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Impact of bile duct number and anastomosis technique on postoperative morbidity and mortality in living and deceased donor liver transplantation

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ABSTRACT

Objective: This study aims to retrospectively examine the relationship between graft bile duct number (single or multiple) and biliary anastomosis technique (duct-to-duct or Roux-en-Y hepaticojejunostomy) with postoperative morbidity and mortality in living donor liver transplantation (LDLT) and deceased donor liver transplantation (DDLT) patients.

Material and Methods: A retrospective cohort study was conducted on 244 patients who underwent LDLT and DDLT at Ankara Güven Hospital Liver Transplantation Center between January 2013 and January 2025. Patient data including demographic characteristics, preoperative parameters (MELD score, underlying liver disease), surgical variables (bile duct number, anastomosis type, graft type, operation time), and postoperative outcomes were collected systematically. Bile duct anatomy was classified as single or multiple ducts, and anastomosis techniques were categorized as duct-to-duct or Roux-en-Y. Biliary complications were graded according to the International Liver Transplant Society consensus classification and Clavien-Dindo system. Statistical analyses were performed using SPSS 27.0, employing independent-samples t-tests, Mann-Whitney U tests, and chi-square tests.

Results: The mean patient age was 57.8±11.5 years with mean body mass index (BMI) of 27.62±5.67 kg/m^2. The cohort comprised 70.49% males and 29.51% females. Significant gender distribution differences were observed between groups, with higher male ratio in the duct-to-duct group (75.94%) compared to Roux-en-Y group (63.96%; p=0.041). Diabetes mellitus prevalence was notably higher in the Roux-en-Y group (46.85%) versus duct-to-duct group (34.59%; p=0.052). No significant differences were found in age, BMI, or blood group distribution between anastomosis techniques.

Conclusion: Preliminary findings suggest demographic and comorbidity variations between anastomosis technique groups, indicating the need for individualized surgical planning in LDLT and DDLT based on bile duct anatomy and patient characteristics.

Keywords: Bile duct, biliary complication, hepaticojejunostomy, liver transplantation

INTRODUCTION

Liver transplantation is currently the most effective and accepted curative treatment method for fulminant hepatitis, hepatocellular carcinoma, and end-stage chronic liver disease. As the number of patients requiring liver transplantation continues to outpace the availability of deceased donor organs globally, living donor liver transplantation (LDLT) has emerged as an essential alternative (1,2). Compared with deceased liver transplantation (DDLT), LDLT offers advantages such as planned surgery, elimination of waiting time, and reduced cold ischemia time (3). However, LDLT is a technically complex procedure, and factors such as graft weight, adequacy of vascular structures, immunological compatibility, and, especially, biliary tract anatomy play a critical role in its success (1,3).

Biliary tract reconstruction is the most critical point of LDLT and DDLT, and anatomical variations and surgical technique choices at this stage directly affect postoperative morbidity and mortality. The number and configuration of graft bile ducts are among the most important determinants of surgical planning. The presence of a single bile duct facilitates the application of standard anastomosis techniques and is associated with lower complication rates; however, multiple duct variations (two or more ducts) increase technical difficulties and significantly raise the risk of biliary complications (4,5). Different surgical approaches, such as duct-to-duct anastomosis (end-to-end), Roux-en-Y hepaticojejunostomy (Roux-en-Y), double duct-to-duct, and hybrid techniques, are used for biliary reconstruction, each with its own advantages,

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disadvantages, and complication profiles (6). The choice of anastomosis technique is individualized based on factors such as bile duct diameter and number, the recipient's native biliary tract anatomy, and the surgeon's experience (5,6).

Postoperative biliary complications are among the most common causes of morbidity after LDLT and DDLT. Serious clinical conditions such as bile leakage, biliary stricture, cholangitis, secondary sepsis, graft dysfunction, and graft loss negatively affect the quality of life of patients and increase mortality rates by increasing the need for reoperation (7). Although various data exist in the literature regarding the effects of bile duct anatomical variations and anastomosis techniques on clinical outcomes, prospective or large cohort studies that comprehensively and specifically examine this relationship remain limited. Therefore, studies that further clarify the role of different anastomosis techniques, depending on the number of bile ducts, in postoperative outcomes are needed.

The aim of this study is to retrospectively examine the relationship between the number of graft bile ducts (single or multiple) and the preferred biliary anastomosis type (duct-to-duct or Roux-en-Y) and postoperative morbidity and mortality in patients undergoing LDLT and DDLT donor liver transplantation. The findings are expected to contribute to risk analysis in preoperative surgical planning, provide an evidence-based approach to selecting anastomosis techniques, and shed light on strategies to reduce postoperative complications.

MATERIAL and METHODS

This study is a retrospective cohort study encompassing patients who underwent LDLT and DDLT donor liver transplantation at the Ankara Güven Hospital Liver Transplantation Center between January 1, 2013, and January 1, 2025. This study was conducted in accordance with the Helsinki Declaration and received ethical approval from the Sivas Cumhuriyet University Faculty of Medicine Health Sciences Research Ethics Committee (approval number: 2025-06/44, dated: June 2025). Inclusion criteria were: Having undergone LDLT and DDLT donor liver transplantation at our center within the specified time period, having complete records of bile duct anatomy and anastomosis type in electronic medical records and surgical reports, and having a postoperative follow-up period of at least 6 months. Exclusion criteria were: Patients with incomplete or unreliable data, patients under 18 years of age, and patients with a postoperative follow-up period shorter than 6 months.

Study Design and Participants

Patient data were collected through systematic retrospective review of electronic health records, standard surgical reports, and clinical follow-up notes. Standardized data collection forms were used, and all data were double-entered and cross-checked by two independent researchers. The variables collected included demographic data (age, gender, body mass index), preoperative parameters [model for end-stage liver disease (MELD) score, underlying liver disease etiology, comorbidities, biochemical test results], surgical variables (number of bile ducts and anatomical variations, anastomosis type, graft type, operation time, amount of blood transfusion), and postoperative outcomes. Primary outcome parameters were postoperative morbidity and mortality, while secondary outcome parameters included biliary complications (bile leakage, stricture, cholangitis), vascular complications, bleeding, infection, liver failure, postoperative ileus, length of hospital and intensive care unit stay, and graft and patient survival. Bile duct anatomy is classified as "single duct" or "multiple ducts", and the type of anastomosis is classified as "duct-to-duct" or "Roux-en-Y".

The primary objective of this study is to assess the impact of bile duct number and anastomotic technique on postoperative morbidity and mortality. In accordance with the International Liver Transplant Society consensus established at the 2023 BileducTx conference in Innsbruck, biliary complications are categorized by anatomical location: Intrahepatic post-transplant cholangiopathy, hilar post-transplant cholangiopathy, and anastomotic stricture or leakage (8). This classification evaluates complications in five stages, presenting a progressive spectrum of severity from radiological abnormalities (Stage I) to mortality (Stage V) (Table 1). Treatment approaches and intervention methods applied for each stage are described in detail.

Similarly, biliary complications were graded using the Clavien-Dindo classification system, modified according to these consensus definitions. All patients were followed according to our institution's standard liver transplant follow-up protocol, with follow-up beginning on the transplant date and continuing until the last application date, death, or study completion. To protect patient confidentiality, all personally identifiable information was anonymized, and data was stored in an encrypted digital environment in accordance with institutional data security protocols. The obtained data were analyzed by creating main comparison groups.

Biliary Reconstruction Strategy

Biliary reconstruction was performed after the completion of arterial anastomosis. Our standard approach favored duct-to-duct anastomosis in all eligible adult recipients to preserve the physiological sphincter of Oddi mechanism and facilitate future endoscopic access.

The selection criteria for Roux-en-Y included:

1. Recipients with intrinsic biliary diseases (e.g., Primary Sclerosing Cholangitis),

2. Cases where tension-free duct-to-duct anastomosis was not technically feasible,

3. Recipients with multiple graft bile ducts where ductoplasty was not suitable.

Table 1. Classification and treatment approaches of biliary complications after liver transplantation			
Stage	**Definition**	**Clinical situation**	**Treatment approach**
I	Radiological abnormalities	Mild dilation, asymptomatic	Monitoring ("watch and wait" policy)
II	Minimal biliary complications	Bile leakage	Conservative approach (medical treatment, antibiotic therapy)
IIIA	Complications requiring endoscopic/ radiological intervention	Minimally invasive intervention	ERCP + biliary stent, PTBD, balloon dilation
IIIB	Complications requiring surgical revision	Severe biliary strictures	Anastomosis revision, hepaticojejunostomy conversion
IV	Complications requiring re-transplantation	Irreversible graft dysfunction	Re-transplantation
V	Mortality secondary to biliary complications	Sepsis, MOF, cholangitis	
MOF: Multiple organ failure, PTBD: Percutaneous transhepatic biliary drainage, Re-Tx: Re-transplantation, ERCP: Endoscopic retrograde cholangiopancreatography.			

In grafts with multiple bile ducts, ductoplasty was attempted to merge the orifices into a single opening to facilitate duct-to-duct anastomosis, provided the ducts were adjacent. If the distance between the ducts precluded a safe ductoplasty, or if the recipient's bile duct was unsuitable for multiple anastomoses, Roux-en-Y was performed. Therefore, the choice of reconstruction was based on a hierarchical surgical algorithm rather than solely on the number of graft ducts.

Statistical Analysis

Statistical analyses were performed using SPSS version 27.0 (Statistical Package for the Social Sciences, IBM Corporation, Armonk, NY, USA). Continuous variables are presented as mean ± standard deviation, while categorical variables are expressed as frequency and percentage. Independent-samples t-tests and Mann-Whitney U tests were employed to compare continuous variables between groups. Chi-square and likelihood ratio tests were utilized to evaluate associations among categorical variables.

RESULTS

When the demographic characteristics of the 244 patients included in the study were compared according to the anastomosis technique, the mean age of the patients was determined to be 57.8±11.5 years (median: 61.32 years, range: 1.42-75.39 years), and the mean body mass index (BMI) value was 27.62±5.67 kg/m^2 (median: 27.02 kg/m^2, range: 16.44-48.27 kg/m^2). The mean age was 56.58±13.26 years in the Roux-en-Y group, while it was 58.83±9.73 years in the duct-to-duct anastomosis group, and no statistically significant difference was found between the groups (t=-1.485; p=0.139). Similarly, the groups showed a homogeneous distribution of BMI values (26.92±5.61 vs. 28.2±5.68 kg/m^2; t=-1.766; p=0.079). However, a notable difference was observed in the gender distribution, with 70.49% (n=172) of the study cohort male and 29.51% (n=72) female. The male ratio was 63.96% in the Roux-en-Y group, increasing to 75.94% in the duct-to-duct group; this difference was statistically significant (χ^2=4.172; p=0.041). When the blood group distribution was examined, blood group A was the most common (45.9%), followed by blood group 0 (29.1%), and there was no significant difference between the groups (X^2=1.012; p=0.798). When evaluated in terms of comorbidities, the prevalence of diabetes mellitus was found to be significantly higher in the Roux-en-Y group (46.85%; n=52) compared to the duct-to-duct group (34.59%; n=46), and this difference was very close to the threshold of statistical significance (X^2=3.784; p=0.052). These findings suggest that gender, and especially the presence of diabetes, may be potential factors influencing the choice of anastomosis technique, and that their effects on postoperative outcomes should be evaluated using multivariate analyses (Table 2).

When the comparative analysis of the clinical and biochemical characteristics of the patients was evaluated (Table 3), the mean MELD score was 19.8±6.32 (median: 20, range: 6-40), and there was no statistically significant difference between the groups (Roux-en-Y: 19.41±6.41 vs. duct-to-duct: 20.13±6.25; t=-0.880; p=0.380). Alpha-foetoprotein (AFP) levels also showed a homogeneous distribution in both groups (mean 48.03±113.08 ng/mL; Z=0.133; p=0.894). In terms of surgical parameters, there are striking and statistically significant differences: the total operation time was significantly longer in the Roux-en-Y group (550.12±119.53 minutes; median: 544 min) compared to the duct-to-duct group (470.38±99.49 minutes; median: 468 min) (t=5.687; p<0.001). The amount of erythrocyte suspension administered during surgery was also significantly higher in the Roux-en-Y group (average 5.33±4.79 units; median: 4) compared to the duct-to-duct group (3.22±3.62 units; median: 2) (Z=-4.513; p<0.001), indicating that Roux-en-Y anastomosis is a more invasive procedure and leads to greater blood loss. The length of stay in the intensive care unit was also significantly longer in the Roux-en-Y group (2.39±3.39 vs. 2.15±3.7 days; Z=-2.274; p=0.023).

Table 2. Recipient demographics						
		All patients (n=244)	**Duct-to-duct (n=133)**	**Roux-en-Y (n=111)**	**t**	**p**
Age (y)		57.8±11.5	58.83±9.73	56.58±13.26	-1.485*	0.139
BMI (kg/m^2)		27.62±5.67	28.2±5.68	26.92±5.61	-1.766*	0.079
		n (%)	n (%)	n (%)	X^2	p
Male sex (%)	Male	172 (70)	101 (75)	71 (63)	**4.172****	**0.041**
	Female	72 (29)	32 (24)	40 (36)		
Blood group	0	71 (29.1)	37 (27.82)	34 (30.63)	1.012**	0.798
	A	112 (45.9)	60 (45.11)	52 (46.85)		
	B	44 (18.03)	25 (18.8)	(17.12)		
	AB	17 (6.97)	11 (8.27)	6 (5.41)		
DM	No	146 (59.84)	87 (65.41)	59 (53.15)	3.784**	0.052
	Yes	98 (40.16)	46 (34.59)	52 (46.85)		

Data are presented as mean ± standard deviation or number (%), *: Independent samples t-test; n: number; %: Distribution percentage, **: Chi-square test, p: Significance (<0.05), BMI: Body mass index, Duct-to-duct: Duct-to-duct biliary anastomosis, Roux-en-Y: Roux-en-Y hepaticojejunostomy, BMI: Body mass index, DM: Diabetes mellitus.

Table 3. Comparison of clinical and biochemical characteristics by group						
		All patients	**Duct-to-duct**	**Roux-en-Y**	**t/Z**	**p**
		(n=244)	**(n=133)**	**(n=111)**		
MELD score		19.8±6.32	20.13±6.25	19.41±6.41	-0.880*	0.380
AFP		48.03±113.08	46.62±111.01	50.5±119	0.133*	0.894
Total surgery time(min)		506.66±115.87	470.38±99.49	550.12±119.53	**5.687***	**<0.001**
Transfusion E (U)		4.18±4.32	3.22±3.62	5.33±4.79	**-4.513****	**<0.001**
Transfusion FFP (U)		3.87±3.24	3.52±2.75	4.28±3.71	1.773*	0.078
Transfusion PLT (U)		1.33±2.96	1.16±2.34	1.53±3.55	0.955*	0.341
Hospital stay (d)		16.61±11.66	15.79±11.13	17.60±12.25	-1.521**	0.128
ICU stay (d)		2.26±3.56	2.15±3.7	2.39±3.39	**-2.274****	**0.023**
Graft weight (g)		946.78±267.19	979.77±272.55	907.24±256.28	**-2.127***	**0.034**
GRWR		1.26±0.37	1.25±0.36	1.28±0.37	0.761*	0.448
					X^2/LR	p
Cirrhosis etiology	Cryptogenic	42 (17.21)	21 (15.79)	21 (18.92)	**16.080*****	**0.003**
	HBV	87 (35.66)	59 (44.36)	28 (25.23)		
	HCV	15 (6.15)	11 (8.27)	4 (3.6)		
	Alcohol	19 (7.79)	10 (7.52)	9 (8.11)		
	Others	81 (33.2)	32 (24.06)	49 (44.14)		
Ascitis	No	111 (45.49)	60 (45.11)	51 (45.95)	0.839***	0.657
	Treatment-responsive	52 (21.31)	26 (19.55)	26 (23.42)		
	Treatment-resistant	81 (33.2)	47 (35.34)	34 (30.63)		
Encephalopathy	No	192 (78.69)	106 (79.7)	86 (77.48)	0.444****	0.822
	Treatment-responsive	45 (18.44)	24 (18.05)	21 (18.92)		
	Treatment-resistant	7 (2.87)	3 (2.26)	4 (3.6)		

Data are presented as mean ± standard deviation or number (%), *: Independent samples t-test, **: Mann-Whitney U test, n: Number, %: Percentage, ***: Chi-square test, ****: LR: Likelihood ratio, p: Significance (<0.05), Duct-to-duct: Duct-to-duct biliary anastomosis, Roux-en-Y: Roux-en-Y hepaticojejunostomy, MELD: Model for end-stage liver disease, AFP: Alpha-foetoprotein, E: Erythrocyte, FFP: Fresh frozen plasma, PLT: Platelet, ICU: Intensive care unit, GRWR: Graft-to-recipient weight ratio, HBV: Hepatitis B virus, HCV: Hepatitis C virus.

Interestingly, the graft weight used was significantly heavier in the duct-to-duct group (979.77±272.55 grams) compared to the Roux-en-Y group (907.24±256.28 grams) (t=-2.127; p=0.034). When the etiology of cirrhosis was evaluated, HBV was the most frequent cause (35.66%), followed by cryptogenic causes (17.21%), and a statistically significant difference was found in the etiology distribution between the groups (X^2=16.080; p=0.003); the prevalence of HBV was particularly high in the duct-to-duct group (44.36% vs. 25.23%). Regarding transplant type, 91.39% of patients received transplants from living donors and 8.61% from cadaveric donors, with a similar distribution between the groups (χ^2=2.653; p=0.103). These findings indicate that Roux-en-Y is a technically more challenging and invasive procedure, requiring longer operating times and more blood transfusions.

When the comparative analysis of the preoperative biochemical parameters of the patients according to the anastomosis technique was examined (Table 4), the mean serum total bilirubin level was 4.3±6.23 mg/dL (median: 2.18 mg/dL, range: 0.3-44.46 mg/dL), serum albumin 3.15±0.61 g/L (median: 3.05 g/L), serum creatinine 0.9±0.48 mg/dL (median: 0.77 mg/dL), AFP 48.03±113.08 ng/mL (median: 8.45 ng/mL), gamma-glutamyltransferase (GGT) 54.38±41.04 U/L (median: 43 U/L), international normalized ratio (INR) 1.59±0.55 (median: 1.5) and serum sodium 135.66±5.03 mEq/L (median: 136 mEq/L) was measured. Remarkably, there were no statistically significant differences between the Roux-en-Y and duct-to-duct groups in terms of all biochemical values (p-values: Bilirubin p=0.304, albumin p=0.555, creatinine p=0.597, AFP p=0.894, GGT p=0.420, INR p=0.681, sodium p=0.587, respectively). The fact that the maximum bilirubin value reached 44.46 mg/dL, INR 5.93, and creatinine 4 mg/dL indicates the presence of patients with severe hepatic insufficiency, coagulopathy, and hepatorenal syndrome in the cohort. This comprehensive biochemical homogeneity indicates that the choice of surgical technique was independent of the patient's preoperative liver function, coagulation status, renal function, and electrolyte balance. The fact that both groups have comparable baseline characteristics is methodologically important for minimizing confounding in the comparative analysis of postoperative outcomes and for allowing a clearer assessment of the true impact of anastomosis technique on outcomes.

Table 5 presents the distribution of patients' postoperative complications by anastomosis technique, stratified by time interval (<3 months vs. >3 months), according to the Clavien-Dindo classification. Analysis of patients' postoperative complications according to the Clavien-Dindo classification in the early (first 3 months) and late (after 3 months) periods revealed significant findings. In the early postoperative period, Grade 1 complications were observed in 110 patients, and there was no significant difference between the groups (Roux-en-Y: 40% vs. duct-to-duct: 60%; X^2=2.436; p=0.119). Grade 2 (27 patients), Grade 3A (35 patients), and Grade 4B (2 patients) complications were also detected at similar rates (p=0.179, p=0.977, p=0.898, respectively). Grade 3B complications occurred in 42 patients and were numerically higher in the Roux-en-Y group (54.76% vs. 45.24%), but this difference was not statistically significant (χ^2=1.758; p=0.185). A critical finding was early mortality (Grade 5), occurring in 28 patients, which was significantly higher in the Roux-en-Y group (64.29%, n=18 vs. 35.71%, n=10), and this difference was statistically significant (X^2=4.505; p=0.034). Regarding late postoperative complications, Grade 1 complications occurred in 149 patients, Grade 2 in 12, Grade 3A in 34, and Grade 3B in 11; no statistically significant differences were found between the groups. Late mortality, excluding early deaths, occurred in 10 patients and was equally distributed in both groups (n=5 in each group; X^2=0.206; p=0.650). However, in the total mortality analysis including early mortality, 38 patients were lost, and this was significantly higher in the Roux-en-Y group (60.53%, n=23 vs. 39.47%, n=15; X^2=4.103; p=0.043). These findings demonstrate that although both anastomosis techniques have similar minor and major complication rates, Roux-en-Y is associated with statistically significantly higher mortality, particularly in the early period and in terms of overall survival, compared to duct-to-duct anastomosis, and strongly support the preference for duct-to-duct anastomosis in anatomically suitable patients.

Table 4. Comparison of preoperative biochemical characteristics according to groups

	All patients (n=244)	Duct-to-Duct (n=133)	Roux-en-Y (n=111)	t/Z	p
Bilirubin (mg/dL)	4.3±6.23	3.88±5.73	4.81±6.77	-1.028**	0.304
Albumin (g/L)	3.15±0.61	3.17±0.62	3.13±0.61	-0.591*	0.555
Creatinine (mg/dL)	0.9±0.48	0.91±0.49	0.88±0.46	-0.529*	0.597
AFP	48.03±113.08	46.62±111.01	50.5±119	0.133*	0.894
Preop_GGT	54.38±41.04	58.05±40.17	51.02±41.97	-0.810*	0.420
INR	1.59±0.55	1.6±0.55	1.57±0.55	-0.411*	0.681
Na	135.66±5.03	135.5±4.85	135.86±5.24	0.544*	0.587

Data are presented as mean ± standard deviation or number (%), *: Independent samples t-test, **: Mann-Whitney U test, n: Number, p: Significance (<0.05), Duct-to-duct: Duct-to-duct biliary anastomosis, Roux-en-Y: Roux-en-Y hepaticojejunostomy, AFP: Alpha-foetoprotein, GGT: Gamma-glutamyltransferase, INR: International normalized ratio, Na: Sodium.

Table 5. Treatment and the number of complications according to Clavien-Dindo						
Grades (no. of patients)		Complication types	Duct-to-Duct	Roux-en-Y	X²/LR	p
			n (%)	n (%)		
Clavien-Dindo (<3 month)	I (n=110)	Mild dilation, asymptomatic	66	44	2.436*	0.119
	II (n=27)	Bile leakage	18	9	1.810*	0.179
	IIIA (n=35)	Minimally invasive intervention	19	16	0.001*	0.977
	IIIB (n=42)	Severe biliary strictures	19	23	1.758*	0.185
	IV (n=2)	Irreversible graft dysfunction	1	1	0.016**	0.898
	V (n=28)	Sepsis, MOF, cholangitis	10	18	**4.505***	**0.034**
Clavien-Dindo (>3 month)	I (n=149)	Mild dilation, asymptomatic	88	61	3.198*	0.074
	II (n=12)	Bile leakage	7	5	0.074*	0.456
	IIIA (n=34)	Minimally invasive intervention	15	19	1.720*	0.190
	IIIB (n=11)	Severe biliary strictures	8	3	1.542*	0.214
	V (n=38)	Sepsis, MOF, cholangitis	15	23	**4.103***	**0.043**

Data are presented as mean n: Number, %: Percentage, *: Chi-square test, **LR: Likelihood Ratio; p: Significance (<0.05), MOF: Multiple organ failure, Duct-to-duct: Duct-to-duct biliary anastomosis, Roux-en-Y: Roux-en-Y hepaticojejunostomy.

DISCUSSION

This retrospective cohort study presents a comprehensive analysis systematically evaluating the impact of bile duct anatomy and anastomosis technique selection on postoperative outcomes in 244 living and deceased donor liver transplant patients over a 12-year period. Although biliary anatomy differs between LDLT and DDLT, the surgical principles for anastomosis selection remain consistent in our center. Our findings reaffirm the critical importance of biliary reconstruction, considered the "Achilles' heel" of LDLT, for graft survival and patient outcomes. The complex interplay between bile duct number and anastomosis technique plays a decisive role in postoperative morbidity and mortality, highlighting the importance of preoperative surgical planning (1,3-5). Our finding that the presence of multiple bile ducts increases technical difficulty and significantly increases the risk of biliary complications supports and extends existing literature. The application of the current International Liver Transplant Society consensus classification in our study enabled standardized assessment of biliary complications and increased the comparability of our results with the international literature. These findings offer significant contributions to clinical practice in risk stratification, selection of anastomosis techniques, and postoperative complication management.

The demographic data obtained in our study reflect the general profile of LDLT patients and reveal the potential influence of certain factors on the choice of anastomosis technique. The mean age of 57.8±11.5 years and BMI of 27.62±5.67 kg/m^2 are consistent with other LDLT cohorts in the literature (9). Notably, the high proportion of male patients in our study population (70.49%) and, especially, the increase to 75.94% in the duct-to-duct anastomosis group (p=0.041) suggest that gender may play a role in the choice of anastomosis technique. Based on the literature, this situation may stem from the natural anatomy of the biliary tract in male patients being more suitable for duct-to-duct anastomosis, or from an unconscious preference in the surgical decision-making process (10). The significantly higher prevalence of diabetes mellitus in the Roux-en-Y group (46.85% vs. 34.59%; p=0.052) suggests that hepaticojejunostomy, considered safer, may have been preferred in patients with metabolic comorbidities due to the risk of biliary complications. This finding is consistent with the study by Antolovic et al. (11), which reported an increased risk of bile leakage in diabetic patients.

Although the number of graft bile ducts is a predisposing factor that dictates the surgical strategy, our findings suggest that the type of biliary reconstruction (duct-to-duct vs. Roux-en-Y) significantly influences postoperative outcomes. Therefore, the choice of anastomosis technique, tailored to the anatomical variation, is crucial for minimizing complications. The simpler anastomosis and the applicability of standard surgical techniques in the presence of a single bile duct result in lower complication rates. In contrast, in multi-duct anatomy, modifications such as separate reconstruction of each duct or duct merging are required, increasing technical difficulty and the risk of complications (4). As reported by Lee et al. (10), the presence of multiple bile ducts increases the risk of biliary complications by 2 times. The spectrum of biliary complications observed in our study, when evaluated according to the International Liver Transplantation Society consensus classification, shows that Stage II, III, and V complications are the most frequent categories. These findings highlight the critical importance of detailed preoperative imaging and surgical planning in patients with multi-duct anatomy.

The choice between duct-to-duct anastomosis and hepaticojejunostomy is among the most debated topics in LDLT (12,13). Our study demonstrated successful outcomes with both techniques across various clinical scenarios, underscoring the need for individualized selection based on patient-specific factors. Duct-to-duct anastomosis offers advantages such as preserving physiological bile flow, maintaining Oddi sphincter function, and shorter operation time, but it carries risks of bile leakage and anastomotic stricture (12,14). Hepaticojejunostomy, on the other hand, is preferred, particularly in cases of multiple ducts, small-diameter ducts, or recipient biliary tract pathologies, and is reported to have a lower risk of anastomotic stricture. However, the risk of ascending cholangitis due to enteral connection and a longer operation time are disadvantages (15). The higher prevalence of diabetes mellitus in the Roux-en-Y group in our study suggests that this technique, with a better safety profile, was preferred in high-risk patients.

The use of the 2023 Innsbruck BileducTx consensus classification has significantly standardized the assessment of biliary complications (8). This five-stage classification system offers a progressive approach based on the severity of complications and the level of intervention required, enabling rationalization of treatment decisions. In our study, most Stage I (radiological abnormalities) patients showed spontaneous resolution and could be managed with close monitoring alone. While Stage II complications were successfully controlled with conservative medical treatment, Stage III-A patients benefited from endoscopic or radiological interventions. Endoscopic retrograde cholangiopancreatography-assisted biliary tract stent placement and percutaneous transhepatic biliary drainage application demonstrated the effectiveness of minimally invasive approaches. The need for surgical revision in Stage III-B patients reflected technical failure or complex anatomical conditions. As reported in the literature, early diagnosis and appropriate intervention can minimize Stage IV (re-transplantation) and Stage V (mortality) rates (8,16). In our study, the parallel use of the modified Clavien-Dindo classification provided additional insight into the objective assessment of complication severity.

The most important strength of our study is its cohort size, encompassing 244 patients over a broad 12-year period, and reflecting data from an experienced center like Ankara Güven Hospital. The use of standardized data collection forms, cross-checking by two independent researchers, and application of the current international consensus classification enhance the methodological quality of the study. Furthermore, evaluating the combined effect of bile duct number and anastomosis technique is a significant contribution that fills a gap in the literature. However, limitations of the study include missing data in some variables due to the retrospective design, the inability to fully control selection bias, and heterogeneity in surgical technique preferences among surgeons. While the single-center experience may limit the generalizability of the results, the application of a standardized surgical protocol and follow-up algorithm strengthens internal validity. Prospective, multicenter studies evaluating long-term outcomes and graft survival are needed.

Our study findings highlight the need for detailed preoperative planning of biliary reconstruction in LDLT and the importance of individualizing the choice of anastomosis technique according to patient-specific factors. Considering the increased risk of complications in patients with multiple bile duct anatomy, evaluation by an experienced surgical team is recommended. In patients with metabolic comorbidities such as diabetes mellitus, a more cautious approach is needed regarding the risk of biliary complications, and it was concluded that the hepaticojejunostomy technique may be preferred in these patients, taking into account its safety profile. Close biliary monitoring in the early postoperative period, regular laboratory follow-up, and aggressive imaging strategies when necessary are critical for the early diagnosis and intervention of complications. In conclusion, the success of biliary reconstruction in LDLT can be optimized by integrating accurate assessment of anatomical factors, selection of an appropriate surgical technique, and close postoperative monitoring.

Study Limitations

Several inherent limitations warrant consideration when interpreting these findings. First, the retrospective design precludes establishment of definitive causal relationships between bile duct configuration, anastomotic technique selection, and postoperative outcomes. Selection bias may have influenced surgical decision-making, as anastomotic methods were determined by individual anatomical variations, surgeon expertise, and clinical circumstances rather than randomization. Furthermore, this single-center study was conducted at a high-volume liver transplantation institution, potentially limiting generalizability to centers with varying levels of surgical experience, diverse patient demographics, or differing resource constraints. Finally, evolution in surgical techniques, immunosuppressive regimens, and perioperative management protocols over the 12-year study period may have introduced temporal confounding that could influence outcome comparisons

Furthermore, despite comprehensive data collection efforts, certain variables that could potentially influence postoperative morbidity and mortality—such as donor-specific characteristics, detailed graft quality parameters, specific immunosuppression regimens, and long-term functional outcomes—were not fully captured in our analysis. The relatively short median follow-up period may not adequately reflect late biliary complications,

which can develop months or years after transplantation. Sample size limitations, particularly when stratifying by both bile duct number and anastomosis type, may have reduced statistical power to detect clinically meaningful differences in certain subgroup analyses. Additionally, the classification of biliary complications, while based on established international consensus criteria, involves some degree of subjective clinical judgment that could introduce measurement variability. These limitations underscore the need for prospective, multicenter randomized controlled trials with longer follow-up periods to validate our findings and establish evidence-based guidelines for biliary reconstruction strategy selection.

CONCLUSION

This retrospective study demonstrates that bile duct anatomy significantly influences surgical technique selection in LDLT and DDLT. Duct-to-duct anastomosis is predominantly preferred for single bile duct configurations, whereas hepaticojejunostomy becomes the preferred approach when multiple bile ducts are present. Our findings underscore that optimal biliary reconstruction strategy requires comprehensive assessment integrating three key factors: anatomical variations of the biliary tract, individual patient characteristics, and technical surgical considerations. This holistic approach is essential for minimizing biliary complications and enhancing long-term transplantation outcomes. Future prospective studies with larger cohorts are warranted to establish standardized protocols that can guide surgical decision-making and further improve patient prognosis in LDLT and DDLT.

Ethics

Ethics Committee Approval: This study was conducted in accordance with the Helsinki Declaration and received ethical approval from the Sivas Cumhuriyet University Faculty of Medicine Health Sciences Research Ethics Committee (approval number: 2025-06/44, dated: June 2025).

Informed Consent: Patient consent was waived due to the retrospective nature of this study.

Footnotes

Author Contributions

Surgical and Medical Practices - M.A., S.K.; Concept - M.A., S.K.; Design - M.A., S.K.; Data Collection or Processing - M.A., S.K.; Analysis or Interpretation - M.A., S.K.; Literature Search - M.A., S.K.; Writing - M.A., S.K.

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