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NON-VASCULAR INTERVENTIONAL RADIOLOGY (A THABET, SECTION EDITOR)

Percutaneous Treatment of Iatrogenic and Traumatic Injury of the Biliary System

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Abstract
Purpose of Review Traumatic or iatrogenic bile duct injury (BDI) includes bile leaks, benign stenoses, and fistulae. These complications result in significant morbidity and mortality. This review will provide insight into the presentation, diagnosis, classification, and percutaneous management of BDI.
Recent Findings Prompt diagnosis through non-invasive imaging and minimally invasive procedures is paramount to improved patient outcomes. Numerous classifications of BDI exist, although none are universally accepted. Percutaneous approaches to the management of BDI offer a minimally invasive alternative to traditional surgery. Bile leaks are primarily treated with drainage and decompression; however, adjunctive techniques such as embolization are also presented. Fistulae are routinely treated with embolization even though limited literature exists to provide a consensus treatment algorithm. Benign stenosis is primarily treated with balloon dilation with long-term biliary intubation while placement of bile duct stents is often reserved for patients with recurrent stricture.
Summary Iatrogenic or traumatic BDI typically requires a multidisciplinary team approach, although prompt diagnosis and advances in therapeutic approaches have improved patient outcomes.

Keywords Bile duct injury · BDI · Bile leak · Stenosis · Fistulae · Trauma

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Introduction

Bile duct injury (BDI), including bile leaks, stenoses, and fistulae, is a known complication of hepatobiliary (HPB) procedures whose incidence varies upon the type of procedure, ranging from 0.3 to 0.5% for cholecystectomy up to 30% for liver resection [1–3]. BDI has also been described from minimally invasive interventions typically performed by the interventional radiologist (IR) such as percutaneous tumor ablations and liver abscess drainage [4, 5]. BDI secondary to abdominal trauma is encountered much less frequently [6–8]. BDI typically results from either direct damage to the biliary tree or postoperative inflammatory changes. Furthermore, biliary stenosis is a known but uncommon complication of infection (ascending cholangitis), inflammation (pancreatitis/cholecystitis), ischemia, autoimmune disease (primary sclerosing cholangitis), chemotherapy, and radiation [9–14]. BDI can result in severe morbidity and mortality for the patient [15–17]. Therefore, prompt diagnosis and appropriate management is critical for patient safety and improved outcomes. This review will provide insight into the presentation, diagnosis, classification, and percutaneous management of BDI.

Clinical Presentation

Some patients with BDI may be asymptomatic. Yet, healthcare providers should have a high suspicion for BDI in patients who present in the postoperative period (less than 2 weeks) or after abdominal trauma with abdominal tenderness or bloating, malaise, anorexia, or other signs of infection. Laboratory data demonstrating biliary obstruction or inflammation can aid in patient assessment (Table 1), but the patient's clinical status and physical examination remain crucial for a timely diagnosis as laboratory data can be normal in up to 40% of patients [18]. Prompt recognition of BDI helps to avoid peritonitis, sepsis, and many other serious complications that develop later as a result of BDI [19]. Moreover, the physical examination may be a clue to the type of BDI sustained by the patient. For example, bile leaks (defined as bile discharge from an abdominal wound or drain with total bilirubin >5 mg/mL or three times the serum level, intra-abdominal bile collections confirmed by aspiration, or cholangiographic evidence of biliary contrast extravasation [20•]) and fistulae (defined as an abnormal connection of the biliary tree to the skin or another organ such as the stomach or colon) often present with abdominal tenderness in combination with raised inflammatory markers. On the other hand, biliary stenosis typically presents with obstructive biliary symptoms, including jaundice, dark urine, and steatorrhea.

Diagnosis

Ultrasound

Ultrasound (US) is often one of the initial screening evaluations to assess for BDI and for follow-up imaging. The findings of BDI vary tremendously based on location, presence of infection, and chronicity. An anechoic, well-circumscribed fluid collection adjacent to the liver or in the gallbladder fossa is a common appearance of bilomas from leaks while the presence of complex internal septations and echogenic debris may suggest hemobilia or infection, although this is a non-specific finding [21]. Confirmation of an infected biloma can be achieved with microbiologic analysis after an image-guided needle aspiration. Sonographic evaluation for biliary stenosis may demonstrate focal narrowing of the bile ducts, especially of the common bile duct (CBD) at the porta hepatis, or upstream dilatation of the biliary tree [13, 20•]. The use of US for identifying biliary fistulae is limited but could potentially show an abnormal biliary communication with surrounding structures [13, 20•].

Computed Tomography

BDI has a variety of different appearances on computed tomography (CT) based on degree of injury and location. CT is more sensitive than US in detecting bile leaks and vascular injuries [22]. Bile, especially without superimposed infection or intermixed blood products, tends to have an attenuation of <20 Hounsfield units (HU). High attenuation (>50 HU) of a fluid collection from suspected BDI should raise concern for hemobilia or hematoma, especially in the setting of trauma [23]. On CT, biliary fluid collections appear as either free or loculated low-density collections near the intra- or extrahepatic biliary tree [22]. Additionally, free bile fluid may extend further into the dependent portions of the peritoneum depending on the extent of the leak. Biliary stenosis or stricture can often be recognized on CT as a site of focal narrowing along the biliary tree with upstream dilatation of the remaining bile ducts [24]. Biliary fistulae can be difficult to detect on CT and may have a variety of appearances. Oral contrast can aid in the diagnosis of a bilio-enteric fistula while intravenous contrast can help diagnose a bilio-vascular fistula [25, 26]. Combining CT with intravenous cholangiography has been shown to improve the localization of a BDI by demonstrating communication between the fluid collection and biliary tree [27].

Magnetic Resonance Cholangiopancreatography

Magnetic resonance cholangiopancreatography (MRCP) provides a non-invasive assessment of biliary anatomy. One advantage of MRCP is that it can provide a detailed assessment

Table 1 Laboratory tests of liver function can help indicate the type of BDI

	Hepatocellular injury	Cholestasis without ductal dilatation	Cholestasis with ductal dilatation
Biomarkers	↑AST/ALT ± ↑bili and Alk Phos	↑Alk Phos and bili ± ↑AST/ALT	↑Alk Phos and bili ± ↑AST/ALT
Examples	Viral/autoimmune/drug/alcohol/NASH/vascular/hereditary hepatitis	Cirrhosis/medications/sepsis/PBC	Choledocholithiasis/malignant PSC/BDI

AST aspartate aminotransferase, *ALT* alanine aminotransferase, *Bili* total bilirubin, *Alk Phos* alkaline phosphatase, *NASH* non-alcoholic steatohepatitis, *PBC* primary biliary cirrhosis, *PSC* primary sclerosis cholangitis, *BDI* bile duct injury of the biliary tree without the use of contrast which may pose additional risk in critically ill patients with compromised renal function. However, if possible, it is preferable to give the patient with suspected BDI an MRI-contrast agent that is primarily excreted by the liver such as Eovist (Bayer, Whippany, NJ). MRCP provides improved contrast resolution compared to US or CT and has been shown to be nearly 100% sensitive for detecting bile leaks and up to 85% accurate at localization of the leak when such an agent is utilized [28–30]. The administration of intravenous contrast also aids in the diagnosis of arterial injuries that may be associated with BDI [30].

Hepatic Cholescintigraphy

Hepatobiliary scintigraphy is a highly sensitive and non-invasive method for the detection of BDI that can be especially useful in the detection of small leaks missed on traditional CT [31–34]. Hepatobiliary scintigraphy is performed by the intravenous (IV) administration of technetium-99m (Tc-99m)-labeled iminodiacetic acid (IDA) to the patient. The patient is scanned approximately 1 h after radiotracer administration. Tc-99m IDA is extracted from the serum by hepatocytes and actively transported into the bile canaliculi. Accumulation or communication of a radiotracer outside of the biliary tree is suggestive of BDI. One drawback of this technique is that a high serum bilirubin due to hepatic dysfunction can result in competitive inhibition and limit sensitivity. Additionally, localization of the injury is limited by poor spatial resolution with accuracy as low as 19%, although more precise localization is achievable with the addition of single-photon emission computed tomography (SPECT)/CT [32, 35]. Cholescintigraphy may be most useful to (a) confirm the presence of bile from a BDI within suspected ascites or seromas, (b) rule out biliary obstruction, and (c) confirm resolution of BDI on follow-up imaging [30, 34, 35].

Endoscopic Retrograde Cholangiopancreaography and Percutaneous Transhepatic Cholangiography

Once BDI has been suspected, the next best step is to proceed with an invasive cholangiogram. The cholangiogram allows for a dynamic analysis of the biliary tree, accurate detection and localization of BDI, and an opportunity for intervention within the same session. An invasive cholangiogram is most often obtained through either an endoscopic or a percutaneous approach. Endoscopic retrograde cholangiopancreatography (ERCP) is often the first-line approach for obtaining an invasive cholangiogram and for the treatment of any identified injuries. This is due to the high technical and clinical success rates associated with ERCP for the treatment of BDIs [36, 37]. Moreover, it is usually more comfortable for the patient to have their biliary tree accessed via an endoscopic approach rather than a percutaneous approach. Finally, if a stent is placed during ERCP, it is located completely internal to the patient. This is in contradistinction to the percutaneous biliary drains placed by IR that often have both an internal component (crossing the CBD) and an external component coming out of the patient's body. ERCP can be very effective in evaluating the biliary system distal to the level of injury [38•]. On the other hand, percutaneous transhepatic cholangiography (PTC) is generally better at evaluating the biliary tree proximal to the site of injury (especially in cases of major duct transection) and in its ability to identify the presence of an aberrant right hepatic bile duct that is often overlooked during ERCP [39–44]. PTC is also indicated in several other instances, including failed ERCP, patients' inability to tolerate ERCP, septic patients that require rapid decompression of the biliary tree, and the presence of altered anatomy that does not permit an endoscopic approach [43]. The main contraindication to PTC is an uncorrectable coagulopathy.

Classification of Bile Duct Injuries

Multiple classification systems have been proposed for BDI; however, none is universally accepted and none takes into account all therapeutic and prognostic implications [41]. The Strasberg, Hannover, and Nagano classifications of BDI are probably the most commonly recognized classification schema and will be discussed below. Familiarity with these classifications is important for the surgeon, endoscopist, or IR and are worthy of discussion here because the type or class of BDI can dictate the mode of management.

The Strasberg classification was first reported in 1995 and is considered by some to be the most complete and easy to understand of the different schema [38•]. It divides BDI into five categories (class A to E). In this scheme, class A injury refers to a bile leak from a cystic duct stump or minor biliary radical in the gallbladder fossa with an intact CBD. Class B injuries have an occlusion or blockage of a right posterior duct with continuity to the CBD while class C injuries have a leak arising from this same duct with no continuity to the CBD. Class D injuries have a partial tear of the CBD without loss of continuity with the rest of the biliary system. Finally, class E is a complete transection of the bile duct with multiple subtypes according to the length of the stump.

The Hannover classification, published in 2007, also divides BDI into five types (A to E) according to their relationship to the biliary confluence and includes vascular injuries as well [45•]. In this scheme, type A injuries represent damage to the cystic duct or a gallbladder bed leak. Type B injuries include complete and incomplete stenoses of the CBD secondary to a surgical staple. Type C represents lateral tangential injuries. Type D injuries refer to a complete transection of the CBD associated with concomitant hepatic arterial or portal venous injury. Type E injuries refer to a CBD stricture without leak.

The Nagano classification, first reported in 2003, breaks BDI into four types (A to D) [20•]. According to Nagano et al., a type A BDI is a minor leak from small biliary radicles on the surface of the liver. These injuries are usually self-limiting. Type B BDIs represent leaks from inadequate closure of the major bile duct branches on the liver's surface. Type C is injury to the main duct, commonly near the hilum, while type D refers to leakage due to a transected duct disconnected from the main duct. One attractive feature of this classification system is that it also provides the physician with an algorithmic approach to patient management depending on the type of injury. Of course, individual patients and local practice patterns may require deviation from this type of approach but, at the very least, does provide initial guidance to the healthcare team on therapeutic options.

Percutaneous Management of Bile Duct Injuries

PTC is the imaging modality of choice when interventions such as placement of a percutaneous transhepatic biliary drain (PTBD) are required to decompress the biliary system. Treatment of BDI by percutaneous intervention involves drainage of any fluid collections, dilatation of strictures, biliary diversion from the injury, and sealing the biliary tree with embolization or stent placement [46–49].

Patient Preparation It is critical that the IR review the patient's imaging prior to beginning the procedure. This will allow for an understanding of the type of BDI the patient may have and for the creation of an appropriate plan for obtaining access to the biliary tree. A detailed analysis of pre-procedure imaging can clue the IR to any problems or pitfalls that he or she may encounter during the procedure such as variant anatomy. Assessment of the patient's clinical status is obtained through a focused history and physical exam. This includes a determination of their physical status according to the American Society of Anesthesiology (ASA) guidelines (Table 2) and an estimation of their ability to tolerate a potentially protracted procedure. These decisions will help the IR decide whether to proceed using moderate conscious sedation or general anesthesia. In either case, the patient should have had nothing to eat for at least 6 h prior to the procedure in order to reduce the risk of aspiration. The IR should be aware of the patient's allergies with particular attention to any history of reaction to iodinated contrast media or antibiotics. Finally, an examination of the patient's abdomen with and without the use of US can inform the decision about where to access the biliary tree. It is recommended that all patients have an international normalized ratio (INR) of 1.5 or less, a platelet count of 50,000/dL or more, and an activated partial thromboplastin time (aPTT) of less than 1.5× normal prior to undergoing the procedure. Periprocedural antibiotics should also be administered prior to performing a percutaneous biliary intervention in order to decrease the risk of sepsis. The hepatic vasculature is often exposed to the contents of the biliary tree during these interventions; thus, broad-spectrum coverage for both gram-positive and gram-negative organisms is required. At our institution, we use a third-generation cephalosporin like ceftriaxone.

Table 2 The American Society of Anesthesiologists patient classification status

Class I—Normal healthy patient
Class II—Patient with mild systemic disease
Class III—Patient with severe systemic disease
Class IV—Patient with severe systemic disease that is a constant threat to life
Class V—Moribund patient that is not expected to live without the procedure
Class VI—Brain-dead patient being evaluated for organ transplant

Technical Aspects of Percutaneous Biliary Access Most IRs gain access to the biliary system for management of BDI using either a "one-stick" or "two-stick" technique. In a two-stick approach, a needle (usually a 21- or 22-gauge Chiba) is passed into the hepatic parenchyma either under fluoroscopic or under sonographic guidance. Once access to the biliary system is confirmed by contrast injection (Fig. 1a), a more suitable duct is then selected for definitive access and targeted by a second Chiba needle under fluoroscopic guidance (Fig. 1b). The selected duct is typically peripheral (reduces the risk of bleeding), inferior (reduces the risk of pleural damage), and has a good trajectory toward the CBD (facilitates a mechanical advantage). However, the duct selected will depend on the goals of the procedure. After obtaining wire access into the selected duct, a microwire is passed through the needle toward the CBD (Fig. 1c). Then, a transitional dilator set such as the Neff Percutaneous Access Set (Cook Medical, Bloomington, IN) is passed over the wire to convert the micro-access system to a more stable 0.035″ or 0.038″ wire system (Fig. 1d). In the single-stick approach, a needle is passed into the hepatic parenchyma toward the biliary system either under fluoroscopic or under sonographic guidance. If the accessed duct is adequately peripheral and has a reasonable course to the CBD after contrast injection through the needle, then a micro-wire is passed through the needle toward the CBD and the procedure proceeds in a similar fashion as the two-stick technique. For right-sided biliary access, the needle is advanced between the 9th and 11th intercostal space in the mid-axillary line. For

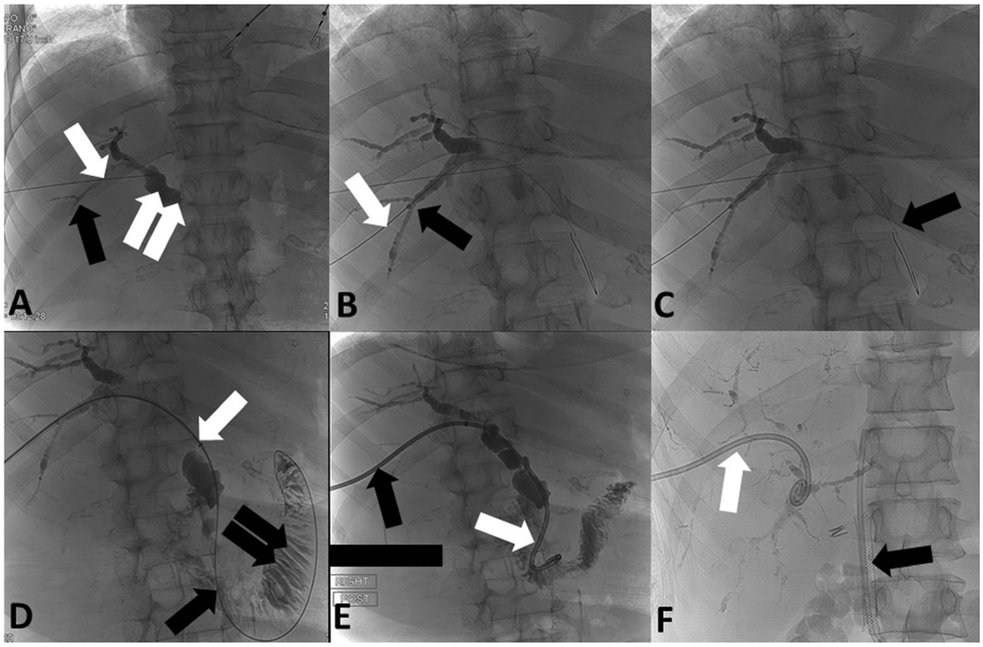

Fig. 1 PTBD in a patient who presented with obstructive jaundice from choledocholithiasis after a failed ERCP attempt (**a**–**e**). **a** A 22-gauge needle (*white arrow*) was passed centrally under fluoroscopic guidance and then withdrawn slowly while gently injecting contrast until the biliary system is opacified (*double white arrow* = CBD, *black arrow* = peripheral biliary duct). **b** A second 21-gauge needle (*white arrow*) is then used to fluoroscopically target the more peripheral duct (*black arrow*). **c** A micro-wire (*black arrow*) is passed through the needle into the CBD. **d** Stable 0.035″ wire (*black arrow*) is now in the small bowel (*double black arrow*). The *white arrow* denotes the tip of a vascular sheath used in this case to help provide support for crossing the CBD stenosis. **e** Cholangiogram after placement of an internal-external PTBD which has an external portion exiting the patient (*black arrow*) and an internal portion (*white arrow*) that crosses the CBD into the small bowel. **f** Cholangiogram after placement of an external biliary drain (*white arrow*) in a patient with cholangitis. The patient previously had a malignant stricture of the CBD managed with both plastic and metal stents (*black arrow*) which became occluded. Notice that there is no portion of the drain crossing the CBD

left-sided biliary access, the needle is placed in the sub-xiphoid region. Left-sided approaches to the biliary system are less common, most likely due to technical challenges in catheter and wire manipulation. Yet, a left-sided approach can be more comfortable for patients as the intercostal muscles are spared. Moreover, there is a lower risk of diaphragmatic injury during a left-sided approach.

After access is obtained, a cholangiogram can map the biliary tree and localize the site of injury. It should be noted that the biliary tree should not be over-distended with contrast during opacification, which can lead to sepsis [50]. If stable access across the CBD or BDI is obtained, then the operator can either place an internal-external biliary drain for biliary diversion (Fig. 1e) or leave a sheath in place for further treatments during the same session. If the operator is unable to get across the CBD or the site of BDI, an external biliary drain can be placed (Fig. 1f). This drain can decompress the biliary system and divert bile away from the site of BDI for a short period (usually 48–72 h) at which point crossing of the CBD or BDI can be re-attempted. In our experience, these subsequent attempts to cross the CBD or site of BDI are usually much more successful, possibly because some of the acute inflammatory changes in the biliary system have had a chance to subside.

Percutaneous Management Strategies for Biliary Leak

The classical management of biliary leaks has been to place an internal-external biliary drain across the area of leakage. This diverts additional bile from crossing the leak and allows the biliary system to heal around the catheter. The healing process is periodically evaluated with over-the-wire cholangiograms during routine biliary tube exchange. Once the leak is no longer identified and there is unimpeded flow of bile into the small bowel, the catheter can be removed (Fig. 2). Another traditional approach to biliary leaks, especially for CBD or hilar injury, is the percutaneous placement of U-tubes. A U-tube is a single drainage catheter with multiple side holes along its mid-portion. The U-tube drainage catheter is passed across the site of injury and through the biloma via two percutaneous exit sites. Some advantages of the U-tube is that it is more secure than two separate drainage catheters, empties into one bag for patient convenience, and diverts bile away from the peritoneum. Placement of PTBD for biliary diversion and drainage has a success rate ranging from 70 to 80% alone and up to 96% when used with other modalities such as ERCP [51••].

Transections of the primary bile ducts (Nagano-type D injuries) are particularly complex problems. Patients may require initial stabilization with percutaneous placement of a

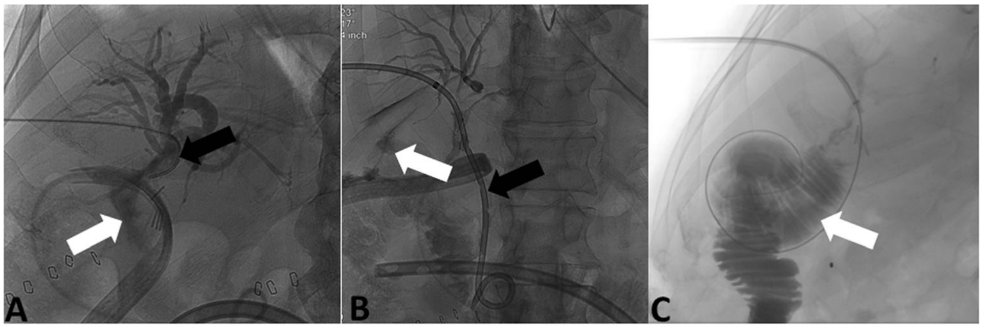

Fig. 2 PTBD in a patient with biliary leak after hepaticojejunostomy. **a** Initial cholangiogram through a catheter (*black arrow*) demonstrates a bile leak (*white arrow*). **b** An internal-external PTBD (*black arrow*) is placed to divert bile away from the leak (white arrow). **c** Follow-up over-the-wire cholangiogram several months later shows no evidence of leak with free flow of contrast into the small bowel (*white arrow*). The catheter was removed

PTBD with or without placement of an additional percutaneous catheter to drain off any associated collections until definitive surgical repair can be attempted. Yet, surgery may not be an option for many patients due to their clinical condition, type of BDI, or other co-morbidities. In these cases, a combined "rendezvous" approach between endoscopy and IR may be attempted [52••]. This is accomplished when the IR gains percutaneous transhepatic access to the biliary system while the endoscopist does the same via an endoscopic approach. Wires are navigated from either approach into the region of biliary leak. The opposing access is then used to snare the wire, thus gaining "through-and-through" access across the BDI. At this point, a covered stent can be placed over the wire to seal the area of leakage. This technique has been shown to have a high clinical success rate with medium-term follow-up reported [52••].

Despite the relatively high success rates for treating bile leaks with biliary diversion, providers should be prepared with adjunctive measures to use in cases of recalcitrant leaks or to aid in the healing process. Our institution has had success in treating biliary leaks percutaneously with a variety of embolic agents. One could consider embolizing the leak with Gelfoam® (Upjohn, Kalamazoo, MI), a water-soluble agent prepared from purified skin gelatin. Gelfoam® is relatively inexpensive, easy to use, and familiar to most IRs as a vascular occlusion material. Gelfoam® only provides temporary occlusion, and if the leak is not healed by that time, there is a risk for re-development unless followed by a permanent embolic agent. *N*-Butyl cyanoacrylate (NBCA, or "glue") is another off-label consideration for the embolization of biliary leaks (Fig. 3). Glue is a permanent embolic that is often mixed with ethiodol to both delay its polymerization and allow for better visualization. A higher ratio of ethiodol to glue will allow the mixture to flow more distally before polymerizing. It provides the advantages of rapid embolization that, because of its liquid nature, can conform to its surroundings. Drawbacks of its use include its expense and the delicacy with which it needs to be handled. Another liquid embolic agent that could be used off-label in the management of bile leaks is an ethylene vinyl alcohol copolymer (Onyx®, Micro Therapeutics, Inc., Irvine, CA), a biocompatible agent whose delivery is potentially easier than that of glue [53]. Again, a significant drawback of Onyx® is its cost and incompatibility with certain catheters. Coils are permanent stainless steel or platinum occlusive devices that can have additional coatings, such as hydrogel and Dacron fibers, that increase surface area and thus the speed of occlusion. Coils can be delivered in an off-label indication to close a biliary leak via either a transbiliary or a transcutaneous route (Fig. 4). Coils have the advantage of being readily available and very familiar to most IRs. Another approach to treat the patient with a biliary leak would be to employ a micro-vascular plug (MVP, Covidien, Medtronic, Minneapolis, MN). These devices are relatively newer to the market but do create permanent occlusion, and the delivery wire allows for precise placement. A single MVP can be used in place of a coil in the biliary tree as an off-label indication; however, plugs can only be deployed in a relatively straight segment with minimal tapering.

Percutaneous Management of Biliary Fistula

The management of biliary fistulae is primarily based on single-institution retrospective studies or case reports. In general, embolization and stenting are the primary percutaneous interventions for biliary fistulae [47, 48]. Bilio-vascular fistulae, including arterial, and broncho-biliary fistulae are typically treated with embolization [48, 54].

For bilio-vascular fistulae, biliary access can be used to place a covered metal stent over the fistulous tract. Broncho-biliary fistulas are more common worldwide due to infection with hydatid cysts but can be seen as complications of radiofrequency ablation and right upper quadrant trauma [54]. Embolization of these fistulae through a transbiliary approach with micro-coils or placing covered stents has been effective at closing the fistulous tract and reducing reoperation [32, 55]. Bilio-biliary fistulas have been treated with coil embolization as well as the endoscopic-radiographic "rendezvous"

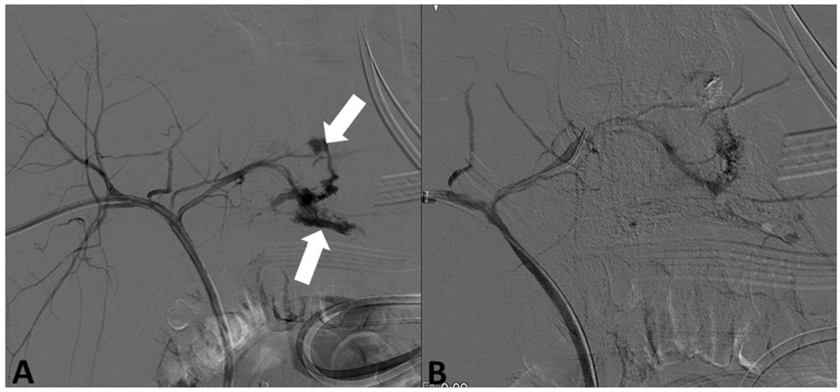

Fig. 3 Embolization in a patient with BDI after a gunshot wound. **a** PTC demonstrates a bile leak (*white arrows*) from at least two left hepatic ducts. **b** The leaking hepatic ducts were successfully catheterized and embolized via a transhepatic approach with Gelfoam® followed by NBCA

technique, as reported in a case involving right posterior segment duct to left hepatic duct fistula [56].

Percutaneous Management of Benign Biliary Stenosis

ERCP is first-line therapy for biliary stenosis. Nonetheless, there are several groups of patients for which percutaneous management is warranted. These would include overall poor patient condition precluding endoscopy, altered anatomy that would limit an endoscopic approach, those patients who have failed endoscopic attempts, and patients that require rapid decompression of the biliary tree. After the stricture has been identified via cholangiogram (Fig. 5a), every attempt should be made to cross the area with catheter and wire combinations as long as the patient's clinical condition allows. Guidewire access across the stenosis then permits cholangioplasty, catheter placement, and stenting (Fig. 5b). Treatment is aimed at relieving the obstruction and providing the patient with long-term biliary patency.

Percutaneous balloon dilation and stenting are the mainstay of therapy for benign biliary stenosis [49, 57]. Protocols for the management of benign strictures vary among institutions. Regardless, most protocols rely on a gradual increase of drainage catheter size over time in order to achieve forward biliary flow [58–60]. At each visit, an over-the-wire cholangiogram is performed to examine the

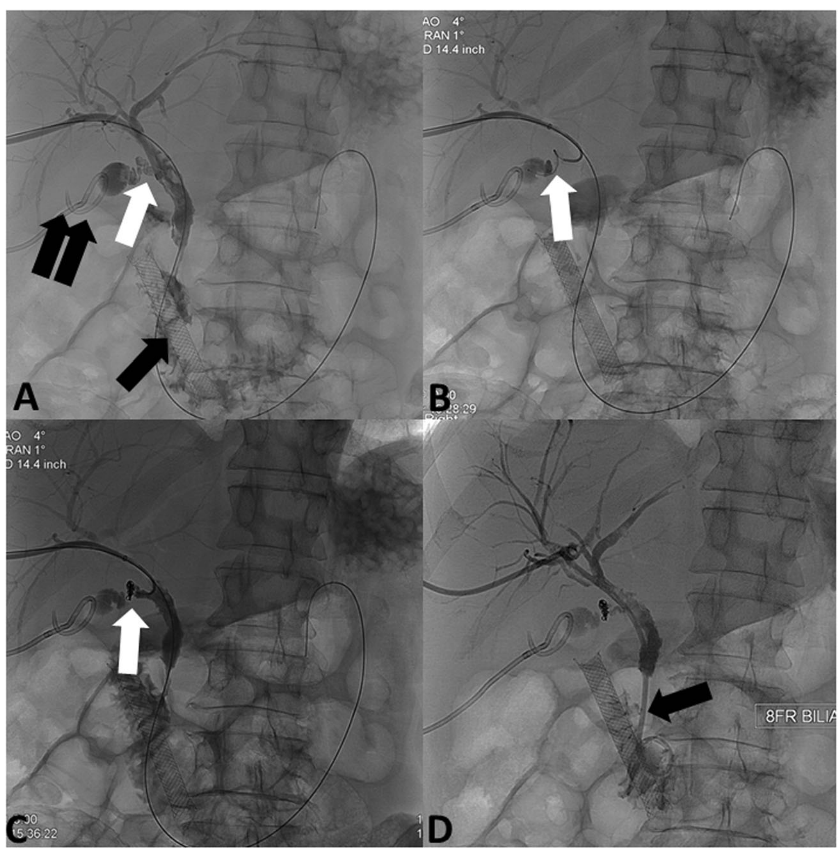

Fig. 4 Biliary leak from the cystic duct stump after cholecystectomy. **a** PTC demonstrates the leak (*white arrow*). Percutaneous biloma drain (*double black arrows*) and a migrated endoscopically placed biliary stent (*black arrow*) are also seen. **b** The site of leak is cannulated with a micro-catheter (*white arrow*). **c** Micro-coils are deployed to seal the leak (*white arrow*). **d** Follow-up cholangiogram through an internal-external PTBD (*black arrow*) shows no residual leak after coil embolization. The catheter was removed on a subsequent visit

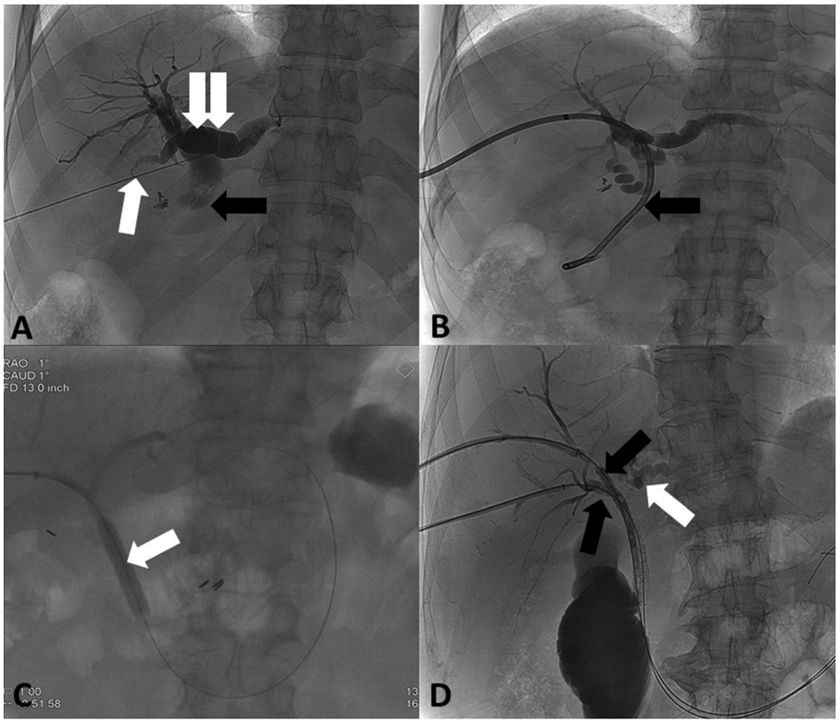

Fig. 5 Biliary stenosis. **a** PTC with needle contrast injection (*white arrow*) in a jaundiced patient after hepaticojejunostomy; a tight stenosis (*black arrow*) at the anastomosis with severe intra-hepatic ductal dilatation (*double white arrow*) is demonstrated. **b** Cholangiogram in the same patient after placing a PTBD for decompression. **c** Transhepatic cholangioplasty using a 10-mm balloon (*white arrow*) in a different patient with a CBD stricture thought to be secondary to prior endoscopic biliary interventions. **d** Cholangiogram in a patient with biliary strictures secondary to radiation that recurred after attempts were made to treat the stenosis with balloon cholangioplasty. Stents (*black arrows*) were placed across two proximal right biliary strictures through the CBD. Uncovered stents were used to preserve forward flow of the left ductal system (*white arrow*)

patient's progress. If cholangioplasty is needed, the balloon size should be tailored to the size of the patient's biliary ducts (Fig. 5c). A general rule of thumb would be to use a ~6-mm balloon for intra-hepatic ducts and a ~10-mm balloon for the CBD [32]. It should be noted that larger balloon sizes (potentially up to 20 mm) may be required for biliary-enteric anastomotic strictures. Even after the goal catheter size is reached, the patient should return to IR for periodic catheter exchange, cholangiography, and cholangioplasty. Most patients will require long-term biliary intubation lasting anywhere from 3 to 12 months in order to achieve a lasting result. Success is considered when less than 30% stenosis of the normal duct diameter remains within three dilation sessions [59]. Once a satisfactory cholangiographic result is achieved, some IRs would remove the biliary catheter and follow the patient clinically. Others may leave a capped external biliary drain above the stenotic region as a clinical test for a short period of time. One advantage of this method is that access to the biliary tree is maintained in the event that the patient experiences pain, fevers, or worsening liver function tests. Of course, this method leaves the patient with a catheter. Still, other groups employ a biliary "Whitaker" test where increasing amounts of contrast are instilled via the percutaneous access while pressures and fluoroscopic images are obtained. Patency after percutaneous balloon dilatation treatment varies widely in the literature, ranging from 30 to 90% [57, 59].

Recurrent stricture of benign biliary stenosis may occur in 29–58% of patients [61, 62]. In these cases, placement of a stent may be necessary (Fig. 5d). While stent placement for malignant strictures is commonplace, stent placement for benign strictures is not routine practice at all centers. Many patients with benign stenoses may have a lifespan that outmatches the patency of their stent, leading to occlusion and recurrent biliary obstruction. Such an outcome can be frustrating for both the patient and the physician. Nevertheless, newer stent technology may help in shifting the paradigm in favor of stenting. More recent studies utilizing fully covered biliary stents have shown stenosis resolution in up to 95% of patients with strictures after liver transplantation [63••]. Additionally, "retrievable" metal stents may also help improve patency rates. For instance, one study evaluated 79 patients who underwent placement of a partially covered stent (WALLSTENT; Boston Scientific, Natick, MA) for benign biliary stenosis. In this study, the authors noted a 90% resolution of the strictures and were able to remove all the stents endoscopically [63••]. Another retrospective analysis found that covered stents provided patients with an 87% patency at

3 years [64]. Improved technology and patient selection may result in significant changes in how these patients are managed in the future.

Complications

Major complications of percutaneous interventions include infection (sepsis, cholangitis), hemobilia, bile leak, hemorrhage, pleural injury, and death [65, 66]. Overall, the major complication rate is approximately 2% for PTC and 2.5% for PTBD [65]. Some complications can be treated medically, while others require intervention. Transient hemobilia is a common occurrence after percutaneous intervention; however, patients with persistent hemobilia or deteriorating clinical status should prompt further evaluation [49]. Arterial hemobilia is assumed in unstable patients with hemobilia or patients with pulsatile hemobilia and should be treated with hepatic artery embolization. Venous hemobilia is more common and usually arises from a portal vein. Typically, patients are hemodynamically stable with persistent hemobilia. Initial treatment involves visualizing the venous leak with cholangiogram, exchanging to a larger drainage catheter, and capping to allow for tamponade [49]. If hemobilia continues, a new transhepatic drain can be placed followed by embolization of the portal vein [66, 67]. Avoiding the central ducts when placing biliary drains reduces the risk of major hemobilia, and preferentially using a right-sided PTBD approach when possible minimizes the risk of arterial hemobilia. If necessary, percutaneous drains can be placed for major hemorrhage resulting in hematoma or pleural complications. Other minor complications are more common and self-limiting, including pain, minor bleeding/hemobilia, and transiently elevated liver enzymes.

Conclusion

Iatrogenic or traumatic BDI resulting in bile leak, fistula, or stenosis typically requires a multidisciplinary team approach. Prompt diagnosis, especially with imaging, and stabilization are important to reduce patient morbidity and mortality. Treatment of BDI, especially bile leak, is based on the type and severity of injury. Bile leaks are treated with biliary diversion and drainage or embolization in more complex cases. Fistulas are typically managed with embolization; however, approach varies widely depending on fistula type. Benign biliary stenosis is managed primarily with balloon dilation with covered stenting reserved for recurrent stricture. Major complications of BDI are rare but typically require further percutaneous or surgical treatment. Percutaneous intervention for BDI, in conjunction with other treatment modalities, improves patient care and outcomes.

Compliance with Ethical Standards

Conflict of Interest Dr. Saddekni reports personal fees from St. Jude Medical and SIRTex, outside the submitted work. Dr. Kamel Abdel Aal reports personal fees from St. Jude Medical, Boston Scientific, Bard Peripheral Vascular, Baxter Healthcare, W.L Gore, and Surefire Medical, as well as grants from BTG, SIRTex, Bard, Covidien, Boston Scientific, and Celonova, outside the submitted work. The other authors declare no conflicts of interest relevant to this manuscript.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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•• Of major importance

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