Bile Duct Injury in the Laparoscopic Era: Clinical Spectrum, Optimal Management and Outcomes from Dual Tertiary Care Centres of North India

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Abstract

Background: Bile duct injury (BDI) is one of the most serious complications of cholecystectomy associated with substantial risk of morbidity and mortality. Although surgical techniques have evolved, bile duct injuries continue to occur with notable frequency.

Aim: To evaluate the demographic profile, presentation, classification, management, and outcomes of patients with BDI following laparoscopic cholecystectomy.

Methods: A dual center prospective study was conducted from June 2022 to June 2024 at Jawaharlal Nehru Medical College, Aligarh and Sir Ganga Ram Hospital, New Delhi. Sixty patients with post laparoscopic cholecystectomy BDI were included. Data were collected on demographic profile, clinical features at presentation, Strasberg–Bismuth classification, management, post operative complications and overall outcome at six months.

Results: The mean age was 38.1 years with female predominance (F:M ratio 2.3:1). Common symptoms were abdominal pain (81.7%) and jaundice (73.3%). Injuries were most frequently Strasberg class E4 (25%) and E2 (23.3%), followed by class A (23.3%). Hepaticojejunostomy was performed in 75% of patients, ERCP with sphincterotomy in 16.7% (two failures) and 8.3% were managed conservatively. At six months, 93.3% of patients improved, while overall mortality occurred in 6.7% (n=4). Early postoperative symptoms including pain and icterus showed steady resolution, and most patients had satisfactory recovery.

Conclusion: BDI continues to challenge surgeons in the laparoscopic era, with complex injuries often managed at specialized centers. Hepaticojejunostomy remains the cornerstone of management for high-grade injuries, while ERCP offers effective minimally invasive approach for biliary leaks. Early recognition, accurate classification, and specialized multidisciplinary care are critical for optimizing outcomes and minimizing long-term complications.

Keywords: Bile duct injury, Cholecystectomy, Strasberg classification, Hepaticojejunostomy, ERCP

Introduction

Post-cholecystectomy bile duct injury (BDI) remains a critical postoperative complication because of its considerable morbidity and mortality [1,2]. The incidence of BDI is closely linked to the surgeon's experience and expertise. BDI is notably higher following laparoscopic cholecystectomy (LC) compared to open cholecystectomy (OC), with rates of 0.4–0.6% for LC versus 0.1–0.2% for OC [3,4]. which has significantly reduced owing to advancements in surgical technique and laparoscopic experience [5]. The classification of bile duct injuries using the Bismuth-Strasberg system based on the location within the biliary tract, aid in diagnosis and planning further management. Morbidities resulting from bile duct injury, such as biliary fistula, jaundice, and bile duct stenosis, not only affect patients' long-term prognosis but also impose substantial medical burdens, significantly impacting quality of life [6].

Preventing bile duct injury (BDI) is crucial step from the surgeon's perspective. Effective prevention strategies involve a deep understanding of how BDIs occur, recognizing the critical view of safety, and making appropriate patient selections [7–9].

Early identification of BDI is vital in reducing major morbidity, especially in patients exhibiting an unusual postoperative course after cholecystectomy. Various diagnostic tools, include intraoperative cholangiogram, intraoperative ultrasound or indocyanine green fluorescence cholangiography and postoperative imaging modalities such as Endoscopic Retrograde Cholangiopancreatography (ERCP), Magnetic Resonance Cholangiopancreatography (MRCP), Contrast enhanced CT, and Percutaneous Transhepatic Cholangiography (PTC) are used to detect BDIs.

Despite advancements in surgical safety and diagnostic modalities, bile duct injury continues to carry significant long-term consequences. Outcomes largely depend on the timing of recognition, the extent of ductal damage and the expertise of the surgical team. Delayed or inappropriate management may lead to recurrent cholangitis, secondary biliary cirrhosis, portal hypertension, and even liver failure. Thus, timely recognition and specialized surgical reconstruction can restore satisfactory biliary drainage and improve prognosis. This study underscores the importance of early detection and multidisciplinary management in optimizing patient survival and quality of life.

The primary objectives were to analyze the demographic profile of patients with BDI, evaluate the clinical spectrum of presentations such as abdominal pain, abdominal distension, jaundice, and bile leak through drain, classify injuries according to the Strasberg–Bismuth classification and assess the treatment modalities employed.

The secondary objective was to study postoperative complications and overall outcome following repair of BDIs up to six months after the procedure, including bile leak or fistula, cholangitis, stricture/stenosis and mortality.

Material and Methods

This prospective dual-centric study was conducted over a period of two years from June 2022 to June 2024. A total of 60 patients who sustained bile duct injury (BDI) following cholecystectomy were included in the study. Ethical clearance was granted by the institutional board and written informed consent was obtained from all patients after explaining the voluntary nature of participation and strict confidentiality of patient data. Patients aged more than 14 years with bile duct injuries related to cholecystectomy who provided informed consent were enrolled in the study and patients with bleeding diathesis and bile duct injury not related to cholecystectomy were excluded.

Clinical features such as abdominal pain, distension, jaundice, bile leak, and fever at the time of presentation were recorded. Complete blood count (CBC), renal function tests, serum electrolytes and imaging studies such as ultrasound, MRCP were done in all the patients and CT scan, ERCP, PTC and per operative cholangiogram were done as indicated.

S. No.	Procedure	No. of Cases (n=60)
1	Ultrasound Whole Abdomen	60 (100 %)
2	MRCP	60 (100%)
3	CECT Whole Abdomen	18 (30%)
4	PTC	2 (3.3%)
5	Per-Operative Cholangiogram	5 (8.3%)

Figure 1. Illustration showing intraoperative cholangiogram delineating the anatomy.
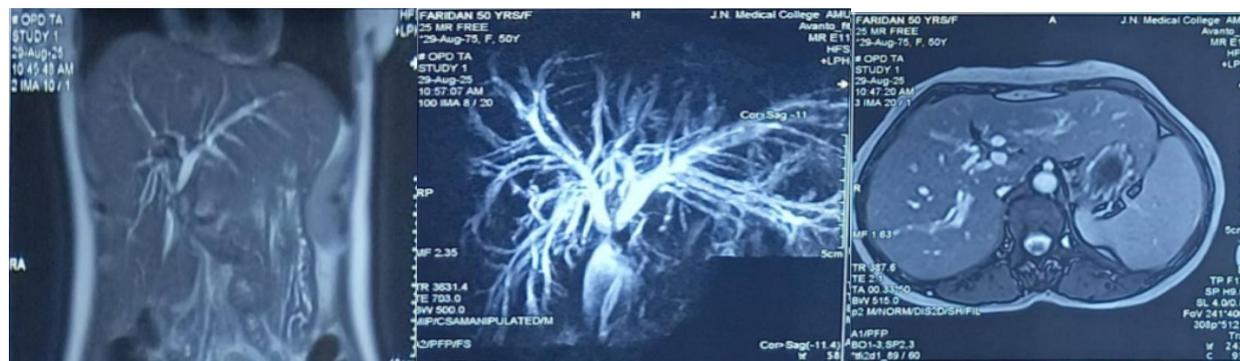
Figure 2. Illustration showing magnetic resonance cholangiopancreatography delineating type E4 biliary structure. **a.** Coronal T2 weighted, **b.** 3d maximum intensity projection, c. Axial T2 weighted.

Management principles

1. Infection Control, limiting inflammation

   - Parenteral antibiotics
   - Percutaneous drainage of periportal fluid collections

2. Clear and thorough delineation of entire biliary anatomy

   - Magnetic resonance cholangiopancreatography within 3–7 days if the patient was stable and bile leak was suspected soon after surgery (within few days); wait 7–10 days with ongoing sepsis, peritonitis. If no ongoing bile leak, injury suspected or missed intraoperatively then done 2–3 weeks of the index surgery [10,11].

   - Percutaneous transhepatic cholangiography (especially when MRCP is inconclusive)

   - Endoscopic retrograde cholangiopancreatography (especially if cystic duct stump leak is suspected).

3. Reestablishment of biliary-enteric continuity

   - Tension-free, mucosa-to-mucosa anastomosis
   - Roux-en-Y hepaticojejunostomy
   - Long-term trans anastomotic stents if bifurcation or higher is involved.

Injury classification

Bile duct injuries will be classified according to the Strasberg Bismuth classification system [10]. This system categorizes bile duct injuries based on their anatomical location relative to the biliary confluence:

1. Type A: Leak from the cystic duct or small ducts in the gallbladder or liver bed.

2. Type B: Occlusion of an aberrant right hepatic duct.

3. Type C: Transection of an aberrant right hepatic duct with leakage.

4. Type D: Injury to the lateral bile duct involving less than 50% of its circumference.

5. Type E: CBD injury with circumference involving more the 50 % of its circumference and strictures in the hepatic ducts, further divided based on the proximal extent (E1, E2, E3, E4, E5).

   - E1 (distal): Injury to CBD ≥2 cm from confluence.
   - E2 (proximal): Injury to CBD <2 cm from confluence.
   - E3: Injury at confluence with intact confluence.
   - E4: Injury at confluence with obliteration of confluence.
   - E5: Type C with concomitant CHD injury.

Intervention according to type of injury [10–12]

Type of Injury	Intervention
Type A	ERCP with sphincterotomy, Hepaticojejunostomy, Conservative
Type B	Surgical (Segmental Drainage, Hepaticojejunostomy)
Type C	Surgical (Segmental Drainage, Hepaticojejunostomy)
Type D	ERCP with sphincterotomy + Stent (if Partial), Hepaticojejunostomy (if major)
Type E	Hepaticojejunostomy

Data collection and analysis

Data were collected prospectively using a structured proforma, which included demographic details, clinical presentation, type and classification of bile duct injury,

treatment modality, and postoperative outcomes. Patients were followed for a period of six months to document complications. Data were entered into Microsoft Excel and analyzed using SPSS software (version 28). Continuous variables were expressed as mean ± standard deviation (SD), while categorical variables were presented as frequencies and percentages. Comparative analysis between categorical variables was performed using the Chi-square test or Fisher's exact test as appropriate, and continuous variables were compared using the student's t-test. A p-value of <0.05 was considered statistically significant.

Results

Patient demographics and pre-operative data

Total of 60 patients with bile duct injury (BDI) following cholecystectomy were included in the study. The mean age of the study population was 38.13 ± 11.96 years. The largest proportion of patients was observed in the 31–40 years age group (22 cases, 36.7%), followed by the 21–30 years group (17 cases, 28.3%). Regarding sex distribution,

females predominated with 42 cases (70.0%), whereas males accounted for 18 cases (30.0%), giving a female-to-male ratio of 2.33:1. The combined age and sex distribution is presented in **Table 1**.

Clinical features

Out of 60 cases pain in abdomen in 49 cases (81.7%) and icterus in 44 cases (73.3%) were the most frequent presenting symptom. Abdominal distension was present in 32 cases (53.3%), fever in 33 cases (55.0%) and significant drain output in 30 cases (50%) respectively as shown in **Table 2**.

Classification of bile duct injury

The most common categories are A and E2, each accounting for 23.3% of the cases, while E4 is the most prevalent classification, representing 25.0% of the total. Categories C and D each have 3.3% respectively, indicating minimal representation. E1 and E3 include 8.3% and 11.7% of the cases, respectively, and E5 has the smallest proportion at 1.7%. Class B had no patient as depicted in **Table 3**.

Table 1. Demographic profile of patients: (mean age ± sd: 38.13 ± 11.96 years).

Age Group (years)	Male (n=18, 30%)	Female (n=42, 70%)	p-value
≤ 20	1 (1.7%)	0 (0%)	0.300
21–30	6 (10.0%)	11 (18.3%)	0.755
31–40	5 (8.3%)	17 (28.3%)	0.396
41–50	3 (5.0%)	5 (8.3%)	0.686
51–60	2 (3.3%)	7 (11.7%)	0.710
61–70	1 (1.7%)	2 (3.3%)	1.00

Table 2. Clinical manifestation of postoperative bile duct injury.

S. No	Primary Clinical Feature	Cases (n=60)	P value
1	Pain in Abdomen	49 (81.7%)	<0.001
2	Abdominal Distension	32 (53.3%	<0.001
3	Icterus	44 (73.3%)	<0.001
4	Drain output	30 (50.0%)	<0.001
5	Fever	33 (55.0%)	<0.001

Table 3. Distribution of cases as per Strasberg Bismuth classification system.

S. No.	Classification	Cases (n=60)	p-value
1	A	14 (23.3%)	0.017
2	C	2 (3.3%)	0.029
3	D	2 (3.3%)	0.029
4	E1	5 (8.3%)	0.434
5	E2	14 (23.3%)	0.017
6	E3	7 (11.7%)	1.0
7	E4	15 (25.0%)	0.009
8	E5	1 (1.7%)	0.005

Distribution of interventions

Various interventions were carried out in the study population. Most patients (45 cases, 75%) underwent hepaticojejunostomy. ERCP with sphincterotomy was performed in 10 cases (16.7%) with failed ERCP in 2 patients (3.3%) and 5 cases (8.33%) were managed conservatively as mentioned in **Table 4**.

Table 4. Distribution of cases based on intervention.

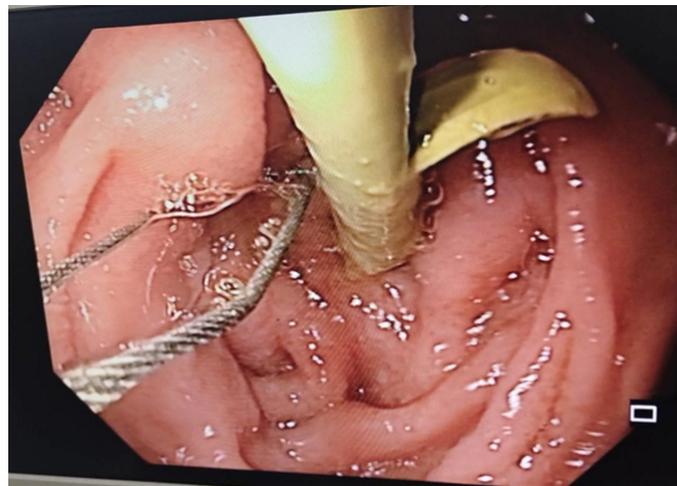| S. No.	Intervention	Cases (n=60)	p-value
1	Hepaticojejunostomy	45 (75.0%)	<0.001
2	ERCP with Sphincterotomy	10 (16.7%)	0.006
3	Conservative Management	5 (8.3%)	<0.001

Figure 3. Illustration showing endoscopic retrograde cholangiopancreatography with common bile duct stent *in-situ*.
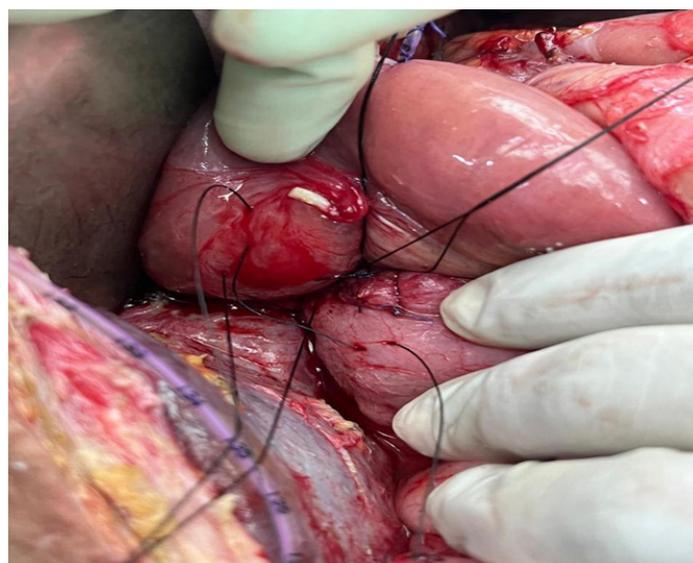

Figure 4. Illustration showing Roux-en y Hepatico-Jejunostomy with stay sutures using silk-2-0 round body.

Figure 5. Illustration showing Roux-en y Hepatico-Jejunostomy anastomosis done using Vicryl 3-0 round body.

Distribution of interventions based on BDI classification

The most common intervention was hepaticojejunostomy, performed in 75.0% of cases, predominantly for class E4 (25.0%), E2 (23.3%) and E3 (11.7%). ERCP with sphincterotomy was used in 16.7% of cases, mainly for class C (11.7%). Conservative management was employed in 8.3% of cases, with the majority in classification A (8.3%) as shown in **Table 5**.

Temporal distribution of cases on the basis of time of injury and time of intervention

In our study majority intervention occurred after 6 weeks in 58% (32 cases) between 2–6 weeks in 38% (21 cases) and within 2 weeks in 4% (2 cases) (**Table 6**).

Follow up and outcomes (**Table 7**)

TLC count

Leucocyte count decreased significantly following intervention from 11,575.25 ± 5,374.88 to 8,963.28 ± 2,819.43 cells/μL (t=3.853, p<0.001).

Total bilirubin

Total bilirubin (TB) levels decreased significantly after intervention from 5.22 ± 6.50 mg/dL, to 2.17 ± 1.93 mg/dl. (t=4.164, p-value <0.001).

Table 5. Distribution of interventions based on BDI classification.

Classification	Hepaticojejunostomy	ERCP with Sphincterotomy	Conservative Management	Total	p-value	Fisher Exact p value
	Cases (n=45)	Cases (n=10)	Cases (n=5)	Cases (n=60)		
A	2 (3.3%)	7 (11.7%)	5 (8.3%)	14 (23.3%)	<0.001	<0.001
C	1 (1.7%)	1 (1.7%)	0 (0.0%)	2 (3.3%)	0.422	0.441
D	0 (0.0%)	2 (3.3%)	0 (0.0%)	2 (3.3%)	0.006	0.059
E1	5 (8.3%)	0 (0.0%)	0 (0.0%)	5 (8.3%)	0.403	0.318
E2	14 (23.3%)	0 (0.0%)	0 (0.0%)	14 (23.3%)	0.048	0.013
E3	7 (11.7%)	0 (0.0%)	0 (0.0%)	7 (1.7%)	-	-
E4	15 (25.0%)	0 (0.0%)	0 (0.0%)	15 (25.0%)	-	-
E5	1 (1.7%)	0 (0.0%)	0 (0.0%)	1 (1.7%)	-	-

Table 6. Temporal relationship between time of injury and intervention.

S. No.	Duration From Injury (weeks)	No. of Cases (n=55)	(%)	p-value
1	<2 weeks	2	3.6%	<0.001
2	2–6 weeks	21	38.0%	0.475
3	>6 weeks	32	58.0%	<0.001

Table 7. Follow up parameters pre and post intervention.

Parameter	Pre-intervention (Mean ± SD)	Post-intervention (Mean ± SD)	t-value	p-value	Interpretation
TLC (cells/µL)	11,575.25 ± 5,374.88	8,963.28 ± 2,819.43	3.853	< 0.001	Significant reduction
Total Bilirubin (mg/dL)	5.22 ± 6.50	2.17 ± 1.93	4.164	< 0.001	Significant reduction
Total Bilirubin (with icterus)	6.72 ± 6.70	2.55 ± 2.10	—	0.002 / 0.013*	Significant reduction
Direct Bilirubin (mg/dL)	4.42 ± 5.97	1.66 ± 1.42	3.796	< 0.001	Significant reduction
Direct Bilirubin (with icterus)	5.83 ± 6.24	1.99 ± 1.50	3.180	0.002	Significant reduction
Alkaline Phosphatase (U/L)	486.72 ± 502.32	332.62 ± 285.43	2.349	0.023	Significant reduction
ALP (with icterus)	530.68 ± 534.51	350.05 ± 297.80	—	—	Significant reduction
ALP (without icterus)	357.50 ± 320.26	279.00 ± 246.34	—	—	Reduction (non-significant trend)

Total bilirubin levels in patients with icterus

Total bilirubin (TB) levels significantly decreased in patients with icterus, from 6.72 ± 6.70 mg/dL to 2.55 ± 2.10 mg/dL (p-value =0.002 pre, 0.013 post).

Direct bilirubin

The mean DB level before the intervention was 4.42 ± 5.97 mg/dL, which decreased significantly to 1.66 ± 1.42 mg/dL post-intervention (t= 3.796, p=0.001).

Direct bilirubin levels in patients with icterus

For patients with icterus, the mean DB level significantly decreased from 5.83 ± 6.24 mg/dL before intervention to 1.99 ± 1.50 mg/dL after intervention. (t= 3.180 and a p<0.002).

Alkaline phosphatase (ALP)

The mean ALP level before the intervention was 486.72 ± 502.32 U/L, which decreased to 332.62 ± 285.43 U/L. (t= 2.349, p< 0.023).

Alkaline phosphatase (alp) in patients with icterus

For patients with icterus, the pre-intervention ALP mean was 530.68 ± 534.51, which decreased to 350.05 ± 297.80. In contrast, patients without icterus had a pre intervention ALP mean of 357.50 ± 320.26, reducing to 279.00 ± 246.34.

Outcome according to Strasberg-Bismuth classification

Our study revealed significant variation in outcomes across different classifications. The majority of patients classified as A (23.3%) and E2 (23.3%) showed improvement, with no mortality reported in these groups. Classifications C, D, and E1 had limited cases, with only one mortality in E5 and no other outcomes reported. The E4 classification had a considerable number of patients improving (18.3%) but also reported three mortalities (5.0%) (**Table 8**).

Overall outcome

Table 9 presents the outcomes for the study population, with 93.3% of cases showing improvement. Only 5% of cases required referral to a higher center, while 6.7% resulted in mortality.

Table 8. Classification wise outcome distributions.

Classification	Improved (n=56)	Mortality (n=4)	P-value
A	14 (23.3%)	0 (0.0%)	0.564
C	2 (3.3%)	0 (0.0%)	1.0
D	2 (3.3%)	0 (0.0%)	1.0
E1	5 (8.3%)	0 (0.0%)	1.0
E2	14 (23.3%)	0 (0.0%)	0.564
E3	7 (11.7%)	0 (0.0%)	1.0
E4	12 (20.0%)	3 (5.0%)	0.044
E5	0 (0.0%)	1 (1.7%)	0.066

Table 9. Overall outcome.

S. No.	Outcome	No. of Cases	p-value
1	Improved	56 (93.33%)	<0.001
2	Mortality	4 (6.66%)	<0.001

Table 10. Probable causes of mortality in patients undergoing biliary reconstruction (n = 4).

Case No.	Age / Sex	Strasberg–Bismuth Classification	Timing of Repair (post-injury)	Preoperative Findings	Type of Intervention	Postoperative Course / Complications	Probable Cause of Mortality
1	45 /F	E4	Late (>6 weeks)	Obstructive jaundice, cholangitis	Hepaticojejunostomy	Persistent bile leak, sepsis, multiorgan failure	Postoperative sepsis due to anastomotic leak
2	52 /M	E5	Early (<2 weeks)	Bile peritonitis, high bilirubin	Hepaticojejunostomy + stenting	Uncontrolled infection, septic shock	Repair performed during sepsis leading to septic shock
3	60 /F	E4	Delayed (3–4 weeks)	Elevated bilirubin, hepatic dysfunction	Hepaticojejunostomy	Post-op bleeding, transfusion, hepatic failure	Liver failure secondary to prolonged cholestasis
4	40 /M	E4	Late (>6 weeks)	No sepsis, previous ERCP attempt	Revision Hepaticojejunostomy	Bile leak, secondary peritonitis	Anastomotic leak with bile peritonitis

Table 11. Postoperative outcomes and complications following repair of bile duct injuries (n = 60) up to 6 months.

Outcome / Complication	No. of Patients (n)	Percentage (%)	Remarks / Clinical Course
Improved Outcome	56	93.3%	Uneventful recovery with progressive normalization of liver function tests and resolution of jaundice.
Bile Leak / External Fistula	5	8.3%	Minor controlled bile leak through drain in 3 cases; 2 required re-exploration. All resolved with conservative management except one mortality due to sepsis.
Cholangitis	6	10.0%	Managed conservatively with IV antibiotics and biliary drainage; no residual stricture at 6 months.
Stricture / Anastomotic Stenosis	4	6.7%	Diagnosed on imaging during follow-up (MRCP/ERCP); 2 managed with balloon dilatation, 2 required re-operation.
Biliary Peritonitis	3	5.0%	Following anastomotic leak; all required re-exploration; contributed to 2 mortalities.
Wound Infection / Superficial SSI	7	11.7%	Responded to local care and antibiotics; no long-term sequelae.
Intra-abdominal Abscess	2	3.3%	Managed by percutaneous drainage under USG guidance.
Mortality	4	6.7%	Causes included sepsis due to bile leak (n = 2), hepatic failure (n = 1), and biliary peritonitis (n = 1).
Total Patients Followed Up	60	100.0%	Minimum follow-up: 6 months. No recurrence or late stricture in remaining cases.

Discussion

In our study overall improvement was observed in 93% of cases, underscoring the effectiveness of current surgical strategies with 6.7% mortality rate. Our observations contribute to understanding intervention efficacy and emerging trends in the management of bile duct injuries.

Age distribution

In our study the mean age of study population was 38.13 years. The majority of cases, 22 cases (36.7%) were in the 31–40 years range, followed by 17 (28.3%) cases in the 21–30 years range. Our findings are in concordance with the study conducted by Zidan *et al.* [13] which showed mean age 37.97

years. Similarly to our study, Çavuşoğlu *et al.* [14], study showed mean age of bile duct injury patients to be 51.1 years. Ma *et al.* [15] in their study also showed similar age predilection with mean age of 49.9 years.

Sex distribution

The sex distribution in our study reveals that 42 (70%) out of 60 cases were females and 18 (30%) were males with female to male ratio 2.33:1. Study conducted by Ray *et al.* [16] showed similar results with 179 (78.5%) patients out of 261 being females and (21.5%) 49 patients being males. Jain *et al.* [17] conducted systemic review whose results are in concordance with our study—it showed 94 (73.4%) patients out of 128 patients were females and 34 (26.6%) were males. Geers [18] showed that 13 (61.9%) out of 21 patients of bile duct injury were females and 8 patients (38%) were males. These findings are also similar to our results.

Clinical features

In our study, 49 (81.7%) patients out of 60 had abdominal pain as the most prevalent symptom, icterus was present in 44 (73.3%) patients and fever in 33 (55%) cases. Abdominal distension was present in 32 (53.3%) patients while bile leak was present in 30 (50%) patients. Carannante [19] showed patients of bile duct injury presented with similar clinical features, pain in abdomen was present in 81 (93.1%) out of 87 cases, fever was present in 65 (74.7%) and jaundice was present in 59 (67.8%) participants. Bile leak was present in 75 patients (92%) out of 81 patients. Pandit *et al.* [20] showed jaundice was present in 5 patients (29.4%) out of 18 patients of BDIs. Ahmad *et al.* [21] showed out of 32 patients of BDIs, 20 patients (64%) had jaundice, 19 patients (59%) had bile leak, 24 patients (75%) had abdominal pain, 15 patients (47%) had fever, and 14 patients (45%) had abdominal distension. Similar trends were observed in our study.

PTC procedure outcome

Percutaneous Transhepatic Cholangiography (PTC) was performed in 2 patients out of 60 patients (3.3%). This reflects the general trend in literature, where PTC is often reserved for more complex or challenging cases that are not amenable to ERCP. Stilling *et al.* [22] suggests that PTC is typically used as a secondary option, particularly in cases where ERCP is not feasible or has failed. In their study 6.04% of patients underwent PTC. Our limited use of PTC aligns with the experiences from Pottakkat *et al.* [23] where PTC was used in specific clinical scenarios, often involving more intricate or high-risk procedures. They observed that 5.2% underwent PTC. This low usage rate suggests that PTC is primarily a fallback option, utilized when other less invasive methods are insufficient. The preference for less invasive techniques, such

as ERCP, is likely due to their lower complication rates and the ability to manage a wider range of BDI-related issues without the need for more invasive procedures.

Per-operative cholangiogram

Per operative cholangiogram was performed in 5 (8.3%) patients out of 60 in our study. This selective application is consistent with recommendations by Pesce *et al.* [24] and Giger *et al.* [25] who discussed the tailored use of intraoperative imaging techniques based on the specific type and severity of the bile duct injury. In their study, 8% of patients also underwent per operative cholangiogram. The infrequent use of per operative cholangiogram also reflects a broader trend in surgical practice, that it was performed when there was difficulty in delineating anatomy per operatively at the time of bile duct injury repair.

Bile duct injury classification

In our study we utilized the Strasberg classification system to categorize bile duct injuries, reveals most common class was type E4, it was observed in 15 (25.0%) patients out of 60. Type A and type E2 were second most common classes, each having 14 (23.3%) patients. Class E3 has 7 (11.7%) patients, Class E1 has 5 (8.3%) patients, and Class C and D have two patients each (3.3% in each class). Class E5 has 1 (1.7%) patient. There was no case of class B reported in our study. In the study by Pandit *et al.* (2020) [20], type A injury was present in 9 (50%) out of 18 patients, type D was present in 1 (5.5%), type E1 injury was present in 5 patients (27.8%), type E2 injury was present in 1 (5.5%) and 2 (11.1%) patients showed type E3 injuries. Similarly, Malla *et al.* [26] showed that out of 35 cases of BDIs, type A injuries were present in 27 cases (77.14%), type E1 in 3 cases (8.57%), type E2 injuries in 3 cases (8.57%) and type E3 was present in 2 cases (5.71%). Ray *et al.* [16] showed that out of 228 patients, type E1 injuries were present in 13 patients (5.7%), type E2 injury were present in 68 patients (29.82%), type E3 injuries were present in 108 patients (47.36%), type E4 injuries were present in 28 patients (12.28%) and type E5 injuries were present in 11 patients (4.82%). This pattern parallels findings of our study except for higher incidence of E4 injuries in our study. This may be because of the fact that our institute is a tertiary referral center so the patients of Type A injury may have been managed at primary or secondary level but only more complex injuries like E4 are being referred.

Intervention

Hepaticojejunostomy

In our study, 45 patients out of 60 patients (75%) underwent hepaticojejunostomy. Zidan *et al.* [13] showed 17 (48.6%) out 35 BDIs patients underwent hepaticojejunostomy. Çavuşoğlu

et al. [14] showed that 27 (32.6%) out of 83 patients of BDIs underwent hepaticojejunostomy. Vu *et al.* [27] showed that hepaticojejunostomy was performed in 12 (42.9%) out of 28 patients of BDIs. This predominance likely reflects referral bias, as complex E4 injuries are typically managed in tertiary centers.

ERCP with sphincterotomy

In our study, ERCP with sphincterotomy was performed in 10 (16.6%) cases out of 60 patients. ERCP failed in 2 patients (3.3%). This corroborates with the findings of the study done by Vu *et al.* [27] that showed ERCP with stenting was done in 6 patients (21.4%) out of 28 patients.

Conservative management

Five (8.3%) patients out of 60 patients were managed conservatively. Vu *et al.* [27] showed similar results where conservative management was done in two patients (7.1%) out of 28 patients. Carannante *et al.* [19] also showed that 19 (10.5%) out of 180 patients of BDIs were managed conservatively. These findings are consistent with our study.

Outcomes

Our study demonstrated an overall improvement rate of 93%, reflecting the effectiveness of current surgical management strategies, while the observed mortality rate was 6.7%. This aligns with findings from Schmidt *et al.* [28] who reported high success rates for hepaticojejunostomy. However, the mortality rate highlights challenges and potential complications associated with severe bile duct injuries. Our study's outcomes are consistent with Barrett *et al.* [29] who reported varying morbidity rates but reflected on the overall effectiveness of interventions. The mortality rate in our study reflects the inherent difficulties in managing severe cases.

Follow-up assessments

Postoperative morbidity primarily involved wound infection (~12%), cholangitis (10%) and controlled bile leak (8%). Biliary strictures developed in 4 patients (6.7%) during follow-up, two of whom underwent successful balloon dilatation, and two required surgical revision. Intra-abdominal abscesses occurred in 3.3% of cases and were managed by USG guided drainage. These percentages in our study correspond with previously reported ranges by de Reuver *et al.* [11], Schreuder *et al.* [30] and Ahmad *et al.* [31]. The resolution of symptoms underscores the success of the treatment strategies employed, consistent with the follow-up outcomes reported by Pottakkat *et al.* [21], which emphasized the importance of ongoing assessment, meticulous surgical reconstruction, infection control, and structured follow-up are crucial in improving long-term outcomes and minimizing late biliary complications in patients undergoing repair of bile duct injuries.

Conclusion

This study identified key trends across demographic, clinical, and procedural outcomes among patients with bile-duct injury: 1. Majority of patients were females with Female to male ratio was 2.33:1. 2. Abdominal pain was the most predominant presenting complaint 49 (81.7%). 3. Most common type of bile duct injury was Strasberg class E4 in 15 (25%) cases. 4. Hepaticojejunostomy done in 45 (75%) cases was the most common intervention, leading to an overall improvement in the majority of cases. 5. Mortality was limited to 4 patients (6.7%) out of 60 cases. 6. During follow up, symptoms like pain, distension and jaundice are resolved, indicating effectiveness of the interventions. 7. Follow-up data highlights the continued resolution and improved overall outcome thus affirming the overall success and safety of the interventions. Future studies should focus on multicenter prospective data, optimal timing of repair, evaluation of standardized and minimally invasive management strategies, and long-term follow-up assessing late biliary complications and quality-of-life outcomes.

Strengths and Limitations

This prospective dual-center study reduces recall bias and reflects real-world referral patterns of complex bile duct injuries. Use of standardized Strasberg–Bismuth classification, structured multidisciplinary management, objective biochemical outcome measures, and complete six-month follow-up strengthen clinical validity. However, the small sample size and tertiary-care setting introduce referral bias and limit generalizability. The short follow-up may not capture late biliary complications, and the absence of a comparative control group restricts inference regarding optimal timing and technique of repair.

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