

Bile Duct Injury Following Cholecystectomy: Diagnosis, Timing of Repair, And Surgical Reconstruction

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ABSTRACT

Iatrogenic bile duct injury (BDI) remains one of the most serious complications of cholecystectomy. Although uncommon, BDI may result in bile leakage, biliary peritonitis, sepsis, obstruction, recurrent cholangitis, anastomotic stricture, secondary biliary cirrhosis, and repeated interventions. Outcomes are influenced by the timing of recognition, effective source control, complete definition of biliary and vascular anatomy, preservation of ductal blood supply, and access to an experienced hepatopancreatobiliary (HPB) team. This narrative review synthesizes evidence published between 2022 and 2026 regarding epidemiology, mechanisms of injury, classification, diagnosis, endoscopic and percutaneous management, timing of definitive repair, and surgical reconstruction. Minor injuries with preserved ductal continuity are frequently amenable to endoscopic decompression and selective stent placement. Major injuries, particularly Strasberg type E lesions, most commonly require bilioenteric reconstruction, with Roux-en-Y hepaticojejunostomy representing the most established reconstructive option. Contemporary evidence supports favorable outcomes after both carefully selected early repair and delayed reconstruction; however, the 2025 SAGES-AHPBA guideline conditionally favors definitive repair after 6 weeks when the clinical setting permits. Across contemporary series, favorable long-term outcomes are consistently associated with early referral to specialist HPB centers, adequate control of sepsis and bile collections, and construction of a wide, well-vascularized, tension-free mucosa-to-mucosa anastomosis. Long-term surveillance is essential because biliary strictures may develop years after reconstruction.

KEYWORDS: bile duct injury, cholecystectomy, hepaticojejunostomy, biliary reconstruction, Strasberg classification.

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INTRODUCTION

Bile duct injury (BDI) following cholecystectomy is uncommon, but its clinical consequences can be substantial. A population-based analysis of 76,345 elective cholecystectomies identified 186 major injuries requiring reconstruction (0.24%), illustrating that the risk has not disappeared even in contemporary surgical systems [1]. Population-based studies also confirm that a substantial proportion of injuries are not recognized during the index operation and become evident only after surgery, resulting in readmissions, drainage procedures, endoscopic or

percutaneous interventions, and, in some patients, definitive reconstruction [2].

Risk is not uniformly distributed. In a meta-analysis including more than 6.5 million cholecystectomies, male sex and acute cholecystitis were associated with a higher probability of bile duct injury, reinforcing the concept that inflammation, anatomic distortion, and technical difficulty modify baseline risk [3]. In practice, injury usually results from a combination of anatomic misperception, traction-induced hilar distortion, dissection in an incorrect plane, thermal energy, or associated vascular injury. Difficult cholecystectomy requires early recognition of the point at which anatomy no longer permits

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safe continuation of the conventional strategy and a bailout procedure should be adopted [4].

The aim of this review is to integrate recent evidence around three clinically decisive questions: how to diagnose and delineate the injury, when definitive repair should be performed, and how the biliary tract should be reconstructed to maximize long-term patency. Particular attention is given to early referral to HPB centers, Roux-en-Y hepaticojejunostomy, and complex scenarios including hilar, sectoral, and vasculobiliary injuries.

REVIEW METHODOLOGY

This article was developed as a targeted narrative review of recent literature indexed in PubMed/MEDLINE and was updated through September 2026. Priority was given to publications from 2022 to 2026 addressing cholecystectomy-related BDI, diagnostic imaging, injury classification, endoscopic retrograde cholangiopancreatography (ERCP), percutaneous transhepatic biliary drainage, timing of repair, hepaticojejunostomy, minimally invasive reconstruction, anastomotic stricture, and long-term outcomes. Search concepts included the MeSH terms and free-text keywords “bile duct injury,” “cholecystectomy,” “biliary reconstruction,” “hepaticojejunostomy,” “timing of repair,” “ERCP,” “percutaneous biliary drainage,” “critical view of safety,” “intraoperative cholangiography,” and “indocyanine green.” Guidelines, systematic reviews, meta-analyses, population-based studies, multicenter cohorts, and referral-center series were preferentially selected; case reports were used only to illustrate uncommon technical scenarios. Because the objective was a focused narrative synthesis rather than a systematic review, no pooled effect estimate was generated and PRISMA-style study selection was not applied. References were numbered according to first appearance. The nine clinical figures were selected from four open-access publications distributed under the Creative Commons Attribution 4.0 (CC BY 4.0) license, and their legends and clinical descriptions were checked against the published versions.

EPIDEMIOLOGY, MECHANISMS, AND PREVENTION

Mechanisms of Injury

Most major BDIs are not explained by simple accidental transection of a correctly identified duct, but rather by misidentification of biliary anatomy. In the classic mechanism, the common bile duct or common hepatic duct is mistaken for the cystic duct and is clipped or divided; excessive cephalad traction can convert three-dimensional anatomy into an apparent cystic duct–common bile duct continuity. Thermal injury deserves separate consideration because microscopic damage may extend beyond the visible margin and later present as necrosis or stricture. Right hepatic artery injury, particularly when associated with a high hilar

lesion, may aggravate ductal ischemia and alter the reconstructive strategy.

Critical View of Safety and Bailout Strategies

The Critical View of Safety (CVS) remains a cornerstone of anatomic identification during laparoscopic cholecystectomy. A systematic review including 150 publications found that the CVS was achieved in 92.5% of cases in quantitative studies and that the associated BDI rate was low; however, it also showed that implementation and documentation remain inconsistent [5]. Technically, the CVS requires clearance of fat and fibrous tissue from the hepatocystic triangle, separation of the lower third of the gallbladder from the liver bed, and visualization of only two structures entering the gallbladder before division. When these conditions cannot be achieved safely, further dissection in the expectation that the anatomy will eventually become apparent may increase risk. Bailout strategies include subtotal cholecystectomy, selective use of intraoperative imaging, and conversion when this is expected to improve exposure or facilitate specialist assistance; conversion alone does not eliminate the risk of BDI.

Gupta emphasized that the CVS should not be understood as a final photograph but as a reproducible and verifiable dissection process, particularly in severe inflammation or altered anatomy [6]. Intraoperative cholangiography (IOC) can provide anatomic information and identify injury or choledocholithiasis; a systematic review and meta-analysis of 14 studies included more than 440,000 patients, but heterogeneity between routine and selective strategies prevents IOC from being viewed as an isolated guarantee of injury prevention [7].

Indocyanine green (ICG) fluorescence provides real-time, non-ionizing visualization. A recent meta-analysis of randomized trials demonstrated improved identification of biliary structures, although it did not conclusively demonstrate a reduction in BDI because the event is uncommon [8]. A contemporary multicenter cohort of more than 1.2 million patients found an association between intraoperative ICG fluorescence cholangiography and a lower rate of common bile duct injury, although the observational design does not establish causality [9]. Fluorescence should therefore be regarded as an adjunct to, rather than a substitute for, safe dissection. In parallel, a series of 5,675 cholecystectomies showed that standardized technical maneuvers and attention to cystic duct closure can reduce preventable postoperative bile leakage [10]. These measures primarily address postoperative leakage and should be distinguished from strategies aimed at preventing major ductal misidentification injuries.

CLASSIFICATION AND INTRAOPERATIVE RECOGNITION

Strasberg Classification

The Strasberg classification remains the most practical system for correlating anatomy with treatment. Type A

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injuries are bile leaks with preserved continuity of the biliary tree, typically from the cystic duct stump or subvesical ducts; type B injuries are occlusions of an aberrant duct; type C injuries are transections of an aberrant duct without ligation; type D injuries are lateral injuries to a major duct; and type E injuries involve transection or stricture of the common hepatic duct or hilum. E1–E3 lesions are classified according to the distance from, and preservation of, the biliary confluence; E4 denotes separation or destruction of the right-left confluence; and E5 denotes injury or stricture of an aberrant right sectoral duct in combination with injury or stricture of the main hepatic duct. Contemporary surgical reviews also recommend documenting tissue loss, vascular injury, sepsis, and previous interventions because two injuries

within the same Strasberg category may require very different operations [11].

Intraoperative recognition changes the clinical course because it allows contamination to be limited, cholangiography to be obtained, and improvised repairs to be avoided. The priority is not to “repair immediately” at any cost, but to define the injury and determine whether an HPB team with the expertise required for definitive reconstruction is available. If such expertise is not available, drainage, documentation of the anatomy, avoidance of further hilar dissection, and referral are preferable [12]. In the cohort reported by Zidan et al., 28.6% of injuries were identified during the operation; visible bile leakage was one mechanism of recognition, and their series illustrates injuries ranging from Strasberg A lesions to laparoscopic reconstruction [13].

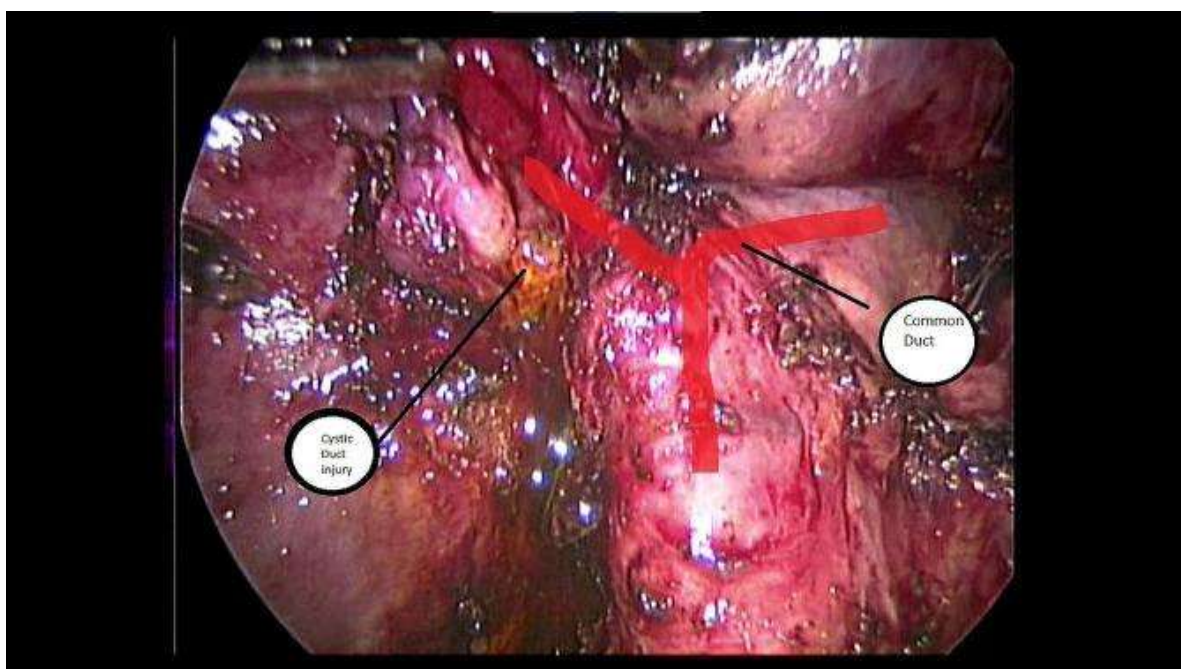


Figure 1. Intraoperatively detected bile leak corresponding to a Strasberg type A injury.

The operative photograph demonstrates visible bile leakage during cholecystectomy, illustrating a minor injury with preserved ductal continuity. Immediate recognition allows local control and rational selection of endoscopic or surgical management according to the source and magnitude of leakage. [13] Reproduced from: Zidan MHED, Seif-Eldeen M, Ghazal AA, Refaie M. Post-cholecystectomy bile duct injuries: a retrospective cohort study. *BMC Surg.* 2024;24:8, Fig. 2. DOI: 10.1186/s12893-023-02301-2. Licensed under the Creative Commons Attribution 4.0 International License (CC BY 4.0; <https://creativecommons.org/licenses/by/4.0/>). Legend verified against the corrected article version (Correction DOI: 10.1186/s12893-024-02332-3). When a major injury is recognized intraoperatively and immediate specialist support is available, reconstruction may be considered during the same operation; a recent report even described an unconventional intraoperative endoscopic approach to a common bile duct injury, although such a

strategy should be regarded as highly selected rather than a universal standard [14].

CLINICAL PRESENTATION AND POSTOPERATIVE DIAGNOSIS

Presentation depends on whether leakage, obstruction, or both predominate. During the first postoperative days, persistent abdominal pain, fever, tachycardia, ileus, distension, oral intolerance, bile through a drain, biloma, or sepsis are common. Frank jaundice more strongly suggests impaired biliary drainage or obstruction; it may also accompany a major transection when bile flow to the duodenum is interrupted. By contrast, a free intraperitoneal bile leak may initially occur with only minor changes in serum bilirubin. Siiki et al. proposed that any post-cholecystectomy course that appears disproportionate to the expected recovery should trigger early laboratory and

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imaging assessment rather than waiting for cholangitis or peritonitis to develop [15].

In the acute setting, the initial diagnostic evaluation should answer four questions: Is there a collection or biliary peritonitis? Is there ductal dilatation or obstruction? Is continuity preserved between the proximal ducts and the duodenum? Is there an associated vascular injury? Current triage algorithms integrate physiologic stability, the pattern of leakage, ductal anatomy, and feasibility of drainage to guide the choice among endoscopy, interventional radiology, and surgery [16]. A 15-year series confirms that clinical presentation and outcomes are heterogeneous and that management must be individualized according to injury type and patient condition [17].

Ultrasonography, Computed Tomography, and Magnetic Resonance Imaging

Ultrasonography and computed tomography (CT) are excellent for demonstrating free fluid, bilomas, abscesses, ductal dilatation, and vascular complications, but a collection alone does not definitively establish the presence of a bile leak. Percutaneous aspiration yielding bile can confirm the nature of the collection while simultaneously providing source control. Magnetic resonance cholangiopancreatography (MRCP) delineates proximal anatomy without instrumenting the biliary tract and is particularly valuable in complete transections, hilar injuries, and sectoral duct lesions. MRI with hepatobiliary contrast such as gadoxetate disodium (gadoxetic acid) can demonstrate active contrast extravasation and localize the site of leakage [18].



Figure 2. Biloma secondary to cystic duct stump leakage after cholecystectomy.

A 59-year-old patient underwent cholecystectomy for acute-on-chronic cholecystitis. CT demonstrated a postoperative collection in the gallbladder fossa and expected postoperative pneumoperitoneum. CT-guided aspiration yielded bilious fluid, and ERCP confirmed a low-grade cystic duct leak, which was treated with biliary sphincterotomy and stent placement. Reproduced from: Kazi IA, Siddiqui MA,

Thimmappa ND, et al. Post-operative complications of cholecystectomy: what the radiologist needs to know. *Abdom Radiol (NY)*. 2025;50:109-130, Fig. 7. DOI: 10.1007/s00261-024-04387-5. Licensed under the Creative Commons Attribution 4.0 International License (CC BY 4.0; <https://creativecommons.org/licenses/by/4.0/>), unless a specific third-party credit indicates otherwise.

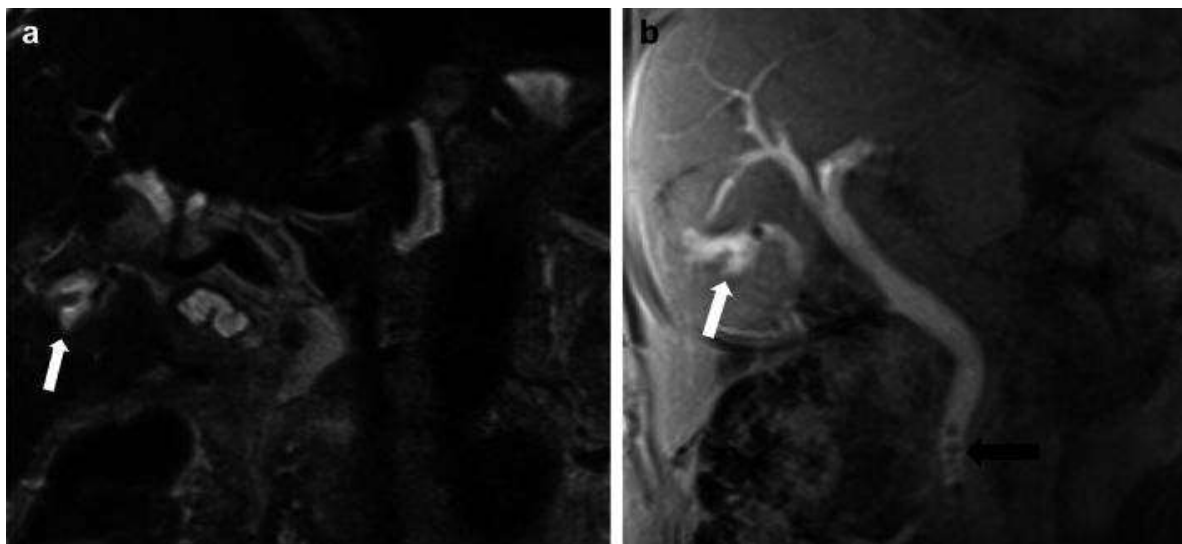


Figure 3. Confirmation of bile leakage using hepatobiliary contrast-enhanced MRI.

An 84-year-old man after laparoscopic cholecystectomy for biliary pancreatitis underwent coronal T2-weighted and 90-minute delayed T1-weighted imaging after gadoxetate disodium administration. A collection in the gallbladder fossa demonstrated excreted contrast material, confirming a bile leak. A cystic duct stump leak was subsequently confirmed by ERCP. Reproduced from: Kazi IA, Siddiqui MA, Thimmappa ND, et al. Post-operative complications of cholecystectomy: what the radiologist needs to know. *Abdom Radiol (NY)*. 2025;50:109-130, Fig. 8. DOI: 10.1007/s00261-024-04387-5. Licensed under the Creative Commons Attribution 4.0 International License (CC BY 4.0; <https://creativecommons.org/licenses/by/4.0/>).

ERCP and Percutaneous Transhepatic Cholangiography

ERCP is both diagnostic and therapeutic when ductal continuity is preserved. It can localize leaks and reduce the transpapillary pressure gradient through biliary stenting, with or without sphincterotomy, thereby preferentially directing bile flow toward the duodenum. Leaks from subvesical ducts may be difficult to identify, and their management depends on whether the injured duct communicates with the main biliary tree; a recent systematic review emphasized the importance of recognizing these variants to avoid unnecessary procedures [19]. In selected patients with adequate external drainage, some low-output leaks may close spontaneously; however, this approach requires close surveillance and the absence of distal obstruction or sepsis [20].

Endoscopic therapy has its principal role in minor injuries, whereas complete transection and hilar injuries cannot be treated by simple transpapillary stenting. A contemporary review emphasizes that the role of endoscopy should be defined by injury classification and ductal continuity rather than by a desire to avoid surgery [21]. In series of postoperative bile leaks, success rates are high when leakage is isolated and lower when a concomitant stricture is present, supporting combined approaches in complex cases [22]. Tringali et al. emphasized that modern endoscopic therapy may include multiple plastic stents and, in selected settings, fully covered self-expandable metal stents, although efficacy must be balanced against migration and ductal injury [23]. The timing of ERCP has also been evaluated recently. A systematic review of cohort studies reported high overall closure rates and suggested better outcomes when endoscopy is not excessively delayed, although heterogeneity and the retrospective nature of the data prevent adoption of a single mandatory time window [24]. Percutaneous transhepatic cholangiography (PTC) is particularly useful when proximal ducts are disconnected, a high hilar injury is present, or ERCP cannot opacify the injured segment. Percutaneous transhepatic access provides cholangiographic delineation of the proximal ducts and, when required, permits placement of an internal-external biliary drain (percutaneous transhepatic biliary drainage, PTBD) for decompression and sepsis control.

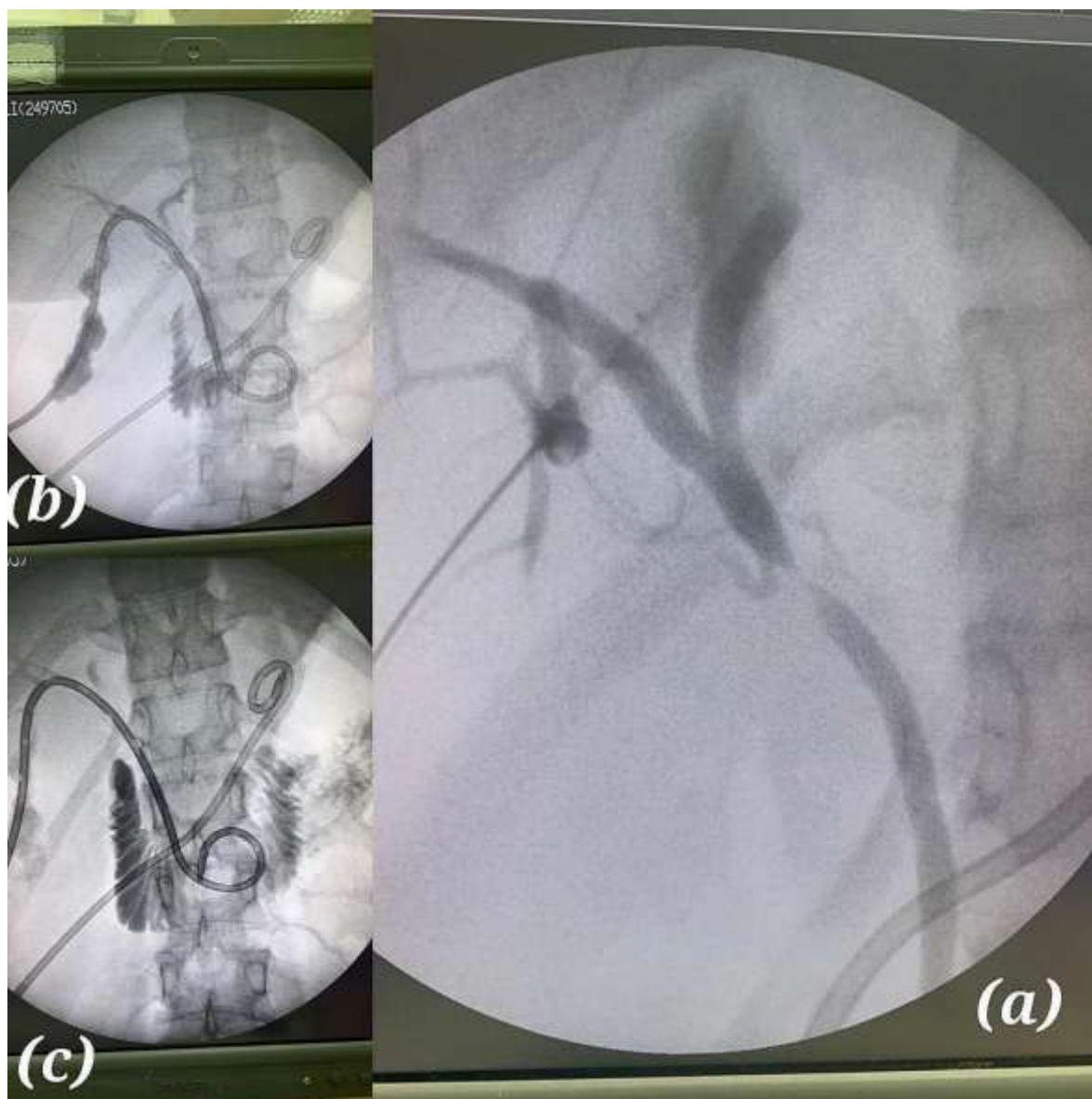


Figure 4. Percutaneous transhepatic drainage as a bridge to definitive reconstruction.

In a patient managed with delayed repair, PTC performed with a Chiba needle demonstrated a lateral leak and common hepatic duct stricture; an internal-external transhepatic biliary drain was advanced into the duodenum. Ten days later, follow-up cholangiography showed no contrast extravasation. The sequence illustrates the value of interventional radiology for anatomic definition and leak control before definitive repair. Reproduced from: Zidan

MHED, Seif-Eldeen M, Ghazal AA, Refaie M. Post-cholecystectomy bile duct injuries: a retrospective cohort study. BMC Surg. 2024;24:8, Fig. 5. DOI: 10.1186/s12893-023-02301-2. Licensed under CC BY 4.0 (<https://creativecommons.org/licenses/by/4.0/>). Legend verified against the corrected article version (Correction DOI: 10.1186/s12893-024-02332-3).

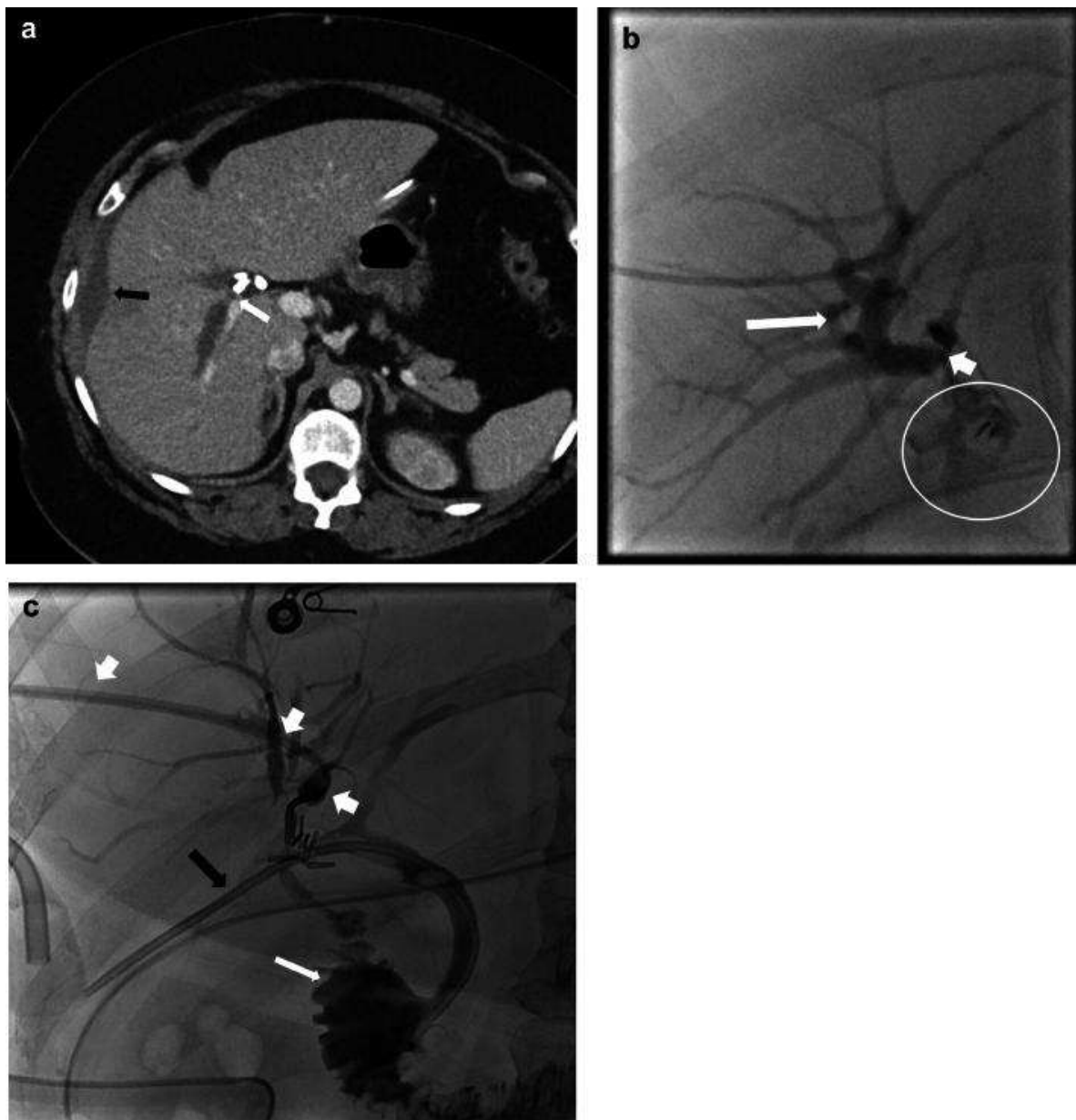


Figure 5. Right posterior hepatic duct injury with leakage and obstruction.

A 46-year-old woman had dilation of the right posterior sectoral ducts on CT with abrupt narrowing adjacent to a hilar clip and a perihepatic collection. PTC confirmed proximal ductal dilatation, leakage, and the relationship to the clip; after recanalization and internal-external drainage, contrast passage into the duodenum was restored. This case illustrates a sectoral duct injury that may not be adequately characterized by ERCP alone. Reproduced from: Kazi IA, Siddiqui MA, Thimmappa ND, et al. Post-operative complications of cholecystectomy: what the radiologist needs to know. *Abdom Radiol (NY)*. 2025;50:109-130, Fig. 10. DOI: 10.1007/s00261-024-04387-5. Licensed under the Creative Commons Attribution 4.0 International License (CC BY 4.0; <https://creativecommons.org/licenses/by/4.0/>).

Anatomic Definition and Vasculobiliary Assessment

Before major reconstruction, the anatomy must be understood in three dimensions: level of interruption, patency of the confluence, number of proximal ductal openings, and

drainage of the right anterior, right posterior, and left sectors. Classifying an injury as E3, E4, or E5 changes the required hilar exposure and determines whether a single anastomosis is feasible. Current reviews also recommend documenting the length of tissue loss and previous procedures because clipping, cautery, or re-exploration can extend injury beyond the visible margin [12].

Vascular assessment is particularly important in high injuries. Multiphase CT can evaluate the right hepatic artery, pseudoaneurysm, thrombosis, areas of hypoperfusion, and segmental atrophy. When a sectoral duct injury is associated with arterial compromise, the strategy must account for the risk of ischemia and anastomotic failure. Vascular information also helps avoid attempted reconstruction to a duct that is unlikely to remain viable postoperatively.

ERCP and PTC are complementary rather than competing investigations. ERCP is most useful when the distal biliary tract remains in continuity; PTC provides direct access to

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disconnected proximal segments and can convert a septic emergency into a controlled situation through drainage. In complex injuries, combined endoscopic-radiologic treatment may serve as a bridge to surgery or, in selected minor injuries, provide definitive resolution [21].

INITIAL MANAGEMENT AND TIMING OF REPAIR

Physiologic Priority: Control of Sepsis and Contamination

Before discussing the calendar of reconstruction, “time from injury” must be separated from “conditions for a safe anastomosis.” A patient with biliary peritonitis, sepsis, undrained abscesses, organ failure, malnutrition, or incompletely defined anatomy first requires source control, antibiotics, drainage of collections, and restoration of biliary drainage. An anatomically correct repair performed on edematous, contaminated, or ischemic tissue may fail; therefore, optimal timing is inseparable from physiologic status and team expertise.

Early, Intermediate, and Delayed Repair

Temporal definitions vary across studies. A 2022 systematic review included 24 studies and more than 15,000 patients and emphasized that comparisons among “early,” “intermediate,” and “late” repair are limited by heterogeneous definitions, patient selection, and mixing of primary and secondary

repairs [25]. This heterogeneity helps explain why apparently similar studies sometimes reach opposing conclusions.

A multicenter randomized trial published in 2023 reported that early repair after sepsis control achieved outcomes comparable with delayed reconstruction, whereas early reconstruction in the presence of uncontrolled sepsis was associated with more reinterventions and poorer outcomes. Subsequent guideline appraisal identified important methodological limitations, including substantial dropout in the septic early-repair cohort, and considered the study at high risk of bias [26]. The practical interpretation is therefore not that “early is always better,” but that immediate or early reconstruction requires rapid recognition, a stable patient, well-defined anatomy, controlled sepsis, and an HPB surgeon capable of providing high-quality definitive repair.

The experience reported by Giuliante et al. with Hepp-Couinaud hepaticojejunostomy provides a complementary perspective. Among 114 patients, most underwent repair after 6 weeks; with a median follow-up approaching 9 years, primary patency was high, and timing of repair was not associated with loss of patency when patients reached reconstruction without sepsis or uncontrolled leakage [27]. These findings support a “physiology first” approach: stabilize the patient, define the anatomy, and choose the time at which repair can be performed under optimal conditions.

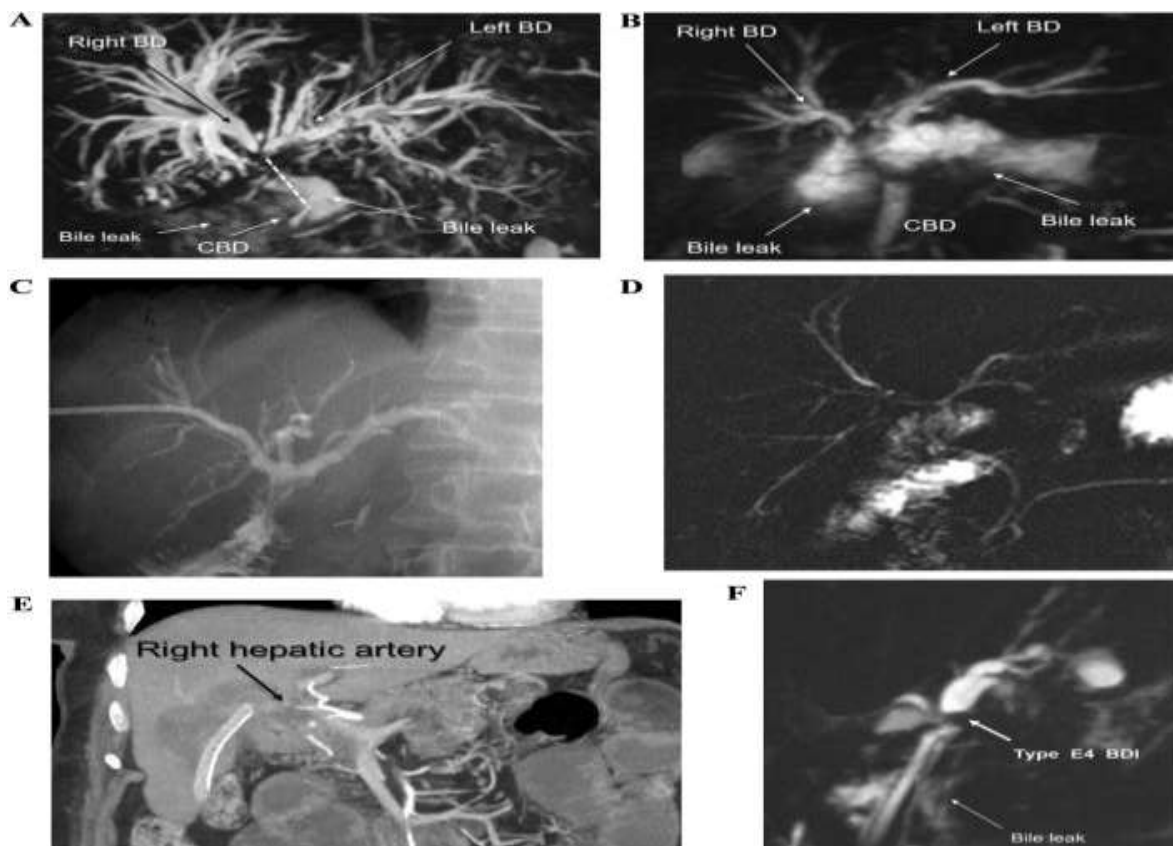


Figure 6. Strasberg E4/E5 injuries and reconstruction with Hepp-Couinaud hepaticojejunostomy.

The original composite figure includes MRCP of a Strasberg E4 injury with bile leakage, MRCP of an E5 injury, percutaneous cholangiography and MRCP after Hepp-

Couinaud hepaticojejunostomy, and an E4 lesion associated with right hepatic artery injury. The sequence highlights the importance of mapping both ducts and vascular anatomy

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before reconstruction. [27] Reproduced from: Giulianti F, Panettieri E, De Rose AM, et al. Bile duct injury after cholecystectomy: timing of surgical repair should be based on clinical presentation. The experience of a tertiary referral center with Hepp-Couinaud hepatico-jejunostomy. *Updates Surg.* 2023;75:1509-1517, Fig. 1. DOI: 10.1007/s13304-023-01611-7. Reuse is permitted under CC BY 4.0; images are included unless a specific third-party credit states otherwise. The 2025 SAGES-AHPBA guideline, published in 2026, conditionally suggests delayed definitive repair (>6 weeks) by an experienced HPB surgeon when clinically feasible; the overall certainty of evidence for this recommendation was rated very low [28]. This recommendation must be interpreted in the context of patient selection: early repair may still be considered when the injury is well defined, sepsis is controlled, and appropriate HPB expertise and adjunctive resources are available. It does not justify delaying source control, referral, or biliary drainage.

Conversely, a contemporary retrospective series of 54 patients defined “early” repair as intraoperative repair or repair within 3 days and “late” repair as repair after 3 days; the authors reported favorable outcomes with early repair, but this definition differs substantially from the <6-week threshold used by SAGES-AHPBA and limits direct comparison across studies [29]. The meta-analysis by Pirianu et al., which synthesized data from more than 18,000 patients, reported lower morbidity after early (<2 weeks) or delayed (>6 weeks) repair than after repair during the 2–6-week interval and also found fewer complications after referral to HPB centers; these findings should be interpreted in light of heterogeneity among the included studies [30]. An individual patient data review likewise underscored that injury severity, physiologic status, treating center, and previous interventions modify the apparent effect of timing [31].

DEFINITIVE SURGICAL RECONSTRUCTION

Reconstructive Principles

Definitive reconstruction of a major BDI aims to restore drainage from all functional liver segments through a wide, well-vascularized, tension-free anastomosis. Roux-en-Y hepaticojejunostomy is the most widely used and best-established reconstruction for Strasberg type E injuries and complex benign strictures because it permits anastomosis to healthy proximal duct and avoids dependence on an injured distal segment. The SAGES-AHPBA guideline allows either hepaticojejunostomy or hepaticoduodenostomy in selected settings, but the certainty of comparative evidence is very low [28]. The state-of-the-art review by Marichez et al.

summarizes the essential principles: identify a well-perfused proximal duct, avoid unnecessary circumferential dissection, expose viable mucosa, obtain adequate anastomotic caliber, preserve the periductal blood supply, and create a precise mucosa-to-mucosa anastomosis [32].

Long-term outcomes can be excellent in referral centers. Ahmad et al. reported a cohort of 87 patients treated with hepaticojejunostomy, with low mortality and favorable estimated 10-year stricture-free survival among patients with extended follow-up [33]. The problem does not end with the operation: anastomotic stricture is the main mode of late failure, and its risk is influenced by previous repairs, sepsis, leakage, and technical factors. A multicenter study developed prediction models for stricture after hepaticojejunostomy and confirmed the importance of both patient-related and reconstruction-related variables [34].

Suture technique has also been studied. A recent meta-analysis comparing continuous and interrupted suturing in hepaticojejunostomy did not identify a single universally superior strategy; in practice, duct caliber, tissue quality, and surgeon experience determine the choice [35]. More important than the suture pattern is avoidance of a narrow, ischemic, or tensioned anastomosis.

Hepp-Couinaud Technique

In proximal injuries, longitudinal opening of the left hepatic duct along the hilar plate creates a wide, well-vascularized stoma. The Hepp-Couinaud technique is particularly useful when the common hepatic duct stump is short or scarred. Dissection should be limited and preserve perfusion; the hilar plate is lowered sufficiently to expose the left duct, which is opened longitudinally and anastomosed to a Roux-en-Y jejunal limb. In E4 and E5 injuries, incorporation of several ductal openings by ductoplasty or construction of more than one anastomosis may be required.

E4/E5 and Vasculobiliary Injuries

Strasberg E4 injuries are particularly complex because the right and left ductal systems are separated. A recent series focused on E4 injuries described anatomy-adapted strategies including hilar reconstruction and, in selected patients with irreversible sectoral or vascular damage, hepatic resection; such procedures should be restricted to highly experienced centers [36]. Associated arterial injury modifies ductal viability and can result in necrosis, abscess formation, or segmental ischemia. Not every right hepatic artery injury requires vascular reconstruction, but identification by multiphase CT or angiography may explain why a ductal margin that initially appears healthy later develops stricture.

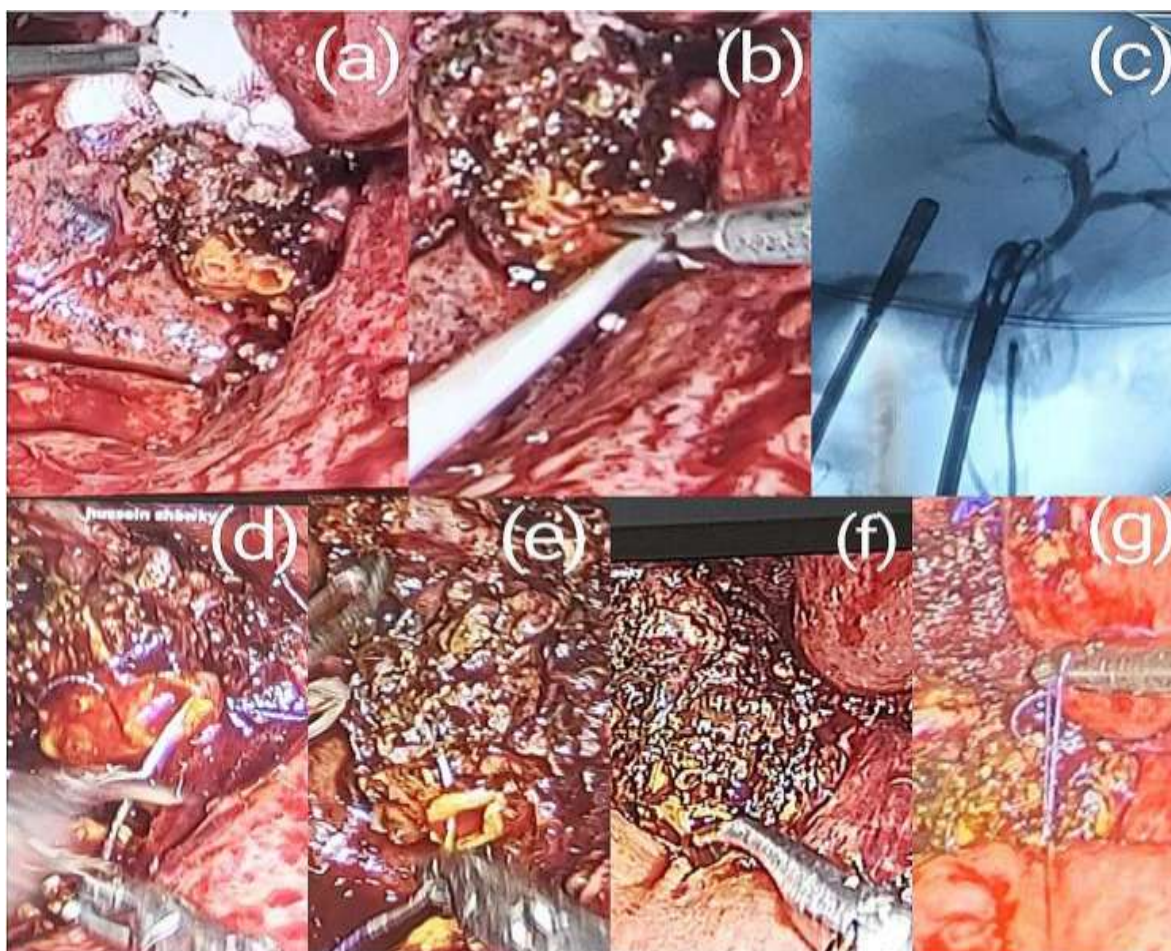


Figure 7. Laparoscopic reconstruction with Roux-en-Y hepaticojejunostomy.

The original operative sequence shows a transected bile duct, introduction of a catheter for intraoperative cholangiography with opacification of both hepatic lobes, placement of sutures in the proximal duct, and completion of laparoscopic hepaticojejunostomy with the jejunal limb approximated to the duct. Source: Zidan MHED, Seif-Eldeen M, Ghazal AA,

Refaie M. Post-cholecystectomy bile duct injuries: a retrospective cohort study. BMC Surg. 2024;24:8, Fig. 3. DOI: 10.1186/s12893-023-02301-2. Reuse is permitted under CC BY 4.0. The legend should be taken from the corrected version of the article (Correction DOI: 10.1186/s12893-024-02332-3).



Figure 8. Complete common bile duct transection and reconstruction with Roux-en-Y hepaticojejunostomy.

A 28-year-old woman sustained complete common bile duct transection during cholecystectomy and presented with jaundice on postoperative day 6. MRCP and percutaneous cholangiography demonstrated abrupt interruption of the common bile duct with proximal dilatation. CT after reconstruction shows the Roux jejunal limb and a stent within the bilioenteric pathway. Reproduced from: Kazi IA, Siddiqui MA, Thimmappa ND, et al. Post-operative complications of cholecystectomy: what the radiologist needs to know. *Abdom Radiol (NY)*. 2025;50:109-130, Fig. 12. DOI: 10.1007/s00261-024-04387-5. Reuse is permitted under CC BY 4.0.

Roux-en-Y Hepaticojejunostomy: Step-by-Step Technical Considerations

Preparation begins with careful hilar exposure and review of all preoperative imaging. The ducts draining each hemiliver, their relationship to clips or necrotic areas, and the presence of arterial injury must be identified. Aggressive dissection of ductal stumps should be avoided because it can devascularize segments supplied longitudinally by the peribiliary plexus. The duct is divided or refreshed only until a macroscopically viable edge is reached; in high injuries, lowering the hilar plate and opening the left hepatic duct longitudinally increase the usable diameter of the anastomosis. These principles form the basis of contemporary hepaticojejunostomy for iatrogenic injury [32].

The jejunal limb is selected with sufficient length to reach the hilum without tension or twisting. A Roux-en-Y configuration is usually created and the limb brought to the hilum through a route that avoids mesenteric compression. The anastomosis should incorporate the entire available lumen; interrupted or continuous suturing may be used according to duct caliber, tissue quality, and surgeon preference, because current comparative evidence does not establish a universally superior suture pattern [35]. The posterior and anterior walls should be approximated without luminal narrowing, with meticulous atraumatic tissue handling.

In E4 injuries, the goal is to incorporate drainage from both right and left systems. When ductal openings are close, ductoplasty can create a common channel; when they are separated, double anastomosis may be required. If one hemiliver is severely ischemic, atrophic, or associated with irreversible vascular injury, hepatic resection may form part of the strategy, although this is an exceptional indication reserved for high-complexity centers [36]. More extensive salvage procedures are exceptional and fall outside the principal evidence base reviewed here.

The role of routine transanastomotic stenting remains controversial, and practice varies among specialized centers. When a stent is used selectively, it should be regarded as an adjunct rather than a substitute for a wide, well-perfused, tension-free anastomosis. Likewise, abdominal drainage may facilitate recognition or control of a postoperative bile leak

but does not compensate for inadequate reconstruction. These decisions should be individualized according to anatomy, tissue quality, and local expertise.

CENTRALIZATION, HPB EXPERTISE, AND EVOLUTION OF TECHNIQUE

The success of the first reconstruction is critical because each failed attempt adds fibrosis, reduces usable duct length, and may compromise vascularity. A cohort of 907 repairs from a high-volume Latin American center documented technical evolution over four decades and confirmed that E4–E5 injuries carry a higher risk of recurrent cholangitis and reintervention than E1–E3 injuries [37]. The value of these data lies in showing that outcomes depend on accumulated expertise and adaptation of the technique to anatomy, not solely on injury category.

A European referral-center experience also reported high patency after specialist repair, reinforcing the importance of structured referral [38]. Recent series from other regions convey the same message: causes, referral patterns, and outcomes vary, but definitive reconstruction in HPB units enables standardization of diagnosis, drainage, and follow-up [39]. In a cohort of major injuries repaired at a North African HPB center, morbidity was substantial, but the large majority of survivors maintained favorable long-term functional outcomes, illustrating both the severity of the disease and the potential of expert reconstruction [40].

Reoperation for Late Failure

Late failure typically presents as stricture, recurrent cholangitis, or intrahepatic lithiasis. Ray et al. analyzed reoperative surgery after failed repairs and showed that repeat reconstruction can restore drainage, although the procedure is more complex and outcomes tend to be inferior to those achieved after a well-performed primary repair [41]. Therefore, evaluation after a failed previous reconstruction should include MRCP, selective drainage of obstructed segments, and planning of a proximal anastomosis on viable tissue.

Alternatives to classic hepaticojejunostomy have been described, including end-to-end biliary anastomosis supported by transhepatic drainage in highly selected cases with minimal tissue loss and viable edges; however, these strategies do not replace bilioenteric reconstruction when there is tissue loss, ischemia, or high transection [42].

MINIMALLY INVASIVE AND ROBOTIC SURGERY

Minimally invasive surgery for post-cholecystectomy biliary stricture and reconstruction has evolved but requires advanced HPB expertise and intracorporeal suturing skills. A review of the evidence highlights that patient selection, injury level, and previous interventions determine feasibility [43]. A series of laparoscopic BDI repair showed that the approach can be feasible in expert hands with acceptable early

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outcomes, although patient numbers remain small compared with the accumulated open-surgery experience [44].

The robotic platform provides stable visualization, wristed articulation, and ergonomics for fine anastomotic work. Early comparisons between robotic and open reconstruction suggest feasibility, but small series and selection bias preclude conclusions of superiority [45]. Robotic revision of hepaticojejunostomy for benign stricture has also been described [46], as has delayed robotic repair of an E2 injury [47]. Consistently, the SAGES-AHPBA guideline accepts both open and minimally invasive repair but grades the certainty of evidence as very low; therefore, approach selection should follow center expertise rather than technological preference.

COMPLEX RECONSTRUCTIONS AND MULTIPLE ANASTOMOSES

Central injuries may leave several separate biliary openings and require a combination of ductoplasty, multiple anastomoses, and transhepatic drains. Ordieres et al. described a patient with a complex central injury after cholecystectomy in whom three ductal openings were identified; the two left-sided ducts were unified and reconstructed with one hepaticojejunostomy, whereas the right duct required a second hepaticojejunostomy to the same Roux limb [48]. This scenario illustrates why anatomic classification must be accompanied by a segmental strategy: the goal is not to reconstruct “a duct,” but to ensure drainage of all functional liver parenchyma.

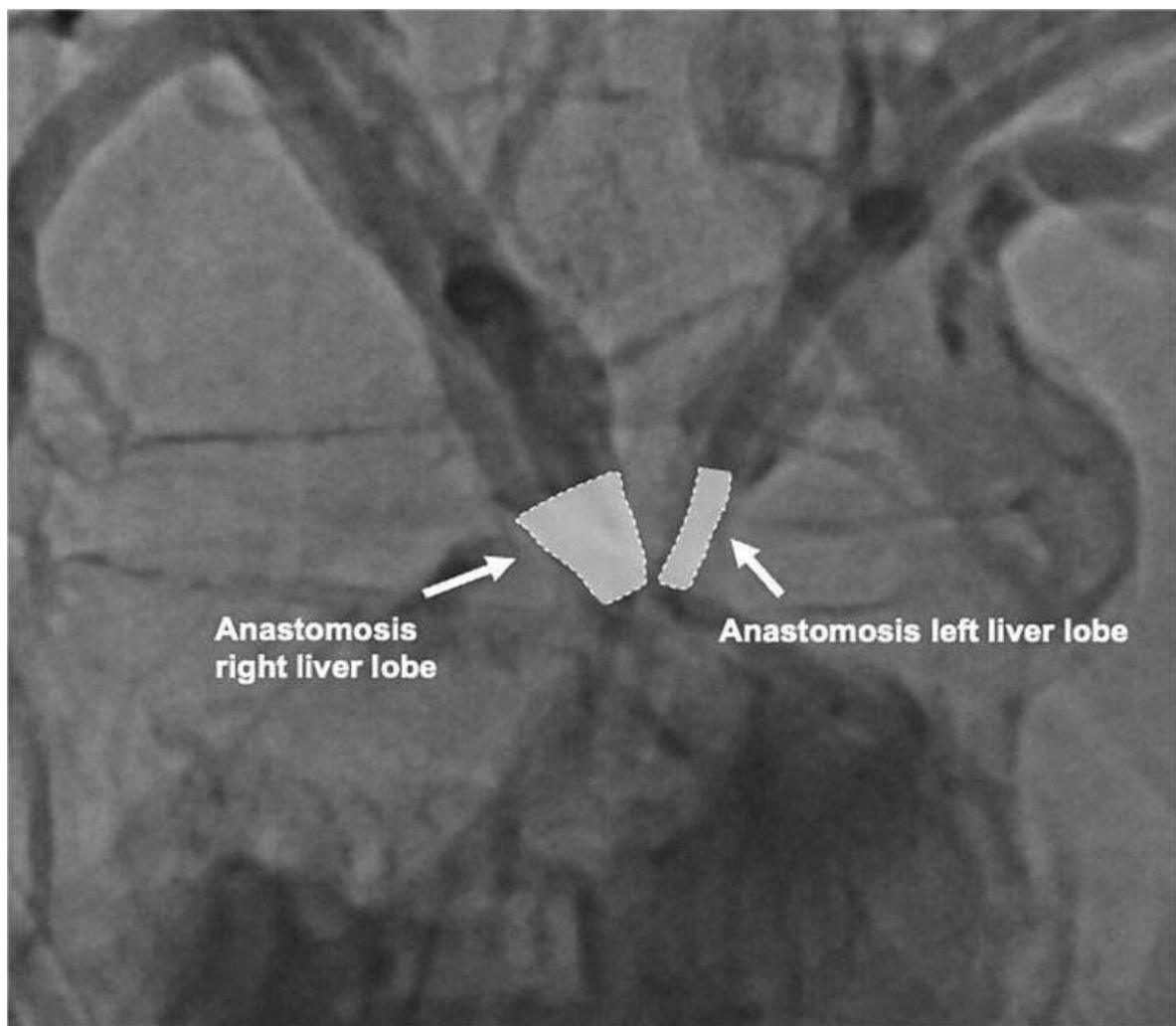


Figure 9. Double hepaticojejunostomy after reconstruction of a complex central bile duct injury.

A 64-year-old woman with obesity, severe acute cholecystitis, and choledocholithiasis underwent sphincterotomy and endoscopic stenting followed by laparoscopic cholecystectomy. On postoperative day 1, approximately 400 mL of bile was observed through the drain. Re-exploration was converted to open surgery and revealed three separate biliary openings above the confluence. Two hepaticojejunostomies with transhepatic drains were constructed. The original contrast study obtained

4 weeks later demonstrates both anastomoses. At 18 months, the patient remained free of biliary complications. [48] Reproduced from: Ordieres M, Beyer L, Möller J, Marusch F, Schmidt SC. Management of a complex central bile duct injury associated with laparoscopic cholecystectomy: a case report of double hepaticojejunostomy and advanced transhepatic interventional drainage technique. *J Surg Case Rep.* 2025;2025(9):rjaf726, Fig. 3. DOI: 10.1093/jscr/rjaf726. Licensed under the Creative Commons

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OUTCOMES, COMPLICATIONS, AND FOLLOW-UP

After an apparently successful reconstruction, surveillance should focus on stricture, cholangitis, intrahepatic lithiasis, liver abscess, segmental atrophy, and secondary biliary cirrhosis. Recurrence may be late, and normal liver tests during the first postoperative months do not guarantee durable patency. A contemporary single-center series reported substantial postoperative morbidity, with early complications in 50% of patients and late complications in 22.7%, underscoring the potential long-term burden of major BDI [49].

Long-term follow-up should include periodic clinical assessment and liver biochemical tests. Ultrasonography is useful for detecting ductal dilatation, whereas MRCP is appropriate when biochemical abnormalities, recurrent cholangitis, or suspected anastomotic stricture occur. In patients with hepaticojejunostomy, recurrent fever or cholangitis should prompt investigation even when ductal dilatation is modest. Strictures can initially be treated through percutaneous access, dilatation, and drainage; reoperation is reserved for failure of interventional treatment, inaccessible anatomy, or complex segmental disease.

Detection and Management of Anastomotic Stricture

Hepaticojejunostomy stricture may present with asymptomatic cholestasis, episodes of cholangitis, liver abscesses, or intrahepatic lithiasis. The absence of marked ductal dilatation on ultrasonography does not exclude clinically relevant obstruction, particularly when only one sector is affected. When stricture is suspected, MRCP maps the distribution of ductal dilatation and can guide percutaneous access. Contemporary risk models identify sepsis, bile leakage, and previous repairs among factors associated with stricture, reinforcing the importance of patient optimization before the first reconstruction [34].

The initial approach to a stricture is usually percutaneous: cholangiography, traversal of the anastomosis, progressive dilatation, and internal-external drainage. Treatment may

require several months and multiple sessions. Reoperation should be considered when the stricture cannot be crossed, recurs after adequate percutaneous therapy, the anastomosis is anatomically inadequate, or segmental disease cannot be resolved by interventional radiology.

Long-Term Outcomes and Surveillance

Long-term outcome after BDI should not be assessed solely by perioperative mortality or immediate anatomic patency. Recurrent cholangitis, repeated procedures, and late anastomotic stricture can generate substantial long-term morbidity. Durable reconstruction therefore requires both technical success and sustained surveillance. Series with extended follow-up demonstrate that a well-constructed hepaticojejunostomy can provide favorable long-term stricture-free outcomes [33].

Surveillance should be individualized according to injury severity, the complexity of reconstruction, and previous repair attempts. Unexplained fever, right upper quadrant pain, cholestatic liver-test abnormalities, or recurrent cholangitis should prompt reassessment. In patients with E4/E5 reconstructions, associated vascular injury, or previous failed repairs, a lower threshold for cross-sectional biliary imaging is appropriate.

PRACTICAL MANAGEMENT ALGORITHM

A useful clinical algorithm can be summarized in five steps. First, recognize the suspicion of BDI: bile through a drain, biloma, persistent pain or fever, jaundice, sepsis, or cholestasis after cholecystectomy. Second, stabilize the patient and obtain source control with antibiotics, drainage of collections, and organ support. Third, define the anatomy with CT and MRCP; use ERCP when continuity is preserved and therapeutic intervention is anticipated, and PTC when proximal ducts are inaccessible or a high transection is present. Fourth, classify the injury and determine whether it is minor and amenable to endoscopic/percutaneous management or major and likely to require reconstruction. Fifth, perform definitive repair only when HPB expertise is available, anatomy is defined, drainage is adequate, and tissue is suitable for a durable anastomosis.

Table 1. Practical Approach According to the Timing of Recognition

Scenario	Immediate objective	Definitive reconstruction	Key point
Intraoperative, minor injury	Control leakage; confirm anatomy	Often not required	Avoid extending the injury; postoperative ERCP if leakage persists.
Intraoperative, major injury	IOC when safe; document anatomy; drainage	Immediate only by an expert HPB team	Do not perform an improvised complex repair.
<2 weeks, stable patient	Drain collections and define anatomy	May be considered early in expert centers	Physiology and expertise are as important as elapsed time.

2-6 weeks	Control sepsis, drain, and optimize the patient	Often defer when inflammation is significant	This interval has been associated with poorer outcomes in several evidence syntheses.
>6 weeks	Optimize and plan reconstruction	Classic delayed window	Conditionally favored by SAGES-AHPBA when clinically feasible.

CURRENT CONTROVERSIES AND RESEARCH PRIORITIES

Four major controversies remain. The first concerns timing: the best recent evidence supports avoiding reconstruction during uncontrolled sepsis and recognizes that both selected early repair and delayed repair can yield good outcomes; guidelines nevertheless continue to conditionally favor repair after 6 weeks because of uncertainty in the evidence. The second concerns operative approach: open, laparoscopic, and robotic reconstruction may all be valid, but anastomotic quality and team expertise are more important than the platform itself. The third controversy concerns transanastomotic stents. Some teams use them in small, multiple, or inflamed ducts, whereas others avoid them because of infection, migration, or the need for subsequent procedures. Current evidence is insufficient to recommend routine use. The fourth concerns prevention through intraoperative imaging: IOC and ICG fluorescence improve anatomic visualization, but neither compensates for unsafe dissection nor eliminates the need for bailout strategies when the CVS cannot be achieved.

CONCLUSIONS

Bile duct injury following cholecystectomy should be approached as a time-sensitive diagnostic problem and, when major reconstruction is required, as a highly specialized HPB procedure. Early recognition, control of sepsis and bilomas, complete definition of biliary and vascular anatomy, and early referral to an HPB center are the most consistent determinants of a favorable outcome. Minor injuries with preserved ductal continuity usually respond to endoscopic therapy; major injuries frequently require Roux-en-Y hepaticojejunostomy. Timing should be individualized: immediate or early repair may be appropriate when the patient is stable and HPB expertise is available, whereas delayed reconstruction after 6 weeks remains a robust strategy and is conditionally supported by the SAGES-AHPBA guideline. The central technical principle is a wide, mucosa-to-mucosa, well-vascularized, tension-free anastomosis. Because of the risk of late stricture, follow-up should continue for years.

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