Outcomes of 6000 living donor liver transplantation procedures: a pioneering experience at ASAN Medical Center

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Abstract

Living donor liver transplantation (LDLT) has emerged as a favorable alternative to deceased donor liver transplantation, significantly reducing waitlist mortality, particularly in Asian countries with very low deceased organ donation rates. Asan Medical Center (AMC) in South Korea has pioneered innovative LDLT surgical techniques and become established as an extremely high-volume center for LDLT. This retrospective study analyzed 6000 consecutive LDLT procedures, including 510 dual-graft procedures, performed at AMC between December 1994 and January 2021. Of these, 312 LDLT procedures were performed in children aged < 18 years. In adult recipients, liver cirrhosis (LC) related to viral hepatitis was the most common indication, occurring in 69.8% of cases. Biliary atresia (46.8%) was the most common indication for pediatric LDLT. This study demonstrated outstanding long-term outcomes, with patient survival rates at 1, 5, 10, and 20 years of 92.7%, 85.9%, 82.1%, and 70.9%, respectively, in LDLT group for adults aged 50 and under at the time of LDLT, and 92.9%, 89.0%, 88.1%, and 81.9%, respectively, in the pediatric group. The in-hospital mortality rate of adult recipients was 3.8% ($n = 214/5688$). This study demonstrates the importance of refined surgical techniques, selection of grafts tailored to the recipient, and comprehensive multidisciplinary perioperative patient care in expanding the scope of LDLT and improving recipient outcomes.

Keywords Living donor liver transplantation · Outcomes · Survival · Graft selection

Introduction

Living donor liver transplantation (LDLT) is now a practical alternative to deceased donor liver transplantation (DDLT) aimed at overcoming organ shortages and consequently reducing the risk of waitlist mortality [1, 2]. The impact of LDLT has been significantly greater in Asia, where access to donor grafts is limited by the extremely low rate of organ donation from deceased donors, and LDLT has made rapid advances in Asia with favorable outcomes for both donors and recipients, and has become the mainstay of liver transplantation (LT) [3–5].

The Asan Medical Center (AMC) LT program was launched in August 1992 with DDLT. In 1994, pediatric LDLT was successfully performed at AMC, representing the first LDLT procedure conducted in South Korea. The adult-to-adult LDLT program using right-lobe grafts was initiated in 1997; however, early results were unsatisfactory as severe graft congestion of the anterior sector led to graft dysfunction. To address congestion problems related to middle hepatic vein drainage, the LDLT procedure was altered to include the modification of right-lobe grafts, which involves reconstructing the middle hepatic vein prior to transplantation [6, 7]. This landmark development has substantially improved recipient outcomes in right-lobe LDLT, ensuring donor safety and providing an innovative solution to the severe shortage of deceased donors in Asian countries.

Extensive experience has resulted in a standardized surgical technique and multidisciplinary perioperative patient management, which has established AMC as an extremely high-volume center responsible for one-third of all LDLT procedures in South Korea. The purpose of the current study was to present the long-term outcomes of 6000 consecutive LDLT procedures performed since the start of the LDLT program in 1994 at our institution and describe the strategies

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used to select grafts according to the requirements of the recipients, based on our accumulated experience.

Methods

Study population and design

A total of 8128 LT procedures (1356 DDLT and 6772 LDLT) have been performed at AMC, University of Ulsan College of Medicine, Seoul, South Korea, from the first DDLT in August 1992 to December 2022. Since 2010, over 300 LDLT procedures per year have been performed at AMC. Remarkably, even during the 3 years of the coronavirus disease 2019 pandemic, the center conducted 400 LDLT procedures each year, including cases requiring highly complex surgical techniques (Fig. 1).

Data collected from the medical records of the 6000 consecutive patients undergoing LDLT between December 1994 and January 2021 were retrospectively analyzed. An adult recipient was defined as one aged 18 years or older. All LDLT procedures were performed after obtaining approval from the Korean Network for Organ Sharing, affiliated with the Korean Ministry of Health. This study was approved by the Institutional Review Board of AMC (Approval Number 2022–1218) and conducted in accordance with the principles outlined in the Declaration of Helsinki.

Preoperative evaluation and donor and recipient surgical procedures

The preoperative evaluation and surgical procedure performed on the living donor have been described previously [1, 8]. Briefly, after an interview to determine their willingness to donate and confirm the absence of any known conditions that significantly increased perioperative risk or contraindicated donation such as significant hepatic steatosis and insufficient remnant liver volume, extensive serological evaluations and imaging tests were performed to confirm their suitability. Imaging tests included mesenteric Doppler ultrasound, volumetric computed tomography (CT), and magnetic resonance (MR) cholangiography to evaluate liver echogenicity, measure liver size, and assess the vasculobiliary anatomy. Percutaneous liver biopsies were selectively performed on candidate donors with a high body mass index (≥ 30 kg/m^2), increased levels of AST, ALT, or total bilirubin, any abnormal findings on CT or US indicating hepatic steatosis, or a family history of hereditary liver diseases [8]. Donor hepatectomy was performed using various approaches, including conventional, mini-incision, hand-assisted laparoscopic, and pure laparoscopic techniques, according to the individual donor. The indications for each surgical technique have been described in detail previously [9–11].

Liver Transplantation at the Asan Medical Center (Aug. 1992 - Dec. 2022)

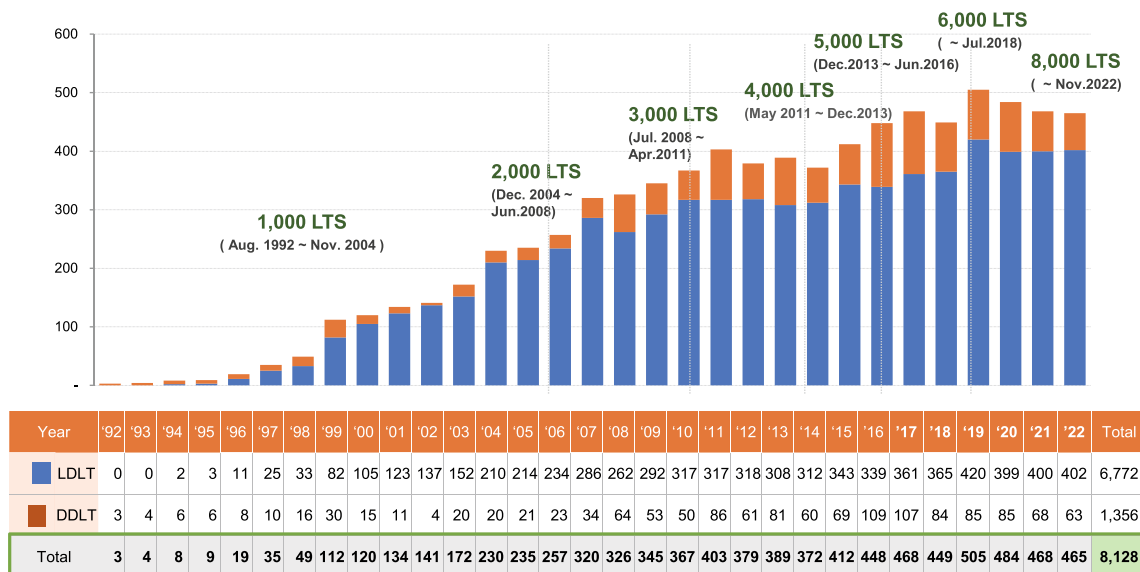| Year	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15	'16	'17	'18	'19	'20	'21	'22	Total
LDLT	0	0	2	3	11	25	33	82	105	123	137	152	210	214	234	286	262	292	317	317	318	308	312	343	339	361	365	420	399	400	402	6,772
DDLT	3	4	6	6	8	10	16	30	15	11	4	20	20	21	23	34	64	53	50	86	61	81	60	69	109	107	84	85	85	68	63	1,356
Total	3	4	8	9	19	35	49	112	120	134	141	172	230	235	257	320	326	345	367	403	379	389	372	412	448	468	449	505	484	468	465	8,128

Fig. 1 The annual number of LDLT procedures performed at AMC

The preoperative evaluation and surgical procedure performed on the recipient have been described elsewhere [1, 12]. All LT candidates underwent a comprehensive assessment, including imaging using mesenteric Doppler ultrasound, abdominal and chest contrast-enhanced CT, positron emission tomography-CT, and/or MR. An indirect portogram was selectively performed in recipients with portal vein thrombus. If portal vein obliteration was observed on preoperative CT scans, an indirect portogram through the superior mesenteric artery was selectively performed. In addition, all candidates underwent thorough cardiopulmonary and cerebrovascular screening to evaluate perioperative risks. Our standardized LDLT techniques are based on sufficient portal and arterial inflows, good hepatic vein outflow, and secure bile duct anastomosis [1]. All the most hepatic arterial reconstructions were performed by surgeons skilled in reconstructive microsurgery [13]. Hepaticojejunostomy with a Roux limb was the standard procedure for biliary reconstruction until January 2000. From February 2000, duct-to-duct anastomosis became the preferred technique for biliary reconstruction, along with an external biliary drain, unless biliary liver anastomosis was not technically feasible due to the length or vascularity of the recipient bile duct or the recipient had biliary disease.

Immunosuppression

The immunosuppressive regimen comprised a calcineurin inhibitor (CNI), mycophenolate mofetil, and corticosteroids with anti-interleukin 2 induction, with the dose of CNIs and corticosteroids varying depending on the preoperative condition of the recipient. Everolimus, in combination with a CNI, was administered to recipients at a high risk of hepatocellular carcinoma recurrence.

For recipient and donor pairings with incompatible blood types, recipients underwent rituximab treatment and plasma exchange prior to transplantation. No special drugs or induction regimens other than rituximab were used. The frequency and timing of plasma exchange were determined based on the hemagglutination titer, with the aim of achieving an antibody titer of $\leq 1:8$ before LT. A detailed description of the desensitization protocol for ABO-incompatible (ABOi) adult LDLT at our institution has been published previously [14–16].

Statistical analyses

Quantitative data are expressed as mean $\pm$ standard deviation or median with interquartile range (IQR). Qualitative data are expressed as number and percentage (%). The Kruskal–Wallis test by ranks was used to evaluate the differences between several groups. Graft and patient survival rates were determined using Kaplan–Meier survival analysis, and comparisons between different groups were performed using log-rank tests. $P < 0.05$ was considered statistically significant.

Results

During the study period of December 1994 to January 2021, 7695 LT procedures were performed at AMC, of which 1695 DDLT procedures were excluded, and 6000 LDLT procedures using grafts from 6570 donors were included in this study. Of these, 312 LT procedures were performed in children aged < 18 years. Figure 1 shows the number of LDLT procedures performed at AMC annually.

Recipient and donor baseline characteristics

The indications for LDLT in adult and pediatric patients are shown in Fig. 2a, b, respectively. In adults, LC related to viral hepatitis, including hepatitis B and C viruses, was the most common indication for liver transplantation, occurring in 69.8% of recipients. This was followed by alcoholic LC (15.0%) and cryptogenic LC (5.0%). Hepatocellular carcinoma was present in 2551 recipients (42.5%). Biliary atresia (46.8%) was the most common indication for liver transplantation in pediatric recipients, followed by fulminant hepatic failure (18.3%).

The demographic and clinical data of the recipients and donors of 6000 LDLT procedures are shown in Table 1. In pediatric LDLT, the 312 recipients had a mean age of 4.2 ± 4.8 years (range: 3 months–17 years). The median pediatric end-stage liver disease score was 19 (IQR: 11–27). The donors were mostly the parents of the recipients, with a mean donor age of 34.4 ± 6.4 (range: 30–50) years. Only 1.9% of donors had a blood type incompatible with that of the recipient. In adult LDLT, the 5688 recipients had a mean age of 52.1 ± 9.0 (range: 18–78) years; 4198 were male and 1490 were female. The median model for end-stage liver disease (MELD) score was 14 (IQR: 10–22). Among the 5688 LDLT procedures, 757 (13.3%) were ABOi and 40 (0.7%) were re-transplantation surgeries. Of the total 6256 donors, there were 34 domino donors. The majority of the donors were the children of the recipients ($n = 3631$; 70.0%) followed by other close relatives, with a mean donor age of 28.3 ± 8.2 (range: 16–65) years. The mean recipient-to-graft weight ratio (GRWR) was 1.09 ± 0.24, and the mean graft volume (GV)/standard liver volume (SLV) ratio was $60.3 \pm 11.1\%$. In adult LDLT, right-lobe grafts were the most commonly procured ($n = 4853$; 85.3%). In cases of dual grafts (DG), the left lobe/left lobe or left lateral segment graft combination was the most commonly used ($n = 332$; 58.2%). The demographic and clinical data of the recipients
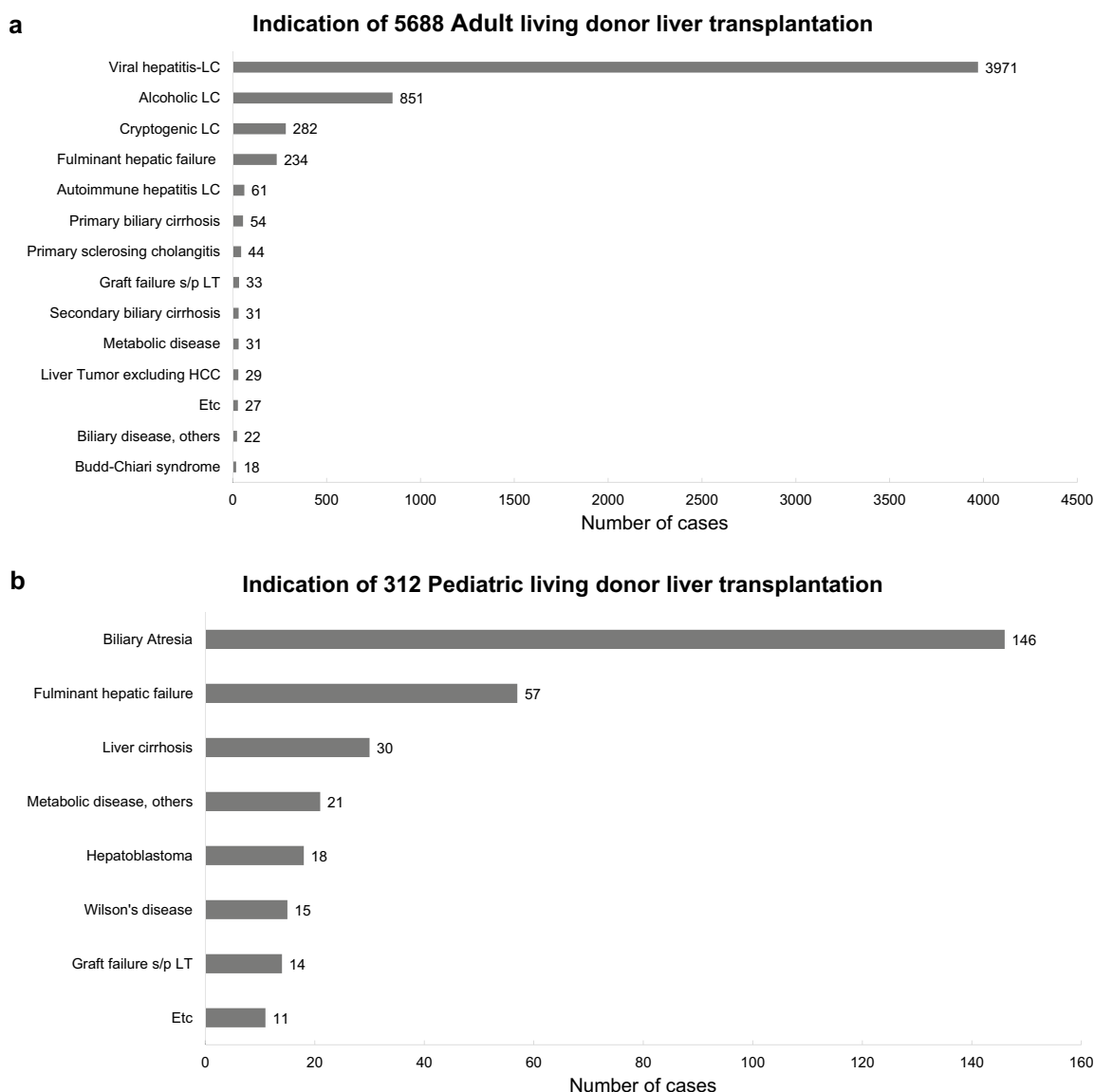
a **Indication of 5688 Adult living donor liver transplantation**

b **Indication of 312 Pediatric living donor liver transplantation**

Fig. 2 Etiology of liver disease in **a** adults and **b** pediatric recipients of living donor liver transplants at Asan Medical Center

and donors of the 5688 adult LDLT procedures are presented according to graft type in Table 2.

Operative outcomes of adult LDLT according to graft type

Intraoperative and postoperative data from the 5688 adult LDLT procedures, classified by graft type, are presented in Table 2. The mean red blood cell transfusion requirement was highest in the DG group, with 14 (IQR: 8–26) units needed ($P < 0.0001$). In addition, the mean operative duration was the longest in the DG group, at 1068 (IQR: 961–1176) min ($P < 0.0001$). In contrast, the mean postoperative hospital stay was longest in the single left graft group, at 38 (IQR: 28–55) days ($P < 0.0001$). The

incidence of biliary complications including stricture and leak was 19.0% in the single right graft group, 26.1% in the single left graft group, and 30.7% in the DG group ($P < 0.0001$). Hepatic artery-related complications such as dissection and thrombosis occurred in 3.0% of cases in the single right graft group, 5.1% in the single left graft group, and 3.6% in the DG group ($P = 0.057$). In the single left graft group, 21 of 253 (8.3%) cases required re-transplantation due to graft failure after transplantation, compared with 242 of 4865 (5.0%) cases in the single right graft group and 29 of 570 (5.1%) cases in the DG group ($P = 0.065$). In addition, in-hospital mortality was the highest in the DG group at 7.0% and lowest in the right graft group at 3.0% ($P < 0.0001$).

Table 1 Demographic and clinical data of recipients and donors involved in living donor liver transplantation

Characteristic	Adult recipients (≥ 18 years)	Pediatric recipients (< 18 years)
Recipients	(n = 5688)	(n = 312)
Age, years, mean ± SD	52.1 ± 9.0	4.2 ± 4.8
Sex, male/female	4198/1490	143/169
BMI, kg/m^2, mean ± SD	23.9 ± 3.5	17.5 ± 3.5
MELD score/PELD score, median (IQR)	14 (10–22)	19 (11–27)
ABO incompatible, n (%)	757 (13.3%)	6 (1.9%)
Re-transplantation, n (%)	40 (0.7%)	17 (5.4%)
Graft type, n (%)		
Single graft	5118 (90.0%)	310 (99.4%)
Right lobe	4853 (85.3%)	22 (7.1%)
Left lobe	250 (4.4%)	136 (43.6%)
Left lateral lobe	2 (0.0%)	152 (48.7%)
Right posterior lobe	12 (0.2%)	0 (0.0%)
Left trisection lobe	1 (0.0%)	0 (0.0%)
Dual graft	570 (10.0%)	2 (0.6%)
Portal HTN symptoms, n (%)		
History of varix bleeding	1422 (25.0%)	23 (7.4%)
History of SBP	334 (5.9%)	4 (1.3%)
Intractable ascites	1457 (25.6%)	26 (8.3%)
Hepatic encephalopathy	830 (14.6%)	41 (13.1%)
Condition at the time of LT, n (%)		
ICU stay, n (%)	349 (6.1%)	75 (24.0%)
Ventilator care, n (%)	298 (5.2%)	30 (9.6%)
Dialysis, n (%)	285 (5.0%)	17 (5.4%)
Vasopressor use, n (%)	137 (2.4%)	11 (3.5%)
Sepsis, n (%)	31 (0.5%)	1 (0.3%)
HEP, grade ≥ 2, n (%)	470 (8.3%)	50 (16.0%)
Donors	(n = 6256)	(n = 314)
Age, years, mean ± SD	28.3 ± 8.2	34.4 ± 6.4
Sex, male/female	3628/1563	123/187
BMI, kg/m^2, mean ± SD	23.1 ± 2.9	23.0 ± 3.2
Relationship to recipient, n (%)		
Son/daughter	3631 (70.0%)	0 (0.0%)
Father/mother	18 (0.3%)	269 (86.8%)
Brother/sister	423 (8.2%)	8 (2.6%)
Husband/wife	267 (5.2%)	0 (0.0%)
Other	845 (16.3%)	33 (10.6%)
GRWR, mean ± SD	1.09 ± 0.24	2.29 ± 1.06
GV/SLV, mean ± SD	60.3 ± 11.1	75.6 ± 25.0

BMI, body mass index, *GRWR* graft-recipient-weight ratio, *GV* graft volume, *HEP* hepatic encephalopathy, *HTN* hypertension, *ICU* intensive care unit, *IQR* interquartile range, *LT* liver transplantation, *MELD* model for end-stage liver disease, *PELD* pediatric end-stage liver disease, *SBP* spontaneous bacterial peritonitis, *SD* standard deviation, *SLV* standard liver volume

Patient survival

The patient survival rates at 1, 5, 10, and 20 years of 92.7%, 85.9%, 82.1%, and 70.9%, respectively, for adult recipients aged 50 and under, and 92.8%, 83.2%, 76.7%, and 60.1%, respectively, in adult recipients over 50 years of age. In addition, the patient survival rates at 1, 5, 10, and 20 years were 92.9%, 89.0%, 88.1%, and 81.9%, respectively, for pediatric recipients (P < 0.0001) (Fig. 3a). When patient survival was compared based on the MELD/PELD score, as depicted in Fig. 3b, the group with a MELD score of 31–40 showed the lowest survival rates (P < 0.0001), being 82.9%, 76.8%, 72.7%, and 59.4% at 1, 5, 10, and 20 years, respectively. There were no statistically significant differences between ABOi and ABO-compatible LDLT groups, with 1-, 5-, and 10-year survival rates of 92.5%, 84.5%, and 79.5%, respectively, in the ABO-compatible group, and 94.9%, 84.1%, and 78.8%, respectively, in the ABOi group (P = 0.9958; Fig. 3c). The patient survival rates of the re-transplantation group were significantly lower than those of the primary LDLT group, with 1-, 5-, 10-, and 20 year survival rates of 77.2%, 64.5%, 61.0%, and 40.6%, respectively (Fig. 3d). When patient survival was compared according to graft type (single graft versus DG), as shown in Fig. 3e, the DG group showed lower survival rates of 90.0%, 82.0%, 76.0%, and 64.7% compared with 93.1%, 84.8%, 79.8%, and 66.7% for the single-graft group at 1, 5, 10, and 20 years, respectively (P = 0.0571).

Discussion

This study represents the most extensive report of LDLT with the longest follow-up period, conducted at a leading Asian center that has pioneered innovative surgical techniques [7, 17–19]. Our study demonstrated outstanding LDLT outcomes, with 10 year overall patient survival rates of 88.1% and 82.1%, and 20-year overall patient survival rates of 81.9% and 70.9% in children and adults aged 50 and under, respectively. The in-hospital mortality rate among adult recipients undergoing LDLT was 3.8% (n = 214/5688), and was even relatively low in patients with increased MELD scores: 0.8% (n = 14/1701) for scores up to 10, 2.2% (n = 51/2340) for scores of 11–20, 7.2% (n = 72/1002) for scores of 21–30, and 11.9% (n = 77/645) for scores of 31–40. These results include the poor outcomes observed in the early stages of the LDLT program; in-hospital mortality has improved over time [7] to 2.3% (27/1163), despite the coronavirus disease 2019 pandemic. In 2017, our institution achieved an extraordinary 0% in-hospital mortality in 361 LDLTs. These findings confirm the effectiveness and safety of LDLT in prolonging the survival of patients with

Table 2 Demographic, clinical, and postoperative data of recipients of adult-to-adult living donor liver transplants according to graft type

Characteristic	Single graft		Dual graft	P-value
	Right graft	Left graft		
Recipients	(n=4865)	(n=253)	(n=570)	
Age, years, mean ± SD	52.4 ± 8.8	50.0 ± 9.9	50.4 ± 9.9	< 0.0001
Sex, male/female	3623/1242	106/147	469/101	< 0.0001
BMI, kg/m^2, mean ± SD	23.8 ± 3.4	21.7 ± 2.9	25.5 ± 3.8	< 0.0001
MELD score, n (%)				< 0.0001
0–10	1537 (31.6%)	37 (14.6%)	127 (22.3%)	
11–20	2007 (41.3%)	108 (42.7%)	225 (39.5%)	
21–30	817 (16.8%)	63 (24.9%)	122 (21.4%)	
31–40	504 (10.4%)	45 (17.8%)	96 (16.8%)	
ABO incompatible, n (%)	672 (13.8%)	8 (3.2%)	77 (13.5%)	< 0.0001
Re-transplantation, n (%)	38 (0.8%)	2 (0.8%)	0 (0.0%)	0.0582
Graft type, n				
	Modified RL: 4594	LL: 185	RL/LL or LLS: 204	
	RL: 138	LL with S1: 67	RPS/LL or LLS: 28	
	Extended RL: 121	LTS: 1	LL/LL or LLS: 332	
	RPS: 12		LLS/LLS: 6	
Etiology of liver disease, n (%)				0.0003
Viral disease (B/C)	3356 (69.0%)	190 (75.1%)	423 (74.2%)	
Alcoholic disease	761 (15.6%)	15 (5.9%)	75 (13.2%)	
Acute liver disease	202 (4.2%)	10 (4.0%)	21 (3.7%)	
Autoimmune disease	152 (3.1%)	12 (4.7%)	8 (1.4%)	
Others	394 (8.1%)	26 (10.3%)	43 (7.5%)	
HCC, n (%)	2222 (45.7%)	85 (33.6%)	244 (42.8%)	0.0005
Portal HTN symptoms, n (%)				
History of varix bleeding	1264 (26.0%)	48 (19.0%)	110 (19.3%)	0.0002
Recurrent SBP	266 (5.5%)	30 (11.9%)	38 (6.7%)	< 0.0001
Intractable ascites	1245 (25.6%)	67 (26.5%)	145 (25.4%)	0.9462
Recurrent HEP	691 (14.2%)	38 (15.0%)	101 (17.7%)	0.0781
Condition at the time of LT, n (%)				
ICU stay	282 (5.8%)	13 (5.1%)	54 (9.5%)	0.0020
Ventilator care	246 (5.1%)	8 (3.2%)	44 (7.7%)	0.0083
Dialysis	248 (5.1%)	6 (2.4%)	31 (5.4%)	0.1354
Vasopressor use	113 (2.3%)	8 (3.2%)	16 (2.8%)	0.5631
Sepsis	22 (0.5%)	3 (1.2%)	6 (1.1%)	0.0386
HEP, grade ≥ 2	392 (8.1%)	16 (6.3%)	62 (10.9%)	0.0357
GRWR, mean ± SD	1.11 ± 0.25	0.87 ± 0.15	1.07 ± 0.19	< 0.0001
GV/SLV, mean ± SD	60.9 ± 10.9	45.4 ± 6.6	61.3 ± 9.6	< 0.0001
Operative time, min, median (IQR)	772 (695–861)	822 (755–910)	1068 (961–1176)	< 0.0001
RBC transfusion, units, median (IQR)	8 (3–14)	10 (6–15)	14 (8–26)	< 0.0001
Hospital stay, days, median (IQR)	23 (18–32)	38 (28–55)	32 (25–46)	< 0.0001
Morbidity, n (%)				
Biliary complications	925 (19.0%)	66 (26.1%)	175 (30.7%)	< 0.0001
Biliary stricture	887 (18.2%)	64 (25.3%)	159 (27.9%)	< 0.0001
Bile leak	62 (1.3%)	2 (0.8%)	26 (4.6%)	< 0.0001
HA related complications	144 (3.0%)	13 (5.1%)	22 (3.6%)	0.057
Re-LT due to graft failure, n (%)	242 (5.0%)	21 (8.3%)	29 (5.1%)	0.065
In-hospital mortality, n (%)	148 (3.0%)	26 (10.3%)	40 (7.0%)	< 0.0001
Donors	(n=4865)	(n=253)	(n=1140)	
Age, years, mean ± SD	28.0 ± 8.1	30.6 ± 8.4	38.7 ± 10.8	< 0.0001
Sex, male/female	3368/1497	234/19	638/502	< 0.0001
Body mass index, kg/m^2	23.0 ± 2.9	25.6 ± 3.7	24.6 ± 3.2	< 0.0001

Table 2 (continued)

BMI body mass index, *GRWR* graft-recipient-weight ratio, *GV* graft volume, *HA* hepatic artery, *HEP*, hepatic encephalopathy, *HCC* hepatocellular carcinoma, *HTN* hypertension, *ICU* intensive care unit, *IQR* interquartile range, *LL* left lobe, *LTS* left tri-segment, *LLS* left lateral segment, *LT* liver transplantation, *MELD* model for end-stage liver disease, *RBC* red blood cell, *RL* right lobe, *RPS* right posterior sector, *SBP* spontaneous bacterial peritonitis, *SD* standard deviation, *SLV* standard liver volume
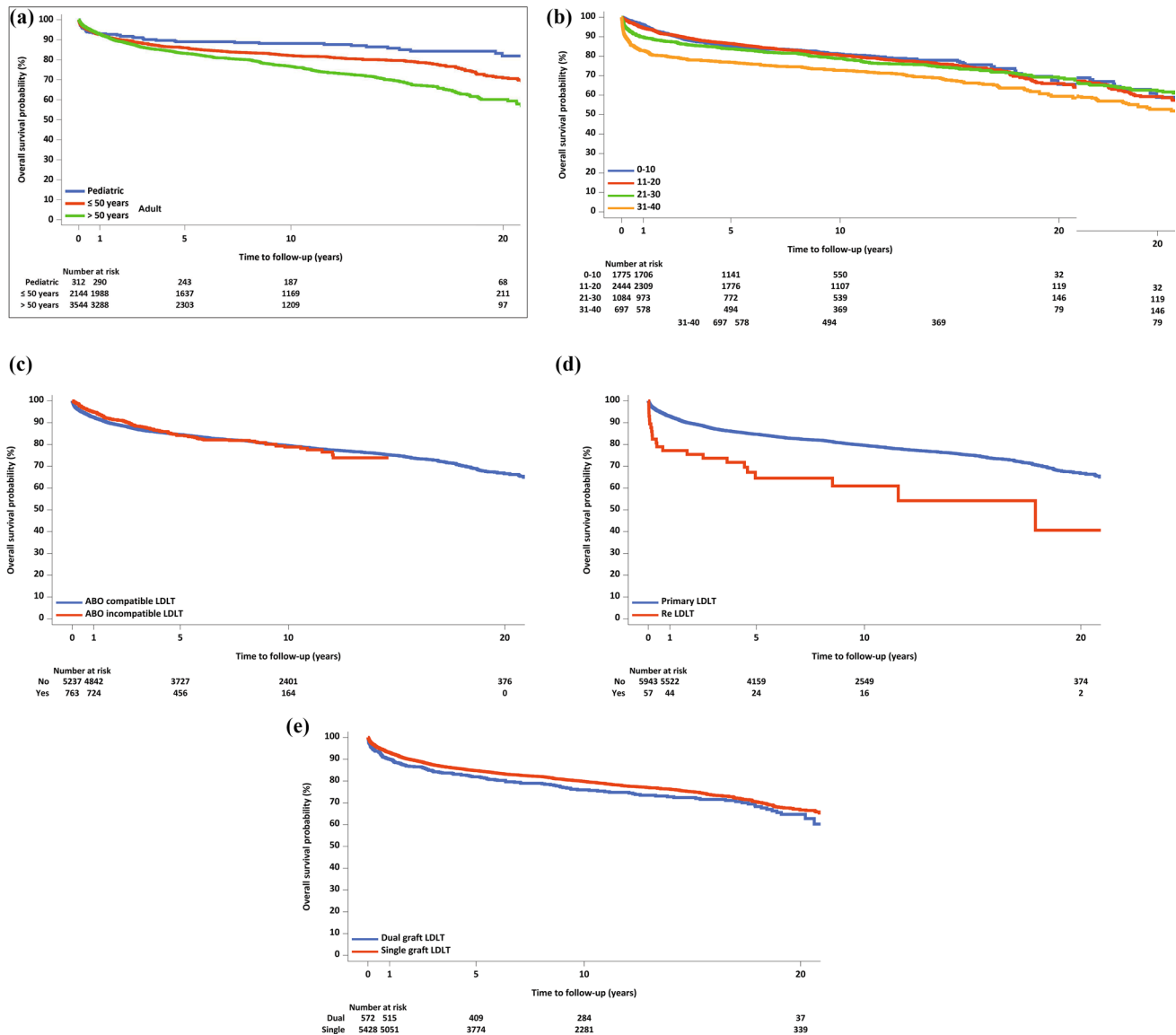
Fig. 3 Overall patient survival rates of LDLT recipients according to **a** Age (adult versus pediatrics) **b** MELD score, **c** ABO incompatibility, **d** LT type (re-transplantation versus primary transplantation) and **e** graft type (Single versus Dual graft). *LDLT* living donor liver transplantation, *LT* liver transplantation, *MELD* model for end-stage liver disease

end-stage liver disease without relying on organs from deceased donors.

Over the past 20 years, the success of LDLT has led to an expansion in the eligibility criteria for recipients. Patients previously considered high-risk owing to factors such as advanced age, ultra-high MELD scores, or comorbidities are now considered candidates for LDLT [20]. Furthermore,

traditional donor selection criteria are being challenged and broadened, while balancing donor safety with recipient and graft survival [21]. Prioritizing donor safety and selecting the appropriate graft for each recipient are fundamental considerations in LDLT. Several centers have demonstrated the need for careful donor selection for older recipients, who are increasingly undergoing LDLT [22, 23]. We have previously

proposed a GV of > 1.0% of the GRWR or > 50% of the GV/SLV from a donor aged ≤ 35 years as the ideal graft for patients aged ≥ 70 years [12]. For severely ill patients with high MELD scores, our center prefers using a graft with a GRWR close to 1.0, young donor age, and simple graft anatomy to provide sufficient volume to meet metabolic requirements and minimize the risk of complications. These strict graft selection criteria have contributed greatly to the excellent results of LDLT observed in our high-risk recipients.

However, as the availability of grafts is frequently limited, even from living donors, it can be challenging to secure an ideal graft in every case. At our institution, dual and ABOi grafts have been actively utilized in adult LDLT to expand the donor pool [7]. DG LDLT, which was first introduced in the form of "two left-lobes" in 2000 [24], has been performed with various graft combinations, as detailed in Table 2, depending on recipient and donor factors. This has allowed the utilization of grafts from older donors and those with severe steatosis, significantly reducing donor risk and minimizing the risk of small-for-size syndrome, a major concern in LDLT, in recipients [25]. In this study, although DG LDLT resulted in lower overall patient survival rates ($P = 0.0571$) and a higher in-hospital mortality rate ($P < 0.0001$) than single-graft LDLT, it is essential to consider the higher MELD scores in the DG group while interpreting these findings. A previous study that compared 346 DG LDLT procedures conducted at our institution with propensity-score-matched single-graft LDLT procedures revealed no significant differences in long-term outcomes [26]. With the introduction of rituximab and an improved desensitization protocol, the use of ABOi grafts is gradually increasing, along with its indications. ABOi LDLT now constitutes approximately 25% of all adult LDLT procedures at AMC, with outcomes comparable to those of ABO-compatible LDLT. It has been cautiously implemented in patients with high MELD scores, acute liver failure, and hepatocellular carcinoma, with previous studies showing satisfactory results [16, 17]. However, severe antibody-mediated rejection and biliary and infectious complications still affect outcomes. At our institution, the indications for ABOi LDLT are the same as those for ABO-compatible LDLT; however, we closely monitor cases with an increased risk of biliary complications, such as multiple duct openings. Ongoing efforts are needed to develop a desensitization protocol that can minimize the risk of infection and antibody-mediated rejection, and to develop a rapid and accurate diagnostic method for antibody-mediated rejection.

This study has several limitations. First, this was a single-center retrospective data analysis. More importantly, historical bias may have arisen because of the approximately 27-year study period, over which time significant advances in preoperative evaluation, surgical techniques, and perioperative care have been made. For instance, in the initial phase of LDLT, the left lobe was used preferentially. However, it was found that modifying the right-lobe grafts ensured donor safety and provided satisfactory recipient outcomes, and LDLT using a modified right lobe is now the standard technique at our institution. The inferior surgical outcomes observed in the single left lobe group in this study may therefore be a result of historical biases and should be interpreted with caution.

Conclusion

A surgical technique refined through extensive experience plays a crucial role in achieving successful LDLT outcomes. In recent decades, most technical challenges related to adult and pediatric LDLT donor and recipient procedures have been effectively resolved. Implementing appropriate graft selection strategies tailored to the recipient and employing comprehensive multidisciplinary perioperative patient management involving experienced LT surgeons, anesthesiologists, critical care medicine specialists, interventional radiologists, and pathologists can expand the scope of LDLT and enhance recipient outcomes.

Declarations

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