e-ISSN: 0976-822X, p-ISSN:2961-6042

Available online on http://www.ijcpr.com/

International Journal of Current Pharmaceutical Review and Research 2026; 18(4); 802-810

Original Research Article

Study of Biliary Anatomy and Biliary Out Come in Children Undergoing Liver Transplantation

Manjuladevi E.[1], Sanjay Rao[2], Ashley Lucien Joseph D. Cruz [3]

[1]Assistant Professor, Department of Paediatric Surgery, SAT Hospital, Government Medical College, Thiruvananthapuram

[2]Senior Consultant, Paediatric Surgeon, Department of Paediatric Surgery, Narayana Hrudayalaya Hospital, Bangalore, Karnataka, India

[3]Senior Consultant, Paediatric Surgeon, Department of Paediatric Surgery, Narayana Hrudayalaya Hospital, Bangalore, Karnataka, India

Received: 06-02-2026 / Revised: 16-03-2026 / Accepted: 10-04-2026

Corresponding Author: Dr. Manjuladevi E

Conflict of interest: Nil

Abstract

Background: Pediatric liver transplantation is the definitive treatment for many children with end-stage liver disease and selected metabolic and hepatobiliary disorders. Despite advances in surgical techniques and perioperative care, biliary complications remain a major cause of postoperative morbidity, particularly in living donor liver transplantation where graft biliary anatomy and reconstruction are technically demanding. The present study was undertaken to describe the clinicopathological and surgical profile of pediatric liver transplant recipients and to analyse the incidence and risk factors of biliary complications.

Materials and Methods: This retrospective descriptive study included 47 children who underwent liver transplantation at a tertiary care center. Data were collected from medical records, operative notes, imaging records, and follow-up documentation. Recipient characteristics, indications for transplantation, donor profile, graft type, number of graft bile ducts, type of biliary reconstruction, and early postoperative surgical complications were recorded. For biliary outcome analysis, 42 children with adequate follow-up were included. Categorical variables were expressed as frequency and percentage, and continuous variables as Mean±SD. Fisher's exact test was used to assess associations between selected variables and biliary complications. Odds ratios with 95% confidence intervals were calculated for statistically significant risk factors.

Results: The mean age of recipients was 35.2±29.7 months and mean weight was 10.9±5.1 kg; 72.3% were male. Biliary atresia was the most common indication for transplantation (51.1%), followed by metabolic disorders (14.9%). Most grafts were from living donors (93.6%), predominantly mothers (63.8%), and the left lateral segment was the commonest graft type (85.1%). A single bile duct was present in 65.9% of grafts, while multiple bile ducts were observed in the remainder. Roux-en-Y choledochojejunostomy was the principal method of biliary reconstruction (95.7%). Early postoperative surgical complications occurred in 42.6% of recipients, with biliary leak being the most frequent. Among the 42 children included in the biliary analysis, 12 (28.6%) developed biliary complications. Multiple bile ducts in the graft were significantly associated with biliary complications (53.3% vs 14.8%; p=0.013; OR 6.57, 95% CI: 1.51–28.54). Hepatic artery thrombosis was also a significant risk factor, with all affected children developing biliary complications (p=0.004; OR 32.29, 95% CI: 1.58–661.13). Other variables were not significantly associated.

Conclusion: Pediatric liver transplantation in this cohort was performed predominantly in young children with biliary atresia using living donor left lateral segment grafts. Biliary complications represented a substantial source of postoperative morbidity. Multiple graft bile ducts and hepatic artery thrombosis were the principal risk factors for biliary complications. Careful preoperative assessment, meticulous biliary reconstruction, and close postoperative vascular and biliary surveillance are essential to reduce biliary morbidity and improve outcomes after pediatric liver transplantation.

Keywords: Pediatric liver transplantation; living donor liver transplantation; biliary complications; biliary atresia; hepatic artery thrombosis; Roux-en-Y choledochojejunostomy.

DOI: 10.25258/ijcpr.18.4.129

Introduction

Pediatric liver transplantation is the definitive treatment for many children with end-stage liver disease and selected metabolic or hepatobiliary disorders, offering the prospect of prolonged

survival and better quality of life. Over time, major advances in surgical techniques, perioperative care, immunosuppressive therapy, and donor selection have substantially improved transplant outcomes. Despite these developments, postoperative complications—particularly biliary complications—continue to be a major source of morbidity after transplantation. In children, these challenges are often more pronounced because of small recipient size, complex and variable biliary anatomy, and the frequent use of living donor grafts. Therefore, a clear understanding of recipient profile, donor and graft characteristics, methods of biliary reconstruction, and factors contributing to biliary complications is essential for improving postoperative outcomes.

Pediatric liver transplantation presents distinctive technical and clinical challenges, especially with regard to biliary reconstruction, anatomical variation, and postoperative biliary morbidity. Biliary complications remain one of the most important causes of morbidity after pediatric liver transplantation, with reported incidences varying widely across studies and with significant implications for graft function and overall patient outcome [1, 2, 3]. In living donor liver transplantation (LDLT), donor biliary anatomy and the number of bile ducts in the graft play a crucial role in determining the risk of postoperative biliary complications, and several studies have identified multiple ducts and donor biliary anomalies as important risk factors [4, 5, 6]. Improvements in preoperative biliary imaging, careful biliary dissection, and refined reconstructive techniques—such as duct-to-duct anastomosis and Roux-en-Y hepaticojejunostomy (RYHJ)—have been introduced to reduce the occurrence and severity of biliary leaks and strictures, especially in children receiving left lateral segment or reduced-size grafts from living donors [1, 4, 7]. Previous pediatric liver transplantation literature has also associated higher biliary complication rates with factors such as younger age, lower body weight, grafts containing multiple bile ducts, Roux-en-Y biliary reconstruction, preformed Roux loops, hepatic artery thrombosis, and CMV infection, although the strength of these associations has differed across studies [1, 3, 4, 7]. In this context, the present study examines a cohort of pediatric recipients undergoing LDLT, with particular focus on donor and recipient biliary anatomy, graft characteristics, incidence of biliary complications, associated risk factors, and the range of management strategies and outcomes. By integrating these donor-, graft-, and recipient-related factors, the study seeks to provide deeper insight into biliary morbidity after pediatric liver transplantation and to identify areas where such complications may be better predicted and prevented. Against this background, the present study was undertaken to describe the clinicopathological and surgical characteristics of pediatric liver transplant recipients and to analyse the incidence and risk factors of biliary complications in this cohort.

Materials and Methods

This retrospective descriptive study was conducted in the Department of Pediatric Surgery, Division of Solid Organ Transplantation, Narayana Hrudayalaya Woman and Child Institute, Bangalore, India. It included pediatric liver transplant recipients operated between October 2005 and June 2013. A total of 47 pediatric liver transplant recipients constituted the study cohort. For the specific analysis of biliary complications, children with adequate postoperative biliary follow-up data were included, yielding a biliary study subgroup of 42 patients. Data were collected from hospital medical records, transplant database records, operative notes, imaging records, and follow-up documentation using a structured data extraction proforma. Variables recorded included recipient characteristics such as age, sex, weight, and Pediatric End-Stage Liver Disease (PELD) score; indication for transplantation; donor characteristics; graft type; number and anatomy of graft bile ducts; and type of biliary reconstruction performed. Early postoperative surgical complications, including biliary leak, bleeding requiring re-exploration, bowel complications, hepatic artery thrombosis, portal vein thrombosis, and cytomegalovirus (CMV) infection, were also documented.

The primary outcome of interest was the occurrence of biliary complications following transplantation. Biliary complications were identified from clinical records, imaging findings, interventional procedure notes, and operative or endoscopic documentation. Risk factor analysis was carried out to assess the association between biliary complications and selected recipient-, donor-, graft-, and surgery-related variables, including age, weight, indication for transplantation, donor bile duct anomaly, number of bile ducts in the graft, type of biliary anastomosis, type of Roux-en-Y loop, hepatic artery thrombosis, bowel complications, and CMV infection. Data were entered and analysed using appropriate statistical software. Categorical variables were summarized as frequency and percentage, while continuous variables were expressed as mean ± SD. Fisher's exact test was used to examine associations between categorical variables and biliary complications. Odds ratios (OR) with 95% confidence intervals (CI) were calculated for statistically significant risk factors. A p value of less than 0.05 was considered statistically significant. This study is based on data collected by author during Diplomate of National

Board (DNB) training. The study was approved by the Institutional Review Committee and Institutional Ethics Committee of Narayana Hrudayalaya, Bangalore, and was accepted as a thesis by the National Board of Examinations (DNB), New Delhi. Confidentiality of patient information was maintained throughout the study.

The results describe the clinical profile of pediatric liver transplant recipients, along with donor, graft, and biliary reconstruction characteristics.

They also present the incidence of postoperative surgical and biliary complications and analyse the factors associated with biliary morbidity.

Results

Table 1: Clinical Characteristics

		No	%
Age (months)	<12	6	12.8
	12-59	33	70.2
	60-120	6	12.8
	≥120 months	2	4.3
	Mean±SD	35.2±29.7	
Gender	Male	34	72.30
	Female	13	27.70
Recipient weight in kilogram (kg)	< 10	26	55.30
	11-20	18	38.30
	>20	3	6.40
	Mean±SD	10.9±5.1	
PELD Score	<10	16	34.00
	10-20	13	27.70
	21-30	14	29.80
	31-50	4	8.50
	Mean±SD	16.7±10.9	

Table 1 presents the baseline clinical profile of the 47 pediatric liver transplant recipients. Most children were very young, with 33 (70.2%) aged 12–59 months, while 6 children (12.8%) were younger than 12 months, 6 (12.8%) were aged 60–120 months, and only 2 (4.3%) were aged 120 months or more. The mean age was 35.2±29.7 months, indicating that liver transplantation was performed predominantly in infants and young children. There was a clear male predominance, with 34 boys (72.3%) and 13 girls (27.7%). Recipient weight also reflected the young age of the cohort: more than half of the children, 26 (55.3%), weighed less than 10 kg, 18 (38.3%) weighed 11–20 kg, and only 3 (6.4%) weighed more than 20 kg. The mean recipient weight was 10.9±5.1 kg. The distribution of Pediatric End-Stage Liver Disease (PELD) scores showed that the severity of liver disease at transplantation was variable but generally moderate. Sixteen children (34.0%) had a PELD score below 10, 13 (27.7%) had scores between 10 and 20, 14 (29.8%) had scores between 21 and 30, and 4 (8.5%) had very high scores between 31 and 50. The mean PELD score was 16.7±10.9. Overall, these findings indicate that the study population mainly consisted of young, low-weight male children undergoing transplantation for clinically significant liver disease, with a substantial proportion having moderate to severe pre-transplant illness.

Table 2: Indications for liver transplantation in the study cohort

Etiology	No	(%)
1. Biliary atresia (n = 24)	24	51.1
a) Previous Kasai	16	34.0
b) No previous Kasai	8	17.0
2. Metabolic disorders (n = 7)	7	14.9
a) Wilson's disease	2	4.3
b) Oxalosis	1	2.1
c) Tyrosinemia	3	6.4
d) Glycogen storage disorder (Type 4)	1	2.1
3. Progressive familial Intrahepatic cholestasis	3	6.4
4. Cirrhosis-cryptogenic	2	4.3
5. Caroli's disease	2	4.3
6. Paucity of intrahepatic bile ducts	2	4.3
7. Budd Chiari Syndrome	2	4.3
8. Fulminant hepatic failure	1	2.1

9. Hepatoblastoma	1	2.1
10. Primary Sclerosing Cholangitis	1	2.1
11. Alagille's Syndrome	1	2.1
12. Congenital Hepatic Fibrosis	1	2.1
Total	47	100

Table 2 shows that biliary atresia was the leading indication for liver transplantation, accounting for 24 of the 47 children (51.1%). Among these, 16 children (34.0%) had previously undergone a Kasai procedure, whereas 8 (17.0%) had no prior Kasai surgery. This finding highlights biliary atresia as the single most important underlying diagnosis in the study cohort and suggests that a substantial proportion of children ultimately required transplantation despite prior surgical intervention.

The second most common indication was metabolic liver disease, seen in 7 children (14.9%). Within this group, tyrosinemia was the most frequent metabolic disorder, affecting 3 children (6.4%), followed by Wilson's disease in 2 (4.3%), and oxalosis and glycogen storage disorder type 4 in 1 child each (2.1%). Progressive familial intrahepatic cholestasis accounted for 3 cases (6.4%). Several other conditions each contributed a smaller proportion of transplants, including cryptogenic cirrhosis, Caroli's disease, paucity of intrahepatic bile ducts, and Budd–Chiari syndrome, with 2 cases each (4.3%). Less common indications included fulminant hepatic failure, hepatoblastoma, primary sclerosing cholangitis, Alagille syndrome, and congenital hepatic fibrosis, each contributing 1 case (2.1%). Overall, the findings indicate that liver transplantation in this cohort was performed for a broad spectrum of pediatric liver diseases, but the burden was clearly dominated by biliary atresia, followed by metabolic disorders and cholestatic liver diseases. This pattern emphasizes the central role of congenital and inherited hepatobiliary disorders in pediatric liver transplantation.

Table 3: Donor Characteristics

Donor	No	%
Mother	30	63.80
Father	9	19.20
Relative (second degree)	4	8.50
Altruistic	1	2.10
Deceased(cadaveric)	3	6.40
Total	47	100

Table 3 depicts the donor profile of the study cohort and shows that living related donation, particularly from mothers, was the predominant source of grafts. Mothers constituted the largest donor group, accounting for 30 of the 47 donors (63.8%), followed by fathers in 9 cases (19.2%). Thus, parents together contributed more than four-fifths of all donations, underlining the central role of immediate family members in facilitating pediatric liver transplantation. A smaller proportion of grafts came from second-degree relatives, who accounted for 4 donations (8.5%). Deceased donor transplantation was performed in 3 children (6.4%), while altruistic donation was observed in only 1 case (2.1%). Overall, these findings indicate that the transplant program relied predominantly on living donor liver transplantation, with maternal donors forming the backbone of the donor pool. This pattern reflects the practical importance of family-based donation in pediatric liver transplantation, where timely graft availability is crucial and deceased donor organs may be limited.

Table 4: Type of Graft

Type of Graft	No	%
Living donor graft	44	93.6
a) Left lateral segment	40	85.1
b) Full left lobe	4	8.5
Cadaveric grafts	3	6.4
Full organ	1	2.1
Reduced right lobe	1	2.1
Reduced Left lobe	1	2.1
Total	47	100.0

Table 4 shows that living donor grafts overwhelmingly predominated in this series, being used in 44 of the 47 transplant procedures (93.6%), whereas only 3 transplants (6.4%) utilized cadaveric grafts. This finding is consistent with the donor profile of the cohort and indicates that the transplant program was largely dependent on living donor liver transplantation. Among the living donor

grafts, the left lateral segment was by far the most commonly used graft type, accounting for 40 cases (85.1%), while the full left lobe was used in 4 cases (8.5%).

This pattern suggests that the left lateral segment was the preferred graft for most recipients, likely reflecting the young age and relatively small body size of the children in the study. In the cadaveric transplant group, each graft type—full organ, reduced right lobe, and reduced left lobe—was used in 1 case (2.1% each).

Overall, the findings demonstrate that pediatric liver transplantation in this cohort was chiefly performed using living donor left lateral segment grafts, with cadaveric grafting contributing only a small minority of cases.

Table 5: Number of bile ducts in the graft

Number of bile ducts in the graft	No	%
Single bile duct	31	65.9
Two bile ducts	10	21.3
Three bile ducts	3	6.4
Four bile ducts	1	2.1
Confluence of bile ducts	2	4.3
Total	47	100

Table 5 describes the biliary anatomy of the grafts and shows that a single bile duct was present in the majority of grafts, observed in 31 of the 47 cases (65.9%). This indicates that in nearly two-thirds of transplants, biliary reconstruction may have been relatively straightforward from an anatomical perspective.

However, a considerable proportion of grafts showed more complex biliary anatomy. Two bile ducts were identified in 10 grafts (21.3%), while 3 grafts (6.4%) had three bile ducts and 1 graft (2.1%) had four bile ducts. In addition, 2 grafts (4.3%) demonstrated a confluence of bile ducts. Taken together, these findings suggest that although most grafts had a single duct, more than one-third had multiple ducts or ductal confluence, which could increase the technical complexity of biliary reconstruction during transplantation.

Overall, the table highlights the anatomical variability of graft bile ducts and the need for careful operative planning in a notable subset of patients.

Table 6: Type of Bile duct reconstruction

Bile duct reconstruction	No	%
Roux en Y Choledochojejunostomy	45	95.7
Duct to duct anastomosis	2	4.3
Total	47	100

Table 6 shows that Roux-en-Y choledochojejunostomy was the predominant method of biliary reconstruction, performed in 45 of the 47 transplant recipients (95.7%). In contrast, duct-to-duct anastomosis was used in only 2 cases (4.3%). This clearly indicates that Roux-en-Y reconstruction was the standard surgical approach in this cohort.

The overwhelming preference for Roux-en-Y choledochojejunostomy likely reflects the clinical and anatomical characteristics of the study population, particularly the high proportion of children transplanted for biliary atresia and other cholestatic disorders, in whom the native extrahepatic bile duct is often absent, diseased, or unsuitable for direct reconstruction.

Overall, these findings suggest that biliary-enteric reconstruction was considered the most feasible and appropriate option in the vast majority of pediatric liver transplants in this series, while duct-to-duct reconstruction was reserved for a small and selected subset of patients.

Table 7: Early postoperative surgical problems

Early postoperative surgical problems	No	%
Present	20	42.6
(i)Biliary leak	12	25.5
(ii)Re-exploration for bleeding	6	12.8
(iii)Early bowel complications	6	12.8
(iv)Hepatic artery thrombosis (HAT)	4	8.5
(v)Portal vein thrombosis	3	6.4
Absent	27	57.4

Table 7 shows that early postoperative surgical complications were observed in 20 of the 47 children (42.6%), while 27 children (57.4%) had no such complications in the immediate postoperative

period. This indicates that although more than half of the recipients had an uncomplicated early surgical course, a substantial proportion experienced important postoperative events requiring close monitoring and management. Among the individual complications, biliary leak was the most common early surgical problem, occurring in 12 patients (25.5%). Re-exploration for bleeding and early bowel complications were each reported in 6 patients (12.8%).

Vascular complications were also noted, with hepatic artery thrombosis (HAT) occurring in 4 children (8.5%) and portal vein thrombosis in 3 children (6.4%). Overall, these findings suggest that early postoperative morbidity was considerable in this cohort, with biliary complications forming the major share, followed by bleeding, bowel-related complications, and vascular thrombosis.

This pattern highlights the technically demanding nature of pediatric liver transplantation and the importance of vigilant postoperative surveillance for prompt identification and treatment of surgical complications.

Table 8: Incidence of biliary complications among study group

Biliary study	No	%
Children included in the biliary complications study(n=42)	42	100.0
a) Complications Present	30	71.4
b) Absent	12	28.6

Table 8 presents the overall incidence of biliary complications among the 42 children included in the biliary outcome analysis. Of these, 30 children (71.4%) developed biliary complications, whereas only 12 children (28.6%) remained free of biliary complications. This indicates that biliary morbidity was highly prevalent in the study population. These findings suggest that biliary complications constituted a major postoperative concern in this cohort, affecting nearly three-fourths of the children evaluated. Considering that biliary reconstruction is one of the most technically delicate aspects of pediatric liver transplantation, this high incidence highlights the need for meticulous surgical technique, careful postoperative monitoring, and timely intervention.

Table 9: Risk Factors Analysis for Development of Biliary Complications

		Biliary complications			Fishers Exact Test
		Yes	No	Total	
Age	<2 years	7 (36.8)	12 (63.2)	19(100)	0.322
	>2 years	5 (21.7)	18 (78.3)	23(100)	
Weight (kg)	<10	8 (30.8)	18 (69.2)	26(100)	0.742
	>10	4 (25)	12(75)	16(100)	
Indication of liver transplant	Biliary atresia	9(40.9)	13(59.1)	22(100)	0.091
	Non-biliary atresia	3(15)	17(85)	20(100)	
Donor bile duct anomaly	Present	1 (33.3)	2(66.7)	3 (100)	1.000
	Absent	11(28.2)	28(71.8)	39 (100)	
Number of bile ducts	Multiple bile ducts	8(53.3)	7(46.7)	15(100)	0.013
	Single bile duct	4(14.8)	23(85.2)	27(100)	
Type of biliary anastomosis	Roux-en-Y loop anastomosis	12(30)	28(70)	40(100)	1.000
	Duct to duct anastomosis	0	2(100)	2(100)	
Type of Roux-en-Y loop	Pre-constructed loop	5(33.3)	10(66.7)	15(100)	0.726
	New loop	7(25.9)	20 (74.1)	27(100)	
Hepatic artery thrombosis	Hepatic artery thrombosis present	4(100)	Zero	4(100)	0.004
	No hepatic artery thrombosis	8(21.1)	30(78.9)	38 (100)	
Bowel complications	Bowel complications present	5(50.0)	5(50.0)	10(100)	0.1167
	No bowel complications	7(21.9)	25(78.1)	32(100)	
CMV infection (blood PCR quantitative positive)	Present	4(50.0)	4(50.0)	8(100)	0.1954
	Absent	8(23.5)	26(76.5)	34(100)	
	Total	12(28.6)	30(71.4)	42(100.0)	

Table 9 presents the risk factor analysis for biliary complications among the 42 children included in the biliary follow-up. Of the variables examined, two factors showed a statistically significant association with the development of biliary complications: multiple bile ducts in the graft and hepatic artery thrombosis (HAT).

Children receiving grafts with multiple bile ducts had a significantly higher incidence of biliary

complications compared with those with a single bile duct (53.3% vs 14.8%; Fisher's exact test, p=0.013). The odds of developing biliary complications were 6.57 times higher among children with multiple bile ducts compared with those with a single bile duct (OR = 6.57; 95% CI: 1.51–28.54). This suggests that complex biliary anatomy substantially increased the risk of postoperative biliary morbidity.Similarly, hepatic artery thrombosis showed a strong and statistically significant association with biliary complications (p=0.004). All 4 children with HAT developed biliary complications, compared with only 21.1% of those without HAT.

Discussion

Overall, the study shows that pediatric liver transplantation in this cohort was performed predominantly in young, low-weight children, most of whom were below 5 years of age, with a clear male predominance. Biliary atresia emerged as the leading indication for transplantation, followed by metabolic liver diseases and other cholestatic disorders. The donor and graft profile revealed a strong dependence on living donor liver transplantation, especially from mothers, with the left lateral segment graft being the most frequently used. In most cases, biliary reconstruction was carried out using Roux-en-Y choledochojejunostomy, reflecting the underlying disease profile and anatomical considerations in pediatric recipients. The postoperative findings indicate that surgical morbidity was substantial, with early postoperative surgical problems occurring in a considerable proportion of children, most commonly biliary leak, bleeding requiring re-exploration, bowel complications, and vascular thrombosis. More importantly, biliary complications were highly prevalent among those evaluated, affecting nearly three-fourths of the study group. Risk factor analysis showed that multiple bile ducts in the graft and hepatic artery thrombosis were the two significant determinants of biliary complications, while other clinical and operative variables were not significantly associated.

Incidence and overall burden of biliary complications: Consistent with prior pediatric LT literature, biliary complications occurred in a substantial minority of cases in our LDLT cohort, with 12 of 42 recipients (28.6%) experiencing biliary complications; all presented with early bile leaks, and the majority were managed successfully with conservative drainage, re-exploration, or percutaneous drainage as appropriate Findings. This incidence aligns with reported ranges for pediatric biliary complications after LDLT, which commonly span from single to double-digit proportions and commonly emphasize leaks as the initial and prevalent early event, followed by strictures in a subset of patients [1, 2, 3]. The observation that biliary complications did not translate into a statistically significant increase in overall mortality in this cohort is concordant with several reports indicating that biliary complications, while morbid, do not automatically portend worse survival when promptly recognized and managed, though late complications and biliary sepsis can be fatal in a minority of cases [1, 3]. Notably, the study found that biliary complications were associated with hepatic artery thrombosis, a relationship supported by prior analyses showing arterial supply to the biliary tree as a critical determinant of biliary patency and ischemic cholangiopathy risk [3, 5, 7]. The presence of CMV infection showed a numerical association with biliary complications, but did not reach statistical significance in this cohort, mirroring the variability observed across studies regarding infectious contributors to biliary morbidity [7, 1, 8, 3].

Donor biliary anatomy and number of ducts: implications for reconstruction: Donor biliary anatomy was predominantly normal among donors (41/44 had standard anatomy; 3 had a right posterior segmental duct draining into the left main duct). In our cohort, grafts with multiple bile ducts occurred in a substantial minority (15/42, 35.7%), and these cases were associated with a higher rate of biliary complications (8/15, 53.3% vs 4/27, 14.8% in single-duct grafts; p = 0.013) Findings. This finding corroborates prior reports that multiple donor bile ducts increase the technical complexity of reconstruction and the risk of postoperative biliary complications, particularly in pediatric recipients where duct size is small and anastomoses are more prone to leakage or stricture formation [1, 2, 4, 6].

The Roux-en-Y hepaticojejunostomy was the predominant reconstruction method (in 40/42 cases), and biliary complications clustered within the Roux-en-Y group in our data (12/12 biliary complications occurred in Roux-en-Y reconstructions) though the small sample limits causal inference; this observation echoes the ongoing debate in the literature about when duct-to-duct anastomosis versus Roux-en-Y is preferable in small ducts or multiple-duct grafts [1, 4, 5, 7] . The single duct-to-duct group (2 patients) did not experience biliary complications, but the numbers are too small to draw firm conclusions; other reports emphasize that duct-to-duct anastomosis can be associated with fewer biliary complications when donor ducts are favourable and conduits permit a straightforward anastomosis [4, 5, 6].

Graft type, number of biliary orifices, and preconstructed Roux loops: Graft type analysis showed that the majority of transplants employed left lateral segment grafts or reduced left lobe grafts from living donors, with only a few

cadaveric grafts. In our analysis, the presence of multiple donor biliary ducts was significantly associated with biliary complications, consistent with prior LDLT literature indicating that multiple donor ducts increase complication risk and may necessitate complex reconstructions or staged biliary drainage strategies.

The comparison of preconstructed versus newly created Roux loops did not reach statistical significance for biliary complications, though a trend suggested higher complication rates with preformed Roux loops, potentially due to prior Kasai procedures or donor-recipient anatomy predisposing to biliary challenges; however, the sample size limits robust conclusions. These observations align with broader discussions in the field about customizing biliary reconstruction based on donor duct anatomy, previous surgeries such as Kasai, and recipient anatomy to optimize outcomes [4, 5, 6, 7].

Hepatic artery thrombosis, CMV infection, bowel complications, and their relation to biliary morbidity: Hepatic artery thrombosis (HAT) emerged as a strong risk factor in our cohort for subsequent biliary complications; all four recipients with HAT developed biliary complications compared with 8/38 without HAT ($p = 0.004$). This aligns with the pathophysiology that biliary epithelium depends on hepatic arterial supply, and arterial insufficiency predisposes to biliary ischemia and strictures or leaks [3, 5, 7]. CMV infection showed a numerical association with biliary complications (4/8 with CMV vs 8/34 without CMV; not statistically significant in this sample), reflecting the inconsistent signal across pediatric LT literature regarding infection as a biliary risk factor, while acknowledging its potential contribution in larger cohorts [3, 7, 8].

Bowel complications modestly correlated with biliary complications (5/10 with bowel events had biliary complications vs 7/32 without; not statistically significant in this dataset), consistent with the notion that generalized postoperative morbidity can coexist with biliary issues but does not uniformly predict biliary outcomes in small samples [1, 3].

Management strategies and outcomes for biliary leaks and persistent biliary complications: Early biliary leaks were managed with a spectrum of approaches: spontaneous resolution with prolonged drainage, re-laparotomy with biloma drainage, re-exploration for major leaks and revision of biliary anastomosis, and catheter-based drainage (PIGTAIL). Twelve of forty-two children had biliary complications, with 10 resolving either conservatively or surgically and two evolving into chronic biliary fistula. These results reinforce the common clinical pathway in pediatric LT: initial drainage and conservative measures for leaks, escalation to revision of the biliary anastomosis or interventional radiology as needed, and recognition that some leaks may progress to chronic fistulas requiring ongoing drainage or eventual reintervention Findings. The literature supports a stepwise approach to biliary leaks in pediatric LT, with percutaneous drainage and endoscopic or radiologic interventions playing increasingly prominent roles, particularly for distal or complex ductal anatomy [9, 1, 2, 10, 11]. In cases of persistent biliary complications, the data suggested a grim prognosis with mortality from biliary sepsis in late complications, stressing the need for vigilant long-term follow-up and timely salvage options, including re-transplantation in select cases where feasible [9, 1, 3].

Survival and impact on overall outcomes: In the study cohort, overall survival of recipients with biliary complications was 83.3% (10/12), while the study-wide survival among all included recipients was 76.2% (32/42). The occurrence of biliary complications did not statistically increase overall mortality compared with those without biliary complications ($p = 0.695$), a finding that resonates with several pediatric LT series where biliary complications increase morbidity but do not universally translate into reduced survival when managed effectively Findings. Nonetheless, late biliary complications culminating in biliary sepsis and death occurred in some patients, underscoring the necessity for long-term multidisciplinary care, including hepatobiliary interventions, infectious disease management, and timely consideration of retransplant when indicated [1, 3, 9].

In summary, biliary complications constituted an important source of postoperative morbidity in this pediatric LDLT cohort, occurring in 28.6% of recipients, with early bile leak being the predominant presentation. Most cases were successfully managed through conservative measures, drainage procedures, or surgical re-exploration, although a small number progressed to persistent fistula or late biliary sepsis. The study identified multiple bile ducts in the graft and hepatic artery thrombosis as the major factors significantly associated with biliary complications, highlighting the importance of graft biliary anatomy and adequate arterial perfusion in determining postoperative biliary outcomes. Other factors such as CMV infection, bowel complications, and type of Roux loop showed possible trends but were not statistically significant in this cohort.

Despite the substantial burden of biliary morbidity, these complications did not significantly reduce overall survival when recognized early and managed appropriately. Overall, the findings emphasize that careful donor selection, meticulous

biliary reconstruction, close vascular surveillance, and prompt multidisciplinary management are crucial for minimizing biliary complications and improving long-term outcomes after pediatric liver transplantation.

Acknowledgement: The author sincerely acknowledges the guidance and support received during this study.
I express deep gratitude to my guide Dr. Ashley L. J. D'Cruz and co-guide Dr. Sanjay Rao for their expert supervision and encouragement.

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