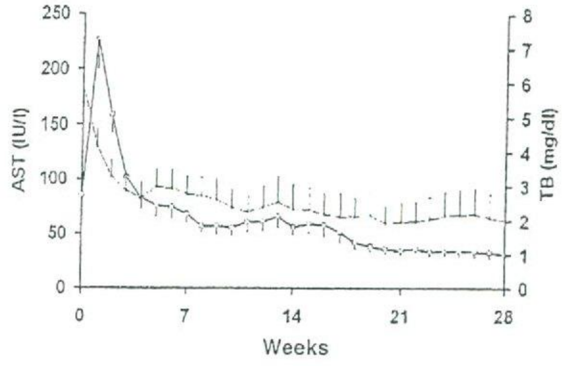

Figure 4. Changes in serum aspartate aminotransferase (AST, open circle with thick line) and total bilirubin level (TB, closed circle with thin line) for three weeks after the operation (n=40). Error bars represent standard error of the means.

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.

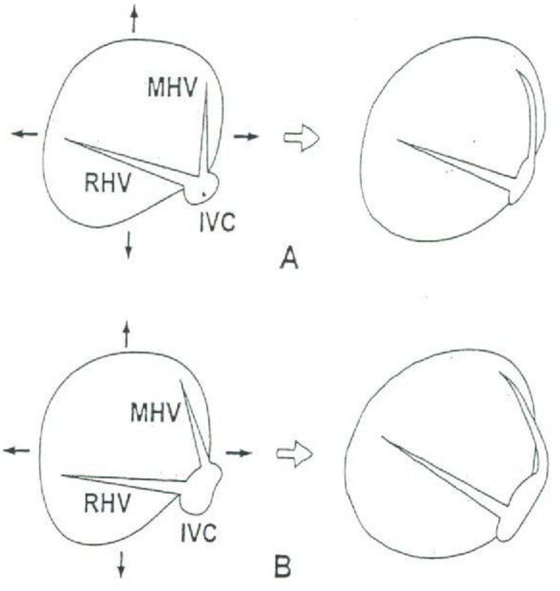

Figure 5. The graft will regenerate (arrows) and rotate toward left and dorsal side because the right subphrenic cavity is not large enough to accommodate the regeneration. (A) Short outflow reconstruction of middle and/or right hepatic vein (MHV or RHV) places the graft riding on the inferior vena cava (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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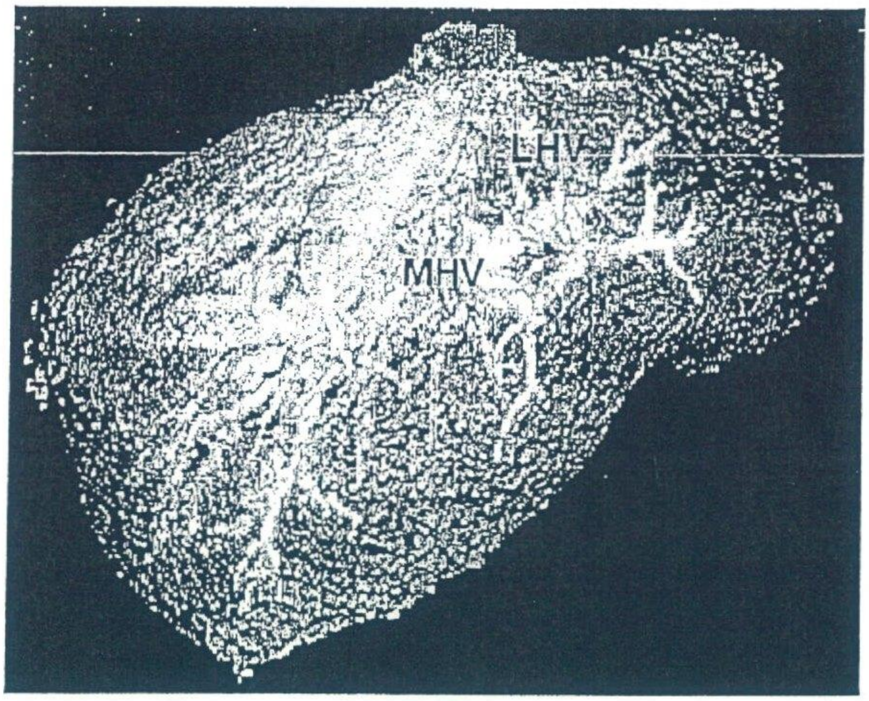

Figure 1. Computer-generated 3-dimensional image of the reconstruction. The red-colored vein indicates a V8 branch that was preserved on the donor side. The area drained by the V8 is shown in light brown. The white line in the left panel shows the dissection line of the hepatic veins. Abbreviations: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

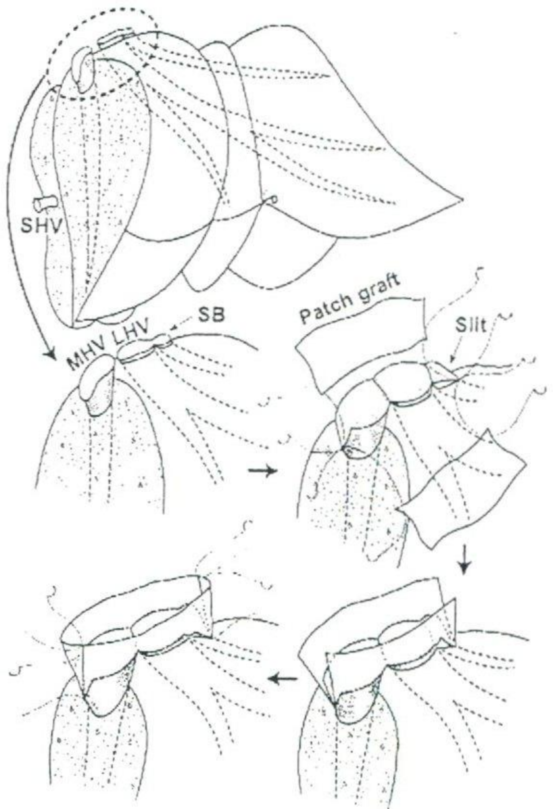

Figure 2. Venoplasty of the stumps using patch grafts. After plasty to make 1 orifice, a slit was made bilaterally to widen the orifice and 2 patches were sutured to the anterior and posterior edges. Each side of the patch was then sutured. The stump was extended and enlarged. Abbreviations: SHV, short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

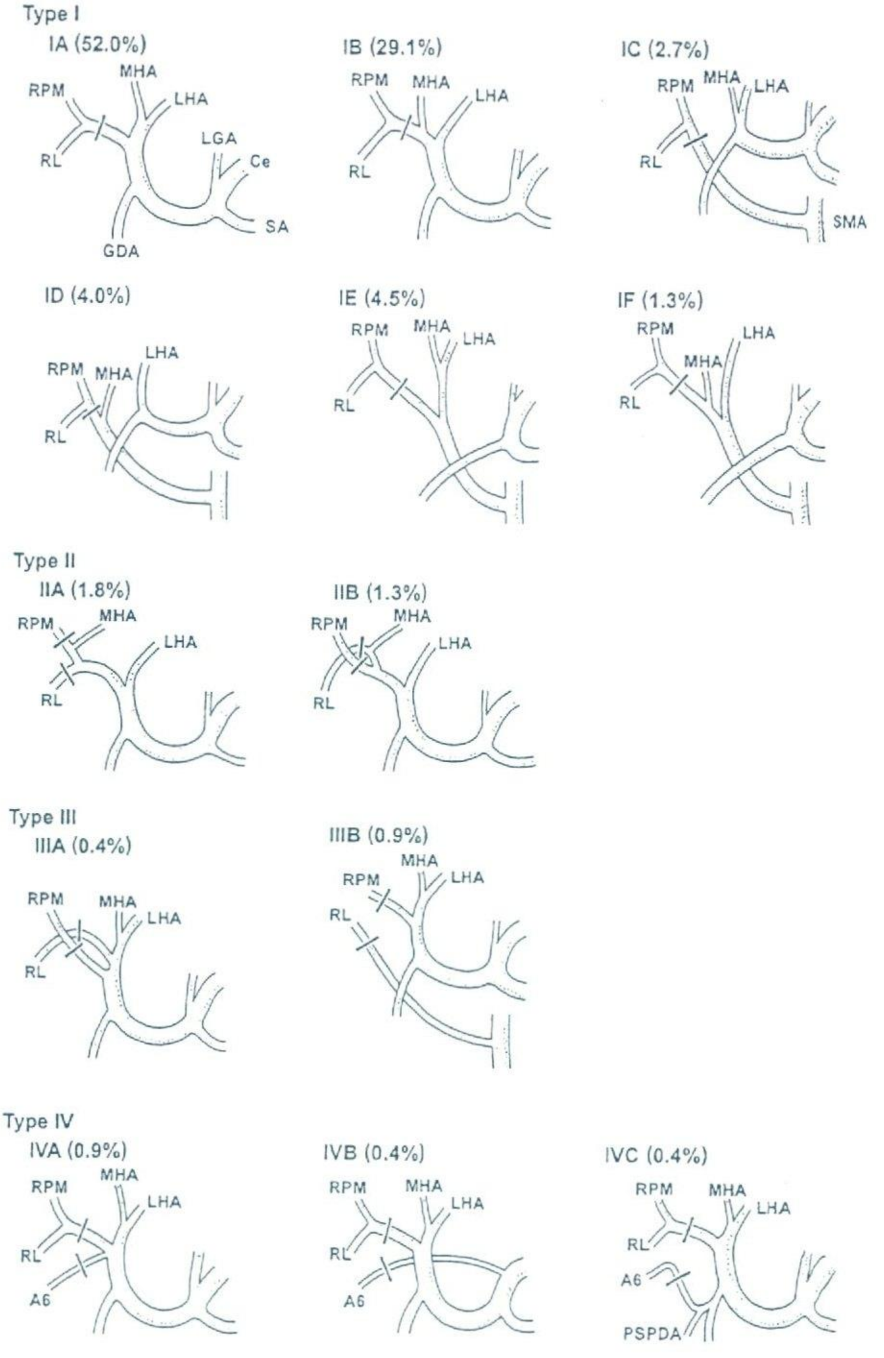

Figure 1. Arterial classification for right liver procurement.

donor who had multiple arterial orifices after right liver harvesting, confirmed during surgery. In this case, pulsatile backflow from A6 was observed after the graft RHA was anastomosed with the recipient's RHA. Therefore, the stump of graft A6 was ligated. As a result, single arterial anastomosis was possible in all right liver grafts in our series.

Clinical Results of the Patients Receiving a Right Liver

The duration of the operation ranged between 650 and 1,890 minutes (median, 915 min). The time for arterial reconstruction was 28 to 92 minutes (median, 43 min). No patients were complicated with hepatic arterial throm-

Table 2. Anatomic Classification of Right Hepatic Artery

Type	Total Donors (n = 223)	Donors of Right Liver (n = 72)
One arterial orifice	209 (94%)	71 (99%)
IA	116	38
IB	65	26
IC	6	1
ID	9	0
IE	10	6
IF	3	0
Multiple arterial orifices	14 (6%)	1 (1%)
IIA	4	0
IIB	3	0
IIIA	1	0
IIIB	2	0
IVA	2	1
IVB	1	0
IVC	1	0

bosis. Portal vein thrombosis was observed in two patients and was repaired by reoperation. Acute rejection was confirmed in 22 patients (31%) with a mean time to rejection of 17 days. Bile-duct leakage and stenosis of the anastomosis, which necessitated surgical revision, occurred in four and six patients, respectively. Two patients died during hospitalization, one for bleeding from the ileum (99 days) and the other for refractory acute rejection (49 days). The hospital-stay duration after LDLT of the survivors ranged from 16 to 143 days (median, 40 days). Four patients experienced late death due to virus-associated hemophagocytic syndrome (n = 2; 146 days and 370 days), hepatocellular carcinoma recurrence (n = 1; 229 days), and cholestatic hepatitis C (n = 1; 351 days). The other patients achieved survival with a median follow-up of 14 months.

Discussion

In the present study, visceral angiography was performed in 223 consecutive donors, and the findings were classified to reflect the number of RHA orifices after right liver harvesting. The results of Michels's data and those in our series were similar, indicating that there is little difference in hepatic arterial anatomy between the Japanese and the population in the United States. The analyses revealed that while the frequency of multiple orifices was predicted to be 6% in the overall series, it was actually only 1% in the donors of right liver resection. The results contrasted with the results of left liver grafts. Sakamoto et al classified hepatic arterial variations in 101 left liver donors.[13] They reported a 53% incidence of multiple arterial stumps in left liver grafts. The high incidence could be due to the MHA, which often originated independently from the LHA.

Our results contrasted with the recent data by Marcos et al.[14] They analyzed the results of 95 consecutive LDLT using right liver grafts, and of these, 11 grafts (12%) had double arteries. The double arterial orifices were sutured with auto Y-shaped arterial grafts at the bench. It is difficult to explain the discrepancy in the difference of anatomic variation in the subjects, because the precise classification was not shown in the previous data[14] They commented that the multiple arterial orifices in some grafts resulted from distal arterial division to spare the main trunk, common bile duct, and MHA. Although the MHA bifurcated from the RHA with 40% possibility (Types IB, ID, IF, and II), the trunk of the RHA could be cut near its root with a short but sufficient margin for its closure.

There is often only a single and very short arterial stump in the graft. The short conduit can be overcome, however, using microsurgical techniques.[15] When the donor's arterial branch was long enough to be clamped and turned over, it could be anastomosed using threads with double needles. Actually, in 72 patients who underwent right liver graft, there was no arterial thrombosis. We preferred not to use the interposition technique proposed as a reversed extension graft.[14] Harvesting an arterial graft for interposition will subject either the donors or recipients to an additional incision or

Table 3. Relation Between Michels's Classification and Ours

Description of RHA	Michels's Classification	Present Classification
Normal	1 + 2 + 5	IA + IB + II + IIIA + IVA
Replaced RHA and replaced MHA from SMA	6 + 8a*	IC
Replaced RHA from SMA	3 + 8b*	ID
CHA from SMA	9	IE + IF
Accessory RHA	7 + 8b	IIIB + IVB + IVC

*The classification was modified as 8a, accessory LHA and replaced RHA; and 8b, replaced LHA and accessory RHA.
Abbreviations: CHA, common hepatic artery; LHA, left hepatic artery; MHA, middle hepatic artery; RHA, right hepatic artery; SMA, superior mesenteric artery.

more extensive dissection. Additionally, the technique takes longer, and the risk of thrombosis in the recipient is increased. We consider the indication of interposition graft in arterial reconstruction quite limited.

It remains a debate in LDLT whether all arterial stumps should be anastomosed. The previous report demonstrated that small arteries supplying the left liver could be ligated safely if pulsatile back-bleeding was observed after anastomosis of the main artery.[16] Marcos et al commented that no portion of the right liver was supplied by secondary arterial perfusion, which was different from segment IV, so that any tributaries should not be ligated[7] In one case of right liver graft with two arterial stumps, however, a simple method of only one anastomosis was sufficient if backflow from another tributary was confirmed. Our experience was limited; however, it might indicate that compensation of arterial perfusion exists in right liver grafts as well.

Less invasive examination is favorable for donors, and the effectiveness of CT angiography and gadolinium-enhanced magnetic resonance angiography was recently proposed for donor evaluation.[17,18] Although the sensitivities of CT angiography and magnetic resonance angiography for the depiction of hepatic arterial variants are reported in several articles, the variants in these studies are limited to those commonly reported.[19,20] Kopka et al described their experiences evaluating hepatic arterial variants in 60 patients using both magnetic resonance angiography and digital subtraction angiography.[20] Magnetic resonance angiography did not correctly depict the visceral anatomy in three cases. We believe that precise and definite assessment of arterial anatomy is necessary, and we will continue to perform digital subtraction angiography for anatomic evaluation until the accuracy of the less invasive examinations are at least as complete as conventional examination.[21]

In conclusion, multiple arterial tributaries in right liver graft procurement are rare. The anatomic characteristics of RHA allow simple and safe anastomosis in a high probability.

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Volume Regeneration After Right Liver Donation

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After right hepatectomy with the middle hepatic vein trunk for a graft, the venous outflow in segment IV is disturbed. There are limited data, however, regarding the effect of middle hepatic vein deprivation on liver regeneration or functional recovery. Living donors who underwent right hepatectomy with preservation of the middle hepatic vein (Group A, n = 58) and those deprived of the middle hepatic vein (Group B, n = 13) were reviewed. When the donor was under 50 years old and the remnant left liver was estimated to be more than 35% of the whole liver, right liver graft harvesting with the middle hepatic vein trunk was considered. Volume regeneration of segments I–III, segment IV, and overall liver volume was assessed at the third postoperative month using computed tomography. The regeneration rate of segment IV was significantly impaired in Group B donors compared with that in Group A donors (125% vs. 45%, $P = 0.008$). In contrast, the regeneration rate of segments I –III was significantly higher than that in Group A (208% vs. 263%, $P = 0.004$). There was no significant difference in the regeneration rate of the whole left liver or functional recovery between groups. Multivariate analysis revealed that the resection type (group) was a significant predictive factor for the regeneration rate of segments I–III and segment IV. When deprived of the middle hepatic vein, liver regeneration of segment IV was impaired but was compensated for by the regeneration of segments I–III. In conclusion, extended right hepatectomy can be safely performed with careful preoperative consideration using these criteria. (*Liver Transpl 2004;10:65–70.*)

The shortage of cadaveric donors has led to an increase in the practice of living donor liver transplantation (LDLT).[1] A vital issue in 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 harvest a hemiliver graft, however, it is impossible to maintain complete venous outflow in both of the bisected livers, because the middle hepatic vein (MHV) can be preserved on only one side.

An extended right liver graft,[2] which includes the MHV trunk, was devised by the Hong Kong group. This method is beneficial with regard to venous drainage of the graft. On the donor side, however, the venous outflow disturbances in segment IV are a concern, and they might disrupt the function of the relevant hepatic region.[3] Consequently, this type of graft is less commonly used than a right liver graft without the MHV trunk.[4]

In our institution, we adopted right hepatectomy with or without MHV as the donor procedures for LDLT in selected donor-recipient combinations. The aim of the present study is to clarify whether deprivation of the MHV truly causes adverse effects in donors, including disturbances in liver regeneration of segment IV or functional recovery.

Materials and Methods

Subjects

From March 2000 through March 2003, 138 consecutive living donors underwent hepatectomy at the University of Tokyo Hospital. Of these, 71 donors with right hepatectomy were investigated. Details regarding selection criteria and evaluation are described elsewhere.[5] All of the donors were related to the recipients. The relationships of the donors to the patients were 29 children, 20 siblings, 10 spouses, eight parents, and four nephews. Preoperative liver biopsy was indicated when the body mass index was over 25, and candidates with more than 30% steatosis on biopsy were rejected as donors.[6] All donors and patients provided written informed consent.

Right liver volume was preoperatively estimated using computed tomography (CT) as described previously.[7] Candidates in whom the right liver comprised more than 70% of the whole liver were rejected as prospective donors. The esti-

Abbreviations: CT, computed tomography; LDLT, living donor liver transplantation; MHV, middle hepatic vein.

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mated ratio of graft volume to recipient standard liver volume was 40%, which 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. When the donor was under 50 years old and the remnant left liver was estimated to be more than 35% of the whole liver, extended right liver graft harvesting was considered. Otherwise, right liver graft harvesting without the MHV trunk was indicated.

The donors were divided into two groups. Group A (control group) included 58 donors who underwent resection of the right liver (segments IV–VIII). In this group, the MHV trunk was preserved in the remnant donor liver, and venous drainage of the right paramedian sector was thoroughly maintained after hepatectomy. Group B consisted of 13 donors with right liver resection involving the MHV. In this group, venous drainage of segment IV was interrupted after hepatectomy. Group A was comprised of 34 men and 24 women with a median age of 38 years (range, 36–61 yr), and Group B was comprised of two men and 11 women with a median age of 37 years (24–54 yr). Postoperative CT with contrast enhancement was routinely conducted 3 months after hepatectomy for evaluation of postoperative liver volume regeneration.

Surgical Technique and Postoperative Care

The surgical techniques of donor hepatectomy were described previously.[9] Briefly, a J-shaped incision was made to enter the abdominal cavity. Hepatectomy started with a careful hilar dissection. Intraoperative ultrasound was then performed to confirm the hepatic vein anatomy and to verify the transection plane. For right liver harvesting without the MHV trunk, the transection line was set at a plane to the right of the MHV. In this type of hepatectomy, MHV tributaries, if present and greater than 5 mm in diameter, were isolated and preserved. In contrast, for right liver harvesting with the MHV trunk, the transection line was set at a plane to the left of the MHV. Attention was paid to preserve a hepatic vein branch draining segment IV.

Parenchymal transection was performed using a combination of the clamp fracture technique and a Cavitron Ultrasonic Surgical Aspirator (SNOP 5000; Aloka Co., Tokyo, Japan). All sizable vascular and biliary structures were divided between ligatures. During transection, the inflow was intermittently occluded by Pringle's maneuver and sometimes selectively to the right portal vein and the paramedian branch of the right hepatic artery.[10] After the transection, the portal flow to segment IV was confirmed by Doppler ultrasound.

Postoperatively, all donors were observed in the intensive care unit for one night. Total bilirubin level, aspartate aminotransferase level, and prothrombin time were measured every day after the operation for 1 week and every other day for the next week.

Volume Regeneration Rate

The term "volume regeneration rate" is defined as "increasing percentage per 3 months," as defined previously[11] Accordingly, the volume regeneration rate of segments I–III and segment IV during the initial 3 postoperative months was calculated using the following formulas:

$$RR_{I\text{-}III} = (V2_{I\text{-}III} - V1_{I\text{-}III}) / V1_{I\text{-}III} \times 100\ (\%)$$
$$RR_{IV} = (V2_{IV} - V1_{IV}) / V1_{IV} \times 100\ (\%)$$
$$RR_{I\text{-}IV} = (V2_{I\text{-}IV} - V1_{I\text{-}IV}) / V1_{I\text{-}IV} \times 100\ (\%)$$

Abbreviations are as follows: RR_n, volume regeneration rate (%) of segment(s) n during the first three postoperative months; $V1_n$, volume (ml) of the segment(s) n on preoperative CT; $V2_n$, volume (ml) of the segment(s) n on CT at the third postoperative month.

The ratio of the remnant liver volume at the third postoperative month to the preoperative whole liver volume (RV), which is another index of liver mass restoration, was also calculated in both groups using the following formula:

$$RV = V2_{I\text{-}IV} / V1_{I\text{-}VIII} \times 100\ (\%)$$

Statistical Analysis

The clinical parameters were defined as follows: resection type (group), donor age, volume of blood loss during the operation, total ischemia time during hepatectomy, preoperatively estimated volume ratio to whole liver, and volume of the segment. These variables, except for resection type, were compared between groups using the Student t test. Multiple regression analysis was then performed to identify predictive factors independently associated with the regeneration rate. The clinical parameters were used as independent factors.

Intergroup comparison of intraoperative data was performed using the Student t test. Postoperative alanine aminotransferase level, total bilirubin level, and prothrombin time of the groups were compared using a two-way repeated measures analysis of variance. Differences were considered significant at a P value of less than 0.05. Values of measured variables were expressed as median and range or mean ± standard deviation.

Results

Operation

The median volume of blood loss was 420 ml (range, 110–1,537 ml), which was replaced by 320 ml (range, 0–1,200 ml) of each donor's own fresh frozen plasma or whole blood. The operation lasted 505 minutes (range, 355–1,495 min). The arterial blood supply was maintained, and venous congestion was not apparent on the remnant right liver surface at the time of hepatectomy. Intraoperative ultrasound, however, revealed hepatofugal portal flow to segment IV in 10 of 13 Group B donors (Fig. 1). In these cases, liver surface discoloration in a part of segment IV was observed after five minutes of clamping of the middle hepatic artery. There was no significant difference between the groups in any of the intraoperative parameters (Table 1).

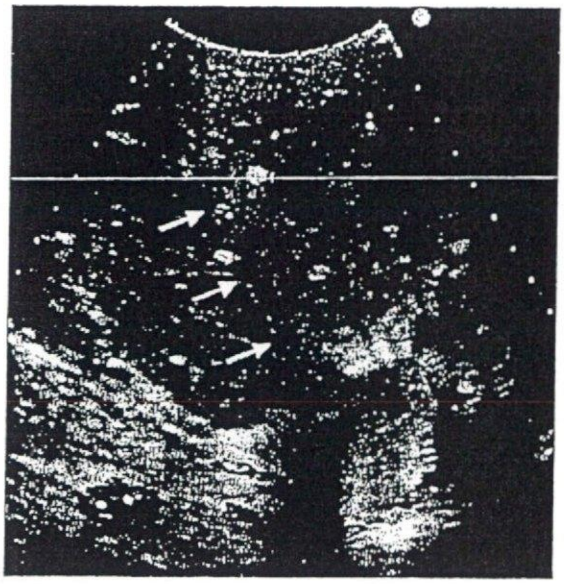

Figure 1. Intraoperative ultrasound after liver transection in a Group B donor. Note the hepatofugal flow to segment IV (arrows).

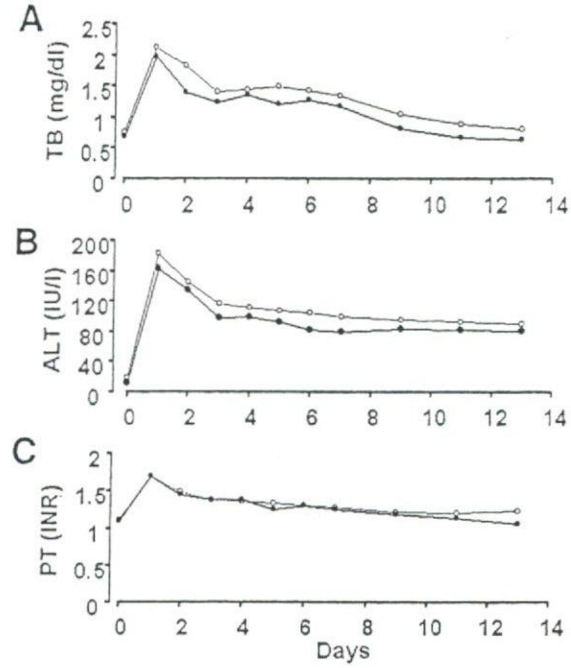

Figure 2. Changes in total bilirubin (A), alanine aminotransferase levels (B), and prothrombin time (C) for 2 weeks after transplantation. Group A is represented by open circles with a thin line (-○-). Group B is represented by closed circles with a thick line (-●-). Abbreviations: TB, total bilirubin; ALT, alanine aminotransferase; PT, prothrombin time.

Postoperative Course and Complications

All donors survived the operation. Postoperative bile leakage occurred in seven donors in Group A and in one donor in Group B. Of these, four donors in Group A required reoperation for repair. Bile leakage was seen from the stump of the right bile duct branch in three and dissection plane of the liver was seen in one, which was closed meticulously. Another donor in Group A was complicated with abscess formation in the dissection plane of the liver and underwent reoperation for drainage.

Laboratory Data

In both groups, total bilirubin level, alanine aminotransferase level, and prothrombin time peaked on the first postoperative day and gradually decreased thereafter (Fig. 2). There was no significant difference between the groups in any of these parameters.

Liver Volumetric Regeneration

The volumetric data are summarized in Table 2 and the volume regeneration rate of each sector is illustrated in Figure 3. There was a significant difference in the ratio of remnant liver volume between the groups. In Group B, RR_{IV} (45 ± 33%) was lower than RR_{I-III} (263 ± 48%, Fig. 4). In Group A, the regeneration rate was more proportional. RR_{IV} in Group B was significantly lower than that in Group A (P = 0.008), whereas RR_{I-III} in Group B was significantly higher than that in Group A (P = 0.004). There was no significant differ-

Table 1. Intraoperative Data

	Group A (n = 58)	Group B (n = 13)	*P* Value
Duration (min)	533 ± 159 (505-1495)	491 ± 75 (395-650)	0.36
Blood Loss (ml)	449 ± 230 (250-1537)	563 ± 268 (165-1125)	0.12
Autologous Blood transfusion (ml)	358 ± 307 (0-1200)	215 ± 289 (0-600)	0.42
Ischemic Time (min)	53 ± 17 (45-89)	59 ± 18 (40-95)	0.23

NOTE: Numbers in parentheses indicate range.

Table 2. Volumetric Data

	Group A (n = 58)	Group B (n = 13)	*P* Value
$V1_{I-IV}/V1_{I-VIII}$ (%)	34 ± 2 (30-39)	37 ± 2 (35-41)	0.04
$V1_{I-III}$ (ml)	228 ± 55 (131-381)	200 ± 38 (141-263)	0.17
$V1_{IV}$ (ml)	136 ± 38 (85-205)	134 ± 37 (83-194)	0.91
$V2_{I-III}$ (ml)	506 ± 124 (348-849)	557 ± 157 (423-935)	0.32
$V2_{IV}$ (ml)	300 ± 105 (150-659)	194 ± 72 (118-343)	0.008
RR_{I-III} (%)	208 ± 32 (149-280)	263 ± 48 (205-337)	0.004
RR_{IV} (%)	125 ± 62 (50-307)	45 ± 33 (9-101)	0.008
RR_{I-IV} (%)	125 ± 38 (72-218)	124 ± 37 (70-180)	0.98
RV (%)	75 ± 10 (56-98)	80 ± 12 (63-98)	0.19

Abbreviations: $V1_n$, volume of the segment(s) *n* on preoperative CT (ml); $V2_n$, volume of the segment(s) *n* on CT at the third postoperative month (ml); RR_n, volume regeneration rate of segment(s) *n* during the first three postoperative months (%); RV, ratio of the remnant liver volume at the third postoperative months to the preoperative whole liver volume given as $V2_{I-IV}/V1_{I-VIII} \times 100$ (%).
NOTE: Numbers in parentheses indicate range.

ence between the groups in RR_{I-IV} or RV ($P = 0.19$ or $P = 0.98$, respectfully).

The results of multiple regression analysis are shown in Table 3. The resection type was the sole significant predictive factor for the regeneration rate of segments I–III and segment IV. In contrast, the preoperative volume percentage rate to the left liver (segments I–IV), but not the graft type, affected the regeneration rate of the remnant liver.

Figure 3. Volume regeneration rate of segments I–III and IV in each group. Group A is represented by open circles. Group B is represented by closed circles. Closed squares and vertical lines indicate the average levels ± standard deviation.

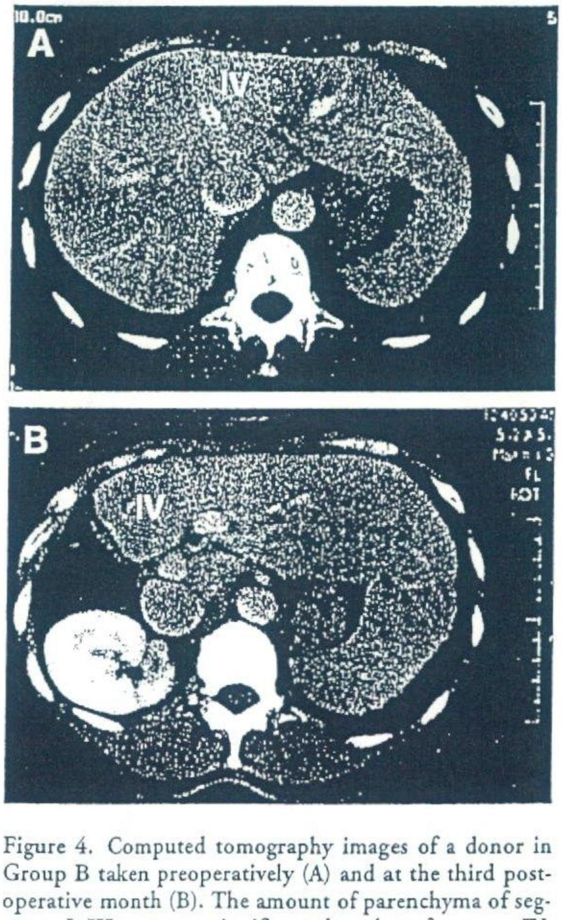

Figure 4. Computed tomography images of a donor in Group B taken preoperatively (A) and at the third postoperative month (B). The amount of parenchyma of segments I–III was more significant than that of segment IV. The broken line was drawn between segments I–III and IV. The regeneration rate of segments I–III and IV in the donor were 205% and 9%, respectively.

Table 3. Predictive Factors for Volume Regression Expressed as *P* Value

	Group	Age	Blood Loss	Ischemic Time	Preoperative Volume Ratio to Whole*	Preoperative Volume*
$RR_{I\text{-}III}$	0.0007	0.66	0.15	0.58	0.21	0.32
RR_{IV}	0.007	0.93	0.44	0.92	0.54	0.61
$RR_{I\text{-}IV}$	0.17	0.95	0.60	0.47	0.001	0.11

NOTE: Numbers indicate *P* values.
*Corresponded to that of the dependent factor.

Discussion

The present study demonstrated effects of outflow deprivation on liver regeneration. The regeneration rate of segments I–III and that of segment IV after right hepatectomy was proportional when the blood circulation was maintained. In contrast, segment IV without the MHV had impaired volume regeneration compared with cases in which the MHV was preserved. Conversely, in such cases, segments I–III underwent accelerated volume regeneration, probably due to a compensatory mechanism. The results are consistent with those of a recent report.[11,12] on the volumetric changes of the right liver after left or right liver donation.

Deprivation of the MHV tributaries induces hepatofugal portal flow of a part of segment IV. [13] Poor portal blood supply leads to unsatisfactory regeneration of segment IV, because portal blood is the most important nutritional supply for the liver parenchyma, and suspension of partial portal blood inflow results in impaired regeneration of the corresponding hepatic area.[14] Cheng et al.[15] reported that in LDLT using the extended right lobe graft (segments II, III, and a part of segment IV), a part of segment IV decreased in volume when the MHV tributaries were not reconstructed. This observation can be explained by the hepatofugal flow of the portal branch of segment IV induced by deprivation of the MHV tributaries. A previous report[16] revealed that in LDLT, venous flow of the ligated MHV tributaries drained into the right hepatic vein by way of the venous collaterals that rapidly develop approximately 1 week after transplantation, which was confirmed by Doppler ultrasonography. Liver regeneration generally begins during the first 3 to 5 days after hepatectomy.[17]

Volume regeneration of segment IV without MHV drainage was not uniform among the individuals, ranging from 9 to 101%. The left medial vein draining the left part of the medial segment is close to the confluence of the middle and left hepatic veins.[18] This tributary flows into the left hepatic vein in the majority of cases, but sometimes it flows into the MHV. The variation in volume enlargement of segment IV might reflect an anatomic difference in left medial vein bifurcation. Thus, detailed recognition of the venous territory pattern on preoperative CT and ultrasonography in individual donors is essential.

As for whole remnant liver regeneration, the ratio of the preoperative left liver to the whole liver was a significant predictor. The results indicate that smaller livers will regenerate more quickly, which is consistent with previous data that regeneration of the partial liver converges to the standard liver volume.[19] In addition, partial venous disruption did not lead to overall retardation of mass restoration with the balance between impaired and accelerated regeneration of respective segments. Additionally, postoperative liver functional recovery was comparable between groups. These results suggest that extended right hepatectomy can be safely performed using our criteria. The procedure may be more frequently adopted, because it was not as risky for donors as previously estimated and could prevent a complex reconstruction strategy in MHV reconstruction in recipients. A previous report[20] suggested that a residual liver volume of 30% of the total volume is the lower limit. We believe, however, that a larger safety margin should be added to the limitation. We made a limitation of age less than 50 years for the donor for extended right hepatectomy. Previous studies reported that liver grafts from older donors had an inferior ability to regenerate.[21,22] The present multivariate analysis, however, failed to support the theoretical background of the age limitation. Nonetheless, without more data we will continue to employ the present criteria for donor selection for extended right hepatectomy.

Although the multivariate analysis revealed that the total blood-loss volume was not a significant predictor for liver regeneration, minimizing blood loss is clearly important for donor safety. Severe bleeding is associated with decreased hepatic blood flow and ischemic injury.[20] Although the upper limitation on ischemic duration should be discussed, previous data[10] indicated a beneficial effect of Pringle's maneuver on graft outcome. As the application of Pringle's maneuver requires no specific skills, surgeons should not hesitate to apply this technique to donor hepatectomy.

In summary, the present data indicated that right hepatectomy with MHV resection was associated with latent impairment in postoperative liver regeneration of segment IV. However, we could perform extended right hepatectomy with low postoperative morbidity 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. For donor safety, careful preoperative consideration should be given on a case-by-case basis to the extent of right liver harvesting.

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