TRANSPLANT INTERNATIONAL

Transplant International ISSN 0934-0874

ORIGINAL ARTICLE

Clinical significance of right hepatectomy along the main portal fissure on donors in living donor liver transplantation

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Keywords
donor safety, living donor liver transplantation, main portal fissure, right hepatectomy.

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Conflicts of Interest
The authors have declared no conflicts of interest.

Received: 3 March 2012
Revision requested: 21 April 2012
Accepted: 19 June 2012
Published online: 17 July 2012

doi:10.1111/j.1432-2277.2012.01538.x

Summary

There might be discordance between inter-lobar borders of the main portal fissure (MPF) using the middle hepatic vein (MHV) and of the portal segmentation. Forty-five living donors who underwent right hepatectomy for the adult recipients from 2007 to 2011 in a tertiary hospital were retrospectively analyzed. The donors were classified into conventional right hepatectomy along the MPF (cRL group, $n = 26$) and modified right hepatectomy along right-side shifted transection plane from the MPF (mRL group, $n = 19$). The cRL donors had higher postoperative peak level of INR (1.84 vs. 1.62; $P = 0.022$), and bilirubin (3.37 mg/dl vs. 2.74 mg/dl; $P = 0.065$) than the mRL donors. cRL donors experienced greater depression of platelet count (144 per nL vs. 168 per nL; $P = 0.042$) and enlargement of splenic volume (52% vs. 37%; $P = 0.025$) than mRL donors for 7 days after hepatectomy. The regeneration of the left lateral sector was more accelerated in the cRL donors than the mRL donors for postoperative 3 months (148% vs. 84%; $P = 0.015$). There were no differences in the post-transplant graft function, incidence of complications, and graft survival rates between the two groups of recipients ($P > 0.05$). This study suggests that the conventional right hepatectomy along the MHV might increase donor risk by reducing parenchymal liver volume of the segment IV.

Introduction

Adult-to-adult living donor liver transplantation (LDLT) has been widely performed for treating end-stage liver disease, especially in countries where deceased donors are scarce [1–3]. A right lobe (RL) graft is preferentially selected in most LDLT programs because it usually satisfies the metabolic demands of an adult recipient. However, one of the major concerns in adult LDLTs using RL grafts is increased surgical risk in a living donor. Donor safety should be ensured by accurate preoperative volumetric assessment of the remnant left lobe (LL) and perfect, flaw-free operative preservation of the LL [4,5].

During parenchymal dissection of living donor right hepatectomy, the middle hepatic vein (MHV) is conventionally regarded as the intra-hepatic landmark of the inter-lobar border between the RL and LL. And this hepatic transection plane of using the MHV is known as the main portal fissure (MPF) [5,6]. However, there might be an anatomical mismatch of the MPF and Couinaud's portal segmentation because the course of the MHV usually runs from the segment IV proximally to the segment V distally. In living donor hepatectomy, the mismatch could be found between the course of the MHV followed by an intra-operative ultrasonography and the inter-lobar demarcation line followed by temporary occlusion of the right or left portal pedicle. In addition, a recent radiological study showed the anatomical mismatch between the MHV and the inter-lobar border [7,8]. Therefore, we suggest that the parenchymal transection along the MHV for the procurement of a RL graft may reduce some viable liver parenchyma of the segment IV, consequently diminishing the remnant LL volume. Thus, it may be necessary that the transection plane for the donor right hepatectomy should be shifted from the MPF to the right side to completely preserve the segment IV in the remnant LL.

We designed this study to determine the clinical significance of right hepatectomy along the MPF on the donor risk in the LDLT. To answer the study question, we performed the donor right hepatectomies using two different parenchymal transection planes. One was a donor right hepatectomy using conventional transection plane of the MPF. The other used a modified transection plane, which was a 2–3 cm right-side shifted plane from the MPF. We retrospectively analyzed data of the donors after right hepatectomy using these two different transection planes.

Patients and methods

Between January 2007 and May 2011, 92 living donor hepatectomies were performed for adult-to-adult LDLT in our institute. RL grafts were recovered from 45 donors, LL grafts from 24, right posterior sector grafts from 14, and extended RL grafts from nine. All donors were related to the recipients. The 45 RL grafts were procured using one of two different parenchymal transection planes, either the conventional MPF (conventional RL graft; cRL group, $n = 26$) or the modified transection plane, which was 2–3 cm right-side shifted from the MPF (modified RL graft; mRL group, $n = 19$). We analyzed peri-operative laboratory and radiological outcomes of the cRL donors and the data were compared with those of the mRL donors to determine the clinical significance of right hepatectomy along the MPF on the risk of living donors.

Selection of cRL and mRL grafts

The selection criteria for the RL grafts were previously described [9,10]. The RL graft was selected by donor age, liver volumetry, and liver histology. For a donor candidate <45 years of age, a RL graft could be selected when the volume of the LL was >30% of the TLV, and normal or minimal steatosis was present (<10 % macrovesicular steatosis) on preoperative liver biopsy. For a candidate ≥45 years of age or a candidate who had a moderate degree (10–30%) of macrovesicular steatosis, the RL could be selected when the volume of the LL exceeded 35% of the TLV. Liver volumetry was performed by a dynamic computed tomography (CT) scan using the Petavision Picture Archiving and Communication System (INFINITT, Seoul, Korea). The lobar or sectoral volume of the donor liver was measured with reference to the terminal branches of the corresponding portal pedicle on the dynamic CT scan. The preoperative volume of the donor RL should satisfy a graft-to-recipient weight ratio (GRWR) >0.8%. Among the suitable candidates of the RL donation, the selection of the cRL or mRL graft was made by preoperative measurement of the GRWR. When the preoperative GRWR determined by the volume of a donor RL was 0.8–1.1%, the cRL graft was selected. The selection of the mRL graft was considered when the GRWR exceeded 1.1% with regard to recipient's condition.

Operative procedures

Procurement of cRL graft

After laparotomy, a wedge biopsy of the liver was performed. The gallbladder was removed and an intra-operative cholangiography was performed via the cystic duct. Operative ultrasonography was performed to identify venous anatomies, especially the course of the MHV. The RL was fully mobilized from the diaphragm and the retrohepatic vena cava. A silastic loop was inserted into the space between the right hepatic vein (RHV) and the MHV for the hanging maneuver. A careful hilar dissection was performed to isolate the right hepatic artery and right portal vein. Those vessels were temporarily clamped to identify the territory of the RL, and the surface marking for transection line was drawn along the ischemic demarcation. Parenchymal transection was performed without the Pringle maneuver using a Cavitron Ultrasonic Surgical Aspirator (CUSA system 200; Valleylab, Boulder, CO, USA) along the MPF, from inter-lobar border on the surface to the right side of the MHV in the parenchyma (Fig. 1a). Small vascular branches on the transection plane were securely ligated and divided. Significant branches from the MHV on the parenchymal dissection plane were identified and carefully divided for venous reconstruction on the back table. The main trunk of the MHV and its branches to segment IV were securely preserved in all cases. After parenchymal transection, the intra-hepatic Glissonian sheath of the right portal pedicle was exposed and a radio-paque marker was placed on the sheath. Then, a cholangiography was performed to identify the appropriate site of bile duct division. Heparin sodium was administered intravenously and the right hepatic duct, artery, portal vein, and RHV were divided in order with fine surgical scissors. Thereafter, the cRL graft was procured.

Procurement of mRL graft

The procurement of a mRL graft was similar to that just described for the conventional right hepatectomy except for the parenchymal transection plane (Fig. 1a). For procurement of a mRL graft, the parenchymal transection line was drawn parallel to the inter-lobar ischemic border,

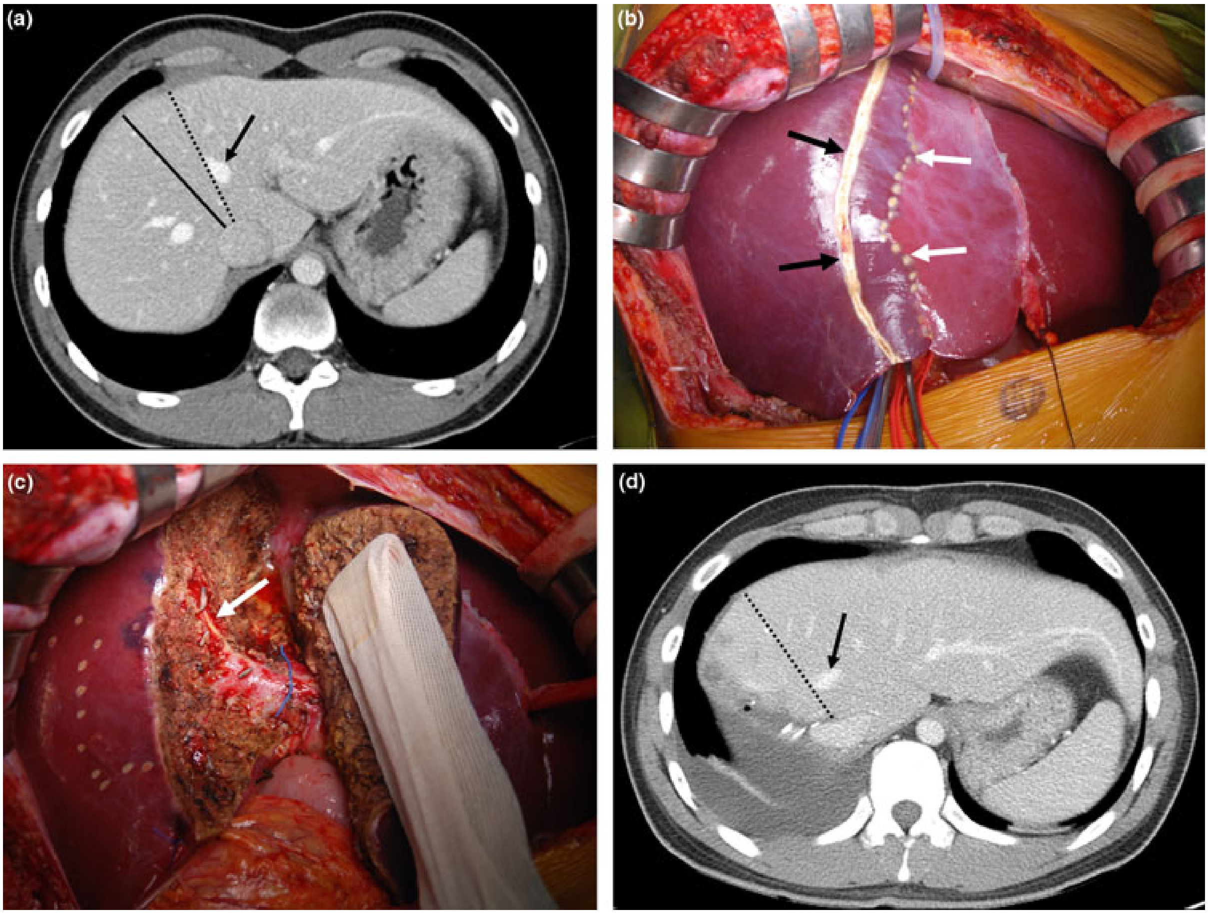

Figure 1 Right hepatectomy for procurement of a mRL graft. (a) The bold line indicates the hepatectomy plane for the mRL graft and the dotted line is the plane of the main portal fissure (MPF). Arrow indicates the middle hepatic vein (MHV). (b) The black arrows indicate hepatic transection line for an mRL graft, and the white arrows for inter-lobar demarcation line. (c) The right anterior portal pedicle was exposed (arrow) after parenchymal transection. (d) Posthepatectomy day 7 CT scan shows the MHV (arrow) is deeply located from the transection plane. The dotted line indicates the transection plane of conventional right hepatectomy.

2–3 cm to the right side from the MPF (Fig. 1b). Therefore, the parenchymal transection plane was located in the right anterior sector and the medial part of the liver parenchyma in segments V and VIII was saved for the donor. The branches from the right anterior portal pedicles and the MHV were securely ligated and divided during parenchymal dissection (Fig. 1c). Significant branches from the MHV on the parenchymal dissection plane were identified and carefully divided for venous reconstruction on the back table. Remaining surgical procedures for the mRL graft were same with that as of the cRL graft. After procurement of the mRL graft, the MHV be was deeply located in the remnant LL (Fig. 1d).

Posthepatectomy evaluations of the donors

The postoperative management of the donors was not different between cRL and mRL donors. All complications after donor hepatectomy were recorded and graded using a classification system proposed by Clavien and co-workers [11]. After donor hepatectomy, the remnant livers of all donors were evaluated daily by laboratory tests of complete blood count, routine chemistry, and the international normalized ratio (INR) of prothrombin time (PT) until normalization of the parameters. We classified donors with a peak serum level of the bilirubin >3 mg/dl and an INR >1.7 after right hepatectomy as hazard donors, with the remaining donors regarded as safe donors.

All donors received CT scans on the postoperative day 7, month 3, and month 6. Volumetric changes of the remnant LL, left lateral sector (LLS), and spleen were analyzed using CT volumetry. The regeneration rate of the remnant liver or increasing rate of the spleen was defined as increasing percentage of the volume after right hepatectomy, and was calculated as (%): [(postoperative volume − preoperative volume)/preoperative volume] × 100. All clinical, laboratory, and radiological data were compared between the cRL and the mRL donors.

Statistical analyses

Statistical values are described as the mean ± SD or median with range. Statistical analyses were performed using a Student's *t*-test or chi-squared test. Survival analysis was performed using the Kaplan–Meier method and survival rates were compared using a log-rank test. A P value <0.05 was considered statistically significant.

Results

Clinical outcomes

All donors were compatible candidates for living liver donation according to the donor selection criteria of our institute. There were no statistical differences in preoperative characteristics between the cRL donors and the mRL donors, such as gender, age, body weight, platelet count, degree of macrovesicular steatosis, volume of the RL, volume ratio of the LL to the TLV, volume ratio of the LLS to the LL, and volume of the spleen. However, the preoperative GRWR by volume of the donor RL were significantly different between two groups (1.11 ± 0.14 in the cRL group and 1.32 ± 0.19 in the mRL group, P = 0.000). The body weight of the recipients was different between the two groups (72.1 ± 7.9 kg in the cRL group vs. 64.6 ± 6.7 kg in the mRL group, P = 0.002). The preoperative characteristics of donors and recipients in the two groups are described in Table 1.

There was no statistical difference in intra-operative characteristics, such as operative time, amount of operative bleeding, and actual graft weight, between the two groups. None of the donors required a blood transfusion during or after the donor hepatectomy. After procurement of the grafts, 21 of 26 cRL grafts (81%) and four of 19 mRL grafts (21%) were performed by reconstruction of the MHV in the back table using cryopreserved veins from a tissue bank in our institute (Table 2).

All donors in this study recovered from the right hepatectomy and discharged with normal liver function. The posthepatectomy laboratory tests showed that the peak level of serum bilirubin was higher in the cRL donors than the mRL donors (3.37 ± 1.26 mg/dl vs. 2.74 ± 0.88 mg/dl, P = 0.065). The postoperative peak INR was higher in the cRL donors (1.84 ± 0.34) than the mRL donors (1.62 ± 0.24), with statistical significance (P = 0.022). The depression of platelet count after the right hepatectomy was more profound in the cRL donors (144 ± 35 per nL of lowest platelet count) than the mRL donors (168 ± 42 per nL of lowest platelet count), with statistical significance (P = 0.042). The serum level of alanine aminotransferase,

Table 1. Preoperative characteristics of living donor liver transplantations using the cRL graft and mRL graft.

Preoperative data	cRL group (*n* = 26)	mRL group (*n* = 19)	*P* value
Donor			
Male sex [*n*, (%)]	13 (50)	12 (63.2)	0.380
Age (years)	29 (18–55)	24 (18–38)	0.113
Body weight (kg)	59 (49–77)	68 (46–81)	0.094
Body mass index	21.7 ± 2.4	22.7 ± 2.5	0.223
>10% of macro-steatosis [*n* (%)]	3 (11.5)	1 (5.3)	0.465
Volume of RL (ml)	795 ± 115	849 ± 156	0.187
GRWR (%)	1.11 ± 0.14	1.32 ± 0.19	0.000
Volume of LL (ml)	437 ± 94	475 ± 110	0.216
Volume ratio of LL–TLV (%)	35.1 ± 3.3	35.8 ± 3.9	0.508
Volume ratio of LLS–LL (%)	54.5 ± 5.2	56.2 ± 4.9	0.273
Volume of spleen (ml)	167 ± 65	173 ± 66	0.751
Platelet count, per nl	243 ± 54	243 ± 50	0.991
Recipient			
Male sex [*n*, (%)]	20 (76.9)	16 (84.2)	0.546
Age (years)	50 (40–65)	48 (37–60)	0.427
Body weight (kg)	71 (60–87)	65 (55–77)	0.002
MELD score	14 (7–36)	12 (6–35)	0.852
ABO-incompatibility [*n*, (%)]	3 (11.5)	5 (26.3)	0.200
Follow-up (months)	31 (1–56)	19 (1–56)	0.160

Data are number (%) or mean ± SD or median (range).

Significance was defined as P < 0.05.

RL, right lobe; GRWR, graft-to-recipient-body weight ratio; LL, left lobe; TLV, total liver volume; LLS, left lateral sector; MELD, Model for End-stage Liver Disease.

Table 2. Intra- and postoperative outcomes between the cRL and mRL donors.

Surgical outcomes	cRL donors (*n* = 26)	mRL donors (*n* = 19)	*P* value
Intra-operative outcomes			
Operative time (min)	341 ± 58	357 ± 40	0.295
Intra-operative blood loss (ml)	364 ± 92	400 ± 136	0.306
Graft weight (g)	628 ± 88	625 ± 87	0.913
Reconstruction of the MHV [*n*, (%)]	21 (80.8)	4 (21.1)	0.000
Postoperative outcomes			
Peak bilirubin level (mg/dl)	3.37 ± 1.26	2.74 ± 0.88	0.065
Peak prothrombin time (INR)	1.84 ± 0.34	1.62 ± 0.24	0.022
Peak ALT (IU/l)	262 ± 87	297 ± 144	0.327
Lowest platelet count (per nl)	144 ± 35	168 ± 42	0.042
Incidence of complications [*n*, (%)]	15 (57.7)	9 (47.4)	0.493
Pos thepatectomy hospital stay (day)	12 (9–15)	12 (10–22)	0.446
Changes of remnant LL* and spleen*			
Volume of LL (ml)	772 ± 122	797 ± 163	0.553
Increasing rates of LL volume† (%)	81 ± 28	70 ± 18	0.150
Volume of LLS (ml)	448 ± 90	415 ± 84	0.216
Increasing rates of LLS volume† (%)	93 ± 38	58 ± 20	0.001
Volume ratio of LLS–LL (%)	58.0 ± 6.2	52.4 ± 5.8	0.003
Volume of spleen (ml)	251 ± 99	233 ± 75	0.513
Increasing rates of spleen† (%)	52 ± 26	37 ± 15	0.025

Data are number (%) or mean ± SD or median (range).
*Volumetric data are measured on postoperative 7th day CT scan.
†Increasing rate of volume was calculated as formula of '(postoperative volume – preoperative volume)/preoperative volume × 100 (%)'.
GRWR, graft-to-recipient-body weight ratio; MHV, middle hepatic vein; INR, international normalized ratio; ALT, serum alanine aminotransferase; LL, left lobe; LLS, left lateral sector.

length of hospital stay, and incidence of postoperative complications after hepatectomy were not different between the two groups of donors (Table 2).

Thirteen of the 45 donors recorded a postoperative level of serum bilirubin >3 mg/dl and INR >1.7 and so were regarded as hazard donors, while the remaining 32 donors were safe donors. The overall comparison between the hazard donors and the safe donors showed that the hazard donors had a smaller preoperative volume ratio of the LL/TLV (33.6 ± 2.2 vs. 36.1 ± 3.8, $P = 0.04$) and underwent more conventional right hepatectomy along the MPF than the safe donors (Table 3). Multivariate analysis revealed that the conventional right hepatectomy along the MPF was the independent risk factor for the hazard donor after right hepatectomy. cRL donors had a 1.83-greater relative risk of being a hazard donor (95% confidence interval: 1.14–23.8, $P = 0.035$), than the mRL donors (Table 4).

Among the 26 cRL donors, the incidence of postoperative complications was 57.7 % ($n = 15$). Of the complica-

Table 3. Overall comparison of the Safe donor and the Hazard donor for living donor right hepatectomy.

	Safe donor (*n* = 32)	Hazard donor (*n* = 13)	*P* value
Male sex [*n* (%)]	17 (53.1)	8 (61.5)	0.745
Age	30 (18–55)	25 (18–53)	0.527
Volume ratio of LL–TLV (%)	36.1 ± 3.8	33.6 ± 2.2	0.040
>10% macrovesicular steatosis [*n* (%)]	2 (6.3)	2 (15.4)	0.567
Body mass index	22.3 ± 2.5	21.8 ± 2.6	0.632
cRL donor* [*n* (%)]	15 (46.9)	11 (84.6)	0.024
Operative time (min)	352 ± 52	344 ± 41	0.663
Intra-operative blood loss (ml)	390 ± 123	348 ± 80	0.240
Posthepatectomy complication [*n* (%)]	17 (53.1)	7 (53.8)	1.000

Data are number (%) or mean ± SD or median (range).
*Conventional right hepatectomy along the main portal fissure.
LL, left lobe; TLV, total liver volume.

Table 4. Multivariate analysis for the Hazard donor (posthepatectomy serum bilirubin >3 mg/dl and INR >1.7).

	n	RR (95% CI)	*P* value
Volume ratio of LL to TLV			
30–35%	25	1.2 (0.71–15.5)	0.128
>35%	20	1	
Hepatectomy plane			
conventional	26	1.83 (1.14–23.8)	0.035
modified	19	1	

LL indicates left lobe; TLV, total liver volume; RR, relative risk; CI, confidence interval.

tions, 11 (73.3 %) were classified as grade I and four (26.7 %) as grade II, according to the Clavien classification. Among the 19 mRL donors, there were nine complications (47.4 %) after the hepatectomies. Of the complications, eight (88.9 %) were classified as grade I and one (11.1 %) as grade II. There was no donor with Clavien's complication grade III or over (Table 5).

The post-transplantation survival rate of the 45 recipients with RL graft was 90.6% at 1 year and 87.0 % at 4 years. The overall survival rates between the cRL recipients (86.7 %) and the mRL recipients (88.0%) had no statistical difference ($P = 0.985$). Postoperative in-hospital mortality developed in one recipient in the cRL group because of *Acinetobacter* pneumonia, and one recipient in the mRL group because of sepsis followed by ABO-incompatible LDLT. The remaining 43 recipients were discharged with favorable graft function. No recipient experienced small-for-size graft syndrome, including prolonged cholestasis, hepatic encephalopathy, and massive ascites after LDLT. Post-transplant graft function was similar between the two groups of recipients in terms of peak serum level of bilirubin, prothrombin time, and alanine aminotransferase. In addition, there was no difference in length of hospital stay and incidence of post-transplant complications (Table 6).

Radiological changes of the donor remnant liver

Changes of the donor remnant liver after right hepatectomy
The preoperative CT volumetry of total 45 donor livers showed that the volumes of the LL and the LLS were 453 ± 102 ml and 250 ± 61 ml, respectively. The volume of LLS was 55.2 ± 5.1 % of the LL volume. There was no difference in preoperative liver volumetry between the cRL and mRL donors (Table 1).

The serial changes in the remnant liver volume after right hepatectomy are shown in Figs 2 and 3. Seven days after right hepatectomy of 45 donors, the volumes of the LL and the LLS were increased up to 783 ± 140 and 434 ± 88 ml, respectively. The regenerative rate of the LL and LLS for 7 days was 76 ± 25% and 79 ± 36%, respectively. The regenerative rates of the remnant LL were similar (81 ± 28 % in cRL donors vs. 70 ± 18 % in mRL donors, $P = 0.150$). However, the regenerative rates of the LLS were 93 ± 38% in cRL donors and 58 ± 20% in mRL donors, which were statistically significant ($P = 0.001$). The volume ratio of the LLS to the LL was significantly different between two groups of donors 7 days after hepatectomy. The volumes of the LLS were 58 ± 6% of the LL in the cRL donors and 52 ± 6% in the mRL donors ($P = 0.003$) on the day 7 posthepatectomy CT scan. The data are detailed in Table 2.

The CT scans taken 3 and 6 months postoperatively showed that the remnant liver after right hepatectomy continued to increase in volume (Fig. 2). There was no difference in the regenerative rate of the remnant LL between the two groups ($P > 0.05$). However, the regen-

Table 5. Donor complications after right hepatectomy.

	Incidence of complication							
	cRL donors (*n* = 26)				mRL donors (*n* = 19)			
	I	II	III	IV	I	II	III	IV
Abdominal complications								
Skin Wound infection	1	1				1		
Intra-abdominal fluid collection	4				3			
Bile leakage					1			
Ileus	1							
Peptic ulcer		1						
Hyperamylasemia (>300 IU/l)	1							
Extra-abdominal complications								
Pleural effusion	4				4			
Pulmonary edema		1						
Cardiac arrhythmia		1						
Total	11	4			8	1		

Table 6. Intra- and postoperative outcomes between the cRL and mRL recipients.

Surgical outcomes	cRL recipients (*n* = 26)	mRL recipients (*n* = 19)	*P* value
Actual GRWR (%)	0.88 ± 0.12	0.98 ± 0.16	0.023
Operative time (min)	698 ± 220	649 ± 189	0.328
Intra-operative blood loss (ml)	1815 ± 1692	1479 ± 1521	0.332
Post-LTx peak bilirubin (mg/dl)	5.56 ± 2.91	4.51 ± 1.53	0.155
Post-LTx peak prothrombin time (INR)	2.81 ± 0.62	2.54 ± 0.43	0.504
Post-LTx peak ALT (IU/l)	164 ± 74	149 ± 72	0.114
Post-LTx ICU stay (day)	3 (2–32)	3 (2–14)	0.521
Post-LTx hospital stay (day)	31 (21–75)	29 (19–38)	0.389
Post-LTx complications			
In-hospital mortality	1 (3.8 %)	1 (5.3 %)	0.820
Postoperative hemorrhage	2 (7.7 %)	1 (5.3 %)	0.747
Infection	4 (15.4 %)	2 (10.5 %)	0.636
Bile leakage	1 (3.8 %)	0	0.387
Biliary stricture	1 (3.8 %)	1 (5.3 %)	0.820
Acute cellular rejection	3 (11.5 %)	4 (21.1 %)	0.384
Overall 4-year survival rates (%)	86.7	88	0.985

Data are number (%) or mean ± SD or median (range).

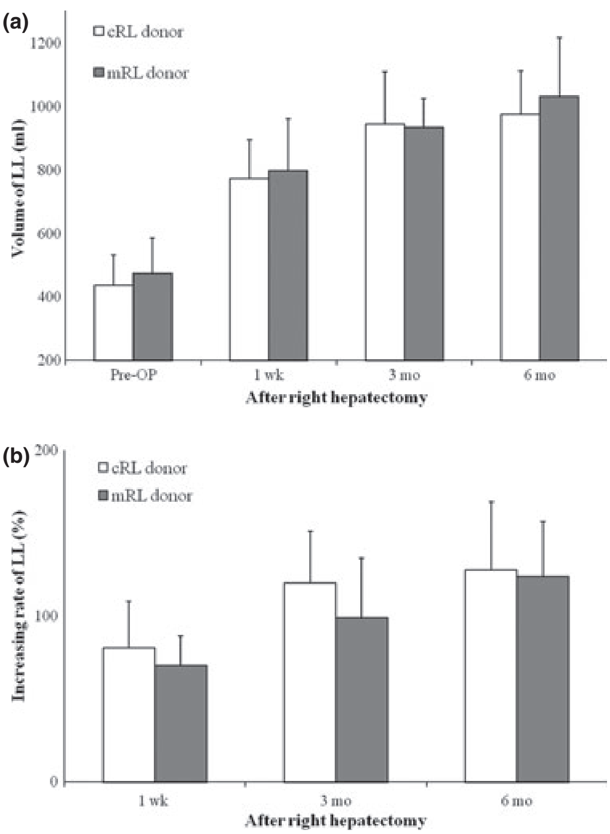

Figure 2 Volumetric changes (a) and regenerative rate (b) of the remnant left liver after right hepatectomy. There is no statistical difference between two groups.

erative rate of the LLS was significantly greater in the cRL group (148 ± 51%) than the mRL group (84 ± 39%) at postoperative month 3 ($P = 0.015$). Moreover, the ratio of the LLS volume to the LL volume at 3 and 6 months postoperatively CT scan was significantly greater in the cRL donors than in the mRL donors ($P < 0.05$). The regenerative pattern of the LLS in the remnant LL after right hepatectomy was compared between the two groups; the results are shown in Fig. 3.

Changes in the spleen volume after right hepatectomy

Preoperative volume of the spleen of the 45 donors was 170 ± 61 ml. The volume of the spleen was enlarged to 244 ± 89 ml at postoperative day 7, 242 ± 112 ml at month 3, and 190 ± 63 ml at month 6 after right hepatectomy. In this study, the volume of the spleen was rapidly increased for the first 7 days postoperatively and then slowly decreased for the next 6 months after hepatectomy (Table 2). The CT scan obtained at posthepatectomy day 7 showed that the enlargement of the spleen was more accelerated in the cRL donors than the mRL donors (52 ± 26 % vs. 37 ± 15 % of the preoperative spleen volume, $P = 0.025$). The volume changes of the spleen after right hepatectomy are shown in Fig. 4.

Discussion

Since the first success of the adult LDLT using a RL graft in 1994 [12], the RL graft has been widely selected in most liver transplant programs for adult recipients. However, the procurement of a RL could bring higher risk to the living donor than other type of donor hepatectomy [13–15]. In the selection of a RL donor, it is generally accepted that the minimum selection criterion of the residual liver volume should be >30% of the TLV to avoid serious complications of a living donor [4]. And there are technical variations from one center to another

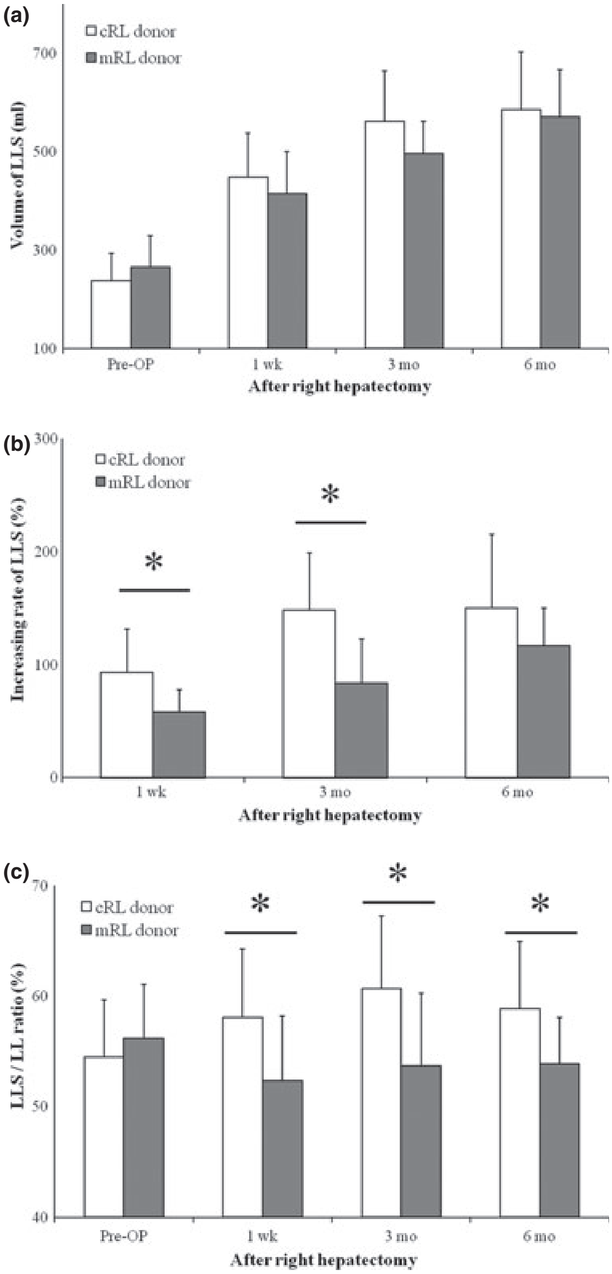

Figure 3 Volumetric changes (a), regenerative rate (b) of the left lateral sector (LLS) after right hepatectomy. Changes in volumetric ratio of the LLS in remnant left liver after right hepatectomy (c). *indicates statistical difference of $P < 0.05$ between two groups.

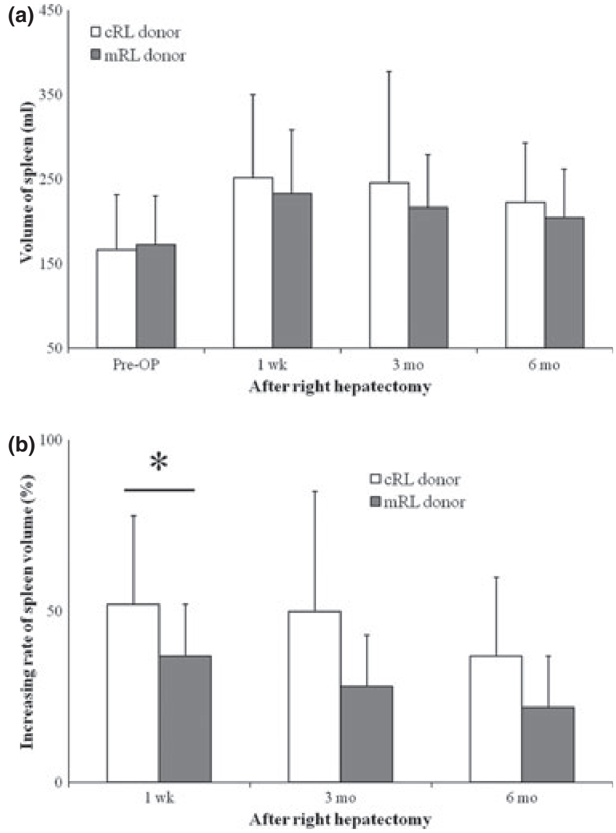

Figure 4 Volumetric changes (a) and increasing rate (b) of the spleen after right hepatectomy. *indicates statistical difference of $P < 0.05$ between two groups.

for procurement of a RL graft, such as division of bile duct, use of the Pringle maneuver, methods of parenchymal transection, and so on [16–19]. However, the MHV is conventionally regarded as a reference of intra-hepatic inter-lobar border for parenchymal transection of right hepatectomy by most donor surgeons [5,20,21].

In this study, we assumed that the conventional right hepatectomy along the MPF could reduce viable remnant liver because the proximal MHV is mainly embedded in segment IV. To verify the clinical risk of conventional right hepatectomy, we performed modified right hepatectomy which could completely preserve the whole left liver and the two types of donor right hepatectomy were compared. As a result of strict selection criteria for RL donors in this study, all donors recovered from the right hepatectomy without serious complications. There was no statistical difference in incidence or severity of posthepatectomy complications between mRL and cRL donors (Tables 2 and 5). However, we designed this study to not only evaluate overt surgical complications of RL donors, but also the potential risk of recovery of liver function after living donor right hepatectomy along the MPF. It is well known that the disturbance of restoration of liver function after hepatectomy is closely related with serious complications, such as liver failure [22–24]. In this study, there were differences in the posthepatectomy liver functions and in morphology of regeneration of the remnant LL between two groups of donors. The cRL donors showed more deteriorated liver function after right hepatectomy than the mRL donors, in terms of the peak INR and serum bilirubin level. Presently, we classified the donors as hazard and safe donors according to the posthepatectomy peak level of the INR (1.7) and serum bilirubin (3 mg/dl). The value of 1.7 of INR corresponds to 50% of PT and a serum bilirubin of 3 mg/dl corresponds to a value of 50 mol/l. Balzan *et al.* reported that the prolonged status of abnormal PT < 50% (or INR >1.7) and hyperbilirubinemia >50 mol/l (or bilirubin >3 mg/dl) for 5 days after hepatectomy ('50–50 criteria' on postoperative day 5) correlated with high incidence of serious complications such as liver failure and/or mortality [24]. However, in our study, no donors had prolonged coagulopathy and hyperbilirubinemia for more than 5 days after right hepatectomy. Thus, we modified the criteria and defined a hazard donor when the posthepatectomy peak serum value of the INR >1.7 and bilirubin >3 mg/dl, regardless of postoperative days. And 13 of 45 donors showed hazard values of the peak INR and bilirubin after the RL donation. Multivariate analysis showed that the conventional donor right hepatectomy along the MPF was a unique independent risk factor for the hazard value of liver function tests after hepatectomy, with an 83% greater relative risk of hazard donor than the right hepatectomy along the modified plane. These findings could mean that the cRL donor had less amount of remnant liver volume after right hepatectomy than the mRL donors, because it is well known that the degree of liver dysfunction after hepatectomy mainly depends on the amount of the remnant liver volume [25,26]. And the cRL donors had more depression of platelet count and greater increase of the splenic volume after right hepatectomy than the mRL donor for postoperative 7 days. The results may suggest that the posthepatectomy increase in the portal pressure is greater in the cRL donors than in the mRL donors, and supports the reduced amount of the remnant liver parenchyma in the cRL donors than mRL donors after right hepatectomy.

In this study, to evaluate morphological changes of the remnant liver, we measured the LLS volume in the remnant LL instead of segment IV. There were two reasons for this. First, the volume of the LLS could be precisely measured on CT scan along the border of the umbilical portion of the portal pedicle. Second, the LLS was intact area from surgical procedure of right hepatectomy while segment IV had variable transection planes that differed between the two groups of donors. The segmental volumetry of the remnant LL after right hepatectomy showed that cRL donors had a prominent regeneration rate of the LLS compared with the mRL donors for postoperative radiological follow-up period of 6 months (Fig. 3). Such disproportionately accelerated regeneration of the LLS in the cRL donors, compared with the mRL donors, might be because the conventional right hepatectomy along the MPF resulted in a reduced amount of segment IV parenchyma in the remnant LL than in the modified right hepatectomy. In the CT scan 6 months posthepatectomy, liver parenchyma of segment IV appeared to be more voluminous in the mRL than in the cRL donor, according to the location of the MHV (Fig. 5)

Therefore, we suggest that the right hepatectomy along the MPF could result in reduced parenchymal volume in segment IV of the remnant LL compared with the right-side shifted transection plane from the MPF. The volumetric disadvantage of the remnant liver in the cRL donors or the advantage in the mRL donors might be because of one of following two reasons or both. First, the conventional donor right hepatectomy along the MPF may eliminate a portion of segment IV liver parenchyma on the right side of the MHV. Second, the additional right anterior sector liver tissue on the remnant LL following the right heptectomy along the modified transection plane could be functional. However, it is difficult to

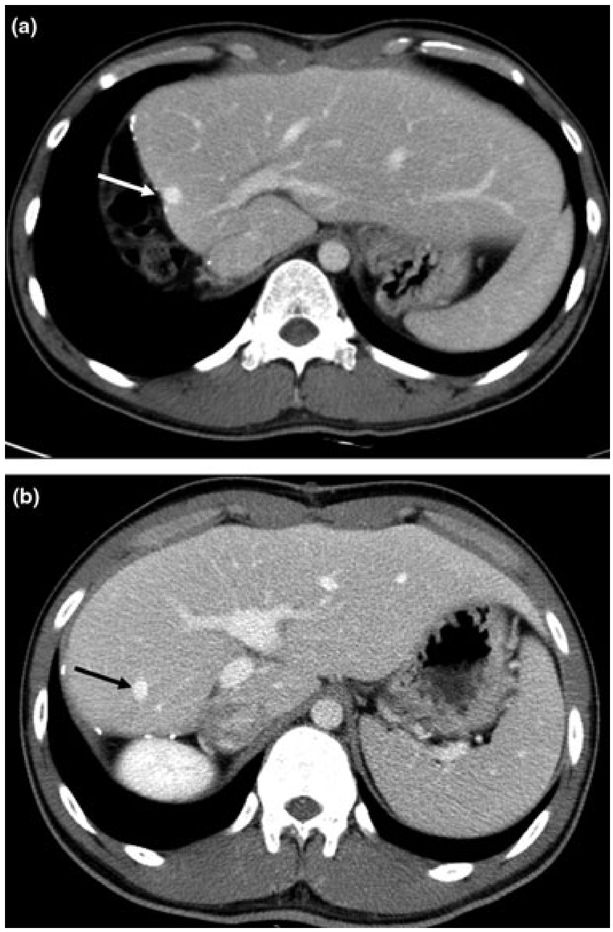

Figure 5 Postoperative CT scans taken 6 months after right hepatectomy. (a) In the cRL donor, the middle hepatic vein (MHV) is located on the resection margin (white arrow). (b) In the mRL donor, the MHV is deeply located in the segment IV (black arrow).

evaluate whether the vascular compromised liver tissue without portal inflow could be functional or not. Ikegami *et al.* performed modified left hepatectomy in living liver donors using a similar transection plane for the mRL graft in our study to increase the volume of the LL graft. Their results demonstrated that the technique should provide more volume of the LL graft than conventional left hepatectomy using MPF. They suggested that this was because of the additional right anterior liver tissue on the LL graft being functional and regenerative [27]. However, it is controversial that the liver tissue without portal pedicle could be functional because clinical experience has shown that the liver parenchyme without portal inflow results in atrophy rather than regeneration [28,29]. Nevertheless, the inflow-deprived liver tissue might not develop complications during the atrophic changes [30,31]. In this study, the shed portal branch from the anterior portal pedicle on the remnant left liver also showed thrombotic and atrophic change (Fig. 6). Thus, we suggest that the disadvantage of the remnant liver volume in the cRL donors, compared with the mRL donor results from the tendency of conventional right hepatectomy using MHV plane to remove some liver parenchyma of segment IV on the right side of the MHV. Consequently, the surgical reduction of segment IV volume following conventional right hepatectomy could worsen postoperative liver function of the living donors. In other words, the complete preservation of segment IV using the modified transection plane for right hepatectomy could have clinical advantages on donor safety than the conventional right hepatectomy along the MPF.

This study may be limited by the nonrandomized design, relatively small number of cases, and potential bias of graft selection. Designing this study, we considered selecting a mRL graft when the preoperative volume of a RL exceeded 1.1% of the recipient's body weight, because the mRL graft was a reduced-size graft compared with a cRL graft. Conducting the study following this criterion yielded no post-transplant complications related with graft size. To gain satisfactory results of the recipient by using the mRL graft, we recommend that the transplant candidate who has a marginal preoperative GRWR with donor RL volume should avoid receiving a mRL graft. We suggest that the most beneficial situation with the mRL graft in adult-to-adult LDLT is when the volume of a donor RL could sufficiently satisfy the GRWR of his/her recipient and the donor remnant LL has a marginal volume.

In this study, the mRL graft had less incidence of the MHV reconstruction than the cRL graft (Table 2). We believe that this was because of the right-side shifted hepatectomy plane for the mRL graft dividing the MHV more distally than conventional right hepatectomy. Consequently, the cut surface of the mRL graft may have rare significant branches of the MHV that require vascular reconstruction. One of concerns in procurement of the mRL graft is possible bile leak from liver cut surface, because the transection plane crosses the ventral branches of right anterior portal pedicle. We experienced one bile leakage among the mRL donors, which was spontaneously closed. However, to avoid bile leakage after procurement of an mRL graft, fine and meticulous surgical technique should be applied for the hepatectomy.

This study highlights the clinical significance of conventional right hepatectomy along the MPF on the risk of the living donor. In conclusion, the conventional right hepatectomy along the MPF might increase donor risk by reducing parenchymal liver volume of the segment IV in the remnant left liver.

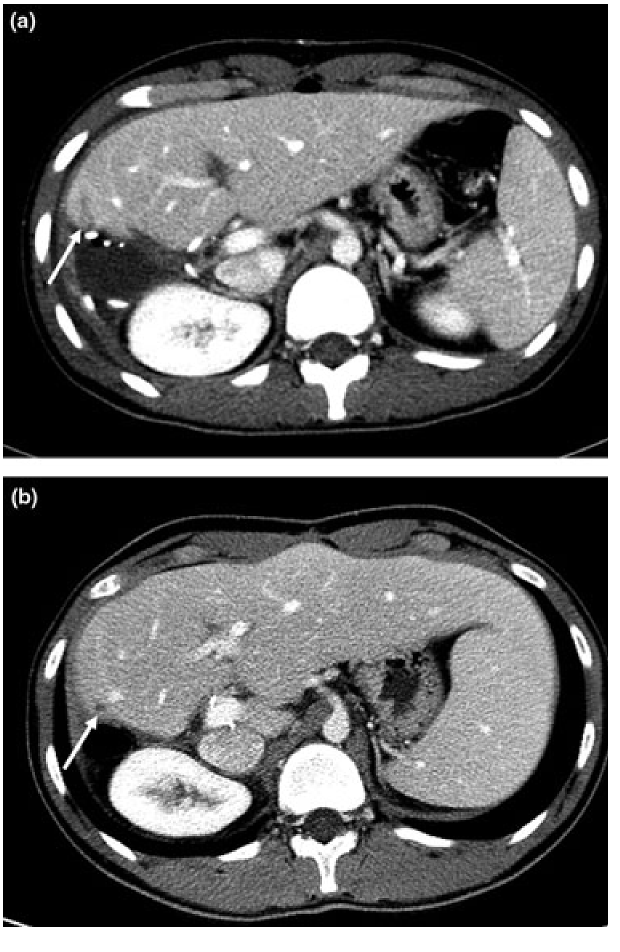

Figure 6 Postoperative changes of the anterior portal pedicle on the remnant left liver after modified right hepatectomy along the right-side shifted transection plane from the main portal fissure. (a) Post-hepatectomy day 7 CT scan shows partially thrombosed anterior portal branch (arrow). (b) In the same donor, the portal branch was completely thrombosed and atrophied on postoperative month 3 CT scan (arrow).

Authorship

B-WK: contributed to the study proposal, data analysis, and writing of manuscript. Y-KP, WX, and H-JW: collected and analyzed data. All authors significantly contributed to the study and reviewed the manuscript.

Funding

The authors have declared no funding.

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