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REVIEW ARTICLE

Postcholecystectomy bile duct injury and its sequelae: Pathogenesis, classification, and management

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Abstract A bile duct injury sustained during cholecystectomy can change the life of patients who submit themselves to a seemingly innocuous surgery. It has far-reaching medical, socioeconomic, and legal ramifications. Attention to detail, proper interpretation of variant anatomy, use of intraoperative cholangiography, and conversion to an open procedure in cases of difficulty can avoid/lessen the impact of some of these injuries. Once suspected, the aims of investigation are to establish the type and extent of injury and to plan the timing and mode of intervention. The principles of treatment are to control sepsis and to establish drainage of all liver segments with minimum chances of restricturing. Availability of expertise, morbidity, mortality, and quality of life issues dictate the modality of treatment chosen. Endoscopic intervention is the treatment of choice for minor leaks and provides outcomes comparable to surgery in selected patients with lateral injuries and partial strictures. A Roux-en-Y hepaticojejunostomy (HJ) by a specialist surgeon is the gold standard for high strictures, complete bile duct transection and has been shown to provide excellent long-term outcomes. Percutaneous intervention is invaluable in draining bile collections and is useful in treating post-HJ strictures. Combined biliovascular injuries, segmental atrophy, and secondary biliary cirrhosis with portal hypertension are special circumstances which are best managed by a multidisciplinary team at an experienced center for optimal outcomes.

Keywords Bile duct stricture · Complications · Laparoscopic cholecystectomy

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Introduction

Bile duct injury (BDI) during cholecystectomy is a problem with far-reaching medical, economic, and legal implications. It is liable to occur even in experienced hands when one is past the so-called learning curve [1]. All efforts must be made to prevent this complication, as an error on the part of the surgeon can significantly impair the patient's quality of life (QOL) [2] or even endanger it [3]. Evidence suggests that these injuries are best managed at an experienced hepatobiliary unit for optimal results [4]. Though it is nearly two decades since laparoscopic cholecystectomy (LC) has become established as the gold standard for patients with symptomatic gallstone disease, the incidence of BDI remains higher than with open cholecystectomy (0.2 % to 0.7 % vs. 0.1 % to 0.3 %) [3]. It has been reported that, when compared with open surgery, biliary injuries sustained during LC are more likely to present earlier, more often associated with persistent bile leaks, and usually closer to the porta hepatis [5]. Due to the enormity of the impact of a BDI, it is worthwhile to always endeavor to prevent rather than treat one. Evaluation of a patient with BDI, stratification of the type and extent of injury, and planning the appropriate timing and type of intervention require the input of specialists with special interest in this area for optimal outcome.

Pathogenesis

Risk factors

Risk factors for BDI during cholecystectomy can be thought to occur due to anatomical factors, nature of the pathology, and operator-dependent factors. Of these, only the last is modifiable by adopting safe surgical practices. In cases where the gallbladder is adherent to the common bile duct (CBD) or common hepatic duct (CHD), traditional techniques like the infundibular or fundus-first techniques can become error traps resulting in serious biliovascular injuries [6]. At the beginning of the laparoscopic era, BDI occurred with increasing frequency in the initial part of the learning curve of surgeons who switched from a conventional open approach, with loss of haptic sensation and three-dimensional orientation. In the present day, most surgical trainees learn LC under the supervision of preceptors who have more experience. Although most injuries occur within the surgeon's first 100 laparoscopic cholecystectomies, one third happen after the surgeon has performed more than 200 cases [7]; it is more than inexperience that leads to BDI [7]. BDI during laparoscopy tends to be more complex by being more proximal and associated with concomitant vascular injury. A classic laparoscopic injury occurs when the CBD is mistaken for the cystic duct and is caused by excessive cephalad retraction of the fundus of the gallbladder in which the cystic and common ducts become closely aligned. The surgeon, erroneously thinking the cystic duct has been successfully divided, continues to dissect the common duct proximally and eventually transects the CHD [8]. The right hepatic artery (RHA) is also typically injured or ligated because of its proximity. It is reported that BDI more often than not occurs due to an error in perception rather than due to a lack of knowledge, skill, or judgment [9]. The cognitive misperception of anatomy is so compelling that injuries are seldom recognized at the time of surgery and the operation may be thought to be normal [9].

Prevention of BDI

Demonstration of the critical view of safety as described by Strasberg et al. [10] identifies the cystic duct and artery as they enter the gallbladder and permits safe clipping and division of these structures. The main reason for inadvertent transection of the CBD is mistaking it to be the cystic duct [9, 11, 12]. Rouveire's sulcus [13] and Hartmann's pouch are important landmarks; however, care is taken in cases where the latter is distorted or abolished as in patients with atrophic cholecystitis, impacted cystic duct stone, and adhesions between cystic duct and the neck of gallbladder and in incorrect dissection [14]. The traction on the gallbladder in LC should be in a lateral direction rather than in a superior direction to prevent tenting of the CBD and inadvertent injury during clipping.

Bleeding obscures the operating field and there is no place for panic or blind application of clips or electrocautery. In many instances, pressure for a few minutes will control bleeding and permit accurate hemostasis [15]. In cases of uncontrolled bleeding, conversion to an open procedure is a wise option. Use of a 30° scope permits proper visualization. In some instances of acute cholecystitis, it may be a good idea to open the gallbladder (when one is reasonably sure that there is no malignancy) at a safe area, extract the stones, oversew the cystic duct, and complete the cholecystectomy [16]. A prudent approach in such cases would be to do a cholecystostomy which would entail the least risk [15].

Population-based studies [3] have shown a reduction in risk if surgeons perform routine intraoperative cholangiography, although all are subject to bias. Routine use of cholangiography is cost-effective [17], with maximum efficiency achieved when used by inexperienced surgeons or when complex disease is encountered. Though intraoperative cholangiography does not prevent an injury, it does give the opportunity to identify it early. Archer et al. [7] report that 81 % of bile duct injuries were detected at the time of initial surgery when a cholangiogram was obtained in comparison to only 45 % when it was not employed. This has significant implications for the patient given the improved outcome associated with early appropriate repair.

Surgery should be unhurried, keeping patient safety paramount. Inadvertent injuries of the bile duct are reported to occur due to casual approach, overconfidence, and ignorance of difficult situations [12]. Using analogies from aviation safety, there are excellent expert reviews on methods to prevent BDI during LC [15, 18]. The central tenet of safe surgery is to recognize danger signs well in advance and avoid it. It cannot be emphasized enough that timely conversion to an open procedure is a smart decision rather than a failure [9, 15]. Heightened awareness to the possibility of BDI in every case of cholecystectomy, adoption of safe surgical practices, and knowing when to back out/call for help should be important aspects of resident training. Risk factors for BDI and possible preventive measures are summarized in Table 1.

Classification

Most classification systems for BDI encountered during laparoscopy describe a spectrum ranging from minor cystic duct leaks to complete transection [10], even excision of the CBD with or without a concomitant vascular injury [19, 20]. Most large series from experienced authors also elucidate the mechanisms of these injuries and preventive strategies [10, 19, 20]. Although classifications are useful for standardization of outcome reporting and guiding management decisions, there is no ideal system. Most current versions fail to take into account important short-term prognostic factors, including mode of presentation, attempts at previous repair, presence of concomitant sepsis, and stability of the patient [21]. Other important issues like concomitant vascular injury, presence of secondary biliary cirrhosis, portal hypertension, and segmental atrophy are also not considered routinely in all systems.

The salient features of most prevailing classification systems are detailed in Table 2 [22–30]. Bismuth proposed a classification system (Fig. 1) based on the lowest level at which healthy biliary mucosa is available for anastomosis [22]. This classification is applicable while evaluating long-

Table 1 Risk factors and prevention of BDI during cholecystectomy

Risk factor	Measures to prevent BDI
Anatomical variants	
Low insertion of the right posterior sectoral duct, cystic duct opening into the right hepatic duct, RHA looping into the Calot's triangle	Awareness of common variant anatomy Careful interpretation of preoperative imaging if available Unhurried dissection, division of cystic duct and artery close to gallbladder
Difficult pathology	
Acute cholecystitis, acute biliary pancreatitis, bleeding in Calot's triangle, severely scarred or shrunken gallbladder, large impacted gallstone in Hartmann's pouch, short cystic duct, Mirizzi's syndrome	Optimal timing of surgery Establishing critical view of safety Avoiding dissection near the hilum, separation of duodenum or colon in case of very dense adhesions Early conversion, call for help Opting for subtotal cholecystectomy or cholecystostomy Use of ultrasonic activated scalpel for dissection in select cases, stapling device to tackle the Hartmann's pouch or wide cystic duct
Operator-dependent factors	
Learning curve, errors of perception, oversight of safety protocols	Supervised training during residency Use of anatomical landmarks Visualization of the position of CBD at the start of surgery and beginning dissection at a safe area Staying ventral to the Rouviere's sulcus [13]. The cystic lymph node serves as a guide to the position of the cystic artery Hartmann's pouch is useful to orient the surgeon to the cystic duct–gallbladder junction Safety protocols Electrocautery should be used judiciously, in short bursts, in the minimum required settings and always under vision, targeting only a specific small area to prevent mishaps related to inadvertent thermal injury Use of intraoperative cholangiography when the anatomy is not clear Clear checkpoints for conversion—failure of progression of the dissection, anatomic disorientation, difficulty in visualization of the field, and inability of the laparoscopic equipment to carry out usual tasks such as grasping of the gallbladder or separation of tissues [15]

BDI bile duct injury, *CBD* common bile duct, *RHA* right hepatic artery

term sequelae following BDI. The laparoscopic era has seen reports of complex and high injuries, often accompanied by damage to the RHA. Strasberg's classification of laparoscopic biliary injuries is stratified from classes A to E [10]. Class E injuries are further subdivided into E1 to E5 according to Bismuth's classification system.

There are numerous other classifications from reputed centers (Table 2). All these grade the extent of the severity of biliary injury and describe varying types of injuries to the extrahepatic bile ducts and the mechanisms responsible for these. Despite the presence of so many classification systems, the Bismuth and Strasberg systems remain most popular and widely used. Till a comprehensive and ideal system becomes widely established, it is important to document BDI descriptively in medical records, both for better understanding of factors that lead to the injury and for medicolegal purposes.

Management

Initial evaluation

Management depends on the timing of recognition of injury, the extent of BDI, the patient's condition, and the availability of expertise. A high index of suspicion is required to diagnose BDI in the postoperative period as only about 20 % to 30 % of injuries are diagnosed at the time of initial surgery [9]. The aim of evaluation is, firstly, to assess and tackle any acute conditions such as bile collections or ongoing bleeding. The second step is to assess the extent and type of injury to plan the timing and mode of intervention. If the patient has been referred from another hospital, it is useful to review the operating notes and talk to the primary surgeon. The importance of accurate, unhurried, and frank communication with patients and their relatives with clear documentation in medical records cannot be overemphasized. Initial symptoms [31] may be nonspecific; patients are discharged from the hospital frequently only to present a few days later with jaundice, biliary drainage from an existing drain, biliary ascites, or bile peritonitis [9]. Late presentation is in the form of a stricture which is usually diagnosed on imaging with deranged liver function tests (LFT) (elevated bilirubin and alkaline phosphatase) in the face of recurrent bouts of cholangitis. In some instances, patients present with secondary biliary cirrhosis and

Table 2 Classification systems for postcholecystectomy BDI

Classification system	Subtypes	Salient points
Bismuth [22, 23]	Type I—common duct stump longer than 2 cm, can be repaired without opening the left duct and without lowering the hilar plate	Good correlation with final outcome after surgical repair; simplicity, universal appeal, basis on sound surgical principles
	Type II—stump shorter than 2 cm, requires opening the left duct for a satisfactory anastomosis	Introduced in the open era of cholecystectomy and useful for strictures though also applied in the acute setting
	Type III—ceiling of the biliary confluence is intact, requires lowering the hilar plate and anastomosis on the left ductal system	The established stricture is generally one level higher than the level of the injury because of ischemic damage, compensatory shortening that accompanies proximal dilatation
	Type IV—confluence is interrupted and requires either reconstruction or two or more anastomoses	In practice, lowering the hilar plate and opening of the left duct can be accomplished safely and quickly in most cases. Therefore these procedures may be adopted safely for all type of biliary strictures to obtain the widest possible anastomosis and the least chance of recurrence
	Type V—strictures of the hepatic duct associated with a stricture on a separate right branch, and the branch must be included in the repair	
Sikora et al. [24]	Subclassified type III Bismuth strictures as type III A where the confluence is healthy and type III B where the roof of the confluence is healthy and right and left ductal continuity is maintained, although the floor of the confluence is scarred	The operative blood loss, blood transfused and operating time were significantly longer in type III B strictures Hence, it is proposed that type III B strictures be subclassified along with type IV strictures
Strasberg et al. [10]	A—cystic duct leaks or leaks from small ducts in the liver bed (bile leak from a minor duct still in continuity with the CBD)	Class A leaks have the potential to subside spontaneously and will most certainly resolve after ERC stenting
	B—occlusion of a part of the biliary tree, almost invariably the aberrant right hepatic ducts	Class B injuries can be missed and may remain asymptomatic or present late with features of cholangitis due to an occluded sectoral duct, requiring a hepatectomy for resolution of symptoms
	C—Transection without ligation of the aberrant right hepatic ducts (bile leak from the duct not in the communication with the CBD)	Class C injuries present in the postoperative period with bile leaks/collection and cannot be demonstrated by ERC as the duct is not in continuity with the CBD. Careful review of cholangiograms is necessary to avoid missing these injuries (Fig. 3)
	D—lateral injuries to major bile ducts	Class D injuries when detected on table can be managed with primary repair with or without a T-tube, but rates of stricture formation are high when there is tissue loss
	E—Subdivided as per Bismuth's classification into E1 to E5	Classes C, D, and E injuries are best treated with a Roux-en-Y HJ following standard principles of surgical repair
		Used widely to describe the type of acute BDI and has management implications
McMahon et al. [25]	Type of injury may be subdivided into bile duct laceration, transection, excision, and stricture	Minor injury can usually be managed by simple suture repair and/or insertion of a T-tube
	The level of stricture may be further graded according to Bismuth's classification	Major injury usually requires HJ
	Minor ductal injury–laceration of CBD <25 % of diameter, laceration of cystic–CBD junction	
	Major ductal injury–laceration >25 % of bile duct diameter, transection of CHD or CBD, development of postoperative bile duct stricture	
Amsterdam Academic	Type A—cystic duct leaks or leakage from	Majority of type A and most type B lesions are

Table 2 (continued)

Classification system	Subtypes	Salient points
Medical Center [26]	aberrant or peripheral hepatic radicles	amenable to ERC stenting
	Type B—major bile duct leaks with or without concomitant biliary strictures	Majority of type C and all type D lesions require surgical intervention
	Type C—bile duct strictures without bile leakage	
	Type D—includes complete transection of the duct with or without excision of some portion of the biliary tree	
Neuhaus et al. [27]	Describes varying grades of peripheral bile leaks, occlusion, lateral injury, transection and stenosis of the CBD	Treatment strategies can be tailored according to the anatomical type of injury
		Does not account for vascular injuries
Csendes et al. [28]	Type I—a small tear of the hepatic duct or right hepatic branch caused by dissection with the hook or scissors during the dissection of Calot's triangle	Describes the mechanism of injury in detail and hence is useful while applying preventive strategies
	Type II—lesions of the cysticocholedochal junction due to excessive traction, the use of a Dormia catheter, electrocautery or section of the cystic duct very close or at the junction with the CBD	Does not account for vascular injuries
	Type III—a partial or complete section of the CBD	
	Type IV—resection of more than 10 mm of the CBD	
Stewart-Way et al. [19]	Class I—CBD mistaken for cystic duct, but recognized on cholangiogram; incision in cystic duct extended on to CBD	Details the mechanisms and possible reasons for various classes of injuries
	Class II—bleeding, poor visibility	Also makes provision for combined biliovascular injuries
	Multiple clips placed on CBD/CHD	
	Class III—CBD mistaken for cystic duct, not recognized. CBD, CHD, or right or left hepatic ducts transected and/or resected	
	Class IV—right hepatic duct (or right sectoral duct) mistaken for cystic duct	
	RHA mistaken for cystic artery	
	Right hepatic duct (or right sectoral duct) and RHA transected	
Lau et al. [20]	Type I—leaks from the cystic duct stump or small ducts in liver bed	Classification system with increasing grades of severity, different mechanisms of injury
	Type 2—partial CBD/CHD wall injuries without (2A) or with (2B) tissue loss	Emphasizes attention to operative detail to prevent these injuries
	Type 3—CBD/CHD transection without (3A) or with (3B) tissue loss	The magnitude of treatment differs according to the type of injury
	Type 4—hepatic duct or sectoral duct injuries without (4A) or with (4B) tissue loss	
	Type 5—BDI associated with vascular injuries	
Kapoor [29]	A simple "BCD" system which describes whether there was presence or absence of bile leak, whether the circumference injured was partial or total and the duct injured was significant or not	Also makes provision for associated vascular injuries and is conceptually appealing and easy to remember
		Guides management and predicts the outcome of a BDI
Hannover system [30]	Type A—cystic and/or gallbladder bed leaks	Classifies injuries in relationship to the confluence and also includes vascular injuries
	Type B—complete or incomplete stenosis caused by a surgical staple	Reproducible and ensures uniformity of reporting
	Type C—lateral tangential injuries	
	Type D—complete transection of the CBD emphasizing the distance from the confluence as well as concomitant hepatic artery and portal vein injuries	
	Type E—late bile duct stenosis at varying distances from the confluence	

CBD common bile duct, *BDI* bile duct injury, *ERC* endoscopic retrograde cholangiography, *HJ* hepaticojejunostomy, *CHD* common hepatic duct, *RHA* right hepatic artery

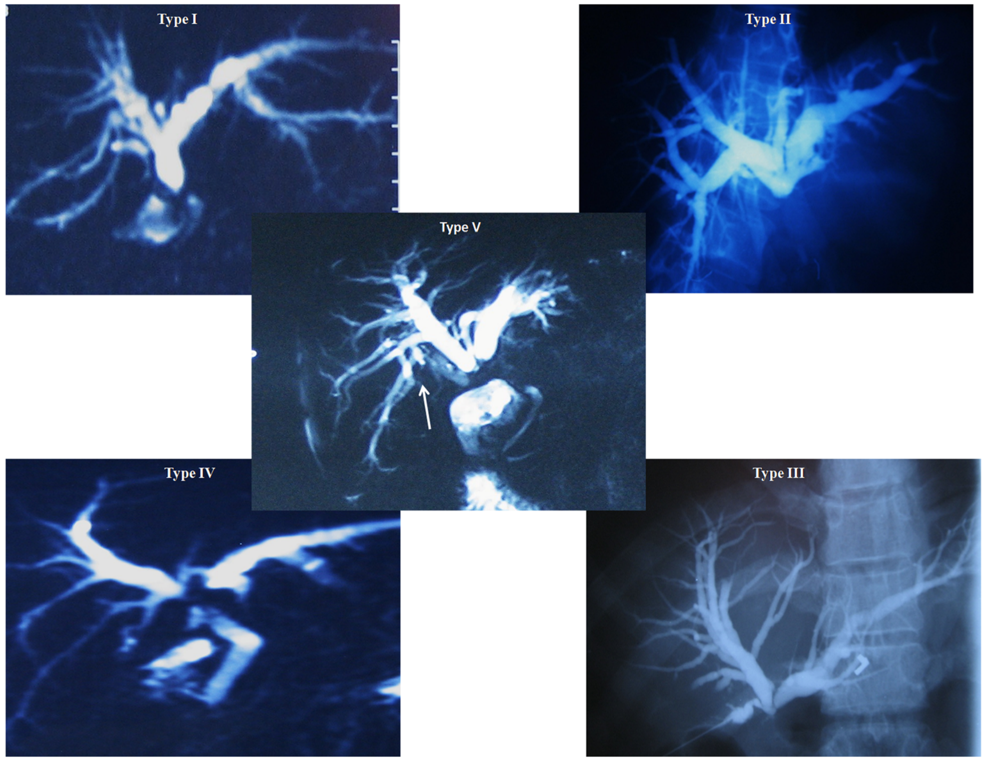


Fig. 1 Magnetic resonance images illustrating the different types of postcholecystectomy bile duct strictures as per the Bismuth classification. The *arrow* in the central figure points to clips applied to the segment 6 duct

its complications. Persistent increase in bilirubin or alkaline phosphatase after a couple of days after cholecystectomy should prompt the assessment of a BDI. Abdominal ultrasound (USG) will evaluate the presence of fluid collections and intrahepatic biliary dilatation. A computed tomography (CT) has better sensitivity than USG (96 % vs. 70 %) [31] in detecting fluid collections (Fig. 2) and is useful if the latter is equivocal. If BDI is strongly suspected or image-guided aspiration shows bile, a cholangiogram is indicated. A magnetic resonance cholangiogram (MRC) is usually the investigation of choice. Both a percutaneous transhepatic cholangiogram (PTC) and MRC are comparable with regard to image quality, detection of intrahepatic bile duct dilatation, assessment of the level of injury, and detection of abnormalities such as intraductal calculi, cholangitic liver abscesses, and atrophy of liver lobes. MRC is, however, noninvasive and provides additional information on associated fluid collections and portal hypertension [32]. A percutaneous drain, if placed at the time of surgery, may be used to perform a cholangiogram. If a leak from the cystic duct or bile duct, a lateral injury, or a noncircumferential stricture is apparent on MRC, an endoscopic retrograde cholangiography (ERC) is indicated as it has therapeutic potential. ERC will not be helpful if there is a complete cutoff with no continuity of the extrahepatic biliary tree. While interpreting cholangiograms, it is important to confirm integrity of all sectoral bile ducts [6]. It is easy to miss a sectoral duct injury unless specifically sought for (Fig. 3). There is no role for diagnostic exploratory laparotomy/relaparoscopy to delineate biliary anatomy. Emergency surgery in this setting is done for peritoneal lavage and drainage in order to establish a controlled biliary fistula. Once referred to a specialist unit for management, an assessment of vascular anatomy is required as vascular injury is present in 12 % to 40 % of patients [33]. Vascular assessment is particularly important if there has been a previous attempt at repair and in the management of more proximal injury, which may be associated with damage to the RHA. This is of significance when an early repair is contemplated. It should be remembered that a malignant stricture can very rarely masquerade as a postcholecystectomy benign stricture [34].

Selection of patients for percutaneous, endoscopic, or surgical management

In the management of postcholecystectomy BDI, interventional radiology, endoscopy, and surgery have complementary rather than competing roles. Before embarking on any mode of intervention, it is important to take stock of the patient's general condition, the type of injury, and the expected benefits and risks in light of the published results of the procedure. Free bile in the peritoneal cavity should be a high alert situation. It is often seen that different patients react differently to it and a particular patient may throw up an unexpectedly severe systemic response after a quiescent course. Multiple image-guided percutaneous catheters can be used by a skillful interventional radiologist to obtain drainage and establish a controlled external biliary fistula. ERC and stenting can stop an ongoing leak. However, the presence of peritonitis calls for surgical intervention. Where expertise is available, a thorough laparoscopic lavage and drain placement under direct vision can achieve the objective of containing systemic sepsis without the need for a laparotomy. The emphasis is on multidisciplinary management. An algorithm for the management of BDI utilizing different modalities of treatment is depicted in Fig. 4. In class A injuries, ERC and stenting has a 99 % success rate and is clearly the treatment of choice [35]. Class B injuries may remain asymptomatic or present late with atrophy–hypertrophy complex (Fig. 5) and sectoral cholangitis. The latter may require hepatectomy. An isolated sectoral duct injury may present with ongoing biliary leak (class C) despite an ERC interpreted mistakenly as being normal [36]. In this setting, percutaneous drainage of the isolated segment allows proximal control of the biliary leak in many cases [36]. In patients who require surgery, hepaticojejunostomy (HJ) is the treatment of choice [37] and the catheter acts as guide at the time of surgery [38]. For class D injuries without tissue loss, a reasonable surgical option is primary closure with fine absorbable sutures and subhepatic drainage, rather than placement of a T-tube; experience in liver transplantation has shown that a T-tube placed within a choledochocholedochostomy is associated with a significantly higher stricture rate than with repair without a T-tube (25 % vs. 11 %) [39]. In patients with significant loss of duct substance, an HJ is the preferred option, although end-to-end repair may be considered in select cases [40]. Surgical repair is indicated for injuries with complete transection of the bile duct and for most E4 and E5 injuries.

There is no prospective data on the optimal treatment of biliary injuries that lead to strictures. For major duct injuries without complete transection (class D) or injuries leading to stricture (E1–E4), endoscopic therapy with stenting and traditional surgical HJ are treatment options [41]. In a recent review [33], of 48 such patients selected for endoscopic therapy, successfully cannulated patients received endoscopic sphincterotomy and placement of a single plastic 10-F stent. Endoscopic intervention was suspended in patients who had biliary strictures longer than 2 cm or a lateral wall defect larger than one half the bile duct diameter with a concomitant bile leak. ERCs were repeated every 3 months to change the stents and to evaluate the strictures. Bile duct strictures were dilated by 6- to 8-mm pneumatic balloons and between one and three plastic stents were placed to help maintain duct patency. The average treatment interval for stenting was 12.2±9.8 months. No deaths occurred during the treatment interval. The mean follow up time was 31±24 months. Thirty-six patients had effective stricture resolution. Ten patients (22 %) had symptomatic recurrence after completing the yearlong treatment protocol, with either biliary colic or cholangitis. Four of them ultimately needed surgery. There was no mortality, the morbidity rate was low (8 %), and a good outcome was seen in 91 % of the patients. If the stricture did not resolve after four endoscopic treatments, they were converted to surgical bilioenteric bypasses.

In a recent publication from Mayo Clinic [35] evaluating the merits of endoscopic therapy, seven patients had class D BDI; four were managed surgically and three endoscopically (median duration of stenting was 5 months with good to excellent outcomes). Of 66 patients with E1 to E4 BDI, 44 (67 %) were initially managed surgically and 22 (33 %) endoscopically. Thirteen of the latter 22 underwent sustained endoscopic therapy (median stent time, 7 months), which was successful in 10 (77 %). All four patients with E5 injuries were managed surgically. Median follow up was 45 months. The authors concluded that, although surgical management remains the preferred therapy, short-term endoscopic treatment for E1 to E4 injuries can optimize the patient and operative field for reconstruction. Prolonged stenting in select patients with E1 to E4 injuries characterized by stenosis is successful in the majority. These data suggest that endoscopy is a viable option for the management of BDIs in cases where continuity of duct is maintained proximal and distal to the injury and in patients with strictures amenable to negotiation by the endoscopist [35]. However, they caution that endoscopy requires repeated interventions and frequent follow up which has a bearing on the cost and QOL of patients. Surgical reconstruction by an experienced surgeon at a specialist hepatobiliary center is an effective treatment with immediate relief of symptoms and excellent long-term outcomes [4, 42], even in E3 and E4 strictures. In BDI where the biliary confluence is intact (Strasberg types E1, E2, and select E3 [Sikora type III A]), a high HJ onto the extrahepatic left duct gives excellent results [43]. In E4 and E5 strictures, surgery is invariably the treatment of choice. QOL studies comparing patients with BDI managed surgically to uncomplicated LC

Fig. 2 Coronal section of a computed tomogram depicting diffuse intra-abdominal fluid which turned out to be bile. Clips in the hepatic hilum following laparoscopic cholecystectomy are well seen

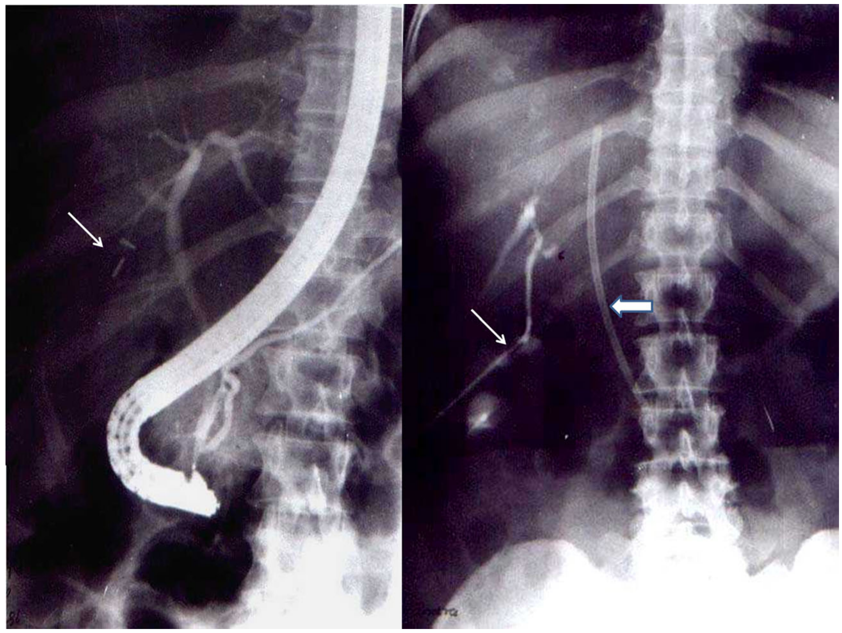


Fig. 3 The *panel on the left side* depicts an endoscopic retrograde cholangiogram (ERC) which can be erroneously interpreted as normal. The *arrow* points to clips applied during LC. The *panel on the right side* shows a tubogram in the same patient filling the injured right posterior sectoral duct. The *bold arrow* points to the stent inserted at the time of ERC

patients report similar rates of minor symptomatology and comparable QOL scores in physical, social, and mental health indices [44, 45]. The Mayo Clinic group [35] believes that, although endoscopy has a proven role, it should be entertained in a select population: patients who refuse surgery, are not optimal surgical candidates in whom surgical risks outweigh the benefits, or for those in whom stricture develops after surgical reconstruction. Advances in endoscopic treatment, rendezvous procedures, and use of removable self-expanding metal stents are promising new areas which may extend the benefits of minimally invasive treatment to a select subgroup of patients.

Percutaneous transhepatic dilatation/stenting is an alternative to endoscopic therapy in select class E injuries and is also particularly useful in recurrent strictures after HJ, where endoscopic access is not feasible [46, 47]. In patients with a complete cutoff, percutaneous transhepatic drains are useful as a temporizing measure before surgery in patients with bile leak or cholangitis [48]. They serve as a guide during surgery and can be converted to long-term transanastomotic stents in select cases where the bile duct is thin walled and small in diameter (3–4 mm) [49]. Complications of PTC are not uncommon, occurring in up to 26 % of patients, and include cholangitis, hemobilia, bleeding from hepatic parenchyma or adjacent vessels, pleural violation with pneumothorax, biliopleural fistula, and inadvertent injury to adjacent structures [50]. Multidisciplinary efforts to select appropriate candidates for a particular approach after informed consent seems to be a reasonable option till we have level 1 evidence. This would of course require the cooperation of many high-volume centers to recruit patients with strict inclusion criteria and long-term well-defined follow up data.

Early vs. delayed surgical repair

The timing of repair (early/late) is determined by the general condition of the patient, favorable local abdominal factors for successful repair (absence of sepsis, collections, and inflammation), and expertise of the operating surgeon. It is believed that the first repair when performed by an experienced hepatobiliary surgeon gives the best chance of success. In an oft-quoted early paper [51], only 17 % of repairs were successful in those performed by a nontertiary-level surgeon compared with 94 % of those performed by a specialist, and the hospital stay was three times longer when managed by a nonspecialist surgeon (78 vs. 222 days). The morbidity and mortality of those treated by a nonspecialist compared with specialist was 58 % and 1.6 % vs. 4 % and 0 %, respectively [51]. If expertise is unavailable, transfer of the patient should be considered after adequate drainage is achieved by large-bore drains [49]. As depicted in Fig. 4, the primary care surgeon should achieve damage control by stopping ongoing bleed by at least packing and establishing a controlled biliary fistula using a subhepatic drain. Injudicious attempts at exploration of the bile leak and repair by the primary surgeon may exacerbate the injury [52]. Immediate detection and repair are associated with an improved outcome, and the minimum standard of care after recognition of a BDI is immediate referral to an experienced surgeon [20]. Also, the operative findings should be clearly and accurately documented and communicated at the time of referral. It cannot be overemphasized that the patient and relatives should be made aware of the complication in a frank and lucid manner. The Birmingham group has demonstrated the safety and feasibility of on-table repair of BDI as an outreach service by specialist surgeons with minimal disruption to the patient pathway [53]. Despite reports of good

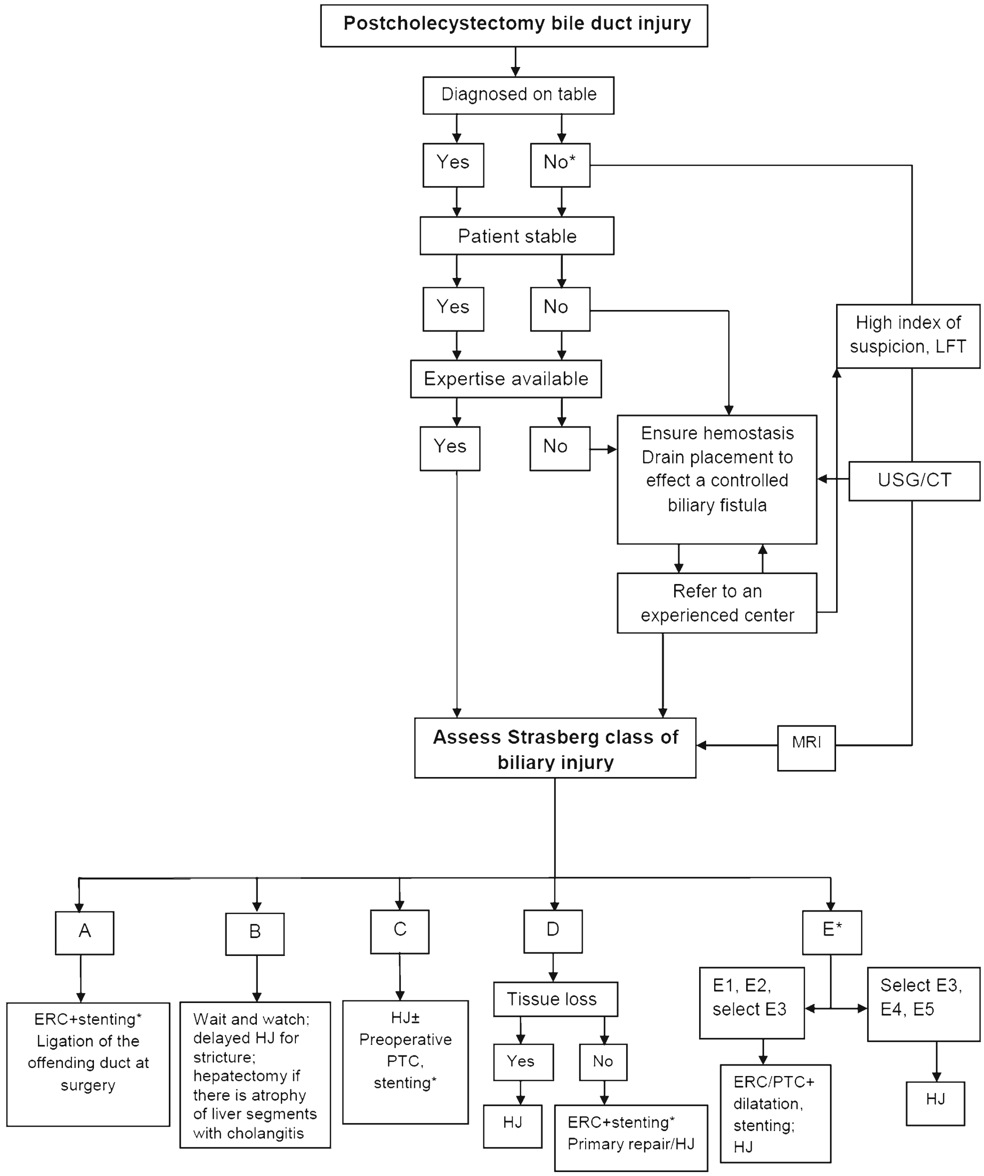


Fig. 4 Algorithm depicting management strategies in patients presenting with postcholecystectomy BDI. *LFT* liver function tests, *USG* ultrasonography, *CT* computed tomography, *MRI* magnetic resonance imaging, *HJ* hepaticojejunostomy, *PTC* percutaneous transhepatic cholangiogram. *Asterisk* represents patients not diagnosed at the time of initial surgery, the preferred initial management strategy in this group

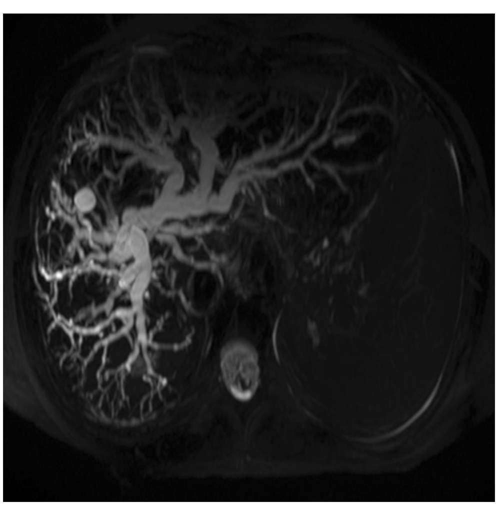


Fig. 5 Atrophy–hypertrophy complex, evident on MRI by crowding of right-sided ducts and hypertrophied left-sided ducts

results with a choledocho-hepaticoduodenostomy [54], a Roux-en-Y HJ is the gold standard for the reconstruction of bile ducts injured during cholecystectomy. End-to-end anastomosis can be utilized as a treatment strategy if BDI is detected during surgery, in particular if there is no extensive tissue loss, the local anatomy is clear, and there is no inflammation [55]. Postoperative complications can adequately be managed by endoscopic or percutaneous drainage in majority of the patients. Reconstructive surgery after a complicated end-to-end anastomosis is associated with low morbidity and no mortality.

Factors associated with an improved outcome include the use of absorbable sutures, single-layer anastomosis, and debridement back to healthy noninflamed or scarred tissue [51]. To ensure an adequate length of anastomosis, the left hepatic duct can be exposed along its extrahepatic course (Fig. 6) at the base of segment 4 [22, 56] to perform a Roux-en-Y HJ and obtain wide drainage of the bile duct. For patients with high injuries and disruption of the confluence, Lillemoe et al. [57] have described a technique similar to that used for a left-sided approach. By resecting the base of the gallbladder fossa, the right ducts are exposed to allow separate anastomoses to be fashioned. If the criteria for a successful anastomosis cannot be met, as in the event of disruption of the confluence with an associated vascular injury, significant diathermy injury, or surrounding sepsis, it may be prudent to delay repair and establish a controlled fistula [15]. This allows the final level of the injury to demarcate and inflammation to subside, determines the need for concomitant hepatic resection, and allows the ducts to dilate and mature to improve the likelihood of a successful result [15]. Nutritional status should be optimized with bile refeeding if feasible to maintain intestinal barrier function [58] and overcome fat-soluble vitamin deficiency, particularly in patients receiving enteral nutrition. In the presence of a biliary fistula with stricture, there is no consensus on the optimal duration of waiting before a HJ can be performed. It generally ranges from 3 to 6 months during which time the fistula is likely to close/get controlled without an undue risk of secondary biliary cirrhosis. Delayed repair has shown excellent long-term outcomes with a very low risk of mortality [59]. If the patient's condition is optimal and the repair is performed at an experienced center, both early and delayed repair have comparable long-term outcomes [60].

Biliovascular injuries

The pathophysiology of concurrent biliary and vascular injury has been most recently described in detail in a review by Strasberg and Helton [33]. In published series on BDI following LC, concomitant injury of a hepatic artery has been reported in 12 % to 40 % of patients [33, 61, 62]. Of those with damage to the RHA, around 10 % develop hepatic infarction [33]. Elimination of the compensatory collateral flow through marginal arteries and hilar shunt by a high BDI exacerbates the hepatic ischemia when the RHA is occluded [33]. High injuries and vascular injuries are a risk factor for hepatectomy for BDI [63, 64]. In a recent review, Truant et al. [64] found a total of 99 hepatectomies reported among 1,756 (5.6 %) patients referred for postcholecystectomy BDI. Strasberg E4 and E5 injuries were independent factors associated with hepatectomy. Patients with combined arterial and Strasberg E4 or E5 injury were 43.3 times more likely to undergo hepatectomy (95 % confidence interval, 8.0–234.2) than patients without complex injury [64]. In contrast, when the hilar arcade is preserved and the ischemic stricture has demarcated, a delayed repair in experienced hands has good outcomes even in the presence of arterial injury. A prospective study of 54 patients, which employed the left duct approach to bile duct repair, showed no difference in outcome between those with and without arterial injury [62]. Hence, unless accompanied with massive hepatic necrosis, RHA injury following cholecystectomy does not adversely affect the outcome of biliary injury if a delayed repair is performed. Vascular injury associated with sepsis is an adverse prognostic factor [65]. Hepatectomy in this setting is associated with high postoperative morbidity (60 %) and even mortality (10 %). Liver transplantation may sometimes be required as a last resort after biliovascular injury [66]. Figure 7 depicts an algorithm for the management of RHA injury associated with BDI.

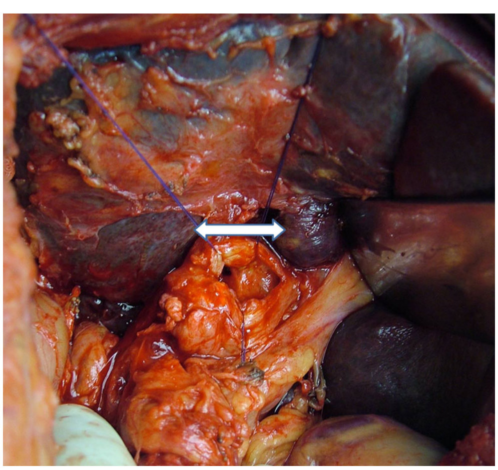
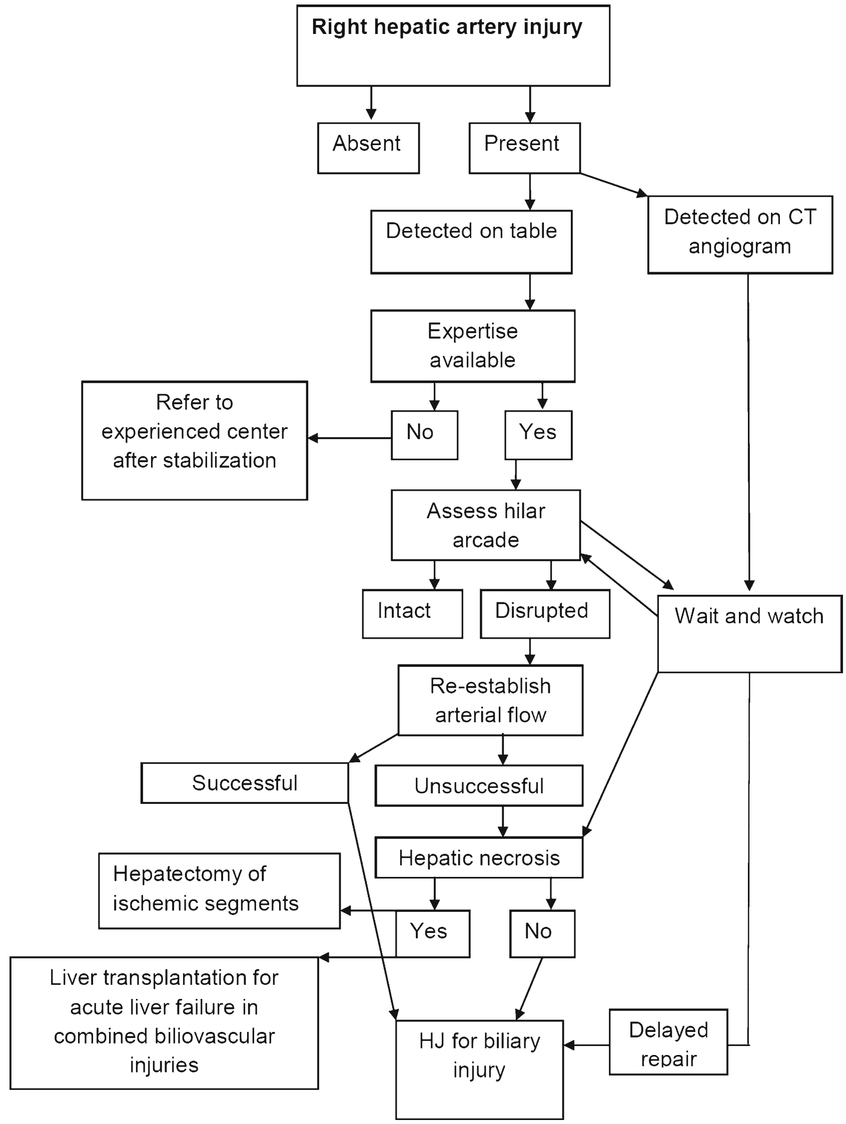


Fig. 6 Intraoperative photograph of the proximal bile duct prepared for a wide anastomosis

Secondary biliary cirrhosis and portal hypertension

Secondary biliary cirrhosis after BDI is uncommon, and its incidence varies from 8 % to 20 % in Indian series [60, 67]. This represents the most important cause of portal hypertension in this subgroup of patients. Risk factors include long duration of symptomatic obstruction, especially recurrent cholangitis, and a long interval between cholecystectomy and HJ and previous attempts at repair [60, 67, 68]. Secondary biliary cirrhosis has been reported to occur at 6 months, but has been reported to occur even as early as 20 weeks from the time of BDI [69]. Early fibrosis is reversible with a timely HJ as proven on follow up biopsies [69]. Duration of biliary obstruction, basal alanine aminotransferase (ALT) level, and time to normalization of ALT level after surgical repair have been shown to be independent predictors of advanced hepatic fibrosis [70]. In patients with extensive collaterals in the hilum, it is a good option to stage the HJ with a shunt in the first stage; however, most patients with mild portal hypertension and a patent portal vein, a single-stage HJ can be performed safely with excellent long-term results [67, 71]. For established cirrhosis, liver transplantation is the ultimate option. Figure 8 depicts an algorithm for the surgical management of secondary biliary cirrhosis in the setting of BDI.

Fig. 7 Algorithm depicting management of right hepatic artery injury associated with postcholecystectomy biliary injury



Long-term outcome

While evaluating outcomes of therapeutic modalities for biliary injuries, clinical, biochemical, and radiological domains are scored. A popular system is that of McDonald et al. [72] in which grades A and B incorporate asymptomatic patients with normal LFT or mild elevation of LFT, respectively. Grade C includes symptomatic patients with abnormal LFT, while grade D includes patients who require intervention (percutaneous dilatation/surgical revision). The degree of hepatic fibrosis is a very important predictor of abnormal recovery pattern of LFT [73], and Sikora et al. [69] have proposed that this be part of scoring systems to stratify patient outcome. While evaluating the success of an intervention, long-term follow up of at least 5 years is recommended as delayed strictures are reported [74]. While surgical series have shown excellent long-term outcomes both for primary and recurrent strictures [75, 76], contemporary endoscopic series [35, 41, 77] have shown comparable outcomes in a select subset of patients (Table 3). The definitions for the classification of BDI, the type of patients selected for interventions, and the outcome data should be comparable while evaluating surgical and endoscopic treatment. Also, QOL issues are important, considering that patients who undergo LC with a normal course are discharged many a time as day cases, while those with problems are subject to months of morbidity and risk of mortality. QOL after BDI is inadequately studied. The Amsterdam group has reported as early as 2001 that QOL is adversely affected in patients who sustain a BDI despite excellent medical outcomes such as normal LFT and radiology [2]. In a longitudinal study published after 11 years of follow up, the QOL scores did not improve [78]. Moore et al. [79] also noted long-term detrimental effects on health-related QOL in patients with BDI. Only a case–control study

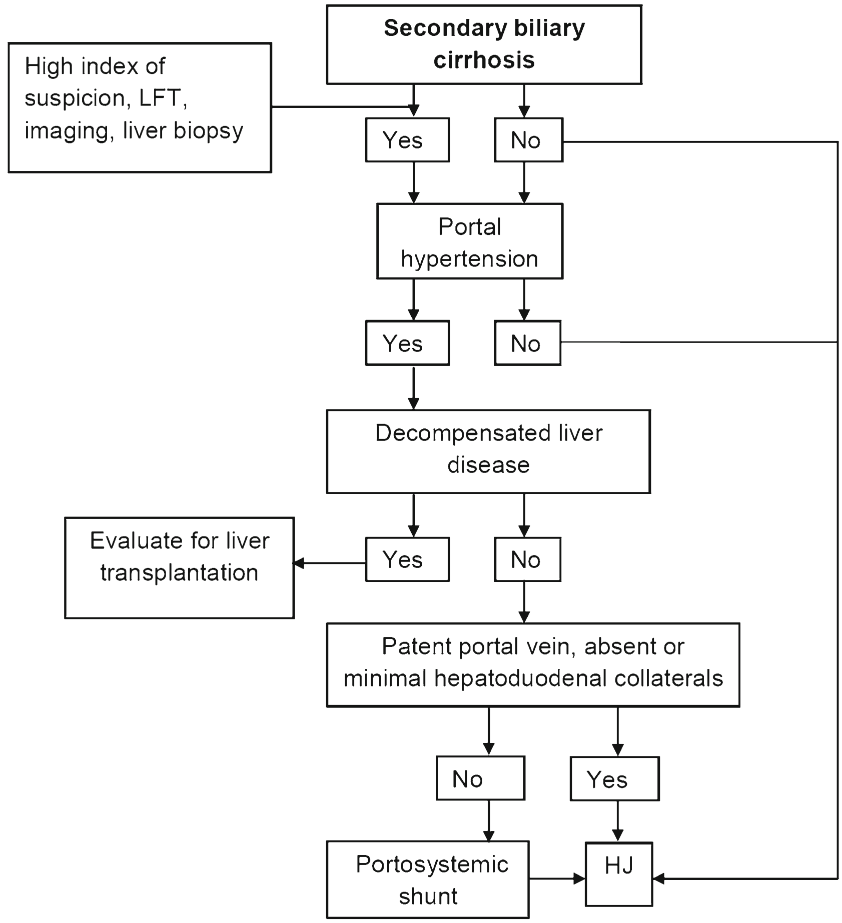


Fig. 8 Algorithm for surgical management of secondary biliary cirrhosis in the setting of postcholecystectomy biliary injury

by Hogan et al. [80] has demonstrated comparable outcomes in terms of QOL in patients who had a BDI vs. those with uncomplicated cholecystectomy. In these studies, it has been noted that pending litigation claims do influence the way a

Table 3 Long-term outcome after surgical/endoscopic treatment for postcholecystectomy BDI

Author [reference]	Year	Type of series	Number of patients	Median duration of follow up (years)	Percentage with E3, E4, and E5 injuries	Outcome
Lillemoe et al. [48]	2000	Surgical	156	4.9	55	91 % success rate without need for further intervention
Sikora et al. [60]	2006	Surgical	300	7.5	51	Excellent in 90 %; poor outcome in 8 patients; 4 died
de Reuver et al. [52]	2007	Surgical	151	4.5	27	90 % success rate; of the 15 patients with recurrent strictures, 3 required revision surgery, while 12 were managed with percutaneous transhepatic dilatation
Winslow et al. [74]	2009	Surgical	109	4.9	44	Excellent in >95 %; 5 patients—managed with stenting±dilatation
Vitale et al. [41]	2008	Endoscopic	48	2.5	37.5[a]	Good outcomes in 91 %—treated with mandatory stent exchange every 3 months
Fatima et al. [35]	2010	Endoscopic	159	3.7	20.1	Three E3 patients and one E4 patient were eligible for endoscopic therapy; of these, one of them failed this treatment and underwent surgery
Costamagna et al. [77]	2010	Endoscopic	42	13.7	43	Multiple stent insertion; excellent outcome in 80 %; 7 patients required reintervention for stricture/stone and were successfully managed endoscopically; 7 patients died of unrelated causes

[a] Type C by Amsterdam classification

patient perceives his or her current status and these patients tend to score worse on QOL indices.

Summary and Conclusions

Preventive strategies and safe surgery are of utmost importance to minimize BDI during cholecystectomy. The importance of frank communication with the patient and accurate documentation cannot be overemphasized. Diagnosis requires a high index of suspicion with focused clinical, biochemical, and radiological examination. Widely accepted classification systems include the Bismuth and Strasberg systems. In addition to providing a uniform terminology for accurate documentation and reporting, they also stratify patients based on the complexity of the injury and possible management strategies. Irrespective of the modality of treatment chosen, the initial strategy is to control sepsis and bleeding. ERC stenting is the treatment of choice for class A injuries and has a role to play in select class D injuries without tissue loss. Aberrant hepatic duct injuries without and with a leak (classes B and C) are managed according to the timing and severity of their presentation and can be challenging to diagnose and treat. The gold standard for the treatment of class E injuries is surgery by a Roux-en-Y HJ with data to support long-term excellent outcomes both for early and delayed repairs. ERC/PTC stricture dilatation has a role to play in some of those injuries where there is a partial stricture without complete transection. Combined high biliovascular injuries are associated with a poorer outcome, especially when an associated RHA injury has to be tackled at the time of an early repair by the primary operating surgeon. Long-standing biliary obstruction can lead to secondary biliary cirrhosis with portal hypertension. Liver transplantation is rarely required in BDI due either to acute liver failure following biliovascular injury or refractory secondary biliary cirrhosis with portal hypertension. A multidisciplinary approach-driven management protocol can follow a structured algorithm, tailoring the best available evidence to suit individual patient circumstances.

Conflict of interest The authors declare that there are no financial disclosures or potential conflicts of interest.

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