Original Article

Anatomical complexity of the right-lobe grafts: influence on the outcomes in living donor liver transplantation

Seung Hyuk Yim[1,2#^], Incheon Kang[3#^], Deok-Gie Kim[1,4^], Eun-Ki Min[1,4^], Jae Geun Lee[1,4^], Dai Hoon Han[1,4^], Gi Hong Choi[1,4^], Myoung Soo Kim[1,4^], Dong Jin Joo[1,4^]

[1]Department of Surgery, Yonsei University College of Medicine, Seoul, South Korea; [2]Department of Surgery, Yongin Severance Hospital, Gyeonggi-do, South Korea; [3]Department of Surgery, CHA Bundang Medical Center, CHA University, Gyeonggi-do, South Korea; [4]The Research Institute for Transplantation, Yonsei University College of Medicine, Seoul, South Korea

Contributions: (I) Conception and design: SH Yim, I Kang, DG Kim; (II) Administrative support: DG Kim; (III) Provision of study materials or patients: DG Kim, JG Lee, DH Han, GH Choi, MS Kim, DJ Joo; (IV) Collection and assembly of data: SH Yim, I Kang, DG Kim; (V) Data analysis and interpretation: SH Yim, I Kang, DG Kim; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

[#]These authors contributed equally to this work.

Correspondence to: Deok-Gie Kim, MD. Department of Surgery, The Research Institute for Transplantation, Yonsei University College of Medicine, 50-1 Yonsei-ro, Seodaemun-gu, Seoul 03722, South Korea. Email: mppl01@yuhs.ac.

Background: The effect of graft anatomical complexity on post-transplant outcomes in living donor liver transplantation (LDLT) has not been fully elucidated. This retrospective study investigated the association between graft anatomical complexity and long-term graft survival in patients undergoing LDLT.

Methods: Overall, 908 adult LDLT recipients of right-lobe grafts were categorized into complex (n=418) and control (n=490) groups based on graft anatomical complexities, such as multiple branches of the hepatic artery, portal vein, inferior hepatic vein (IHV), and bile duct (BD). Outcomes of both donors and recipients were compared, including matched analyses for each anatomical complexity.

Results: Five-year graft survival rates were similar between the complex and control groups (83.1% *vs.* 77.9%, P=0.16), confirmed by propensity score matching (82.7% *vs.* 77.5%, P=0.27) and multivariate analysis [adjusted hazard ratio (aHR) 0.79, P=0.16]. Graft complexity was associated with an increased risk of BD complications (aHR 1.26, P=0.02). In the matched analyses for each anatomical complexity, grafts with two hepatic arteries showed comparable complication rates (7.7% *vs.* 3.4%, P=0.53) and higher BD complication rates than controls (79.5% *vs.* 43.4%, P=0.02). Interestingly, multiple IHV grafts were associated with better graft survival compared to those with one or fewer IHVs (93.4% *vs.* 75.4%, P=0.003), despite higher hepatic vein complication rates (8.2% *vs.* 3.5%, P=0.04). Major postoperative complications in living donors were similar in both groups (3.3%, P=0.99).

Conclusions: Anatomical complexities of right-lobe grafts do not affect graft survival in LDLT, despite higher BD complications. Notably, multiple IHVs may be a positive factor for graft survival after LDLT.

Keywords: Liver transplantation (LT); complex grafts; inferior hepatic vein (IHV); graft survival; surgical complications

Submitted May 27, 2024. Accepted for publication Aug 16, 2024. Published online Nov 05, 2024.

doi: 10.21037/hbsn-24-293

View this article at: https://dx.doi.org/10.21037/hbsn-24-293

^ ORCID: Seung Hyuk Yim, 0000-0003-2146-3592; Incheon Kang, 0000-0003-4236-5094; Deok-Gie Kim, 0000-0001-9653-926X; Eun-Ki Min, 0000-0003-3255-1942; Jae Geun Lee, 0000-0002-6722-0257; Dai Hoon Han, 0000-0003-2787-7876; Gi Hong Choi, 0000-0002-1593-3773; Myoung Soo Kim, 0000-0002-8975-8381; Dong Jin Joo, 0000-0001-8405-1531.

Introduction

Living donor liver transplantation (LDLT) has emerged as a vital surgical alternative for patients suffering from end-stage liver disease; it offers a solution to severe organ shortage from deceased donors (1). Especially in far East Asian countries, the progressive organ shortage has led to a reliance on LDLT rather than deceased donor liver transplantation (LT) (2-4). To minimize risks to the donor and maximize benefits for the recipient, strict criteria to utilize the liver graft from the living donor have been applied (5-8). Substantial development of surgical and postoperative management techniques over the years has significantly improved LT outcomes (9-11). Nonetheless, LDLT remains a complex surgical procedure with several challenges, particularly in terms of the anatomical complexity of the graft (12).

The impact of the anatomical complexity of the graft, characterized by variations in the vascular and biliary anatomy, on post-transplant outcomes is not yet fully understood. Recent studies have suggested that grafts with multiple stumps of arteries, veins, or bile ducts (BDs) may increase postoperative complications such as hepatic artery (HA) thrombosis, portal vein (PV) stenosis, and biliary leakage or strictures (13,14). These complications can adversely affect graft survival, posing significant challenges in the postoperative management of LDLT recipients (15).

However, until the present, none of the large-scale long-term studies have analyzed the influence of graft anatomical complexity on LDLT outcomes. Therefore, in this study, we aimed to investigate the association between graft anatomical complexity and long-term graft survival in patients undergoing LDLT. We present this article in accordance with the STROBE reporting checklist (available at https://hbsn.amegroups.com/article/view/10.21037/hbsn-24-293/rc).

Highlight box

Key findings

- Anatomical graft complexities in right-lobe grafts do not significantly impact 5-year graft survival in living donor liver transplantation (LDLT), despite of increased risk of bile duct (BD) complications. Multiple inferior hepatic veins (IHVs) improve graft survival despite higher hepatic vein complication rates.

What is known and what is new?

- The impact of graft anatomical features on LDLT outcomes was uncertain.
- Anatomical complexities do not compromise graft survival, and multiple IHVs are beneficial for graft survival despite associated complications.

What is the implication, and what should change now?

- Complex right-lobe grafts can be used without affecting long-term survival. However, vigilant monitoring for BD complications in complex grafts is necessary.

Methods

Data collection and study population

The prospectively recorded data of 1,059 patients who underwent LDLT at a Severance Hospital between July 2005 and December 2022 were retrospectively reviewed. Patients aged under 18 years (n=92), recipients of dual living donors (n=4), or those who underwent combined organ transplantation (n=8) were excluded. Three patients who underwent re-transplantation and 42 patients with graft types other than right-lobe grafts were also excluded. After excluding two recipients with incomplete data, overall, 908 eligible LDLT recipients were included (Figure S1).

The study was conducted in accordance with the Declaration of Helsinki and its subsequent amendments. The study was approved by the Institutional Review Board of Severance Hospital (No. 4-2024-0447), and individual consent for this retrospective analysis was waived because of its retrospective design.

Definition and outcomes

Complex grafts were defined as right-lobe liver grafts with multiple anatomical structures, specifically those with more than one of the following: HA, PV, inferior hepatic vein (IHV), and BD. The study population was divided into two groups according to the anatomical complexity: complex (n=418) and control (n=490). The primary outcome was graft survival, which was defined as patient death or liver re-transplantation. The secondary outcome included complications, which were defined as grade ≥3 complications using the Clavien-Dindo classification system (16). These complications were categorized into vascular complications (HA, PV, and hepatic vein), and BD complications. All types of major complications (grade ≥3) and readmissions were analyzed for all living donors. Pretransplant evaluations and postoperative management are described in Appendix 1.

Surgical techniques for anatomical complexities in grafts

HA anastomosis was painstakingly performed using 8-0 or 9-0 monofilament interrupted sutures either under microscopic guidance or with 5× magnification loupes. For grafts with two HAs, partial reconstruction was performed, and the larger branch was anastomosed first (17). Based on intraoperative Doppler ultrasound measurements of intrahepatic communication and pulsatile back bleeding, the decision was made to either ligate the smaller branch or perform an additional anastomosis. Right and left HAs were generally employed on the recipient side; however, in cases of unhealthy recipient HA, other arteries such as the gastroduodenal artery or right gastroepiploic artery were utilized.

For grafts with two PVs, we initially considered conjoined unification venoplasty when two PV branches are placed close enough (the distance between the two branches is shorter than the diameter of smaller branch) or when the larger branch has a diameter shorter than 1.5 times that of smaller branch. Otherwise, we considered using an interposition Y-graft, taking into account other anatomical branches to be reconstructed (such as HA or BD) and the availability of interposition grafts. In cases where the recipient's PV is intact without presence of hepatocellular carcinoma, an autologous conduit was preferred. However, if patient has hepatocellular carcinoma or an unsuitable PV bifurcation, a frozen homologous vein graft was utilized. A prosthetic vessel interposition graft was considered the last option to utilize. In cases of obliterated recipient PV, alternative PV anastomosis sites, such as the renal vein (in the case of a large splenorenal shunt), superior mesenteric vein, and collateral vein, were selected with or without the use of a conduit.

IHVs with a diameter >3 mm were anastomosed to the inferior vena cava in an end-to-side manner, in most cases. For multiple IHVs, a separate anastomosis to the inferior vena cava or conjoined unification venoplasty was performed depending on the distance and diameter of each IHV.

For grafts with multiple BDs, the choice between ductoplasty for a single anastomosis and separate anastomoses was determined by assessing the diameter and viability of the BDs in both donors and recipients. In most cases, except for cancer invasion or primary sclerosing cholangitis, duct-to-duct anastomosis was preferred to Roux-en-Y hepaticojejunostomy.

Statistical analysis

The results are presented as numbers (percentages) for categorical variables. For continuous variables, the results are shown as means with standard deviations or medians with interquartile ranges. The complex and control groups were matched using propensity scores in a ratio of 1:1. Propensity score matching (PSM) utilized the nearest neighbor technique with a caliper width of 0.1 to ensure precise matching. Propensity scores were derived from a comprehensive analysis of all initial patient characteristics. The matching process was considered successful when the standardized mean differences for all baseline variables did not exceed 0.1 (18). Cases without a suitable match were excluded.

For both, entire and PSM populations, categorical data were compared using the chi-squared test, while continuous variables were compared using the *t*- or Mann-Whitney *U* tests, depending on whether the variables had a normal distribution. Kaplan-Meier analysis with the log-rank test was performed to compare graft survival. For the entire population, the hazard ratio (HR) for graft complexity was evaluated using covariate-adjusted and propensity score-matched multivariate Cox models. Clinically important variables and variables with a P value ≤0.1 in univariate analyses were introduced into multivariate Cox regression models. Sensitivity analyses were also performed for these subgroups. Furthermore, to evaluate the effect of each graft complexity component on LDLT outcomes, PSM was applied according to the multiplicity of HA (1:3), PV (1:3), IHV (1:3), and BD (1:1). The matching ratios were determined based on the number of patients in whom a complex graft was used. For each matching process, other anatomical variations were matched to distinguish the effects of each graft anatomy. Kaplan-Meier analysis was conducted to compare the outcomes between each matched population. All analyses were performed using the R statistical package, version 4.2.2, for MacOS (http://cran.r-project.org, R Foundation for Statistical Computing, Vienna, Austria), with the threshold for significance set at P<0.05.

Results

Baseline characteristics

Table 1 presents the baseline characteristics of the 908

Table 1 Baseline characteristics before and after matching

Variables	Before matching			After matching		
	Complex (n=418)	Control (n=490)	P	Complex (n=313)	Control (n=313)	SMD
Age, years	55 [50–60]	55 [50–60]	0.39	55 [50–60]	56 [51–61]	–0.065
Sex ratio (male:female)	288:130	380:110	0.004	226:87	225:88	–0.007
BMI, kg/m^2	23.9 [22.1–26.3]	23.8 [22.0–25.7]	0.18	23.6 [22.0–25.8]	23.9 [22.0–25.8]	–0.023
Year of transplantation			<0.001			–0.016
2007–2013	87 (20.8)	192 (39.2)		85 (27.2)	87 (27.8)	
2014–2018	114 (27.3)	167 (34.1)		98 (31.3)	104 (33.2)	
2019–2022	217 (51.9)	131 (26.7)		130 (41.5)	122 (39.0)	
Hypertension	89 (21.3)	120 (24.5)	0.29	72 (23.0)	75 (24.0)	–0.023
Diabetes mellitus	132 (31.6)	156 (31.8)	0.99	99 (31.6)	102 (32.6)	–0.021
Cardiovascular disease	26 (6.2)	31 (6.3)	0.99	22 (7.0)	21 (6.7)	0.013
Underlying liver disease			0.002			–0.032
Viral	240 (57.4)	333 (68.0)		195 (62.3)	200 (63.9)	
Alcoholic	98 (23.4)	97 (19.8)		64 (20.4)	64 (20.4)	
Others	80 (19.1)	60 (12.2)		54 (17.3)	49 (15.7)	
Hepatocellular carcinoma	227 (54.3)	293 (59.8)	0.11	173 (55.3)	183 (58.5)	–0.064
Pretransplant MELD	12 [9–17]	12 [9–17]	0.81	12 [9–17]	12 [9–16]	0.053
Pretransplant stay			0.38			0.013
Out-patient	270 (64.6)	319 (65.1)		203 (64.9)	201 (64.2)	
Ward	139 (33.3)	166 (33.9)		104 (33.2)	107 (34.2)	
Intensive care unit	9 (2.2)	5 (1.0)		6 (1.9)	5 (1.6)	
Refractory ascites	53 (12.7)	72 (14.7)	0.44	42 (13.4)	37 (11.8)	0.048
Encephalopathy	84 (20.1)	84 (17.1)	0.29	63 (20.1)	61 (19.5)	0.016
Operation time, min	630 [534–708]	657 [564–736]	0.001	642 [546–720]	644 [540–729]	–0.094
Cold ischemic time, min	130 [102–156]	131 [103–160]	0.83	130 [102–156]	130 [105–156]	–0.071
RBC transfusion, pack	3 [1–7]	4 [1–8]	0.23	3 [1–7]	3 [1–8]	–0.042
Portal flow modulation	34 (8.1)	29 (5.9)	0.24	23 (7.3)	22 (7.0)	0.012
Donor age, years	33 [25–45]	30 [24–39]	<0.001	32 [24–44]	32 [25–39]	0.054
Donor sex, female	185 (44.3)	177 (36.1)	0.02	133 (42.5)	129 (41.2)	0.026
Donor BMI, kg/m^2	22.8 [21.1–24.8]	22.7 [20.8–24.4]	0.24	22.9 [21.0–24.8]	22.8 [21.0–24.5]	0.033
ABO incompatibility	90 (21.5)	101 (20.6)	0.80	69 (22.0)	66 (21.1)	0.023
GRWR <0.8	25 (6.0)	12 (2.4)	0.01	12 (3.8)	12 (3.8)	0.000
Macrovesicular steatosis >10%	54 (14.1)	62 (12.7)	0.75	40 (12.8)	40 (12.8)	0.022
Donor minimally invasive surgery	110 (26.3)	90 (18.4)	0.005	75 (24.0)	72 (23.0)	0.048

Data are presented as number (percentage) or median [interquartile range]. BMI, body mass index; GRWR, graft to recipient weight ratio; MELD, model for end-stage liver disease; RBC, red blood cell; SMD, standardized mean difference.

Table 2 Detailed information of graft anatomy and anastomotic methods in the complex group

Variables	Number (%)
HA anastomosis for two HAs (N=18)	
Partial reconstruction	4 (22.2)
Separately	13 (72.2)
Conjoining arterioplasty	1 (5.6)
Recipient PV anastomosis site (N=44)	
PV	43 (97.7)
Renal vein	1 (2.3)
PV interposition graft (N=44)	23 (52.3)
Autologous	11 (25.0)
Homologous	5 (11.4)
Prosthetic	7 (15.9)
Number of IHVs (N=94)	
Two	82 (87.2)
Three	11 (11.7)
Four	1 (1.1)
Number of BDs (N=343)	
Two	298 (86.9)
Three	41 (12.0)
Four	4 (1.2)
BD anastomotic method (N=343)	
Duct-to-duct after conjoining ductoplasty	251 (73.2)
Separately duct-to-duct	31 (9.0)
Roux-en-Y hepaticojejunostomy	61 (17.8)

BD, bile duct; HA, hepatic artery; IHV, inferior hepatic vein; PV, portal vein.

patients divided into complex (n=418) and control (n=490) groups before PSM and into 313 matched pairs after PSM. Prior to matching, the median age was similar across groups at 55.0 years, as were the prevalence rates of hypertension (21.3% *vs.* 24.5%), diabetes (31.6% *vs.* 31.8%), and cardiovascular disease (6.2% *vs.* 6.3%). Patient health conditions were comparable, considering the similar model for end-stage liver disease scores and length of pre-transplant stays. However, only a few significant differences were observed. The complex group exhibited a higher proportion of females (31.1% in complex group *vs.* 22.4% in control group, P=0.004), cases of alcoholic liver disease (23.4% *vs.* 19.8%, P=0.002), and female donors (44.3% *vs.* 36.1%). There was also a significant difference in the year of transplantation. A total of 51.9% patients from the complex group underwent LDLT between 2019 and 2022, whereas only 26.7% patients from the control group received LDLT during the same period (P<0.001). However, after PSM, the standardized mean differences for all variables significantly reduced.

Anastomosis procedure for complex grafts

Table 2 depicts the frequency of each anatomical complexity and provides detailed information on the anastomoses within the complex group. Among the 18 patients presenting with two HAs, 4 (22.3%) underwent partial reconstruction, whereas 13 (72.2%) received additional separate anastomosis. The remaining 1 (5.5%) patient was treated with conjoined arterioplasty. Among the 44 patients with two PVs, 43 (97.7%) had their graft anastomosed to the PV, while 1 (2.3%) underwent an exceptional renoportal anastomosis. Out of these, in 23 (52.3%) patients, an interposition graft was used; specifically, in 11 (25.1%), 5 (11.5%), and 7 (15.9%) patients, autologous, homologous, and prosthetic grafts, were used, respectively. The group of 94 patients with multiple IHVs included 82 (87.2%) with two IHVs, 11 (11.7%) with three IHVs, and 1 (1.1%) with four IHVs. Within the subgroup of 343 patients with multiple BDs, 298 (86.9%) had two BDs, 41 (12.0%) had three BDs, and 4 (1.2%) had four BDs. In terms of the anastomotic technique, 251 (73.2%) underwent conjoining ductoplasty with a duct-to-duct anastomosis, 31 (9.0%) underwent separate anastomoses using the duct-to-duct method, and 61 (17.8%) were treated with Roux-en-Y hepaticojejunostomy.

Graft survival rates

Graft survival rates before and after PSM are shown in *Figure 1*. Prior to matching, the survival probability of the complex group was similar to that of the control group (P=0.16). The 1-, 3-, and 5-year survival rates were 89.6%, 85.6%, and 83.1% in the complex group and 90.2%, 82.8%, and 77.9% in the control group, respectively. The 5-year graft survival rates according to graft complexity were also comparable after PSM (P=0.27). The results of the multivariate Cox regression analysis revealed that graft complexity was not independently associated with a high risk of graft loss (aHR 0.79; P=0.16, Table S1). A

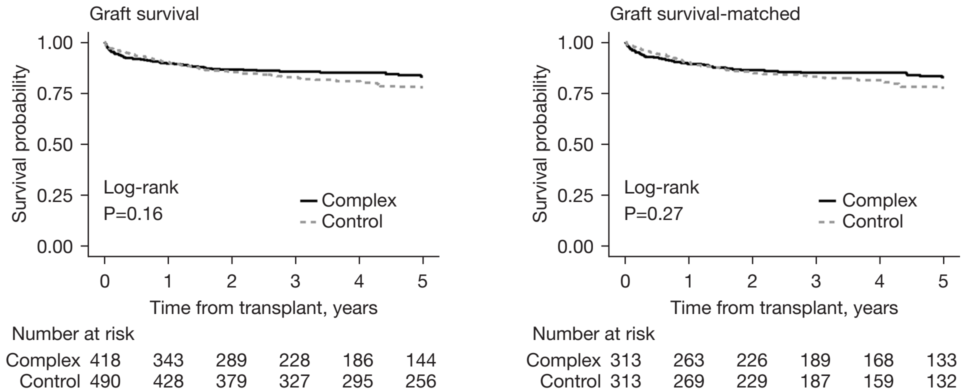

Figure 1 Kaplan-Meier curves for graft survival pre- and post-matching.

Table 3 Surgical complications

Types of complication	Cumulative incidence, %			Unadjusted		Adjusted†	
	1-year	3-year	5-year	HR (95% CI)	P	HR (95% CI)	P
Total vascular complication							
Control	5.5	6.7	7.7	Reference		Reference	
Complex	10.0	12.3	12.8	1.74 (1.12–2.71)	0.01	1.48 (0.93–2.38)	0.10
Hepatic artery							
Control	2.1	2.4	2.7	Reference		Reference	
Complex	3.0	3.3	3.3	1.31 (0.60–2.87)	0.50	1.29 (0.58–2.89)	0.54
Portal vein							
Control	2.3	3.1	3.5	Reference		Reference	
Complex	4.3	5.2	5.8	1.73 (0.89–3.35)	0.11	1.68 (0.83–3.38)	0.15
Hepatic vein							
Control	1.7	1.9	2.3	Reference		Reference	
Complex	3.1	4.2	4.2	1.85 (0.83–4.11)	0.13	1.97 (0.86–4.50)	0.11
Total bile duct complication							
Control	34.0	41.4	43.8	Reference		Reference	
Complex	40.2	48.2	51.3	1.25 (1.02–1.52)	0.03	1.26 (1.04–1.54)	0.02

†, adjusted Cox regression models were established including covariates of which P values were <0.10 in univariate analyses. HR, hazard ratio; CI, confidence interval.

sensitivity analysis was conducted to evaluate the association between graft complexity and LDLT outcomes (Table S2). In subgroups with or without hepatocellular carcinoma, as well as those with graft-to-recipient weight ratio >0.8, the complex group was not associated with worse outcomes. Moreover, the complex group showed a similar risk of graft loss in both subgroups of open donor surgery (aHR 0.78, P=0.17) and minimally invasive surgery (aHR 0.83, P=0.69).

Surgical complications of the recipients and living donors

As shown in *Table 3*, the 5-year incidences of complications regarding HA (3.3% in the complex group *vs.* 2.7% in the control group, aHR 1.29, P=0.54), PV (5.8% *vs.* 3.5%, aHR

Table 4 Living donor outcomes

Variables	Complex (n=418)	Control (n=490)	P
Major complications (grade ≥3)			0.99
Grade IIIa	8 (1.9)	11 (2.2)	
Grade IIIb	6 (1.4)	4 (0.8)	
Grade IV	0	1 (0.2)	
Total	14 (3.3)	16 (3.3)	
Types of major complication			
Bile duct complication	7 (1.7)	8 (1.6)	
Bowel perforation	0	1 (0.2)	
Gastrointestinal tract bleeding	0	2 (0.4)	
Incisional hernia	1 (0.2)	2 (0.4)	
Intestinal obstruction	1 (0.2)	1 (0.2)	
Operation site bleeding	2 (0.5)	1 (0.2)	
Pleural effusion	2 (0.5)	0	
Portal vein thrombus	1 (0.2)	0	
Others	0	1 (0.2)	
Re-admission within a year	20 (4.8)	21 (4.3)	0.84
Causes of re-admission			
Bile duct complication	6 (1.4)	7 (1.4)	
Gastrointestinal tract obstruction	2 (0.5)	2 (0.4)	
Abdominal discomfort	2 (0.5)	1 (0.2)	
Infection	0	4 (0.8)	
Pain	0	1 (0.2)	
Psychiatric problem	2 (0.5)	1 (0.2)	
Respiratory problem	1 (0.2)	0	
Wound complication	2 (0.5)	2 (0.4)	
Others	5 (1.2)	3 (0.6)	

Data are presented as number (percentage).

1.68, P=0.15), and the hepatic vein (4.2% *vs.* 2.3%, aHR 1.97, P=0.11) were not significantly different between the complex and the control groups. The sum of all vascular complications was numerically higher in the complex group, without significance, after adjusting for covariates (12.8% *vs.* 7.7%, aHR 1.48; P=0.10). However, the graft complexity was independently associated with higher BD complication rates (51.3% *vs.* 43.8%, aHR 1.26; P=0.02). The most common complication in HA was thrombosis, while the most common complication in the PV and hepatic vein was stenosis (Table S3).

The incidences of major complications (grade ≥3) in living donors were comparable between the complex and the control groups (3.3% *vs.* 3.3%, P=0.99, *Table 4*). In both groups, BD complications were most frequent (1.7% *vs.* 1.6%). One (0.2%) living donor in the complex group suffered PV thrombosis. The readmission rates within 1 year were comparable (4.8% *vs.* 4.3%, P=0.84), with BD complications being the most common cause of readmission in both groups.

Propensity score-matched analyses by each graft complexity

In the matched population according to each anatomical complexity, no significant survival differences were observed, regardless of the multiplicity of the HAs (69.6% in the two HA groups *vs.* 83.3% in the one HA group, P=0.23, *Figure 2*), PVs (86.0% in the two PV groups *vs.* 80.1% in the one PV group, P=0.64), and BDs (82.5% in the multiple BD group *vs.* 80.0% in the single BD group, P=0.56). However, the IHV ≥2 group showed significantly higher graft survival than the IHV ≤1 group (93.4% *vs.* 75.4%, P=0.003).

HA complications were not significantly different, regardless of the number of HAs (7.7% *vs.* 3.4%, P=0.53, Table S4). However, those with two HAs showed higher BD stricture rates compared to those with one HA (79.5% in two HAs *vs.* 43.4% in one HA, P=0.02). Those with two PVs showed similar PV complication rates (5.6% *vs.* 7.5%, P=0.72), but marginally higher BD leakage (33.7% *vs.* 18.0%, P=0.07) rates than those with one PV. The IHVs ≥2 group had significantly higher hepatic vein complication rates compared to the IHV ≤1 group (8.2% *vs.* 3.5%, P=0.04). BD complication rates were not different regardless of the BD multiplicity (40.1% *vs.* 44.9%, P=0.12).

Discussion

In the context of the growing demand for LDLT due to organ shortages, the anatomical complexity of the graft presents a significant surgical challenge for both recipients and donors. Multiple HA or BD structures are associated with an increased rate of surgical complications. However, only a limited number of studies have reported the effects on LDLT outcomes through a comprehensive review of donor anatomy. This study suggested that LDLT with a complex right-lobe graft had similar recipient and donor

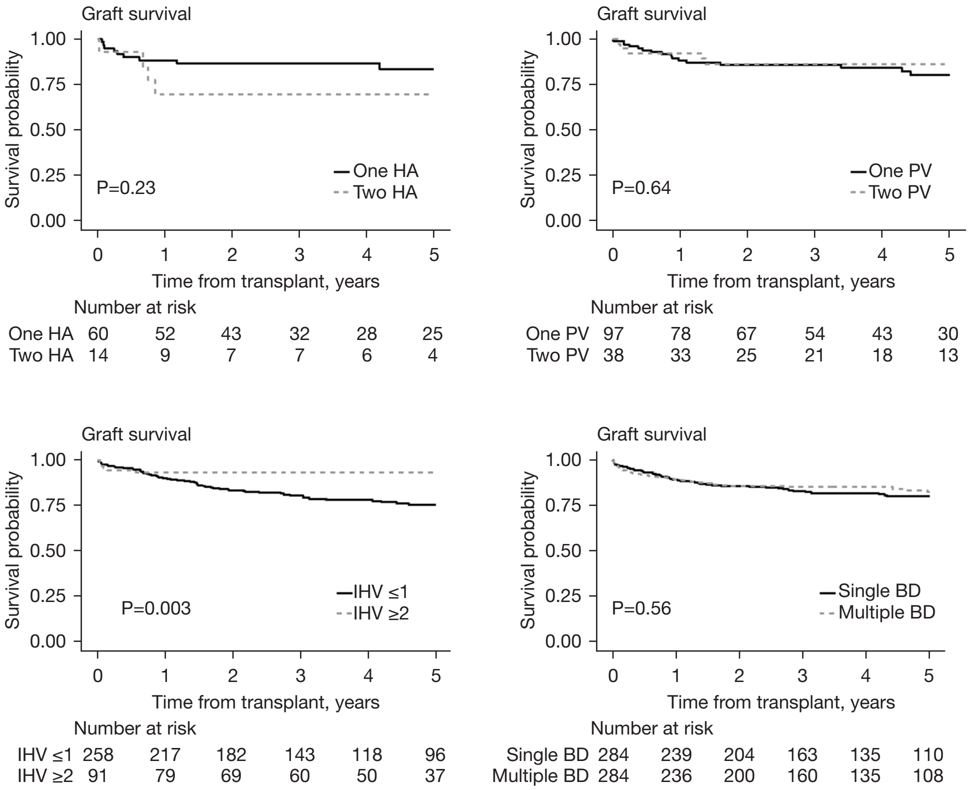

Figure 2 Graft survival by each anatomical complexity after matching. BD, bile duct; HA, hepatic artery; IHV, inferior hepatic vein; PV, portal vein.

outcomes, despite higher biliary complication rates than those without anatomical complexity. With an appropriate surgical approach, a right-lobe graft with anatomical complexity could be safely used for LDLT without concerns of poorer outcomes.

The strength of our study is that it used data from a high-volume center in South Korea, renowned for having the highest rate of LDLTs with excellent outcomes (19). Moreover, our data include thorough descriptions of graft anatomy and anastomotic methods for LDLT. As a result, we could demonstrate not only the feasibility of multiple types of complex grafts but also the influence of each anatomical complexity on outcomes in appropriately matched cohorts, based on patient characteristics and other graft anatomies.

In the complex group, grafts with two HAs were associated with lower graft survival rates before PSM; however, this statistical significance vanished post-PSM (P=0.23). This result is consistent with those of previous studies, suggesting that the partial reconstruction of multiple HAs does not adversely affect graft survival. However, in contrast to previous research, we noted an elevated incidence of biliary strictures in patients treated with two HAs. This discrepancy could be attributed to the possibility that although communicating intrahepatic arterial flow was verified, the arterial supply to the BDs might have been insufficient. Although this aspect is crucial, it is beyond the scope of the present study. Consequently, this underscores the importance of vigilant monitoring for biliary complications in recipients with two HAs.

Several methods have been reported for reconstructing multiple PV branches, ranging from direct venoplasty to Y-graft interposition (20-24). In our study, most patients underwent reconstruction using Y-graft interposition. We observed that the presence of multiple PV branches did not significantly affect graft survival or the rate of complications, which is consistent with the results of previous studies (25,26).

Previous reports have suggested that grafts with multiple BDs show no significant differences in biliary complication rates compared with those with a single BD (27,28). However, there is ongoing debate about whether to perform duct-to-duct anastomosis or Roux-en-Y hepaticojejunostomy (29). While duct-to-duct anastomosis offers the advantage of being a simpler procedure with more physiological anatomy techniques, it is associated with a higher rate of anastomotic strictures compared to Roux-en-Y hepaticojejunostomy (30). Consequently, as the incidence of Roux-en-Y hepaticojejunostomy in our cohort among patients with multiple BDs was higher compared to those with a single BD (17.8% *vs.* 10.4%, P<0.001), the presence of multiple BDs did not significantly influence the graft survival rates.

Interestingly, grafts with two or more IHVs have shown improved graft survival rates, indicating that enhanced venous outflow capacity may have a protective effect on graft survival (31-33). This is thought to result from the multiple IHVs preventing venous congestion, which is a key factor for immediate postoperative success (34,35). Unlike the conventional right lobe graft, modified right lobe grafts have the advantage of preventing venous congestion by reconstructing branches of V5 and V8. The IHVs are responsible for the venous outflow of segment VI (36) and the presence of multiple IHVs offers protection against the potential obstruction of a single right hepatic vein (37). However, it was also observed that patients with two or more IHVs experienced an increased rate of hepatic vein complications after PSM (8.2% *vs.* 3.5%, P=0.04), highlighting a paradox where multiple IHVs correlate with both improved graft survival and increased risk of venous complications. Further research on the intrahepatic hemodynamics of grafts with multiple IHVs is essential to conclusively determine the impact of multiple IHVs on post-transplant outcomes, particularly concerning vascular complications.

In the early stages (2007–2013) of the LDLT program at our center, the selection of optimal living donors was primarily limited to those offering simple graft anatomies, prioritizing the safety of both recipients and donors (6). As our surgical expertise evolved and as we gathered more empirical evidence on post-transplant management, there has been a pivotal shift in donor selection criteria. This evolution has resulted in a transition from favoring simple to embracing complex graft anatomies, as detailed in Figure S2 (10,11,38). From 2019 to 2022, a substantial number of surgeries performed involved complex grafts. This development challenges the conventional belief that the complexity of the graft anatomy necessarily leads to a longer operation time. Contrary to these expectations, our analysis revealed that recent operations, despite their complexity, were completed within operative times comparable to those of simpler grafts. Moreover, our findings contest the notion that complex graft anatomies intrinsically lead to prolonged cold ischemic times, suggesting that a proficient and well-coordinated surgical team can effectively reduce the expected time-consuming procedures of LT (39). This advancement also contributes to a reduction in red blood cell transfusion units and an increase in the proportion of minimally invasive surgeries for living donors.

It is essential to acknowledge the limitations of this study. Although we described detailed data with consistent surgical techniques and postoperative care, it was hard to calculate the exact duration of time since the occurrence of complication to treatment intervention, due to the nature of retrospective design of this study. Further, the single-center data may have limited the generalizability of our findings. While we used PSM to generate balanced cohorts, the possibility of residual confounding factors cannot be entirely excluded. Despite the experience of surgical team was adjusted by matching the era of LT, the evolving nature of surgical practices over time represents a variable that is difficult to quantify, but undeniably influences outcomes. The experience of individual surgeon was not reflected.

Conclusions

The use of complex grafts in LDLT has been shown to yield comparable graft survival rates and acceptable donor complication rates. However, the increased risk of BD complications associated with complex grafts highlights the need for enhanced postoperative surveillance and interventional strategies. Further studies analyzing graft complexity may provide more accurate information for selecting a suitable graft and determining postoperative prognosis, thereby fostering personalized and effective transplant medicine.

Acknowledgments

None.

Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://hbsn.amegroups.com/article/view/10.21037/hbsn-24-293/rc

Data Sharing Statement: Available at https://hbsn.amegroups.com/article/view/10.21037/hbsn-24-293/dss

Peer Review File: Available at https://hbsn.amegroups.com/article/view/10.21037/hbsn-24-293/prf

Funding: None.

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://hbsn.amegroups.com/article/view/10.21037/hbsn-24-293/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki and its subsequent amendments. The study was approved by the Institutional Review Board of Severance Hospital (No. 4-2024-0447), and individual consent for this retrospective analysis was waived because of its retrospective design.

References

1. Lee SG. A complete treatment of adult living donor liver transplantation: a review of surgical technique and current challenges to expand indication of patients. Am J Transplant 2015;15:17-38.
2. Choi HJ. Current status and outcome of liver transplantation in South Korea. Clin Mol Hepatol 2022;28:117-9.
3. Goldaracena N, Barbas AS. Living donor liver transplantation. Curr Opin Organ Transplant 2019;24:131-7.
4. Li MT, Hillyer GC, Husain SA, et al. Cultural barriers to organ donation among Chinese and Korean individuals in the United States: a systematic review. Transpl Int 2019;32:1001-18.
5. Miller CM, Quintini C, Dhawan A, et al. The International Liver Transplantation Society Living Donor Liver Transplant Recipient Guideline. Transplantation 2017;101:938-44.
6. Ikegami T, Yoshizumi T, Ohira M, et al. Indication of living donor liver transplantation for septuagenarians from double equipoise theory. Am J Transplant 2018;18:278-9.
7. Yagi S, Singhal A, Jung DH, et al. Living-donor liver transplantation: Right versus left. Int J Surg 2020;82S:128-33.
8. Jesse MT, Jackson WE, Liapakis A, et al. Living donor liver transplant candidate and donor selection and engagement: Meeting report from the living donor liver transplant consensus conference. Clin Transplant 2023;37:e14954.
9. Yim SH, Min EK, Choi MC, et al. Unusual grafts for living-donor liver transplantation. Eur J Med Res 2023;28:454.
10. Rhu J, Kim JM, Choi GS, et al. Impact of Extra-anatomical Hepatic Artery Reconstruction During Living Donor Liver Transplantation on Biliary Complications and Graft and Patient Survival. Transplantation 2019;103:1893-902.
11. Harada N, Yoshizumi T, Matsuura T, et al. Usefulness of microsurgical back-table angioplasty for multiple hepatic arteries in living donor liver transplantation. Ann Gastroenterol Surg 2020;4:735-40.
12. Pamecha V, Sinha PK, Mukund A, et al. Hepatic artery-related complications after live donor liver transplantation. Langenbecks Arch Surg 2023;408:24.
13. Fonseca-Neto OCLD, Lima HCS, Rabelo P, et al. Anatomic variations of hepatic artery: a study in 479 liver transplantations. Arq Bras Cir Dig 2017;30:35-7.
14. Malviya KK, Verma A. Importance of Anatomical Variation of the Hepatic Artery for Complicated Liver and Pancreatic Surgeries: A Review Emphasizing Origin and Branching. Diagnostics (Basel) 2023;13:1233.
15. Song S, Kwon CH, Moon HH, et al. Single-Center Experience of Consecutive 522 Cases of Hepatic Artery Anastomosis in Living-Donor Liver Transplantation. Transplant Proc 2015;47:1905-11.
16. Dindo D, Demartines N, Clavien PA. Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. Ann Surg 2004;240:205-13.
17. Lee KW, Lee S, Huh J, et al. Outcome of living donor liver transplantation using right liver allografts with multiple arterial supply. Liver Transpl 2016;22:1649-55.
18. Austin PC. Balance diagnostics for comparing the distribution of baseline covariates between treatment groups in propensity-score matched samples. Stat Med 2009;28:3083-107.
19. International Registry in Organ Donation and

Transplantation. Worldwide Liver Transplant From Living Donors. 2022. Available online: https://www.irodat.org/?p=database. Accessed April 9, 2024.
20. Shehta A, Elshobari M, Salah T, et al. Feasibility and outcomes of living-donor liver transplantation utilizing the right hemi-liver graft with portal vein anatomical variations. Langenbecks Arch Surg 2023;408:387.
21. Marcos A, Orloff M, Mieles L, et al. Reconstruction of double hepatic arterial and portal venous branches for right-lobe living donor liver transplantation. Liver Transpl 2001;7:673-9.
22. Xu M, Yan L, Zhao J, et al. U-graft anastomosis for anomalous portal venous branching reconstruction in right lobe living donor liver transplantation. Liver Transpl 2007;13:1062-4.
23. Yilmaz S, Kayaalp C, Isik B, et al. Reconstruction of Anomalous Portal Venous Branching in Right Lobe Living Donor Liver Transplantation: Malatya Approach. Liver Transpl 2017;23:751-61.
24. Hwang S, Ha TY, Song GW, et al. Conjoined Unification Venoplasty for Double Portal Vein Branches of Right Liver Graft: 1-Year Experience at a High-Volume Living Donor Liver Transplantation Center. J Gastrointest Surg 2016;20:199-205.
25. Kim TY, Kim JD, Choi DL. Simplified Unification Patch Venoplasty for Anomalous Portal Vein Branching in Living Donor Liver Transplantation With Right Lobe Graft. Transplant Proc 2018;50:2664-7.
26. Yoo SY, Hwang S, Ha TY, et al. Long-term results of conjoined unification venoplasty for multiple portal vein branches of the right liver graft in living donor liver transplantations. Korean J Transplant 2019;33:106-11.
27. Arikan T, Emek E, Bozkurt B, et al. Does Multiple Bile Duct Anastomosis in Living Donor Liver Transplantation Affect the Postoperative Biliary Complications? Transplant Proc 2019;51:2473-7.
28. Lee DH, Kim D, Choi ST, et al. The Impact of the Multiple Bile Ducts on Postoperative Biliary Complications In Patients Undergoing Living Donor Liver Transplantation. Transplant Proc 2023;55:934-9.
29. Jung DH, Ikegami T, Balci D, et al. Biliary reconstruction and complications in living donor liver transplantation. Int J Surg 2020;82S:138-44.
30. Chok KS, Lo CM. Systematic review and meta-analysis of studies of biliary reconstruction in adult living donor liver transplantation. ANZ J Surg 2017;87:121-5.
31. Tan CHN, Hwang S, Bonney GK, et al. The influence of the middle hepatic vein and its impact on outcomes in right lobe living donor liver transplantation. HPB (Oxford) 2019;21:547-56.
32. Guo HJ, Wang K, Chen KC, et al. Middle hepatic vein reconstruction in adult right lobe living donor liver transplantation improves recipient survival. Hepatobiliary Pancreat Dis Int 2019;18:125-31.
33. Hwang S, Ha TY, Ahn CS, et al. Reconstruction of inferior right hepatic veins in living donor liver transplantation using right liver grafts. Liver Transpl 2012;18:238-47.
34. Yang J, Rhu J, Kwon J, et al. Hepatic venous territory mapping in living donor liver transplantation using right liver graft: an objective parameter for venous reconstruction. Ann Surg Treat Res 2023;104:348-57.
35. Fujiki M, Hashimoto K, Quintini C, et al. Living Donor Liver Transplantation With Augmented Venous Outflow and Splenectomy: A Promised Land for Small Left Lobe Grafts. Ann Surg 2022;276:838-45.
36. Machado MA, Herman P, Makdissi FF, et al. Feasibility of bisegmentectomy 7-8 is independent of the presence of a large inferior right hepatic vein. J Surg Oncol 2006;93:338-42.
37. Balci D, Kirimker EO. Hepatic vein in living donor liver transplantation. Hepatobiliary Pancreat Dis Int 2020;19:318-23.
38. Balci D, Kirimker EO, Raptis DA, et al. Uses of a dedicated 3D reconstruction software with augmented and mixed reality in planning and performing advanced liver surgery and living donor liver transplantation (with videos). Hepatobiliary Pancreat Dis Int 2022;21:455-61.
39. Sibulesky L, Li M, Hansen RN, et al. Impact of Cold Ischemia Time on Outcomes of Liver Transplantation: A Single Center Experience. Ann Transplant 2016;21:145-51.

Cite this article as: Yim SH, Kang I, Kim DG, Min EK, Lee JG, Han DH, Choi GH, Kim MS, Joo DJ. Anatomical complexity of the right-lobe grafts: influence on the outcomes in living donor liver transplantation. HepatoBiliary Surg Nutr 2025;14(6):963-973. doi: 10.21037/hbsn-24-293