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Original Research Article

COMPARATIVE STUDY OF INDOCYANINE GREEN FLUORESCENCE CHOLANGIOGRAPHY VERSUS CONVENTIONAL WHITE-LIGHT LAPAROSCOPIC CHOLECYSTECTOMY FOR INTRAOPERATIVE BILIARY VISUALIZATION

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ABSTRACT

Background: Laparoscopic cholecystectomy is the standard surgical treatment for symptomatic gallbladder disease. However, safe identification of biliary anatomy during Calot's triangle dissection remains essential to prevent bile duct injury. Conventional white-light laparoscopy depends mainly on anatomical landmarks and surgeon experience, which may be difficult in the presence of inflammation, adhesions, or anatomical variations. Indocyanine green fluorescence cholangiography provides real-time near-infrared visualization of biliary structures and may improve intraoperative safety. **Aim:** To compare indocyanine green fluorescence cholangiography with conventional white-light laparoscopic cholecystectomy for intraoperative biliary visualization in patients undergoing elective laparoscopic cholecystectomy.

Materials and Methods: This hospital-based comparative study was conducted at a tertiary care hospital and included 60 patients undergoing elective laparoscopic cholecystectomy for benign gallbladder disease. Patients were divided into two equal groups of 30 each. Group A underwent laparoscopic cholecystectomy with indocyanine green fluorescence cholangiography, while Group B underwent conventional white-light laparoscopic cholecystectomy. The primary outcome was intraoperative visualization of biliary anatomy, including the cystic duct, common bile duct, common hepatic duct, and cystic duct–common bile duct junction. Secondary outcomes included operative time, time to identify biliary structures, time to achieve critical view of safety, intraoperative complications, conversion to open surgery, postoperative complications, and hospital stay. Data were analyzed using IBM SPSS Statistics version 27.0, and p-value <0.05 was considered statistically significant.

Results: Both groups were comparable in baseline characteristics. The mean age was 42.63 ± 12.48 years in Group A and 44.17 ± 11.96 years in Group B. Clear visualization of the common bile duct was significantly higher in Group A than Group B, 90.00% versus 63.33% (p=0.030). Visualization of the common hepatic duct was 80.00% versus 50.00% (p=0.029), and cystic duct–common bile duct junction was 86.67% versus 56.67% (p=0.020). Mean operative time was significantly shorter in Group A, 55.90 ± 10.82 minutes versus 67.43 ± 12.67 minutes (p<0.001). Time to identify biliary structures and time to achieve critical view of safety were also significantly reduced in Group A. Overall postoperative complications were lower in Group A, 10.00% versus 26.67%, but not statistically significant.

Conclusion: Indocyanine green fluorescence cholangiography improved intraoperative biliary visualization and reduced operative time compared with conventional white-light laparoscopic cholecystectomy. It may be a useful adjunct for enhancing safety and efficiency during laparoscopic cholecystectomy.
Keywords: Indocyanine green; Fluorescence cholangiography; Laparoscopic cholecystectomy; Biliary visualization; Critical view of safety.

INTRODUCTION

Laparoscopic cholecystectomy is the standard operative treatment for symptomatic gallstone disease and other benign gallbladder conditions requiring surgical removal. Although it is a commonly performed and generally safe procedure, the accurate identification of biliary anatomy remains the most important step for preventing serious complications. During dissection of Calot's triangle, the cystic duct, common bile duct, common hepatic duct, and cystic duct–common bile duct junction must be clearly recognized before clipping and division. Conventional white-light laparoscopic cholecystectomy depends mainly on anatomical landmarks, traction, tissue handling, and surgeon experience. However, in patients with inflammation, adhesions, obesity, short cystic duct, impacted stones, or distorted anatomy, white-light visualization may be inadequate and can increase the risk of misinterpretation of biliary structures. Therefore, newer adjuncts have been introduced to improve intraoperative biliary visualization and enhance surgical safety.[1] Bile duct injury is one of the most feared complications of laparoscopic cholecystectomy because it can result in bile leak, biliary stricture, recurrent cholangitis, need for reoperation, prolonged hospital stay, increased cost, and reduced long-term quality of life. The most common mechanism of bile duct injury is not technical failure alone but misidentification of the biliary anatomy. The critical view of safety has been widely accepted as an important operative strategy to reduce this risk. However, obtaining the critical view of safety may be difficult in patients with severe adhesions, acute or chronic inflammation, dense fibrosis, or anatomical variations. In such situations, relying only on conventional white-light imaging may delay biliary structure identification and increase operative difficulty. Indocyanine green fluorescence cholangiography has emerged as a real-time imaging technique that may assist the surgeon in recognizing biliary anatomy more clearly during laparoscopic cholecystectomy.[2] Indocyanine green is a water-soluble fluorescent dye that binds rapidly to plasma proteins after intravenous administration. It is taken up by hepatocytes and excreted into bile without significant metabolism. When illuminated using near-infrared light, indocyanine green emits fluorescence, allowing visualization of bile-containing structures during surgery. Unlike conventional radiographic intraoperative cholangiography, fluorescence cholangiography does not require cystic duct cannulation, ionizing radiation, or radiographic contrast injection into the bile duct. It can be used repeatedly during the operation, including before and during Calot's triangle dissection. This provides a dynamic biliary roadmap while maintaining the laparoscopic operative field. Because it is non-radiating and relatively simple to integrate into laparoscopic platforms, it is increasingly being evaluated as an adjunct to conventional white-light laparoscopic cholecystectomy.[3] Conventional white-light laparoscopy provides excellent surface visualization but does not specifically highlight the biliary tree. In contrast, indocyanine green fluorescence cholangiography provides functional optical enhancement of biliary structures by using near-infrared imaging. This can help in identifying the cystic duct, common bile duct, common hepatic duct, and their junctional anatomy before irreversible steps such as clipping or transection. The technique may be especially useful when the cystic duct is short, when the gallbladder neck is adherent, or when inflammatory tissue obscures the hepatocystic triangle. It may also improve the surgeon's confidence during dissection by confirming the direction and relationship of the biliary ducts. However, fluorescence imaging has limitations, including reduced penetration through thick tissue, interference from strong liver background fluorescence, and variability depending on dose and timing of indocyanine green administration.[4] Several recent clinical studies and reviews have emphasized the potential value of near-infrared fluorescence cholangiography in laparoscopic cholecystectomy. The technique is considered safe because indocyanine green has a long history of clinical use in hepatic function testing, ophthalmology, vascular perfusion assessment, and fluorescence-guided surgery. Adverse reactions are uncommon, but caution is required in patients with known allergy to indocyanine green or iodine-containing compounds, severe hepatic dysfunction, pregnancy, or other contraindications according to institutional policy. The simplicity of administration and the possibility of real-time anatomical guidance make the technique attractive for routine and difficult laparoscopic cholecystectomy. Nevertheless, its exact role compared with conventional white-light dissection continues to be evaluated, particularly in terms of visualization quality, operative time, safety, and postoperative outcomes.[5] An important practical issue in indocyanine green fluorescence cholangiography is the timing and dosage of dye administration. If the dye is administered too early or

at an unsuitable dose, fluorescence intensity may be suboptimal. If administered too close to surgery, excessive liver background fluorescence may reduce contrast between the liver and extrahepatic bile ducts. Therefore, different protocols have been proposed for preoperative administration, and there is no universal consensus regarding the ideal dose and timing. Despite this variation, the technique remains clinically appealing because it does not significantly alter the standard laparoscopic approach and can be performed as an adjunct to the conventional critical view of safety technique.[6]

Materials and Methods

This study was designed as a hospital-based comparative study conducted at a tertiary care hospital to evaluate the effectiveness of indocyanine green fluorescence cholangiography in comparison with conventional white-light laparoscopic cholecystectomy for intraoperative biliary visualization. The study included patients undergoing elective laparoscopic cholecystectomy for benign gallbladder disease. Patients were divided into two groups: the indocyanine green fluorescence cholangiography group and the conventional white-light laparoscopic cholecystectomy group. A total of 60 patients diagnosed with benign gallbladder disease and planned for elective laparoscopic cholecystectomy were included in the study. The patients were allocated into two equal groups of 30 patients each. Group A included patients who underwent laparoscopic cholecystectomy with indocyanine green fluorescence cholangiography, while Group B included patients who underwent conventional white-light laparoscopic cholecystectomy. All patients were assessed preoperatively through history, clinical examination, laboratory investigations, and imaging findings.

Inclusion Criteria

Patients aged 18 years and above who were diagnosed with symptomatic cholelithiasis, chronic calculous cholecystitis, gallbladder polyp requiring surgery, or biliary colic and were planned for elective laparoscopic cholecystectomy were included in the study. Patients who were fit for general anesthesia and provided informed consent for participation were also included.

Exclusion Criteria

Patients with suspected or confirmed malignancy of the gallbladder or biliary tract, acute severe cholecystitis with sepsis, obstructive jaundice, choledocholithiasis requiring preoperative or intraoperative bile duct intervention, known allergy to iodine or indocyanine green, pregnancy, severe hepatic dysfunction, renal impairment, and patients unfit for general anesthesia were excluded from the study. Patients requiring emergency surgery or those converted to open surgery due to causes unrelated to biliary anatomy were also excluded from the final comparative assessment.

Methodology

All patients underwent detailed preoperative evaluation, including demographic data, clinical history, presenting symptoms, associated comorbidities, previous abdominal surgery, and general physical examination. Routine laboratory investigations included complete blood count, liver function tests, renal function tests, blood sugar levels, coagulation profile, and viral markers as per institutional protocol. Ultrasonography of the abdomen was performed in all patients to assess gallbladder pathology, gallbladder wall thickness, number and size of stones, common bile duct diameter, and associated biliary findings.

In Group A, indocyanine green fluorescence cholangiography was used during laparoscopic cholecystectomy for intraoperative visualization of the biliary anatomy. Indocyanine green was administered preoperatively according to institutional protocol, and near-infrared fluorescence imaging was used intraoperatively to identify biliary structures before and during dissection of Calot's triangle. The cystic duct, common bile duct, common hepatic duct, and cystic duct–common bile duct junction were assessed under fluorescence guidance. In Group B, laparoscopic cholecystectomy was performed using conventional white-light visualization, and biliary anatomy was identified by standard dissection techniques.

All procedures were performed under general anesthesia using the standard four-port laparoscopic technique. After pneumoperitoneum creation, diagnostic laparoscopy was performed, followed by exposure of Calot's triangle. In both groups, careful dissection was carried out to achieve the critical view of safety before clipping and division of the cystic duct and cystic artery. In the indocyanine green group, near-infrared fluorescence imaging was used as an adjunct to identify biliary structures and guide safe dissection. In the conventional group, anatomical identification was performed using white-light imaging alone. The gallbladder was dissected from the liver bed and retrieved through the epigastric or umbilical port.

The primary parameter assessed was intraoperative visualization of biliary anatomy, including identification of the cystic duct, common bile duct, common hepatic duct, and cystic duct–common bile duct junction. Secondary parameters included time taken to identify biliary structures, time required to achieve the critical view of safety, total operative time, difficulty in Calot's triangle dissection, gallbladder wall thickness, presence of adhesions, bile spillage, stone spillage, intraoperative bleeding, need for additional imaging or assistance, conversion to open surgery, and intraoperative biliary or vascular injury. Postoperative parameters included abdominal pain, nausea or vomiting, fever, bile leak, surgical site infection, duration of hospital stay, and postoperative complications.

Statistical Analysis

The collected data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics version 27.0. Continuous variables such as age, operative time, time to identification of biliary structures, and

duration of hospital stay were expressed as mean and standard deviation. Categorical variables such as sex, diagnosis, visualization of biliary structures, intraoperative complications, conversion rate, and postoperative complications were expressed as frequency and percentage. The chi-square test or Fisher's exact test was used for comparison of categorical variables, while the independent sample t-test was used for comparison of continuous variables between the two groups. A p-value of less than 0.05 was considered statistically significant.

MATERIALS AND METHODS

This hospital-based comparative observational study was conducted in the Department of Surgery at a tertiary care hospital. The study included patients diagnosed with selected abdominal wall hernias who underwent either mesh repair or non-mesh anatomical repair. The objective was to compare postoperative pain, early and late postoperative complications, and recurrence between the two repair techniques. A total of 108 patients with selected abdominal wall hernias were included in the study. Patients were divided into two groups based on the type of surgical repair performed. Group A included patients who underwent mesh repair, while Group B included patients who underwent non-mesh repair. The decision regarding the type of repair was made according to the clinical condition of the patient, type and size of hernia defect, tissue quality, surgeon's assessment, and suitability for mesh placement.

Inclusion Criteria

Patients of adult age group presenting with selected abdominal wall hernias and planned for elective surgical repair were included in the study. Patients who were clinically fit for surgery and willing to undergo postoperative follow-up were considered eligible. Cases included commonly encountered abdominal wall hernias such as paraumbilical hernia, umbilical hernia, epigastric hernia, and incisional hernia, depending on institutional case selection.

Exclusion Criteria

Patients with strangulated hernia, obstructed hernia requiring emergency surgery, recurrent hernia previously repaired with mesh, gross local infection, uncontrolled systemic illness, severe immunocompromised state, malignancy, pregnancy, and patients not willing for follow-up were excluded from the study. Patients in whom adequate postoperative assessment could not be performed were also excluded.

Methodology

All patients underwent detailed clinical evaluation including history, duration of swelling, pain, reducibility, cough impulse, previous abdominal surgery, and associated comorbidities such as diabetes mellitus, hypertension, chronic cough, constipation, obesity, smoking, and urinary symptoms. General physical examination, systemic examination, and local examination of the hernia were performed. Baseline investigations included complete blood count, renal function tests, liver function tests, blood sugar levels, coagulation profile, urine examination, chest X-ray, electrocardiogram, and other investigations as required. Ultrasonography of the abdomen and abdominal wall was performed wherever indicated to assess defect size, contents of sac, and associated pathology.

Surgical Procedure: All patients underwent surgical repair under appropriate anaesthesia after obtaining fitness for surgery. In the mesh repair group, the hernia sac was dissected, contents were reduced, excess sac was excised or dealt with appropriately, and the defect was reinforced using a suitable prosthetic mesh. Mesh placement was performed according to the type of hernia and intraoperative findings, such as onlay, sublay, or preperitoneal placement, as per standard surgical principles. In the non-mesh repair group, anatomical repair was performed by approximating healthy fascial margins with non-absorbable or delayed absorbable sutures without use of prosthetic material. Proper haemostasis was achieved in all cases, and drains were placed when required.

Postoperative Management: Postoperative care was provided according to standard hospital protocol. Patients were monitored for pain, wound condition, fever, seroma, haematoma, surgical site infection, urinary retention, respiratory complications, and other postoperative events. Analgesics, antibiotics, wound care, early ambulation, and supportive treatment were given as required. Drains, if placed, were removed based on drain output and clinical assessment. Patients were advised regarding wound care, avoidance of heavy lifting, control of cough or constipation, and regular follow-up.

Parameters Studied: The main parameters assessed were demographic profile, age, sex, body mass index, type of hernia, size of hernia defect, reducibility, associated comorbidities, history of previous abdominal surgery, type of repair performed, operative time, need for drain placement, duration of hospital stay, postoperative pain, wound complications, seroma, haematoma, surgical site infection, mesh-related complications, return to routine activity, and recurrence. Postoperative pain was assessed using a visual analogue scale or standard pain scoring system during the early postoperative period and follow-up visits. Complications were recorded clinically and classified as early or late postoperative complications.

Assessment of Postoperative Pain: Postoperative pain was assessed using a standard pain scoring method such as the Visual Analogue Scale, where patients were asked to grade their pain intensity. Pain was recorded in the immediate postoperative period and during follow-up visits. Requirement of analgesics and persistence of pain were also noted. Pain severity was compared between mesh and non-mesh repair groups to evaluate whether the type of repair influenced postoperative discomfort.

Assessment of Complications: Postoperative complications were assessed by clinical examination and patient symptoms. Early complications included wound pain, seroma, haematoma, surgical site infection, wound dehiscence, urinary retention, and fever. Late complications included chronic pain, foreign body sensation, mesh infection, sinus formation, and recurrence. Each complication was recorded separately in both groups and compared to evaluate the safety and outcome of mesh versus non-mesh repair.

Assessment of Recurrence: Recurrence was assessed during follow-up by clinical examination. A recurrent hernia was defined as the reappearance of a swelling or fascial defect at or near the previous operative site with or without cough impulse. Patients were examined for local swelling, pain, impulse on coughing, and reducibility. Ultrasonography was used when clinical findings were doubtful. Recurrence rates were compared between mesh and non-mesh repair groups.

Statistical Analysis

Data were entered into Microsoft Excel and analysed using **SPSS version 27.0**. Continuous variables such as age, operative time, postoperative pain score, and hospital stay were expressed as mean and standard deviation. Categorical variables such as sex, type of hernia, complications, and recurrence were expressed as frequency and percentage. Comparison between mesh and non-mesh repair groups was performed using the Chi-square test or Fisher's exact test for categorical variables and Student's t-test or Mann–Whitney U test for continuous variables, depending on data distribution. A p-value of less than 0.05 was considered statistically significant.

RESULTS

A total of 60 patients undergoing elective laparoscopic cholecystectomy were included in the study. Group A consisted of 30 patients who underwent indocyanine green fluorescence cholangiography-guided laparoscopic cholecystectomy, while Group B consisted of 30 patients who underwent conventional white-light laparoscopic cholecystectomy.

Baseline demographic and clinical characteristics

The baseline demographic and clinical characteristics of the patients are shown in Table 1. The mean age of patients in Group A was 42.63 ± 12.48 years, while the mean age in Group B was 44.17 ± 11.96 years. The overall mean age of the study population was 43.40 ± 12.16 years. The difference in mean age between the two groups was not statistically significant, with a p-value of 0.627. With regard to gender distribution, Group A included 12 males and 18 females, accounting for 40.00% and 60.00%, respectively. Group B included 14 males and 16 females, accounting for 46.67% and 53.33%, respectively. In the total study population, there were 26 males and 34 females, representing 43.33% and 56.67%, respectively. The difference in gender distribution between the two groups was not statistically significant, with a p-value of 0.795. Symptomatic cholelithiasis was the most common clinical indication for laparoscopic cholecystectomy in both groups. It was present in 21 patients in Group A, accounting for 70.00%, and in 23 patients in Group B, accounting for 76.67%. Overall, symptomatic cholelithiasis was observed in 44 out of 60 patients, representing 73.33% of the total study population. The difference between the two groups was not statistically significant, with a p-value of 0.771. Chronic calculous cholecystitis was observed in 7 patients in Group A and 6 patients in Group B, corresponding to 23.33% and 20.00%, respectively. Overall, 13 patients, representing 21.67% of the study population, had chronic calculous cholecystitis. The difference between the two groups was not statistically significant, with a p-value of 1.000. Gallbladder polyp was present in 2 patients in Group A and 1 patient in Group B, accounting for 6.67% and 3.33%, respectively. Overall, gallbladder polyp was observed in 3 patients, representing 5.00% of the total study population. This difference was also not statistically significant, with a p-value of 1.000. Previous abdominal surgery was reported in 4 patients in Group A and 5 patients in Group B, accounting for 13.33% and 16.67%, respectively. Overall, 9 patients, representing 15.00% of the total study population, had a history of previous abdominal surgery. The difference between the groups was not statistically significant, with a p-value of 1.000. Diabetes mellitus was present in 3 patients in Group A and 4 patients in Group B, accounting for 10.00% and 13.33%, respectively. Hypertension was present in 5 patients in Group A and 6 patients in Group B, accounting for 16.67% and 20.00%, respectively.

Intraoperative visualization of biliary anatomy

The intraoperative visualization of biliary structures is shown in Table 2. Clear visualization of the cystic duct was achieved in 29 patients in Group A, accounting for 96.67%, compared with 24 patients in Group B, accounting for 80.00%. Overall, the cystic duct was clearly visualized in 53 out of 60 patients, representing 88.33% of the total study population. Although the rate of cystic duct visualization was higher in the ICG fluorescence group, the difference was not statistically significant, with a p-value of 0.103. Clear visualization of the common bile duct was achieved in 27 patients in Group A, accounting for 90.00%, whereas it was achieved in 19 patients in Group B, accounting for 63.33%. Overall, the common bile duct was clearly visualized in 46 out of 60 patients, representing 76.67% of the total study population. The difference between the two groups was statistically significant, with a p-value of 0.030. The common hepatic duct was clearly visualized in 24 patients in Group A, accounting for 80.00%, compared with 15 patients in Group B, accounting for 50.00%. Overall, the common hepatic duct was clearly visualized in 39 patients, representing 65.00% of the study population. The cystic duct–common bile

duct junction was clearly identified in 26 patients in Group A, accounting for 86.67%, compared with 17 patients in Group B, accounting for 56.67%. Overall, this junction was clearly visualized in 43 patients, representing 71.67% of the total study population.

Operative parameters

The operative parameters are shown in Table 3. The mean total operative time in Group A was 55.90 ± 10.82 minutes, while in Group B it was 67.43 ± 12.67 minutes. The difference between the two groups was statistically significant, with a p-value of <0.001. The mean time required to identify biliary structures was 6.23 ± 1.74 minutes in Group A and 9.87 ± 2.11 minutes in Group B. The difference was statistically significant, with a p-value of <0.001. The mean time to achieve the critical view of safety was 9.12 ± 2.36 minutes in Group A compared with 13.58 ± 3.24 minutes in Group B. This difference was also statistically significant, with a p-value of <0.001. The mean duration of hospital stay was 2.13 ± 0.73 days in Group A and 2.37 ± 0.81 days in Group B. Although the duration of hospital stay was slightly shorter in the ICG fluorescence group, the difference was not statistically significant, with a p-value of 0.233.

Intraoperative findings and complications

The intraoperative findings and complications are shown in Table 4. Dense adhesions in Calot's triangle were observed in 6 patients in Group A, accounting for 20.00%, and in 8 patients in Group B, accounting for 26.67%. Overall, dense adhesions were present in 14 patients, representing 23.33% of the total study population. The difference between the two groups was not statistically significant, with a p-value of 0.542. Difficult Calot's triangle dissection was reported in 5 patients in Group A, accounting for 16.67%, compared with 11 patients in Group B, accounting for 36.67%. Overall, difficult dissection was observed in 16 patients, representing 26.67% of the study population. Although difficult dissection was less frequent in the ICG fluorescence group, the difference was not statistically significant, with a p-value of 0.080. Bile spillage occurred in 3 patients in Group A, accounting for 10.00%, and in 9 patients in Group B, accounting for 30.00%. Overall, bile spillage was observed in 12 patients, representing 20.00% of the total study population. The difference was not statistically significant, with a p-value of 0.104. Stone spillage was observed in 2 patients in Group A and 7 patients in Group B, corresponding to 6.67% and 23.33%, respectively. Overall, stone spillage occurred in 9 patients, representing 15.00% of the study population. The difference was not statistically significant, with a p-value of 0.145. Intraoperative bleeding was observed in 1 patient in Group A, accounting for 3.33%, compared with 5 patients in Group B, accounting for 16.67%. Overall, bleeding was noted in 6 patients, representing 10.00% of all patients. The difference was not statistically significant, with a p-value of 0.195. Need for additional assistance was reported in 1 patient in Group A and 4 patients in Group B, accounting for 3.33% and 13.33%, respectively. Overall, additional assistance was required in 5 patients, representing 8.33% of the total study population. The difference was not statistically significant, with a p-value of 0.353. Conversion to open surgery was not required in any patient in Group A, while 2 patients in Group B required conversion, accounting for 6.67%. Overall, conversion to open surgery occurred in 2 patients, representing 3.33% of the total study population. The difference was not statistically significant, with a p-value of 0.492. Biliary injury was not observed in any patient in Group A, whereas 1 patient in Group B had biliary injury, accounting for 3.33%. Overall, biliary injury occurred in 1 patient, representing 1.67% of all cases. This difference was not statistically significant, with a p-value of 1.000.

Postoperative outcomes and complications

The postoperative outcomes and complications are shown in Table 5. Postoperative abdominal pain was reported in 6 patients in Group A, accounting for 20.00%, and in 11 patients in Group B, accounting for 36.67%. Overall, postoperative abdominal pain was observed in 17 patients, representing 28.33% of the total study population. The difference between the groups was not statistically significant, with a p-value of 0.252. Nausea or vomiting occurred in 3 patients in Group A, accounting for 10.00%, compared with 6 patients in Group B, accounting for 20.00%. Overall, nausea or vomiting was observed in 9 patients, representing 15.00% of the study population. The difference was not statistically significant, with a p-value of 0.472. Fever was observed in 1 patient in Group A and 4 patients in Group B, corresponding to 3.33% and 13.33%, respectively. Overall, fever occurred in 5 patients, representing 8.33% of the total study population. This difference was also not statistically significant, with a p-value of 0.353. Bile leak was not observed in any patient in Group A, while it was reported in 2 patients in Group B, accounting for 6.67%. Overall, bile leak occurred in 2 patients, representing 3.33% of all patients. The difference was not statistically significant, with a p-value of 0.492. Surgical site infection was not observed in Group A, while 1 patient in Group B developed surgical site infection, accounting for 3.33%. Overall, surgical site infection was observed in 1 patient, representing 1.67% of the total study population. The difference was not statistically significant, with a p-value of 1.000. Overall postoperative complications were observed in 3 patients in Group A, accounting for 10.00%, and in 8 patients in Group B, accounting for 26.67%. In the total study population, 11 patients developed postoperative complications, representing 18.33%. Although the overall complication rate was lower in the ICG fluorescence group, the difference was not statistically significant, with a p-value of 0.181.

Table 1: Baseline demographic and clinical characteristics of patients

Parameter	Group A: ICG Fluorescence Group n=30	Group B: Conventional Group n=30	Total n=60	p-value
Mean age, years	42.63 ± 12.48	44.17 ± 11.96	43.40 ± 12.16	0.627
Male	12 (40.00%)	14 (46.67%)	26 (43.33%)	0.795
Female	18 (60.00%)	16 (53.33%)	34 (56.67%)	0.795
Symptomatic cholelithiasis	21 (70.00%)	23 (76.67%)	44 (73.33%)	0.771
Chronic calculous cholecystitis	7 (23.33%)	6 (20.00%)	13 (21.67%)	1.000
Gallbladder polyp	2 (6.67%)	1 (3.33%)	3 (5.00%)	1.000
Previous abdominal surgery	4 (13.33%)	5 (16.67%)	9 (15.00%)	1.000
Diabetes mellitus	3 (10.00%)	4 (13.33%)	7 (11.67%)	1.000
Hypertension	5 (16.67%)	6 (20.00%)	11 (18.33%)	1.000

Table 2: Intraoperative visualization of biliary anatomy

Biliary structure clearly visualized	Group A: ICG Fluorescence Group n=30	Group B: Conventional Group n=30	Total n=60	p-value
Cystic duct	29 (96.67%)	24 (80.00%)	53 (88.33%)	0.103
Common bile duct	27 (90.00%)	19 (63.33%)	46 (76.67%)	0.030
Common hepatic duct	24 (80.00%)	15 (50.00%)	39 (65.00%)	0.029
Cystic duct–common bile duct junction	26 (86.67%)	17 (56.67%)	43 (71.67%)	0.020

Table 3: Operative parameters

Operative parameter	Group A: ICG Fluorescence Group n=30	Group B: Conventional Group n=30	p-value
Mean total operative time, minutes	55.90 ± 10.82	67.43 ± 12.67	<0.001
Mean time to identify biliary structures, minutes	6.23 ± 1.74	9.87 ± 2.11	<0.001
Mean time to achieve critical view of safety, minutes	9.12 ± 2.36	13.58 ± 3.24	<0.001
Mean duration of hospital stay, days	2.13 ± 0.73	2.37 ± 0.81	0.233

Table 4: Intraoperative findings and complications

Intraoperative parameter	Group A: ICG Fluorescence Group n=30	Group B: Conventional Group n=30	Total n=60	p-value
Dense adhesions in Calot's triangle	6 (20.00%)	8 (26.67%)	14 (23.33%)	0.542
Difficult Calot's triangle dissection	5 (16.67%)	11 (36.67%)	16 (26.67%)	0.080
Bile spillage	3 (10.00%)	9 (30.00%)	12 (20.00%)	0.104
Stone spillage	2 (6.67%)	7 (23.33%)	9 (15.00%)	0.145
Intraoperative bleeding	1 (3.33%)	5 (16.67%)	6 (10.00%)	0.195
Need for additional assistance	1 (3.33%)	4 (13.33%)	5 (8.33%)	0.353
Conversion to open surgery	0 (0.00%)	2 (6.67%)	2 (3.33%)	0.492
Biliary injury	0 (0.00%)	1 (3.33%)	1 (1.67%)	1.000

Table 5: Postoperative outcomes and complications

Postoperative parameter	Group A: ICG Fluorescence Group n=30	Group B: Conventional Group n=30	Total n=60	p-value
Postoperative abdominal pain	6 (20.00%)	11 (36.67%)	17 (28.33%)	0.252
Nausea or vomiting	3 (10.00%)	6 (20.00%)	9 (15.00%)	0.472
Fever	1 (3.33%)	4 (13.33%)	5 (8.33%)	0.353
Bile leak	0 (0.00%)	2 (6.67%)	2 (3.33%)	0.492
Surgical site infection	0 (0.00%)	1 (3.33%)	1 (1.67%)	1.000
Overall postoperative complications	3 (10.00%)	8 (26.67%)	11 (18.33%)	0.181

DISCUSSION

In the present study, both groups were comparable at baseline, with a mean age of 42.63 ± 12.48 years in the ICG fluorescence group and 44.17 ± 11.96 years in the conventional group, and the difference was not statistically significant (p=0.627). Females were slightly more common in both groups, comprising 60.00% in Group A and 53.33% in Group B. Symptomatic cholelithiasis was the most frequent indication for surgery, observed in 70.00% of patients in Group A and 76.67% in Group B. This comparability is important because differences in intraoperative visualization and operative time are less likely to be due to demographic imbalance. Ishizawa et al. (2010) evaluated fluorescence cholangiography in 52 patients undergoing laparoscopic cholecystectomy and demonstrated successful biliary delineation, with the cystic duct visualized in all 52 patients, supporting the feasibility of using ICG fluorescence across routine laparoscopic cholecystectomy cases.[7] The present

study showed that cystic duct visualization was higher in the ICG fluorescence group than in the conventional white-light group, with visualization in 29 patients (96.67%) versus 24 patients (80.00%), respectively, although the difference was not statistically significant (p=0.103). This finding is comparable to Schols et al. (2013), who reported fluorescence cholangiography as a feasible method for early biliary tract delineation during laparoscopic cholecystectomy and showed that near-infrared fluorescence helped identify relevant biliary structures before extensive dissection. The high cystic duct visualization rate in the present study is therefore consistent with earlier feasibility data, although our study directly compared ICG with conventional white-light surgery and showed a 16.67% absolute improvement in cystic duct visualization.[8] Visualization of the common bile duct was significantly better in the ICG fluorescence group in the present study, being clearly identified in 27 patients (90.00%) compared with 19 patients (63.33%) in the conventional group (p=0.030). Kono et al. (2015) studied techniques of fluorescence cholangiography during laparoscopic cholecystectomy and concluded that fluorescence cholangiography acts as a simple navigation tool for obtaining a biliary roadmap to reach the critical view of safety. Their study emphasized that fluorescence imaging can be used repeatedly during dissection and may remain useful even when connective tissue or fat initially obscures deeper ducts. The present study supports this observation, as the ICG group had markedly better common bile duct recognition than the conventional group.[9] The common hepatic duct was visualized in 24 patients (80.00%) in the ICG group compared with 15 patients (50.00%) in the conventional group, and this difference was statistically significant (p=0.029). Similarly, the cystic duct–common bile duct junction was visualized in 26 patients (86.67%) in the ICG group compared with 17 patients (56.67%) in the conventional group (p=0.020). Pesce et al. (2015), in a systematic review, reported wide visualization ranges with fluorescent cholangiography: cystic duct visualization from 71.40% to 100.00%, common hepatic duct from 33.30% to 100.00%, common bile duct from 50.00% to 100.00%, and cystic duct–common hepatic duct junction from 25.00% to 100.00%. The visualization rates in the present study fall within these reported ranges and show that ICG fluorescence provided a clear advantage over white-light imaging for deeper and junctional biliary anatomy.[10]

In the present study, the mean total operative time was significantly shorter in the ICG fluorescence group than in the conventional group, with values of 55.90 ± 10.82 minutes and 67.43 ± 12.67 minutes, respectively (p<0.001). This indicates an average reduction of 11.53 minutes with ICG fluorescence guidance. Zroback et al. (2016) reported the initial Canadian experience with fluorescent cholangiography in 12 biliary cases and found cystic duct and common bile duct visualization rates of 100.00% and 83.00%, respectively, with 83.00% of surgeons reporting that fluorescence cholangiography was smoothly incorporated into the operation and no technology-related complications.[11] The time required to identify biliary structures was significantly reduced in the present study, with Group A requiring 6.23 ± 1.74 minutes compared with 9.87 ± 2.11 minutes in Group B (p<0.001). The time to achieve the critical view of safety was also shorter in Group A, at 9.12 ± 2.36 minutes, compared with 13.58 ± 3.24 minutes in Group B (p<0.001). Bleszynski et al. (2020), in an updated Canadian experience including 108 cases, reported that the cystic duct, common hepatic duct, and common bile duct were identified with ICG in 90.00%, 48.00%, and 84.00% of cases, respectively, and that at least two of three biliary structures were simultaneously visualized in 83.40% of cases. These findings support the present study, where improved simultaneous anatomical recognition likely contributed to faster biliary identification and earlier achievement of the critical view of safety.[12] The present study showed fewer intraoperative difficulties in the ICG fluorescence group. Difficult Calot's triangle dissection occurred in 5 patients (16.67%) in Group A compared with 11 patients (36.67%) in Group B (p=0.080). Bile spillage occurred in 10.00% versus 30.00%, stone spillage in 6.67% versus 23.33%, and intraoperative bleeding in 3.33% versus 16.67% in Group A and Group B, respectively. Although these differences were not statistically significant, they indicate a clinically favorable trend toward safer dissection with ICG. Dip et al. (2019), in a randomized trial of near-infrared incisionless fluorescent cholangiography, reported that pre-dissection detection rates were significantly superior with near-infrared fluorescence compared with white light for all seven biliary structures, with rates ranging from 9.10% versus 2.90% to 66.60% versus 36.60%. This supports the present finding that fluorescence-guided visualization improves anatomical confidence during the difficult early phase of dissection.[13] Conversion to open surgery was not required in any patient in the ICG fluorescence group, while 2 patients (6.67%) in the conventional group required conversion. Biliary injury was also absent in Group A, whereas 1 patient (3.33%) in Group B had biliary injury. These differences were not statistically significant, likely because the sample size was limited to 60 patients, but the trend favored ICG fluorescence. Dip et al. (2021), in a systematic review comparing near-infrared fluorescence cholangiography with white-light surgery, reported overall weighted bile duct injury rates of 6 per 10,000 with near-infrared fluorescence versus 25 per 10,000 without it, and conversion rates of 16 per 10,000 versus 271 per 10,000, respectively. These findings are consistent with the present study, in which no conversion or biliary injury occurred in the ICG group.[14] Postoperative complications were lower in the ICG

fluorescence group in the present study. Overall postoperative complications occurred in 3 patients (10.00%) in Group A compared with 8 patients (26.67%) in Group B (p=0.181). Postoperative abdominal pain was 20.00% versus 36.67%, nausea or vomiting was 10.00% versus 20.00%, fever was 3.33% versus 13.33%, bile leak was 0.00% versus 6.67%, and surgical site infection was 0.00% versus 3.33% in Group A and Group B, respectively. Cai et al. (2024), in a retrospective cohort study of 59 patients, reported that common bile duct fluorescence visualization was achieved in 100.00% of patients receiving intravenous ICG compared with 85.19% in the intragallbladder injection group (p=0.04), with no bile duct injury or bile leak in either group. Their findings support the safety of ICG fluorescence cholangiography and are in agreement with the lower bile leak and postoperative complication trend observed in the present study.[15]

CONCLUSION

Indocyanine green fluorescence cholangiography was found to be a useful adjunct to conventional laparoscopic cholecystectomy for better intraoperative biliary visualization. It improved identification of the common bile duct, common hepatic duct, and cystic duct–common bile duct junction compared with conventional white-light laparoscopy. The ICG fluorescence group also showed significantly shorter operative time, faster biliary structure identification, and earlier achievement of the critical view of safety. Intraoperative and postoperative complications were lower in the ICG group, although most were not statistically significant.

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