BILIARY COMPLICATIONS AFTER LIVING DONOR LIVER TRANSPLANTATION DEPENDING ON THE ANATOMY STRUCTUREOF BILE DUCT ACCORDING TO THE MODIFIED HUANG CLASSIFICATION (TYPES A, B, AND C)

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Abstract

Background: Biliary complications are the most common postoperative adverse events after living donor liver transplantation, largely determined by variations in biliary anatomy.

Materials and Methods: A retrospective analysis of 208 adult living donor liver transplantation recipients (2011–2024). Clinical, perioperative, and anatomical variables, including Modified Huang bile duct types, were evaluated. Early (≤3 months) and late (>3 months) complications were compared.

Results: Biliary complications occurred in 24.5% of recipients. Type C anatomy showed the highest risk (56.5%, p = 0.0140). Prolonged cold ischemia time was strongly associated with biliary complications (p = 0.0001). Early biliary complications were mainly bile leaks, while late biliary complications were predominantly strictures requiring more interventions. Overall survival was 91.8% at 1 year and 72.1% at 10 years.

Conclusion: Biliary complications after living donor liver transplantation are primarily determined by biliary anatomical variation. Type C ducts significantly increase the risk of postoperative complications. Early identification of high-risk anatomy and individualized surgical planning may reduce biliary morbidity.

Introduction

Liver transplantation remains the only curative treatment for patients with end-stage liver disease or acute hepatic failure. Living donor liver transplantation (LDLT) has become an essential alternative to deceased donor transplantation, particularly in regions with donor shortage, offering 1-year and 5-year survival rates of approximately 85–90% and 70%, respectively.[1] Despite significant progress in surgical technique, perioperative management, and immunosuppression, biliary complications remain the most frequent and challenging adverse events after LDLT.[2,3]

The reported incidence of biliary complications ranges from 11% to 40%.[3,4,5] These complications—primarily bile leaks and anastomotic strictures—may lead to graft dysfunction, cholangitis, sepsis, and even graft loss. Most biliary complications develop within the first three postoperative months, although late strictures may occur years after transplantation.[3,6]

Biliary complications are multifactorial in origin and influenced by surgical, anatomical, and other factors. Surgical causes include small bile duct diameter, multiple bile duct orifices, right posterior sector grafts, and intimal or ischemic injury during dissection.[5,6,7] Anatomical variability of the donor biliary system plays a crucial role. In LDLT, the most clinically relevant variations are described by Huang's bile duct classification (Types A–C), which categorizes the drainage patterns, number of ducts, and their convergence. These biliary anatomical types directly affect the complexity of biliary reconstruction and the risk of postoperative complications.

Non-surgical factors contributing to biliary complications include arterial hypoperfusion secondary to portal hyperten-

sion, prolonged cold ischemia time, and immunologic injury during reperfusion.[6,8]

Compared with deceased donor transplantation, LDLT is associated with a higher incidence of biliary complications due to the use of partial grafts and multiple small ducts, particularly in grafts with complex biliary drainage patterns.[9] Reliable biliary reconstruction remains essential for surgical success. Reconstruction strategies include duct-to-duct anastomosis, ductoplasty for adjacent ducts, and double anastomosis for separate sectoral ducts, whereas choledochojejunostomy is reserved for specific indications, including retransplantation.[2,7-10]

The role of internal stenting is controversial. Some studies report reduced postoperative complications,[11,12] while others demonstrate no benefit or increased cholangitis and strictures.[13,14]

Given the clinical significance and effect of biliary complications on graft survival, understanding biliary anatomical patterns—particularly those classified by Huang—may guide surgical planning and improve outcomes.[15,16]

The aim of this study was to evaluate the incidence, risk factors, and outcomes of biliary complications after LDLT, with a specific focus on the relationship between biliary complications and biliary anatomical variations according to Huang's classification (Types A–C). We hypothesize that the incidence and severity of biliary complications after LDLT are significantly influenced by biliary drainage patterns defined by Huang's classification (Types A–C). Incorporating these anatomical variations into preoperative planning, surgical strategy, and minimally invasive management can reduce postoperative biliary complications and improve overall graft outcomes.

Materials and methods

Research design is a retrospective observation study that was conducted at the Department of Hepatobiliary Surgery of the Syzganov National Scientific Center of Surgery. This study was conducted in accordance with ethical guidelines.

From 2011 to 2024, 208 liver transplants were performed in adults. Our study included recipients aged 19 to 68 years (median 42 years). 85 (40.9%) men and 123 (59.1%) women were included in this study.

Liver transplantation was performed in accordance with internationally accepted technical standards.

Inclusion Criteria:

- All adult patients who underwent living donor liver transplantation (LDLT) between 2011 and 2024 at the Syzganov National Scientific Center of Surgery.
- Availability of complete clinical and follow-up data on postoperative biliary outcomes.
- Patients with biliary reconstruction via duct-to-duct anastomosis.

Exclusion Criteria:

- Patients who underwent cholangiojejunostomy reconstruction (n = 7).
- Pediatric liver transplantation recipients (n = 50).
- Recipients of deceased donor liver transplantation (n = 29).
- Patients with incomplete medical records or lost to follow-up.

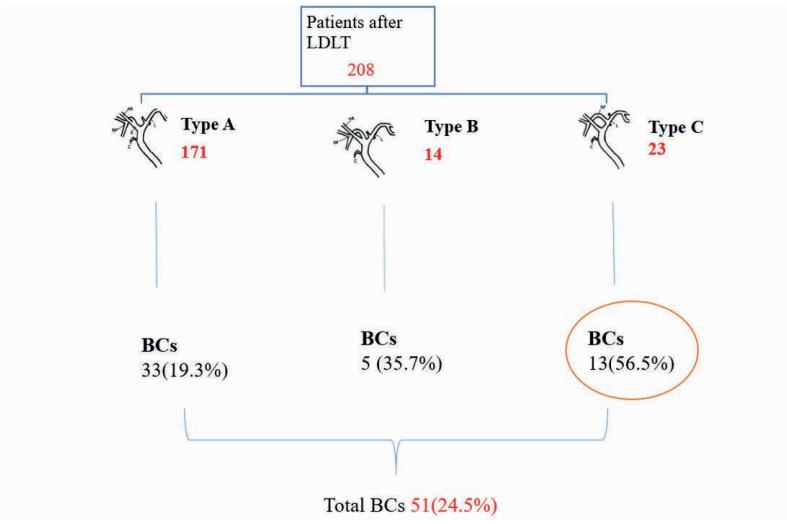

Figure 1. Study design and distribution of biliary complications after LDLT.

The study aimed to evaluate the incidence, risk factors, and outcomes of biliary complications (BCs) following LDLT. Patients were stratified according to Huang's bile duct anatomical classification (Types A–C), based on intraoperative findings and donor biliary anatomy. (Figure 1) Biliary complications were defined as bile leakage, strictures, and mixed complications, confirmed through imaging (ultrasound, MRCP, CT), laboratory parameters, endoscopic retrograde cholangiopancreatography (ERCP).

Ethical approval: This study was carried out in compliance with the principles outlined in the Declaration of Helsinki (revised in 2013).The study protocol received approval from the Local Ethics Committee of the Syzganov National Scientific Center of Surgery (Protocol No. 4, dated November 10, 2023).

Statistical analysis. Study subjects were followed from the time of transplant to death or the last available follow-up. Descriptive statistics were presented as means and standard deviations for continuous variables or as proportions for categorical variables. To examine the association between biliary reconstruction and complications, the time to first biliary complication was examined using Kaplan-Meier curves stratified by the 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 performed using SAS version 9.4 (*SAS Institute, Cary, NC*). Between-group comparisons were assessed for numerical variables, and the Chi square test and Fisher's exact test were used for categorical variables. P≤0.05 was considered statistically significant. Analysis of main risk factors and the corresponding causal relationship was evaluated by calculating the odds ratio (OR).

Results

The study included 208 adult recipients who underwent living donor liver transplantation (LDLT) between 2011 and 2024. The mean donor age was 31 years (range: 18–59 years). Male donors predominated (n = 117; 56.3%). All donors were either ABO-identical or compatible with their corresponding recipients. The overall incidence of biliary complications (BCs) after LDLT was 51 cases (24.5%) among the study population.

Pre- and perioperative characteristics

Pre- and perioperative characteristics of the study cohort are summarized in Table 1.The most significant factors associated with the development of biliary complications were ischemia-related variables. Patients who developed biliary complications had a substantially longer cold ischemia time compared with those without complications (95.5 ± 7.4 vs. 85.5 ± 7.6 minutes, p = 0.0001), which emerged as the strongest predictor among perioperative variables. Warm ischemia time was also significantly different between groups (32.4 ± 9.1 vs. 36.4 ± 9.3 minutes, p = 0.007). In contrast, baseline liver disease severity, reflected by MELD scores and CHILD class distribution, showed no significant differences. Similarly, the rates of portal vein thrombosis and arterial complications were comparable between groups, indicating no association with the occurrence of biliary complications.

Table 1.
Comparison of baseline clinical and perioperative characteristics between patients with and without biliary complications after LDLT.

Main characteristics	LDLT n =208		Chi-squared	Z statistic	p-value
	BCs n=51	BCs no n=157			
MELD	17.3±7.3	17.4±7.5	-	0.083	0.934
CHILDA	9 (17.65%)	8(5.09%)	0.610	-	0.435
B	25(49.02%)	93(59.24%)	0.877	-	0.349
C	17(33.33%)	56 (35.67%)	0.025	-	0.874
Cold ischemia duration (minutes)	95.5±7.4	85.5±7.6	-	8.22*	0.0001*
Warm ischemia duration (minutes)	32.4±9.1	36.4±9.3	-	2.68*	0.007*

Portal thrombus	1 (1.96%)	4 (2.55%)	0.001	-	0.976
Arterialcomplications	2 (3.92%)	12 (7.64%)	0.033	-	0.857
BCs — biliary complications; MELD — Model for End-Stage Liver Disease; LDLT - Living donor liver transplantation; *z-test and P -value≤0.05 were considered statistically significant					

Biliary complications according to bile duct type (Modified Huang Classification)

The distribution of biliary complications according to bile duct type based on the Modified Huang Classification is presented in Table 2. A clear trend was observed, indicating that the anatomical duct configuration influences the likelihood of developing postoperative biliary complications.

For overall biliary complications, Type C ducts demonstrated the highest incidence (56.5%) compared with Type A (19.3%) and Type B (35.7%). The comparison between Types A and C reached statistical significance (p = 0.0140), confirming a meaningful association between more complex ductal anatomy and increased risk. In contrast, the A vs B and B vs C comparisons were not significant.

When analyzing stricture and bile leakage separately, no statistically significant differences were identified across duct types. Stricture rates were comparable among Type A (13.5%), Type B (14.3%), and Type C (13.0%), with all pair wise comparisons yielding non-significant p-values. Similarly, bile leakage occurred at low but variable frequencies—5.8% in Type A, 21.4% in Type B, and 4.3% in Type C yet none of the comparisons reached statistical significance.

Overall, the table indicates that only the total incidence of biliary complications shows a statistically significant association with duct type, driven primarily by the substantially higher complication rate observed in Type C ducts. Individual complication subtypes (stricture and bile leakage) did not differ significantly across anatomical groups.

Table 2. Complications depending on the type of bile duct (depending on the Modified Huang Classification)

BCs type (n= 51)	Bile duct type			p-value		
	A (n=171)	B (n=14)	C (n=23)			
BCs overall	33(19.3%) α β	5 (35.7%) α γ	13 (56.5%) β γ	0.198 α	0.0140 β*	0.313 γ
Stricture	23(13.5%) α β	2 (14.3%) α γ	3 (13.0%) β γ	0.916 α	0.981 β	0.970 γ
Bileleakage	10 (5.8%) α β	3(21.4%) α γ	1(4.3%) β γ	0.435 α	0.953 β	0.734 γ
BCs — biliary complications; Comparison between groups: α- A and B; β- A and C; γ- B and C; *P -value≤0.05 was considered statistically significant						

Comparison of Early and Late Biliary Complications After LDLT

Table 3 summarizes the comparative characteristics of early (≤3 months) and late (>3 months) biliary complications among 51 affected recipients. Early complications were observed in 28 patients and were predominantly bile leaks (64.3%), whereas late complications occurred in 23 patients and were mainly strictures (65.2%). Mixed complications were more frequent in late presentations (17.4%) compared with early ones (10.7%), reflecting the progression from acute epithelial injury to chronic fibroinflammatory changes.

Systemic inflammatory signs differed markedly between the two groups. Fever ≥38°C was present in more than half of early cases (57.1%) but was less common in late complications (21.7%). In contrast, cholangitis occurred significantly more often in late BCs (52.2%) than in early BCs (28.6%), consistent with obstructive pathology in stricture-dominant late presentations. The likelihood of developing fever ≥38°C was 4.8-fold higher in early biliary complications compared with late presentations (p = 0.013).

The risk of developing complications in the form of bile leakage is 8.6 times higher in the early stages (p = 0.0015),

while the development of strictures is statistically significantly in 5.6 times higher in the late stages (p = 0.005).

Biochemical markers followed the same pattern: early BCs were associated with higher total bilirubin levels (56.8 ± 22.1 μmol/L), while late BCs showed increased GGT levels (287 ± 110 U/L), indicating prolonged cholestasis.

Management strategies also differed. ERCP was more frequently used for early BCs (67.9%), whereas PTBD was required more often in late BCs (31.8%). Late complications required a greater number of procedures (2.4 ± 1.2 vs. 1.7 ± 0.9) and had a longer treatment duration (36.2 ± 9.7 vs. 22.6 ± 8.1 days), highlighting their higher therapeutic burden.

Table 3.
Early and late biliary complications

Type of complication	BCs		Z statistic	OR	95%CI	P value
	Early (n =28)	Late (n = 23)				
Leaks, *n*	18 (64.3%)	4 (18.2%)	-	8.6γ	[2.3;32.2]	0.0015*
Strictures, *n*	7 (25.0%)	15 (65.2%)	-	0.018β	[0.05;0.6]	0.005*
Mixed complications, *n*	3 (10.7%)	4 (17.4%)	-	0.712 β	[1.4;3.6]	0.682
Fever **> 38°C**, *n*	16 (57.1%)	5 (21.7%)	-	4.8 γ	[1.4;16.6]	0.013*
Cholangitis, *n*	8 (28.6%)	12 (52.2%)	-	0.366 β	[0.1;1.2]	0.089
Total bilirubin, *μmol/L*	56.8 ± 22.1	42.3 ± 19.8	2.44*		[26.4;2.6]	0.018*
GGT,*U/L*	214 ± 92	287 ± 110	2.58*	-	[16.2;129.8]	
ERCP, *n*	19 (67.9%)	10 (45.5%)	-	2.7 γ	[0.8;8.6]	0.084
PTBD, *n*	6 (21.4%)	7 (31.8%)	-	0.62 β	[0.2;2.2]	0.465
Number of procedures, *n*	1.7 ± 0.9	2.4 ± 1.2	2.38*	-	[0.1;1.3]	0.021*
Duration of treatment, *day*	22.6 ± 8.1	36.2 ± 9.7	5.46*	-	[8.6;18.6]	0.0001*

OR: Odds ratio; α: OR=1 means that the odds are equal in both groups; β: OR<1 means that the event has an inverse relationship and the chance to occur in the second group; γ: OR>1 means that the event is directly related and has a chance of occurring in the first group;
*z-test statistical significance and P -value≤0.05 was considered statistically significant

Postoperative outcomes and survival

The morbidity rate due to BCs after LDLT was 24.5%.The overall survival rate after LDLT was 91.8% at 1 year and 72.1% at 10 years, as shown in Figure 2.In recipients with biliary complications, the 1-year survival rate was 84.2%, and 10-year survival was 77.7%, slightly lower than in patients without BCs (Figure 3).

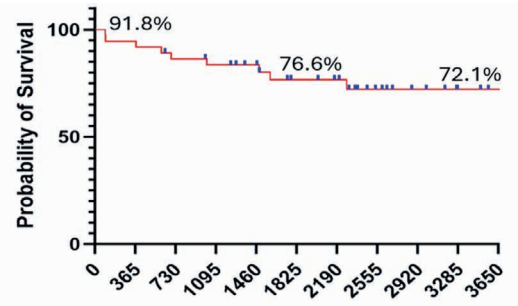

Figure 2.
Overall survival after LDLT

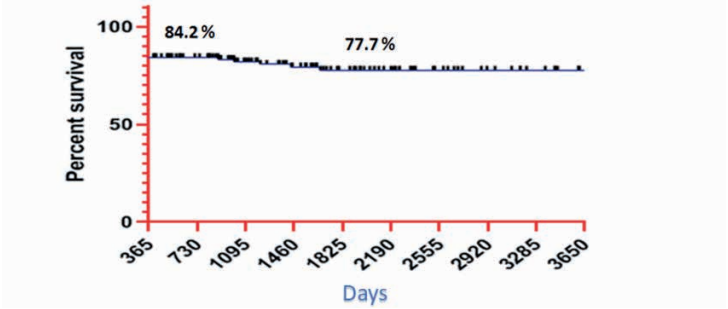

Figure 3. Survival rate with the presence of BCs

Discussion

In this study, biliary complications occurred in 24.5% of LDLT recipients, and their incidence was strongly influenced by biliary anatomical variation and ischemia-related factors. This rate is consistent with international reports, where the incidence of postoperative biliary complications ranges from 13% to 31%.[17-19] *Tsujino et al.* similarly described a 19% incidence in a multicenter series of 2,812 cases LDLT, further emphasizing the clinical relevance of biliary complications after LDLT.[20] The higher morbidity observed in grafts with Type C bile duct anatomy underscores the dominant role of anatomical configuration in determining postoperative risk.

The markedly higher incidence of complications in Type C anatomy reflects intrinsic structural challenges, as these configurations often include narrower ducts or more complex confluence patterns requiring technically demanding reconstruction. Such anatomical variations may increase the likelihood of diameter mismatch, suture line tension, and disruption of the peribiliary arterial plexus. Given that the peribiliary capillary network provides nearly the entire arterial supply to the bile duct, even subtle microvascular disturbances can lead to epithelial necrosis, impaired healing, and eventually leakage or stricture formation.[21,22] These mechanisms explain why Type C ducts, which are particularly vulnerable to perfusion instability, demonstrated the highest rate of complications in our cohort.

The significant association between ischemia-related variables and biliary morbidity further supports the central role of microvascular injury. Recipients with biliary complications had prolonged cold and warm ischemia times, consistent with evidence that biliary epithelial cells are more susceptible to ischemia–reperfusion injury than hepatocytes.[23] Prolonged ischemia exacerbates oxidative stress, endothelial dysfunction, and microthrombosis within the peribiliary plexus, increasing the likelihood of anastomotic failure. In our study, this translated into a clear temporal pattern: early complications manifested primarily as bile leaks resulting from acute epithelial disruption, while late complications were dominated by strictures, reflecting progressive fibroinflammatory remodeling.

Prolonged cold ischemia time in LDLT often reflects technical complexity during graft retrieval or back-table preparation, which may indirectly indicate increased vulnerability of peribiliary microvasculature.

Longer warm ischemia time may be associated with more time-consuming vascular reconstruction, which could further compromise microcirculation to the bile ducts.

These findings align with published data demonstrating that early bile leaks represent technical or ischemic-anastomotic failures, whereas late strictures reflect chronic ischemic consequences.[10,12] Early complications in our cohort presented with higher rates of fever and elevated bilirubin, findings typical of acute biliary leakage. Late strictures, on the other hand, were associated with higher GGT levels and a significantly higher incidence of cholangitis, consistent with prolonged cholestasis. The increased number of interventions and longer treatment duration required for late strictures further support the interpretation that they arise from chronic biliary injury, often requiring repeated endoscopic or percutaneous management.

In contrast to ischemia and anatomy, preoperative recipient severity—reflected by MELD score and Child–Pugh

class—was not associated with postoperative biliary complications in our study; a finding consistent with other reports suggesting that systemic disease severity plays a limited role in biliary outcomes after LDLT.[24-26] Likewise, arterial and portal vein complications were not statistically associated with biliary complications in our cohort, which may reflect improved intraoperative Doppler assessment and rapid correction—strategies known to reduce the risk of ischemic cholangiopathy.[23]

Although biliary complications increased postoperative morbidity, long-term survival remained acceptable in both groups. Patients with biliary complications demonstrated slightly lower survival rates at 1 and 10 years; however, overall survival remained favorable, supporting the notion that timely diagnosis and appropriate intervention can prevent progression to graft loss.[27,28]

Collectively, our findings reinforce the concept that biliary complications after LDLT arise from the combined effects of ischemic vulnerability and anatomical complexity. Early injuries may evolve into late strictures through progressive fibroinflammatory remodeling, underscoring the importance of meticulous microvascular preservation, optimization of ischemia times, and early identification of high-risk anatomical variants. Enhanced preoperative anatomical assessment and individualized operative planning may significantly reduce postoperative morbidity and improve long-term graft outcomes.

Limitations. This study has several limitations. First, the number of patients with biliary complications was limited, reducing the power of subgroup analyses. Second, it represents a single-center experience, and outcomes may vary depending on institutional expertise. Finally, while the retrospective design enables a broad overview, prospective multicenter studies are needed to confirm these findings.

What's known? Potential risk factors for biliary complications after liver transplantation, diagnostic methods, and treatment approaches for complications are known.

What's new? This study evaluates the risk of biliary complications depending on bile duct anatomy according to the Modified Huang Classification (Types A–C).

Conclusion

Biliary complications after LDLT remain closely linked to biliary anatomy and ischemia-related injury. Type C anatomy and longer ischemia times significantly increase complication risk, while early leaks and late strictures reflect different phases of biliary damage. Careful preoperative anatomical assessment, minimization of ischemia, and timely management are essential to improving postoperative outcomes and long-term graft survival.

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