How to Avoid Common Bile Duct Injuries and Their Classification

15

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Abbreviations

BDI	Bile duct injuries
CBD	Common bile duct
CHD	Common hepatic duct
CVS	Critical view of safety
ERCP	Endoscopic retrograde cholangiopancreatography
ICG	Indocyanine green;
IOC	Intraoperative cholangiography
IOUS	Intraoperative ultrasonography
LC	Laparoscopic cholecystectomy
PTC	Percutaneous transhepatic cholangiography
RHD	Right hepatic duct

15.1 Introduction

Laparoscopic cholecystectomy has become the gold standard for the management of symptomatic cholelithiasis and other gallbladder diseases. However, several reports demonstrated that the incidence of bile duct injuries (BDI) has risen from 0.2–0.3% in the era of conventional open cholecystectomy to 0.5–0.8% in the era of laparoscopic cholecystectomy [1–4]. Wrong or incomplete dissection of Calot's triangle, especially in cases of significant inflammation at the surgical site, or aberrant anatomy of the bile duct may result in bile duct injuries (BDI) [5, 6]. Iatrogenic BDI are associated with significant postoperative morbidity and mortality, decreased long-term survival, and quality of life and their management constitute a surgical challenge. The goal in these cases is the restoration of the biliary tree and the prevention of complications such as strictures, recurrent cholangitis and secondary biliary cirrhosis, abscess, and fistulae. Management depends on the timing of recognition of injury, the extent of bile duct injury, the patient's condition, and the availability of experienced hepatobiliary surgeons. Technical difficulty of repair, operative risk, and long-term outcome of bile duct injuries vary considerably and are mainly associated with the location and the extent of the injury. Consequently, several classifications with therapeutic and prognostic implications have been established [1–4]. However, as the precise causes of injury are becoming better understood, technical refinements for prevention are emerging. Prevention should be the goal and this requires adherence to strict principles of meticulous and safe dissection of the identified structures.

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15.2 Risk Factors for Biliary Injury

There are many factors that increase the incidence of BDI during laparoscopic cholecystectomy. First of all, the camera provides a monocular view from a direction quite different from that of open surgery, thus the CBD is not usually seen from this angle. The high rate of biliary injury in early reports was due in part to inexperience in the procedure. This was called the "learning curve" effect [7]. Indeed, experience contributes to BDI, but several other factors are responsible, as well.

Biliary injuries are more likely to occur during difficult laparoscopic cholecystectomies [8, 9]. The incidence of BDI when laparoscopic cholecystectomy is performed for acute cholecystitis (0.51%) was reported to be three times higher than that for elective laparoscopic cholecystectomy and twice as high as that for open cholecystectomy for acute cholecystitis [9, 10]. Severity of coexisting inflammation in the operating field with dense scarring contribute as well to intraoperative bleeding that obscures the field. Furthermore, the presence of abundant adipose tissue around the hepatoduodenal ligament, especially in obese patients, increases the difficulty of surgery and promotes BDI. Adverse factors include higher age (>65 years), male gender, morbid obesity and long duration of symptoms prior to surgery, upper abdominal surgery, history of attacks of acute cholecystitis, or previously established cholecystostomy [10].

Aberrant anatomy or anatomic variants and anomalies undoubtedly contribute to biliary injuries. The aberrant right hepatic duct anomaly is the most common problem because the duct may be mistakenly regarded as the cystic duct and ligated or cut. Excessive, more than is necessary, dissection around the hepatoduodenal ligament during cholecystectomy may lead to damage to the axial arteries running along the CBD. Vascular damage is the cause of postoperative biliary strictures due to ischemia.

Last but not least, maintenance of laparoscopic equipment is of paramount importance. Focal loss of insulation on electrocautery instruments may lead to thermal injuries [6].

15.3 Prevention of Bile Duct Injuries

Laparoscopic cholecystectomy is performed in an area adjacent to many vital structures such as the portal vein, hepatic artery, and extrahepatic biliary tract, and thus, thorough knowledge of the relevant anatomy as is of paramount importance for a safe procedure. The surgeon should be aware of anatomical variations and the anatomical distortion due to acute or chronic inflammation.

A number of factors predictive of difficult cholecystectomy have been universally recognized and should be identified in both acute cholecystitis and elective cases. The presence of these risk factors should alert surgeons with limited experience, for careful patient selection. On the other hand, the experienced surgeon should be prepared for the possibility of conversion to an open cholecystectomy, or need for various bailout procedures, such as the establishment of a tube cholecystectomy, subtotal or fundus first cholecystectomy, either laparoscopic or open [10–12]. The exposure and cautious dissection of Calot's triangle with judicious use of energy and meticulous attention to technique in order to achieve "the critical view of safety (CVS)" is an essential step of laparoscopic cholecystectomy.

It is important for the operating surgeon to be able to recognize when the dissection is becoming unsafe with a high potential for BDI. More than two tubular structures entering the gallbladder, unusually large presumed cystic artery or artery pulsations behind the presumed cystic duct which cannot be occluded with medium–large clips and is surrounded by excessive fibrofatty tissue, bile leakage with intact gallbladder, and/or bleeding requiring blood transfusion, are important indicators of unsafe dissection [10–14]. In such cases, the dissection should be stopped temporarily and reconsider alternative technical plans for a safe dissection, seek for a second opinion from another surgeon, preferably an experienced one. Various intraoperative imaging techniques, such as intraoperative cholangiography (IOC), laparoscopic ultrasound, and near-infrared fluorescent cholangiography, may be used to assess the biliary anatomy, as well [10, 13, 14]. Intraoperative team communication is obviously significant but the surgeon should know when to call for help and recognize the need for conversion or an alternative procedure, such as subtotal cholecystectomy [15]. However, converting to an open procedure does not safeguard against BDI (Table 15.1).

Table 15.1 Essential steps to reduce BDI during laparoscopic cholecystectomy

Preoperative evaluation of predictors of a difficult cholecystectomy [male gender, obesity, age >65 years, previous attacks of biliary colic, increased interval between onset and presentation (>72–96 h), upper abdominal surgery, prior attempted cholecystectomy, fever, high ASA score, raised CRP and white blood cell count, thickened gallbladder wall (>5 mm), small contracted or distended gallbladder with impacted stone, cirrhosis etc]
Use an angled (30^0 or 45^0) laparoscope
Use high-quality imaging equipment
Cooperation with a dedicated and experiences assistant
Application of appropriate lateral traction of the fundus
Use Rouviere's sulcus and the base of segment IV as landmarks to aid orientation
Dissection and correct exposure of the Calot's triangle end establishment of CVS: (a) hepatocystic triangle is cleared of fat and fibrous tissues; (b) the lower one-third of the gallbladder is separated from the liver to expose the cystic plate; (c) two and only two structures should be seen entering in the gallbladder
Judicious use of energy devices at Calot's triangle
Dissection of the liver bed along the cystic plate
Avoid dissection on the left side of the hepatoduodenal ligament
Knowledge of anatomical variations, both biliary and vascular Early recognition if dissection becomes unsafe Seek a second opinion from another surgeon I difficult or unexpected situations
Use of intraoperative imaging when the anatomy is not clarified; obtain intraoperative cholangiograms, liberally
Implement bail-out procedures, such as subtotal cholecystectomy, or fundus-first cholecystectomy in cases of severe inflammation and/or inability to perform CVS
Do not hesitate to convert to open cholecystectomy in cases where CVS cannot be achieved and bail-out strategies could not be implemented

Adaptation of well-proven principles of open surgery is the best prevention of biliary lesions in laparoscopic cholecystectomy as well as the readiness to convert early to the open procedure.

15.3.1 Critical View of Safety and Technical Points

A surgeon is always required to apply reliable surgical techniques to achieve division of the cystic duct and artery in either open or laparoscopic cholecystectomy. Misidentification of the extrahepatic bile duct anatomy during LC is the main cause of bile duct injury [5]. Meticulous dissection of the Calot's triangle and preparation of all relevant structures are the cornerstone of a safe laparoscopic cholecystectomy.

The CVS technique, which was first described by Strasberg et al. in 1995 [5], was introduced to reduce the risk of bile duct injury. A recent Society of American Gastrointestinal and Endoscopic Surgeons (SAGES) expert Delphi consensus deemed the CVS as being the most important factor for overall safety [15]. Nowadays, the CVS technique is the gold standard to perform a safe cholecystectomy with identification of the vital structures such as the cystic duct.

The reviewed literature suggests that judicious establishment of CVS could decrease bile duct injury rate, from an average 0.4% to nearly 0% [16].

To establish CVS, two windows need to be created during dissection of Calot's triangle: one window between the cystic artery, cystic duct, and gallbladder, and another one between the cystic artery, gallbladder, and liver. The CVS technique is aimed especially at mobilizing the gallbladder neck from the liver in the appropriate cystic plate to obtain a circumferential identification of the cystic duct and its transition into the gallbladder [5]. The guiding structure for dissection should be the wall of the gallbladder. Proper retraction of the fundus cephalad and of the infundibulum posteriorly and laterally is necessary, and tenting by excessive lateral pulling on the gallbladder should be avoided. Cephalad traction on the fundus compresses Calot's triangle, while lateral traction on Hartmann's pouch tents up the CBD, which may then be mistaken for the cystic duct, especially when that duct is very short. The cystic duct should be dissected in a retrograde fashion, starting at gallbladder proceeding with the identification of the cystic duct–gallbladder junction on both sides and the visualization of the cystic duct–common bile duct junction prior to clipping. Calot's triangle should be dissected from all fibrous and fatty tissues. At the end of the dissection, only the cystic duct and artery cystica should enter the gallbladder and the bottom of the liver bed should be visible. The CBD is not necessary to be exposed. Failure to achieve the CVS is an absolute indication for conversion or additional bile duct imaging [6]. The CVS should be described in the operative report.

Connor et al. and Wakabayashi et al. elegantly describe five key initial steps in performing safe laparoscopic cholecystectomy: (1) retract the gallbladder laterally to a 10 o'clock position relative to the principle plane of the liver (Cantlie's line); (2) confirm Hartmann's pouch is retracted up and towards segment IV; (3) identify Rouviere's sulcus which marks the level of the right posterior portal pedicle and is identifiable in >80% of the patients. An imaginary line drawn along the sulcus and carried across to the base of segment IV shows the level ventral to which dissection is "safe" and dorsal to which it is not; (4) dissect the posterior peritoneum of the hepatobiliary or hepatocystic triangle; and (5) confirm the critical view is obtained [12, 17].

Energy devices should be used cautiously in the of Calot's triangle with low cautery settings (<30 W), coagulation of small pieces of tissue at one time, and being sure that the coagulating surface is free of any adjacent tissue [6]. There are few data on the comparison between different energy devices in LC with respect to safety. Nevertheless, there was no significant difference between the use of ultrasonic and electrocautery energy with respect to postoperative bile leakage [15]. Sharp dissection increases the risk of bleeding, which presents added problems in controlling the bleeding when clips must be used blindly, or thermocoagulation is applied near the porta hepatis. Instruments should be kept in the field of vision at all times during dissection and instrument changes. Before ligation and division of any structure, its anatomical position should be defined clearly. Clips should be applied so that their tips are seen projecting beyond the duct, free of any extraneous material. In cases of thickened cystic duct, use of ligature loops or intracorporeal ligation is recommended instead of clips. Two loops should be applied on the side of the cystic duct to be retained. Applying extra clips is not the answer and may, in fact, lead to tenting injury [6].

15.3.2 Role of Intraoperative Cholangiography, Ultrasonography, and Fluorescence Imaging

Intraoperative cholangiography (IOC) is the most frequently applied technique for intraoperative assessment of the biliary anatomy. Although, for years, it has been speculated that IOC may decrease both the incidence and the severity of BDI, reports on the protective effect of routine IOC against BDI are conflicting, ranging from no benefit to a 40% risk reduction [18]. Van de Graaf et al. [19] in their systematic review compared routine versus selective use of IOC, and no clear conclusions could be drawn. IOC has been demonstrated to be a helpful tool in both prevention and intraoperative recognition of BDI. However, routinely application of this modality is not definitively recommended due to limited available supporting evidence. Accordingly, Ford et al. in their review made a similar conclusion: no robust evidence currently exists to either support or abandon the use of IOC in the prevention of BDI [20]. Additionally, IOC is prone to failure with a median reported success rate at 89%, involves radiation exposure, and requires additional equipment and manpower. An IOC has to be correctly performed and interpreted to assist the surgeon in identifying the CBD, and injuries may occur even if an IOC has been performed. A normal cholangiogram reveals flow of the contrast media into the duodenum, visualization of the proximal hepatic duct along with the right anterior and posterior sectoral ducts and left main duct, no filling defects within CBD, and presence of spiral valves within cystic duct. Advocates for omission of IOC also state that this technique might even be harmful to the patients due to the additional operative time and the risk of iatrogenic major BDI [19]. Moreover, the interpretation of an intraoperative cholangiography with potentially distorted anatomy clearly depends on the expertise of the surgeon. Thus, it may be argued that the absolute risk reduction associated with IOC does not warrant the added time and cost. Perhaps even more relevant than whether IOC in itself is useful is the question of whether it should be performed routinely or selectively.

Intraoperative ultrasonography (IOUS) is another imaging modality to identify and clarify the anatomy at Calot's triangle and hepatoduodenal ligament, less invasive than IOC. It has the potential to achieve high accuracy, with reports of completely visualizing the biliary tract in 92–100% of cases, with a failure rate that is lower than IOC [19, 21]. Although, the learning curve in the performance and interpretation of the ultrasonogram constitutes a major disadvantage [22, 23]. All evidence shows excellent results with laparoscopic IOUS in delineating the biliary anatomy. The advantages of laparoscopic IOUS over IOC are the shorter procedure time, its noninvasive nature, and lack of use of radiation. Furthermore, it may be performed prior to dissection in Calot's triangle and repeated in uncertain cases [24].

Indocyanine green (ICG) enhanced fluorescence near-infrared imaging is an emerging minimally invasive and easy modality for the visualization of the easier intraoperative recognition of the biliary anatomy. ICG can be injected into the human blood stream and becomes fluorescent once excited with specific light in the near-infrared spectrum, as it is exclusively by the liver after intravenous administration and has a very well-known pharmacokinetic and safety profile. ICG imaging allows repeatable and real-time exploration of the biliary system, something that is not possible with radiological IOC and provides relevant high detection rates of biliary tree structure, with specifically high detection rates of the cystic duct. Real-time simultaneous imaging of the bile ducts and the arterial anatomy (i.e., hepatic and cystic arteries) also can be obtained. Neither radiological support nor additional intervention such as opening the cystic or CBD is required, making it an easy, real-time, and flexible technique to use during surgery. However, the routine use of ICG fluorescence laparoscopy has not gained wide clinical acceptance yet due to a lack of high-quality clinical data. Furthermore, increased costs are involved in terms of the light source, camera, and fluorescent dye [25].

15.4 Classification of Bile Duct Injuries (BDI)

Several classification systems, such as Bismuth's classification, Hanover classification, Neuhaus classification, Siewert classification, Stewart-Way classification, and Strasberg classification, have been used to stratify bile duct injuries [5, 26–30]. Although the abovementioned systems are useful for standardization of outcome reporting and management decision-making, most of them fail to take into consideration significant prognostic factors, such as the mode of presentation, associated vascular injuries—particularly injuries to the right hepatic artery—, any longitudinal strictures of the common bile duct due to failed repair attempts, the presence of concomitant sepsis or secondary biliary cirrhosis, or segmental liver atrophy [31].

Classification of bile duct injuries is of paramount importance before planning any intervention because the type of treatment and optimal timing of treatment vary significant among the various types of BDI [32]. Relaparotomy should never be undertaken before adequate classification. Many injuries can be treated endoscopically with or without percutaneous drainage of any collections (i.e., bilomas). It is extremely important to identify the exact location of a BDI in order to select the optimal strategy for their management [32, 33].

Despite the presence of so many classification systems, the Bismuth and Strasberg systems remain the most popular and are used widely with the former being the first established in 1982 [27].

15.4.1 Bismuth Classification

Bismuth proposed a classification system of post-cholecystectomy benign biliary strictures (Fig. 15.1, Table 15.2) which was based on the lowest level at which healthy biliary mucosa is available for anastomosis, measured from the confluence of the right and left hepatic ducts [27]. It reveals a good correlation with the final outcome after attempted repair. Bismuth classification intended to help the surgeon to choose the appropriate technique for the repair and, although, it was established for biliary strictures, it is commonly implemented to acute BDI. This classification included five types (I to V) of bile duct injuries according to the level of the injury, the distance from the biliary bifurcation, the involvement of the bifurcation, or an anomalous right sectoral duct [34].

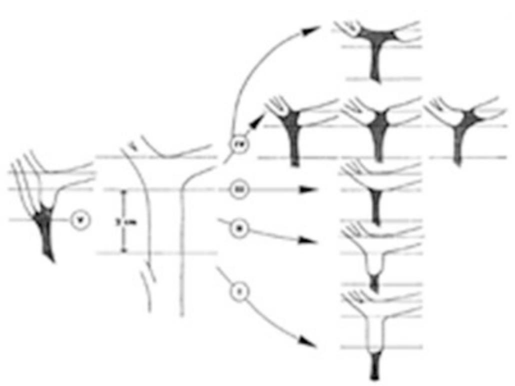


Fig. 15.1 Bismuth classification. (From [34], with permission)

Table 15.2 Bismuth classification

Type	Injury type
I	Low CHD stricture, with a length of the CBD stump of >2 cm
II	Proximal CHD stricture with a length of the CBD stump <2 cm
III	Hilar stricture, no residual CBD, but the hepatic ducts' confluence is preserved
IV	Hilar stricture, with involvement of the confluence and loss of communication between right and left hepatic ducts
V	Involvement of an aberrant right sectorial hepatic duct alone or with concomitant stricture of the CHD or CBD

Type I is associated with low common hepatic duct strictures, with a common hepatic bile duct stump longer than 2 cm, and can be repaired without opening the left hepatic duct and without lowering the hilar plate. Type II refers to proximal strictures, with a stump shorter than 2 cm, and requires opening of the left hepatic duct for a satisfactory anastomosis. Lowering the hilar plate is not always necessary, although it may improve the exposure. Type III lesions in the hilum, in which only the ceiling of the biliary confluence is intact, require lowering the hilar plate and anastomosis on the left ductal system. There is no need to open the right duct if the communication between the ducts is wide. With type IV lesions, the biliary confluence is interrupted and requires either reconstruction or two or more anastomoses, after lowering the hilar plate. Type V lesions are strictures of the hepatic duct (type I, II, or III) associated with a stricture on a separate aberrant right sectorial hepatic duct alone and that branch must be included in the repair [27, 34].

Although, this classification is applicable while evaluating long-term complications following bile duct injuries, it does not include the wide spectrum of all possible biliary injuries.

Sikora et al. [35] proposed that progression of fibrosis results in an intermediate stage between type III and type IV—according to Bismuth—strictures, where the floor of the confluence of the right and left hepatic ducts is scarred, although complete hilar isolation has not occurred. Consequently, hilar benign biliary strictures need to be subclassified, based on whether the floor of the confluence is healthy or scarred, as assessed by cholangiography or intraoperatively, because it influences the degree of operative difficulty and morbidity. Thus, patients with type III—according to Bismuth classification—strictures are subclassified into type IIIA hilar strictures, where the floor of the confluence was healthy and type IIIB hilar strictures, where the scarring involved the floor of the confluence. It is proposed that type IIIB strictures should be subclassified along with type IV strictures.

15.4.2 Strasberg Classification

Strasberg et al. [5, 36] reviewed the patterns of biliary injury and proposed a simplified, holistic classification based on the location of the injury in the biliary tract, combining not only the injuries proposed by Bismuth but also the early injuries. Although, this classification is very useful in determining the prognosis of an attempted repair, it does not take into consideration any additional vascular injuries. According to this system, there are five types (Fig. 15.2, Table 15.3) of common BDI (A–E).

Type A injuries occur due to leakage from the cystic duct stump or minor accessory radicals draining directly into the gallbladder (ducts of Luschka) and present as a biliary leakage and/or subhepatic biloma. Type B injuries are defined as ligation and division of an anomalous segmental duct—typically the duct draining segment VI—or right posterior sectoral duct (draining both segments VI and VII). This injury is often facilitated by the associated anomaly where the cystic duct drains into the right posterior duct. Type B injuries are usually subclinical or may have a delayed onset with abdominal pain or cholangitis involving the occluded liver segment. The occluded liver parenchyma will atrophy over time. Type C injuries occur in the same anatomic setting as type B injuries, though the proximal ductal segment is just divided and not occluded. Consequently, it leaks freely into the peritoneal cavity. This type of injury is often misdiagnosed, as ERCP typically misses the leaking segment because it is not opacified via the main biliary tree. Cholangiography should be carefully inspected to make sure all liver segments are visualized. In cases where the right posterior segments are not depicted, PTC may be not only diagnostic but will also allow leakage control. In type D injuries, a lateral injury—without major tissue loss—to the main bile duct occurs. This type of injury results either in an early leakage or

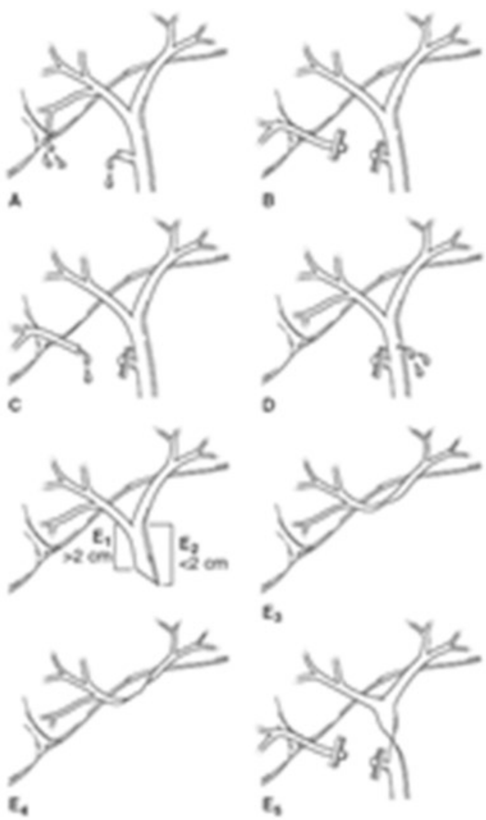


Fig. 15.2 Strasberg classification [5, 36]

Table 15.3 Strasberg classification

Type	Injury type
A	Injury of small bile ducts in communication with the main biliary system, with leakage from cystic duct or from small ducts in the liver bed
B	Occlusion of an aberrant hepatic duct (almost invariably the right posterior sectoral duct)
C	Sectioning without ligation of an aberrant right hepatic duct
D	Lateral injury of the CBD
E1	CBD injury at a distance>2 cm from the hepatic duct confluence
E2	CBD injury at a distance<2 cm from the hepatic duct confluence
E3	Hilar injury with preservation of the confluence of the hepatic ducts
E4	Hilar injury with involvement of the confluence and loss of communication between the right and left hepatic ducts
E5	Injury to an aberrant right sector hepatic duct or associated with a concomitant injury to the CBD

in a delayed stricture and may be diagnosed accurately by ERCP, which can also provide a definitive treatment. Type E injuries are defined by complete disruption of the main bile duct due to transection, excision, and/or ligation of the extrahepatic biliary tree. Injuries that include a free biliary leakage will prevent early bile peritonitis and sepsis. Injuries with occlusion of the proximal hepatic drainage may present in a delayed fashion with jaundice and/or cholangitis. Type E injuries are further stratified to five subtypes (E1 to E5), according to Bismuth's classification system. E1 and E2 injuries result from a transected CBD or a stricture more or less than 2 cm from the biliary bifurcation, respectively. E3 injuries refer to a stricture of the biliary bifurcation with right and left hepatic ducts in communication. In type E4, the stricture of the biliary bifurcation results in separation of right and left hepatic ducts, whereas in type E5 a stricture of the main bile duct is associated with a transected right posterior sectoral duct. The majority of type E injuries will require PTC to definitively reveal the anatomic details of the injury and to establish stable biliary drainage.

Neither the Strasberg nor the Bismuth classification clearly describes one of the most serious injuries, namely that which presents as a biliary leak with separation of the right and left ducts resulting from excision of the extrahepatic biliary tree. For that, Connor et al. [31] proposed a sixth subdivision in type E injuries (E6), which is associated with complete excision of the extrahepatic ducts involving the confluence of the left and right hepatic ducts.

15.4.3 Siewert Classification

Siewert et al. [37] proposed four different types of BDI (Table 15.4). The most severe case is the lesion with a structural defect of the CBD or CHD with (IVa) or without (IVb) concomitant vascular injury. Tangential lesions without structural loss of the duct should be denominated as type III (stratified as IIIa and IIIB, according to the presence or not of additional vascular injury, respectively). Type II comprehends late strictures without obvious intraoperative trauma to the duct. Type I includes immediate biliary fistulae of usually good prognosis.

Table 15.4 Siewert classification

Type	Injury type
I	Immediate biliary fistulae
II	Late strictures without obvious intraoperative trauma to the duct
III IIIa IIIb	Tangential lesions without structural loss of the duct With additional vascular injury Without additional vascular injury
IV Iva IVb	Lesion with a structural defect of the CBD or CHD With additional vascular injury Without additional vascular injury

Table 15.5 Mattox classification

Type	Injury type
I	Contusion of the gallbladder or portal triad
II	Partial gallbladder avulsion from liver bed; cystic duct intact Laceration or perforation of the gallbladder
III	Complete gallbladder avulsion from liver bed Cystic duct laceration/transection
IV	Partial or complete right hepatic duct laceration Partial or complete left hepatic duct laceration Partial common hepatic duct laceration (≤ 50%) Partial common bile duct laceration (≤ 50%)
V	> 50% transection of common hepatic duct > 50% transection of common bile duct Combined right and left hepatic duct injuries Intraduodenal or intrapancreatic bile duct injuries

15.4.4 Mattox Classification

The Mattox classification (Table 15.5) of BDI takes into consideration a variety of injure patterns such as contusion, laceration, perforation, and transection of the biliary tree [38, 39].

15.4.5 McMahon Classification

McMahon et al. suggested that the type of injury may be subdivided into bile duct laceration, bile duct transection or excision, and bile duct stricture [40]. The level of stricture may be further graded according to the Bismuth's classification. Based on this classification, lacerations under 25% of the bile duct diameter or cystic–common bile duct junction ("buttonhole tear") were classified as minor ductal injury, whereas transection of CBD or CHD, or lacerations over 25% of bile duct diameter and postoperative bile duct stricture were classified as major injury [40]. Minor injury can usually be managed by simple suture repair and/or insertion of a T-tube, and major injury usually requires hepaticojejunostomy.

15.4.6 Amsterdam Academic Medical Center's Classification

Bergman et al. [41] from the "Amsterdam Academic Medical Center" identified four types of BDI (A–D). Type A is a leakage from the cystic duct or an aberrant or from peripheral hepatic radicles. Type B represents major bile duct leakage with or without concomitant biliary strictures, whereas type C corresponds to bile duct strictures without bile leakage. Type D refers to complete transection of the bile duct with or without excision of some portion of the biliary tree. The site of the ductal lesion was determined by its most proximal border (Table 15.6). Majority of type A and most type B lesions are amenable to stenting during ERCP, whereas majority of type C and all type D lesions require surgical intervention.

15.4.7 Neuhaus Classification

Neuhaus classification (Fig. 15.3) encompasses minor leaks from the gallbladder fossa or the cystic duct (type A) and major BDI including: occlusion of the CBD, CHD, right or left hepatic ducts by clips, either incomplete or complete (types B1 and B2, respectively), lateral lesions of the CBD, either small (<5 mm) or extended (>5 mm) (types C1 and C2, respectively), complete transections of the CBD or CHD, either without or with structural defect (types D1 and D2, respectively), and late strictures with stenosis of the extrahepatic bile ducts (type E). The latter group of BDI (E) is further stratified into four types: E1 and E2 with short (<5 mm) or long (>5 mm) stenosis of the CBD, respectively, E3 when the stenosis affects the confluence of the hepatic ducts, and E4 when there is stenosis of the right hepatic or a segmental duct (Table 15.7) [26, 42].

The advantage of the Neuhaus' classification may be the ability to discriminate different injury patterns and recurrent cholangitis in the long term. Treatment strategies may be tailored according to the anatomical type of injury. However, this classification does not account for any concomitant vascular injuries [42].

Table 15.6 Amsterdam Academic Medical Center's classification

Type	Injury type
A	Cystic duct leaks or leakage from aberrant or peripheral hepatic radicles
B	Major bile duct leaks with or without concomitant biliary strictures
C	Bile duct strictures without bile leakage
D	Complete transection of the duct with or without excision of some portion of the biliary tree

15.4.8 Csendes Classification

Csendes et al. [43] proposed another classification, consisted of four types (I–IV) which has the advantage of classifying the severity of the lesions and proposing the appropriate management (Table 15.8). This system describes the mechanism of injury in detail and hence is useful while applying preventive strategies. However, it does not account for vascular injuries.

Type I corresponds to 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. Type II, which is a new type of injury which was seldom seen during open surgery, corresponds to lesions of the cysticocholedochal junction due to excessive traction, the use of a Dormia catheter, section of the cystic duct very close or at the junction with the CBD, or to a burning of the cysticocholedochal junction by electrocautery. Type III corresponds to a partial or complete section of the CBD whereas type

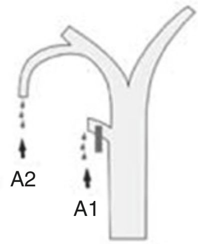
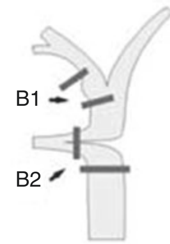
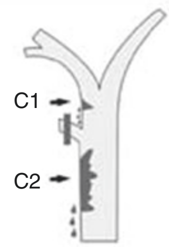
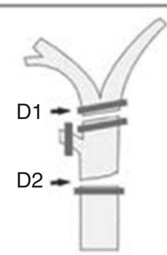
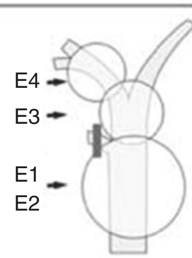
Type A	**Peripheral bile leak** (in communication with the CBD) A1: Cystic duct leak A2: Bile leak from the liver bed	
Type B	**Occlusion of the CBD** (or right resp. left hepatic duct, i.e. Clip, ligation) B1: Incomplete B2: Complete	
Type C	**Lateral injury of the CBD** C1: Small lesion (< 5 mm) C2: Extended lesion (> 5 mm)	
Type D	**Transsection of the CBD** (or right hepatic duct not in communication with the CBD) D1: Without structural defect D2: With structural defect	
Type E	**Stenosis of the CBD** E1: CBD with short stenosis (< 5 mm) E2: CBD with long stenosis (> 5 mm) E3: Confluence E4: RIght hepatic duct/Segmental duct	

Fig. 15.3 Neuhaus classification. (From [26], with permission)

Table 15.7 Neuhaus classification

Type	Injury type
A	Peripheral bile leak from the cystic duct (A1) or an accessory hepatic duct within gallbladder fossa (A2)
B	Occlusion of the CBD, or right/left hepatic duct (i.e clip, ligation): incomplete (B1) or complete (B2)
C	Lateral injury of CBD over a distance of up to 5 mm (small lesion, C1) or more than 5 mm (extended lesion, C2)
D	Transection of the CBD, or right hepatic duct not in communication with the CBD) without (D1) or with structural defect (D2)
E	Stenosis of the CBD
E1	CBD with short stenosis (<5 mm)
E2	CBD with long stenosis (>5 mm)
E3	Confluence
E4	Right hepatic duct or segmental duct

Table 15.8 Csendes classification

Type	Injury 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
II	Lesions of the cysticocholedochal junction due to excessive traction, the use of a Dormia catheter, section of the cystic duct very close or at the junction with the CBD, or to a burning of the cysticocholedochal junction by electrocautery
III	A partial or complete section of the CBD
IV	Resection of more than 10 mm of the CBD

IV corresponds to resection of more than 10 mm of the CBD [43].

15.4.9 Stewart-Way Classification

Stewart-Way classification (Fig. 15.4) details the mechanisms and possible reasons for various classes of injuries and makes provision for combined biliovascular injuries, as well. This classification arose from the analysis of operative reports, providing the human mistakes and cognitive processes involved in the mechanisms of BDI. Stewart-Way classification groups BDI according to anatomic pattern and causation (Table 15.9) and encompasses four classes [44].

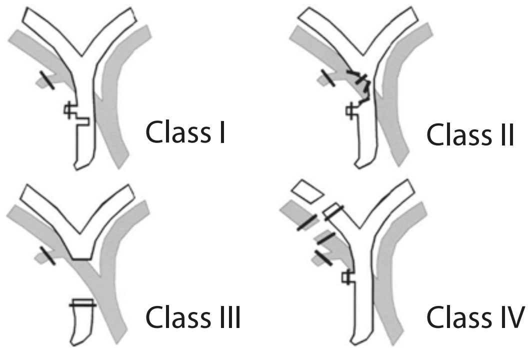


Fig. 15.4 Stewart-Way classification. (From [44], with permission)

Table 15.9 Stewart-Way classification

Type	Injury type
I	Small incisions or incomplete intersections of the CBD Cholangiogram incision in cystic duct extended into CBD
II	Lateral damage or stricture of the CBD caused by thermal injury or clips
III	Total transection or excision of the or CBD, CHD or the right or left hepatic ducts
IV	RHD mistaken for cystic duct, RHA mistaken for cystic artery RHD and RHA transected Lateral damage to the RHD from cautery or clips placed on duct

Class I injury occurs when CBD is mistaken for the cystic duct, but the error is recognized, usually by intraoperative cholangiography, before CBD is divided, or when the incision made in the cystic duct for the cholangiography is extended on to CBD. Class II injuries involve lateral damage to CHD from clips or cautery used too close to the duct. This often occurs in cases where visibility is limited due to inflammation or bleeding and results in stricture and/or fistula formation. Class III injury, the most common type, occurs when CBD is not recognized and mistaken for the cystic duct. The CBD, CHD, right or left hepatic ducts are transected, and a variable portion including the junction of the cystic and CBD is excised. Class IV injuries involve damage to the RHD or a right segmental hepatic duct, either because this structure is mistaken for the cystic duct or because it is injured during dissection or from cautery and/or clips placed on duct, often with injury of the right hepatic artery because it is mistaken for cystic artery (Fig. 15.4) [44].

15.4.10 Lau–CUHK (Chinese University of Hong Kong) Classification

This system stratifies the biliary injuries in an ascending order of severity from type 1 to 5 and emphasizes attention to operative detail to prevent these injuries. Type 1 injuries describe leaks from cystic duct stump or small ducts in liver bed. Type 2 refers to partial common hepatic or bile duct wall injuries without (2A) or with (2B) tissue loss, whereas type 3 to common bile or hepatic duct transection without (3A) or with (3B) tissue loss. Right or left hepatic duct or sectorial duct injuries without (4A) or with (4B) tissue loss constitute type 4 injuries. All bile duct injuries associated with vascular injuries encompass type 5 injuries (Table 15.10) [45].

15.4.11 Kapoor Classification

Kapoor [46] in a letter to the editor published a classification similar to ATOM [47] established by EAES, in that letters pertaining to the type of injury were used (nominal), rather than a categorical sequence. The proposed classification consisted of three types of injury (B,C,D) describing bile leakage, circumference involvement, and duct injury, respectively (Table 15.11). Every type has two subdivisions: By for open duct and Bn for ligated or clipped ducts, Cf when full circumference was involved due to either transection or excision and Cp when partial circumference was involved (clip, cautery, hole, excision), and Ds for significant duct (CBD,CHD, RHD, right sectoral, or segmental duct) injury and Di for insignificant duct (cystic duct, subsegmental duct, subvesical duct) injury. Vascular injury was included (the letter V is added when there is associated vascular injury), but there was no clear description of the level of the injury. However, the proposed classification is simple and easy to remember, reproduce, and interpret.

Table 15.10 Lau - CUHK classification

Type	Injury type
1	Leaks from cystic duct stump or small ducts in liver bed
2	Partial CBD/CHD wall injuries without (2A) or with (2B) tissue loss
3	CBD/CHD transection without (3A) or with (3B) tissue loss
4	Right or left hepatic duct or sectorial duct injuries without (4A) or with (4B) tissue loss
5	Bile duct injuries associated with vascular injuries

Table 15.11 Kapoor classification

Type	Injury type
B	Bile leak By-yes (open duct) Bn-no(ligated/clipped duct)
C	Circumference involved Cf-full circumference (transection or excision) Cp-partial circumference (clip, cautery, hole, excision)
D	Duct injured Ds-significant duct (CBD, CHD, RHD, right sectoral or segmental duct) Di-insignificant duct (cystic duct, subsegmental duct, subvesical duct)

15.4.12 Hannover Classification

Hannover classification delineated the injury patterns, including information regarding distal bile duct injuries and concomitant vascular injuries within the liver hilum. This classification provides discriminators for the localization of tangentially or completely transected bile ducts above or below the bifurcation of the hepatic duct, which is a major drawback of other classification systems. Furthermore, it is reproducible and ensures uniformity of reporting. In this classification, BDI were divided into five types from A to E [48].

According to Hannover classification, a type A injury describes a peripheral biliary leakage, either originating from the cystic duct (A1) or from the gallbladder bed (A2) with reconnection to the main bile duct system. This type of injury corresponds to type A and 1 injury according to Strasberg and Siewert classification, respectively, but Hannover classification further distinguishes a type A1 injury that leads to biliary leakage from the cystic duct and type A2 that is leakage from the liver bed of the gallbladder. Both Siewert and Strasberg classification systems do not clarify whether the leakage is from the cystic duct or the liver bed. Additionally, Bismuth and Stewart-Way systems do not delineate these types of lesions.

A type B injury describes either an incomplete (B1) or complete (B2) occlusion of the common or main bile duct or the right hepatic duct by clips or ligation without injury. Type C corresponds to a tangential injury of the CBD or CHD with further subdivisions: C1 for small punctiform lesions (<5 mm), C2 for extensive lesions (>5 mm) below the confluence, C3 for extensive lesions at the level of the hepatic bifurcation, and C4 for extensive lesions above the level of the confluence. Type D refers to a completely transected bile duct with further stratification as follows: D1 without defect below the hepatic bifurcation, D2 with defect below the hepatic bifurcation, D3 at hepatic duct confluence level (with or without defect), and D4 above the hepatic bifurcation level (with or without defect). Vascular injuries are included in type C and type D (Fig. 15.5). Type E injury is associated with strictures of the main bile duct at a late postoperative state at varying distances from the confluence and is classified into four subtypes: E1 when the stricture is short circular (<5 mm) at the main bile duct, E2 when the stricture is longitudinal

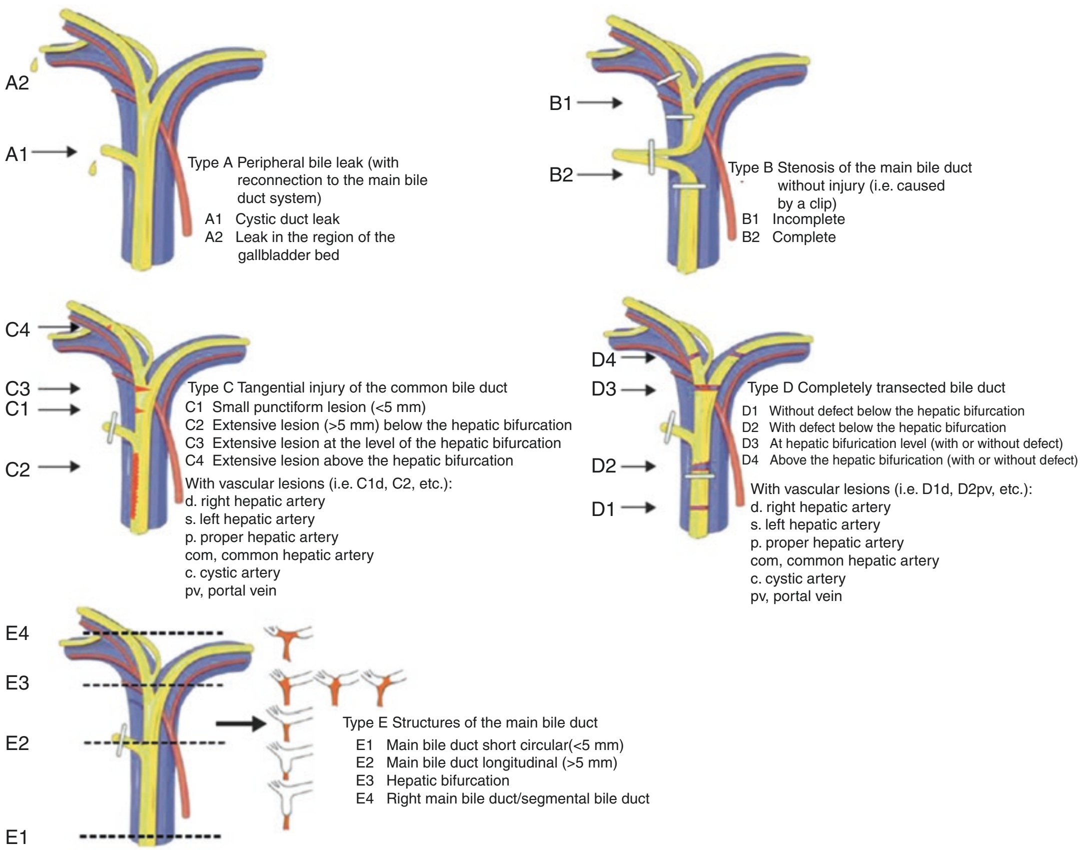


Fig. 15.5 Hanover classification. (From [28], with permission)

Table 15.12 Hannover classification

Type	Injury type
A	Peripheal bile leakage (in communication with main biliary system)
A1	Bile leakage from the cystic duct
A2	Bile leakage from the gallbalder fossa
B	CHD or CBD stricture without damage (eg caused by a clip)
B1	Incomplete
B2	Complete
C	Lateral CHD or CBD injury
C1	Small spot injury (<5 mm)
C2	Large injury (>5 mm) below the hepatic ducts confluence
C3	Large injury at the level of the hepatic ducts confluence
C4	Large injury above the hepatic ducts confluence
D	Total transsection of CHD or CBD
D1	Without ductal loss below the hepatic ducts confluence
D2	With ductal loss below the hepatic ducts confluence
D3	At the level of the hepatic ducts confluence
D4	Above the hepatic ducts confluence (with or without ductal loss)
E	CHD or CBD stricture/stenosis
E1	Short, circular (<5 mm) CBD stricture
E2	Longitudinal CBD stricture (>5 mm)
E3	Stricture at the level of the hepatic bifurcation
E4	Stricture of the right hepatic duct or segmental duct

(>5 mm) at the main bile duct, E3 when affects the hepatic confluence, and E4 when affects the right main bile duct or a segmental bile duct (Table 15.12) [48].

15.4.13 Cannon Classification

Cannon et al. [49] devised a simple, three-tier classification scheme with the primary goal of stratifying injuries based on the financial cost of definitive management. Grade I injuries consisted of leaks from the cystic duct stump, duct of Luschka, or accessory right hepatic ducts. Grade II injuries consisted of all other levels of biliary injury, including those to the common bile duct or intrahepatic bile ducts. Grade III includes all combined vascular and biliary injuries. However, this system does not provide the precise anatomic information afforded by current classification schemes, though its simplicity makes it applicable to routine clinical practice.

15.4.14 ATOM Classification

Several classifications have been proposed to stratify the type of injury and to standardize the treatment strategy [47]. For each classification, however, one or more relevant features of BDI necessary to thoroughly describe its complexity are lacking [50–52]. For this reason, the European Association for Endoscopic Surgery (EAES) proposed an all-inclusive BDI nominal classification system (ATOM), which includes the anatomy of damage and occurrence of vascular injury (A), the timing of detection (To), and the mechanism of damage (M) [47, 50–52] (Table 15.13).

The parameter "anatomic characteristics of the injury" includes the anatomic level on the biliary tree of the initial injury and concomitant vasculobiliary injury [47]. The biliary tree is divided into the main and nonmain biliary ducts. The main biliary duct (MBD in the EAES classification) (including the CBD, the CHD, and the right and left hepatic ducts) derived from the Bismuth, Strasberg, Neuhaus, Connor, McMahon, and Lau classifications [5, 6, 26, 31, 34, 40, 45]. The anatomic localization is as follows: type 1, low main BDI ≥2 cm distal to inferior border of superior hepatic confluence; type 2, middle main BDI <2 cm distal to inferior border of superior hepatic confluence; type 3, high main BDI involving the superior hepatic confluence but the left–right communication is preserved, usually on the roof; type 4, high main BDI involving the superior hepatic confluence but left–right communication is interrupted, including the E6 injury of Connor and Garden [31]; type 5, left or right hepatic duct injuries without injury to the superior confluence; and type 6, isolated segmental hepatic duct injury [53].

The nonmain biliary duct (NMBD in the EAES classification) includes the cystic aberrant and accessory (hepatic bed, subhepatic, or Luschka) ducts, corresponding to Strasberg types A and C, Neuhaus A, Lau 1, and Amsterdam type

Table 15.13 EAES classification matrix for bile duct injuries

Anatomical characteristics							Time of detection			Mechanism	
Anatomic level	Type and extent of injury					Vasculobiliary injury (yes = VBI+) and name of injured vessel (RHA, LHA, CHA, PV, MV); (no = VBI-)	Ei (de visu, bile leak, IOC)	Ep	L	Me	ED
	Occlusion		Division								
	C	P[a]	C	P[b]	LS[b]						
MBD											
1											
2											
3											
4											
5											
6											
NMBD											

For each injury, the surgeon fills in the following matrix: (1) single injury (yes/no); (2) multiple injuries (yes/no). Then one matrix is filled in for each injury, as appropriate. For example, an injury made by an energy-driven (ultrasonic) dissector involving the superior biliary confluence with interruption of the right and left hepatic ducts, detected (intraoperatively) during the operation by the presence of bile would be classed as MBD4 CVBI Ei, ED. The Connor Garden E6 injury is in fact a type 4 with LS: MBD 4 LS

EAES European Association for Endoscopic Surgery, *MBD* main biliary duct, *NMBD* nonmain biliary duct (Luschka duct, aberrant duct, accessory duct), *level 1* ≥ 2 cm from lower border of superior biliary confluent, *level 2* < 2 cm from lower border of superior biliary confluent, *level 3* involves the superior biliary confluent but communication right left is preserved, *level 4* involves superior biliary confluent but communication right left is interrupted, *level 5a* right or left hepatic duct, *level 5b* right sectorial duct but bile duct still in continuity, *C* complete, *P* partial, *LS* loss of substance, *Me* mechanical, *ED* energy driven, *VBI* vasculobiliary involvement, *RHA* right hepatic artery, *LHA* left hepatic artery, *CHA* common hepatic artery, *PV* portal vein, *MV* marginal vessels, *Ei* early intraoperative, *Ep* early postoperative, *L* late, *OC* intra-operative cholangiogram

[a]Indicate percentage of circumference, if known

[b]Indicate length, if known

A [5, 26, 33, 34, 42, 45]. The type as well as the circumferential and longitudinal extent of injury depends on whether the injured bile duct was initially occluded (O) (ligation, clip, sealed) or divided (D) and leaked. In both of these, the lowercase letter "c" is added to stand for complete interruption (ligation, clip, sealing, or division), while a partial interruption (ligation, clip, sealing, or division) is labeled "p," followed by the percentage of the circumference involved whenever this detail is known, whether there was a loss of substance between two divisions, irrespective of whether one or both of the extremities was occluded or divided (LS; the length in centimeters, whenever known, is indicated in parentheses). Concomitant vasculobiliary injury (VBI) is defined as an injury to both a bile duct and a nearby vessel [5]. Our definition also includes vascular injury that occurs alone in the index operation but results in injury, such as septic complications, stricture, or liver atrophy.

The parameter "time of detection" is classified as early (E), either intraoperative or late (L). The early detection group is further stratified according to the intraoperative (Ei) or immediate postoperative detection, whereas the former is usually discovered by the presence of bile in the operative field or at intraoperative cholangiography [27, 31, 45].

The parameter "mechanism of injury" may be classified as mechanical (Me) (e.g., scissors) or energy driven (ED) (e.g., cautery or ultrasonic) injury. The EAES classification label for BDI thus includes a series of acronyms: MBD for main bile duct (followed by a number 1–6, corresponding to the anatomic level on the main bile duct), NMBD for nonmain bile duct, followed by the relevant acronyms (Table 15.13): O or D, each with the suffix c or p (%), LS (cm), VBI (RHA, LHA, CHA, PV, marginal vessel [MV]), Ei, Ep, or L, and Me or ED. If for some reason a parameter is unknown, the suffix "?" is added [47].

Although, the classification may appear complex, ATOM is the only classification that allows true comparisons with the others because it is all-inclusive, and there are no missing details (as in the case with others) [50–52]. It includes objective data and not subjective terms, such as major, minor, peripheral, central, significant, and insignificant. It allows comparisons of mechanisms and timing of BDI between the other classifications. Last but not least, it emphasizes the underlying mechanism that led to the injury, the most relevant aspect for didactic purposes aiming at prevention [50–53].

15.5 Conclusions

Preventive strategies and safe surgery are of utmost importance to minimize BDI during laparoscopic cholecystectomy. Although many methods used in the prevention of BDI have demonstrated promising results, there is no consensus regarding a systematic reporting system of BDI. Currently, CVS seems to be the cornerstone for a safe laparoscopic cholecystectomy. In difficult cases, a sufficient attention to alternative techniques should be apprehended. In such cases, intraoperative imaging may delineate the biliary anatomy.

In order to define the type of BDI, several classifications have been proposed, but none is universally accepted. The heterogeneity of these classifications reduces their clinical utility and each of them has limitations. Although, they are useful for standardization of outcome and predictive quality, important short-term prognostic factors, including recognition of injury, mode of presentation, previously attempted repairs, presence of concomitant sepsis, and stability of the patient, are not accounted in most of the classification systems, and the documentation of an associated vascular injury has been described only recently. Furthermore, their complexity makes their routine incorporation into clinical use difficult. Among them, Bismuth's and Strasberg's classifications are most commonly used by clinicians. Recently, EAES devised an all-inclusive, semantics-based, nominal classification "ATOM" (Anatomic, Time Of detection, Mechanism) combining all existing classification items, which enables combination of all information on BDI, irrespective of the original classification used.

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