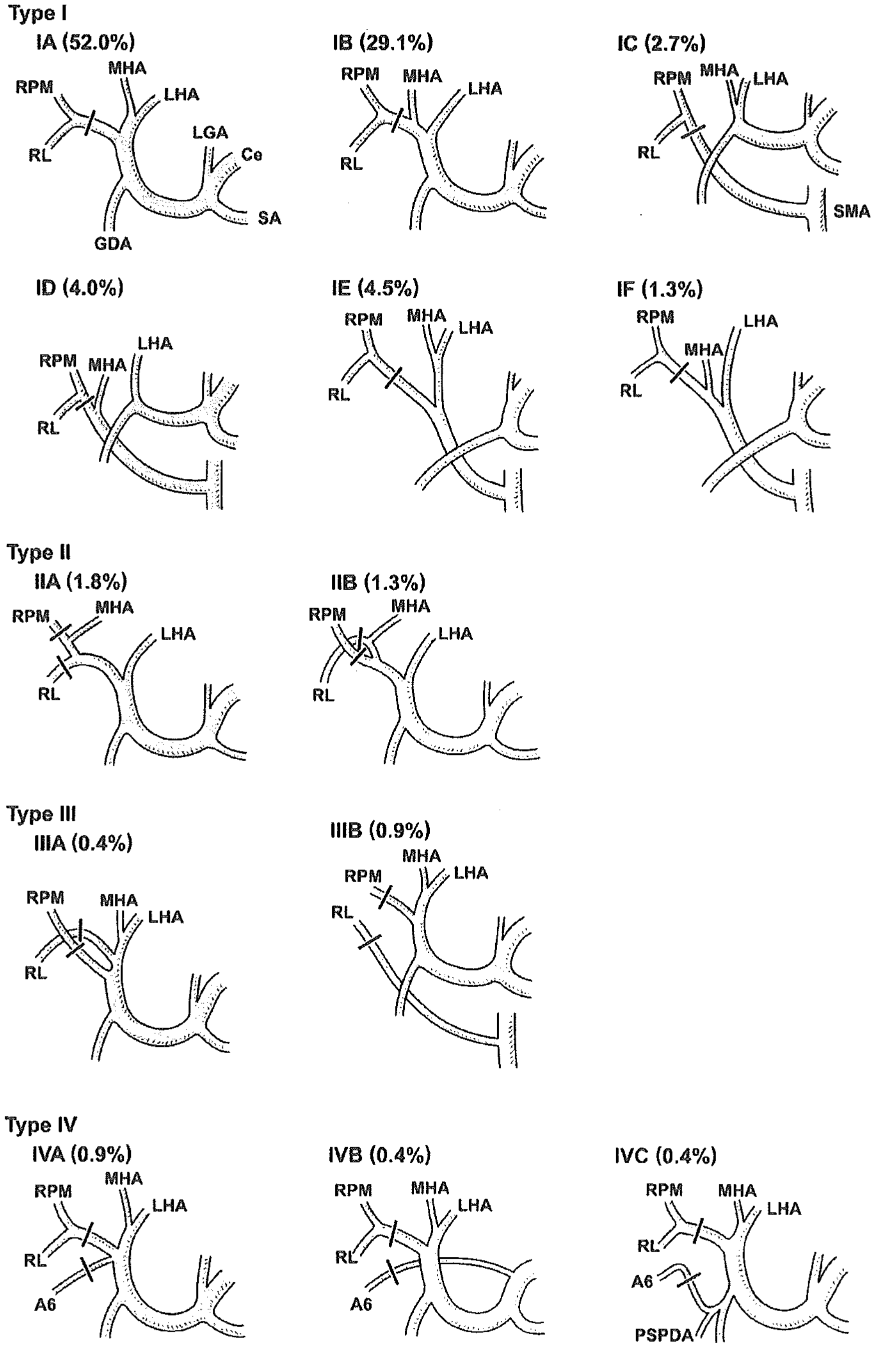


**Figure 1. Arterial classification for right liver procurement.**

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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*Supported by a Grant-in-aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology of Japan, and a Grant-in-aid for Research on Human Genome, Tissue Engineering, Food Biotechnology, Health Sciences Research Grants from the Ministry of Health, Labor and Welfare of Japan.*

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*Published online in Wiley InterScience (www.interscience.wiley.com).*
*DOI 10.1002/lt.20006*

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:

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

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:

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

### 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).

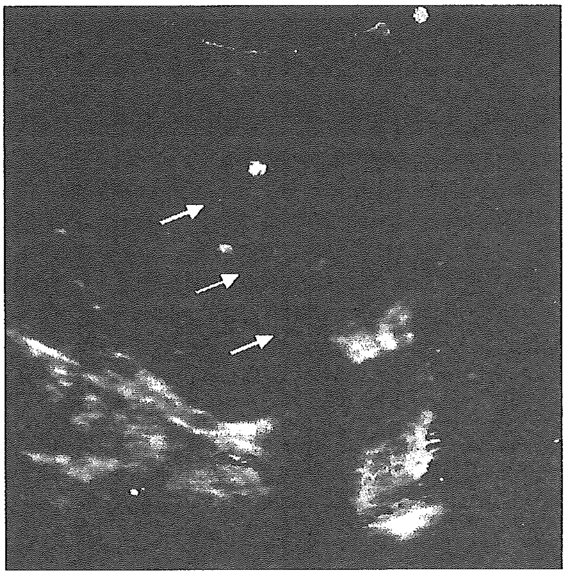

**Figure 1. Intraoperative ultrasound after liver transection in a Group B donor. Note the hepatofugal flow to segment IV (arrows).**

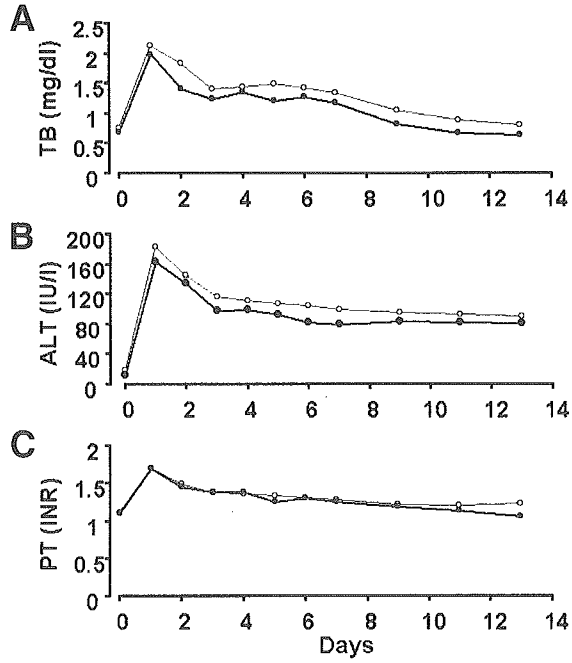


**Figure 2. Changes in total bilirubin (A), alanine aminotransferase levels (B), and prothrombin time (C) for 2 weeks after transplantation. Group A is represented by open circles with a thin line (-○-). Group B is represented by closed circles with a thick line (-●-). Abbreviations: TB, total bilirubin; 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 |
| $V1_{I\text{-}IV}/V1_{I\text{-}VIII}$ (%) | 34 ± 2 (30-39) | 37 ± 2 (35-41) | 0.04 |
| $V1_{I\text{-}III}$ (ml) | 228 ± 55 (131-381) | 200 ± 38 (141-263) | 0.17 |
| $V1_{IV}$ (ml) | 136 ± 38 (85-205) | 134 ± 37 (83-194) | 0.91 |
| $V2_{I\text{-}III}$ (ml) | 506 ± 124 (348-849) | 557 ± 157 (423-935) | 0.32 |
| $V2_{IV}$ (ml) | 300 ± 105 (150-659) | 194 ± 72 (118-343) | 0.008 |
| $RR_{I\text{-}III}$ (%) | 208 ± 32 (149-280) | 263 ± 48 (205-337) | 0.004 |
| $RR_{IV}$ (%) | 125 ± 62 (50-307) | 45 ± 33 (9-101) | 0.008 |
| $RR_{I\text{-}IV}$ (%) | 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 $V2_{I\text{-}IV}/V1_{I\text{-}VIII} \times 100$ (%).
NOTE: Numbers in parentheses indicate range.

ence between the groups in $RR_{I\text{–}IV}$ 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.

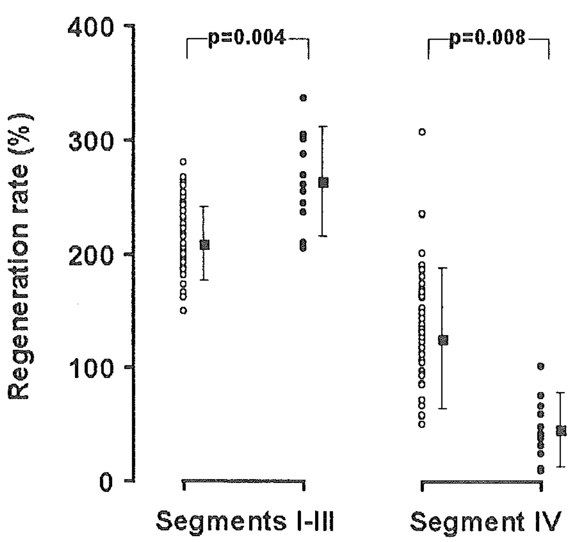


Figure 3. Volume regeneration rate of segments I–III and IV in each group. Group A is represented by open circles. Group B is represented by closed circles. Closed squares and vertical lines indicate the average levels ± standard deviation.

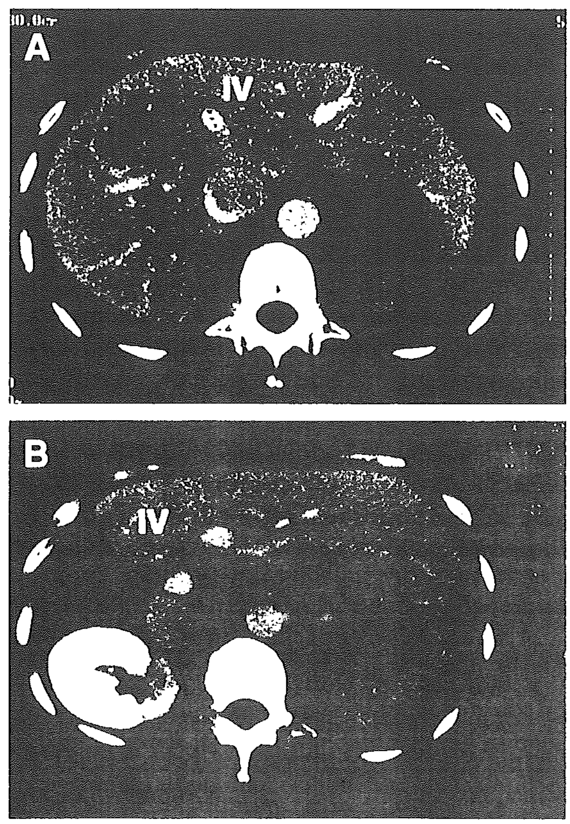


Figure 4. Computed tomography images of a donor in Group B taken preoperatively (A) and at the third postoperative month (B). The amount of parenchyma of segments I–III was more significant than that of segment IV. The broken line was drawn between segments I–III and IV. The regeneration rate of segments 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* |
|---|---|---|---|---|---|---|
| $RR_{I-III}$ | 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 |
| $RR_{I-IV}$ | 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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# 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),

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**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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*This work was supported by a grant-in-aid for scientific research from the Ministry of Education, Culture, Sports, Science and Technology of Japan and a grant-in-aid for research on Human Genome, Tissue Engineering, Food Biotechnology, Health Sciences research grants and grant-in-aid for Clinical Study on Indication and Effectiveness of Liver Transplantation for Patients with Hepatocellular Carcinoma from the Ministry of Health, Labor and Welfare of Japan.*

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*Published online in Wiley InterScience (www.interscience.wiley.com).*
*DOI 10.1002/lt.20129*

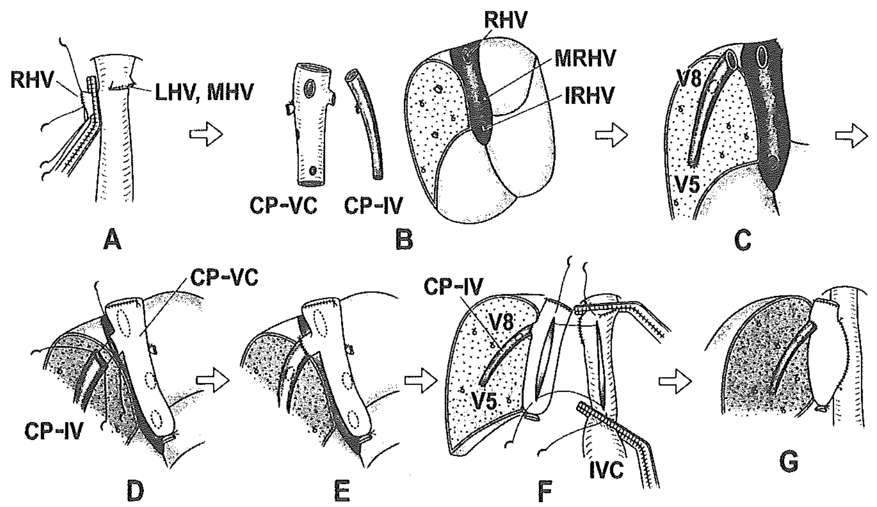


**Figure 1. Schematic view of double vena cava technique. (A) All hepatic vein trunks of the recipient (LHV, MHV, RHV) were sutured at their roots. (B) Three side holes were created in the wall of the cryopreserved vena cava graft (CP-VC) for anastomosis with the right hepatic vein and the short hepatic 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

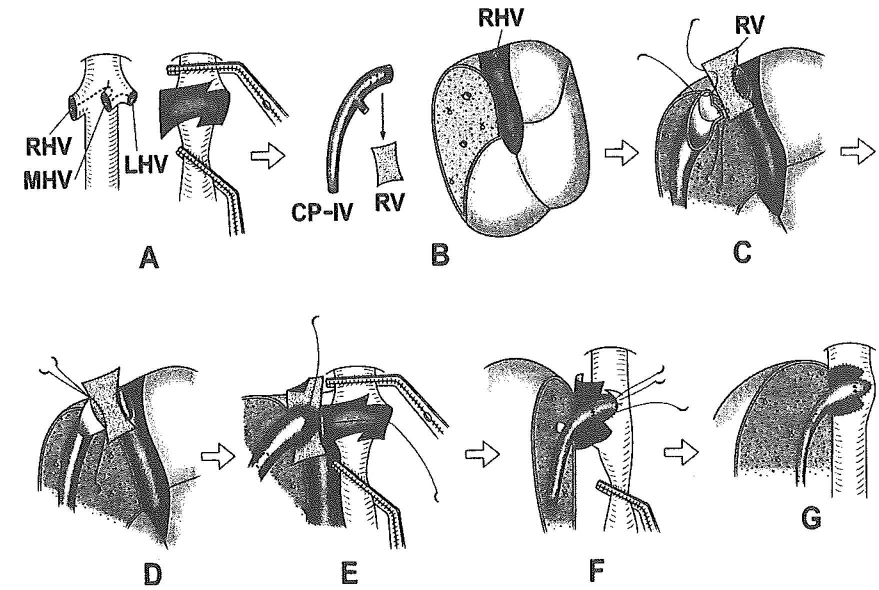


**Figure 2. Schematic view of rectangular shaped patch method. (A) All hepatic vein trunks of the recipient (LHV, MHV, RHV) were cut and one wide single orifice was made. (B) The cryopreserved vein graft (CP-IV) was used for interposition graft for MHV reconstruction. A proximal part of the CP-IV was 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

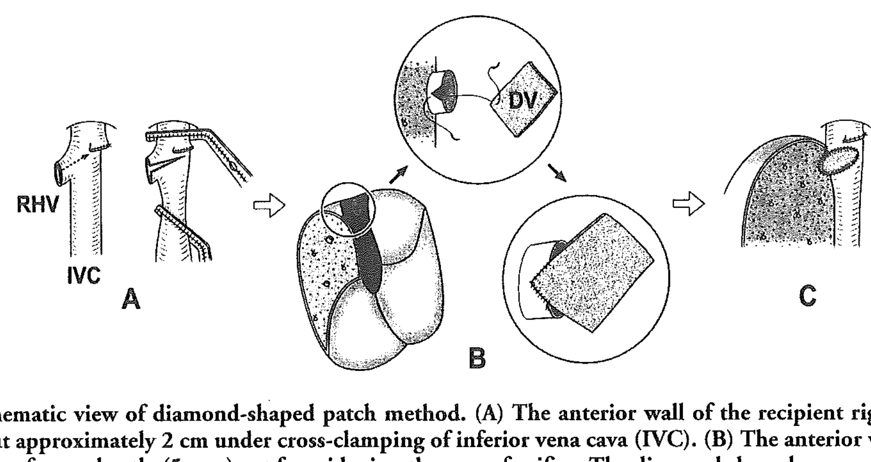


**Figure 3. Schematic view of diamond-shaped patch method. (A) The anterior wall of the recipient right hepatic vein (RHV) was cut approximately 2 cm under cross-clamping of inferior vena cava (IVC). (B) The anterior wall of the RHV orifice of the graft was shortly (5 mm) cut for widening the area of 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.**

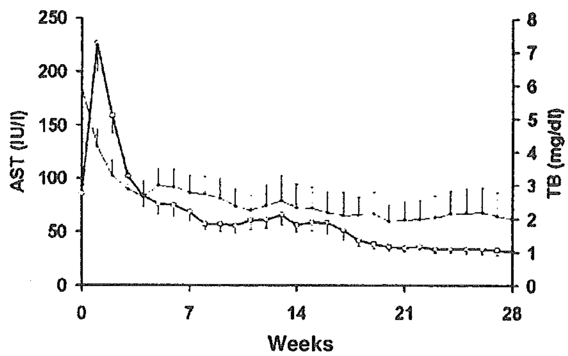


**Figure 4. Changes in serum aspartate aminotransferase (AST, open circle with thick line) and total bilirubin level (TB, closed circle with thin line) for three weeks after the operation (n=40). Error bars represent standard error of the means.**

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 | Reconstruction | | |
|---|---|---|---|---|
| | RLG:ERLG | 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.

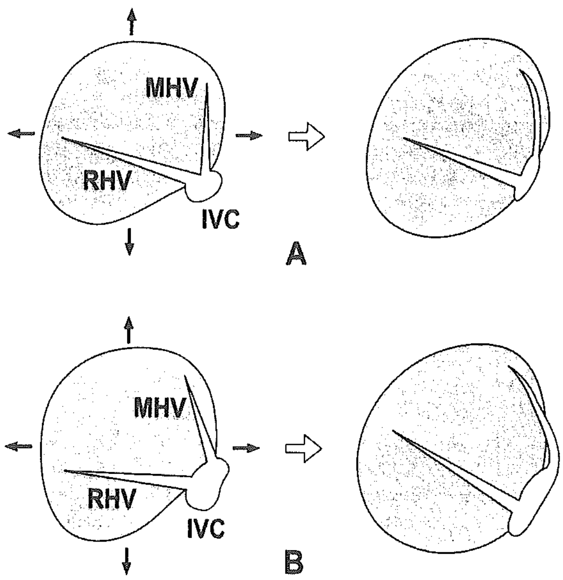


**Figure 5. The graft will regenerate (arrows) and rotate toward left and dorsal side because the right subphrenic cavity is not large enough to accommodate the regeneration. (A) Short outflow reconstruction of middle and/or right hepatic vein (MHV or RHV) places the graft riding on the inferior vena 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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# 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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*Supported by a Grant-in-aid for Scientific Research from the Ministry of Education, Culture, Sports, Science, and Technology of Japan, and Grants-in-aid for Research on HIV/AIDS and Research on Measures for Intractable Diseases from the Ministry of Health, Labor, and Welfare of Japan.*

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*Published online in Wiley InterScience (www.interscience.wiley.com).*
*DOI 10.1002/lt.20179*

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:

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

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.