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Role of Indocyanine Green Fluorescence Imaging in Performing Safe Laparoscopic Cholecystectomy: A Randomized Controlled Trial

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Abstract

Background: Laparoscopic cholecystectomy (LC) is the standard treatment for symptomatic gallstone disease; however, bile duct injury remains a serious complication, primarily due to misidentification of biliary anatomy. Indocyanine green (ICG) fluorescence imaging enables real-time visualization of the biliary tree and may improve operative safety.

Methods: This prospective randomized controlled study included 100 participants with symptomatic gallstone disease undergoing elective LC. Participants were randomly allocated into two groups: Group A underwent ICG fluorescence-guided LC (n=50) and Group B underwent conventional LC (n=50). Baseline demographic, clinical, radiological, intraoperative, and postoperative data were recorded. Primary outcomes included intraoperative complications and operative duration, while postoperative complications and duration of hospital stay were evaluated as secondary outcomes. Statistical analysis was performed using Student's t-test, Chi-square test, or Fisher's exact test, with p value <0.05 considered statistically significant.

Results: Baseline demographic, clinical, and radiological characteristics were comparable between the two groups. Intraoperative findings, including gallbladder pathology, biliary anatomy, and operative

complexity, were similar. However, intraoperative complications were significantly lower in the ICG group (p=0.002). Common bile duct (CBD) injury, vascular injury, gallbladder perforation, spilled gallstones, and conversion to open surgery occurred only in the conventional group. The mean operative duration was significantly shorter in the ICG group (p<0.01). Postoperative complications, particularly surgical site infection, were less frequent in the ICG group, although the difference was not statistically significant. Duration of hospital stay was comparable between the groups.

Conclusion: ICG fluorescence imaging is a safe and effective adjunct during LC. It significantly reduces intraoperative complications and operative time by improving real-time visualization of biliary anatomy, while maintaining comparable postoperative outcomes. Routine use of ICG fluorescence may enhance the safety of LC, particularly in patients with difficult anatomy and inflammatory gallbladder disease.

Keywords: Laparoscopic Cholecystectomy, Indocyanine Green, Mirizzi syndrome.

Introduction

Laparoscopic cholecystectomy (LC) is the gold standard treatment for symptomatic gallstone disease and is among the most frequently performed abdominal operations worldwide. Compared with open cholecystectomy, LC offers several advantages, including reduced postoperative pain, shorter hospital stay, faster recovery, lower wound-related morbidity, and superior cosmetic outcomes. With advances in minimally invasive surgery, its application has expanded to complex gallbladder conditions such as acute cholecystitis, empyema, Mirizzi syndrome, and cases with dense upper abdominal adhesions[1]

Despite its widespread acceptance, LC remains associated with complications, the most serious being bile duct injury, which carries substantial morbidity and can significantly impair long-term quality of life. The incidence of major bile duct injury during LC is reported to be approximately 0.3–0.5%, exceeding that observed with open cholecystectomy, particularly in the presence of acute inflammation, distorted anatomy, or technically challenging dissections[2]. Most bile duct injuries result from misidentification of biliary structures rather than technical incompetence. Inflammatory changes, dense adhesions, fibrosis, and anatomical variations of the cystic duct, hepatic ducts, or vascular structures may obscure the hepatocystic triangle, increasing the likelihood of inadvertent biliary or vascular injury[3]. Pathological conditions such as acute or chronic cholecystitis, empyema, gangrenous gallbladder, and xanthogranulomatous cholecystitis further distort tissue planes, making achievement of the Critical View of Safety more difficult[4]. Operative factors including excessive traction, thermal injury, and unsafe dissection techniques also contribute to the risk of bile duct injury[5]. Several strategies have been adopted to improve the safety of LC, including meticulous adherence to the Critical View of Safety, careful dissection techniques, bailout procedures, and intraoperative decision-making protocols. However, bile duct injuries continue to occur, highlighting the need for adjunctive imaging techniques that provide accurate real-time delineation of biliary anatomy[6]. Intraoperative cholangiography has traditionally been regarded as the standard imaging modality for biliary mapping but is limited by radiation exposure, increased operative time, the need for cystic duct cannulation, and specialized expertise[7,8]. Similarly, intraoperative ultrasonography avoids radiation but is

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highly operator dependent and has limited routine applicability[9].

Indocyanine green (ICG) fluorescence cholangiography has emerged as a promising alternative for real-time intraoperative visualization of the biliary tree. Following intravenous administration, ICG is selectively excreted into bile and visualized using near-infrared imaging, allowing clear identification of the cystic duct, common bile duct, and biliary confluence without radiation exposure or duct cannulation[10,11]. Owing to its safety, ease of use, and ability to enhance anatomical identification, ICG fluorescence has gained widespread application in several surgical specialties, including hepatobiliary surgery, gastrointestinal surgery, lymphatic mapping, and organ perfusion assessment[12,13]. Previous studies have also demonstrated improved operative outcomes, particularly in difficult cholecystectomy cases, with reductions in operative time, blood loss, length of hospital stay, and adverse events[14].

Given the persistent risk of bile duct injury and the need for improved intraoperative visualization, evaluating the effectiveness of ICG fluorescence imaging during LC remains clinically important.

Hence the current study aimed to determine the role of ICG fluorescent imaging in performing safe LC. The primary objective of this study was to assess the role of Indocyanine Green Flourescent Imaging in perioperative outcomes of laparoscopic cholecystectomy in terms of:

a) Intraoperative complications like biliary tract injury and vascular injury in both the groups.
b) Operative time in both groups
c) The length of hospital stay in both the groups.
d) To identify the anatomy as well as the anatomical variations in all the cases of laparoscopic cholecystectomy.

Materials and Methods

Study Design: This was a hospital-based prospective randomized controlled study conducted to evaluate the role of ICG fluorescent imaging in performing safe LC by comparing intraoperative and postoperative outcomes between patients undergoing LC with and without ICG fluorescence guidance. In both the groups surgery was performed by a single experienced GI surgeon.

Study Area: The study was conducted in the Department of General Surgery and the Department of Surgical Gastroenterology at Geetanjali Medical College and Hospital, Udaipur, Rajasthan.

Study Period: The study was carried out over a period of 18 months following approval from the Institutional Research Review Committee and the Hospital Research Ethics Committee.

Study Population: The study population comprised patients admitted with symptomatic gallstone disease who were planned for elective LC at Geetanjali Medical College and Hospital.

Inclusion Criteria

- Adults aged ≥18 years.
- Patients diagnosed with symptomatic gallstone disease and planned for LC.
- Patients willing to participate in study and provide written informed consent.

Exclusion Criteria

- Patients who are unfit for General Anaesthesia
- Patients with allergy to Indocyanine Green Dye
- Patients with malignant lesions of gallbladder
- Emergency laparoscopic cholecystectomy surgery patients.

Sample Size: 100 participants were enrolled and randomized equally into two study groups.

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Sampling Methodology: Eligible participants satisfying the inclusion criteria were recruited consecutively during the study period and randomly allocated into two groups using a computer-generated randomization sequence.

Data Collection and Procedure:

- Written informed consent was obtained from all eligible participants before enrolment.
- Baseline demographic details, clinical history, physical examination findings, and routine preoperative investigations were recorded using a predesigned proforma.
- Participants were randomly allocated into two groups: Group A (Case Group) comprised participants undergoing LC with ICG fluorescent imaging, while Group B (Control Group) comprised participants undergoing conventional LC without ICG fluorescence imaging.
- In the intervention group, ICG was administered intravenously in a dose ranging from 1 mL to 2 mL, approximately 45 minutes before surgery (as per ISFGS guidelines), with additional intraoperative administration of ICG, used to identify the vascular anatomy.
- LC was then performed according to standard surgical techniques. In the ICG group, fluorescence imaging was used after exposure of Calot's triangle to facilitate visualization of the biliary anatomy and identify any anatomical variations. Intraoperative ICG fluorescence was also utilized to aid identification of the vascular anatomy.
- Both groups were evaluated for operative outcomes including biliary tract injury, vascular injury, operative time and duration of hospital stay. These parameters were compared between the two groups to assess the effectiveness of ICG fluorescence imaging in improving surgical safety.

Data Analysis

- Data were entered into Microsoft Excel and analysed using SPSS software version 22.0.
- Continuous variables were expressed as mean ± standard deviation, while categorical variables were expressed as frequency and percentage.
- Continuous variables were compared using Student's t-test, and categorical variables were analysed using the Chi-square test or Fisher's exact test, wherever applicable.
- A p-value <0.05 was considered statistically significant.

Ethical Considerations

- The study was conducted in accordance with the ethical principles of the Declaration of Helsinki and Ethical approval was obtained from the IRRC and the HREC of Geetanjali Medical College and Hospital, GU/HREC/EC/2024/2459
- Confidentiality of participants information was maintained throughout the study, and all collected data were anonymized and securely stored.

Results

The baseline demographic and clinical characteristics of the study participants were comparable between Group A and Group B. There were no statistically significant differences between the groups with respect to gender distribution, age-group distribution, mean age, body mass index (BMI), occupation, residence, socioeconomic status according to the Modified Kuppuswamy Scale, or addiction profile, indicating that the two groups were well matched at baseline (Table 1).

The preoperative clinical characteristics and radiological findings of the study participants are summarized in

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Table 2. Pain abdomen was the most common presenting complaint, followed by vomiting, indigestion, and fever. The distribution of comorbidities, including diabetes mellitus, hypertension, coronary artery disease, chronic obstructive pulmonary disease, bronchial asthma, tuberculosis, and hypothyroidism, was comparable between the two groups, with no statistically significant difference.

Clinical examination findings demonstrated similar proportions of pallor, icterus, abdominal distension, positive Murphy's sign, palpable gallbladder, and guarding/rigidity in both groups. Ultrasonographic evaluation predominantly showed a normal gallbladder wall or cholelithiasis with multiple calculi, while other findings included gallbladder wall thickening, dilated gallbladder, pericholecystic adhesions, acute calculous cholecystitis, empyema, gangrenous cholecystitis, mucocele, and emphysematous cholecystitis. No cases of gallbladder perforation were identified on ultrasonography (Table 2).

MRCP findings revealed cases of common bile duct dilatation, choledocholithiasis, dilatation of intrahepatic biliary radicals (IHBR), and gallstone pancreatitis in both groups. ERCP was performed in 43 participants based on clinical indications, while the remaining patients did not require the procedure (Table 2).

Intraoperative findings were comparable between the two groups, with similar gallbladder wall characteristics, presence of pyocele and mucocele, condition of the gallbladder, cystic duct morphology, cystic artery anatomy, common bile duct status, and the presence of pericholecystic adhesions and collections (Table 3). Intraoperative complications were significantly less frequent in the ICG fluorescence group than in the conventional LC group. Common bile duct injury, vascular injury, gallbladder perforation, spilled gallstones, and conversion to open surgery were observed only in the conventional group, while bowel and liver bed injuries were not encountered in either group. Trocar-site bleeding occurred in both groups but was more frequent in the conventional group (Table 3).

The mean duration of surgery was significantly shorter in Group A compared with Group B, indicating improved operative efficiency with the use of ICG fluorescence imaging (Table 4). Although postoperative complications, particularly surgical site infections, were less frequent in Group A than in Group B, the difference was not statistically significant. Rare postoperative complications, including cystic duct stones, post-cholecystectomy syndrome, biliary peritonitis, and biliary fistula, were either absent or occurred infrequently in both groups (Table 4). The duration of hospital stay was comparable between the two groups, with no statistically significant difference observed (Table 4).

Table 1: Baseline Demographic and Clinical Characteristics of the Study Participants. Data are presented as n (%) unless otherwise specified. Values for age and BMI are expressed as mean ± standard deviation.

Variable	Category	Group A (n=50)	Group B (n=50)	p value
Gender	Female	30 (60.0%)	28 (56.0%)	0.68
	Male	20 (40.0%)	22 (44.0%)	
Age Group (years)	18–30	19 (38.0%)	18 (36.0%)	0.46
	31–45	22 (44.0%)	18 (36.0%)	
	>46	9 (18.0%)	14 (28.0%)	
Age (years)	Mean ± SD	35.74 ± 7.99	36.80 ± 6.25	0.64
Body Mass Index (kg/m²)	Mean ± SD	29.05 ± 10.93	27.52 ± 11.45	0.29
Occupation	Farmer	9 (18.0%)	9 (18.0%)	0.99
	Government Employee	6 (12.0%)	5 (10.0%)	

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	Housewife	12 (24.0%)	14 (28.0%)	
	Labourer	8 (16.0%)	7 (14.0%)	
	Private Employee	9 (18.0%)	10 (20.0%)	
	Others	6 (12.0%)	5 (10.0%)	
Residence	Urban	7 (14.0%)	12 (24.0%)	0.20
	Rural	43 (86.0%)	38 (76.0%)	
Socioeconomic Status	Lower	5 (10.0%)	3 (6.0%)	0.63
	Upper Lower	21 (42.0%)	24 (48.0%)	
	Lower Middle	21 (42.0%)	22 (44.0%)	
	Upper Middle	3 (6.0%)	1 (2.0%)	
Addictions	Smoking	5 (10.0%)	8 (16.0%)	0.26
	Tobacco chewing	8 (16.0%)	6 (12.0%)	
	Alcohol	7 (14.0%)	5 (10.0%)	
	Other addictions	20 (40.0%)	19 (38.0%)	

Table 2: Preoperative Clinical Characteristics and Radiological Findings of the Study Participants. Data are presented as n (%).

Variable	Category	Group A (n=50)	Group B (n=50)
Chief complaints	Pain abdomen	50 (100.0%)	50 (100.0%)
	Vomiting	28 (56.0%)	30 (60.0%)
	Fever	8 (16.0%)	13 (26.0%)
	Indigestion	16 (32.0%)	12 (24.0%)
Comorbidities ($\chi^2 = 2.04$, $p = 0.91$)	Diabetes mellitus	3 (6.0%)	5 (10.0%)
	Hypertension	7 (14.0%)	6 (12.0%)
	Coronary artery disease (CAD)	2 (4.0%)	2 (4.0%)
	Chronic Obstructive Pulmonary Disease (COPD)	2 (4.0%)	3 (6.0%)
	Bronchial asthma	4 (8.0%)	4 (8.0%)
	H/O Treated Tuberculosis	5 (10.0%)	2 (4.0%)
	Hypothyroidism (Controlled on thyroxine)	5 (10.0%)	5 (10.0%)
Clinical examination	Pallor present	16 (32.0%)	17 (34.0%)
	Icterus present	8 (16.0%)	11 (22.0%)
	Abdomen soft	42 (84.0%)	39 (78.0%)
	Abdomen distended	8 (16.0%)	11 (22.0%)
	Murphy's sign positive	24 (48.0%)	26 (52.0%)
	GB palpable/mass	7 (14.0%)	8 (16.0%)
	Guarding/rigidity present	8 (16.0%)	11 (22.0%)
USG findings	GB wall normal	46 (92.0%)	37 (74.0%)
	GB wall thickened	4 (8.0%)	13 (26.0%)
	Solitary calculi	12 (24.0%)	17 (34.0%)
	Multiple calculi	38 (76.0%)	33 (66.0%)
	Distended GB	8 (16.0%)	10 (20.0%)
	Pericholecystic fluid	12 (24.0%)	14 (28.0%)
	Acute calculous cholecystitis	14 (28.0%)	12 (24.0%)
	Cholelithiasis	26 (52.0%)	32 (64.0%)
	Empyema gallbladder	3 (6.0%)	3 (6.0%)
	Gangrenous cholecystitis	1 (2.0%)	2 (4.0%)
	Mucocele gallbladder	1 (2.0%)	2 (4.0%)
	Emphysematous cholecystitis	1 (2.0%)	0 (0.0%)
	Perforation of gallbladder	0 (0.0%)	0 (0.0%)
MRCP findings	CBD dilatation	5 (10.0%)	3 (6.0%)
	Choledocholithiasis	3 (6.0%)	2 (4.0%)
	Dilatation of intrahepatic biliary radicals	11 (22.0%)	10 (20.0%)
	Gallstone pancreatitis	5 (10.0%)	7 (14.0%)
ERCP	Done	24 (48.0%)	19 (38.0%)

Table 3: Intraoperative Findings and Complications Among the Study Participants. Data are presented as n (%).

Variable	Category	Group A (n=50)	Group B (n=50)
Gallbladder wall	Normal	30 (60.0%)	28 (56.0%)
	Thickened	20 (40.0%)	22 (44.0%)
Pyocele	Present	2 (4.0%)	4 (8.0%)
	Absent	48 (96.0%)	46 (92.0%)
Mucocele	Present	3 (6.0%)	4 (8.0%)
	Absent	47 (94.0%)	46 (92.0%)
Condition of gallbladder	Contracted	10 (20.0%)	12 (24.0%)
	Normal	25 (50.0%)	23 (46.0%)
	Distended	15 (30.0%)	15 (30.0%)
Cystic duct	Normal	38 (76.0%)	40 (80.0%)
	Long	9 (18.0%)	5 (10.0%)
	Short	3 (6.0%)	5 (10.0%)
Cystic artery	Normal	43 (86.0%)	45 (90.0%)
	Anatomical variation	7 (14.0%)	5 (10.0%)
Common bile duct (CBD)	Normal	42 (84.0%)	44 (88.0%)
	Dilated with stent in situ	8 (16.0%)	6 (12.0%)
Pericholecystic adhesions	Present	18 (36.0%)	19 (38.0%)

Pericholecystic collections	Present	16 (32%)	15 (30%)
Intraoperative complications (χ^2 = 9.54, p = 0.002)	CBD injury	0 (0.0%)	1 (2.0%)
	Bowel injury	0 (0.0%)	0 (0.0%)
	Vascular injury	0 (0.0%)	1 (2.0%)
	Gallbladder perforation	0 (0.0%)	2 (4.0%)
	Spilled gallstones	0 (0.0%)	2 (4.0%)
	Liver bed injury	0 (0.0%)	0 (0.0%)
	Trocar-site bleeding	2 (4.0%)	4 (8.0%)
	Conversion to open surgery	0 (0.0%)	1 (2.0%)

Table 4: Operative and Postoperative Outcomes of the Study Participants. Data are presented as mean ± standard deviation or n (%), as appropriate.

Outcome	Category	Group A (n=50)	Group B (n=50)	p value
Duration of surgery (min)	Mean ± SD	65.0 ± 3.0	75.0 ± 3.0	<0.01
Postoperative complications	Surgical site infection (SSI)	10 (20.0%)	17 (34.0%)	0.07
	Cystic duct stones	0 (0.0%)	1 (2.0%)	
	Post-cholecystectomy syndrome	0 (0.0%)	0 (0.0%)	
	Biliary peritonitis	0 (0.0%)	0 (0.0%)	
	Biliary fistula	0 (0.0%)	0 (0.0%)	
Duration of hospital stay (days)	Mean ± SD	2.70 ± 0.71	2.92 ± 0.75	0.13

Discussion

This randomized controlled study evaluated the role of ICG fluorescent imaging in enhancing the safety and efficiency of LC. Baseline demographic, clinical, and radiological characteristics were comparable between the two study groups, confirming successful randomization and minimizing the influence of confounding variables on surgical outcomes.

The two groups were well matched with respect to age, gender, BMI, socioeconomic status, occupation, residence, addictions, presenting symptoms, comorbidities, and clinical examination findings. Such baseline equivalence strengthens the internal validity of the study and allows differences in operative and postoperative outcomes to be attributed primarily to the use of ICG fluorescence imaging rather than patient-related factors.

Ravikumar S et al.[15] similarly reported comparable baseline characteristics between the ICG-assisted and conventional groups in their randomized controlled trial, supporting the adequacy of randomization. Although their study demonstrated a male predominance compared with the female predominance observed in the present study, both investigations established homogeneous study populations before intervention. Likewise, Haverinen S et al.[16] reported comparable baseline demographic characteristics despite including an older patient population, reinforcing the importance of balanced baseline characteristics in accurately evaluating the effect of ICG fluorescence.

The socioeconomic profile of the present study demonstrated that most patients belonged to rural areas and lower or lower-middle socioeconomic classes. Similar demographic trends were observed by Rout T et al.[17] and Farook AR, et al.[18], who reported that gallbladder diseases predominantly affected rural and economically disadvantaged populations. These findings suggest that the burden of gallstone disease remains substantial in resource-limited settings, where the incorporation of adjunctive technologies such as ICG fluorescence may improve operative safety despite existing healthcare constraints.

Similarly, anthropometric characteristics, presenting symptoms, and comorbidity profiles were comparable between the study groups. Patil S, Inamdar PS[19]. Observed that operative difficulty was more closely

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associated with anatomical and disease-related factors than demographic variables, supporting the present findings that balanced baseline clinical characteristics facilitate unbiased assessment of surgical interventions.

Preoperative ultrasonography, MRCP, and ERCP findings demonstrated comparable biliary pathology between the two groups. Although gallbladder wall thickening was observed more frequently in the conventional group, the overall distribution of gallstones, acute calculous cholecystitis, empyema, mucocele, CBD dilatation, choledocholithiasis, and ERCP utilization was broadly similar, indicating equivalent disease complexity before surgery.

Comparable radiological findings were reported by Akeel M, et al.[20], who observed similar ultrasonographic characteristics in both ICG and non-ICG groups, suggesting appropriate baseline comparability. Abdallah HS, et al.[21] further emphasized that sonographic findings such as gallbladder wall thickening, pericholecystic collections, impacted stones, and CBD dilatation are important predictors of difficult LC. The presence of these features in the present study highlights the value of detailed preoperative imaging in identifying patients who may particularly benefit from enhanced intraoperative biliary visualization using ICG fluorescence.

The intraoperative findings demonstrated comparable operative complexity between the two groups. Gallbladder wall thickening, pyocele, mucocele, anatomical variations of the cystic duct and cystic artery, CBD abnormalities, and pericholecystic adhesions occurred with similar frequency, indicating that both groups faced equivalent technical challenges during surgery.

Despite similar operative findings, intraoperative complications were considerably fewer in the ICG group. No common bile duct injury, vascular injury, gallbladder perforation, spilled gallstones, or conversion to open surgery occurred in the ICG-assisted group, whereas these complications were observed in the conventional group. The overall reduction in intraoperative complications suggests that ICG fluorescence provided improved real-time delineation of biliary anatomy, facilitating safer dissection and minimizing inadvertent injury.

These findings are consistent with those of Rana RA et al.[22] who demonstrated significantly lower bile duct injury and conversion rates in difficult LC using ICG fluorescence. Similarly, Tang et al.[11], in a meta-analysis of 26 studies, reported lower conversion rates and fewer overall complications with fluorescence-guided LC, supporting the beneficial effect of enhanced biliary visualization. Ravikumar et al.[13] also reported very low rates of major intraoperative complications in both study groups, further confirming the safety profile of ICG-assisted surgery. Collectively, these findings reinforce that improved visualization of Calot's triangle and biliary anatomy contributes substantially to safer LC.

The comparable distribution of anatomical variations observed in the present study further highlights the clinical importance of fluorescence imaging. Yoo D.[23] demonstrated that ICG successfully identified an unusual biliary anomaly that was not detected on preoperative imaging, while Triantafyllou G, et al.[24] emphasized that cystic duct and cystic artery variations remain common anatomical challenges. These observations support the routine use of ICG fluorescence to improve identification of biliary structures, particularly in

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patients with distorted anatomy or inflammatory changes.

An important finding of the present study was the significant reduction in operative duration in the ICG group. Improved visualization of biliary structures likely facilitated earlier identification of the cystic duct and common hepatic duct, reducing dissection time and enabling faster achievement of the critical view of safety.

This finding agrees with Ravikumar S, et al.[13], who reported significantly shorter operative times in the ICG-assisted group. Tang et al.[11] similarly demonstrated a significant reduction in operative time in their meta-analysis, while Manasseh et al.91 concluded that ICG fluorescence substantially improves operative efficiency, particularly in difficult cholecystectomy. The consistent reduction in operative duration across these studies suggests that fluorescence-guided surgery enhances both surgical precision and workflow efficiency without compromising safety.

Although postoperative complications were numerically lower in the ICG group, the differences did not achieve statistical significance. Surgical site infection was the most common postoperative complication, whereas biliary fistula, biliary peritonitis, and post-cholecystectomy syndrome were absent in both groups. Hospital stay was also comparable between the groups.

These findings are comparable to those reported by Haverinen S et al.[16], who observed similar postoperative complication rates and hospital stay between ICG and conventional LC despite a trend toward lower readmissions with ICG. Likewise, Akeel M, et al.[20] demonstrated no significant difference in hospital stay while reporting lower gallbladder perforation and bile spillage with ICG-assisted surgery. Chartkitchareon A, Tullavardhana T[25] also reported minimal postoperative biliary morbidity following ICG-guided cholecystectomy.

The lower incidence of gallbladder perforation and spilled gallstones observed intraoperatively in the present study may have contributed to the reduced frequency of surgical site infection. Hossain A, et al.[26] demonstrated that intraoperative bile spillage is associated with increased postoperative surgical site infection and prolonged hospital stay, supporting the concept that improved biliary visualization with ICG may indirectly reduce postoperative morbidity by minimizing intraoperative contamination.

Conclusion

The findings of the present study demonstrate that ICG fluorescence imaging is a valuable adjunct during LC. By improving visualization of biliary anatomy, it significantly reduces intraoperative complications and operative duration while maintaining excellent postoperative outcomes. These findings support the incorporation of ICG fluorescence imaging into routine LC, particularly in patients with difficult anatomy or inflammatory gallbladder disease, where accurate biliary identification is essential for achieving a safe cholecystectomy.

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