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PREVENTING BILE DUCT INJURY IN LAPAROSCOPIC CHOLECYSTECTOMY: ANATOMICAL SAFETY AND INTRAOPERATIVE IMAGING

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Abstract. Background: Bile duct injury (BDI) is an uncommon but consequential complication of laparoscopic cholecystectomy. This narrative evidence review examines anatomical identification, intraoperative imaging, and bailout strategies for safer gallbladder surgery. Methods: Selected multi-society guidelines, systematic reviews, and comparative studies were examined, with emphasis on the critical view of safety (CVS), cholangiography, indocyanine green (ICG) fluorescence, and subtotal cholecystectomy. Results: Guidelines endorse routine efforts to obtain CVS, imaging when anatomy remains uncertain, and consideration of subtotal cholecystectomy when safe dissection is not feasible. ICG fluorescence often improves anatomical visualization, but randomized evidence has not established a statistically significant reduction in rare BDI events. Conclusion: A stepwise safety culture combining anatomical verification, timely imaging, appropriate bailout decisions, and specialist referral offers a pragmatic prevention framework; more high-quality studies are required to quantify incremental benefits of new imaging methods.

Keywords: laparoscopic cholecystectomy; bile duct injury; critical view of safety; indocyanine green; fluorescence cholangiography; subtotal cholecystectomy.

1. INTRODUCTION

Laparoscopic cholecystectomy is a common operation for symptomatic gallstone disease and selected inflammatory gallbladder conditions. Its minimally invasive benefits do not remove the danger of misidentifying ducts and arteries in Calot's triangle. Bile duct injuries may entail repeat interventions, strictures, prolonged treatment, impaired quality of life and substantial healthcare costs. Because injury is infrequent, an apparently favorable result in a small case series does not necessarily establish the effectiveness of a preventive intervention [1].

Severe inflammation, adhesions, fibrosis, bleeding, anatomical variants and poor exposure can distort normal landmarks. A frequently described mechanism is perceptual error: the surgeon believes a structure is the cystic duct when it is part of the main biliary tree. The key challenge is therefore not merely to dissect with technical precision but to determine when anatomical identification is sufficiently reliable to continue [1,2].

The critical view of safety (CVS) seeks to transform this judgment into a reproducible anatomical endpoint. Alternative approaches include intraoperative cholangiography (IOC), laparoscopic ultrasonography and near-infrared fluorescence cholangiography using ICG. When anatomy remains undefined, a planned bailout approach may be safer than progressively aggressive dissection. This review synthesizes those strategies and proposes a practical, resource-sensitive operative pathway.

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2. MATERIALS AND METHODS

A structured narrative review was prepared using publicly available surgical society recommendations and peer-reviewed systematic reviews and meta-analyses. Priority was given to the SAGES-led multi-society safe cholecystectomy guideline, reports evaluating ICG fluorescence or conventional cholangiography, and literature on difficult cholecystectomy [1–5]. Evidence was organized under four domains: (1) anatomical recognition, (2) adjunctive visualization, (3) bailout and referral, and (4) implementation and audit. This manuscript is not a registered systematic review; no new patient data were collected, no original trial was conducted, and no pooled effect estimates were calculated independently.

The principal outcome of interest was prevention of major BDI. Because many available studies are underpowered for this rare outcome, secondary endpoints—visualization of biliary structures, operative time and conversion to open surgery—were treated as indirect indicators rather than replacements for patient-important outcomes. Differences between observational and randomized evidence were preserved during interpretation.

3. RESULTS

3.1. Critical view of safety and structured verification. Multi-society guidance suggests using CVS for identification of the cystic duct and cystic artery during laparoscopic cholecystectomy [1]. Three elements are commonly required: clearance of fibrofatty tissue from the hepatocystic triangle, separation of the lower gallbladder from the cystic plate, and demonstration that only two structures enter the gallbladder. The intent is to establish identity before division, not to insist on dissection in a hazardous plane. A brief deliberate pause before clipping or transection can prompt the team to reassess whether these conditions are actually met [1,2].

3.2. Conventional intraoperative imaging. When the anatomy is uncertain or an injury is suspected, the multi-society guideline strongly recommends intraoperative biliary imaging [1]. IOC outlines the ductal system through contrast injection and may reveal unexpected anatomy or possible injury. Its use depends on available equipment, local expertise and the clinical situation. Imaging is an aid to judgment rather than permission to divide a structure whose identity remains unclear. Visual evidence must be interpreted in combination with operative findings and the limits of the chosen technique.

3.3. Fluorescence cholangiography. ICG near-infrared imaging permits real-time visualization of fluorescent biliary structures without the ionizing radiation used in fluoroscopic IOC. A systematic review of 22 studies comprising 3,457 patients reported improved identification of the cystic duct and common bile duct as well as lower conversion rates in its pooled comparisons; however, between-study heterogeneity and risk of bias affect certainty [3]. A separate meta-analysis evaluating 1,586 patients across eight randomized trials found no statistically significant reduction in BDI (odds ratio 0.73; 95% confidence interval 0.05–10.80), underscoring the imprecision associated with rare adverse events [4].

3.4. Difficult gallbladder and bailout procedures. When CVS cannot be obtained and imaging does not clarify anatomy, continuing total dissection may worsen risk. The multi-society panel suggests considering subtotal cholecystectomy instead of a fundus-first total cholecystectomy in this

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circumstance [1]. Subtotal surgery can avoid dangerous dissection around the main duct but may lead to bile leakage, retained stones or subsequent procedures. Conversion to an open operation, additional expert assistance or stopping for further evaluation may also be appropriate, depending on patient stability and the operative setting.

3.5. Recognition and referral. Suspected or confirmed BDI demands prompt characterization, avoidance of blind repair and timely communication. Guidance recommends referral to an experienced surgeon or multidisciplinary hepatobiliary team [1]. Clear operative documentation—including what anatomy was seen, whether CVS was achieved, what images were obtained and the reason for bailout—facilitates subsequent management and quality review.

Safety measure	Potential benefit	Key limitation
Critical view of safety	Standardized anatomical identification	May be unattainable with severe inflammation
IOC or other biliary imaging	Clarifies uncertain anatomy; identifies possible injury	Equipment, expertise and interpretation required
ICG fluorescence imaging	Real-time visualization without fluoroscopy	No conclusive randomized BDI reduction
Subtotal cholecystectomy	Avoids unsafe hilar dissection	Bile leak or retained-stone risk
Specialist referral	Improves access to complex injury management	Requires timely regional coordination

Table 1. Selected prevention strategies and their practical limitations (qualitative evidence synthesis).

4. DISCUSSION

The available evidence favors a layered prevention model rather than dependence on a single device or surgical maneuver. CVS addresses a common cognitive failure—mistaken anatomical identity—while adjunct imaging may reduce uncertainty when direct observation is inconclusive. However, stronger visualization is not synonymous with proved prevention of major BDI. Fluorescence studies often document improved identification or efficiency, whereas rare clinically serious injuries require much larger studies to demonstrate reliable outcome differences [3,4].

A methodological distinction is especially important for journal readers. Observational comparisons may favor imaging because of case selection, surgeon experience, differences in inflammation severity or institutional protocols. Conversely, randomized trials can remain inconclusive when the outcome is very uncommon. For example, the wide confidence interval reported in the randomized evidence on ICG fluorescence permits both potentially important benefit and no benefit; it should not be interpreted as definitive equivalence [4]. Existing guidelines consequently combine evidence grading with expert consensus and frequently issue conditional recommendations [1].

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Anatomical uncertainty should trigger deliberate changes in plan. A safety pause may reveal a mismatch between an assumed and demonstrated structure. If imaging is available, it should be used to resolve the question. If a clear ductal map or CVS still cannot be established, stopping unsafe dissection and selecting an appropriate bailout is a sign of good decision-making, not an operative failure. The choice between subtotal operation, conversion, drainage or other management must consider severity of inflammation, available personnel and the patient's condition [1,2].

Implementation does not require every hospital to purchase advanced fluorescence platforms. Core interventions applicable in resource-constrained departments include explicit CVS training, a verbal verification step before ductal division, standardized escalation criteria, quality review of difficult cases, and a referral agreement with a hepatobiliary center. Where ICG equipment is introduced, operators require training in image interpretation, contraindication assessment and an understanding that fluorescence has limits in deep tissue, severe inflammation and poor exposure. Institutional audits should report not just device use but documentation of CVS, use of bailout and meaningful complication outcomes.

A practical decision sequence can be incorporated into a routine theatre checklist. Before traction and dissection, the team should review preoperative imaging and anticipate factors that make exposure difficult. During dissection, progressive anatomical landmarks should be checked rather than inferred from the direction of a single tubular structure. Before division, the surgeon should confirm the essential CVS criteria and invite a second opinion if there is disagreement. If the anatomy remains uncertain, additional imaging or a change of operative strategy should precede any irreversible step. This sequence is a proposed operational synthesis of safety principles, not a formally tested intervention [1,2].

Documentation quality is itself an implementation target. Operative notes often focus on completion of the procedure, while safety evaluation requires information about the uncertainty encountered. Hospitals could develop a short structured template recording inflammation grade, CVS status, whether a verification pause occurred, the reason for imaging, and the rationale for subtotal operation or conversion. Where lawful and feasible, annotated still images can support multidisciplinary review and resident education. Such documentation should not replace clinical judgment or become an incentive to pursue CVS despite unsafe conditions.

A further research priority is separating technical success from outcomes that matter to patients. Time saved in identifying a duct or higher visualization scores can be worthwhile, but must be distinguished from prevention of injury, bile leakage, return to hospital, patient-reported quality of life and long-term stricture. Studies that report only favorable visualization endpoints risk overstating clinical benefit. Future pragmatic trials should stratify by acute versus elective surgery and by preoperative markers of difficult dissection, while allowing predefined bailout management. A standardized core outcome set and adequate follow-up could make evidence across regions more comparable.

Several limitations apply to this review. The selection was narrative rather than exhaustive, there was no formal risk-of-bias reappraisal of each primary study, and studies differed in their definitions of difficult cholecystectomy. Some published endpoints are surrogates for BDI. Accordingly, conclusions describe a reasoned evidence-informed approach, not a newly validated clinical pathway. Prospective

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multicenter studies, consistent outcome definitions and cost-effectiveness analyses are needed, especially in low-resource healthcare systems.

5. CONCLUSION

Prevention of bile duct injury during laparoscopic cholecystectomy begins with safe anatomical identification and the willingness to stop when certainty is lost. Routine efforts to establish the critical view of safety, targeted intraoperative imaging, prudent bailout procedures and early referral of suspected injury form a coherent safety strategy. ICG fluorescence is a promising adjunct for biliary visualization, but current randomized evidence does not conclusively demonstrate that it reduces major duct injuries. Surgical training and institutional decision protocols remain essential alongside technological advances.

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