Advances in Adult Living Donor Liver Transplantation: A Review Based on Reports From the 10th Anniversary of the Adult-to-Adult Living Donor Liver Transplantation Meeting in Tokyo

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In 1993, the Shinshu Group performed the first successful adult-to-adult living donor liver transplantation (LDLT). During the first 10 years of LDLT, many technical innovations have been reported. The major limitation of LDLT for adult recipients is the size of the graft. To overcome the problem, several graft types were designed, including left liver graft with caudate lobe, right liver, modified right liver, and right lateral sector and dual grafts. The necessity and criteria of reconstruction of middle hepatic vein is still on debate in right liver graft without trunk of middle hepatic vein. Biliary reconstruction remains a significant source of morbidity in LDLT. Donor safety must always be the primary consideration in LDLT and the selection criteria and management of the living donor must continue to be refined. On February 21, 2004, the 10th anniversary of the adult-to-adult LDLT meeting was held in Tokyo to review the accumulated experience and the presented information is summarized. (*Liver Transpl 2004;10:715–720.*)

Living donor liver transplantation (LDLT) was first introduced among the pediatric population in 1989,[1] and the first successful case in the total occurred in 1990.[2] On November 2, 1993, the Shinshu Group performed the first successful adult-to-adult LDLT.[3] The patient, who was a 53-year-old woman with primary biliary cirrhosis, received a left liver graft from her son. The number of LDLT procedures for adult patients has increased rapidly since then. By June 2002, there were 433 adult LDLT cases recorded in the European Liver Transplantation Registry[4] with 3-year graft and patient survival rates of 65% and 68%, respectively.

According to the United Network for Organ Sharing,[5] 731 adult LDLT cases had been performed in the United States by October 2001. The 3-year graft survival was 47% between 1998 and 1999 (n = 156), but it improved significantly to 61% between July 1999 and June 2000 (n = 285). According to the Japanese Liver Transplantation Society,[6] 1063 adult LDLT procedures were performed in Japan by the end of 2002. All of the donors were related to the patients; most of them were within the third degree of consanguinity. During the same period, only 10 adult patients underwent liver transplantation using grafts from deceased donors. Death of one living donor was reported from Japan. The donor was a woman in her 40s with complicated mild hypertension and fatty liver preoperatively. Right liver resection was performed, and estimated remnant liver volume was 29% of the total. Postoperatively the donor progressed to liver failure and received a whole liver from a familial amyloid polyneuropathy patient 5 months after her donation. However, she expired 8 months after the donation. The 5-year survival rates were 83% in children and 69% in adults. The lesser outcome in adults compared to that in children ($P <$ .0001) indicates that problems remain in adult LDLT.

During the first 10 years of LDLT, many technical innovations have been reported. Now appears to be a good time to review the accumulated experience. On February 21, 2004, the 10th anniversary of the adult-to-adult LDLT meeting was held in Tokyo. The presented information is summarized below.

Donor Safety

Selection and evaluation of a living liver donor for adult recipients is a complex process that involves optimizing graft size in relation to the safety of donors and recipi-

Abbreviations: LDLT, living donor liver transplantation; MHV, middle hepatic vein; HBV, hepatitis B virus; HCV, hepatitis C virus; RHV, right hepatic vein.

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ents, technical details of liver procurement, and ethical problems of using nonrelated live donors. As in most countries, including the United States and Japan, no legal restrictions exist in for living donation, local ethics committees confirm whether the candidates are appropriate potential donors. Voluntarism is the primary selection criterion and medical evaluation can only be started after confirmation of the voluntary nature of the donation.

Volumetric study using computed tomography scans is mandatory. For patients with advanced liver disease, a graft volume of greater than 40% of the recipient standard liver volume is necessary,[7] while for the living donor the remnant liver mass must be more than 30% of the whole liver.[8] The term "standard liver volume"[9] has become a key concept in LDLT. Estimated liver volume on computed tomography in healthy volunteers is proportional to body surface area and is calculated using the following formula:

$$\text{liver volume (mL)} = 706.2 \times \text{body surface area } (m^2) + 2.4$$

Donor safety must always be the primary consideration in LDLT. At least 3 cases of donor death have been reported in the United States[10] and 1 in Japan. Therefore, the selection criteria and management of the living donor must continue to be refined. Cherqui et al. reported on laparoscopic left lateral segmentectomy in a living donor for pediatric liver transplantation.[11] This laparoscopic technique was used in 8 donors, and early graft function was satisfactory in all cases. Unfortunately, 2 patients were complicated with hepatic arterial thrombosis, and 1 of them died. The application of laparoscopic donor hepatectomy for adult liver transplantation requires further technical advances but should be possible in the near future.

Small-for-Size Graft Problem

The major limitation of LDLT for adult recipients is the size of the graft that can be procured from a living donor, because a small-for-size graft might not meet the metabolic demands of an adult recipient.

Left Liver Graft

In the initial adult LDLT procedures, only a left liver graft was used. In 1998, the Shinshu group reported satisfactory results using a left liver graft in 13 patients.[12] The donor was selected if, based on computed tomography volume examination, the calculated size of the liver graft was larger than 30% of the recipient's standard liver volume. By January, 2004, the group had performed 95 adult LDLTs using left liver grafts. The 5-year graft and patient survival rates were 81% and 82%, respectively. Graft survival did not appear to be related to the graft volume / patient standard liver volume ratio. One-year graft survival was 83%, 83%, and 100% in patients who received grafts with graft volume / patient standard liver volume ratios ranging from 30% to 39%, 40% to 49%, and more than 50%, respectively. Their data indicate that left liver graft provides satisfactory results for appropriately selected recipients.

Miyagawa et al[13] reported on LDLT using the left liver grafts including the left-side caudate lobe (the Spiegel lobe and the left side of the paracaval portion of the caudate lobe). Takayama et al.[14] designed a similar procedure with direct anastomosis to the vena cava of the hepatic vein from the caudate lobe. The caudate lobe corresponds to only 3% to 4% of the whole liver volume. In conjunction with a left liver graft, however, the caudate lobe increases the graft weight by 8% to 12%.

Fifty-six percent of the patients in the University of Tokyo program received a left liver or left liver with caudate lobe graft with patient and graft 5-year-survival rates of 82% and 84%, respectively.[15] The strategy for selection of left or right liver graft, is influenced by the patient's preoperative condition,[16] as patients with advanced liver disease require a larger liver mass. The model for end-stage liver disease score[17] could become a satisfactory criterion for differentiating between high- and low-risk patients and therefore to determine the type of graft to use.

Extended Right Liver Graft

Use of right liver grafts has had a large impact on the results of adult LDLT. The Hong Kong group was the first to transplant a right liver graft including reconstruction of the middle hepatic vein (MHV) in 1996,[18] terming it an extended right liver graft. The outcome of the initial 8 donors and recipients were not without complications. One recipient died, and the recipients as well as the donors experienced high morbidity. The next 92 patients subsequently received extended right liver grafts with the following innovations: elimination of veno-venous bypass from the routine protocol, preservation of segment IV venous drainage in the donor, venoplasty of MHV and right hepatic vein into a single orifice for better venous return and easy vein reconstruction in recipients,[19] and preservation of blood supply to the right hepatic ducts. Over time, the mortality rate of the recipients decreased from 16% in the initial 50 cases to 0% in 50 more recent patients.

Right Liver Graft

In 1998, the University of Colorado group[20] introduced the right liver graft without reconstruction of the MHV trunk in adult LDLT. From January 1997 until

July 2003, the group performed 80 adult LDLTs. In the first 10 cases, in which the MHV branches of the graft were not preserved, 3 grafts were lost. Based on the group's preliminary experience, the resection line of the graft in the donor was moved to the left to preserve the MHV branches and their connections with the right hepatic vein (RHV).[21] The new transsection line was set between the right border of the MHV and the left margin of the gallbladder bed. In the subsequent 70 cases, no graft loss due to venous congestion was experienced.

Right Lateral Sector Graft

The small graft problem related to the left liver graft has been overcome by the use of a right liver graft. Right hepatectomy, however, imposes an increased surgical risk on the donor, due to the reduced residual liver volume. Fan and associates[8] concluded that safe donation was possible only when the estimated residual liver volume was over 30%. A recent report indicated that in 25% of the potential donors the right liver had an estimated volume of more than 70% of the whole.[22] Thus, based on these volumetric considerations, right hepatectomy is not possible for some potential donors.

The University of Tokyo group was the first to design the right lateral sector graft, consisting of segments VI and VII.[23] The indication for harvesting this type of graft includes a right liver of over 70% of the estimated total donor liver volume, while the estimated volume of the 2 right lateral sectors is greater than that of the left liver. In addition, this graft needs to be larger than 40% of the recipient's standard liver volume. Between January, 2000, and April, 2001, 6 of 32 adult-to-adult LDLTs with a right lateral sector graft[24] were performed at our institution. The postoperative course was uneventful in all donors. All recipients survived the operation. Three patients experienced bile leakage from the dissection plane of the graft. By January, 2004, 16 adult patients had received right lateral sector grafts, and 15 patients were still alive, with normal graft function.

From a technical point of view, careful attention must be paid to transecting the bile duct of the right lateral sector. When the right lateral duct enters the common bile duct separately (caudal right lateral duct), the duct is divided at its origin. Otherwise, after the right portal branch is dissected first and pulled cranially, the right lateral duct is dissected as far as possible from surrounding connective tissues.

Dual Grafts

Lee et al. were the first to devise dual grafts from two living donors.[25] Most commonly, both donors donate the left liver or left lateral segments, although various combinations of graft types can be used.[26] The first left liver graft is orthotopically implanted at the original left position. The second left liver graft is rotated 180 degrees and positioned heterotopically in the right upper quadrant fossa. Modifications in the surgical technique are needed for implantation of the second graft. Because the bile duct is now located behind the portal vein and the hepatic artery, bile duct reconstruction is necessary before reconstruction of the vessels. An interposition vein graft might be necessary for the reconstruction of the hepatic or portal vein, because the second left liver graft is too small to bridge the distance between the hepatic and portal veins. By the end of 2003, this technique was used in 93 patients with satisfactory results. Also, the Kyoto group has implanted dual grafts in 1 adult patient.[27] However, the procedure has limited appeal due to the high requirements of economic and medical resources: 3 operating rooms and 3 surgical teams are required simultaneously. Therefore, liver transplantation using dual grafts is clearly technically demanding and not widely performed around the world.

MHV Reconstruction in Right Liver Graft

A right liver graft without the MHV trunk can cause severe congestion of the right paramedian sector. However, a strategy to prevent such congestion or the necessity to reconstruct the MHV has not been discussed in detail.

Cons

In the meeting, Igal Kam et al. reported that only 2 of 70 patients who received a right liver graft without the MHV trunk required reconstruction of the MHV tributaries. Their research stated that, in general, the MHV can be ligated during the procurement of right liver graft, as connecting the MHV to the vena cava is unnecessary. They emphasized that reconstruction of the MHV is mainly indicated when right hepatic vein of the graft is small. This policy might[50] affect the selection of the potential recipients of the right hemiliver graft. Whole liver grafts from deceased donors can be used for poor-risk patients, while hemiliver grafts from living donors can be used for good-risk patients who can tolerate lesser parenchymal liver mass.

Pros

In contrast, Lee et al. aggressively reconstructed the MHV tributaries in right liver grafts without the MHV trunk and named this type of graft a modified right liver graft.[28] As it is difficult to predict the degree of right paramedian sector congestion, they recommended routine reconstruction of MHV tributary veins. Ghobrial et al.[29] also recommended reconstruction of the MHV tributary veins when RHV in graft was less than 1.5 cm in diameter. From July, 1997, to February, 1998, 2 of 5 right lobe grafts without MHV drainage reconstruction were complicated with severe congestion of the paramedian sector. Since then, 42 adult recipients, who received right liver grafts with fairly sized MHV tributaries, underwent reconstruction of these veins.[30] All MHV tributaries with a size of >5 mm were preserved during donor hepatectomy and were reconstructed with the autogenous interposition vein grafts of the recipient during bench surgery.

Indications

It remains unclear whether all modified right liver grafts require MHV drainage. Sano et al.[31] proposed clear criteria for MHV reconstruction. During the donor operation, hepatic venous congestion in the right paramedian sector was investigated after transsection of the liver parenchyma. First, liver surface discoloration in the right paramedian sector was observed after 5 minutes of simultaneous clamping of MHV tributaries and the right hepatic artery. Next, intra-operative Doppler ultrasonography was performed after declamping only the hepatic artery. If the portal flow of the paramedian sector was found to be hepatofugal, the area was considered congested. If the congestive area was significant, as determined by the clamping test and ultrasonography, bench reconstruction of MHV tributaries was performed. Using these criteria, we performed MHV reconstruction in 18 of 30 grafts, resulting in an uneventful functional recovery of all grafts.[32] The necessity of short hepatic vein reconstruction can be determined using the same criteria.

Biliary Reconstruction

Biliary reconstruction remains a significant source of morbidity in liver transplantation, with a complication rate of 6% to 47%. Complications include anastomotic leakage and stenosis, problems related with T or stent tubes, and rarely, nonanastomotic strictures or intrahepatic bilomas. These complications can lead to cholangitis, sepsis, and eventually retransplantation and death. Therefore, due to the diminished functional reserve of the hemiliver graft, it might lead to serious complications in adult LDLT.

Initially, the type of biliary anastomosis commonly used in LDLT was the hepaticojejunostomy. Kiuchi and colleagues[33] were the first to report preliminary results of duct-to-duct biliary reconstruction in adult LDLT. Now duct-to-duct biliary reconstruction is enthusiastically performed in a growing number of programs.[34-39] The reports advocate the advantages of duct-to-duct biliary reconstruction over hepaticojejunostomy, such as an aseptic surgical field and shorter duration for reconstruction. The physiologic bilioenteric circulation and bowel continuity can also be preserved, preventing delayed peristalsis. Duct-to-duct reconstruction allows easy endoscopic access to the biliary tree for diagnostic and therapeutic instrumentation and management. For the management of biliary stenosis, the duct-to-duct anastomosis is usually converted to the hepaticojejunostomy. However, the Kyoto group[40] recently reported that 13 of 14 patients were successfully treated with an internal stent. The endoscopic approach appears to be a therapeutic alternative to reoperation. However, the follow-up period in these patients is still short. Long-term postoperative observation is necessary to confirm the safety and feasibility of this procedure.

Viral Hepatitis and Hepatocellular Carcinoma

Hepatitis B Virus

The results of liver transplantation in patients with hepatitis B (HBV) have improved significantly as a result of the rapid evolution in strategies for postoperative prophylaxis. Hepatitis B immunoglobulin, which is costly, was the first effective prophylactic agent. Lamivudine monotherapy prevents emergence of viral mutants. Now, combination therapy with hepatitis B immunoglobulin and lamivudine has become a widely adopted approach. Other nucleotide analogs, such as adefovir, are promising alternative agents.

The HBV prophylactic regimen at Queen Mary Hospital in Hong Kong consists of lamivudine monotherapy,[41,42] while adefovir is reserved for breakthrough reinfection after transplantation. Lo et al. performed 180 liver transplants for HBV-positive patients (120 LDLT and 60 grafts from deceased donors). The 5-year cumulative mutant-free survival was 86%. In contrast, the Tokyo University group[43] presented satisfactory results of LDLT for HBV (n = 20) using hepatitis B immunoglobulin monotherapy. The use of lamivudine was limited to the perioperative period to avoid generating mutants.

One recent report of active production of HBV-antibodies after liver transplantation suggests the possibility of adoptive transfer of immunity against HBV through a liver graft from an immune donor.[44] Active immunization with standard hepatitis B vaccines was recently reported, with conflicting results.[45]

Hepatitis C Virus

Early experience suggested rapid and severe recurrence of hepatitis C (HCV) following adult LDLT.

Ghobrial et al.[46] reported that the time interval to HCV recurrence (n = 11) was significantly shorter in LDLT patients than in patients who received grafts from deceased donors (n = 510). The University of Colorado group[47] reported that serum alanine aminotransferase and total bilirubin levels increased more rapidly after the operation in LDLT patients (n = 24) than in cadaveric graft recipients (n = 41). In addition, LDLT patients had greater serum aspartate aminotransferase levels at 1, 3, and 6 months, compared with a matched group of cadaveric controls.[48]

Gaglio et al.[49] reported that the overall incidence of severe sequelae of hepatitis C recurrence—either cholestatic hepatitis, grade III-IV inflammation, and/or hepatitis C–induced graft failure requiring retransplantation—were not different between cadaveric grafts (n = 45) and those grafts from living liver donors (n = 23). However, the morbidity of cholestatic hepatitis C was more severe in LDLT patients (0% vs. 17%, respectively; $P = .001$). These preliminary reports indicate that more intensive antiviral therapy might be necessary for recipients of living donor grafts. All of these reports, however, have some limitations, which include small numbers of patients, lack of standard virologic evaluation, and short-term follow-up. The results must be confirmed in larger, multicenter studies.

Hepatocellular Carcinoma

LDLT is an established therapeutic option for patients with hepatocellular carcinoma. From 1990 to the end of 2002, LDLT for hepatocellar carcinoma was performed in 225 cases in Japan.

Prof. Furukawa from the Hokkaido University reported in the Tokyo meeting that 160 patients were alive, with a recurrence rate of 5%, while 65 patients were dead, with a recurrence rate of 32%. Multivariate analysis revealed that alpha-fetoprotein levels, tumor size, and invasion of hepatic and portal veins are significant predictors for outcome. When the subjects were categorized into two groups (patients meeting the Milan criteria, and those beyond), difference both in patient and recurrence-free survival reached significance (76% vs. 52%, respectively; $P = .001$; and 76% vs. 50%,respectively; $P = .001$).

Conclusions

During the 10-year period, many technical innovations have been developed for LDLT, contributing to a better patient outcome. LDLT was originally devised and performed in countries where organs from deceased donors are extremely scarce. The contributions made by Asian countries with regard to the design of several graft types, including left liver graft with caudate lobe, right liver, modified right liver, and right lateral sector grafts, are noteworthy. A recent review by Grewal,[50] however, has failed to acknowledge the significant Asian contribution to LDLT.

In LDLT, the physical and psychological sacrifice by the donor is significant and is associated with high expectations regarding a good outcome for themselves and the recipient. We should not be satisfied with the present outcome and need to strive to achieve 0% donor mortality.[15] Firm criteria for graft selection and further technical advances will be helpful in reaching this goal.

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Refinement of Venous Reconstruction Using Cryopreserved Veins in Right Liver Grafts

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Short and direct vein anastomosis is generally performed in living donor liver transplantation using a right liver graft. The graft will regenerate, however, and might thus compress the anastomosis. We formulated a strategy for outflow reconstruction in right liver graft. When reconstruction of multiple short hepatic veins was necessary, a cryopreserved inferior vena cava graft was anastomosed with the hepatic veins of the graft in a basin. When there were no major short hepatic veins in the graft, a rectangular-shaped vein graft was used to make a single orifice using the middle and right hepatic veins in the graft. When there were no tributaries of the middle hepatic vein to be reconstructed, a diamond-shaped vein patch was anastomosed on the anterior wall of the right hepatic vein orifice of the graft. These techniques were satisfactorily applied in 40 patients with no torsion or tension at the anastomotic site of the hepatic venous reconstruction or other complications in outflow. The present strategy seemed to be technically feasible for outflow reconstruction in a right liver graft. (*Liver Transpl 2004;10: 541–547.*)

Living donor liver transplantation (LDLT) is now widely performed to compensate for the critical cadaveric organ shortage in adult patients.[1] The significant increase might be due to the introduction of right liver graft for adult patients.[2]

An extended right liver graft (ERLG)[3] which includes the trunk of the middle hepatic vein (MHV), was devised by Fan and colleagues. Although the extent of the donor hepatectomy might be increased, this method is beneficial with regard to venous drainage of the graft because the MHV is a major draining vein of the right paramedian sector, and its role in the left paramedian sector is limited.[4] A right liver graft without the MHV trunk (RLG) is now more commonly used. This type of graft, however, can cause severe congestion of the right paramedian sector (segments V and VIII). MHV drainage into the recipient's venous system can be reconstructed using vein grafts[5] to provide a functioning liver mass comparable to an extended right liver.[6]

Vein reconstruction in a right liver graft is technically challenging.[7] The different strategy may be devised according to the existence of thick MHV tributaries or inferior right hepatic vein (IRHV). Additionally, the average right liver graft is only half size for the recipient, and regenerates in all directions after LDLT. As a result, the graft might compress the venous anastomotic site. In the present manuscript, we formulated a strategy for vein reconstruction tolerable to the compression.

Material and Methods

Patients

From January 2002 to April 2003, 62 adult patients underwent LDLT at our hospital. Of these, 40 patients (31 men, 9 women) received a right liver graft and were the subjects of the present study. The age ranged from 20 to 66 years (median age = 52 years). The indications for LDLT in these patients included hepatitis C virus–cirrhosis (n=12), hepatitis B virus–cirrhosis (n=8), primary biliary cirrhosis (n=6), cryptogenic cirrhosis (n=5), fulminant hepatic failure (n=4), biliary atresia (n=2), Wilson's disease (n=1), citrullinemia (n=1), and primary sclerosing cholangitis (n=1).

Donors

The donors were 20 men and 20 women. The age ranged from 20 to 61 years (median age = 36 years). Their relation to the patients included children (n=20), siblings (n=10),

Abbreviations: AST, aspartate aminotransferase; CT, computed tomography; ERLG, extended right liver graft; IRHV, inferior right hepatic vein; IVC, inferior vena cava; LDLT, living donor liver transplantation; LHV, left hepatic vein; MHV, middle hepatic vein; MRHV, middle right hepatic vein; RLG, right liver graft without the MHV trunk; RHV, right hepatic vein; SHV, short hepatic vein; VC, vena cava.

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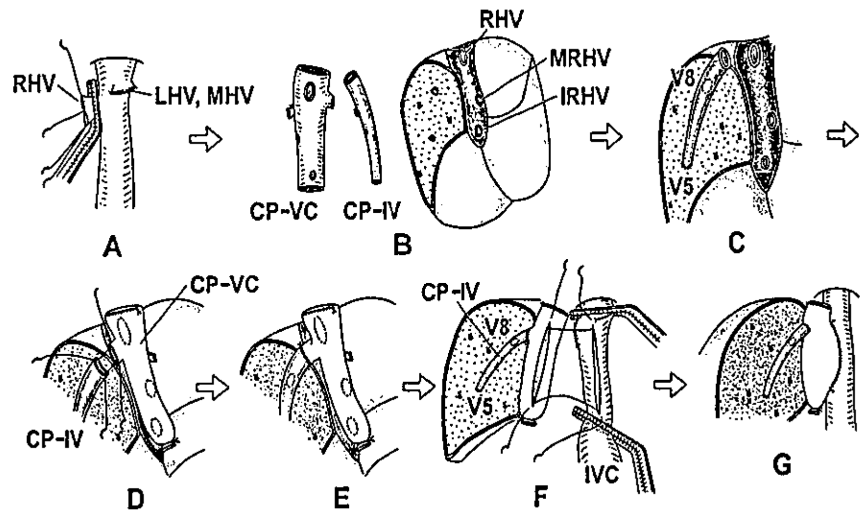

Figure 1. Schematic view of double vena cava technique. (A) All hepatic vein trunks of the recipient (LHV, MHV, RHV) were sutured at their roots. (B) Three side holes were created in the wall of the cryopreserved vena cava graft (CP-VC) for anastomosis with the right hepatic vein and the short hepatic veins (IRHV or MRHV) of the graft. (C, D) Another cryopreserved vein graft (CP-IV) can be used for middle hepatic vein reconstruction. (E) The stump of venous branch was anastomosed with jumping vein graft for the middle hepatic vein reconstruction. (F, G) Side-to-side anastomosis between the recipient inferior vena cava and CP-VC with continuous sutures was performed.

spouses (n=5), parent (n=4), and nephew (n=1). Right liver volume was preoperatively estimated by computed tomography (CT). Candidates in whom the right liver comprised more than 70% of the whole liver were rejected as prospective donors. An estimated graft volume to recipient standard liver volume[8] ratio of 40% was the lower limit for right liver transplantation.

The number and diameter of thick MHV tributaries draining the right paramedian sector were evaluated on CT. The tributaries were classified as V8, which drained the cranial part of the portal trunk of the right paramedian sector, and V5, which drained the corresponding caudal part. When the donor was under 50 years of age and the remnant left liver was estimated to be more than 35% of the whole liver, extended right liver graft (ERLG) harvesting was considered. Otherwise, a right liver graft without the middle hepatic vein trunk (RLG) graft harvesting was indicated. Details regarding the selection criteria and evaluation are described elsewhere.[9]

Homologous Vein Graft Preparation

Vein grafts were provided by the University of Tokyo Tissue Bank. The preservation and thawing methods were described previously.[10] In brief, the vein grafts were obtained from cadavers or nonheart beating donors within 24 hours after cardiac arrest after obtaining informed consent. The specimens were packed in a sterile bag and frozen slowly in a programmable freezer at a rate of 1°C/min to -40°C. They can be semipermanently stored in liquid nitrogen until use.

Surgical Procedure

The right liver was harvested as described previously.[9] In a basin, the graft was flushed with 1 liter of University of Wisconsin solution through a cannula inserted into the right portal vein. When there were major short hepatic veins, including inferior or middle right hepatic veins in the graft, the double vena cava (VC) technique was applied. The method was refined from our previous method.[11] A cryopreserved VC graft was prepared for venoplasty in a basin (Fig. 1). A side hole was made in the wall of the VC, which was anastomosed with the hepatic veins in the graft. When direct anastomosis was difficult for a distance between the orifice of the middle hepatic vein (MHV) tributaries and VC graft, an iliac branch of the VC vein graft was used for the interposition. If the iliac branch was not available, another cryopreserved vein graft was used for interposition. With this technique, there was no need to preserve any hepatic vein trunks of the recipient, which were sutured at their roots. Then, the inferior vena cava (IVC) of the recipient was partially clamped and incised longitudinally approximately 5 cm. The VC graft was similarly incised longitudinally, and then anastomosed side-to-side with the IVC of the recipient.

When there were no major short hepatic veins in the graft or a VC graft was not available, a rectangular-shaped patch method was applied (Fig. 2). The orifices of right hepatic vein (RHV), MHV, or MHV tributaries received venoplasty with a cryopreserved vein graft or recipient left portal vein. They were cut in a rectangular shape and placed on the orifices of the MHV and RHV of the graft. The vein grafts were sutured to the right side of the MHV orifice and the left side of the RHV orifice in a basin. When the distance between the orifice of V8/V5 and that of RHV was too great in RLG, and not appropriate for this technique, another vein graft was substituted as an MHV. Then, a rectangular-shaped vein patch was placed between the right side wall of the interposition graft

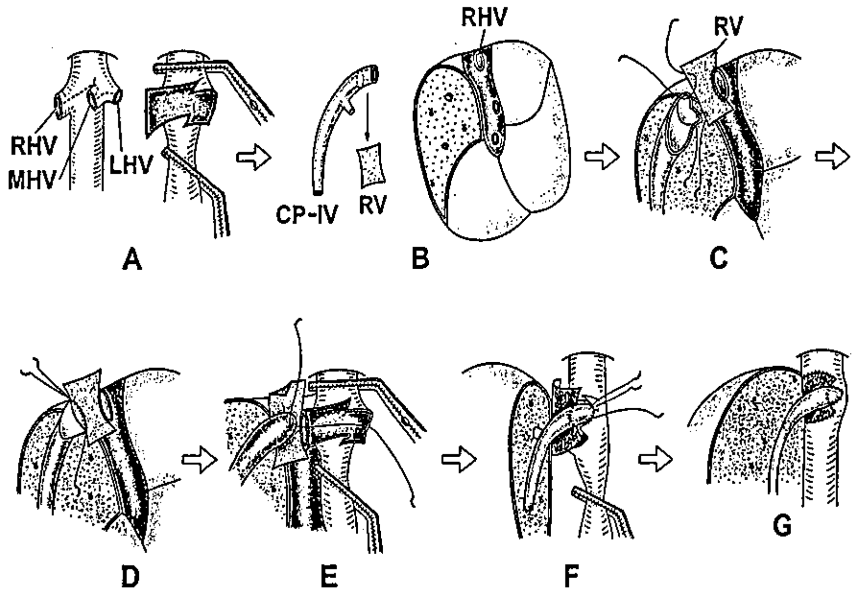

Figure 2. Schematic view of rectangular shaped patch method. (A) All hepatic vein trunks of the recipient (LHV, MHV, RHV) were cut and one wide single orifice was made. (B) The cryopreserved vein graft (CP-IV) was used for interposition graft for MHV reconstruction. A proximal part of the CP-IV was cut and used for patching between the orifice of graft RHV and the interposition graft (RV). (C, D) The RV patch was anastomosed with the left side of the RHV orifice of the graft. The posterior wall of the CP-IV was cut longitudinally, which was anastomosed with another edge of the RV patch. (E) The right side of the RHV orifice of the graft was anastomosed with the edge of the common hepatic vein of the recipient. (F,G) The anterior wall of the CP-V, RV patch and the edge of common hepatic vein of the recipient were sutured together to make a reservoir of outflow between the liver graft and recipient vena cava.

and the left side of the RHV orifice. In the recipient, a wide orifice was created by dividing three hepatic veins. The recipient IVC was cross-clamped above and beneath the roots of the hepatic veins. Anastomosis was started between the right edge of the recipient's common hepatic vein and the right side of the graft RHV orifice. Next, the left edge of the recipient's common hepatic vein and the left side of the graft MHV orifice were put together. Then, the caudal edges of the graft veins and recipient venous wall were sutured and the cranial edges were closed.

When the graft had no major MHV tributaries to be preserved, a diamond-shaped patch method was applied (Fig. 4). The method was refined from our previous method.[12] The anterior wall of the RHV orifice of the graft was cut short to widen the orifice while in the basin. An iliac vein graft or left portal branch of the recipient was anastomosed to the anterior

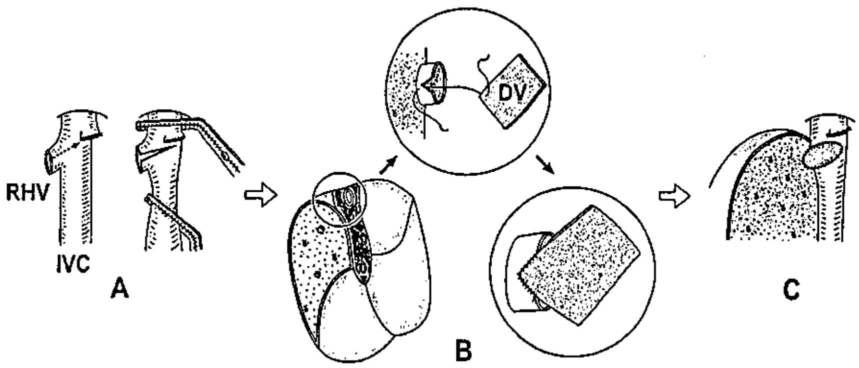

Figure 3. Schematic view of diamond-shaped patch method. (A) The anterior wall of the recipient right hepatic vein (RHV) was cut approximately 2 cm under cross-clamping of inferior vena cava (IVC). (B) The anterior wall of the RHV orifice of the graft was shortly (5 mm) cut for widening the area of orifice. The diamond shaped venous patch (DV) was anastomosed to the orifice of the RHV. (C) End-to-end anastomosis was done between the recipient and graft RHV with continuous sutures.

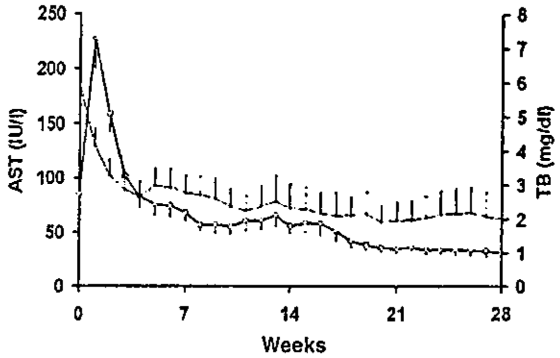

Figure 4. Changes in serum aspartate aminotransferase (AST, open circle with thick line) and total bilirubin level (TB, closed circle with thin line) for three weeks after the operation (n=40). Error bars represent standard error of the means.

wall of the graft RHV orifice. In this technique, the left and middle hepatic veins of the recipient were closed with a running suture. Under cross-clamping of the IVC, the anterior wall of the RHV and the IVC was incised. At first, the posterior wall of the RHV orifice of the graft and that of the recipient RHV were sutured together. Then, the diamond-shaped vein patch and anterior wall of the graft RHV orifice were anastomosed.

Postoperative Evaluation

Vascular flow in the graft or interposition vein patency was checked by Doppler ultrasound every day until the 14th postoperative day and once a week thereafter until hospital discharge. Enhanced CT was performed 1 and 3 months after LDLT to check for vein graft patency. Aspartate aminotransferase and total bilirubin levels were measured every day after LDLT for 4 weeks.

Results

Clinical Outcome of Donors

The graft types harvested consisted of 32 RLGs and 8 ERLGs. The weight of the graft ranged from 411–917 g (median, 607 g) and corresponded to 48–67% (54%) of donors' standard liver volume. Blood loss ranged from 160–1125 g (460 g), which was replaced by 0–1200 ml (310 ml) of the donors' own fresh frozen plasma or whole blood. The operation lasted 355–665 min (458 min). Bile juice leakage from the dissection plane of the liver (n=1) or stump of the bile duct (n=1) necessitated surgical repair. The median hospital stay was 16 days. All of the donors returned to their normal daily lives.

Venous Reconstruction and Patency

The number of grafts using each technique and the number of vein grafts are shown in Tables 1 and 2. A total of 19 of 32 RLG grafts received reconstruction of MHV tributaries. Reconstructed MHV tributaries consisted of both V8 and V5 (n=15), V8 (n=3) and V5 (n=1). No MHV tributaries were reconstructed in 13 grafts because of a negligible area of congestion in 11 and a lack of dominant tributaries in 2.[13] Upon reconstruction of the inflow, good hepatic venous drainage was confirmed by Doppler ultrasound.

The time for outflow reconstruction in each technique is shown in Table 3. The liver graft cold preservation time varied, ranging from 12–142 minutes (median 62 minutes). The median time for the venous reconstruction in the recipient (after the graft was taken off ice) was 27 minutes. Doppler ultrasound and CT examination revealed that all the vein grafts were patent for at least 3 months after LDLT.

Laboratory Data, Morbidity, and Mortality

The graft corresponded to 33–71% (median, 51%) of the standard liver volume of the recipients. The blood loss ranged from 30–961 g per body weight (kg, median, 920 g/kg). The operation lasted 735–1345 min (920 min). Postoperative complications included acute rejection in 11, and bile juice leakage from the anastomosis, which necessitated surgical revision in 2.

Table 1. Detail of MHV Reconstruction

Technique	Graft Type RLG:ERLG	Reconstruction V5	V8	SHV
Double VC (n = 16)	13:3	8/13	9/13	16/16
Using rectangular shaped vein patch (n = 14)	9:5	8/9	9/9	10/14
Using diamond shaped vein patch (n = 10)	10:0	0/10	0/10	5/10

Abbreviations: ERLG, Right liver graft which includes the trunk of the middle hepatic vein; RLG, Right liver graft without the middle hepatic vein trunk; SHV, Short hepatic vein; V5, V8, tributaries of middle hepatic vein; VC, vena cava.

Table 2. Detail of Vein Grafts

Technique	Cryopreserved Vein					Autograft
	IVC	SVC	IV	F	PV	
Double VC (n = 16)	14	2	1*	2*	0	0
Using rectangular shaped vein patch (n = 14)**	0	2	2	5	0	6
Using diamond shaped vein patch (n = 10)	0	0	1	0	1	8

Abbreviations: F, femoral vein; IV, iliac vein; IVC, inferior vena cava; PV, portal vein; SVC, superior vena cava; VC, vena cava.
*Used for middle hepatic vein reconstruction.
**In one patient, cryopreserved femoral vein graft was used for middle hepatic vein reconstruction and auto left portal vein was used for patching.

Aspartate aminotransferase peaked on the first postoperative day, and then decreased gradually thereafter (Fig. 4). The total bilirubin level decreased rapidly after LDLT.

Two patients died 99 and 117 days after LDLT due to multiple graft abscesses after hepatic arterial thrombosis and bleeding from the ileum, respectively. The remaining patients survived the operation and stayed in the hospital for 16–123 (median, 35) days. All but the two patients are alive with a median follow-up of 9 months. There was no evidence of anastomotic stricture or thrombosis in the hepatic vein in any of the patients.

Discussion

Although the appropriate length of the outflow reconstruction is controversial in LDLT using a right liver graft,[14] short and direct anastomosis is generally performed in RHV reconstruction for RLG implantation. Marcos and colleagues created an elliptical defect of approximately 1.5–2.0 times the diameter of the donor RHV in the right side of the IVC.[15] The IVC and the RHV were then anastomosed side-to-end. A recent report presented a similar technique.[16] The stump of the recipient RHV was excised along a portion of the IVC, creating an oval cavotomy. Marcos and colleagues reported no outflow stenosis in their 48 LDLT recipients.[15] In the series by Kinkhabwala and associates, there was only a 2% incidence of outflow complications.[16] There seems to be no evidence to contraindicate these simple and short anastomoses.

The implanted graft is always smaller than the recipient standard volume in adults, however, and will regenerate in the postoperative course. The graft will grow toward the left and ventral sides because the right subphrenic cavity is not large enough to accommodate the regeneration (Fig. 5). When a short anastomosis is performed, the dissection plane of liver graft faces the IVC. The enlarged graft might push on the IVC on the dorsal side. The resulting outflow obstruction could congest the graft, leading the patient to a malignant cycle of further graft expansion and dysfunction. In our technique, the anastomosis is lengthened by adding a venous patch. Long preservation of recipient hepatic veins allowed formation of a reservoir between the liver graft and recipient IVC. With this concept, we have previously presented venous patching at the anastomotic site of RHV[12] and double VC method for ERLG.[11] In the present paper we have a newly devised rectangular-shaped vein graft technique and have formulated our strategy in MHV and RHV reconstruction for right liver graft.

Fan and colleagues analyzed the results of ERLG in 11 patients.[17] Originally, they reconstructed the RHV and MHV separately. For RHV anastomosis, the recipient IVC was incised longitudinally to make the RHV anastomosis as short as possible. The MHV of the graft was anastomosed to the MHV or left hepatic vein of the recipient end-to-end. Using this technique, MHV reconstruction is technically demanding. The MHV position in the graft should not always be constant in relation to the position of the recipient MHV. Addi-

Table 3. Time for Outflow Reconstruction (min)

Technique	On Bench	After Out of Ice
Double VC (n = 16)	62–142 (89)	12–24 (18)
Using rectangular shaped vein patch (n = 14)	33–117 (67)	35–62 (45)
Using diamond shaped vein patch (n = 10)	12–21 (16)	21–42 (30)

Abbreviation: VC, vena cava.
Numbers in parenthesis indicates a median value.

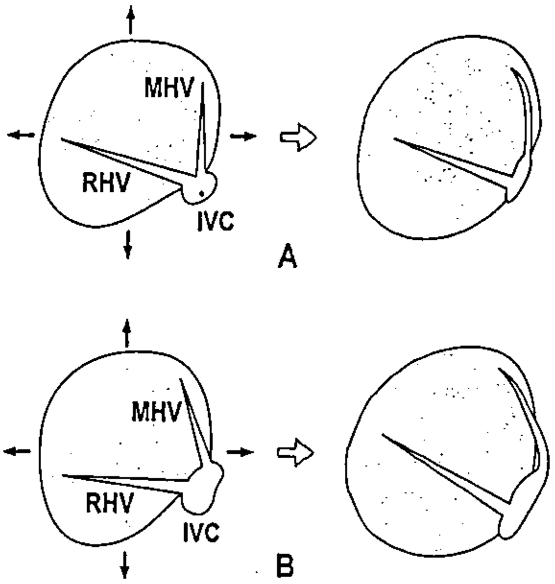

Figure 5. The graft will regenerate (arrows) and rotate toward left and dorsal side because the right subphrenic cavity is not large enough to accommodate the regeneration. (A) Short outflow reconstruction of middle and/or right hepatic vein (MHV or RHV) places the graft riding on the inferior vena cava (IVC). The regenerated graft might push the IVC. (B) Long outflow reconstruction can set the graft in a more natural position. The anastomosis could be maintained wider after graft regeneration.

tionally, expansion of the right liver graft might displace the MHV anastomosis to the left side, provoking stenosis. Recently, Fan et al have revised their technique.[18] In the bench surgery, the adjacent walls of the graft MHV and RHV orifices were sutured. In the recipient, the RHV orifice was enlarged with a transverse incision across the anterior wall of the IVC. In this method, the position of the graft is determined by the triangle-shaped hole in the ventral plane of the IVC. The dissection plane of the graft faces the IVC. Excellent results were achieved after adopting the technique. The possibility remains, however, that the expanded graft will compress the IVC.

There is no consensus regarding the optional strategy for MHV reconstruction in RLG. It would be ideal to reconstruct every significant MHV tributary in RLG. The most likely background in routine MHV deprivation in some institutions is that these veins cannot drain into the IVC without the aid of a jump graft, which necessitates a complex reconstruction strategy. Marcos and associates[15] pointed out some concerns related to MHV reconstruction: 1) that the donor liver cannot be separated safely if the MHV tributaries are not ligated; 2) that construction of jump grafts will prolong the warm ischemic time and increase the risk of bleeding; and 3)that the intrahepatic collaterals will be adequate for acute decompression of right paramedian sector. Some transplant teams have performed reconstruction of the MHV tributaries overcoming these proposed difficulties and obtained satisfactory results. A previous report revealed that in LDLT, venous flow of the ligated MHV tributaries drained into the right hepatic vein by way of the venous collaterals that developed rapidly approximately 1 week after transplantation, which was confirmed by Doppler ultrasonography.[19] There is no evidence that the prompt formation of such collaterals can be generally expected. Cattral and associates reported a case of reconstruction using the recipient's left portal branch.[20] Ghobrial and colleagues reported a venous variant type of the small RHV and large MHV branch and proposed that MHV reconstruction should be performed in such cases.[14] We have reconstructed the MHV tributaries if the congested area was dominant by the clamping test or ultrasonography as proposed by Sano and associates.[13] The reconstructed MHV might be easily compressed by regeneration of the liver graft. The rectangular-shaped vein patch between the reconstructed MHV and the graft RHV is optimal for preventing the displacement of the anastomosis.

The major concern in venous reconstruction using cryopreserved vein grafts is vein graft obstruction or the possibility of narrowing in the long-term observation period. Kuang and associates used cyropreserved grafts for portal vein interposition (iliac vein or saphenous vein, n=7) and hepatic artery interposition (saphenous vein, n=2) in LDLT.[21] The patients were five children and two small adults. Complications of the vein grafts were recognized in eight of the nine grafts including aneurysm (n=4), thrombosis (n=3), and stricture (n=1). Mills and associates reported that incidence of late portal vein stenosis or thrombosis was 51% when cryopreserved vein was used as an interposition graft.[22] The previous discouraging results indicate that long-term follow-up are necessary to confirm the feasibility of the present technique.

In summary, the present techniques seem to be feasible for outflow reconstruction in a right liver graft although there was no evidence that they were advantageous over the conventional simple reconstruction. There remain some problems in our techniques in its complexity and long-term patency of cryopreserved vein grafts.

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Sharing the Middle Hepatic Vein between Donor and Recipient: Left Liver Graft Procurement Preserving a Large Segment VIII Branch in Donor

Yoji Kishi, Yasuhiko Sugawara, Nobuhisa Akamatsu, Junichi Kaneko, Yuichi Matsui, Norihiro Kokudo, and Masatoshi Makuuchi

There are few reported techniques to minimize the congestion in the donor after left liver graft procuring. If a large tributary of the middle hepatic vein (MHV) draining segment VIII (V8) converges into the root of the MHV in a donor of left liver, this branch should be preserved on the donor side. The volume of congested area when the V8 was ligated was predicted preoperatively by computed tomography (CT) and examined intraoperatively by the clamp test. Postoperative regeneration of the donor liver was evaluated by CT volumetry. This technique was used in 3 cases. The regeneration rate after 3 months of the right paramedian sector was 27, 38, and 8%, and that of the right lateral sector was 31, 63, and 39% in each donor, respectively. No severe complications occurred in the donors. In conclusion, V8 preservation in donors who underwent left liver resection led to satisfactory regeneration both of the right paramedian and lateral sectors and can minimize congestion in remnant liver. (*Liver Transpl 2004;10:1208–1212.*)

A vital issue in living donor liver transplantation (LDLT) is the preservation of a satisfactory blood supply and venous return in both the right and left livers to maximize donor safety and graft function. When splitting the liver along the main portal fissure to procure a hemiliver graft, however, it is practically impossible to maintain complete venous outflow in both, because the middle hepatic vein (MHV) can usually be preserved on only one side. Interruptions of regional venous outflow inevitably cause congestion in the liver. Regional venous outflow disturbances will theoretically disrupt the function of the relevant hepatic parenchyma.[1]

In right liver graft transplantation, various strategies have been reported to reduce the congested area of the right paramedian sector, such as the reconstruction of tributaries of the MHV[2,3] or the use of a right liver graft including the MHV.[4] There are, however, few reported techniques to minimize the congestion in the donor after left liver graft procurement. Here we report a left liver graft without a branch of the MHV tributary that drains the cranial part of the right paramedian sector (V8) to minimize congestion of both the graft and remnant donor liver in left liver graft transplantation.

Patients and Methods

From February 1996 to September 2003, 240 consecutive LDLTs were performed at our institution. Left liver with caudate lobe graft was used in 91 patients. In every donor, sectional computed tomography (CT) volumetry was performed preoperatively and a left liver with caudate lobe graft was indicated when the volume was over 40% of the recipient standard liver volume.[5]

The indication for procurement of the left liver graft was as follows: CT volumetry of donor liver was performed; a 3-dimensional image was reconstructed from CT using Region Growing software (Version 0.5a; Hitachi Medical, Chiba, Japan); if the volume drained by a V8 branch was large (Fig. 1), a left liver graft without a V8 branch was considered; three donors had a large V8 converging into the root of the MHV, and this branch drained a large part of right paramedian sector and a part of right lateral sector; then a left liver graft was procured, preserving this tributary in the cases reported here; case 1 was a 42-year-old female with hepatic failure due to primary biliary cirrhosis and the left liver was donated by her 42-year-old husband; case 2 was a 37-year-old female with primary biliary cirrhosis and the donor was her 66-year-old father; case 3 was a 14-year-old female with biliary atresia and the donor was her 45-year-old mother.

In the donor operation, MHV tributaries were confirmed by intraoperative ultrasonography. After dissection of the coronary ligament, the confluence of the left and middle hepatic veins was sufficiently exposed. The dissecting line of the

Abbreviations: CT, computed tomography; LDLT, living donor liver transplantation; MHV, middle hepatic vein; V8, MHV tributary that drains the cranial part of the right paramedian sector.

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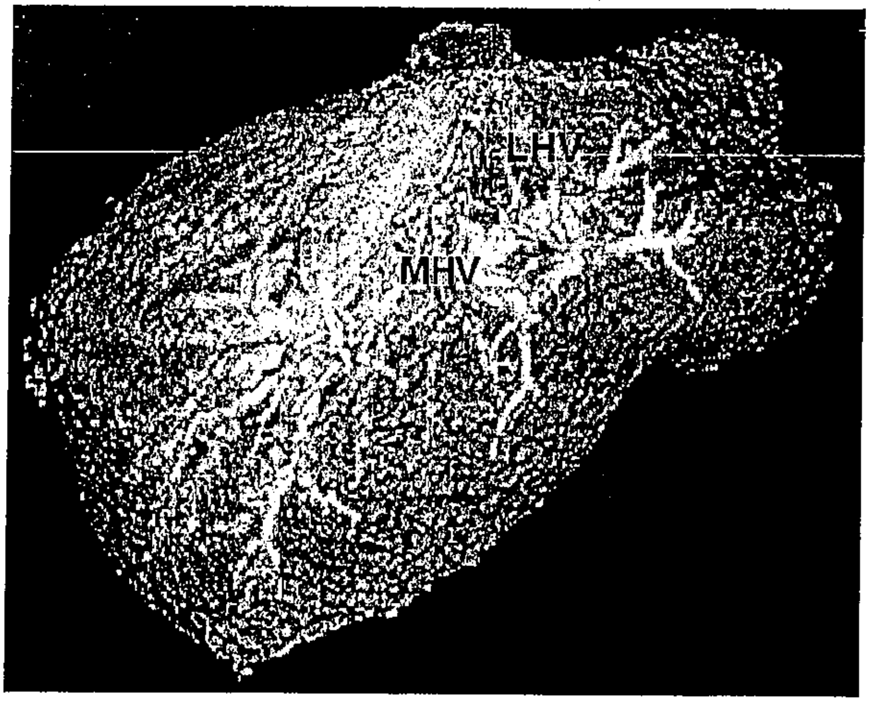

Figure 1. Computer-generated 3-dimensional image of the reconstruction. The red-colored vein indicates a V8 branch that was preserved on the donor side. The area drained by the V8 is shown in light brown. The white line in the left panel shows the dissection line of the hepatic veins. Abbreviations: LHV, left hepatic vein; MHV, middle hepatic vein.

parenchyma was determined according to the demarcation line that appeared by clamping one side of the hepatic artery and portal vein. Dissection of the liver parenchyma was performed using an ultrasonic surgical aspirator (SNP-5000; Aloka, Tokyo, Japan) under Pringle's maneuver.[6,7] During the division of the liver parenchyma, MHV tributaries of more than 5 mm in diameter were preserved using the sling suspension technique.[8] After completion of the parenchymal dissection, the congested area was evaluated as previously described.[9] In brief, after clamping each tributary of the MHV, Doppler ultrasonography was performed to evaluate the portal flow to segment VIII. Subsequently, the right hepatic artery was clamped for a few minutes and the congested area was estimated. When the area of congestion was too large or Doppler ultrasonography indicated reversed portal flow to segment VIII, the MHV was transected proximal to the root of the V8 branch.

The orifice of the hepatic veins of the graft became inevitably separated or became 1 orifice with a septum. Furthermore, the length of the exposed vein was decreased. For easier anastomosis, plasty of the vein orifice on the graft was performed using a cryopreserved deceased donor vein (Fig. 2). To widen the orifice of the superficial branch of the left hepatic vein or that of the MHV, slits were made on the bilateral side of the hepatic vein orifice of the graft. On the recipient side, the venoplasty to make 1 orifice from the left hepatic vein and MHV was performed by the technique described previously.[10] An end-to-end anastomosis was then made between the graft and recipient orifices. The caudate lobe was procured with the left liver and if there were large caudate veins, they were reconstructed.[11]

In recipients, the vascular flow of the graft was checked by Doppler ultrasonography twice a day for the first 14 days and once a week thereafter until hospital discharge. Serum transaminase levels were checked every day for 4 weeks after the operation. In donors, serum transaminase was examined every day for 1 week after the hepatectomy. In both donors and recipients, abdominal CT was performed 3 months after the operation. The regeneration of each sector of the livers was calculated as described elsewhere.[1] The regeneration rates were compared with those of 16 donors who underwent both left hepatectomy with total MHV deprivation and postoperative CT. The Mann-Whitney test was used for the statistical analysis. Measured variables were expressed as range and median. A P value less than .05 was considered significant.

Results

Donors

The operative time and blood loss was 515, 497, and 530 minutes, and 620, 775, and 490 mL, respectively. Postoperatively there were no severe complications to necessitate reoperation. Each donor was discharged on the 12th, 14th, and 16th postoperative day. During the

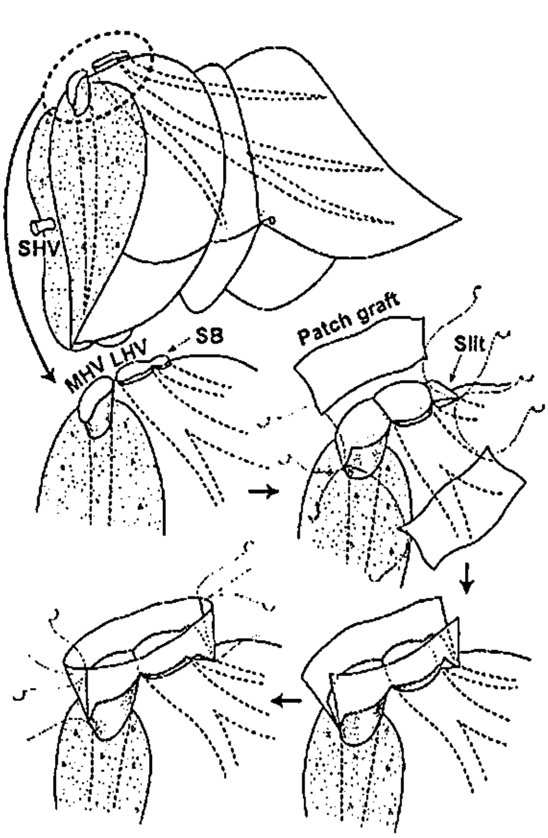

Figure 2. Venoplasty of the stumps using patch grafts. After plasty to make 1 orifice, a slit was made bilaterally to widen the orifice and 2 patches were sutured to the anterior and posterior edges. Each side of the patch was then sutured. The stump was extended and enlarged. Abbreviations: SHV, short hepatic vein; MHV, middle hepatic vein; RHV, right hepatic vein; SB, superficial branch.

3 months after LDLT, comparable regeneration between the right paramedian and lateral sectors was seen in the 3 donors (Table 1).

The regeneration rates of the right paramedian and lateral sector of the 16 donors who underwent left hepatectomy with total MHV deprivation were −20% to 99% (median 3%) and −27% to 118% (median 31%), respectively. There was no significant difference between the 3 cases with V8 preservation and the 16 donors with MHV deprivation in regeneration rate of either the paramedian ($P = .12$) or lateral ($P = .57$) sector.

Recipients

The operative time and blood loss of the 3 patients were 880, 955, and 913 minutes, and 4,276, 5,315 and 2,295 mL, respectively. The cold / warm ischemic time of the graft in each case was 106 / 59, 138 / 64, and 150 / 62 minutes, respectively. In Cases 1 and 3, 1 caudate vein was reconstructed. In Case 2, there was no caudate vein with a diameter of more than 5 mm and the reconstruction was not performed. The hospitalization duration after LDLT was 37, 72, and 30 days. During the hospitalization, Doppler ultrasonography revealed a well-maintained triphasic pattern of venous flow and no findings of arterial or portal venous thrombosis in any patient.

Laboratory data indicated that the maximum serum alanine aminotransferase level (376, 314, and 868 IU/L) occurred within the 2nd postoperative day in all cases. In Case 2, a splenectomy was performed simultaneously because of thrombocytopenia. Pancreatic juice leakage occurred postoperatively, but this was treated conservatively by percutaneous drainage, which resulted in a 72-day-long hospitalization. After discharge, no signs of venous stenosis such as persistent abnormal liver function, hypoalbuminemia, ascites, or pleural effusion were observed in either patient.

Discussion

In LDLT, donor safety must be the 1st priority. Preoperative liver volumetry by CT is one of the most important methods for selecting an appropriate donor. Most transplant centers in Western countries choose right liver graft routinely in adult-to-adult LDLT.[12] Right

Table 1. Liver Regeneration in Donors Estimated by Computed Tomography

	RPM			RLS		
Case	Pre (mL)	Post (mL)	RR (%)	Pre (mL)	Post (mL)	RR (%)
1	498	630	27	298	391	31
2	254	351	38	236	386	63
3	462	562	22	243	338	39

Abbreviations: RPM, right paramedian sector; RLS, right lateral sector; Pre, volume on preoperative CT; Post, volume on CT 3 months after LDLT; RR, volume regeneration rate given by (postoperative volume-preoperative volume)/preoperative volume × 100 (%).

liver procuring, however, could impose a higher surgical risk on donors, as reflected by the volume of the residual liver mass.[13] Furthermore, not all donors can provide their right liver.[14] Fan et al.[15] concluded that safe donation was possible only when the estimated residual liver volume was over 30%. Left liver with the caudate lobe can be used as an alternative graft with[12] or without[16] reconstruction of the caudate vein if it is more than 40% of the recipient's standard liver volume.[15]

The MHV usually drains most of the paramedian sector and has a limited role in draining segment IV.[17] For left liver procuring in adult LDLT, the liver parenchyma is usually divided along the right side of the MHV to maintain high graft viability. Although this procedure can cause congestion and atrophy in the paramedian sector of the remnant right liver,[1] congestion is not a significant clinical problem. A compensatory hypertrophy of the right lateral sector may be induced.[18] According to our previous study,[9] in 26% of donors no significant congestion will occur because the regurgitated blood through the right paramedian vein flows into the right lateral vein via intrahepatic venous communication.

There are, however, some anatomic variations of the MHV. A previous report[19] revealed an MHV variation during resection of the right paramedian sector for tumor resection. When a large tributary of the MHV draining segments V and VI was divided, the surface of segment VI became dark purple. To relieve the congestion of segment VI, the MHV tributaries were reconstructed. The MHV sometimes drains a large part of segment VI, in which case, a trunk of the MHV must be preserved on the donor side.[20]

When segment IV is exclusively drained through left hepatic or scissural vein, the present technique will be less relevant. We must note a large interindividual difference in the graft volume regeneration after partial liver transplantation, which might be due to individual anatomical variation in the venous drainage. In the present analysis, we could not clearly show more satisfactory regeneration in the right paramedian sector by V8 preservation. It might be due to the limited number of cases with the present technique.

Another problem with the present technique might include the possible venous graft failure in the long term.[21] Millis et al.[22] reported a 51% complication rate after using cryopreserved vascular graft. Kuang et al.[23] experienced complications including aneurysm, thrombosis, and stricture in 8 of the 9 cryopreserved vein grafts, which were used for portal vein and hepatic arterial interposition. These previous discouraging results indicate that long-term follow-up will be necessary to confirm the feasibility of the technique.

In this report, we propose an option for left liver graft procurement by preserving a large V8. Postoperative CT revealed comparable regeneration of the right paramedian and lateral sectors in donors. Although the indication for the technique is limited by the MHV anatomy, it will minimize liver congestion and can contribute to reducing donor risk.

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Hepatic Arterial Anatomy for Right Liver Procurement From Living Donors

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Living donor liver transplantation (LDLT) using right liver grafts is now widely performed. Anatomic classifications of the hepatic artery for right liver procurement, however, are limited. In this study, celiac and mesenteric angiograms of 223 consecutive living donors in a single institution were evaluated. Details of the arterial anastomosis and results were reviewed in 72 patients who underwent primary LDLT using right liver grafts. There was a 6% incidence of hepatic arterial bifurcations that might provide multiple orifices in a right liver graft. Only one right liver graft (1%) had multiple arterial orifices. Single arterial anastomosis without interposition was possible in all patients with right liver grafts and none of them were complicated with hepatic arterial thrombosis. Single arterial anastomosis, therefore, has a high probability of success in right liver graft implantation. (*Liver Transpl 2004;10:129–133.*)

Living donor liver transplantation (LDLT) is a preferable treatment for adults with end-stage liver disease due to the limited number of available cadaveric donors.[1] Fundamental to the application of this technique is an understanding of hepatic vascular anatomy.[2] Michels first reported 10 basic types of hepatic arterial supply.[3] Since then, common and rare hepatic artery variants have been reported. Most of these studies, however, focused only on replaced or accessory arterial branches that are helpful for whole-liver harvesting and transplantation. Without information regarding bifurcation of the right hepatic artery (RHA), the classification is of little help for right liver harvesting.

Recently, Marcos et al proposed the use of interposition arterial grafts in right liver graft because double hepatic arteries were common in their series.[7] Their report conflicted with our experience because, in our series, no patients underwent double hepatic artery reconstruction in right liver LDLT. To clarify this inconsistency, we evaluated celiac and mesenteric angiograms of 223 consecutive living donors in a single institution. The aim of the study was to determine a useful anatomic classification of the hepatic arteries for LDLT using right liver grafts.

Materials and Methods

Donors

From January 1996 until May 2003, 223 consecutive living donors underwent hepatectomy at the University of Tokyo Hospital. They comprised 126 men and 97 women with a median age of 34 years (range, 18–63 years). Details regarding selection criteria and evaluation are described elsewhere.[8] Only one case was rejected due to arterial anatomy.[9] All of the donors were related to the recipients. The relation of the donors to the patients was 84 parents, 65 children, 37 siblings, 22 spouses, 9 nephews, and 4 uncles and two cousins. The type of graft was determined by volumetric analysis and not by vascular anatomy. The graft estimate was determined by computed tomography (CT). A graft-volume-to-recipient-standard–liver-volume ratio[10] of 40% was the lower limit. Candidates in whom the right liver comprised more than 70% of the whole liver were rejected as prospective donors. The most common procedure was left liver with or without caudate lobe resection (n = 85), followed by right liver resection (n = 72), left lateral segmentectomy (n = 51), and right lateral resection of right lateral sector (n = 15). All donors provided written informed consent.

Angiography of celiac and mesenteric arteries was performed in each donor to evaluate the anatomy of the donor's hepatic artery. First, the anatomy was reviewed according to Michels's classification.[3] Thereafter, the anatomy was classified from the point of view of whether single or multiple anastomoses were needed in LDLT using the right liver. In

Abbreviations: A6, accessory branch from segment VI; CT, computed tomography; Ce, celiac axis; GDA, gastroduodenal artery; LDLT, living donor liver transplantation; LHA, left hepatic artery; LGA, left gastric artery; MHA, middle hepatic artery; PSPDA, superior pancreaticoduodenal artery; RHA, right hepatic artery; RL, lateral branch of right hepatic artery; RPM, paramedian branch of right hepatic artery; SA, splenic artery; SMA, superior mesenteric artery.

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Table 1. Anatomy Classification Stratified by Michels

Type	Description	Michels's Series (n = 200)	Present Series (n = 223)
1	Normal	55%	61%
2	Replaced LHA from LGA	10%	14%
3	Replaced RHA and MHA from SMA	11%	4%
4	Replaced LHA from LGA, and replaced RHA from SMA	1%	0
5	Accessory LHA	8%	12%
6	Accessory RHA	7%	3%
7	Accessory LHA and accessory RHA	1%	2%
8	Accessory LHA and replaced RHA, or replaced LHA and accessory RHA	2%	0
9	PHA from SMA	4.5%	6%
10	PHA from LGA	0.5%	0

Abbreviations: LGA, left gastric artery; LHA, left hepatic artery; MHA, middle hepatic artery; RHA, right hepatic artery; SMA, superior mesenteric artery.

this classification, the anatomy of the left hepatic artery (LHA) was not always considered.

Patients Receiving Right Liver Grafts

The actual arterial anastomosis was reviewed in 72 patients who underwent primary LDLT using right liver grafts. The patients were 53 males and 19 females with a mean age of 50 years. The indications for LDLT in these patients included hepatitis C virus with cirrhosis (n = 25), hepatitis B virus with cirrhosis (n = 13), primary biliary cirrhosis (n = 12), fulminant hepatic failure (n = 8), cryptogenic cirrhosis (n = 5), metabolic disorders (n = 3), biliary atreasia (n = 3), primary sclerosing cholangitis (n = 2), and autoimmune hepatitis (n = 1).

The surgical details of the recipients were described previously.[11] In brief, hepatic arterial reconstruction was performed under a surgical microscope by a microsurgeon (HA). The donor and recipient arterial branches were anastomosed in an end-to-end manner with interrupted sutures using 9-0 monofilament nylon. When the donor's arterial branch was long enough to turn over, the anterior suture was performed first. Otherwise, the posterior wall was sutured with an inside-outward procedure using double needles; thereafter, the anterior wall was sutured without turning the anastomotic site over.[12] After reconstruction, the intrahepatic arterial signals in each segment were examined using Doppler ultrasonography; the other branches were ligated after confirming pulsatile back-bleeding from the nonanastomosed cut stumps[13] (k). When these criteria were not satisfied, the remaining arteries were anastomosed to the recipient hepatic arteries.

Results

Angiographic Classification

The frequency of each type proposed by Michels is shown in Table 1. There was a similar distribution between types in Michels's series and ours. There were no Michels types 4, 8, and 10 in our series, however.

To predict the number of hepatic artery stumps in right liver LDLT, the anatomy was classified into four types (Fig. 1). The frequency of each type is shown in Table 2. Type I secures a single arterial orifice in the right liver graft. This type is divided into six subcategories. Type IA, normal anatomy in which RHA originates from the common hepatic artery and the middle hepatic artery (MHA) originates from the LHA; Type IB, same variation as Type IA, except that the MHA originated from the RHA; Type IC, replaced RHA from superior mesenteric artery (SMA); Type ID, replaced RHA and MHA from the SMA; Type IE, entire common hepatic artery from the SMA and the MHA from the LHA; Type IF, same as with Type IE except for the MHA originated from the RHA.

The hepatic arterial bifurcations that might provide multiple orifices in the right liver graft were divided into three types. A total of 14 donors (6%) were classified into these types. In Type II, the MHA originated from the paramedian (Type IIA) or lateral branch (Type IIB) of the RHA. In Type III, the right paramedian and lateral branch of the RHA had separated origins. This type was divided into two subtypes with a right lateral branch from the LHA (Type IIIA) or from the SMA (Type IIIB). In Type IV, there was an accessory branch from segment VI (A6). This type was divided into three subtypes according to the root of A6 as follows: Type IVA, from the hepatic artery proper; Type IVB, from the celiac trunk; and Type IVC from the superior pancreaticoduodenal artery. The relation between Michels's classification and ours is shown in Table 3.

Donors of Right Liver Resection

Among the 72 donors who underwent right liver resection, angiographic analysis predicted one Type IVA