Characteristics of Liver Grafts in Living-Donor Adult Liver Transplantation
Comparison Between Right- and Left-Lobe Grafts

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Hypothesis: Few studies have investigated the results of research focused on living-donor adult liver transplantation. Different characteristics between right- and left-lobes have not yet been clarified in living-donor adult liver transplantation. Left-lobe graft remains an important option, even in adult recipients.

Setting: A single liver transplantation center with a long history of hepatic resection.

Patients: Forty-five donors received left-lobe (n=39) and right-lobe (n=6) grafts. The clinicopathological data for the donor, graft, and recipient were compared. All left-lobe grafts were extended grafts that included the middle hepatic vein, and 24 of the 39 left-lobe grafts included the left caudate lobe. No right-lobe graft included a middle hepatic vein.

Results: The postoperative aspartate aminotransferase and total bilirubin values of the donor in the right-lobe graft group were higher, and the postoperative hospital stay was longer than in the left-lobe graft group. Graft weight in the left-lobe graft group was lighter than in the right-lobe graft group (median weight, 450 vs 675 g). The median graft weight divided by the standard liver volume in the left-lobe graft group was 41% (range, 21%-66%), compared with 52% (range, 47%-75%) in the right-lobe graft group. We found no difference in terms of the incidence of postoperative complications between groups. No difference in induced complications of small-for-size grafts such as intractable ascites and persistent hyperbilirubinemia was evident between groups. The survival rate for grafts at 18 months was 75.0% in the right-lobe graft group compared with 85.6% in the left-lobe group. In the right-lobe graft group, we found a few cases in which a marked poor-perfusion area in the anterior segment caused liver dysfunction.

Conclusions: Left-lobe grafts are a feasible option for living-donor adult liver transplantation, and in the case of right-lobe grafts, hepatic venous drainage is one of the most critical problems.

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The number of living-donor liver transplantations has been on the rise because of the chronic shortage of cadaveric livers, originally for children.1-4 Recently, adult recipients have been included in living donor liver transplantations, especially in Japan, where the availability of brain-dead donors is limited. Compared with a cadaveric liver graft, the quality of the liver graft from the living donor is better owing to the shorter preservation time and better maintenance of the systemic hemodynamic state. In contrast, the liver graft volume (GV) is smaller owing to a partial liver graft; therefore, a problem of small-for-size grafts often occurs in the living-donor adult liver transplantations (LDALTs).5,7 The GV for a successful transplant is ideally more than 40% of the standard liver volume (SLV).7,8 In adult recipients, if a left-lobe graft is selected, the GV is often less than 40% of the SLV; therefore, for LDALT, right-lobe liver transplantation was introduced, and this trend has grown rapidly.9-15 From an ethical point of view, the risks involved for the living donor have to be minimized. The risk to the donor of the right-lobe graft is still unknown. Therefore, the extremely high spread of LDALT without any limitations must be regulated at this experimental stage to maintain good results.10 On that ground, instead of right-lobe grafts, left-lobe grafts with or without a caudate lobe should be recommended. As mentioned already, left-lobe grafts face the problem of being a small-for-size graft in adult recipients. Consequently, a right-lobe graft, which is bigger than a left-lobe graft, is necessary. Recently, dual left-lobe grafts from 2 living donors for 1 recipient were obtained to make up for the insufficient graft size and to ensure donor safety.17 From an anatomical viewpoint, when a right-lobe graft is used without a middle hepatic vein, the drainage...
veins of the anterior segment of the right-lobe graft are sacrificed during the parenchymal division. This situation often results in severe congestion in the grafted right lobe, leading to graft loss. To date, little has been reported regarding a detailed analysis of characteristics, including the outcomes for the right- or left-lobe graft in LDALT.

This report outlines our research findings in LDALT and provides a clarification of the characteristics of liver grafts in LDALT by comparing the results of right- and left-lobe grafts.

PATIENTS AND METHODS

Fifty-three living-donor liver transplantations for 51 patients, including 2 cases of retransplantation, have been performed at Kyushu University Hospital, Fukuoka, Japan, from October 1, 1996, through June 30, 2001. Among these, 45 cases were LDALT, which were included in this study. The indication for the LDALTs included fulminant hepatic failure in 17, primary biliary cirrhosis in 11, cirrhosis due to hepatitis C infection in 7, familial amyloid polyneuropathy in 2, primary sclerosing cholangitis in 2, glycogen storage disease in 1, hepatic tumor in 2, biliary atresia in 1, and other indications in 2. The donors included 3 husbands, 3 wives, 10 brothers, 5 sisters, 13 sons, 3 fathers, 3 mothers, 4 daughters, and 1 unrelated donor.

According to the different kinds of liver grafts, the patients were classified into the following 2 groups: a left-lobe graft group (n=39) in which a left lobe with or without a caudate lobe was used, and a right-lobe graft group (n=6) in which a right lobe was used. The clinicopathological data collected from the donor, graft, and recipient were compared between the groups.

According to preoperative clinical patient status such as the Child classification, we further classified the patients into the following 3 groups: Child classification A (n=8), Child classification C (n=20), and fulminant hepatic failure (n=17). We compared the incidences of intractable ascites, hyperbilirubinemia, and graft failure after LDALT among these 3 groups.

SELECTION OF THE GRAFT

The selection criteria used for the liver graft is described elsewhere. Briefly, the SLV was calculated using the formula developed by Ura et al. The liver volume was estimated using a preoperative abdominal computed tomographic (CT) scan. In principle, a minimal requirement for the liver GV was set at greater than 30% of the SLV. Preoperative assessment of a 3-dimensional CT scan is routinely performed, especially to make a decision of the parenchymal division line, including the number and size of draining veins (Figure 1). For patients with more severe portal hypertension, a liver GV of greater than 40% of the SLV is considered to be ideal. The left-lobe graft should be an extended graft and include a caudate lobe. In this study, all left-lobe grafts were extended grafts, including the middle hepatic vein, and 24 of the 39 left-lobe grafts included a left caudate lobe. In the case of the extended left-lobe graft with a caudate lobe, all short hepatic veins in the caudate lobe were divided and were not reconstructed. No right-lobe graft had a middle hepatic vein. A significant large drainage vein from segment 8, according to the liver segmentation by Couinaud, was reconstructed in 1 case, and the right inferior hepatic veins were reconstructed in 2 cases described in this study.

TECHNIQUE OF GRAFT HARVESTING

Graft harvesting in the donor is described elsewhere. Briefly, the right-lobe grafts were excised from the donors using an ultrasonic dissector and electrocautery at the right side of the Cantlie line, which meant that no middle hepatic vein was included in any of the right-lobe grafts. All branches from the middle hepatic vein were divided between the silk ties. All left-lobe grafts included the middle hepatic vein, and 24 of these included a left caudate lobe. After the hepatic hilar dissection, the right first Glisson branch, including the portal vein and hepatic artery, was clamped, and a demarcated line was observed on the right side of the Cantlie line. Parenchymal division was performed along the line 5 mm to the right side of the demarcated line; therefore, all left-lobe grafts included a middle hepatic vein and a part of the anterior segment, which was perfused from the left-side vascular vessels. During the parenchymal division inside the liver, the cutting plane was near the anterior Glisson branch and the right hepatic vein. This cutting plane was similar to the splitting line that was advocated by Colleldan et al.

Surgical techniques used in the recipient and postoperative care are described in detail elsewhere.

STATISTICAL ANALYSIS

The data were expressed as medians. We used the Mann-Whitney test with continuous variables and the χ2 test of in-de-
RESULTS

Table 1 summarizes the comparison of clinicopathological variables between the right- and left-lobe graft groups.

For the donor variables, we found no differences in operation time (median, 420 vs 461 minutes) and intraoperative blood loss (median, 850 vs 900 mL) between the right- and left-lobe graft groups. Only 1 significant postoperative complication of biliary stenosis requiring reoperation occurred in the initial cases in the left-lobe graft group. No other significant complications were found in either group. Postoperative aspartate aminotransferase and total bilirubin values in the right-lobe graft group were higher than in the left-lobe graft group (median aspartate aminotransferase levels, 470 vs 238 U/L; median total bilirubin levels, 4.5 vs 1.6 mg/dL [77.0 vs 27.4 μmol/L]). The postoperative hospital stay in the right-lobe graft group was longer than that in the left-lobe graft group.

The graft weight in the left-lobe graft group was naturally lighter than in the right-lobe graft group (median, 450 vs 675 g). The median GV/SLV in the left-lobe graft group was 41% (range, 21%-66%), whereas the median GV/SLV in the right-lobe graft group was 52% (range, 47%-75%). The liver GV in the right-lobe graft group was significantly larger than in the left-lobe graft group. The rewarmin g time in the right-lobe graft group, ie, the time from removal of the graft from the donor to reperfusion of portal flow in the recipient, was longer than in the left-lobe graft group (median, 50 vs 38 minutes). We found no difference in cold ischemic time between the 2 groups. The total blood and hepatic artery flows were similar in both groups. Theportal vein flow in the right-lobe graft group tended to be larger than in the left-lobe graft group (median, 1250 vs 915 mL/min).

In recipients, the rate of fulminant hepatic failure in the left-lobe graft group was higher than in the right-lobe graft group (17/39 vs 0/6). The operation time in the right-lobe graft group was longer than in the left-lobe graft group (median, 851 vs 723 minutes). The intraoperative blood loss in the right-lobe graft group was greater than that in the left-lobe graft group (median, 9109 vs 4600 mL). We saw no difference in the incidence of postoperative complications between the 2 groups. No difference was seen between groups in the incidence of intractable ascites and hyperbilirubinemia, which was defined as a serum bilirubin value of more than 10 mg/dL (171.0 μmol/L) at posttransplantation day 14. The 18-month graft survival rate in the right-lobe graft group was 73.0%, whereas it was 85.6% in the left-lobe graft group. The causes of graft loss in the right-lobe graft group were graft congestion in 1 patient as shown below, liver abscess in 1, and hepatoma recurrence in 1. In the left-lobe graft group, the causes of graft failure were hepatoma recurrence in 1, hepatic artery thrombosis in 2, Aspergillus infection in 2, abdominal bleeding in 1, adult T-cell leukemia in 1, and humoral rejection in 1.

The incidences of postoperative intractable ascites and hyperbilirubinemia were similar among the groups with Child classification A and C and fulminant hepatic failure (Table 2). The incidence of graft failure in the Child classification A group tended to be lower than in the Child classification C group (Table 2).

Figure 2 demonstrates the postoperative CT scan (postoperative day 6) of a case in which the patient received a right-lobe graft without a middle hepatic vein or any reconstruction of the draining veins from the anterior segment. A marked poor-perfusion area exists in the anterior segment. In this case, the whole GV was estimated to be 764 cm³ by means of CT scan, whereas the poor-perfusion area was estimated to be 268 cm³. Consequently, the functional GV divided by the SLV became 44%. All cases involving left-lobe grafts showed good perfusion on postoperative CT scan (Figure 3).

COMMENT

In this study, the postoperative hospital stay for donors in the right-lobe graft group was longer than in the left-lobe graft group (median, 14 vs 11 days). Furthermore, the postoperative aspartate aminotransferase and total bilirubin values for the right-lobe graft donors were higher than for the left-lobe graft donors. These facts suggest that surgical stress in donors who under go right-lobe hepatectomy is significantly greater than in those who undergo left-lobe hepatectomy, although no difference in operation time and blood loss were seen between the groups. Therefore, a potential risk for the right-lobe graft donors is clearly elucidated. The donor's safety takes precedence over the recipient's outcome; therefore, the remaining liver volume of the donor should not be less than 30% of their total liver volume if a right-lobe graft is harvested.

A right-lobe graft is naturally larger in volume than a left-lobe graft. However, even in the right-lobe graft group, intractable ascites were found in 3 of the 6 cases, which was a sign of small-for-size graft syndrome after LDALT. Congestion of the anterior segment in the right-lobe graft (Figure 2) is considered the main reason why right-lobe grafts do not always work as expected. When a large draining vein was recognized on results of preoperative examinations, including CT scans (Figure 1), we tried to reconstruct those veins as much as possible. However, relatively small veins were sacrificed, and this situation leads to congestion of the anterior segment in recipients with cirrhosis and a large amount of portal blood flow. In the donor hepatectomy, we have seldom experienced such congestion in the anterior segment, even when we divided such draining veins of segment 8 or 3. However, almost all right-lobe grafts were congestive in recipients who usually had severe portal hypertension due to end-stage liver cirrhosis. Despite a limited vascular bed, small grafts presumably receive all of the native portal inflow (a large amount of blood flow), and the hemodynamic consequence of transplantation may then be exaggerated.

Our preliminary study showed that the graft partial liver received 3 or more times the amount of portal...
Table 1. Comparison of Clinical Data Between Right- and Left-Lobe Graft Groups*  

<table>
<thead>
<tr>
<th>Variables</th>
<th>Right-Lobe Graft (n = 6)</th>
<th>Left-Lobe Graft (n = 39)</th>
<th>P Value</th>
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<tr>
<td><strong>Donor</strong></td>
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<tr>
<td>Age, y</td>
<td>47 (46, 49)</td>
<td>34 (25, 50)</td>
<td>.17</td>
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<td>Sex, M:F</td>
<td>1:5</td>
<td>29:10</td>
<td>.01</td>
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<tr>
<td>Operation time, min</td>
<td>420 (420, 511)</td>
<td>461 (371, 519)</td>
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<td>Blood loss, mL</td>
<td>850 (430, 1200)</td>
<td>900 (739, 1345)</td>
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<tr>
<td>No. of significant complications</td>
<td>0</td>
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<tr>
<td>Postoperative liver function tests‡</td>
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<td>AST level, U/L</td>
<td>470 (252, 581)</td>
<td>238 (202, 288)</td>
<td>.048</td>
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<tr>
<td>ALT level, U/L</td>
<td>457 (198, 564)</td>
<td>244 (202, 334)</td>
<td>.26</td>
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<tr>
<td>Total bilirubin level, mg/dL§</td>
<td>4.5 (3.3, 6.7)</td>
<td>1.6 (1.3, 2.4)</td>
<td>.004</td>
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<td><strong>Graft</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Weight, g</td>
<td>675 (560, 730)</td>
<td>450 (368, 550)</td>
<td>.001</td>
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<tr>
<td>GV/SLV, %</td>
<td>52 (49, 65)</td>
<td>41 (31, 44)</td>
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<td>Cold ischemic time, min</td>
<td>64 (47, 71)</td>
<td>57 (38, 77)</td>
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<td>Rewarming time, min</td>
<td>50 (42, 52)</td>
<td>38 (35, 42)</td>
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<tr>
<td>Total blood flow, mL/min</td>
<td>1410 (1115, 1748)</td>
<td>1000 (884, 1316)</td>
<td>.13</td>
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<td>Portal vein flow, mL/min</td>
<td>1250 (1025, 1625)</td>
<td>915 (750, 1200)</td>
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<td>Hepatic artery flow, mL/min</td>
<td>100 (58, 205)</td>
<td>100 (65, 131)</td>
<td>.74</td>
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<td><strong>Recipient</strong></td>
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<td>Age, y</td>
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<td>47 (37, 54)</td>
<td>.24</td>
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<tr>
<td>Sex, M:F</td>
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<td>14:25</td>
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<td>Indication, No. of patients</td>
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<td>Fulminant hepatic failure</td>
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<tr>
<td>Intractable rejection</td>
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<td></td>
</tr>
<tr>
<td>Operation time, min</td>
<td>851 (785, 930)</td>
<td>723 (615, 797)</td>
<td>.02</td>
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<tr>
<td>Blood loss, mL</td>
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<td>4600 (2775, 6644)</td>
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<td>.99</td>
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<td>Hepatic artery thrombosis</td>
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<td>Biliary stenosis</td>
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<td>Acute cellular rejection, No. of patients</td>
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<td>Causes of graft loss, No. of patients</td>
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<td>Graft congestion</td>
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<td>Hepatic artery thrombosis</td>
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<td>Aspergillus infection</td>
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<td>Humoral rejection</td>
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</table>

*Unless otherwise indicated, data are expressed as median (25th percentile, 75th percentile). AST indicates aspartate aminotransferase; ALT, alanine aminotransferase; and GV/SLV, graft volume/standard liver volume.
†Indicates biliary stenosis required reoperation.
‡Those values were peak values within 5 days after transplantation.
§To convert to micromoles per liter, multiply by 17.1.
| Bilirubin value was >10 mg/dL (171.0 µmol/L) at postoperative day 14. |
blood flow, even when right-lobe grafts were implanted. Because of severe portal hypertension reflecting hyperdynamic states of systemic and portal circulation in the recipients with cirrhosis, the grafted liver became an actual small-for-size graft in volume and a relatively small-for-size graft in portal blood flow. Once the right-lobe grafts were implanted in recipients, especially patients with cirrhosis and severe portal hypertension, the blood flow drastically increased, and the grafts became relatively congested. Therefore, even in right-lobe grafts, when draining veins were sacrificed, severe congestion occurred and the functional mass of the grafted right lobe was reduced. This fact leads to a poorly functioning graft in the case of right-lobe grafts. Lee et al.17 have recently reported this critical problem of the right-lobe graft. Marcos et al.25 also reported that a significant correlation was found between the change in portal flow in the right-lobe graft and the graft-to-recipient body weight ratio. They reported that the postoperative peak systolic velocity in a small graft (ratio, <0.9%) was significantly higher (115 cm/s) than in larger grafts (ratio, >1.2%; 50 cm/s). This high shear stress may be one of the most important contributors to dysfunction of small-for-size livers after transplantation. On the other hand, our standard left-lobe graft with a middle hepatic vein and a left caudate lobe had sufficient draining veins. To increase GV, several authors, including us, harvested the left caudate lobe with the left lobe.26-28 Outflow of the left-lobe graft is considered superior to that of the right-lobe graft. This fact represents a great merit of left-lobe grafts. In the right-lobe grafts, when a few significant draining veins (V5 and V8, etc) are divided, those venous branches can be reconstructed. However, those procedures are meticulous and should be avoided to shorten rewarming time of the grafts in implantation. Right-lobe grafts have a larger amount of hepatic mass; however, a right-lobe graft in

<table>
<thead>
<tr>
<th>Preoperative Recipient Status</th>
<th>Intractable Ascites</th>
<th>Hyperbilirubinemia†</th>
<th>Graft Failure</th>
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<tbody>
<tr>
<td>Child class A (n = 8)</td>
<td>3 (38)</td>
<td>2 (25)</td>
<td>1 (12)</td>
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<tr>
<td>Child class C (n = 20)</td>
<td>8 (40)</td>
<td>7 (35)</td>
<td>6 (30)</td>
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<tr>
<td>Fulminant hepatic failure (n = 17)</td>
<td>5 (29)</td>
<td>5 (29)</td>
<td>4 (24)</td>
</tr>
</tbody>
</table>

*Data are given as number (percentage) of patients.
†Indicates bilirubin value was >10 mg/dL (>171.0 µmol/L) on postoperative day 14.
LDALT is not always favorable and possesses significant pitfalls. The operation time for the recipient of the right-lobe graft was longer than that of the recipient of the left-lobe graft, and blood loss in the right-lobe graft was larger than in the left-lobe graft. This finding may reflect the increased number of hepatic vein reconstructions and increased bleeding from the cutting surface (anterior segment), due to congestion of the anterior segment.

Extended right-lobe grafts that include a middle hepatic vein are considered to be ideal as a right-lobe graft from the viewpoint of hepatic venous drainage; however, the risk for the donor was reported to increase. Therefore, from the standpoint of exclusive donor safety, indications for extended right-lobe graft should be extremely limited.

CONCLUSIONS

The left-lobe graft that includes a middle hepatic vein is often a small-for-size graft in LDALT; however, a sufficient venous drainage is secured in the left-lobe grafts. Therefore, left-lobe grafts may be ideal for the donor and the recipient if the immediate early liver support system can work well to reduce the metabolic loads of recipients. On the other hand, right-lobe grafts without a middle hepatic vein have the potential risk for graft congestion. Therefore, a left-lobe graft is a feasible option in LDALT, and in the case of the right-lobe graft, hepatic venous drainage is one of the most critical problems.

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