ORIGINAL ARTICLE

Right lobe donor hepatectomy: is it safe? A retrospective study

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SUMMARY

Donor safety is utmost important in Living donor liver transplantation (LDLT). Small for size syndrome in some recipients with left lobe donors led to the evolution of right lobe LDLT. The aim of the study was to analyze the safety of large series of right lobe (RL) donor hepatectomies and compare outcomes with left lobe (LL) and left lateral segment (LLS) donations. A consecutive cohort of 726 donors from January 2011 to January 2014 were studied; RL ($n = 641$, 88.3%), LL ($n = 36$, 4.9%) or LLS ($n = 49$, 6.8%) depending on the type of donation. The mean age was 34.6 $\pm$ 10 years. The overall complication rate was 22.3%. Most were Clavien grade I and II. Clavien grade IIIa, IIIb, IV and V were noted in 4.2% donors. The incidence of these major complications were comparable among RL ($n = 28$, 4.2%), LL ($n = 1$, 2.7%) and LLS ($n = 2$, 4.08%) ($P = 0.89$). Bile leak was seen in 20 donors (2.7%) and 13 were managed conservatively with prolonged or additional intra-abdominal drainage. Seven underwent re-exploration for bile leak. In centres experienced in right lobe LDLT, morbidity after RL donation is similar to that of LL donation; and with adequate GRWR, same 1-year recipient outcomes.

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Key words
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Introduction

The increasing need and scarcity of the deceased donor organs led to development of Living donor liver transplantation (LDLT). Instances of small for size syndrome with left lobe led to the evolution of right lobe LDLT [1–3]. As donor safety remains of utmost importance, it is logical that large liver remnant will ensure safer outcomes in donors [4]. Left lobe (LL) or left lateral segment (LLS) donation allow larger remnant [5,6]. Hence, LL or LLS donation may be better for donor safety. So, this study was conducted to analyze the safety of large series of RL donations and compares donor outcomes with LL and LLS donation as well as assesses recipient outcomes between RL and LL.

Materials and methods

All 726 consecutive donors who underwent donor hepatectomy from January 2011 to January 2014 were included in the study. Preoperative donor characteristics, intraoperative parameters and postoperative complications were retrieved retrospectively from our prospectively maintained database. Donors were divided into three groups; RL, LL and LLS donors depending on the type of donation. All donors were followed up weekly for 1 month, once in a 3 month for 1 year and then yearly.

Comparison of outcome measures: Postoperative donor liver function tests (day 1, 3 and 7), morbidity and mortality were compared among these groups.

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Grading of the complications was performed according to the classification system given by Clavien *et al.* [7]. The recipient characteristics and outcomes were compared between RL and LL recipients.

In view of disproportionately lesser left lobe donations (to achieve adequate graft recipient weight ratio), an initial analysis of matched control of 1:2 left versus right lobe donor cohorts was performed. This did not yield any significance in outcomes. Because it also failed to give overall perspective of right lobe donation, it was decided to analyze the entire RL donor cohort during the study period and compare with left-sided donation.

Biliary complication was defined as the presence of biloma, bile leak or biliary stricture. Early allograft dysfunction (EAD) was defined as one or more of the following criteria: bilirubin ≥10 mg/dl and INR ≥ 1.6 on POD7, SGOT or SGPT > 2000 units/l within first seven postoperative days [8]. Small for size syndrome (SFS) was diagnosed by the presence of total bilirubin >10 mg/dl on POD 7 and intractable ascites (daily production of ascites of >1 l on POD 14 or >500 ml on POD 28) without other specific causes [9].

Donor selection

Healthy voluntary donors, between 18 and 55 years of age underwent stringent four-phase evaluation.

Phase 1 includes clinical examination of donor, complete blood count, liver function test (LFT), renal function test, viral markers, lipid profile, thyroid function tests and noncontrast computed tomography for liver fat estimation (Liver attenuation Index, LAI).

Phase II included volumetry and evaluation of the vascular anatomy of the liver with triphasic CT scan.

Phase III assessed the fitness for general anaesthesia and pulmonary function test, cardiac evaluation [ECG and stress Echo (donor age >35 years), 2D echo, Tread Mill Test (donor age <35 year), CT calcium score (donor age >50 year)], carotid Doppler (donor age >50 year), chest X-ray, gynaecological and breast evaluation (for females) and evaluation of the biliary anatomy with Magnetic resonance cholangiopancreatography.

Phase IV includes multidisciplinary evaluation by hepatologists, surgeons, anesthesiologist, psychiatrist, cardiologist and gynaecologist (in female donors). Additional investigations were performed in the presence of any significant history including, family history (primary biliary cirrhosis, autoimmune) or history of any addiction (smoking, alcohol, substance abuse). Liver biopsy was performed selectively in donors with body mass index (BMI) > 28 kg/m^2, dyslipidemia, the presence of metabolic risk factors or LAI < 5 (defined as difference of liver and splenic attenuation values on noncontrast CT), low graft to recipient ratio (GRWR < 0.8) or remnant (<35%).

Suitability criteria included 18–55 years of age, normal biochemical laboratory values, hepatic steatosis <20% for right lobe, BMI < 34, GRWR > 0.8 (in selected cases with low disease MELD recipient, lower GRWR up to 0.7 was accepted), and future liver remnant >32% ideal (minimum 30%). Informed written consent was taken from all the donors about the risk associated with the procedure. Some potential liver donors with fatty liver were advised repeat evaluation after weight reduction. Approval from a legal authorization committee is required by state health authority.

Donor operative protocol

The donor skin incision is either reverse L shape or midline. Intraoperative cholangiography was performed. The graft hepatic artery and portal vein were bared to leave the Glissonian sheath and hilar plate tissue intact around the hepatic duct (HD). The HD confluence was defined by the lowering of the hilar plate before the transection.

Right donor hepatectomy

The RHA beyond the segment IV artery and RPV were occluded temporarily to define the interlobar plane. Liver parenchymal transection was performed along this plane using the Cavitron Ultrasonic Surgical Aspirator (Sonoca 400; Söring GmbH, Quickborn, Germany) monopolar and bipolar diathermy.

Three types of right lobe graft were used (right lobe graft with subtotal MHV or partial MHV or modified right lobe graft), selection based primarily on three factors: remnant volume, metabolic demand of recipient and donor, venous anatomy of right lobe. Anterior sector drainage veins more than 5 mm (3 mm occasionally whenever multiple adjacent or marginal GRWR) were all reconstructed on back table. Subtotal MHV meant coring out MHV dividing it caudal to segment IVA vein(s) [10]. The graft HD, covered by its hilar plate Glissonian sheath (HPGS), after complete parenchymal transection was encircled and transected [11]. Graft was perfused with cold UW solution at 4 °C. The HD stump and hilar plate are closed with fine polydioxanone sutures. A leak test using methylene blue and cholangiography were performed.

Left hepatectomy

The steps of left donor hepatectomy was similar to right hepatectomy except the interlobar plane was marked by temporarily occluding LHA and LPV. Left lobe graft was always retrieved with MHV.

Left lateral segment graft

In left lateral segment graft, the line of parenchymal transection was one centimetre to right of falciform ligament.

Postoperative management

All donors were managed in the intensive care unit (ICU) on first postoperative day. Epidural analgesia was administered in all who gave consent for the same. Antibiotics were stopped after 5 days. Oral intake was started on day 1 after the surgery. Early ambulation was encouraged. Complete blood count, liver function test and renal function test were performed daily for the first 1 week during their hospital stay. In their follow-up period, the tests were repeated every 2–3 days until normalization and then after 1, 3 and 12 months.

Statistical methods

Patient baseline characteristics were expressed as mean ± standard deviation (SD) for continuous data. The donor morbidity among different types of liver graft was compared with chi-square test for categorical variable and independent *t* test or ANOVA for continuous variables. A two tailed *P* value of <0.05 was considered statistically significant. All statistical analyses were performed using SPSS version 20.0 for Windows statistical software (SPSS Inc., Chicago, IL, USA).

Results

There were three groups depending on the lobe that was donated: RL (n = 641, 88.3%), LL (n = 36, 4.9%) or LLS (n = 49, 6.8%). The mean age of donors was 34.66 ± 10.09 years (range: 18–55 years), uniformly distributed over the three groups (P = 0.65). The mean BMI was 24.8 ± 3.8 kg/m^2. 404 were female and 322 male (Table 1).

Donor complications

Intraoperatively, there was no significant difference in blood loss among the groups (P = 0.29) (Table 2). Similarly, there was no significant difference in hospital stay [(RL (7.1 ± 2.08) vs. LL (6.8 ± 2.4) vs. LLS (6.5 ± 1.7) days, P = 0.19].

There was no significant difference in biliary complications among the groups (P = 0.95). Bile leak occurred in 20 donors (2.7%). Out of these, 11 were managed with prolonged intra-abdominal drainage, two required additional percutaneous drain (PCD) insertion. Seven

Table 1. Donor demographic profile.

Parameters	Right lobe (n = 641)	Left lobe (n = 36)	Left lateral segment (n = 49)	P value
Age (year)	34.61 ± 10.2	33.94 ± 9.9	35.84 ± 8.8	0.65
Gender, male/female	289/352	18/18	15/34	0.11
Body mass index (kg/m^2)	24.8 ± 3.8	24.6 ± 3.6	24.9 ± 3.9	0.97
Liver attenuation index	12.25 ± 4.9	11.9 ± 5.8	11.8 ± 5.05	0.83
CT estimated remnant (percentage)	35.6 ± 5.38	45.6 ± 13.62	62.6 ± 16.46	0.00

Table 2. Donor morbidity.

Parameters	Right lobe (n = 641)	Left lobe (n = 36)	Left lateral segment (n = 49)	P value
Hospital stay	7.1 ± 2.08	6.8 ± 2.4	6.59 ± 1.7	0.19
Blood loss (ml)	397 ± 315.5	365.7 ± 314.8	321.9 ± 258.1	0.29
Biliary complications	18 (2.8%)	1 (2.8%)	1 (2.04%)	0.95
Intra- abdominal collection	26 (4.1%)	1 (2.8%)	1 (2.04%)	0.73
Pleural effusion	33 (5.3%)	1 (2.8%)	1 (2.04%)	0.52
Pneumonia	4 (0.6%)	1 (2.8%)	0	0.16
Re-exploration	12 (1.9%)	0	1 (2.04%)	0.70
Paralytic ileus	23 (3.5%)	1 (2.8%)	2 (4.1%)	0.93

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underwent early re-exploration (days 1–3), all the leaks were from caudate ducts which were sutured. Two donors underwent ERCP and stenting which were removed subsequently.

Intra-abdominal collection was observed in 28 donors (3.9%), [RL (4.1%) vs. LL (2.8%), LLS vs. (2.04%), $P = 0.73$]. Most of the collections were managed conservatively. Only eight required insertion of a percutaneous (pigtail) catheter drainage and four required percutaneous aspiration. None of the intra-abdominal collection in LL ($n = 1$) or LLS ($n = 1$) required an intervention.

No significant difference in pleural effusion was observed among donors [RL ($n = 33$), LL ($n = 1$) or LLS ($n = 1$) ($P = 0.52$)]. However, four RL donor required intercostal tube drainage for pleural effusion. Others were managed conservatively. Postoperative pneumonia developed in four RL and one LL donors. Four were managed with aggressive physiotherapy and change in antibiotics only. One right lobe donor needed prolonged ventilation for pulmonary sepsis and died on postoperative day 24 due to same.

Thirteen donors (including seven for bile leak mentioned above) underwent re-exploration, of which 12 were in RL donors, and one (for bile leak) in a LLS donor. The reasons for re-exploration were bile leak ($n = 7$), bleeding ($n = 2$) and adhesive intestinal obstruction ($n = 4$) (Table 3). All 10 readmissions were in RL donors. The reasons were pain abdomen ($n = 4$), fever ($n = 3$), intra-abdominal collection ($n = 2$) and bile leak ($n = 1$). There was no significant difference in ileus among the groups [RL ($n = 23$), LL ($n = 1$) and LLS ($n = 2$) ($P = 0.93$)]. Four of the RL donors required exploration for adhesive intestinal obstruction. All others were managed conservatively. There was need of reventilation in one LLS donor due to respiratory acidosis and subcutaneous emphysema. She was extubated 2 days later and discharged home in 7 days.

Table 3. Causes of re-exploration in recipients and donors

Causes in recipient	Right lobe ($n = 54$)	Left lobe ($n = 2$)
Bleeding	25	1
Adhesive intestinal obstruction	5	0
Early bile leak	6	1
Vascular complication	18	0
Causes in donor	**Right lobe ($n = 12$)**	**Left lobe ($n = 1$)**
Early bile leak	6	1
Bleeding	2	0
Adhesive intestinal obstruction	4	0

Classification according to Clavien grading

The overall complication rate was 22.3%. Most of the complications were grade I and II. Major complications (grade IIIa, IIIb and IV) were noted only in 4.2% donors (Table 4). The incidence of such major complications were comparable among RL ($n = 27$, 4.2%), LL ($n = 1$, 2.7%) and LLS ($n = 2$, 4.08%) ($P = 0.89$). There was one right lobe donor who developed dengue fever on postoperative day (POD) 5 and required ICU readmission. He recovered and was discharged from hospital on pod 15 in stable condition. There was one right lobe donor mortality (1 of 1622; 0.06%) in 2012. He was 40 year male, BMI 24.6, remnant 34.6%. He was extubated immediately postoperatively. Towards end of first week, he developed pleural effusion with pneumonitis needing intercostal drainage and reventilation. He died on POD 24 due to pulmonary sepsis (Appendix S1).

Remnant liver functions

The liver function test (Total bilirubin, SGOT, SGPT and INR on postoperative day 1, 3 and 7) was

Table 4. Donor morbidity based on Clavein grade.

Clavein grade	Overall ($n = 726$)	Right lobe ($n = 641$)	Left lobe ($n = 36$)	Left lateral segment ($n = 49$)	*P* value
Grade I	77 (10.6%)	70 (10.9%)	4 (11.1%)	3 (6.1%)	
Grade II	54 (7.4%)	48 (7.5%)	3 (8.3%)	3 (6.1%)	
Grade III a	14 (1.9%)	13 (2%)	0	1 (2%)	
Grade III b	15 (2.1%)	13 (2%)	1 (2.8%)	1 (2%)	
Grade IV	1 (0.13%)	1 (0.15%)	0	0	
Grade V	1 (0.13)	1 (0.15%)	0	0	
Grade III a and more	31 (4.2%)	28 (4.2%)	1 (2.7%)	2 (4.08%)	0.89
Overall	162 (22.3%)	146 (22.6%)	8 (22.2%)	8 (16.3%)	0.99

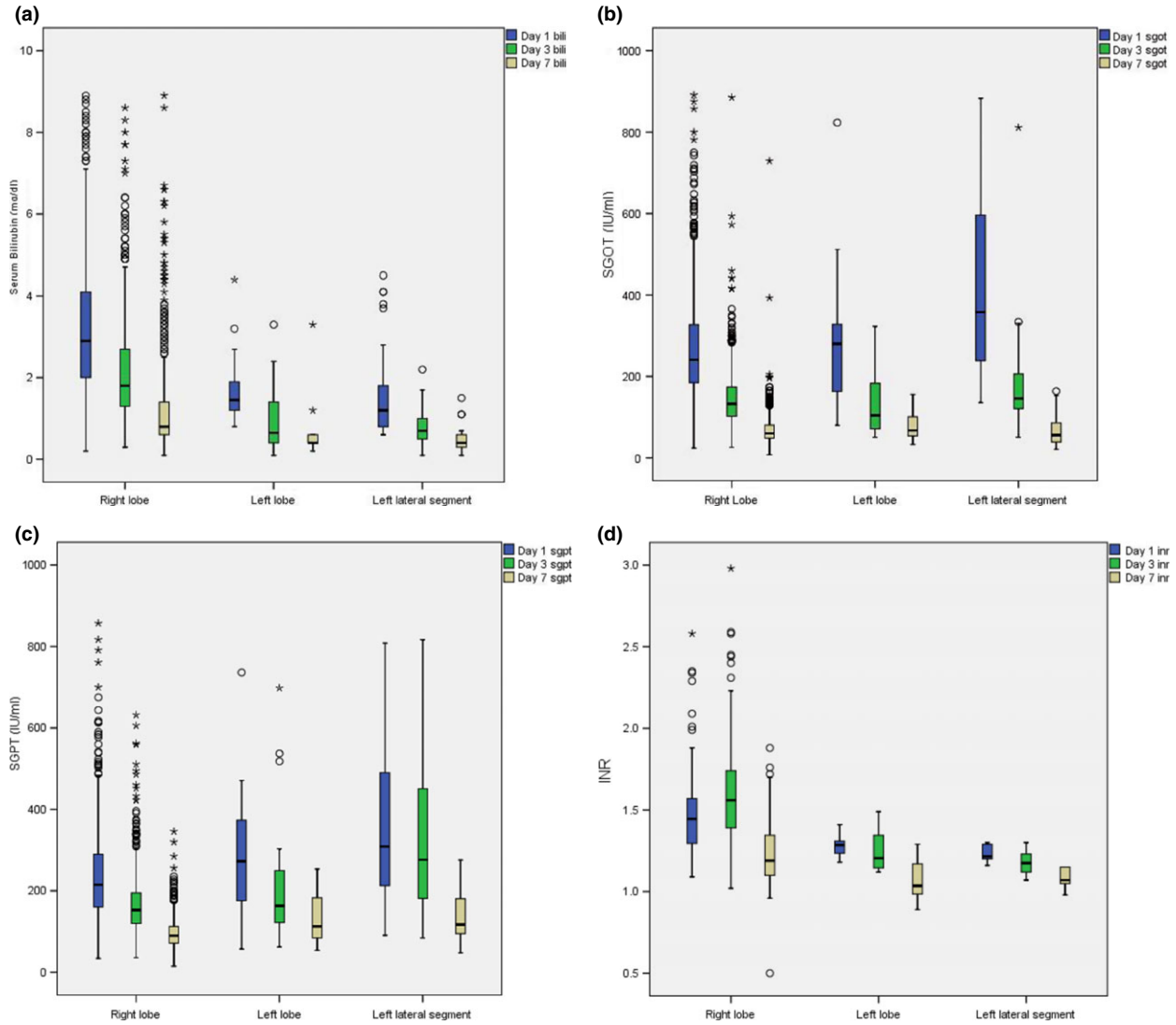

Figure 1 Box-and-whisker plot to depict day 1, 3, 7 (a) Serum Bilirubin, (b) serum glutamic-oxaloacetic transaminase, (c) serum glutamic pyruvic transaminase, (d) internationalized normal ratio levels amongst donors with right lobe, left lobe and left lateral segment graft. Open circle and asterisk both represent outliers. Open circle=outliers. Asterisk = extreme of outliers.

examined for all donors (Fig. 1a–d). The values were highest on day 1, after which a decreasing trend was seen. LLS donors had the least bilirubin and INR but highest SGOT, SGPT on postoperative day 1, 3 and 7 due to transection line being towards right of falciform ligament resulting in ischaemia. However, these parameters improved in all types of graft.

Recipient outcomes

The preoperative recipient characteristics were comparable between the patient who received right and left lobe graft. The mean age of recipient who received either right or left lobe was comparable (49 vs. 47 year, $P = 0.53$). 135 (19.9%) patients had associated HCC. The mean MELD of recipient of RL was 19 (range 6–40) and LL was 16 (range 6–24). Although no difference in MELD score between the groups ($P = 0.17$), none of the recipients of left graft had MELD ≥ 25. Similarly, the aetiology of CLD was comparable between the groups (Table 5). Thirty-five (5.46%) of right lobe recipient were transplanted for acute liver failure, whereas none of the left lobe recipient had ALF. CIT and WIT were significantly higher in right lobe recipient in view of complex bench work and implantation. Mean GRWR was significantly higher in left lobe recipients (1.04 vs. 1.15, $P = 0.001$). There were no significant differences in intraoperative blood loss and blood product transfusion between the groups.

Table 5. Recipient characteristics and outcomes between right and left lobe.

Parameters	Right lobe (n = 641)	Left lobe (n = 36)	P value
Age (year)	49 ± 10	47 ± 14	0.53
Sex – male/female	518/123	25/11	0.12
Hepatitis B virus infection	99 (15.4%)	2 (5.6%)	0.14
Hepatitis C virus infection	180 (28.1%)	6 (16.7%)	0.17
Alcoholic liver disease	243 (37.9%)	15 (41.6%)	0.56
Cryptogenic	119 (18.6%)	8 (22.2%)	0.65
Hepatocellular Carcinoma	132 (20.5%	3 (8.3%)	0.86
CTP	10 ± 2	9 ± 2	0.95
MELD	19 ± 6 (6–40)	16 ± 5 (6–24)	0.17
Hospital stay (days)	18 ± 10	21 ± 10	0.14
Graft weight (g)	720 ± 135	397 ± 113	0.001
Graft recipient weigh ratio	1.04 ± 0.19	1.15 ± 0.36	0.001
Cold ischaemia time (min)	98 ± 57	67 ± 47	0.002
Warm ischaemia time (min)	49 ± 11	38 ± 7	0.001
Cytomegalo virus infection	43 (6.7%)	3 (8.3%)	0.72
Acute cellular rejection	65 (10.1%)	4 (11.1%)	0.77
Vascular complication	24 (3.7%)	1 (2.8%)	1.00
Biliary complication	93 (14.5%)	2 (5.6%)	0.21
Re-exploration	52 (8.1%)	2 (5.6%)	1.00
Blood loss (ml)	1625 ± 870	1690 ± 692	0.78
Early allograft dysfunction	122 (19%)	12 (33.3%)	0.03
Small for size syndrome	19 (3%)	1 (2.8%)	1.00

Table 6. Causes of patient death (n = 87) at 1-year follow-up.

Bacterial sepsis	73 (83.9%)
HCC recurrence	3 (3.4%)
Fungal sepsis	2 (2.2%)
Small for size syndrome	2 (2.2%)
Renal failure	2 (2.2%)
Hepatic artery thrombosis	2 (2.2%)
SMA thrombosis	1 (1.1%)
Primary nonfunction	1 (1.1%)
Intracranial bleed	1 (1.1%)

The postoperative vascular, biliary complications, re-exploration, acute cellular rejection, CMV infection were similar between the groups. Twenty-nine (21.4%) out of 135 HCC patients had post-transplant HCC recurrence. Similarly, 23(12.3%) out of 186 patients with HCV had post-transplant HCV recurrence. No difference in SFS between right and left lobe recipients (3% vs. 2.8%, P = 1.00). EAD was significantly more in left lobe recipient as compared to right lobe recipients. Early (30 days) post-transplant mortality was similar between them (RL-8.3% vs. LL-8.2%). The causes of 1-year patient mortality are shown in Table 6. Similarly, the postoperative hospital stay and 1-year patient survival were comparable between the groups (87.4% vs. 83.3%, P = 0.49) (Fig. 2).

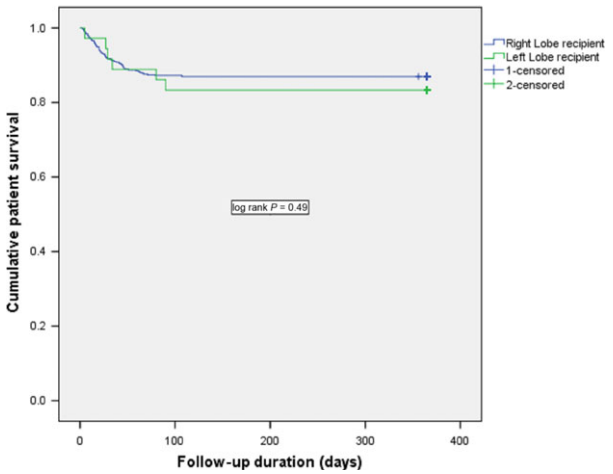

Figure 2 Kaplan–meier patient survuval curve.

Discussion

Great ethical dilemma exists with the use of living donors, where donations are voluntary. Balance is required between the donor's risk of morbidity and safety (related to the liver remnant) and the recipient's risk of morbidity and mortality (related to receiving a graft too small in size) [12]. However, safety of a donor remains prime concern.

The incidence of complications reported in the literature varies from 6–50% in RL to 2–36% in LL to 3–15% in LLS donors [13,14]. The overall incidence of complications in our series was 22.3% (RL-22.6%, LL-22.2%, LLS-16.3%, $P = 0.99$). However, the incidence of grade IIIa, IIIb, IV and V complications in our series (RL 4.2%, LL 2.7% and LLS 4.08%, $P = 0.89$) was comparable to other large series [15–21].

There is no consensus in the literature regarding the donor morbidity among right and left lobe donation. Lida *et al.* [18] have reported significantly higher complication rate in RL donors than that in LL donors (44.2% vs. 18.8%, $P < 0.05$). Although biliary was most common complication, the frequency differed significantly (RL: 12.2% vs. LL: 4.9%; $P < 0.05$). From survey of 1508 donors from five Asian centre, Lo [19], reported higher complication rate in right lobe (28%) than in left lateral segment (9.3%) or left lobe (7.5%) donors. A2ALL study reported 39% donors had one or more complications (707 right lobe and 33 left lobe donors). Most of complications were Clavien grade I and II. 2.8% donors had grade III or IV complications and 80% resolved by 3 months and 95% within the first year of donation [14]. Candido *et al.* [22] have reported 6.2% of Clavien grade $\geq$ III complications among donors and significantly more common after RL than LLS and LL [(14 of 87 (16.1%) vs. 23 of 492 (4.5%) and 6 of 109 (5.5%), respectively, $P < 0.001$]. Multivariate analysis showed that RL resection (OR: 2.81, 95% CI: 1.32–3.01; $P = 0.008$) was one of independent factor associated with complications. Narshiman *et al.* [23] have reported overall morbidity of 31.3% with major complications (Clavien grade III, IV, V) rate of 4.36%. However, the complications were higher in right lobe (38%) as compared to left lobe (28%) and left lateral segment donors (18%).

However, larger series from Japan and Korea have reported similar incidence of complications with right and left lobe donation and decrease in overall complication rate in latest compared to old era [17,20]. Hwang *et al.* [20] have reported over all 3.2% of major complications in 1162 donor hepatectomy over 10 years. Until the end of 2001, major complications occurred in 27 of 401 donors (6.7%). It decreased to 1.3% (10 out of 761 donors) after 2001. Similarly, major complications were more in right lobe donor (10.6% in right lobe vs. 2.1% in left lobe donor in first era. However, the complications rate was similar between right lobe (1.6%) and left lobe donor (1%) after 2001. Similarly, a national-wide survey report of 38 Japanese centres by Hashikura *et al.* in 2006 [17] showed that 8.4% of overall postoperative complication rate after donor hepatectomy with similar complication rate between right lobe (9.4%) and left lobe (8.7%) donors. The Kyoto group [24] have also reported significantly higher overall complications rate in right lobe donor as compared to that of the LL donors (59.5% vs. 30.7%; $P < 0.001$). However, there were no significant differences in severe complications worse than Clavien grade IIIa or in biliary complication rates between the two donor groups. With the inclusion of an innovative surgical approach of hilar dissection preserving the blood supply to the bile duct during donor hepatectomy, the biliary complication rate of the RL donors decreased from 12.2% (from era-1990–2006) to 7.2% (After 2006), and the severity of these complications was significantly lower. Present study shows no significant difference in overall and major complication among groups.

In our study, the incidence of various complications such as intra-abdominal collection, pneumonia, pleural effusion was similar. Similarly, there was no significant difference in the intraoperative blood loss and need for blood transfusion and hospital stay. However, some series have reported higher amount of blood loss in LL donor as compared to RL donor [16,25].

The most worrisome morbidity in a donor is liver failure [21,26,27]. In our study, we have not experienced any incidence of such complications. Liver function improved in all living donors. However, the postoperative recovery of bilirubin and INR were significantly better for the LLS donors as compared to RL and LL donors. Like Suguwara *et al.* [25], peak SGOT levels were highest in LLS groups but, unlike them, bilirubin levels were significantly low in LLS as compared to RL, LL. This is likely to have been due to ischaemia of segment IV following left lateral segment retrieval. Lida *et al.* [18] reported similar results of significantly high enzymes and bilirubin levels with right lobe.

Biliary complications are the most significant complications in a donor. The literature suggests that the incidence of biliary complications is higher with RL (2–12%) as compared to LL (2–5%) and LLS (2–8%). Umeshita *et al.* [15] reported a biliary fistula rate of 10% with RL, 2% with LL and 8.2% with LLS. Taketomi *et al.* [16] reported a biliary complication rate of 10.1% in RL and 2.9% in LL. Lida *et al.* [18] reported a biliary leak rate of 10.6% and 4.7% and biliary stricture rate of 1.6% and 0.3% in RL and LL donors, respectively. Hashikura *et al.* [17] also reported a higher biliary leak rate (3.6% vs. 2%) in RL donors. Lo [19] also had similar findings (bile leak: 6.1% in RL, 2.4% in LL

and 5.5% in LLS). Thus, the incidence of biliary complications is lowest with LL and LLS.

However, we found biliary complication rate of 2.7% among all donors without any significant difference among RL, LL or LLS donors ($P = 0.95$). The Kyoto group [24] reported decrease in the biliary complication rate of the RL donors from 12.2% to 7.2% with increase in surgical experience and modification in surgery.

The common reasons cited in the literature for biliary complication include inappropriate surgical techniques, anatomical aberrations [27,28,29], high predonation alkaline phosphatase [30]. Studies also reveal that graft type (RL or LL) [16], donor age [20] and intraoperative blood transfusion were significantly related to the occurrence of biliary complications. Hwang *et al.* [20] postulated that the lower incidence of biliary complication in elderly donors was because the smooth muscle of the bile ducts (which provides morphologic basis for narrowing of the bile ducts) are thinner and less elastic in senile ducts thus allowing larger orifice and easier suture/ligation of the duct. However, in our study, age of the donor was comparable between those with biliary complications (mean age = 33.55 years) and those without (mean age = 34.69 years).

Re-operation of a donor is a major morbidity that delays recovery. Hashikura *et al.* [17] reported 48 reoperations (1.3%) in a multicenter study; nine for repeat biliary reconstruction; nine for adhesiolysis, eight for closure of bile duct leakage, eight for abdominal drainage, four for hemostasis, three drainage of bile duct, three hernioplasty, two plasty of bile duct, one liver transplantation and one pleural drainage. Taketomi *et al.* [16] also reported three reoperations (1.4%); one choledochoplasty with T-tube for biliary stenosis and two incisional hernia repairs. We report a re-exploration rate of 1.9% with 13 re-explorations (12 in RL) for bile leak ($n = 7$), bleeding ($n = 2$) and adhesive intestinal obstruction ($n = 4$). However, there was no statistically significant difference in re-exploration rate among RL or LL or LLS donor. The most common reason for re-exploration of donor in our study was bile leak ($n = 7$).

The Vancouver forum on LDLT reported death of 34 living donors in 2006 [31]. Four of them were LL donors including one due to suicide. The mortality rate of a living donor in LDLT was estimated to be 0.1% for LL donors and 0.5% for RL donors. There has been one donor mortality (in RL) in our series (1 of 1622; 0.06%) in 2012.

A worldwide web-based survey which included American Society of transplant surgery, Japanese liver transplant society, European and Chinese liver registry, involving 71 LDLT programs and 11 553 LTs, presented at the International Liver Transplant Surgery meeting in 2011, and also reported 34 deaths with a mortality rate of 0.2% [27]. Twenty-four of them had been picked by their survey and 11 others had been reported in the literature. Eighteen of them were RL donors ($n = 8734$), two were LL donors ($n = 994$) and three were left lateral segment (LLS) donors ($n = 2168$). There was no statistical difference between RL versus LL ($P = 0.71$), RL versus LLS ($P = 0.71$) or LL versus LLS ($P = 0.65$). Thus, the mortality rate was no higher in RL as compared to LL. The most common reasons for mortality were sepsis, liver failure, myocardial ischaemia, cerebral haemorrhage, pulmonary embolism and peptic ulcer complication.

It is imperative to take all precautionary measures to guard the safety of the donor. Various methods have been cited to improve donor outcomes after the surgery. It includes careful selection of donor [32,33], reasonable choice of graft type [20], sufficient volume of the remnant [34,35], meticulous surgical technique [36], surgical experience [30,33,37] and volume of the centre [33].

Although the use of LL grafts is preferred for minimizing donor risk, most of high volume LDLT centres prefer RL grafts to decrease the risk of graft insufficiency in recipients [1–4]. A2ALL data [38] demonstrated that 16–19% of LDLT recipients experienced segmental graft dysfunction and receiving a LL graft was one of the risk factors for graft dysfunction. Interestingly, however, graft weight was not a significant predictor of graft dysfunction nor was it associated with graft failure at 90 days post-transplant. The authors concluded that segmental graft dysfunction is likely a complex and multifactorial process that cannot be fully accounted for by graft size alone. Braun *et al.* [39] have shown comparable 5-year graft survival for LL 86% (95% confidence interval, 74–93) compared with 82% (95% confidence interval, 69–89) for RL recipients ($P = 0.85$) or recipient survival (90% vs. 84%; $P = 0.44$) in properly selected donor–recipient pairs. Halazun *et al.* [40] in study of 214 adult LDLT (LL-56, RL-158), there were no significant differences existed in patient or graft survival at 1, 3, and 5 years ($P = 0.74$ and $P = 0.39$, respectively). However, LL graft was associated with significantly increased risk of small-for-size syndrome but no increased risk of re-transplant within 90-days or perioperative mortality in LLG recipients ($P = 0.30$ and $P = 0.93$, respectively).

In our series, we found that when adequate GRWR is given to recipients with either right or left lobe graft,

the postoperative outcomes were comparable. The SFSS was also comparable when adequate GRWR was assured. No significant difference was seen in 1-year patient survival in our series.

The limitation of present study is disproportionately high number in RL group. This resulted from our policy to ensure adequate GRWR and its use in high MELD adult recipients. An initial group matched comparison in ratio of 1:2 failed to reveal any significance in outcomes. Furthermore, such analysis would have failed to show entire spectrum of morbidity and mortality among RL donors which was primary aim of study.

Conclusion

The advantage of greater remnant liver volume and technically less demanding makes left lobe donation intuitively safer, however, with careful selection, meticulous surgery and good postoperative care in centres more experienced in RL LDLT, donor morbidity is similar with comparable 1-year recipient outcomes.

Authorship

ASS, SG, SKY and SS: designed research/study. SKY: collected data. SKY: analyzed data. ASS, SG, SKY: wrote paper.

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Conflict of interest

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Ethical approval

This study was approved by Institutional review board and conducted in accordance with Declaration of Helsinki.

SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article:

Appendix S1. Description of details of protocols, policies and mortality.

REFERENCES

1. Trotter JF, Wachs M, Everson GT, Kam I. Adult-to-adult transplantation of the right hepatic lobe from a living donor. *N Engl J Med* 2002; **346**: 1074.
2. Chan SC, Lo CM, Ng KK, Fan ST. Alleviating the burden of small-for-size graft in right liver living donor liver transplantation through accumulation of experience. *Am J Transplant* 2010; **10**: 859.
3. Yi NJ, Suh KS, Suh SW, *et al.* Excellent outcome in 238 consecutive living donor liver transplantations using the right liver graft in a large volume single center. *World J Surg* 2013; **37**: 1419.
4. Taner CB, Dayangac M, Akin B, *et al.* Donor safety and remnant liver volume in living donor liver transplantation. *Liver Transpl* 2008; **14**: 1174.
5. Cho JY, Suh KS, Kwon CH, *et al.* Outcome of donors with a remnant liver volume of less than 35% after right hepatectomy. *Liver Transpl* 2006; **12**: 201.
6. Reichman TW, Sandroussi C, Azouz SM, *et al.* Living donor hepatectomy: the importance of the residual liver volume. *Liver Transpl* 2011; **17**: 1404.
7. Clavien PA, Camargo CA Jr, Croxford R, Langer B, Levy GA, Greig PD. Definition and classification of negative outcomes in solid organ transplantation. Application in liver transplantation. *Ann Surg* 1994; **220**: 109e5–e16.
8. Olthoff KM, Kulik L, Samstein B, *et al.* Validation of a current definition of early allograft dysfunction in liver transplant recipients and analysis of risk factors. *Liver Transpl* 2010; **16**: 943.
9. Soejima Y, Taketomi A, Yoshizumi T, *et al.* Feasibility of left-lobe living donor liver transplantation between adults: an 8-years, single center experience of 107 cases. *Am J Transpl* 2006; **6**: 1004.
10. Soin AS, Mohanka R, Singla P, *et al.* Segment IV preserving middle hepatic vein retrieval in right lobe living donor liver transplantation. *J Am Coll Surg* 2011; **213**: e5.
11. Soin AS. Smoothing the path: reducing biliary complications, addressing small-for-size syndrome, and making other adaptations to decrease the risk for living donor liver transplant recipients. *Liver Transpl* 2012; **18**: S20.
12. Roll GR, Parekh JR, Parker WF. Left hepatectomy versus right hepatectomy for living donor liver transplantation: shifting the risk from the donor to the recipient. *Liver Transpl* 2013; **19**: 472.
13. Broering DC, Wilms C, Bok P. Evolution of donor morbidity in living related liver transplantation a single-center analysis of 165 cases. *Ann Surg* 2004; **240**: 1013.
14. Abecassis MM, Fisher RA, Olthoff KM, *et al.* Complications of living donor hepatic lobectomy—a comprehensive report. *Am J Transplant* 2012; **12**: 1208.

15. Umeshita K, Fujiwara K, Kiyosawa K, *et al.* Operative morbidity of living liver donors in Japan. *Lancet* 2003; **362**: 687.
16. Taketomi A, Kayashima H, Soejima Y, *et al.* Donor risk in adult-to- adult living donor liver transplantation: impact of left lobe graft. *Transplantation* 2009; **87**: 445.
17. Hashikura Y, Ichida T, Umeshita K, *et al.* Donor complications associated with living donor liver transplantation in Japan. *Transplantation* 2009; **88**: 110.
18. Lida T, Ogura Y, Oike F, *et al.* Surgery-related morbidity in living donors for liver transplantation. *Transplantation* 2010; **89**: 1276.
19. Lo CM. Complications and long-term outcome of living liver donors: a survey of 1,508 cases in five Asian centers. *Transplantation* 2003; **75**(Suppl.): S12.
20. Hwang S, Lee S-G, Lee Y-J. Lessons learned from 1,000 living donor liver transplantations in a single center: how to make living donations safe. *Liver Transpl* 2006; **12**: 920.
21. Usta S, Ates M, Dirican A, Isik B, Yilmaz S. Outcomes of left-lobe donor hepatectomy for living-donor liver transplantation: a single-center experience. *Transplant Proc* 2013; **45**: 961.
22. Candido HL, da Fonseca EA, Feier FH, *et al.* Risk factors associated with increased morbidity in living liver donation. *J Transplant* 2015; **2015**: 949674.
23. Narasimhan G, Safwan M, Kota V, *et al.* Donor outcomes in living donor liver transplantation – analysis of 275 donors from a single centre in India. *Transplantation* 2016; **100**: 1251.
24. Iwasaki J, Iida T, Mizumoto M, *et al.* Donor morbidity in right and left hemiliver living donor liver transplantation: the impact of graft selection and surgical innovation on donor safety. *Transpl Int* 2014; **27**: 1205.
25. Sugawara Y, Makuuchi M, Takayama T, Imamura H, Kaneko J, Ohkubo T. Safe donor hepatectomy for living related liver transplantation. *Liver Transpl* 2002; **8**: 58.
26. Malago M, Testa G, Frilling A, *et al.* Right living donor liver transplantation: an option for adult patients: single institution experience with 74 patients. *Ann Surg* 2003; **238**: 853.
27. Cheah YL, Simpson MA, Pomposelli JJ, Pomfret EA. The incidence of death and potentially life-threatening "near miss" events in living donor hepatic lobectomy: a world-wide survey. *Liver Transpl* 2013; **19**: 499.
28. Shio S, Yazumi S, Ogawa K, *et al.* Biliary complications in donors for living donor liver transplantation. *Am J Gastroenterol* 2008; **103**: 1393.
29. Yuan Y, Gotoh M. Biliary complications in living liver donors. *Surg Today* 2010; **40**: 411.
30. Ghobrial RM, Freise CE, Trotter JF, *et al.* Donor morbidity after living donation for liver transplantation. *Gastroenterology* 2008; **135**: 468.
31. Barr ML, Belghiti J, Villamil FG, *et al.* A report of the Vancouver Forum on the care of the live organ donor: lung, liver, pancreas, and intestine data and medical guidelines. *Transplantation* 2006; **81**: 1373.
32. Li FG, Yan LN, Zeng Y, *et al.* Donor safety in adult living donor liver transplantation using the right lobe: single center experience in China. *World J Gastroenterol* 2007; **21**: 3752.
33. Shah SA, Grant DR, Greig PD, *et al.* Analysis and outcomes of right lobe hepatectomy in 101 consecutive living donors. *Am J Transplant* 2005; **5**: 2764.
34. Ran S, Wen TF, Yan LN, *et al.* Risks faced by donors of right lobe for living donor liver transplantation. *Hepatobiliary Pancreat Dis Int* 2009; **8**: 581.
35. Wen TF, Chen ZY, Yan LN, *et al.* Measures for increasing the safety of donors in living donor liver transplantation using right lobe grafts. *Hepatobiliary Pancreat Dis Int* 2007; **6**: 590.
36. Russo MW, LaPointe-Rudow D, Teixeira A, *et al.* Interpretation of liver chemistries in adult donors after living donor liver transplantation. *J Clin Gastroenterol* 2004; **38**: 810.
37. Marsh JW, Gray E, Ness R, Starzl TE. Complications of right lobe living donor liver transplantation. *J Hepatol* 2009; **51**: 715.
38. Pomposelli JJ, Goodrich JP, Emond JC, *et al.* Segmental graft dysfunction after live donor liver transplantation: it's not all about size. A report from the A2ALL Cohort Study. *Am J Transplant* 2014; **14**: 1.
39. Braun HJ, Dodge JL, Roll GR, Freise CE, Ascher NL, Roberts JP. Impact of graft selection on donor and recipient outcomes after living donor liver transplantation. *Transplantation* 2016; **100**: 1244.
40. Halazun KJ, Przybyszewski EM, Griesemer AD, *et al.* Leaning to the left: increasing the donor pool by using the left lobe, outcomes of the largest single-center North American experience of left lobe adult-to-adult living donor liver transplantation. *Ann Surg* 2016; **264**: 448.