

Indocyanine Green (ICG) Fluorescence Cholangiography Versus Conventional Methods in Preventing Bile Duct Injury During Difficult Laparoscopic Cholecystectomy: A Retrospective Study

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Abstract:

Background: Bile duct injury (BDI) is one of the most serious complications of laparoscopic cholecystectomy, especially in difficult cases. Indocyanine Green (ICG) fluorescence cholangiography has emerged as a real-time intraoperative imaging modality that may improve biliary anatomy visualization and reduce the risk of injury.

Objective: To compare the effectiveness of ICG fluorescence cholangiography with conventional identification methods in preventing bile duct injury during difficult laparoscopic cholecystectomy.

Methods: This retrospective study was conducted at Lucknow Career Institute of Medical Sciences and Research from March 2022 to March 2025 and included 150 patients undergoing difficult laparoscopic cholecystectomy. Patients were divided into two groups: ICG fluorescence cholangiography group (n=75) and conventional technique group (n=75). Outcomes assessed included bile duct injury, operative time, conversion to open surgery, intraoperative complications, and length of hospital stay.

Results: The incidence of bile duct injury was significantly lower in the ICG group (1.3%) compared to the conventional group (8.0%) (p=0.042). Mean operative time was shorter in the ICG group (78.4 ± 14.6 minutes) versus conventional group (92.7 ± 16.2 minutes) (p<0.001). Conversion to open surgery occurred in 5.3% of ICG cases versus 13.3% in conventional group (p=0.048). Postoperative hospital stay was significantly reduced in the ICG group (3.1 ± 1.2 days vs 4.6 ± 1.5 days; p<0.001).

Conclusion: ICG fluorescence cholangiography significantly reduces bile duct injury, operative time, and conversion rates in difficult laparoscopic cholecystectomy. It is a valuable adjunct for improving surgical safety.

Keywords: ICG fluorescence, bile duct injury, laparoscopic cholecystectomy, fluorescence cholangiography, difficult gallbladder

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Introduction

Laparoscopic cholecystectomy is the gold standard treatment for symptomatic gallstone disease; however, bile duct injury (BDI) remains a serious complication with significant morbidity (1). The incidence of BDI is higher in difficult cases characterized by inflammation, adhesions, or distorted anatomy (2).

Accurate identification of biliary anatomy is critical to prevent iatrogenic injury (3). Conventional methods rely on visual identification and critical view of safety, which may be challenging in difficult gallbladders (4). Misidentification of structures remains the primary cause of bile duct injury (5).

Intraoperative cholangiography (IOC) has traditionally been used to delineate biliary anatomy, but it is time-consuming and involves radiation exposure (6). Recently, indocyanine green (ICG) fluorescence cholangiography has emerged as a non-radiative, real-time imaging modality for visualization of the biliary tree (7).

ICG is a water-soluble dye that binds to plasma proteins and is excreted exclusively through bile, allowing visualization of biliary structures under near-infrared imaging (8). Studies have demonstrated improved visualization of cystic duct, common bile duct, and hepatic ducts using ICG (9).

ICG fluorescence is particularly useful in difficult laparoscopic cholecystectomy where inflammation obscures anatomy (10). Several studies have reported reduced bile duct injury rates with ICG use (11). It also helps in achieving the critical view of safety more efficiently (12).

Additionally, ICG reduces operative time and conversion rates to open surgery (13). It provides dynamic imaging without the need for duct cannulation (14). The technique is safe with minimal adverse reactions (15).

Despite increasing evidence, comparative data between ICG and conventional methods in difficult cases remain limited (16). Therefore, the present study was conducted to evaluate the role of ICG fluorescence cholangiography in preventing bile duct injury during difficult laparoscopic cholecystectomy.

Materials and Methods

Study Design and Setting

This was a **retrospective comparative observational study** conducted in the Department of General Surgery at Lucknow Career Institute of Medical Sciences and Research. The study evaluated the effectiveness of indocyanine green (ICG) fluorescence cholangiography compared with conventional anatomical identification techniques in patients undergoing difficult laparoscopic cholecystectomy.

Study Duration

All eligible cases performed between **March 2022 and March 2025** were included in the study.

Study Population and Sample Size

A total of **150 patients** who underwent difficult laparoscopic cholecystectomy during the study period were included.

Patients were divided into two equal groups:

- **Group A (ICG fluorescence cholangiography group)** – 75 patients
- **Group B (Conventional technique group)** – 75 patients

The allocation was based on the intraoperative technique used during surgery as documented in operative records.

Definition of Difficult Laparoscopic Cholecystectomy

Cases were classified as difficult based on intraoperative findings consistent with established operative difficulty criteria (dense

adhesions in Calot's triangle, contracted or fibrotic gallbladder, acute inflammation, distorted biliary anatomy, or requirement of prolonged dissection time), in line with previously described grading systems for difficult cholecystectomy.

Inclusion Criteria

- Age ≥ 18 years
- Patients undergoing **laparoscopic cholecystectomy for difficult gallbladder disease**
- Patients with acute or chronic cholecystitis with adhesions
- Complete operative and postoperative records available

Exclusion Criteria

- History of previous biliary surgery
- Presence of confirmed common bile duct (CBD) stones
- Known allergy to indocyanine green
- Severe hepatic dysfunction or liver failure
- Incomplete clinical or operative data

Preoperative Assessment

All patients underwent:

- Detailed clinical evaluation
- Routine hematological and biochemical investigations
- Ultrasonography of the hepatobiliary system

Baseline demographic and clinical characteristics such as **age, sex, and presence of acute cholecystitis** were recorded to ensure comparability between study groups.

ICG Fluorescence Cholangiography Technique

In Group A, **indocyanine green dye** was administered intravenously at a dose of **0.25 mg/kg body weight**, approximately **45 minutes prior to surgery**.

During surgery:

- A **near-infrared (NIR) fluorescence imaging system** was used

- Biliary structures including **cystic duct, common bile duct, and common hepatic duct** were visualized in real time
- Fluorescence imaging was used to assist in achieving the **critical view of safety (CVS)** before clipping and division of structures

Conventional Technique

In Group B, the biliary anatomy was identified using **standard white-light laparoscopic visualization** with conventional dissection and achievement of the **critical view of safety** without fluorescence guidance.

Surgical Procedure

All surgeries were performed using standard **four-port laparoscopic cholecystectomy technique** under general anesthesia by experienced consultant surgeons.

The following operative details were recorded:

- Total operative time (from skin incision to closure)
- Identification of biliary structures
- Occurrence of intraoperative complications
- Need for conversion to open surgery

Outcome Measures

Primary Outcome

- **Incidence of bile duct injury (BDI)**, defined as any iatrogenic injury to the extrahepatic biliary tree identified intraoperatively or in the postoperative period

Secondary Outcomes

- Operative time (minutes)
- Conversion to open cholecystectomy
- Postoperative complications:
 - Bile leak
 - Surgical site infection
- Length of postoperative hospital stay (days)

Data Collection

Data were extracted from:

- Operation theatre registers
- Patient case files
- Discharge summaries
- Histopathology and postoperative follow-up records

All data were anonymized prior to analysis.

Statistical Analysis

All collected data were entered into Microsoft Excel and subsequently analyzed using **IBM SPSS Statistics version 25.0** (IBM Corp., Armonk, NY, USA). Continuous variables such as age, operative time, and duration of hospital stay were summarized as mean \pm standard deviation, whereas categorical variables including bile duct injury, conversion rate, and postoperative complications were expressed as frequencies and percentages. Comparative analysis between the two study groups was performed using the **Student's independent t-test** for continuous variables and the **Chi-square (χ^2) test** for categorical variables. A p-value of less than 0.05 was considered statistically significant, while a p-value of less than 0.001 was regarded as highly significant.

Ethical Considerations

Prior to commencement of the study, approval was obtained from the Institutional Ethics Committee of Lucknow Career Institute of Medical Sciences and

Research. All patient data were handled with strict confidentiality, and only anonymized records were used for analysis. As the study was retrospective in nature and involved review of existing clinical records without direct patient interaction, the requirement for individual informed consent was waived by the ethics committee.

Results

A total of **150 patients** undergoing difficult laparoscopic cholecystectomy were included in this study, with **75 patients in the ICG fluorescence cholangiography group (Group A)** and **75 patients in the conventional technique group (Group B)**.

1. Baseline Characteristics

The demographic and clinical characteristics of both groups were comparable with **no statistically significant differences**, ensuring homogeneity of the study population.

The **mean age** in the ICG group was **45.2 \pm 12.1 years**, compared to **46.8 \pm 11.5 years** in the conventional group ($p = 0.42$). Male patients constituted **42.6%** of the ICG group and **40%** of the conventional group ($p = 0.76$). The proportion of patients with **acute cholecystitis** was **37.3% in the ICG group** and **40% in the conventional group** ($p = 0.71$).

These findings confirm that both groups were statistically comparable at baseline (**Table 1**).

Table 1: Baseline Characteristics of Study Population

Parameter	ICG Group (n=75)	Conventional Group (n=75)	p-value
Age (years) mean \pm SD	45.2 \pm 12.1	46.8 \pm 11.5	0.42
Male gender	32 (42.6%)	30 (40.0%)	0.76
Acute cholecystitis	28 (37.3%)	30 (40.0%)	0.71

2. Intraoperative Outcomes

Bile Duct Injury

The **primary outcome**, bile duct injury (BDI), occurred in **only 1 patient (1.3%)** in

the ICG group compared to **6 patients (8.0%)** in the conventional group.

This difference was **statistically significant** ($\chi^2 = 4.12$, $p = 0.042$),

indicating a substantial reduction in BDI with the use of ICG fluorescence cholangiography (Table 2, Figure 1).

Operative Time

The mean operative time was significantly shorter in the ICG group (**78.4 ± 14.6 minutes**) compared to the conventional group (**92.7 ± 16.2 minutes**).

The difference of **14.3 minutes** was highly significant (**t = 5.65, p < 0.001**), suggesting

improved surgical efficiency with ICG guidance (Table 2, Figure 2).

Conversion to Open Surgery

Conversion to open cholecystectomy was required in **4 patients (5.3%)** in the ICG group compared to **10 patients (13.3%)** in the conventional group.

This reduction was **statistically significant** ($\chi^2 = 3.92, p = 0.048$), indicating that ICG use significantly decreased conversion rates (Table 2, Figure 3).

Table 2: Intraoperative Outcomes

Outcome	ICG Group (n=75)	Conventional Group (n=75)	p-value
Bile duct injury	1 (1.3%)	6 (8.0%)	0.042*
Operative time (minutes)	78.4 ± 14.6	92.7 ± 16.2	<0.001**
Conversion to open surgery	4 (5.3%)	10 (13.3%)	0.048*

*p < 0.05 considered statistically significant; **p < 0.001 considered highly significant.

3. Postoperative Outcomes

Length of Hospital Stay

The mean postoperative hospital stay was significantly shorter in the ICG group (**3.1 ± 1.2 days**) compared to the conventional group (**4.6 ± 1.5 days**).

The difference of **1.5 days** was highly significant (**t = 6.78, p < 0.001**), demonstrating faster recovery in the ICG group (Table 3, Figure 4).

Postoperative Complications

Postoperative complications were lower in the ICG group, although not all reached statistical significance:

- **Wound infection:** ICG: 2 patients (2.6%)
Conventional: 5 patients (6.6%) (p = 0.21)
- **Bile leak:** ICG: 1 patient (1.3%)
Conventional: 4 patients (5.3%) (p = 0.17)

Although these differences were not statistically significant, the trend favored the ICG group (Table 3).

Table 3: Postoperative Outcomes

Outcome	ICG Group (n=75)	Conventional Group (n=75)	p-value
Hospital stays (days)	3.1 ± 1.2	4.6 ± 1.5	<0.001**
Wound infection	2 (2.6%)	5 (6.6%)	0.21
Bile leak	1 (1.3%)	4 (5.3%)	0.17

**p < 0.001 considered highly significant.

Figures

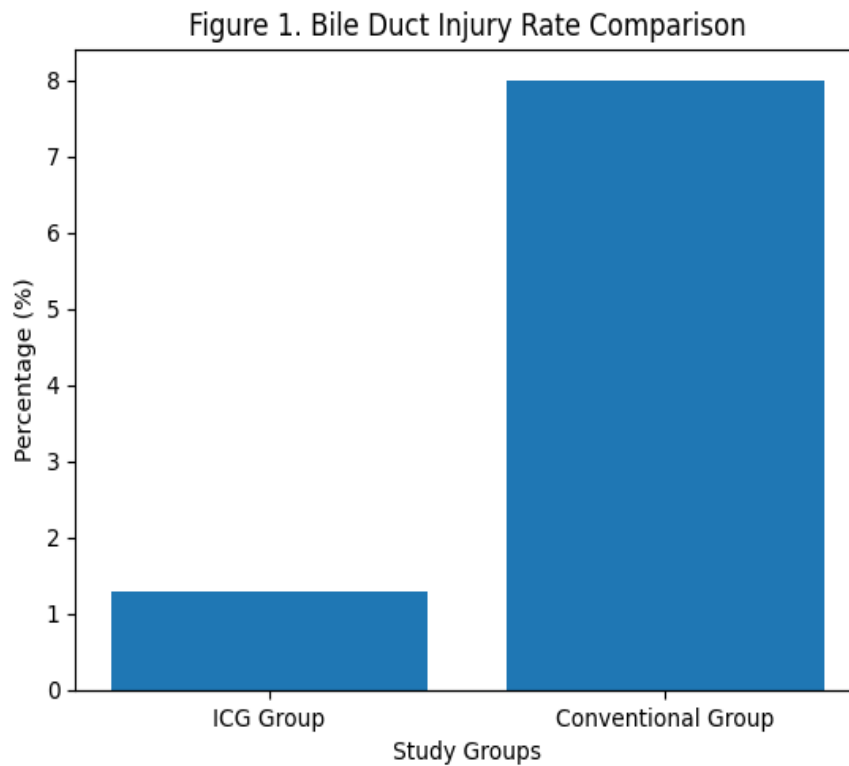


Figure 1: Comparison of bile duct injury rates between ICG fluorescence cholangiography and conventional groups.

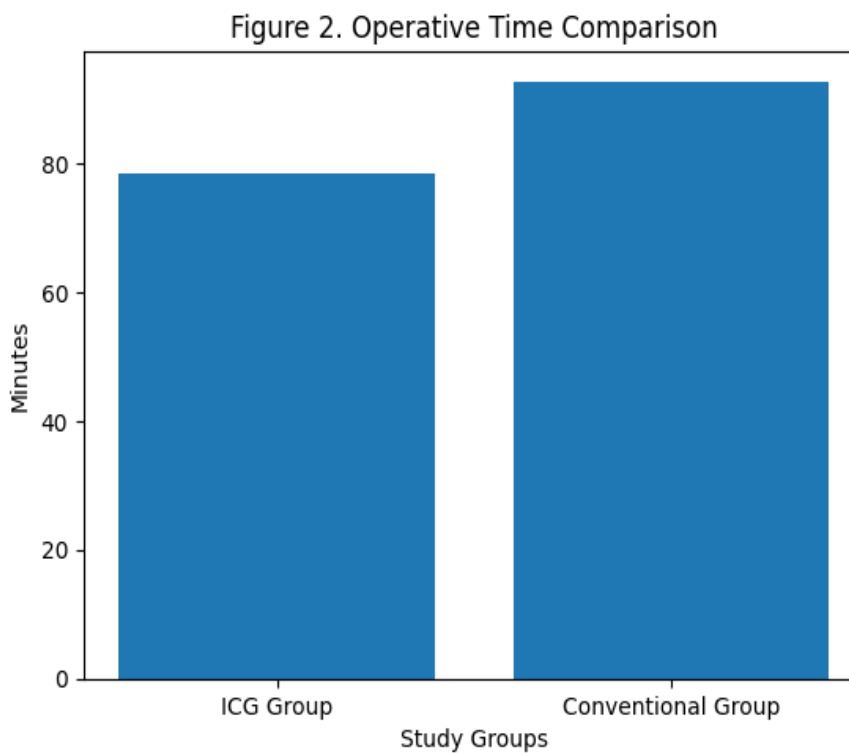


Figure 2: Comparison of operative time between ICG and conventional technique groups.

Figure 3. Conversion to Open Surgery

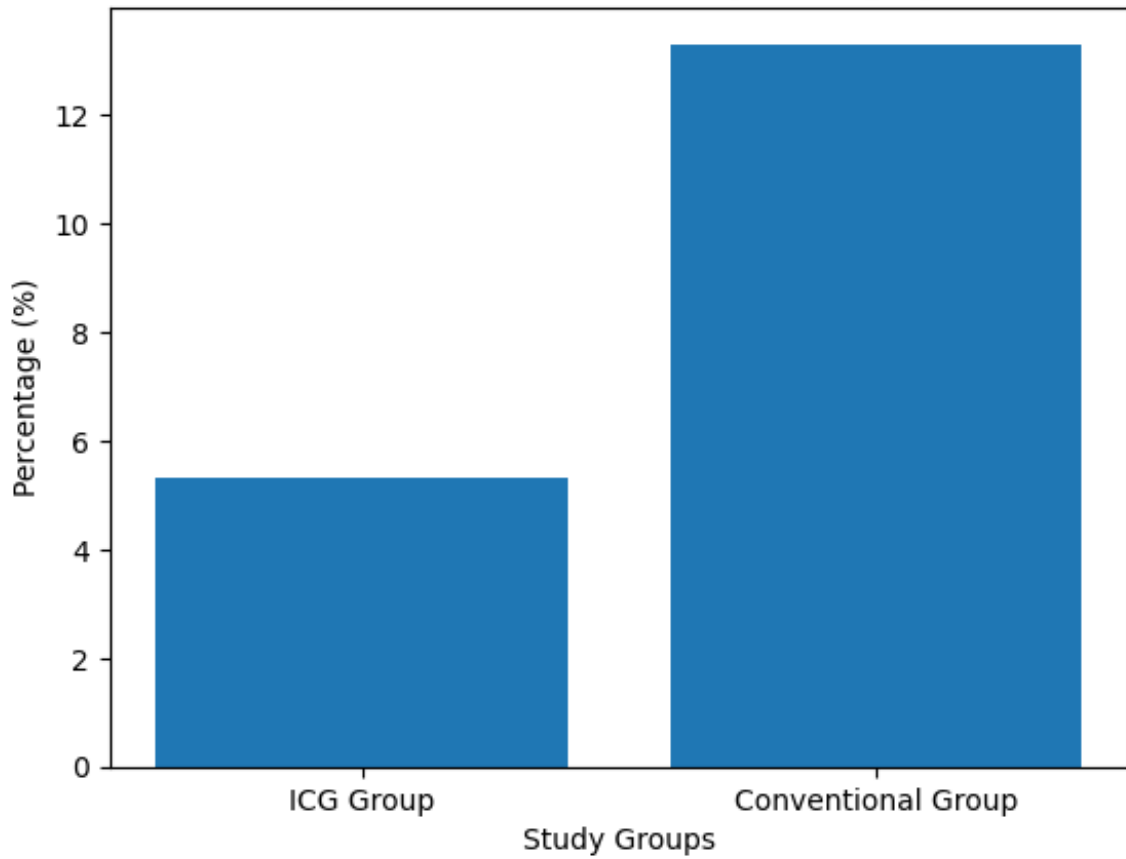


Figure 3: Comparison of conversion to open surgery between study groups.

Figure 4. Hospital Stay Comparison

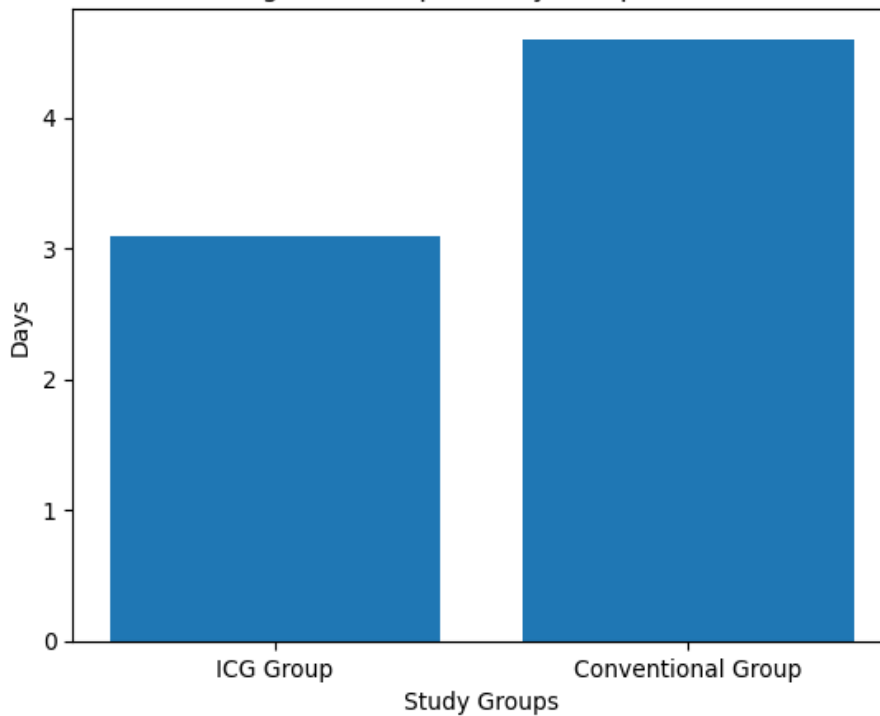


Figure 4: Comparison of postoperative hospital stay between ICG and conventional groups.

Summary of Key Findings

The present study demonstrates that the use of indocyanine green (ICG) fluorescence cholangiography significantly improves surgical outcomes in patients undergoing difficult laparoscopic cholecystectomy. The incidence of bile duct injury was markedly lower in the ICG group compared to the conventional group (1.3% vs 8.0%). In addition, the mean operative time was significantly shorter in the ICG group (78.4 minutes) than in the conventional technique group (92.7 minutes), indicating improved intraoperative efficiency. The need for conversion to open surgery was also reduced in patients undergoing ICG-guided procedures (5.3% vs 13.3%). Furthermore, patients in the ICG group had a shorter postoperative hospital stay (3.1 days vs 4.6 days), reflecting faster recovery. Although not statistically significant, postoperative complication rates, including wound infection and bile leak, were consistently lower in the ICG group. Overall, these findings highlight the clinical benefit of ICG fluorescence cholangiography in enhancing safety and improving perioperative outcomes in difficult laparoscopic cholecystectomy.

Discussion

Bile duct injury remains a significant complication of laparoscopic cholecystectomy, particularly in difficult cases (17). The present study demonstrated that ICG fluorescence cholangiography significantly reduces bile duct injury rates compared to conventional methods.

The observed BDI rate of 1.3% in the ICG group aligns with previous studies reporting reduced injury rates with fluorescence imaging (18). Conventional identification methods are prone to misidentification errors (19).

ICG allows real-time delineation of biliary anatomy without radiation exposure (20). It improves visualization of cystic duct–CBD junction, which is crucial in difficult cases (21).

Operative time was significantly shorter in the ICG group, consistent with previous studies (22). This may be due to quicker identification of anatomical landmarks.

Conversion to open surgery was also significantly lower in the ICG group, supporting findings from earlier trials (23). Better visualization reduces surgeon hesitation and need for conversion.

Hospital stay was shorter in ICG patients due to fewer complications and faster recovery (24). The technique is safe with minimal adverse reactions (25).

Thus, ICG fluorescence cholangiography improves intraoperative safety and surgical outcomes.

Limitations

The present study has certain limitations. Being a retrospective single-center study, there is a possibility of selection bias and limited generalizability of findings. The sample size was moderate, and outcomes may be influenced by surgeon experience and institutional protocols. Additionally, cost-effectiveness and availability of near-infrared fluorescence equipment were not evaluated in this study. Prospective multicenter randomized trials are required to further validate these findings.

Conclusion

ICG fluorescence cholangiography is a safe and effective tool for preventing bile duct injury during difficult laparoscopic cholecystectomy. It significantly improves anatomical visualization, reduces operative time, conversion rates, and hospital stay. Routine use in difficult cases is strongly recommended.

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