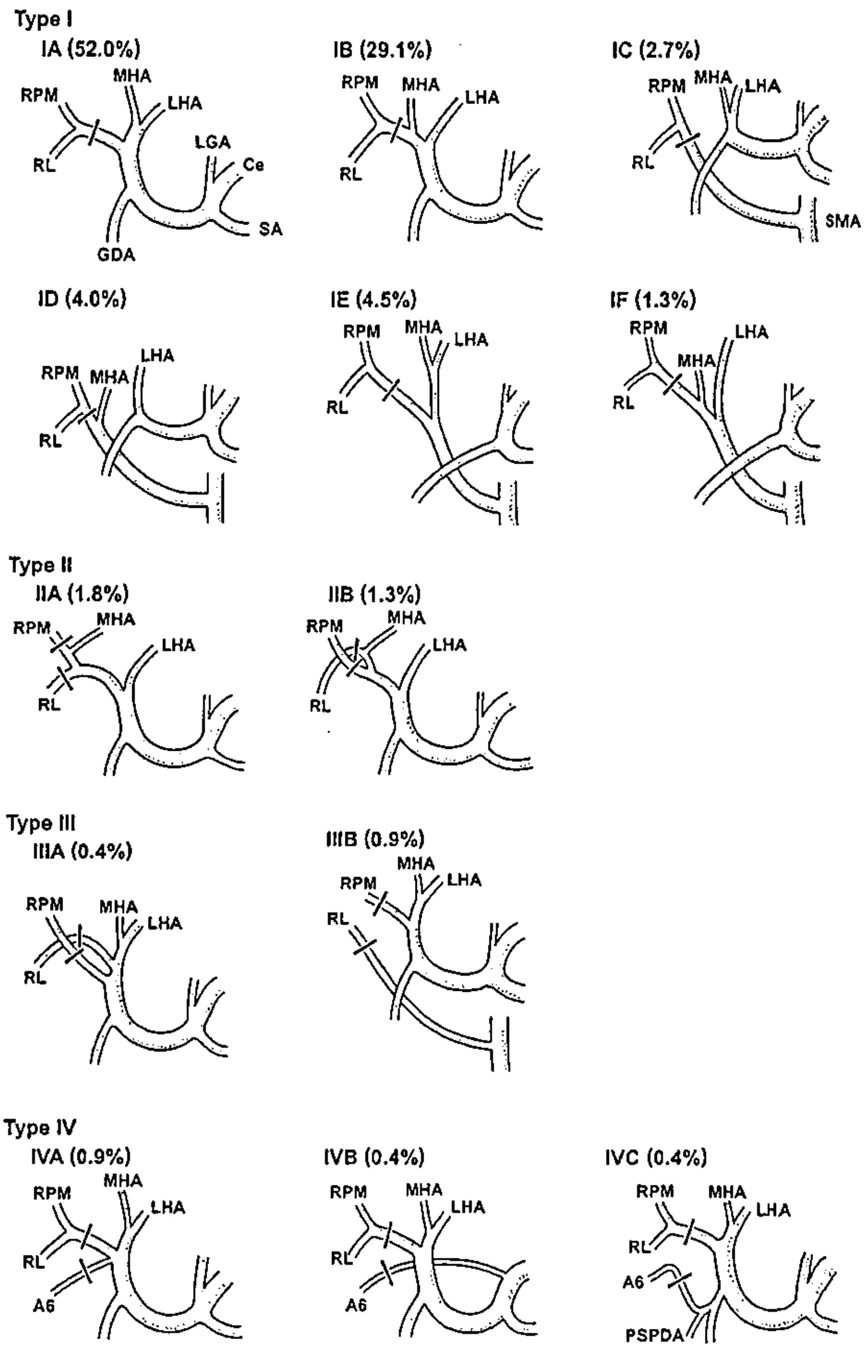

Figure 1. Arterial classification for right liver procurement.

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

Shojiro Hata, Yasuhiko Sugawara, Yoji Kishi, Takashi Niiya, Junichi Kaneko, Keiji Sano, Hiroshi Imamura, Norihiro Kokudo, and Masatoshi Makuuchi

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.

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

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Address reprint requests to Yasuhiko Sugawara, MD, Artificial Organ and Transplantation Division, Department of Surgery, Graduate School of Medicine, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8655, Japan. Telephone: +81-3-3815-5411; FAX: +81-3-5684-3989; E-mail, yasusuga-tky@umin.ac.jp

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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:

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

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).

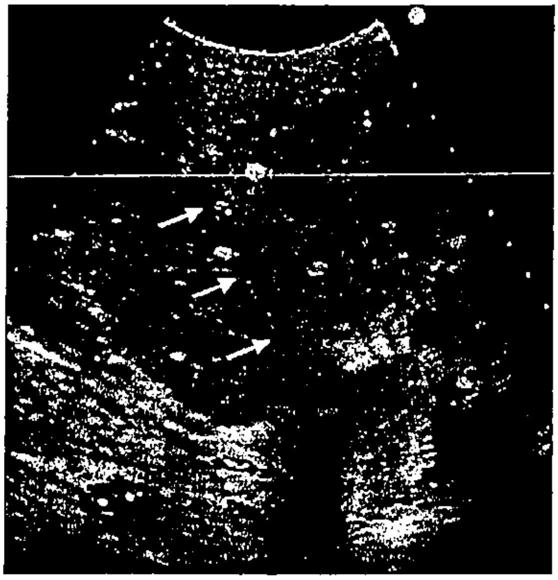

Figure 1. Intraoperative ultrasound after liver transection in a Group B donor. Note the hepatofugal flow to segment IV (arrows).

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.

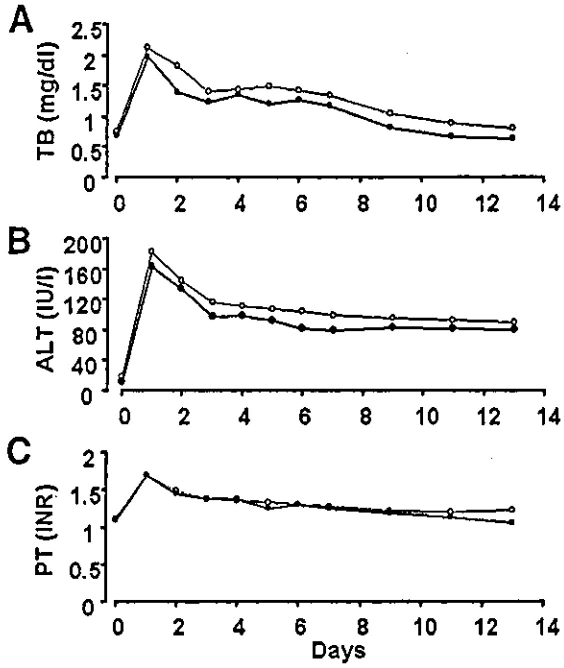

Figure 2. Changes in total bilirubin (A), alanine aminotransferase levels (B), and prothrombin time (C) for 2 weeks after transplantation. Group A is represented by open circles with a thin line (-○-). Group B is represented by closed circles with a thick line (-●-). Abbreviations: TB, total bilirubin;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

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.

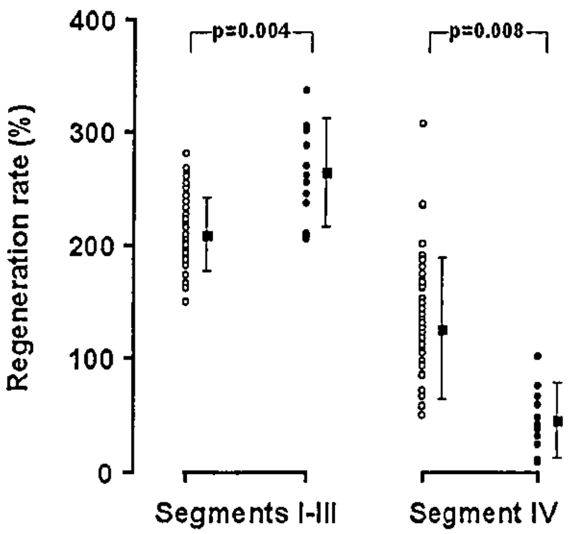

Figure 3. Volume regeneration rate of segments I–III and IV in each group. Group A is represented by open circles. Group B is represented by closed circles. Closed squares and vertical lines indicate the average levels ± standard deviation.

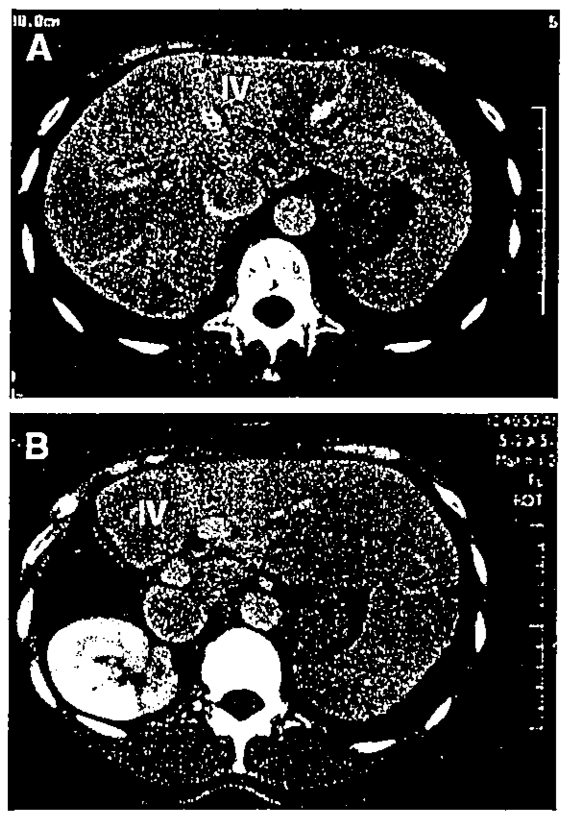

Figure 4. Computed tomography images of a donor in Group B taken preoperatively (A) and at the third postoperative month (B). The amount of parenchyma of segments I–III was more significant than that of segment IV. The broken line was drawn between segments I–III and IV. The regeneration rate of segments 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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SURGICAL REPAIR FOR LATE-ONSET HEPATIC VENOUS OUTFLOW BLOCK AFTER LIVING-DONOR LIVER TRANSPLANTATION

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

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

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

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

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

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

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

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

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

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

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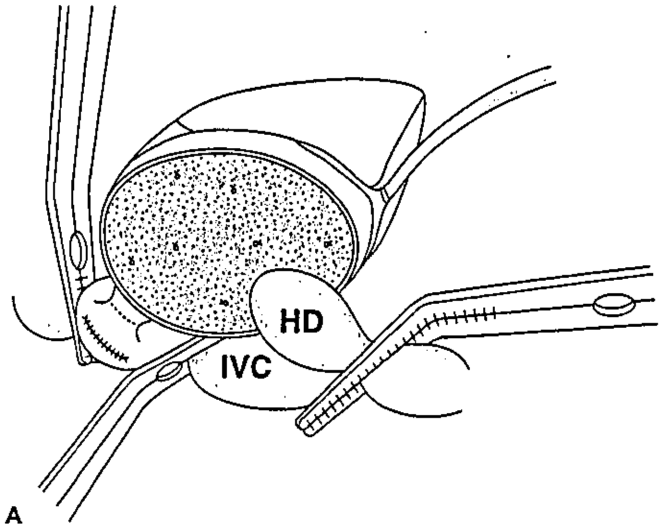

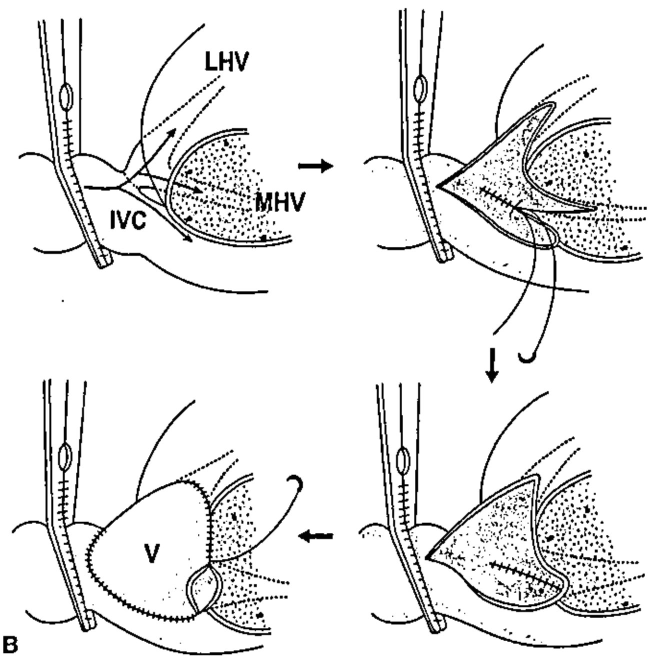

FIGURE 1. **A patch plasty for hepatic venous reconstruction. (A) Total vascular occlusion and cold perfusion of the graft. (B) Venoplasty of the stenotic anastomosis using a venous patch. HD, Hepatic artery, portal vein, and common bile duct; LHV, left hepatic vein; MHV, middle hepatic vein; IVC, inferior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

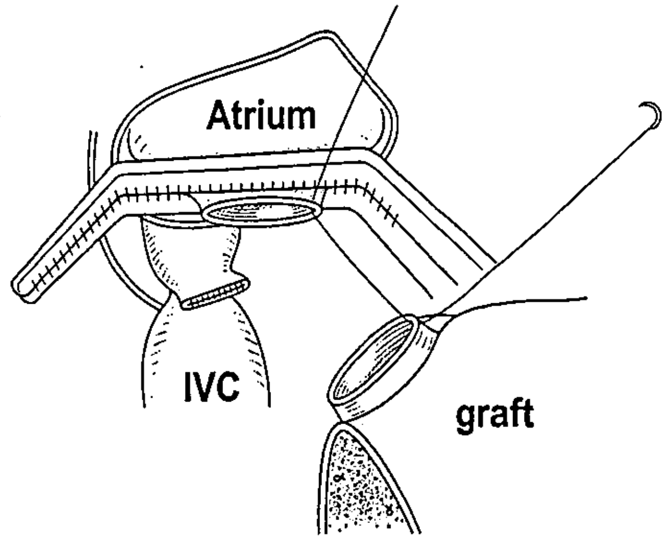

FIGURE 2. **A venoatrial anastomosis. The pericardium was incised. The bottom of the right atrium was then side-clamped and anastomosed with the hepatic veins of the graft. IVC, Inferior vena cava.**

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

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

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

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

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

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

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

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

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

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

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

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

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

Background. Bile duct-to-duct reconstruction is now used in living-donor liver transplantation (LDLT) for adult patients.
Methods. The results of duct-to-duct reconstruction were retrospectively analyzed. The subjects were 81 adult patients who underwent LDLT at the University of Tokyo Hospital with a follow-up period of at least 1 year. The hilar plate of the recipient was dissected to at least the second-order branch of the bile ducts. Duct-to-duct anastomosis was performed with interrupted sutures, and an external stent tube was inserted from the orifice opposite the hilar plate.
Results. During the observation period (median, 664 days), biliary complications were observed in 26 cases (32%). The complications included bile juice leakage at the anastomosis or dissection plane of the graft in 12 patients, anastomotic stenosis in 10 patients, and tube trouble in 6 patients. Two patients had bile juice leakage followed by stenosis. Of the 26 patients, 21 required surgical revision.
Conclusions. The current technique did not reduce morbidity as expected. Further technical advancement and refinement are needed for better results.

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

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

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

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

PATIENTS AND METHODS

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

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

Donor Operation

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

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

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

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

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

Recipient Operation

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

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

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

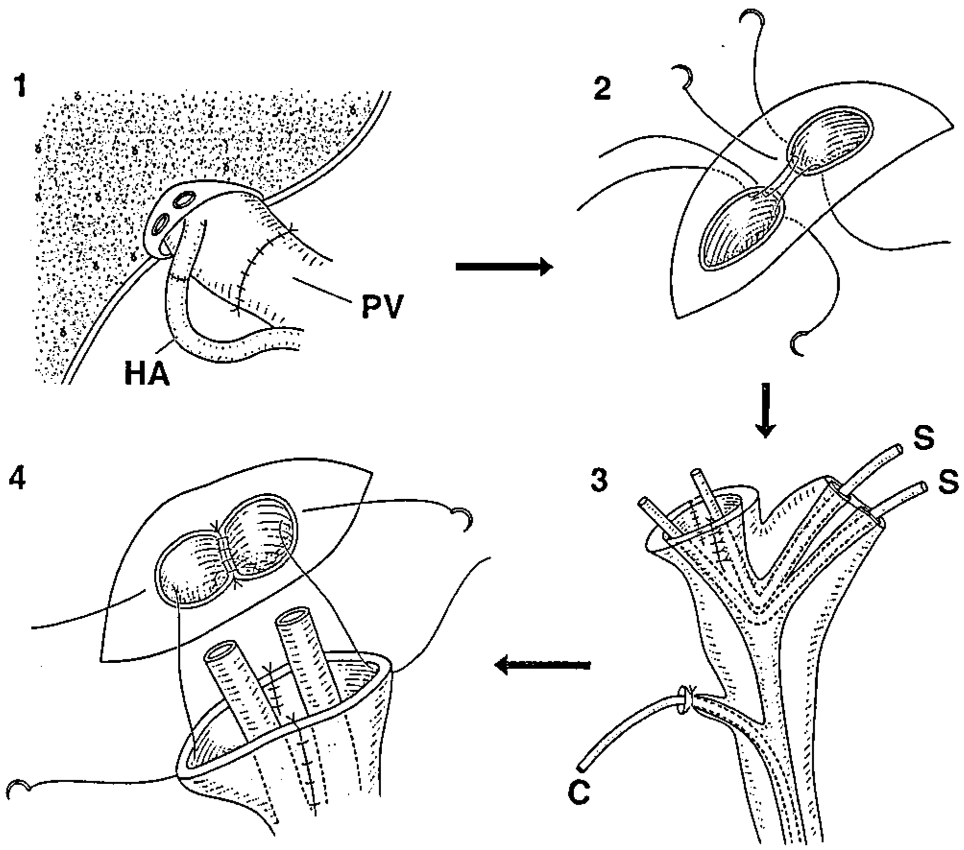

FIGURE 1. When there are two closely located bile duct orifices in the graft, the bile ducts in the hilar plate and graft were sutured into one. A stent tube (*S*) is introduced from the orifice opposite the hilar plate where the tube will be fixed to the plate. For nutrition or bile juice feeding, a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

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

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

RESULTS

Donors

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

Recipients

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

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

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

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

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

TABLE 1. Number of bile duct orifices

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

DISCUSSION

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

TABLE 2. Detail of bile duct stenosis

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

TABLE 3. Multivariate analysis for detecting predictors of biliary complications

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

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

TABLE 4. Comparison with the previous references

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

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

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

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

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

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

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

CONCLUSION

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

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

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

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

Abstract

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

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

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

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

Materials and methods

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

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

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

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

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

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

Results

Clinical results

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

RI levels

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

Ten records in four patients without HAT showed an RI of less than 0.5, recorded on the fourth, fifth, sixth, and ninth days after LDLT. In each patient, the RI level spontaneously

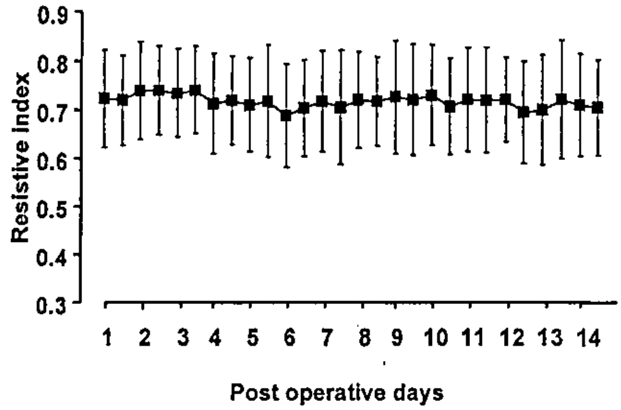

Fig. 1. Changes in RI values in patients without HAT (n = 63). RI was constant around 0.7 during the observation period.

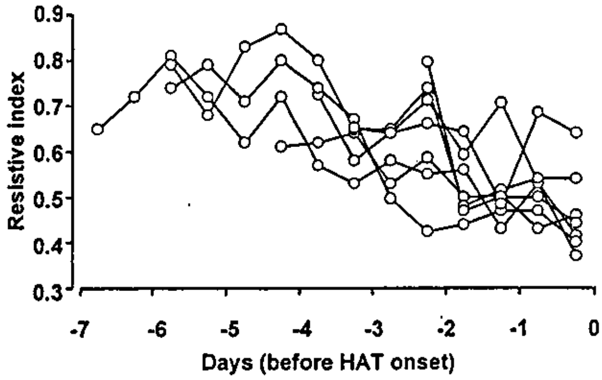

Fig. 2. Changes of RI values in patients with HAT complications (n = 7). RI decreased gradually 2 days before the onset of HAT.

recovered within 12 h. When the threshold was set at 0.6, the sensitivity and specificity of RI for HAT detection were 83% and 85%, respectively (Table 1).

Discussion

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