Biliary Reconstructive Techniques and Associated Anatomic Variants in Adult Living Donor Liver Transplantations: The Adult-to-Adult Living Donor Liver Transplantation Cohort Study Experience

Talia B. Baker,[1] Michael A. Zimmerman,[2] Nathan P. Goodrich,[3] Benjamin Samstein,[4] Elizabeth A. Pomfret,[5] James J. Pomposelli,[5] Brenda W. Gillespie,[6] Carl L. Berg,[7] Jean C. Emond,[4] and Robert M. Merion[3]

[1]Living Donor Liver Program, Comprehensive Transplantation Institute, Department of Surgery, University of Chicago Medicine, Chicago, IL; [2]Department of Surgery, Medical College of Wisconsin, Milwaukee, WI; [3]Arbor Research Collaborative for Health, Ann Arbor, MI; [4]Department of Surgery, Columbia University College of Physicians and Surgeons, New York, NY; [5]Division of Transplant Surgery, University of Colorado Anschutz Medical Campus, Aurora, CO; [6]Department of Biostatistics, University of Michigan, Ann Arbor, MI; and [7]Division of Gastroenterology, Department of Medicine, Duke University Medical Center, Durham, NC

Living donor liver transplantation (LDLT) is a technically demanding endeavor, requiring command of the complex anatomy of partial liver grafts. We examined the influence of anatomic variation and reconstruction techniques on surgical outcomes and graft survival in the 9-center Adult-to-Adult Living Donor Liver Transplantation Cohort Study (A2ALL). Data from 272 adult LDLT recipients (2011-2015) included details on anatomic characteristics and types of intraoperative biliary reconstruction. Associations were tested between reconstruction technique and complications, which included first biliary complication (BC; leak, stricture, or biloma) and first vascular complication (VC; hepatic artery thrombosis [HAT] or portal vein thrombosis [PVT]). Time to patient death, graft failure, and complications were estimated using Kaplan-Meier curves and tested with log-rank tests. Median posttransplant follow-up was 1.2 years. Associations were found between the type of biliary reconstruction and the incidence of VC ($P = 0.03$) and BC ($P = 0.05$). Recipients with Roux-en-Y hepaticojejunostomy had the highest probability of VC. Recipients with biliary reconstruction involving the use of high biliary radicals on the recipient duct had the highest likelihood of developing BC (56% by 1 year) compared with duct-to-duct (42% by 1 year). In conclusion, the varied surgical approaches in the A2ALL centers offer a novel opportunity to compare disparate LDLT approaches. The choice to use higher biliary radicals on the recipient duct for reconstruction was associated with more BC, possibly secondary to devascularization and ischemia. The use of Roux-en-Y biliary reconstruction was associated with VCs (HAT and PVT). These results can be used to guide biliary reconstruction decisions in the setting of anatomic variants and inform further improvements in LDLT reconstructions. Ultimately, this information may contribute to a lower incidence of technical complications after LDLT.

Liver Transplantation 23 1519–1530 2017 AASLD.
Received April 25, 2017; accepted September 12, 2017.

Abbreviations: A2ALL, Adult-to-Adult Living Donor Liver Transplantation Cohort Study; BC, biliary complication; BMI, body mass index; HAT, hepatic artery thrombosis; HCC, hepatocellular carcinoma; LDLT, living donor liver transplantation; LL, left lobe; MELD, Model for End-Stage Liver Disease; OPTN, Organ Procurement and Transplantation Network; PTFE, polytetrafluoroethylene; PVT, portal vein thrombosis; RL, right lobe; SRTR, Scientific Registry of Transplant Recipients; VC, vascular complication.

Although liver transplantation (LT) has become the standard for care for end-stage liver disease and unresectable hepatocellular carcinoma (HCC), at least 14,771 patients await liver transplantation in the United States.[1] With a critical shortage of donated organs, patient wait-list mortality has increased and patients are often critically ill at the time of transplant.[2,3] Living donor liver transplantation (LDLT)

has become widely accepted in the United States as a potential alternative to address this imbalance in organ supply. Several important factors, however, have limited center-specific adoption and growth of LDLT programs. Most significantly, LDLT is an extremely technically challenging procedure that requires sophisticated training as well as institutional and programmatic commitment.[4] Furthermore, there are risks associated with the donor operation, including liver failure and death, which call the ethics of LDLT into question.[5-11] For these reasons, among others, there are a limited number of transplant centers in the United States routinely performing this procedure.

To properly study optimal outcomes and utilization of LDLT in the United States, the US National Institutes of Health organized a consortium of 9 leading transplant centers and established the Adult-to-Adult Living Donor Liver Transplantation Cohort Study (A2ALL) in 2002.[12] The participating centers dedicated themselves to reporting and investigating short-term and longterm outcomes for both recipients and donors. Starting in February 2011, extensive intraoperative and anatomic data were collected for both recipients and donors. Data were recorded chronicling the details of anatomic reconstructive techniques used in the transplant procedures. Although many have described arterial,[4,13-21] portal venous,[22-25] and biliary[26-30] variants and their potential impact on the living donor procedure,[31-39] this is the first multi-institutional investigation with disparate, nonprescribed approaches to biliary reconstructive techniques to study the overall implications of biliary reconstructions and associated anatomic variations on outcomes after LDLT. The aim of this study, in addition to describing the anatomic and surgical variation, was to critically evaluate this unique study cohort to examine the influence of anatomic variations and multiple biliary reconstructive techniques on surgical outcomes and overall graft and patient survival.

Address reprint requests to Talia B. Baker, M.D., Living Donor Liver Program, Comprehensive Transplantation Institute, Department of Surgery, University of Chicago Medicine, 5841 South Maryland Avenue, S207, Chicago, IL 60637. Telephone: 773-702-9046; FAX: 772-702-2126; Email: tbaker1@surgery.bsd.uchicago.edu

This study was presented in part at the annual meeting of the American Transplant Congress, Philadelphia, PA, May 5, 2015.

This is publication number 38 of the Adult-to-Adult Living Donor Liver Transplantation Cohort Study.

The supplemental data reported here have been supplied by the Minneapolis Medical Research Foundation as the contractor for the Scientific Registry of Transplant Recipients (SRTR). The interpretation and reporting of these data are the responsibility of the author(s) and in no way should be seen as an official policy of or interpretation by the SRTR or the U.S. government.

This study was supported by the National Institute of Diabetes and Digestive and Kidney Diseases through cooperative agreements (grants U01-DK62444, U01-DK62467, U01-DK62483, U01-DK62494, U01-DK62498, U01-DK62531, U01-DK62536, U01-DK85515, U01-DK85563, and U01-DK85587).

A list of individuals who were instrumental in the planning and conduct of this study at each of the participating institutions is available in the supporting information.

Additional supporting information may be found in the online version of this article.

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DOI 10.1002/lt.24872

Potential conflict of interest: Nothing to report.

Patients and Methods

PATIENT POPULATION

Subjects in this study, a subset of those enrolled in A2ALL, included those transplanted between April 2011 and January 2014. The A2ALL consortium is a multicenter observational cohort study designed to investigate outcomes in donors and recipients of adult-to-adult LDLT. All subjects were enrolled prospectively at 1 of 9 North American transplant centers (8 in the United States and 1 in Canada) at the time their living donor was accepted for donation. Baseline demographic and clinical data were collected at the time of enrollment. Detailed clinical data were collected prior to transplant, perioperatively, and postoperatively, with prospective follow-up continuing through August 1, 2014. We excluded from analysis 1 adult recipient of a left lateral segment graft. Each center and the data coordinating center had study protocols and consents approved by institutional review boards prior to collection and analysis of data.

This study used data from the Scientific Registry of Transplant Recipients (SRTR) to supplement data on graft failure and mortality for subjects transplanted at centers located in the United States. The SRTR data system includes data on all donors, wait-listed candidates, and transplant recipients in the United States, submitted by members of the Organ Procurement and

TABLE 1. Characteristics of Study Population (n = 272)

Characteristic	RL Grafts (n = 232)	LL Grafts (n = 40)	*P* Value*
Recipient age	51.8 ± 11.5	52.4 ± 14.7	0.80
Recipient BMI, kg/m^2	27.0 ± 5.6	25.6 ± 4.1	0.06
Recipient female	81 (34.9)	19 (47.5)	0.13
Recipient diagnosis HCC	56 (24.1)	6 (15.0)	0.20
Recipient diagnosis HCV	67 (28.8)	16 (40.0)	0.16
MELD score at transplant	16.2 ± 6.2	13.4 ± 4.9	0.003
Recipient on dialysis at transplant	3 (1.3)	0 (0.0)	0.47
Recipient on ventilator at transplant	3 (1.3)	0 (0.0)	0.47
Cold ischemia time, minutes	81.8 ± 101.2	79.7 ± 79.5	0.88
Warm ischemia time, minutes	40.9 ± 15.2	46.8 ± 86.4	0.67
Donor age at donation, years	35.7 ± 11.1	34.3 ± 10.3	0.35
Donor BMI, kg/m^2	26.6 ± 3.9	26.7 ± 3.9	0.74
Donor female	128 (55.2)	20 (50.0)	0.83
Donor relationship to recipient			0.55
Parent	5 (2.2)	1 (2.5)	
Child	77 (33.2)	17 (42.5)	
Sibling	37 (15.9)	6 (15.0)	
Other blood relative	23 (9.9)	5 (12.5)	
Nonblood relative	36 (15.5)	7 (17.5)	
Unrelated	54 (23.3)	4 (10.0)	

NOTE: Data are given as n (%) or mean ± SD.
*Two samples *t* tests were used for continuous variables, and chi-square tests were used for categorical variables.

Transplantation Network (OPTN), and it has been described elsewhere.[40] The Health Resources and Services Administration, US Department of Health and Human Services, provides oversight to the activities of the OPTN and SRTR contractors.

INTRAOPERATIVE DATA COLLECTION

Information on donor anatomy was collected for donors who enrolled in A2ALL. Details on the types of reconstruction used in the transplant procedure were collected intraoperatively. Our primary focus in this study was on the type of biliary reconstruction performed. Reconstruction was categorized into 5 main groups as characterized previously in the literature[32,33]: 1AD, single duct-to-duct; 2CD, ductoplasty to single duct; AJ, all Roux-en-Y anastomoses; ADAJ, a mix of Roux-en-Y and duct-to-duct; and AY, reconstruction using high biliary radicals (ie, cystic duct or right/left hepatic duct radicals). Details on the types of hepatic vein, hepatic artery, and portal vein reconstructions were also collected.

OUTCOME MEASURES

The primary outcomes of interest were biliary (leak, stricture) and vascular (hepatic artery thrombosis [HAT], portal vein thrombosis [PVT]) complications. Because this was a multi-institutional observational study, complications were defined and reported by center-specific criteria without standardization. Graft failure, defined as death or retransplant, and mortality were also examined.

STATISTICAL METHODS

Study subjects were followed from the time of transplant to death or last available follow-up. Descriptive statistics are given as means and standard deviations for continuous variables or as proportions for categorical variables. Demographic, clinical, and reconstruction information is shown separately for left lobe (LL) and right lobe (RL) transplants.

To examine the association between biliary reconstruction and complications, the time to first biliary complication (BC) and time to first vascular complication (VC; both censored at graft failure or death) were examined using Kaplan-Meier curves stratified by type of biliary reconstruction. Differences among reconstruction types were tested using log-rank tests. Graft and patient survival by reconstruction type were also evaluated using Kaplan-Meier survival curves and log-rank tests. Statistical analyses were carried out using SAS, version 9.4 (SAS Institute; Cary, NC). Results with a 2-sided P value ≤ 0.05 were considered statistically significant.

TABLE 2. Recipient Anatomic Characteristics (n = 272)

	RL Grafts (n = 232)	LL Grafts (n = 40)
Graft weight, g	805.2 ± 169.2	478.2 ± 91.8
Back-table ligation of segmental veins	19 (8.2)	0 (0.0)
Middle hepatic vein included		
Yes	23 (9.9)	34 (85.0)
No	209 (90.1)	5 (12.5)
Unknown	0 (0.0)	1 (2.5)
RL hepatic venous reconstruction		
Right vein includes all segments and anastomosed to vena cava	126 (54.3)	
Right vein anastomosed to vena cava and v6 anastomosed separately	39 (16.8)	
Right vein anastomosed to vena cava plus V8 anastomosed to vena cava without interposition	15 (6.5)	
Right vein anastomosed to vena cava plus V8 anastomosed to vena cava with interposition	13 (5.6)	
Right vein anastomosed to vena cava plus V5 anastomosed to vena cava with interposition	13 (5.6)	
Right vein anastomosed to vena cava plus V5 and V8 anastomosed to vena cava with interposition	22 (9.5)	
V5, V6, V7, V8 anastomosed separately with interposition for V5 and V8	4 (1.7)	
Venous conduit type		
Cryopreserved vessel	1 (0.4)	
Fresh homologous vessel	28 (12.1)	
Fresh autologous vessel	10 (4.3)	
PTFE conduit	11 (4.7)	
Unknown/not applicable	182 (78.4)	40 (100.0)
LL venous reconstruction		
Common orifice left and middle hepatic vein to recipient vena cava		22 (55.0)
Common orifice left and middle hepatic vein to recipient common orifice of left and middle hepatic vein		18 (45.0)
Number of hepatic venous anastomoses		
1	165 (71.1)	40 (100.0)
2	41 (17.7)	0 (0.0)
3	22 (9.5)	0 (0.0)
4	4 (1.7)	0 (0.0)
Recipient: portal venous reconstruction		
End-to-end	214 (92.2)	40 (100.0)
Interposition graft	18 (7.8)	0 (0.0)
Portal venous conduit type		
Fresh homologous vessel	9 (3.9)	0 (0.0)
Fresh autologous vessel	8 (3.4)	0 (0.0)
Unknown/not applicable	215 (92.7)	40 (100.0)
Number of hepatic arteries reconstructed		
1	221 (95.3)	30 (75.0)
2	10 (4.3)	10 (25.0)
More than 2	1 (0.4)	0 (0.0)
Number of biliary anastomoses		
1	151 (65.1)	37 (92.5)
2	77 (33.2)	3 (7.5)
3	3 (1.3)	0 (0.0)
Unknown	1 (0.4)	0 (0.0)
Use of Roux-en-Y		
Non-Roux	125 (53.9)	28 (70.0)
All Roux	93 (40.1)	12 (30.0)
Roux and non-Roux	13 (5.6)	0 (0.0)
Unknown	1 (0.4)	0 (0.0)
Accessory duct oversewn	27 (11.6)	0 (0.0)
Stent used in biliary reconstruction	79 (34.1)	9 (22.5)

NOTE: Data are given as n (%) or mean ± SD.

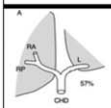
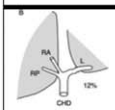
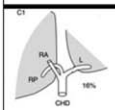
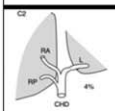
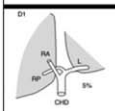
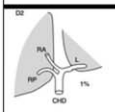
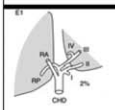
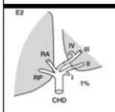
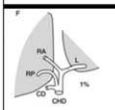
Donor Biliary Anatomy	Graft Type	Recipient Biliary Reconstruction				
		1AD	2CD	AJ	ADAJ	AY
Total	n = 271	92 (34%)	34 (13%)	105 (39%)	13 (5%)	27 (10%)
	RL n = 86	44 (51%)	3 (3%)	35 (41%)		4 (5%)
	LL n = 24	17 (71%)	2 (8%)	5 (21%)		
	RL n = 41	14 (34%)	9 (22%)	17 (42%)		1 (2%)
	LL n = 3	1 (33%)				2 (67%)
	RL n = 25	1 (4%)	11 (44%)	7 (28%)		6 (24%)
	LL n = 4	1 (25%)	1 (25%)	2 (50%)		
	RL n = 13	1 (8%)	1 (8%)	4 (31%)	4 (31%)	3 (23%)
	LL n = 0					
	RL n = 28	2 (7%)	2 (7%)	14 (50%)	5 (18%)	5 (18%)
	LL n = 5	2 (40%)		3 (60%)		
	RL n = 8	1 (13%)	1 (13%)	3 (38%)	1 (13%)	2 (25%)
	LL n = 0					
	RL n = 0					
	LL n = 1		1 (100%)			
	RL n = 1		1 (100%)			
	LL n = 1			1 (100%)		
	RL n = 10	1 (10%)		6 (60%)	1 (10%)	2 (20%)
	LL n = 0					
Other (n = 8 RL) Unknown (n = 11 RL, 2 LL)	RL n = 19	6 (32%)	2 (11%)	7 (37%)	2 (11%)	2 (11%)
	LL n = 2	1 (50%)		1 (50%)		

FIG. 1. Recipient biliary reconstruction by donor biliary anatomy and graft type (RL and LL). Numbers and row percentages are given for each combination. Of the 231 RL and 40 LL grafts with known recipient reconstruction, 220 RL and 38 LL had data for both recipient and donor. Adapted with permission from Deshpande et al.[32] (2002).

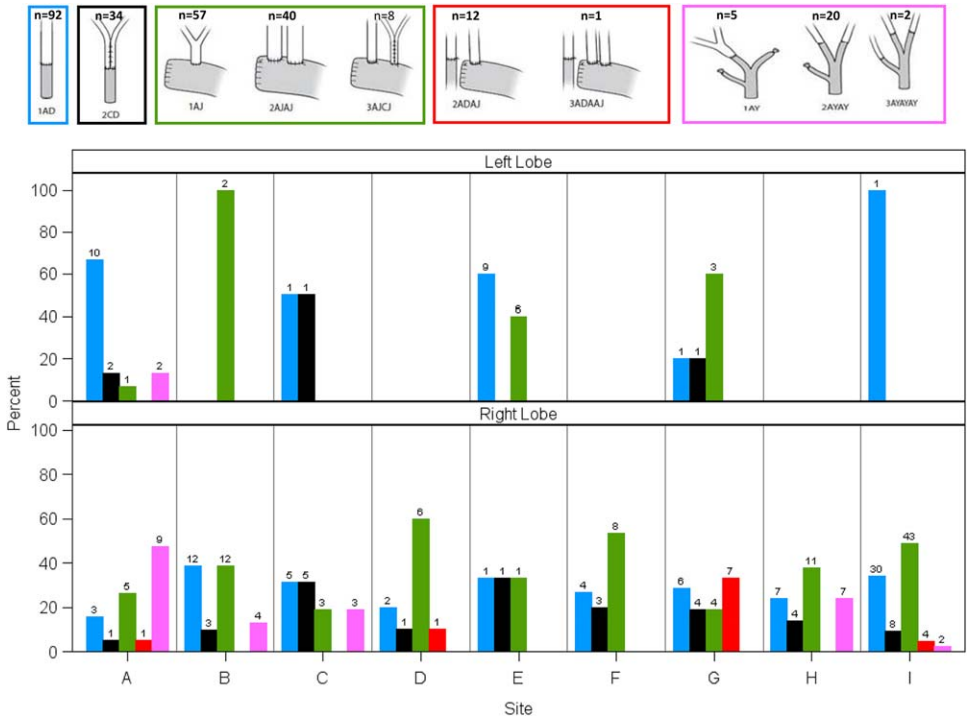


FIG. 2. Recipient biliary reconstruction by transplant center and graft type (LL and RL). Bar heights show percents, and counts are given above each bar. Reconstruction types are duct-to-duct (1AD), ductoplasty (2CD), Roux-en-Y (1AJ, 2AJAJ, 3AJCJ), a combination of duct-to-duct and Roux-en-Y limb (2ADAJ, 3ADAAJ), and use of higher biliary radicals (1AY, 2AYAY, 3AYAYAY).

Results

STUDY POPULATION AND DEMOGRAPHICS

Both recipient and donor characteristics are given in Table 1 by RL and LL. The mean recipient age was approximately 52 years, and 37% were female. Recipients of LL grafts had significantly lower Model for End-Stage Liver Disease (MELD) scores than recipients of RL grafts (13.4 versus 16.2; $P = 0.003$). Few recipients in this cohort were on a ventilator (n = 3) or on dialysis (n = 3) at the time of transplant, and all were RL recipients. No significant differences, by lobe transplanted, were found for recipient age, body mass index (BMI), sex, diagnosis, on dialysis or a ventilator at transplant, and cold or warm ischemia time. Among donors, the mean age was approximately 35 years and mean BMI was nearly 27 kg/m^2. Most donors were blood relatives of the recipient (63%), with the most common relationship being adult to child (35%). No significant differences were found between donors of RLs and LLs for donor age, BMI, sex, and relationship to recipient.

HEPATIC AND BILIARY RECONSTRUCTIVE PATTERNS IN THE A2ALL COHORT

Overall, 85% of grafts in the cohort were RLs (232 versus 40 LLs; Table 2). The majority of RL grafts (90%) did not include the middle hepatic vein; most LL grafts did (85%). For RL recipients, hepatic venous reconstruction was performed from the right hepatic vein to the vena cava (including all segments) in 54%. For LL recipients, a common orifice, including the left and middle hepatic vein, was anastomosed to the vena cava in 55% and the common orifice of the left and middle hepatic vein in 45% of recipients. A total of 18 RL recipients required portal venous interposition grafts, and 10 RL and 10 LL recipients underwent reconstruction of 2 hepatic arteries at implantation.

All (RL) recipients but 1 had data on biliary reconstruction. Of RL recipients, 151 (65%) underwent a single biliary anastomosis versus 37 (93%) of LL recipients. A total of 80 (34%) RL recipients and 3 (8%) LL recipients underwent more than 1 biliary anastomosis, with 27 RL (and no LL) recipients having an accessory duct oversewn.

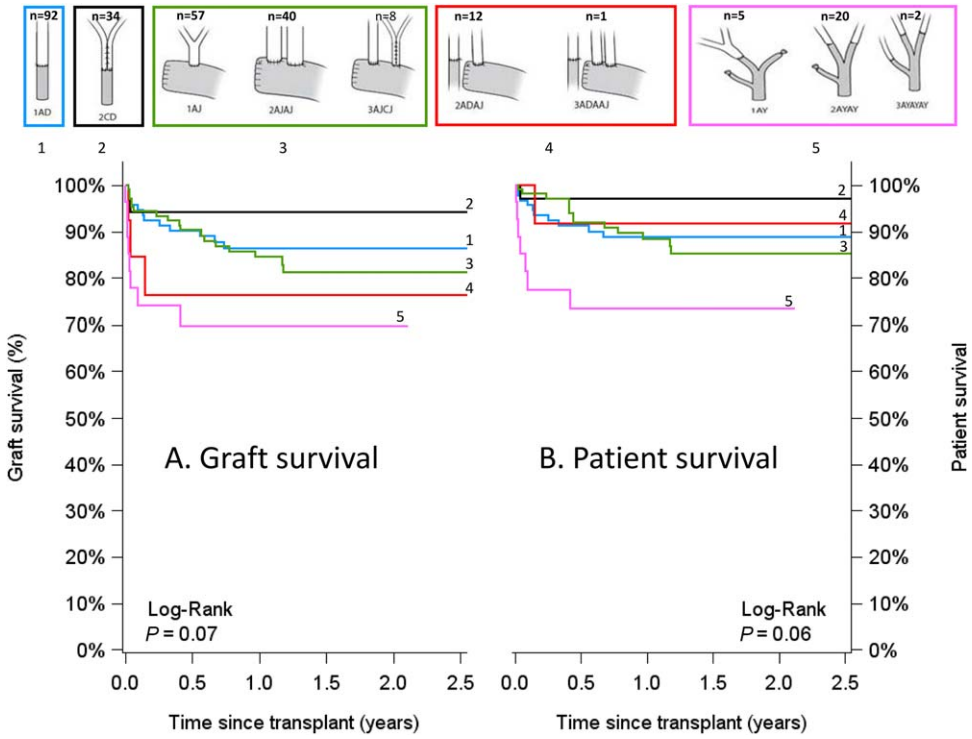


FIG. 3. (A) Graft and (B) patient survival after LDLT, by type of surgical reconstruction. Reconstruction types are duct-to-duct (1AD), ductoplasty (2CD), Roux-en-Y (1AJ, 2AJAJ, 3AJCJ), a combination of duct-to-duct and Roux-en-Y limb (2ADAJ, 3ADAAJ), and use of higher biliary radicals (1AY, 2AYAY, 3AYAYAY). Numbers of events by group [1-5] were [13, 2, 17, 3, 8] for graft failure and [11, 1, 13, 1, 7] for death.

Figure 1 contains biliary reconstruction information on 271 recipients, with detailed biliary anatomy for 250 corresponding donors. Biliary anatomy and reconstructive techniques were recorded and classified as previously reported in the literature.[32,33] Overall, of the 212 RL grafts with known donor biliary anatomy, 86 (41%) contained single right hepatic duct anatomy and most were reconstructed via duct-to-duct (1AD; n = 44) or Roux-en-Y (1AJ, 2AJAJ, 3AJCJ; n = 35) fashion. For 38 LL grafts with known donor anatomy, 36 (95%) contained single left hepatic duct anatomy. Of these, 21 underwent duct-to-duct reconstruction and 10 used Roux-en-Y. Interestingly, multiple hepatic ducts originating from the RL were not universally reconstructed using a roux limb. Thirty RL recipients underwent ductoplasty (2CD) prior to implantation in a duct-to-duct fashion.

Surgical methods, numbers of procedures, and the usage of RLs versus LLs varied among the 9 A2ALL transplant centers (Fig. 2). A total of 6 of the 9 centers performed at least 1 LDLT using the LL, with only 3 centers performing more than 2 LL transplants. The majority of LLs were performed by center A (n = 15) and center E (n = 15). Most of the LL recipients at those 2 centers underwent duct-to-duct reconstruction ± ductoplasty (n = 21/30). For RL recipients, most centers reconstructed the bile duct by duct-to-duct or Roux-en-Y limb, or a combination of the 2. Use of higher biliary radicals for the anastomosis was rare at most centers and was used at least once in 5 of the 9 centers.

ASSOCIATION BETWEEN BILIARY RECONSTRUCTIVE TECHNIQUES AND GRAFT AND PATIENT SURVIVAL

Estimates of overall posttransplant survival at 3 months, 1 year, and 2.5 years, respectively, were 90%, 85%, and 83% for graft survival, and 94%, 88%, and 87% for patient survival. When presented by ductal reconstruction type (Fig. 3), differences are visually apparent, although they do not reach significance for either graft or patient survival ($P = 0.07$ and 0.06, respectively). The most common methods, duct-to-duct and Roux-en-Y, had similar graft survival (86% and 81% at 2.5 years, respectively) and patient survival (89% and 85% at 2.5 years, respectively). Both graft and patient survival were lower when higher biliary radicals (group 5) were used (70% and 73% at 2.5 years), with most events occurring shortly after

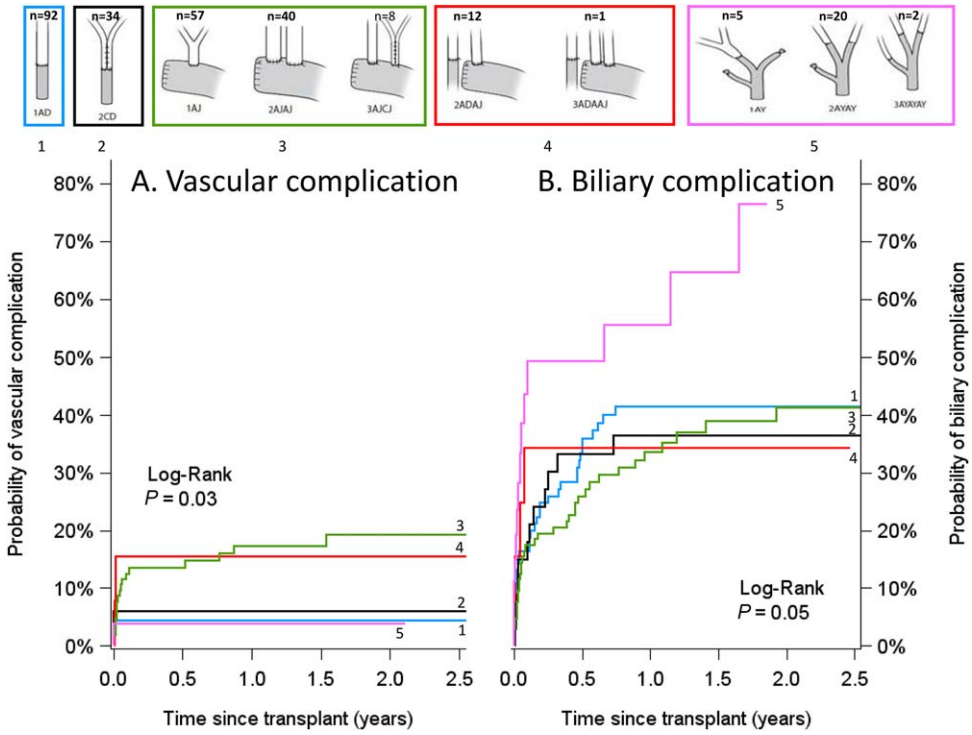


FIG. 4. Probability of (A) VCs and (B) BCs after LDLT. Numbers of events by group [1-5] were [4, 2, 18, 2, 1] for vascular and [35, 12, 36, 4, 14] for BCs.

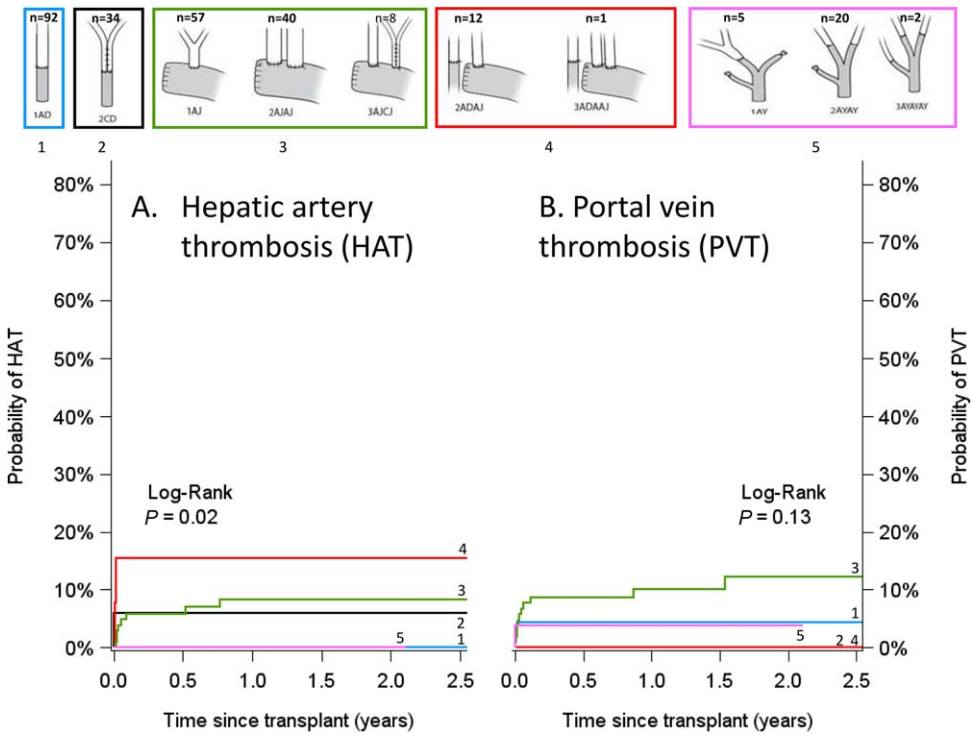


FIG. 5. Probability of (A) HAT and (B) PVT VCs after LDLT. Numbers of events by group [1-5] were [0, 2, 8, 2, 0] for HAT and [4, 0, 11, 0, 1] for PVT complications.

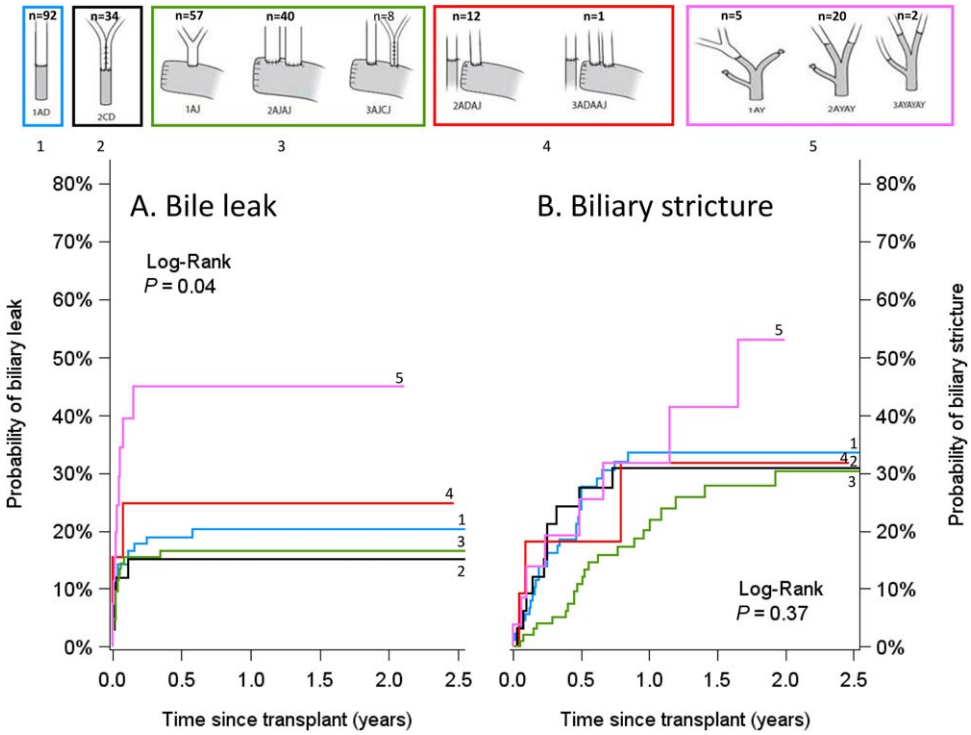


FIG. 6. Probability of (A) bile leak and (B) biliary stricture complications after LDLT. Numbers of events by group [1-5] were [18, 5, 17, 3, 10] for leaks and [27, 10, 22, 3, 8] for strictures.

transplant. The 32 patients undergoing duct-to-duct with ductoplasty had 94% graft survival at 2.5 years.

ASSOCIATION BETWEEN BILIARY RECONSTRUCTIVE TECHNIQUES AND VCS AND BCS

Overall, fewer recipients had VCs (n = 27) than BCs (n = 101), ranging among reconstructive technique groups from 4% to 19% ($P = 0.03$) for VCs and 34% to 76% ($P = 0.05$) for BCs (Fig. 4). For VCs, the highest rates were among recipients with a Roux-en-Y or a combination of Roux-en-Y and duct-to-duct reconstruction (groups 3 and 4). VCs for those without a bowel anastomosis (groups 1, 2, and 5) appear to be limited to the early posttransplant period and have a much lower probability of developing overall.

For BCs, recipients with reconstruction using high biliary radicals had the highest probability of developing a BC (76%). For the common clinical scenario of a dual ductal system, we performed a subgroup analysis to compare outcomes between ductoplasty (2CD) and Roux-en-Y (2AJAJ) and found that these reconstructive approaches did not have disparate complication rates. Ductoplasty (2CD) was associated with earlier BCs, but longterm outcomes were similar. With the exception of group 4 (combination duct-to-duct and Roux-en-Y), the risk of developing a BC appeared to increase steadily in all groups over the first year after transplant.

To further investigate VCs, we tested for associations between biliary reconstruction and either HAT or PVT (Fig. 5). There were significantly different probabilities of HAT among biliary reconstruction groups (Fig. 5A; $P = 0.02$). The highest probability of HAT (15% at 2.5 years) was in the Roux-en-Y and duct-to-duct combination group, with approximately half that probability in the Roux-en-Y (8%) and the duct-to-duct with ductoplasty (6%) groups, and no HAT in the duct-to-duct and higher biliary radicals groups. To see if these results were explained by arterial anatomy, we examined the number of arteries reconstructed. Of the 21 recipients with more than 1 hepatic artery reconstructed, there was only 1 VC noted, obviating the possibility of demonstrating an association. Furthermore, the number of hepatic arteries was not different for Roux-en-Y versus duct-to-duct reconstruction ($P = 0.23$). For Roux-en-Y reconstruction, 3/106 (3%) had more than 1 artery reconstructed. For duct-to-duct reconstruction, 8/125 (6%) had more than 1 hepatic artery reconstructed.

For PVT, differences among reconstruction groups in anatomic variants of portal venous anatomy were not significant (Fig. 5B; $P = 0.13$). The highest probability of PVT, however, was again noted in the Roux-en-Y group. Most events in both HAT and PVT occurred during the first 2 months after transplant, although 2 HAT and 2 PVT events occurred beyond 2 months; all 4 were in the Roux-en-Y group.

BCs included bile leak and biliary stricture. Most bile leaks from either the cut surface or anastomosis occurred in the first 6 months after transplant (Fig. 6A). A comparison of reconstruction groups demonstrated significant differences ($P = 0.04$), with the high biliary radical group (group 5) having the highest risk of bile leak (probability at 1 year of 45% compared with 15%-25% among groups 1-4). In contrast to bile leaks, which occurred shortly after transplant, biliary strictures occurred primarily during the first year but with some events continuing throughout the second year after transplant (Fig. 6B). A comparison of reconstruction groups demonstrated no significant differences ($P = 0.37$).

Discussion

The critical shortage of donor organs in the United States has contributed to a growing interest in the adoption of living donor grafts as a reasonable source of donor organs. Living donor grafts offer equivalent or better outcomes than deceased donor grafts, even though living donor grafts are smaller.[41-44] However, technical challenges[45-50] associated with this procedure and risks to the donor[9-11] have contributed to limited adoption outside Asia. The A2ALL consortium was conceived to study and optimize donor and recipient outcomes in LDLT.

This longitudinal, multicenter North American experience reflected real-world experience with the full gamut of anatomic variants encountered in LDLT and a wide variety of reconstructive surgical techniques. Neither donor selection criteria (including anatomical features) nor operative technique was prescribed. This created the opportunity for the consortium to amass a unique and novel database of anatomic variants in donors and recipients with reconstruction approaches driven by surgeon preference and experience.

The first major finding of the study was related to BCs. Simple duct-to-duct anastomosis was associated with a lower risk of biliary leaks or strictures than reconstruction using higher biliary radicals. Nonetheless, 42% of transplant recipients with duct-to-duct reconstructions had a BC (leak or stricture) within a year, the majority of which ultimately resolved.[30] Reconstruction with higher-order biliary radicals was associated with the highest incidence of BCs, including early biliary leaks and development of late biliary strictures. This is likely secondary to ischemia associated with devascularization of the ducts as they are dissected into the higher radicals. We did not identify a strong association between biliary reconstructive techniques and ultimate graft and patient outcome.

The second major finding was an association between the type of biliary reconstruction and the development of VCs. This finding cannot be explained by the number of reconstructed arteries, which did not differ between Roux-en-Y reconstructed recipients and those with choledochocholedochostomy. Among the 21 recipients with more than 1 hepatic artery reconstructed, there was only 1 VC recorded. The incidence of HAT was significantly higher with the use of a Roux-en-Y reconstruction compared with duct-to-duct anastomoses. This association is thought to be related to the conformation of the reconstructive approach with the Roux-en-Y limb potentially causing compression of the arterial anastomosis. In contrast, PVT incidence was not significantly associated with the type of biliary reconstruction.

The observational nature of the study without standardized criteria for acceptance of anatomic variants, surgical approach, or the use of uniform reconstructive techniques precludes inference of causal relationships for the associations we observed. The consortium relied on the participation of transplant surgeons with expertise in living donation and center-specific practices of evaluation and acceptance of potential living donors based on anatomic considerations, as well as surgeon-specific operative approaches to reconstruction. Furthermore, the small number of some less common anatomic variants included in the study limit the universal applicability of the findings. Nonetheless, the results represent a real-world experience. The novel findings relating biliary reconstruction to the risk of HAT add an important nuance to the well-recognized place held by the bile duct as the Achilles' heel of liver transplantation.

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