokyo, Tokyo, Japan.

Living donor liver transplantation (LDLT) was first successfully performed on a child in 1990 and the Shinshu group performed the same procedure on an adult for the first time in 1994. Over the past few years adult LDLT has been increasing worldwide because of the severe shortage of cadaveric organs, especially in locations where the transplantation of organs from brain-dead donors is rarely practiced. The surgical procedures for LDLT are more technically challenging than those for cadaveric whole liver transplantation. LDLT requires a full understanding of hepatobiliary anatomy and continuous technical refinement of the procedure. The development of innovative techniques is a key factor for a successful LDLT. Some of the technical highlights include selective vascular occlusion techniques for donor hepatectomy, hepatic arterial reconstruction under the microscope, the introduction of intraoperative ultrasound, graft volume estimation, hepatic venous reconstruction using cryopreserved vascular grafts, and the use of the right lateral sector of the liver. These techniques have improved the success rate of LDLT over the past few years. This review focuses on the surgical techniques for LDLT on the basis of our experience with adult LDLT at the Tokyo University Hospital.

Key Words: Living donor liver transplantation, middle hepatic vein, right liver graft

INTRODUCTION

The use of live donors for liver transplantation was initiated more than a decade ago as a solution to the cadaveric donor shortage for pediatric recipients.[1] Since the first successful case of LDLT performed on an adult patient in 1994,[2] this procedure is now widely applied to adult recipients, especially in countries where the availability of brain-dead donors is severely restricted.[3] This includes the United States and European countries where there is a critical shortage of cadaveric organs. In attempts to meet the growing needs of recipients, transplant surgeons have had to develop innovative techniques and appropriate algorithms to overcome deteriorating conditions and complications such as outflow and biliary complications.

In this review, several considerations of LDLT, including donor and graft selection criteria, technical highlights, and critical points necessary for successful patient outcome are discussed on the basis of our experience at the Tokyo University Hospital.

DONOR SELECTION CRITERIA

The first priority when performing LDLT is donor safety. Donor characteristics are the primary determinant of the outcome for both patients. Therefore, careful evaluation and selection of the donor are obligatory. In our department, a preoperative donor evaluation consists of three stages. In the first stage, patients and their families are given explanations about LDLT, including the risk of death for LDLT donors. After evaluating the medical and family history, social support system within the family, and psychological fitness, the donor's understanding of the risks involved with a liver resection and accompanying invasive tests must be confirmed for each donor candidate. The age of acceptable donors at our center is between 20 and 65 years with a

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Reprint address: requests to Dr. Yasuhiko Sugawara, Artificial Organ and Transplantation Division, Department of Surgery, Graduate School of Medicine, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8655, Japan. Tel: 81-3-3815-5411, Fax: 81-3-5684-3989, E-mail: yasusuga-tky@umin.ac.jp

relation to the recipient within the third degree of consanguinity.

The second phase involves performing liver function tests, ABO compatibility testing, lymphocyte cross matching; negative serology for hepatitis B and C, human immunodeficiency and adult T-cell leukemia viruses, cardiopulmonary function tests, the determination of tumor markers of donors over 40 years old, and a pregnancy test for female donors. ABO blood group incompatibility and positive lymphocyte cross matching are not definite exclusion criteria.

If there is no anomaly, the donor candidate can proceed to the third stage; a Doppler ultrasound should be performed for hepatic artery, portal vein, and hepatic vein evaluation. Computed tomography (CT) is used to measure graft volume. Hepatic angiography can be performed to evaluate vessel anatomy. The donor's own blood and plasma are banked preoperatively. Throughout the course of the donor evaluation, the spontaneous willingness of the donor candidate is repeatedly confirmed.[4] Signed informed consent is obtained before the surgery.[5]

Preoperative liver biopsy and steatosis in graft

Preoperative determination of the extent of hepatic steatosis is important to ensure both donor and recipient safety. Donors with significant steatosis may not tolerate surgery as well as those with nonsteatotic livers and they tend to have increased postoperative morbidity, mortality, transfusion requirements, and surgical time.[6] A liver biopsy must be performed for a secure evaluation of the liver. The indications for a liver biopsy, however, must be determined carefully and some patients may require hospitalization after the procedure (5% frequency) or experience serious complications (1%).[7-9]

The degree of steatosis acceptable for LDLT remains controversial. Marcos et al. reported no impairment of function in either the donor or recipient when using grafts containing less than 30% steatosis.[10] Fan et al. do not use a right liver graft with steatosis of 20% or more,[11] whereas other groups use liver grafts with steatosis of less than 50% if the graft volume-to-standard liver volume (SLV) of the recipient ratio is 40% or more.[12] At our center, when hepatic steatosis is suspected by computed tomography and biochemical data (i.e., aspartate aminotransferase < alanine aminotransferase), a liver biopsy for evaluating steatosis is considered. If time permits, the potential donor should undergo a period of prescribed diet and exercise. Livers with less than 10% hepatic macrosteatosis are preferred.[7]

Estimation of the liver graft

A major concern for the application of LDLT to adults is graft size disparity. Small-for-size grafts are defined as functionally insufficient grafts for satisfying the recipient's metabolic demand, which will predispose the recipient to injuries characterized by cholestasis and histologic features of ischemia after implantation.[13] On the other hand, harvesting a larger graft puts the donor at higher risk.[14] The right liver is not indicated as a graft when the estimated volume in donors is over 70%, according to the criteria of Fan et al.[11] We established a method for estimatinggraft volume using CT and the following formula to calculate the SLV (optimal liver mass) in recipients from their body surface area:[15,16]

$$\text{SLV (ml)} = 706.2 \times (\text{body surface area } [m^2]) + 2.4.$$

The volume of each sector of the donor liver is evaluated by CT. The predicted graft volume/SLV ratio is then calculated.[17]

Principally, grafts with a weight/recipient SLV ratio of 40% are preferred for use in adult patients. In low-risk patients, a right liver graft with or without the middle hepatic vein (MHV) are considered. In other words, grafts with an SLV ratio of 40% or less may suffice only in the ideal situation of a good-risk patient as proposed by Lo and associates.[18] Our data indicate that[19] 96% of patients survive with a graft weight ratio of over 40%, while only 80% of patients survive with a graft weight ratio of 40% or less. High-risk patients include those with primary biliary cirrhosis with a Mayo risk score[20-22] of less than,[10] metabolic disease, and fulminant hepatic failure. For higher risk patients, a left liver with or without a caudate lobe should be evaluated by CT volumetric analysis.[23,24] If the volume of the right lateral sector is greater than that of the left liver, the right lateral sector segments VI and VII, according to Coinaud's nomenclature for liver segmentation, should be considered for the graft.[5,22,23]

Objection against routine use of right liver graft

A right liver graft was first used for a pediatric case by Yamaoka et al.[25] It is now commonly used for adult patients. This procedure was followed by the introduction of an extended right liver graft, which includes the trunk of the MHV. This trend has grown rapidly.[26-28] At the same time, however, important ethical issues were raised regarding the execution of an extended hepatectomy on live donors.[3] Although graft size in living donors may be safely expanded, a multidisciplinary approach and meticulous donor evaluation are always necessary. We do not agree with the recent tendency to use a right liver graft routinely for almost all adult patients.[28] Based on our experience, the number of patients who inevitably need a right liver graft with the MHV is limited; we found that less than 10% of the recipients in our series required an extended right liver graft.

Evaluation of donor hepatic arterial anatomy

When planning a donor resection, a preoperative arteriography is necessary to assess the anatomy and quality of the vasculature of the resulting graft.[29] For example, upon performing a right liver LDLT, it is first necessary to determine which of the varied origins of the artery to segment IV is important for defining the optimal points for transection of the artery.[3] Although an angiography is a relatively invasive study with the potential for complications, the information it provides is essential for surgical planning and donor safety. Unfortunately, non-invasive techniques, such as magnetic resonance angiography or CT, are limited in their ability to demonstrate small vessels such as the accessory hepatic arterial branches.[28,30] The techniques for non-invasive imaging of smaller vascular structures are still under evaluation and are not yet sufficiently reliable for these purposes.

Intermittent inflow occlusion technique

In our department, a donor hepatectomy is routinely performed under Pringle's maneuver without any side effects. We postulate that the intermittent inflow occlusion acts as a preconditioning step and reduces blood loss during the hepatectomy.[31]

RECIPIENTS

During an evaluation of a liver transplant candidate for LDLT, there needs to be a balance between the severity of the liver disease and the adequacy of a partial graft for transplantation. Most of the complications associated with acute hepatic failure are reversible if the transplantation can be performed in the early stage.[32] Stable patients with chronic liver disease also benefit from living donors. Transplantation can be performed electively before decompensatory (i.e. fulminant hepatic failure with irreversible encephalopathy) complications occur.

Recipient surgery

The operative technique for recipients is based on the technique of whole liver resection with preservation of the inferior vena cava used for orthotopic liver transplantation.[33] A J-shape incision is made to open the abdominal space as is done for a right thoracotomy. Electrocautery is effective, time-saving, and useful for sharp dissection. An argon beam coagulator is useful to stop bleeding from the hepatic serosa. Each step of this operation requires meticulous maneuvers and great care to achieve an uneventful resection of the whole liver, while avoiding injury to the other visceral organs. It is important to make a large and long opening along the sides of the hepatic veins, and to maintain satisfactory portal, biliary, and hepatic arterial sources for the reconstruction. The right and left hepatic arteries should be dissected out as distally as possible, the left portal vein should be dissected up to the umbilical portion, which is just distal to the point of origin of the branch to segment,[2] and the right portal vein should be dissected up to its bifurcation into the anterior and posterior branches.

In recipients with little portosystemic collateral circulation (i.e., familial amyloid polyneuropathy, citrullinemia, acute hepatic failure), the prevention of portal congestion is necessary during the anhepatic phase. A temporary shunt between the portal vein and the inferior vena cava should be made.[34] Briefly, the portal vein branch, which will not be used for reconstruction, is anastomosed end-to-side or connected by a tube to the inferior vena cava. Blood flow through this shunt is maintained until portal venous reperfusion to the graft is achieved by portal vein anastomosis.

HEPATIC VENOUS RECONSTRUCTION

The provision of an adequate outflow is indispensable for graft function, thus, it is necessary to obtain a wide ostium and a sufficient length of the hepatic vein for anastomosis.

Left liver

Early cases of LDLT entailed an end-to-side anastomosis for hepatic vein reconstruction. A longitudinal cavatomy was made along the anterior aspect, and the hepatic venous branches, which were joined on the bench, were anastomosed end-to-side to the caval window.[3,35] Takayama et al. cautioned,[36] however, that a direct anastomosis of the hepatic veins to a thin inferior vena cava can cause a bend in the inferior vena cava at the anastomotic side, which can result in outflow occlusion.

Currently, an end-to-end anastomosis[37] is preferred. In such cases, size matching is important. The left hepatic vein (LHV) and MHV in the recipient can be joined into one.[38] If the diameter of the joined veins is smaller than the left liver graft's hepatic vein, a wider orifice can be constructed by venoplasty of three hepatic veins[39] in the recipient (Fig. 1).

In the first method for venoplasty, the neighboring walls were simply sutured together. The second method involves the use of the pantaloon technique. The parenchyma around the venous branches is aspirated using an ultrasonic dissector, resulting in elongation of the venous branches. The branches are then cut longitudinally and sutured together. In the third method, the hepatic vein of the liver graft is cut in a perpendicular direction, and then a venous patch is anastomosed to the incised graft hepatic veins. De Villa et al.[40] detailed another venoplasty technique. They reported that when two hepatic veins are connected by a longer intervening septum, a venoplasty is made by an incision perpendicular to the septum by first removing the directly underlying liver parenchyma using a Cavitron ultrasonic surgical aspirator (CUSA).

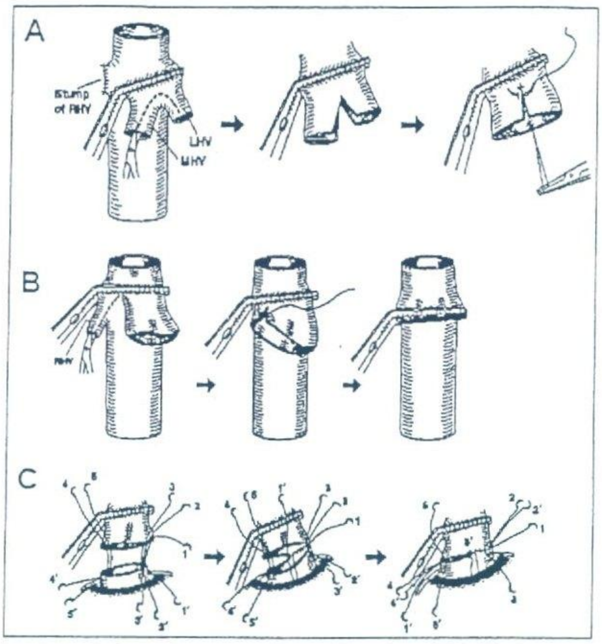

Fig. 1. Recipient venoplasty of the left hepatic vein (LHV) and middle hepatic veins (MHV) (A) or triple hepatic veins (B). (C) The anastomosis was made with continuous sutures (1-5).

Caudate vein reconstruction

Reconstruction of the caudate vein is technically demanding.[41] In the initial LDLT cases,[23] the drainage vein of the caudate lobe was not reconstructed. Takayama and associates[24] emphasized the importance of short hepatic vein reconstruction. According to the cast study by Couinaud, 91% (115/126) of the caudate veins entered directly to the vena cava,[42] thus indicating that one or two veins of the caudate lobe should be reconstructed to prevent venous congestion of the caudate lobe. The hepatic vein of the caudate lobe

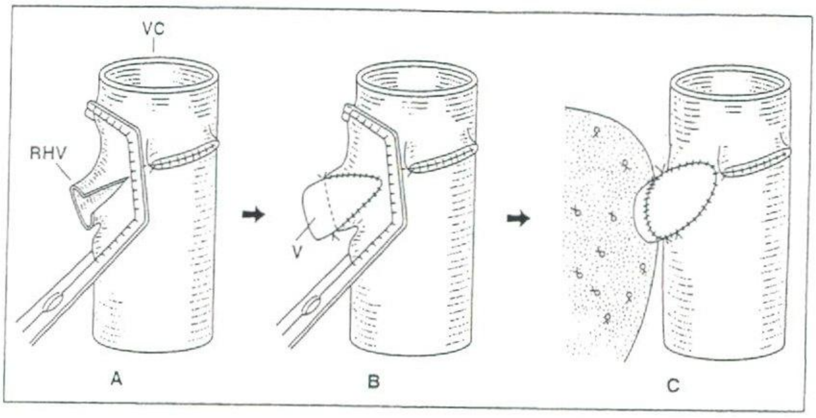

Fig. 2. (A, B) The V-shaped venous patch (V) was anastomosed to the incised anterior wall of the RHV of the recipient. (C) End-to-end anastomosis between the recipient and graft RHVs with continuous sutures.

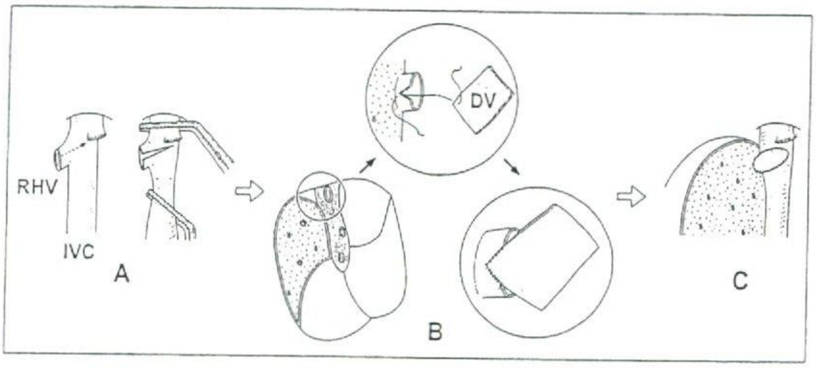

Fig. 3. (A) The anterior wall of the recipient right hepatic vein (RHV) was cut under cross-clamping of the inferior vena cava (IVC) (B) The diamond shaped venous patch (DV) was anastomosed to the incised anterior wall of the recipient's RHV. (C) End-to-end anastomosis was done between the recipient and graft RHV with continuous sutures.

can be resected with a cuff of the vena cava, which resembles a Carrel's patch. In the recipient operation, reconstruction of the caudate hepatic vein is performed and then the trunk of the left and middle hepatic vein of the recipient and the graft are anastomosed. When the orifice of the short hepatic vein is located near those of the LHV and MHV, the caudate vein with a cuff of the inferior vena cava can be sutured to the common orifice of the LHV and MHV (Fig. 4 and 5).[43]

Right liver

To overcome a size discrepancy between the right liver graft and the recipient's hepatic veins, the patch technique can be used. A vascular patch graft can be sutured separately or to both the RHV of the liver graft and the RHV of the recipient (Fig. 2 and 3). Three hepatic veins of the recipient can be joined to create a wide orifice for anastomosis.

The appropriate length for the reconstructed hepatic vein is still controversial and size matching between the liver graft and the recipient's hepatic veins is crucial.[44] Regeneration of the liver graft may compress the venous anastomotic site. Ghobrial et al. suggested that a short hepatic vein places undue tension on the anastomosis[44] and they cautioned that a long vein is predisposed to kinking after reperfusion. In contrast, we believe that it is necessary to obtain a wide ostium and sufficient length of the hepatic vein anastomosis to ensure adequate hepatic venous flow. We usually use a vein graft and make a long and wide anastomosis during the reconstruction.[45]

MHV reconstruction and cryopreserved vascular graft

An extended right liver graft is beneficial with regard to venous drainage of the graft because the MHV is the major draining vein of the right paramedian sector, and its role in the left paramedian sector is limited.[27] On the other hand, a right liver graft without the trunk of the MHV can cause severe congestion of the right paramedian sector (segments V and VIII) without MHV

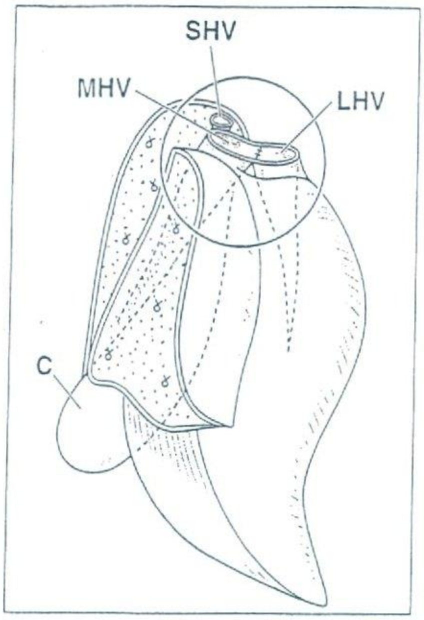

Fig. 4. The thickest hepatic vein (SHV) of the caudate lobe (C) was preserved, which was located near the orifice of the left hepatic vein (LHV) and middle hepatic vein (MHV).

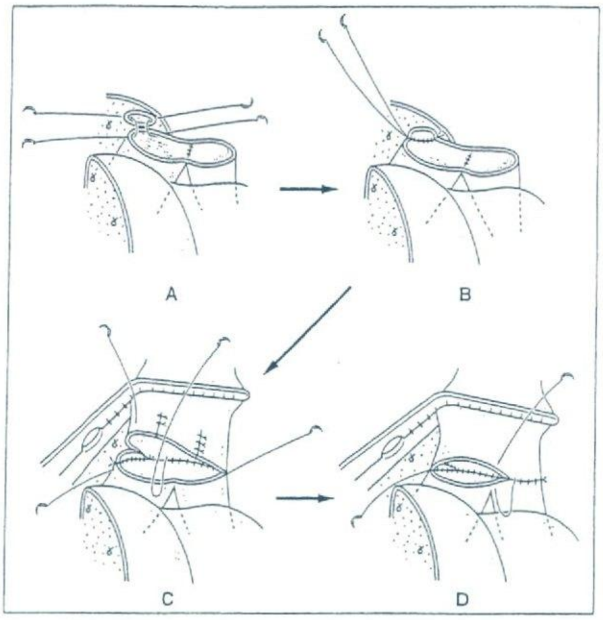

Fig. 5. Short hepatic vein of the caudate lobe sutured to the common orifice of the left and middle hepatic vein of the liver graft from the neighboring wall (A, B) End-to-end anastomosis between the common orifice of the left and middle hepatic vein and newly created hepatic venous orifices of the liver graft (C, D).

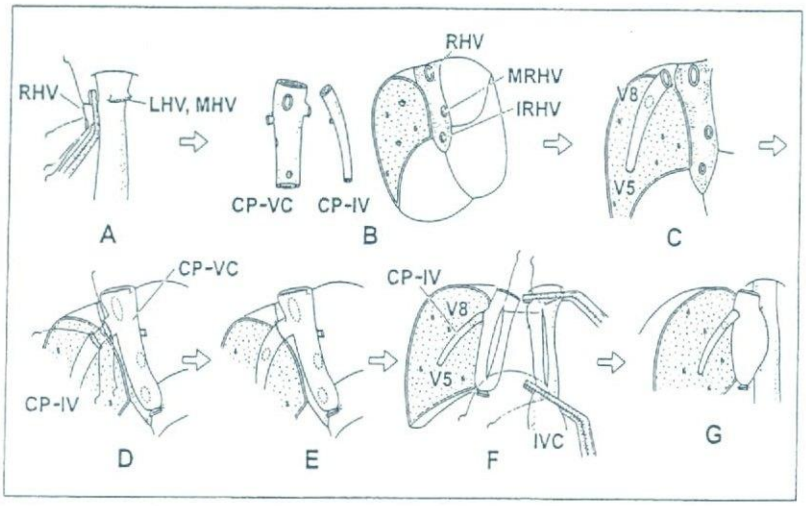

Fig. 6. (A) Left hepatic vein (LHV), middle hepatic vein (MHV) and right hepatic vein (RHV) of the recipient's liver were sutured at their roots. (B) Three side holes were created in the wall of the cryopreserved vena cava graft (CP-VC) for anastomosis with the RHV and the short hepatic veins [inferior right hepatic vein (IRHV) or middle right hepatic vein (MRHV)] of the graft. (C, D) Another cryopreserved vein graft (CP-IV) can be used for middle hepatic vein reconstruction. (E) The stump of the venous branch was anastomosed with a jumping vein graft for middle hepatic vein reconstruction. (F, G) Side-to-side anastomosis between the recipient's inferior vena cava (IVC) and CP-VC with continuous sutures was performed.

reconstruction. To provide a functioning liver mass comparable to an extended right liver, several methods have been devised for MHV reconstruction.[45,46] When a right liver graft has multiple short hepatic veins, use of a cryopreserved vena cava is recommended (Fig. 6).

The major concern in venous reconstruction using cryopreserved vein grafts is vein graft obstruction or the possibility of vein narrowing over the long-term. Mills et al.[47] reported a 51% complication rate after using cryopreserved vascular grafts. Kuang et al.[48] reported complications including an aneurysm, thrombosis, and stricture in 8 of 9 cryopreserved vein grafts that were used for portal vein and hepatic arterial interpositions. To date, we have not experienced any complications using cryopreserved vascular grafts, but previous discouraging results indicate that long-term follow-up is necessary to confirm the feasibility of their use.

Indication for MHV reconstruction

There is no consensus regarding the optimal strategy for MHV reconstruction. Some authors[49] claim that donor liver parenchyma transection without MHV tributary ligation is dangerous and that the reconstruction might increase the warm ischemia time. The development of the collateral circulation that drains the ligated MHV tributaries may occur in approximately 1 week,[50] but there is no evidence that these collaterals always occur or already exist in all patients.[51,52] Nakamura et al. clearly[53] demonstrated that the congestive area, which is due to hepatic vein ligation in the remnant liver, cannot be expected to function with the available parenchyma in the early postoperative period. They established that the congestive area resulted in histologic necrosis of the hepatic parenchyma approximately 24 hours after the ligation, although intrahepatic venous collaterals for draining the congestive area were observed through the sinusoids for 7 days after the ligation.[53]

A careful examination of the preoperative CT scan is useful to detect the number and diameter of the thick MHV tributaries draining the right paramedian sector of the donor liver. Anatomic variations, such as a venous variant type of small RHV with a large MHV might indicate the necessity for MHV reconstruction.[44] The indications for reconstruction of MHV tributaries can be determined based on our objective criteria.[54,55] First, discoloration of the liver surface should be observed after concomitant clamping of the MHV tributary and relevant hepatic artery for 5 minutes. Thereafter, only the hepatic artery is declamped and Doppler ultrasonography is performed. When hepatofugal portal flow is observed, the relevant area of the liver is confirmed to be congested. If the liver volume, excluding the area discolored by occlusion of the artery, is estimated to be insufficient for postoperative metabolic demand, (estimated graft volume less than 40% of the recipient's SLV), the MHV tributaries are reconstructed.

It is not rare to find thick, short hepatic veins during harvesting of a right liver graft (i.e., inferior right hepatic vein, middle right hepatic vein). Reconstruction of these vessels can be determined using the same criteria as for MHV reconstruction.

PORTAL VENOUS ANASTOMOSIS

In the preoperative evaluation of the donor, dynamic CT, visceral angiography, and dynamic CT with three-dimensional reconstruction provide detailed information about portal vein anatomy. Producing an anastomosis that is tension-free with wide enough orifices is a key determinant for successful portal vein anastomosis. Therefore, the portal vein on the recipient side should be dissected at the longest length possible during removal of the liver. On the donor side, a transverse portion of the portal vein has to have a long extrahepatic course to make it easier to obtain a longer portal vein in the left liver grafts than in the right liver grafts.

Portal venous thrombosis, sclerosis, and a size discrepancy between the graft and the recipient's portal vein are other issues that make it difficult or impossible to perform standard end-to-end anastomosis. These problems are usually overcome by use of an interposition vascular graft, vascular patch graft, or portal venoplasty.[56]

Trifurcation of portal vein

A common anomaly that requires attention during the donor operation is trifurcation of the portal vein in which the right lateral and right paramedian sectors are supplied separately. In this anatomic anomaly, the transverse portion of the portal vein is shorter than usual, and this necessitates a complete division of the portal vein tributaries to the caudate lobe when harvesting a left liver graft.

A right liver graft will have two portal branches. Some investigators excise the right paramedian and lateral portal vein with a side wall of the remaining donor portal veins as a patch. Defects in the remaining portal vein on the donor side are repaired with a venous patch, by direct suturing of the defect, or with segmental resection and end-to-end anastomosis. These procedures add to donor risk and result in unsatisfactory portal reconstruction.[57] This anatomic variation can be overcome by one of three ways. First, venoplasty of these portal veins can be performed on the bench and anastomosed as one common orifice to the recipient's portal vein. Second, these branches can be separately anastomosed to the recipient's portal vein. Third, a cryopreserved vascular graft can be used.

ARTERIAL RECONSTRUCTION

The information provided by preoperative angiography is essential for surgical planning and donor safety.[58] Hepatic arteries are subject to many variations.[59,60] Basically, these variations can be summarized as follows: (1) an aberrant left hepatic artery originating from the left gastric artery; (2) an aberrant right hepatic artery originating from the superior mesenteric artery; and (3) aberrant accessory arteries, in addition to the original left (or original middle) hepatic artery, or in addition to the original or replaced right hepatic artery. Division and dissection of the hepatic artery should be planned and meticulously performed according to the preoperative and operative findings.

Hepatic arterial reconstruction in LDLT is technically difficult due to the existence of short and thin hepatic arteries on a liver graft. Marcos et al. reported that anastomosis under a microscope is usually unnecessary in adult recipients, especially with a right liver graft.[28] Hepatic artery thrombosis is a serious complication that occurs after orthotopic liver transplantation, and it might result in hepatic necrosis, biliary leakage, bacteremia, or mortality.[61] Mazzaferro et al.[62] reported a significant association between hepatic arterial thrombosis and the presence of hepatic arteries less than 3 mm in diameter. In LDLT, the median diameter of the arterial branch, especially in a left-sided graft, is less than 3 mm.[60] Thus, microsurgery has an inevitable and indispensable place in LDLT.[63,64]

Is reconstruction of all hepatic arterial branches necessary?

In the early series of LDLT, left liver grafts were mainly used, which had thin, short, and sometimes multiple arterial branches. Broelsch et al.[63] suggested that a double arterial supply to the liver graft is unsuitable for LDLT after two of three of their patients experienced hepatic artery thrombosis. To resolve this problem, Mori et al.[64] reconstructed all hepatic arteries of a liver graft. The Shinshu group,[65] however, demonstrated that reconstruction of all hepatic arterial branches was not necessary in their left liver graft series. Furthermore, Sakamoto revealed that the existence of aberrant hepatic arteries, especially in left liver grafts, allows the physician to obtain a thicker and larger hepatic artery for reconstruction.[60] An additional important note regarding the left liver is that dissection of the perivascular connective tissue around the umbilical portion of the portal vein must be avoided to maintain the collateral circulation among the segmental arteries.[65]

In our previous series, the frequency of multiple arterial orifices was 1% for right-sided liver grafts and 9% for left-sided liver grafts.[59] Whereas recent data from Marcos et al.[66] revealed that 12% (11/95) of consecutive right liver grafts have double arteries. Marcos et al. proposed that reconstruction of all arterial branches of right lobe liver grafts is necessary, claiming that no portion of right liver grafts is supplied by secondary arterial perfusion.[67] In their recent series, they anastomosed double arterial orifices with auto Y-shaped arterial grafts on the bench.[66] It is still controversial, however, whether all arterial stumps must be anastomosed in LDLT. We reported successful results with only one hepatic arterial reconstruction in both a left and right liver graft with multiple arterial stumps.[59,60,65] Redman[68] demonstrated that accessory hepatic arteries usually communicate with the original lobar arteries in the hepatic hilum, but they are not visualized on angiograms unless they actually function as collaterals.

Checking arterial communication in grafts

When multiple hepatic arteries exist, the largest