Concepts in Hepatobiliary Surgery

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The hepatobiliary system is a core component of general surgery. This chapter introduces the most common disorders of the biliary tract and liver and provides the concepts necessary for safe surgery in this region.

Biliary Surgery

Bile and associated products produced in the liver drain through the biliary tree into the duodenum, with the gallbladder serving as a storage area off the main trunk. Disorders along this system are extremely common and can usually be handled uneventfully. However, advanced management of the biliary system requires a clear understanding of the anatomy and physiology involved in order to have a successful outcome.

Biliary Colic and Cholecystitis

Cholelithiasis is extremely common, is most frequently asymptomatic, and is not in itself an indication for surgery (Muhrbeck and Ahlberg 1995). However, once patients develop symptoms of biliary colic or cholecystitis, they should be evaluated for cholecystectomy since recurrent episodes tend to occur.

In biliary colic, gallstones intermittently obstruct the cystic duct, causing pain that lasts 4–6 h and is usually self-limited. Nausea is often present, and vomiting may occur, but this is not the dominant symptom. It is important to note that, while obstruction of the cystic duct is present, infection is not. Therefore true abdominal tenderness should be absent. Bowel rest, intravenous fluids, and pain control are the treatment; cholecystectomy should be performed to prevent future symptoms.

In cholecystitis, the offending gallstone is lodged in the cystic duct, and stasis of bile within the gallbladder allows for bacterial proliferation and infection. These patients will present with complaints similar to biliary colic; however the pain of cholecystitis is persistent and lasts 1–2 days if untreated. On physical examination, tenderness will be present due to the infection and inflammation of the gallbladder. A classic Murphy's sign describes the focal gallbladder tenderness that is elicited when, upon taking a deep breath, the patient abruptly halts inspiration due to the sudden pain that occurs when the descending gallbladder hits the examiner's hand, which is pressed into the right subcostal margin. Fever and mild leukocytosis are typically present, consistent with infection. Importantly, liver function tests should be entirely normal, except for in rare cases of Mirizzi syndrome where a large stone impacted in the gallbladder infundibulum can compresses the adjacent common bile duct (CBD). The treatment of cholecystitis consists of antibiotics, bowel rest with intravenous hydration, pain control, and cholecystectomy.

In the past, delayed cholecystectomy was advocated as safer than cholecystectomy performed during the acute inflammatory phase. However, a meta-analysis of 12 prospective, randomized trials showed that prompt cholecystectomy does not result in higher rates of CBD injury and actually results in significantly lower length of stay and decreased hospital costs (Johansson et al. 2003; Papi et al. 2004). Therefore, unless there are medical contraindications, early cholecystectomy should be performed.

In evaluating a patient for biliary disorders, ultrasound is the method of choice for visualizing stones in the gallbladder. A hepatobiliary scintigraphy scan is the most specific test for cholecystitis, and a patent cystic duct on this

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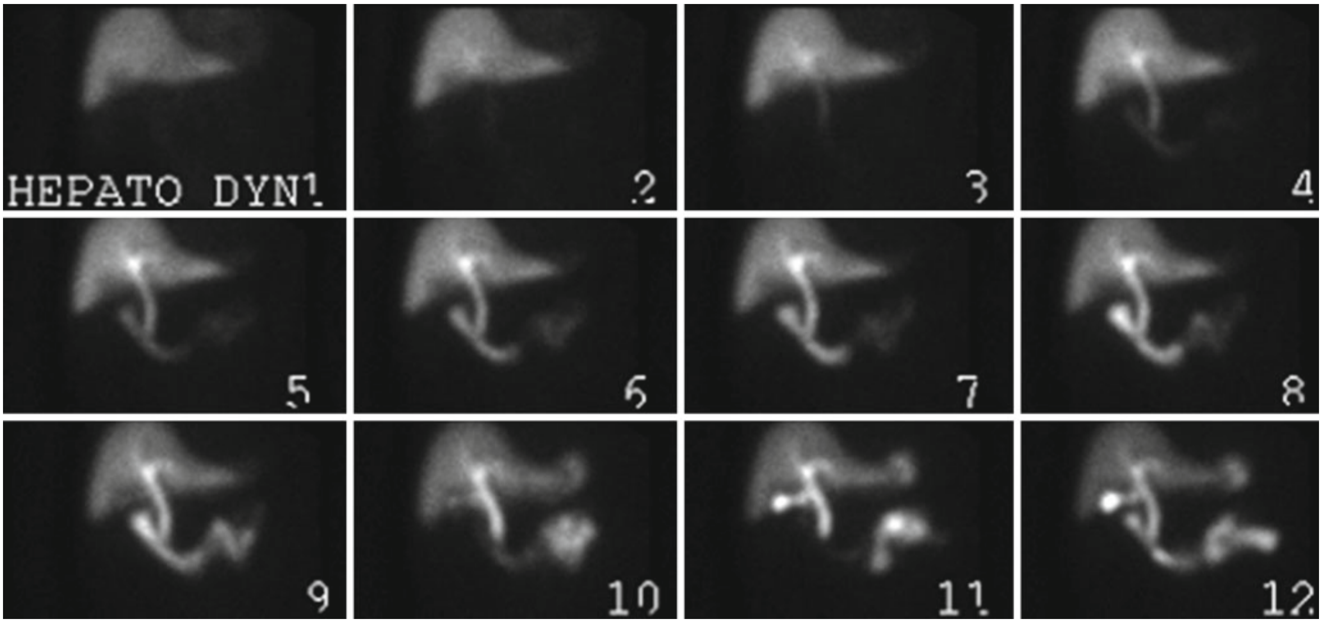

Fig. 76.1 Normal hepatobiliary scintigraphy showing prompt filling of the CBD, gallbladder, and small bowel

study virtually rules out acute cholecystitis (Fig. 76.1) (Velasco et al. 1982). Although CT scans are widely performed, they are not optimal for evaluating the gallbladder for two reasons. First, approximately one-third of gallstones are not radiopaque and will be missed on CT scans; therefore the absence of stones on a CT cannot be used to rule out their presence (Barakos et al. 1987). Second, CT scans are often too sensitive for nonspecific findings such as gallbladder wall thickening or pericholecystic fluid, which are not necessarily indicative of acute cholecystitis.

Cholecystitis During Pregnancy

Cholecystitis is common during pregnancy and is the second most frequent non-gynecologic abdominal complaint after appendicitis (Date et al. 2008). The natural hesitancy of clinicians to image and treat a pregnant patient can lead to a delay in diagnosis and intervention. This delay can be more harmful to the mother and fetus than the cholecystitis itself.

If possible, patients should be treated with bowel rest and intravenous antibiotics so that the pregnancy can be brought to term. However if cholecystectomy is necessary during pregnancy, it is ideally performed during the second trimester since surgery during the first trimester risks fetal loss, and surgery during the third trimester may cause preterm labor (Date et al. 2008).

Cholecystitis in the Hospitalized Patient

The surgeon is often asked to consult on the possibility of cholecystitis as the source of infection in hospitalized patients with a fever of unknown origin. This suspicion may be prompted by an investigatory CT scan showing mild gallbladder wall thickening. Many times this finding is nonspecific and no cholecystitis is present, as previously noted. If feasible, biliary scintigraphy can be used to definitively rule out the gallbladder as the source of infection; however the unwieldy nature of this test makes it difficult to perform in severely ill patients. In a septic patient with multiple comorbidities when the gallbladder cannot be definitively ruled out as a source of infection, ultrasound-guided percutaneous placement of cholecystostomy tube is often the safest temporizing treatment (Byrne et al. 2003). This both relieves cholecystitis if present, and spares the patient the physiologic insult of surgery if the source of infection lies elsewhere.

The exception to this is acalculous cholecystitis, a condition typically seen in severely ill patients on vasopressor support. This condition is thought to develop from hypotension and ischemic end-organ injury and can result in necrosis of the gallbladder (Warren 1992). Once tissue necrosis has set in, simple cholecystostomy tube placement will not ameliorate the condition; cholecystectomy is needed to debride the necrotic infected tissue (Fagan et al. 2003).

Cholecystectomy

The vast majority of cholecystectomies can be performed laparoscopically. As surgeons have become more facile at managing difficult cholecystectomies laparoscopically, the only absolute indications that remain for conversion to open cholecystectomy are brisk hemorrhage and an inability to clarify biliary anatomy. In these cases, prompt conversion to open cholecystectomy should not be considered a technical failure, but a demonstration of sound clinical judgment. Any surgeon operating on the biliary tract must be confident with the technique for open cholecystectomy, as described in subsequent chapters.

Intraoperative Cholangiography

The purpose of cholangiography is twofold: first to confirm the biliary anatomy and second to identify unsuspected stones in the CBD. During cholecystectomy some surgeons use intraoperative cholangiography on a selective basis and others advocate for its routine use.

Selective users perform cholangiography based on certain criteria. Preoperative indications for cholangiography include jaundice or hyperbilirubinemia, gallstone pancreatitis, or the presence of biliary dilatation. If these indications are not present, and the intraoperative anatomy is straightforward, no cholangiogram is performed.

However, proponents of routine cholangiography state that approximately 6 % of asymptomatic patients are found to have incidental CBD stones (Majeed et al. 1999) which should be removed due to the potentially severe consequences of gallstone pancreatitis or cholangitis. Routine cholangiography adds only 10 min to the procedure in experienced hands and also provides a permanent record of the state of the common bile duct at the time of surgery.

Advocates of selective cholangiography respond that incidentally discovered stones are typically small and would pass spontaneously. Furthermore, cholangiography is not entirely without risk, including false-positives caused by the inadvertent introduction of air bubbles within the CBD that are subsequently mistaken for stones.

Regardless of personal preference, there is universal agreement that any confusion about the biliary anatomy or concern for an iatrogenic bile duct injury mandates an immediate intraoperative cholangiogram for evaluation.

Use of Drains

The routine use of closed suction drains is not indicated after cholecystectomy. However, it is wise to leave a drain when bile leakage is considered possible, such as in cases when closure of the cystic duct stump is tenuous due to severe inflammation. The use of a drain allows for a controlled biliary-cutaneous fistula if a bile leak should develop. This is well-tolerated and provides the luxury of time, since most bile leaks are from the cystic duct stump and will resolve spontaneously or with ERCP-guided sphincterotomy (Massoumi et al. 2007). In contrast, an undrained bile collection is both very irritating to the peritoneal cavity and can become infected, requiring emergent imaging-guided percutaneous drainage.

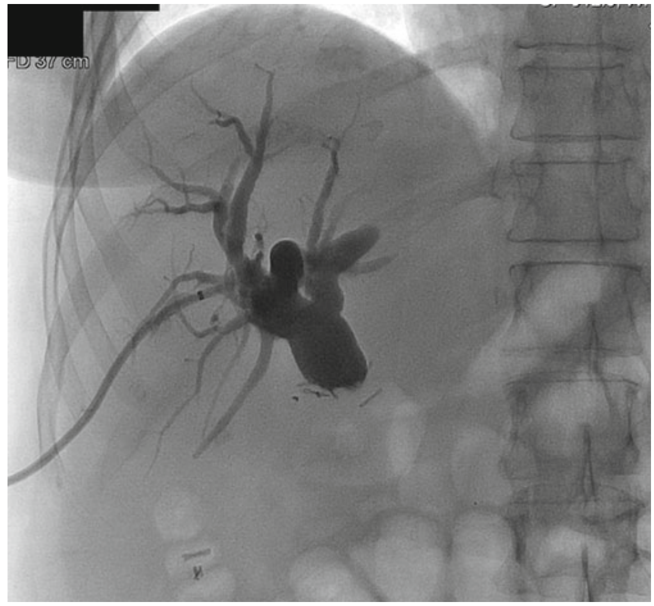

Fig. 76.2 Percutaneous cholangiogram demonstrating iatrogenic ligation of the common bile duct during laparoscopic cholecystectomy. Note the mulitple surgical clips present at the stump of the CBD

Iatrogenic Biliary Injury

The most feared complication of cholecystectomy is that of iatrogenic injury to the common bile duct (Fig. 76.2). A detailed classification of biliary injuries by Strasberg et al. (1995) and Bismuth (1982) outlines the varieties of biliary tree injuries that can occur during cholecystectomy. The surgeon must always be on the alert for potential CBD injury even during apparently straightforward cases. In fact, it is often anecdotally said that CBD injury happens on the easy cases, when attention tends to wane. As a matter of practice, no structure should be divided until its identity is certain.

The classic mechanism of injury is failure to recognize that the structure being dissected is not the cystic duct, but is in fact the common bile duct. This tends to occur when the cystic duct has not been thoroughly dissected out or when excessive traction straightens out the cystic duct/common bile duct junction, as discussed in the following chapters. Often a dual injury can occur, and surgeons must be aware of this pattern: the common bile duct is mistaken for the cystic duct, and – as a part of the illusion – the right hepatic artery is mistaken for the cystic artery. Both structures are unknowingly clipped and divided. Therefore, in all cases of iatrogenic bile duct injury, it is important to also investigate the patency of the right hepatic artery (Strasberg et al. 1995; Davidoff et al. 1992).

If a common bile duct injury is recognized at the time of surgery, it is wise to recruit the assistance of a hepatobiliary surgeon to aid in the reconstruction. Even if the original operating surgeon is skilled in biliary repair, the emotional toll of having caused an iatrogenic injury clouds judgment, and therefore assistance should be sought. A limited, non-thermal, sharp injury to the common bile duct detected at the time of surgery may be repaired over a T-tube; however most laparoscopic bile duct injuries result in complete discontinuity of the biliary tree and will require a Roux-en-Y hepaticojejunostomy. Cautery and crush injuries should *absolutely not* be repaired primarily since the area of tissue damage always extends beyond what is immediately apparent.

Most instances of injury to the biliary tree are not recognized at time of surgery (Lillemoe et al. 1997). Postoperative manifestations may be that of a bile leak, biliary obstruction, or both – depending on the nature of the injury. *Any patient who develops abdominal pain, fever, or jaundice following cholecystectomy has a biliary injury until proven otherwise.* The most important initial steps in managing these patients are to determine the exact anatomy of the injury and to ascertain whether any bile leak is controlled or not. Imaging is the first step in the evaluation of these patients. A CT scan of the abdomen may reveal the presence of intrahepatic biliary dilatation and/or a fluid collection in the liver bed. If a biloma is detected, it should be drained percutaneously by interventional radiology, and a closed suction drain should be left at the site. If the bilious output fails to resolve promptly, this should be investigated by endoscopic cholangiography.

If a CBD injury is ultimately diagnosed, reconstruction with a Roux-en-Y hepaticojejunostomy is necessary to restore biliary-enteric continuity. Over 90 % of these patients will do well, but some may suffer from anastomotic stricture and bouts of cholangitis over their lifetime (Lillemoe et al. 2000). The timing of repair is an important consideration. If the leak or obstruction is diagnosed expeditiously and the patient is stable, it is best to proceed with Roux-en-Y hepaticojejunostomy promptly. However, if the diagnosis has been delayed and a prolonged or uncontrolled bile leak has been present, the patient may be quite ill. Bile peritonitis creates a hostile abdomen which can cause bowel edema and complicate Roux-en-Y hepaticojejunostomy. In these cases it may be optimal to temporize the patient with a stent and drain(s) to allow the inflammation to resolve before proceeding with definitive repair. In cases of iatrogenic ligation of the CBD, without a leak, some surgeons advocate delayed repair to allow the CBD remnant to dilate, which allows for a larger anastomosis. However, this approach obligates the presence of a transhepatic biliary drainage catheter for weeks and is not ideal.

The development of a biliary stricture following cholecystectomy is usually the result of iatrogenic injury to the common bile duct. This may be the result of direct compression of the bile duct by a surgical clip that was placed too close to the CBD. Another common mechanism of injury results from overly aggressive dissection near the junction of the cystic duct with the CBD; this skeletonization of the duct can lead to a delayed ischemic stricture which presents as progressive jaundice weeks after cholecystectomy. Similarly, the use of cautery too close to the CBD can result in a thermal injury with delayed structuring. ERCP with balloon dilation and stenting can be attempted for strictures of the common bile duct; however the stricture may recur over time. Elective Roux-en-Y hepaticojejunostomy may ultimately be necessary for long-term relief.

Choledocholithiasis and Cholangitis

Choledocholithiasis refers to the presence of stones in the common bile duct. In the majority of cases, these stones originate from the gallbladder. Most small stones will pass uneventfully through the ampulla of Vater into the duodenum; however they can also cause serious illness such as gallstone pancreatitis or cholangitis. These can be life-threatening, and in order to prevent them, even asymptomatic incidentally discovered CBD stones should be removed.

Cholangitis occurs when a stone becomes lodged at the ampulla and the obstructed column of bile becomes infected. The presentation of cholangitis is described by *Charcot's Triad*: fever, jaundice, and right upper quadrant pain. Because the liver is a highly vascular organ, infection of the biliary tree rapidly leads to bacteremia. *Reynaud's Pentad* – the addition of hypotension and mental status changes – heralds the onset of sepsis.

Laboratory values will demonstrate leukocytosis and a direct hyperbilirubinemia, often accompanied by mildly elevated transaminases. Ultrasonography will typically reveal intrahepatic biliary dilatation due to downstream obstruction. However, it is important to point out that it can take 24–48 h for appreciable biliary dilatation to develop. Therefore, the absence of biliary dilatation on initial imaging studies does not rule out obstructive cholangitis. If uncertainty exists, an MRI/MRCP can identify the presence and location of stones. However, *if the clinical suspicion for cholangitis is high, it is best to proceed directly to ERCP, which can both diagnose and treat the condition.*

Ductal Drainage Procedures

Antibiotic administration for cholangitis is necessary but not sufficient for its treatment. It is critical to underscore that the urgently needed treatment for cholangitis is decompression (Kinney 2007). This is especially true once suppurative cholangitis has developed, where the mortality is 100 % if the CBD is not drained. Similar to lancing an abscess, drainage is absolutely necessary – antibiotics alone are insufficient to treat the infection.

Drainage of the common bile duct can be accomplished by one of four approaches: (1) endoscopic, (2) transhepatic, (3) laparoscopic, and (4) open CBD exploration. In general, the endoscopic approach is the first choice since it is the least invasive. However, if a qualified gastroenterologist is not promptly available, there should be no hesitation to pursue percutaneous transhepatic drainage. Similarly, if interventional radiology is not available, then the surgeon must pursue operative options without delay. This approach is described in subsequent chapters.

T-Tube Management

Following CBD exploration, a T-tube should be placed to allow access to and provide drainage of the common bile duct. Even though the obstructing stone was removed at CBD exploration, operative instrumentation of the ampulla results in edema that can cause transient obstruction and increased pressure in the biliary system. A T-tube allows the surgeon to decompress the system, thus preventing the bile leak that might have occurred if the duct had been closed primarily.

Initially a T-tube should be placed to straight drainage to allow for decompression. However, once the period of acute inflammation has passed, the T-tube should be capped, which frees the patient of the biliary drainage bag and allows for the return of normal bile-aided absorption of GI contents. Bilirubin levels should be checked 24 h after capping to ensure that bile flow out the ampulla is not obstructed.

Prior to removal of a T-tube, it is advisable to obtain a cholangiogram. This confirms that the biliary system is patent and intact, and that there are no remaining stones present. If necessary, interventional radiologists can use the T-tube to access the common bile duct to remove any residual stones. When a catheter that is 14 French in size is used, stones up to 5 mm can be removed via the T-tube (Blumgart 2006).

In general, T-tubes should not be removed prior to about 6 weeks. This is due to the fact that removal of the tube leaves behind an open hole in the CBD. The only reason that this does not lead to bile peritonitis is that a fibrous tract has developed around the path of the T-tube, excluding it from the peritoneal cavity. Removing the tube before this tract has had a chance to become established increases the risk of a free bile leak.

Even when removed at the appropriate time, some patients will nonetheless develop sudden, severe abdominal pain, indicating a bile leak. These patients should be admitted, made NPO with intravenous fluids, and provided pain medication. Thankfully, most of these leaks are mild and self-limited, with resolution of pain within hours. Persistent pain should be treated the same as de novo bile leaks, with prompt IR drainage and ERCP with stent placement.

Gallbladder Carcinoma

The discovery of early stage gallbladder carcinomas has become increasingly common due to the rise in the number of cholecystectomies performed in the era of laparoscopic surgery. Patients with incidentally discovered gallbladder cancer typically have T1 or T2 disease and may have a favorable long-term prognosis. However, patients who present with symptomatic gallbladder cancer almost always have advanced disease with nodal metastases.

Patients with the finding of T1 disease following cholecystectomy are typically observed without further intervention. Although the data are mixed, most surgeons feel that patients with T2 disease should undergo extended cholecystectomy, which includes a complete hepatoduodenal lymphadenectomy, resection of the liver bed, and excision of at least the trochar site where the gallbladder specimen was extracted. Patients with T3 disease will require major hepatectomy in addition to the node dissection and port site excision (Miller and Jarnagin 2008). Patients whose preoperative imaging demonstrates distant metastases or malignant adenopathy outside the region of lymphadenectomy are not helped by surgical intervention.

Cholangiocarcinoma

Malignancy of the extrahepatic bile ducts typically presents with jaundice. Subsequent imaging reveals the presence of biliary dilatation up to the point of malignant involvement. Unfortunately, most patients will already have metastatic liver satellites or distant lymphadenopathy on presentation. However, a small percentage of patients can be cured with surgical resection. The common bile duct is resected in conjunction with either a liver resection or a pancreaticoduodenectomy, depending on whether the tumor is located proximally or distally in the biliary tree. Extensive neurovascular spread is the norm for cholangiocarcinoma and therefore isolated CBD resections are usually too limited to accomplish tumor clearance. A complete portal lymphadenectomy is also performed as part of the procedure.

In advanced stages, palliative biliary drainage should be performed to relieve the symptoms of obstruction. Although ERCP can be attempted, in most patients with advanced cholangiocarcinoma, the right and left biliary systems become isolated from each other due to tumor infiltration of the bifurcation, making the endoscopic approach in effective. Ultimately, these patients often require bilateral transhepatic drains for relief.

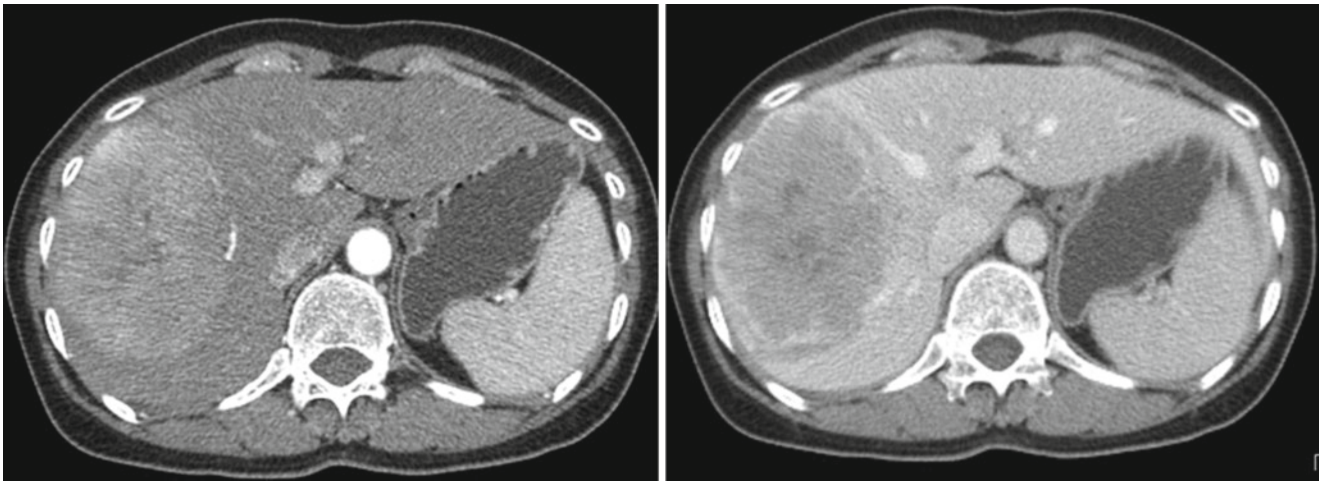

Fig. 76.3 Hepatocellular carcinoma, note the classic pattern of arterial enhancement and venous washout

Hepatic Surgery

Liver resection has become increasingly common due to the rising incidence of hepatocellular carcinoma as well the improvements in survival achieved with hepatic metastasectomy of colorectal tumors. These new indications, coupled with the improved safety of hepatic surgery, have expanded the pool of patients undergoing liver resection.

Hepatocellular Carcinoma

Hepatocellular carcinoma (HCC) is the fifth most common cancer in the world and is one of the few cancers in the United States whose incidence continues to rise (Jemal et al. 2005; El Serag et al. 2001). HCC usually occurs due to the presence of an underlying liver disease – although advanced age may be a risk factor in itself. Cirrhosis due to alcohol abuse, viral infection, or diabetes represents the most common etiology for HCC in the United States and Europe. Notably, chronic hepatitis B infection can cause HCC even in the absence of cirrhosis, and this virus is the most common cause of HCC development in Asia and in sub-Saharan Africa. No biopsy is indicated in the evaluation of HCC since the diagnosis can be definitively made by the radiologic criteria of arterial enhancement and venous washout (Fig. 76.3) (Bruix and Sherman 2011).

The best curative therapies for HCC are hepatic resection or liver transplantation and should therefore be the first choice. In general, transplantation is preferred for patients with multifocal disease or underlying cirrhosis. Resection is preferred in patients with a single-lesion and well-preserved liver function, since it avoids the morbidity of transplantation and the need for lifelong immunosuppression (Bruix and Sherman 2010).

Ablative procedures can also be curative for small lesions (<3 cm in size) but is highly operator dependent and should be reserved for centers with experience. Chemoembolization and oral tyrosine kinase inhibitors are modalities that can slow the progression of the tumor, but are not curative (Bruix and Sherman 2010).

In patients with HCC secondary to underlying hepatitis B infection, it is important to measure the viral load and initiate antiviral treatment as indicated. Not only has this been proven to reduce recurrence of HCC following resection (Kubo et al. 2007), but studies demonstrate that regeneration of the liver remnant is improved if the viral load is kept low in the postoperative period (Li et al. 2010).

Colorectal Liver Metastases

Resection of hepatic metastases has become increasingly accepted as newer chemotherapeutic regimens have allowed for improved long-term survival of patients with colorectal cancer. Liver metastases usually appear as simple, round, nonenhancing lesions, although long-standing or treated lesions can show areas of necrosis or calcification (Fig. 76.4).

The key to successful metastasectomy is proper patient selection. The patients who will benefit the most from hepatic resection are those with metachronous disease, a node-negative primary tumor, a single metastatic lesion, and low carcinoembryonic antigen levels, which are surrogate markers of indolent tumor biology (Fong et al. 1999).

When a patient presents with resectable liver metastases, a limited course of neoadjuvant chemotherapy prior to surgery may be considered. This approach serves two purposes. First, it allows a period of time for the tumor to declare its biology; if the lesion continues to grow on treatment, or other lesions develop, this suggests that the patient would not

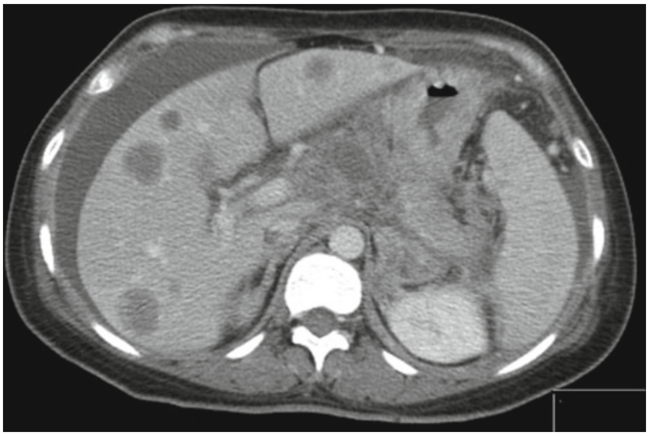

Fig. 76.4 Characteristic CT appearance of liver metastases from colorectal carcinoma

Fig. 76.5 Major hepatic laceration of the right lobe caused by blunt abdominal trauma

benefit from metastasectomy and should remain on systemic treatment. Second, in cases where there is a postoperative complication of hepatectomy, providing chemotherapy upfront ensures that the patient has seen some systemic treatment.

The parenchymal transection itself tends to be more straightforward for colorectal metastases, since – unlike HCC – patients with metastases tend to have noncirrhotic livers. Ablative procedures can also be used as an alternative or to supplement resection. Following metastasectomy, patients should be closely followed with imaging surveillance. If recurrences develop, repeat interventions can be considered.

Hepatic Trauma

The liver is the largest intra-abdominal organ and the most frequently injured by trauma. Fortunately the liver is also very resilient, and as a result most hepatic trauma can be managed nonoperatively provided that the patient is hemodynamically stable. Minor bile leaks after nonoperative management are not unusual, but these can be effectively managed by percutaneous drainage as described above.

The focused assessment by ultrasound for trauma (FAST) is frequently the first diagnostic tool used in the emergency room. However, the presence of free fluid on FAST is not in itself an indication for laparotomy, since as mentioned, minor injuries are self-limited. Stable patients should proceed to CT imaging with intravenous contrast, which is the best modality to visualize the extent of liver injury.

Diagnostic peritoneal lavage (DPL) is another method of detecting blood in the abdomen and can be performed rapidly in an unstable multi-trauma patient if there is uncertainty as to the source of hypotension. The classic example of this situation is the tachycardic patient with blunt abdominal trauma and pelvic fractures. If DPL is negative, the patient can go directly to interventional radiology for embolization of pelvic vessels, thus avoiding a negative laparotomy.

For more serious hepatic injuries (Fig. 76.5), the decision to operate is guided by the clinical picture. Tachycardic or hypotensive patients, or those with clear peritonitis mandate prompt exploration. Patients with a transient response to fluid boluses or those needing repeated blood transfusions to maintain hematocrit levels should also be explored.

At laparotomy, most hemorrhages can be controlled by perihepatic packing (Pachter and Feliciano 1996). To provide sufficient compression, this maneuver requires the placement of laparotomy pads lateral, anterior, and superior to the liver. If hemorrhage continues after packing, the Pringle maneuver can be applied by placement of an atraumatic vascular clamp across the porta hepatis. This provides the surgeon the ability to visualize and repair the site of injury. Liver resection is only indicated in patients with shattered or devascularized hepatic lobes.

Retrohepatic injuries to the inferior vena cava are frequently fatal even with prompt exploration since the mobilization of the liver required to access this portion of the cava is time consuming. Attempts to mobilize the liver may exacerbate bleeding by decompressing the pericaval space that was serving to partially tamponade the bleeding. For this reason, these injuries are often best controlled by packing and resuscitation. The abdomen can be closed with laparotomy pads in place using a temporary vacuum dressing allowing for stabilization in an intensive care unit.

Concepts in Liver Resection

The choice of an anatomic resection versus a non-anatomic (or wedge) resection depends on both the tumor type and the patient's underlying liver reserve. In general, it is wise to preserve liver parenchyma when feasible – particularly in patients with borderline liver function. However, some data suggest that for primary liver cancer, an anatomic resection of the functional liver unit provides improved survival (Wakai et al. 2007). This concept does appear not hold for metastatic colorectal lesions which arrived by hematogenous dissemination and are not based within a functional hepatic unit (Sarpel et al. 2009).

Determining Resectability

In determining resectability, strict rules as to the number and location of hepatic lesions have not proven to be useful in guiding decision making. In certain cases, the resection of massive or multifocal tumors is easily accomplished, while in other settings even small tumors can prove to be unresectable.

In general, the determination of whether a liver lesion is resectable can be guided by ascertaining "inflow, outflow, and parenchyma." In other words, if the proposed hepatectomy were to be performed, the surgeon should consider whether there will remain blood *inflow* to the remnant liver, venous *outflow* from the remnant, and sufficient hepatic *parenchyma* to support liver function. Inflow may be the concern when, for example, a cholangiocarcinoma encases the bifurcation of the hepatic artery or portal vein. Occasionally outflow makes a tumor unresectable, as in the case of a large hepatocellular carcinoma that involves the confluence of the hepatic veins and the vena cava. Most frequently, however, the limiting factor is the parenchyma.

In a noncirrhotic patient with normal liver function, approximately 80 % of the liver can be resected without concern for liver failure. A hepatic trisegmentectomy for multifocal colorectal liver metastases is an example of this type of massive resection of parenchyma that can be performed with low morbidity and mortality in experienced hands. However, this amount of tissue loss would not be tolerated in a cirrhotic patient where even a limited wedge resection can lead to fatal postoperative liver failure.

The determination of precisely how much parenchymal loss will be tolerated is a matter of experience. The Child-Turcotte-Pugh score is a useful starting point, since liver resection is uniformly fatal in Child C cirrhotics, and only the most limited resections are tolerated in select Child B patients. However, the Child A designation is a large umbrella term and contains too wide of a group of patients to be sufficiently sensitive to guide resection (Poon and Fan 2005).

In these patients, certain laboratory values can be used as surrogate markers of the presence of cirrhosis and can help guide decision making. A validated rule of thumb is that patients with a platelet count of $<100 \times 10^9$/L will not tolerate liver resection (Poon et al. 2004). Significant hepatic fibrosis leads to portal hypertension; the back pressure into the splanchnic circulation leads to splenomegaly, which in turn causes platelet sequestration. Through this mechanism, thrombocytopenia serves as a surrogate marker for hepatic fibrosis. The presence of esophageal varices is an alternate marker of portal hypertension resulting from the same pathophysiologic process.

More sophisticated methods of quantifying the function of the future liver remnant have been investigated, but none have proven consistently useful or superior. These methods include direct measurement of portal pressures, the use of indocyanine green clearance, and the calculation of liver remnant volume by imaging (Schulick 2006). Certain patients with borderline liver function can be optimized by portal vein embolization to induce hypertrophy of the future liver remnant (Abulkhir et al. 2008).

Hemostasis

Mortality following liver resection should be rare, with rates of 1–3 % at high-volume centers (Torzilli et al. 1999). The major intraoperative risk of hepatectomy is that of massive hemorrhage. Intimate knowledge of the intrahepatic vasculature – specifically the hepatic veins – is necessary to plan lines of transection and to prevent inadvertent injury. Control of hepatic inflow by clamping the hepatoduodenal ligament, known as the Pringle maneuver, is useful to limit bleeding during transection. The Pringle maneuver can be applied safely for 15 min in cirrhotics and indefinitely in noncirrhotics with intermittent reperfusion (Sakamoto et al. 1999).

In addition, hepatic resection should be performed under low central venous pressure (e.g., CVP of 1–5 mmHg). While this may at first seem counterintuitive, maintenance of low intravascular volume leads to lower blood loss during hepatic transection (Wang et al. 2006). This is due to the fact that although the surgeon can control hepatic inflow using the Pringle maneuver, back bleeding of the inferior vena cava through the hepatic venous branches still occurs. This bleeding is exacerbated when aggressive infusion of intravenous fluids leads to a full vena cava. Maintenance of low intravascular volume requires good communication between the surgical and anesthesia teams; objective measurement of central venous pressure with a central line is not mandatory but may be useful.

There are several acceptable techniques for performing transection of the liver parenchyma, based on surgeon preference. Following transection, localized bleeding from transected vessels should be ligated with gentle figure-of-eight sutures. Generalized oozing from the cut surface of the liver is usually self-limited and responds to pressure and patience. Argon beam cautery and thrombin-soaked foam sponges can be useful adjuncts, but cannot be relied upon to remedy surgical bleeding.

Use of Drains

The use of drains following liver resection is at the discretion of the operating surgeon. Although published reports in the literature have not demonstrated a benefit to routine drainage (Gurusamy et al. 2007), bile leaks from the cut surface are not uncommon following major liver resection, and many hepatic surgeons advocate the routine use of contained self-suction drains to prevent biloma formation. In addition, patients with borderline liver function often develop ascites in the postoperative period. The use of a drain in these patients allows for controlled release of ascitic fluid and prevents the weeping of the ascites through the wound, which can lead to skin maceration, wound infection, and dehiscence.

Postoperative Management

The major complication of hepatectomy in the postoperative period is liver failure. All patients will demonstrate a transaminitis following hepatectomy, but the levels of these enzymes should begin to normalize promptly. Patients with borderline liver function may experience transient liver failure, as evidenced by elevated total bilirubin and coagulation parameters, and the presence of new ascites. These signs typically occur starting on postoperative day three but usually resolve with supportive care.

In borderline patients, the postoperative maintenance of low intravascular volume is once again a key point. Overburdening the remnant liver with high volumes is thought to exacerbate liver failure. Therefore, especially in cirrhotics, many hepatic surgeons allow relatively low urine output and advocate the use of colloids for resuscitation. Ominous signs of irreversible liver failure include worsening jaundice, coagulopathy, and encephalopathy. At this point, little can be done to mitigate fatal liver failure.

Following hepatic resection, the liver will regenerate to completely replace the resected volume. This process begins within the first week after resection, as evidenced by the welcomed drop in serum phosphate levels on postoperative labs, and is usually complete by 6 weeks.

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