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Original Research Article

An Observational Study for Evaluation of Biliary Tract Visualization Using Near-Infrared Fluorescence with Indocyanine Green During Laparoscopic Cholecystectomy

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Conflict of interest: Nil

Abstract:

Background and Objective: Precise identification of biliary structures is fundamental to preventing bile duct injury during laparoscopic cholecystectomy. Conventional intraoperative cholangiography provides valuable information but requires radiation and ductal manipulation. The present study aimed to access the efficacy of Indocyanine green (ICG)-based near-infrared (NIRF) fluorescence in visualizing biliary anatomy intraoperatively.

Methods: In Cuttack, Odisha, at SCB Medical College and Hospital, a prospective observational study was conducted, between October 2022 and March 2024. Two hours prior to surgery, 40 patients who were scheduled for elective LC received intravenous ICG at a dose of 0.25 mg/kg. An illustration of the common bile, common hepatic, and cystic ducts was documented using a NIF laparoscopic system. Operative parameters, including operative time, blood loss, and complications, were analyzed.

Results: The cystic duct was identified in 95% of patients, the common hepatic duct in 85%, and the common bile duct in 80%. The mean operative duration was 72 ± 12.6 minutes, and the average time to obtain the critical view of safety was 17.9 ± 2.9 minutes. Mean intraoperative blood loss was 14.9 mL. No conversions, allergic reactions, or bile duct injuries were recorded.

Conclusion: Real-time biliary anatomy visualization is improved by NIF imaging with ICG without radiation or added operative risk. It is a safe, efficient, and cost-effective adjunct for LC, particularly beneficial in teaching and high-volume centers.

Keywords: Cholangiography, Near-Infrared Imaging, Laparoscopic Cholecystectomy, Biliary Anatomy.

Introduction

Gallstone disease continues to be one of the most common surgical problems worldwide, and laparoscopic cholecystectomy (LC) has established itself as the preferred method for its management. The minimally invasive approach offers reduced surgical discomfort, quicker recuperation, and shorter hospital stays than with open surgery. However, the success of LC depends largely on precise identification of biliary anatomy. Despite refinements in surgical technique, bile duct injury remains a serious concern. Most such injuries are brought on by misinterpretation of the cystic and common hepatic ducts within Calot's triangle, particularly in cases complicated by inflammation, fibrosis, or congenital variations. Even a single ductal injury can lead to significant postoperative morbidity, long-term complications, and the need for reconstructive surgery. Hence, ensuring clear visualization of the biliary tract is vital for operative safety and favorable outcomes.

For many years, biliary architecture mapping and ductal damage prevention have been achieved by the use of conventional intraoperative cholangiography (IOC). Although effective, IOC involves ductal cannulation, additional instrumentation, and exposure to ionizing radiation, which may increase operative time and patient risk. Indocyanine green (ICG)-based near-infrared (NIRF) fluorescence imaging has been created as a safer, radiation-free substitute to get around these problems. ICG attaches itself to plasma proteins after intravenous infusion and is quickly eliminated as bile. When

excited by near-infrared light around 800 nm, the dye emits fluorescence that outlines the bile ducts, allowing real-time visualization of their course and confluence. Unlike IOC, this technique does not require contrast injection or ductal manipulation and can be repeated at any time during surgery. Clinical studies over the past decade have confirmed that ICG fluorescence cholangiography can accurately identify the common bile, common hepatic, and cystic ducts in the majority of cases, significantly enhancing the surgeon's ability to navigate challenging anatomy.

Near-infrared ICG imaging provides several practical benefits. It offers continuous, radiation-free, and dynamic visualization of biliary structures, thereby improving spatial orientation and surgeon confidence. The ability to switch between white light and fluorescence views facilitates repeated confirmation of anatomy during critical stages of dissection, especially in difficult or inflamed cases. Moreover, its noninvasive nature and simplicity make it suitable for use in both experienced and teaching settings. The current observational study was conducted in light of these benefits to assess how well ICG NIRF imaging visualizes the biliary tract during LC. This study, which was carried out at SCB Medical College and Hospital in Cuttack, Odisha, from October 2022 to March 2024, sought to ascertain the rates at which common bile ducts, the hepatic, and could be seen as well as the effect of ICG imaging on surgical parameters like operating time, blood loss, and perioperative safety. By analyzing local data, this study seeks to contribute to the growing evidence that fluorescence cholangiography can serve as a practical, effective, and safe adjunct to standard LC.

Materials and Methods

Study Design and Setting: From October 2022 to March 2024, an observational study was conducted at SCB Medical College and Hospital's general surgery department, Cuttack, Odisha.

Study Population: Forty consecutive patients aged >18 years diagnosed with symptomatic gallstone disease and scheduled for elective LC were included.

Inclusion criteria:

- Patients with ultrasonographically proven cholelithiasis
- Fit for general anesthesia

Exclusion criteria:

- Acute cholecystitis or cholangitis
- Previous upper-abdominal surgery
- Allergy to iodine or ICG

Procedure: Each patient received intravenous ICG 0.25 mg/kg two hours prior to surgery. LC was performed under standard four-port technique. NIR fluorescence imaging was activated intermittently to identify biliary structures prior to Calot's triangle dissection and before clipping the cystic duct and artery.

Data Collection: Demographic variables (age, sex, BMI), intra-operative parameters (difficulty score, time to CVS, operative time, blood loss), visualization rates of biliary ducts, postoperative complications, and hospital stay were recorded.

Statistical Analysis: Data were analyzed using IBM SPSS version 26. Mean ± standard deviation is used to represent continuous variables, whereas frequency and percentage are used to represent categorical data.

Results

40 patients undergoing LC were included in the study between October 2022 and March 2024 at SCB Medical College and Hospital, Cuttack. All patients had symptomatic gallstone disease and successfully underwent laparoscopic procedures without switching to open surgery. There were no documented intraoperative or postoperative problems, and the overall results of the procedure were satisfactory.

Demographic and Baseline Characteristics: The mean age of participants was 53.9 ± 9.5 years (range 29–69). The majority (62.5%) were between 41 and 60 years of age, followed by 27.5% aged 61–80 years and 10% aged ≤ 40 years. Females constituted 57.5% (n = 23) of the study population, showing a mild female predominance consistent with the known gender bias in gallstone disease. The mean BMI was 25.6 ± 4.6 kg/m², with most patients falling in the normal-to-overweight range.

Table 1: Demographic profile of the study population (n = 40)

Parameter	Category	Frequency (n)	Percentage (%)	Mean ± SD
Age (years)	≤ 40 years	4	10.0	53.9 ± 9.5
	41 – 60 years	25	62.5	
	61 – 80 years	11	27.5	
Sex	Female	23	57.5	
	Male	17	42.5	
BMI (kg/m²)	Range = 19.6–37.5	—	—	25.6 ± 4.6

Intra-operative Parameters: Without conversion, all 40 procedures were carried out laparoscopically. The majority of cases were finished in 60 to 90 minutes, with an average operating time of 72 ± 12.6 minutes. In the interim to achieve the CVS was 17.9 ± 2.9 minutes, with more than half of the patients (55%) achieving CVS within 15–18 minutes. There was no need for a blood transfusion, and the average intraoperative blood loss was only 14.9 ± 11.2 mL. The difficulty score was graded as 1 (easy) in 60% of cases and 2 (moderate) in 40%.

Table 2: Intra-operative findings and operative characteristics

Parameter	Category	Frequency (n)	Percentage (%)	Mean ± SD
Difficulty score	Grade 1 (easy)	24	60.0	—
	Grade 2 (moderate)	16	40.0	—
Time to CVS (min)	—	—	—	17.9 ± 2.9
Operative time (min)	—	—	—	72 ± 12.6
Intra-operative bleeding (mL)	—	—	—	14.9 ± 11.2
Conversion to open	—	0	0	—
Intra-operative complication	—	0	0	—

Visualization of Biliary Structures: In 95% of patients, common hepatic duct, common bile duct, and the cystic duct were visible using NIRF with ICG. Visualization typically occurred before dissection in the majority of cases. The remaining patients had suboptimal fluorescence due to dense adhesions or fatty tissue around Calot's triangle.

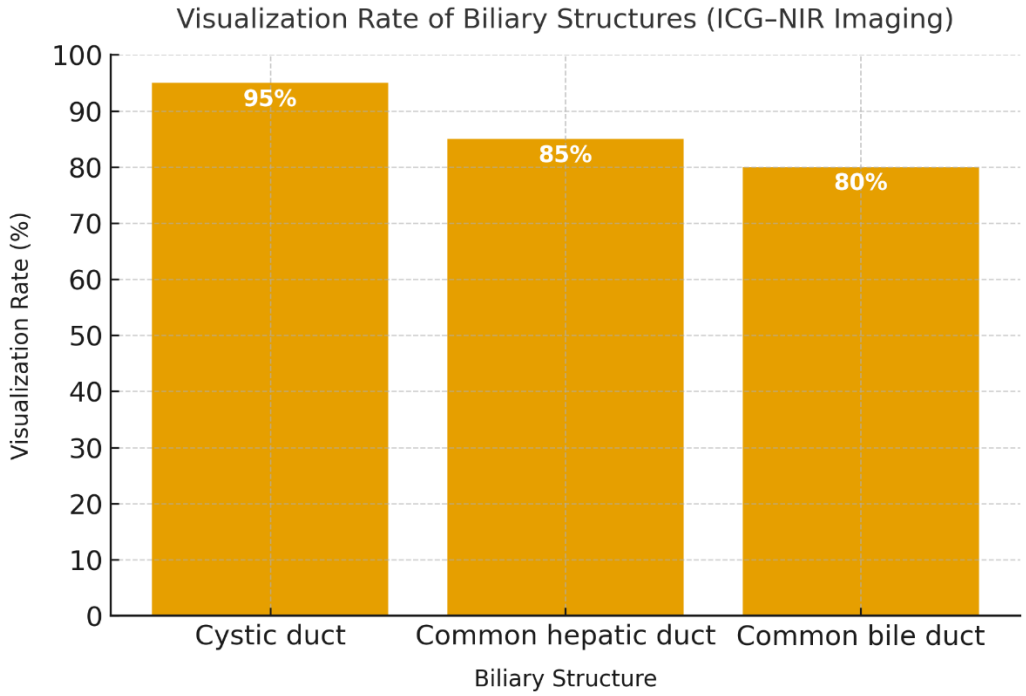

Figure 1: Visualization rate of biliary structures with ICG-NIR imaging

This high success rate demonstrates that ICG-NIR imaging provided clear delineation of the biliary anatomy in nearly all patients, thereby facilitating safer dissection.

Post-operative Outcomes: The duration of hospitalization ranged from 3 to 5 days, with an average of 3.6 ± 0.8 days. By the third postoperative day, most (55%) were released. No wound infection, bile leakage, or re-operation was noted. All patients recovered uneventfully.

Table 3: Post-operative course

Parameter	Mean ± SD / n (%)
Hospital stay (days)	3.6 ± 0.8 (range 3–5)
Complications	None (0%)
Readmission within 7 days	None (0%)

Discussion

LC is still one of the most popular general surgical procedures performed worldwide and is the gold standard for treating gallstone disease. Accurate biliary anatomical identification is essential to the success of this treatment, despite its obvious advantages, which include a speedier recovery, a shorter hospital stay, and less postoperative discomfort. Despite being rare, bile duct damage is one of the most dangerous adverse effects of LC. It frequently happens when the cystic or common hepatic ducts are mistakenly identified during dissection in Calot's triangle. By making biliary anatomy more visible during surgery, near-infrared fluorescence imaging employing ICG gives surgeons an extra visual aid to improve safety.

Intraoperative biliary structural imaging was significantly improved by ICG-based near-infrared fluorescence cholangiography. In 95% of patients, the common bile duct, common hepatic duct, and cystic duct were easily recognized. These visibility rates are consistent with findings from important global series and justify fluorescence imaging as a trustworthy supplemental method for biliary mapping. The comparable mean operating duration of 72 minutes and the mean time to attain the crucial view of safety of 17.9 minutes suggest that the use of fluorescence imaging did not appear to take longer than traditional laparoscopic cholecystectomy. ICG is safe when taken as directed, as seen by this study's lack of serious adverse effects, allergic reactions, or bile duct damage.

ICG imaging offers educational and practical benefits in addition to increased safety. Fluorescence cholangiography is an effective teaching tool for surgical trainees in a teaching hospital setting. It offers real-time anatomical orientation, which improves comprehension of biliary linkages and helps cultivate safe dissection practices. Its usage in extended or recurring situations is made possible by the lack of radiation, which puts the team at no further risk. Furthermore, the method is viable in both resource-rich and developing environments due to the low cost of ICG dye and the growing integration of the imaging system into common laparoscopic platforms. This imaging modality's seamless incorporation into standard cholecystectomy procedures shows how useful it is for facilities that perform a lot of these procedures.

Fluorescence cholangiography offers several distinct advantages compared with conventional intraoperative cholangiography. It provides a dynamic, radiation-free visualization of the biliary tract without requiring cannulation of the cystic duct or injection of contrast medium. This not only reduces the risk of ductal trauma but also eliminates the need for fluoroscopy, making it safer and more convenient for both patient and surgical team. The surgeon can alternate between standard white light and fluorescence mode at any stage of the operation to confirm anatomy. This capability is particularly helpful in identifying anatomical variations such as short cystic ducts, low insertions, or accessory hepatic ducts, all of which can predispose to bile duct injury if unrecognized. In this study, ICG imaging allowed earlier identification of key structures and a clearer distinction between the cystic and common hepatic ducts, facilitating faster and safer dissection.

Another notable strength of the technique is its simplicity and educational value. Fluorescence imaging requires minimal technical expertise and can be adopted easily in both experienced and teaching environments. In academic institutions, it serves as a valuable teaching tool, enabling trainees to appreciate the biliary anatomy in real time. The absence of radiation exposure allows repeated use without health risks, and the relatively low cost of the dye makes it feasible even in resource-limited settings. At high-volume tertiary care hospitals such as SCB Medical College and Hospital, where residents frequently perform laparoscopic cholecystectomies under supervision, ICG-NIR imaging can serve as a reliable guide to improve operative safety. The present study’s absence of complications and smooth postoperative recovery further supports its suitability for training programs and routine practice alike.

Despite these advantages, certain limitations must be recognized. The study only included a small sample size and was carried out in one location, which restricts how broadly the results can be applied. Visualization quality can vary depending on technical and patient-related factors such as obesity, hepatic steatosis, or the presence of acute inflammation, which may attenuate fluorescence intensity. In some cases, the thickened peritoneum or fibrotic tissue around Calot’s triangle can reduce ductal brightness. However, even in such situations, fluorescence provided enough anatomical guidance to complete dissection safely. Another limitation is that fluorescence cholangiography primarily highlights extrahepatic bile ducts; deeper or intrahepatic structures may not be clearly visible due to limited tissue penetration of NIR light. Furthermore, it does not identify choledocholithiasis or intra-ductal pathologies, which still require conventional cholangiography or intraoperative ultrasonography when indicated.

Future research should focus on larger multicentric trials comparing fluorescence imaging directly with conventional intraoperative cholangiography in terms of accuracy, operative time, cost-effectiveness, and postoperative outcomes. Studies exploring quantitative fluorescence analysis and

hybrid imaging technologies may further refine the method's diagnostic potential. Additionally, creating uniform guidelines for the dosage and timing of ICG administration will help optimize results across institutions. As fluorescence imaging becomes increasingly accessible, its role in complex hepatobiliary and reoperative surgeries is also likely to expand. The findings of this study thus contribute to the growing evidence base supporting near-infrared fluorescence imaging as an effective, safe, and efficient adjunct to laparoscopic cholecystectomy, with significant implications for surgical safety and education.

Conclusion

This study confirms that near-infrared fluorescence imaging using ICG enhances biliary tract visualization during LC without increasing operative time or complications. The technique allowed consistent identification of the common bile ducts, cystic, hepatic improving surgeon orientation and confidence. Its real-time, radiation-free imaging offers a practical and safe alternative to conventional intraoperative cholangiography. No allergic reactions, bile duct injuries, or conversions occurred, highlighting its safety and feasibility. Given its simplicity, low cost, and integration with modern laparoscopic systems, fluorescence cholangiography represents a valuable adjunct in both routine and complex cases. Broader implementation in training and high-volume centers may further enhance operative safety and reduce bile duct injury rates.

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