Advanced operative techniques in the management of complex liver injury

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The patient with hepatic injury who requires an operation is generally hemodynamically unstable, the hepatic injury is Grade 4 or 5, and the operation is difficult.[1–8] The mortality for complex liver injury remains greater than 50% in most series (higher for blunt than penetrating), juxtahepatic caval injury continues to have a mortality rate reported as 65% to 100%, and liver resection for trauma is discouraged by most authors.[9–21] However, a recent article from our institution with 215 complex liver injuries reported operative mortality of 9% for major hepatic injury and mortality of 25% for juxtahepatic caval injury.[22] This article will describe operative approaches and maneuvers to major hepatic injury refined for 30 years at the University of Pittsburgh.

Any surgeon who operates on the liver (even rarely) must know the anatomy of the liver particularly because it is so often variable.[23–31] One of the major operative risks in both elective and emergency hepatic surgery is injury to the nontraumatized/noninvolved portal structures. It is critical that the vascular structures associated with the noninjured liver segments be identified and protected when performing resection or hepatorrhaphy for major hepatic injury. The liver is divided into two hemilivers by the main portal fissure (Cantlie's line). This line extends from the middle of the gallbladder fossa running posteriosuperiorly to the suprahepatic inferior vena cava (IVC) (Fig. 1). The right hemiliver consists of segments V through VIII; the liver hemiliver is composed of segments II to IV. The caudate lobe is distinct from the two hemilivers (Segment I). The portal triad is composed of the portal vein, hepatic artery, and bile duct branches to a lobe or segment, runs centrally within segments of the liver and serves these segments, running within a substantial sheath that is an extension of Glisson's capsule. On the other hand, the hepatic veins lie in the "portal scissurae," the planes between lobes and segments, and are not enclosed in a sheath; thus, more likely to tear than the tougher portal triads.

ACCESS POINTS TO THE VARIOUS HEPATIC STRUCTURES

The caudate lobe (Segment I) from the patient's left provides access to all structures of the liver. Segment I encircles the IVC on its posterior side (partially in 90%, fully in 7%).

Access can quickly be gained to the caudate lobe by elevating the left lateral segment and then opening the gastrohepatic omentum, remembering to avoid a left hepatic artery from the left gastric artery. The left triangular ligament can quickly be taken down by placing the left hand (palm up) under the left lateral segment and pulling down on the superior border of the segment. The left triangular ligament can then be divided with electrocautery or scissors over to the insertion of the left phrenic vein into the left hepatic vein. Divide the falciform ligament at this stage as well. The falciform can be safely divided superiorly down to the hepatic veins, which are usually more posteriorly than most surgeons believe. There is no danger of injuring the hepatic veins before the falciform splits into the left and right leaves.

It may also be advantageous to elevate the right side of the liver, but it is not usually necessary in urgent situations. To do this, the right side of the liver should be elevated medially and superiorly, exposing the right triangular ligament inferiorly, which can be cut with electrocautery or scissors. Avoid entry into the liver substance caudally or the diaphragm superiorly with this mobilization. The right adrenal gland should be detached from the underside of the liver. Full mobilization of the right lobe of the liver continues with the assistant retracting the right lobe of the liver to the patient's left; the short hepatic veins are each clipped or tied and divided, proceeding from caudal to cephalad until the right hepatic vein is reached. The dorsal ligament must be divided to fully free the liver from the IVC. (It is often helpful to perform this maneuver early in the mobilization.) These caval ligaments are not simple connective tissues and may bleed unless controlled surgically.

Once the gastrohepatic omentum has been opened, both the infrahepatic vena cava and the hilar structures can be accessed. Although easier to surround from the patient's right, the infrahepatic IVC can be surrounded quickly from either side because there are rarely any branches entering the cava at this point (just superior to the entrance of the renal veins). The vena cava can be surrounded with a finger after the peritoneum has been quickly incised; the vena cava can then be clamped.

In the most urgent circumstances, the suprahepatic IVC can be occluded in one of two ways: the first is to take a curved vascular clamp and clamp straight down in an anterior to posterior direction above the liver. This will occlude all three hepatic veins and at least part of the suprahepatic vena cava.

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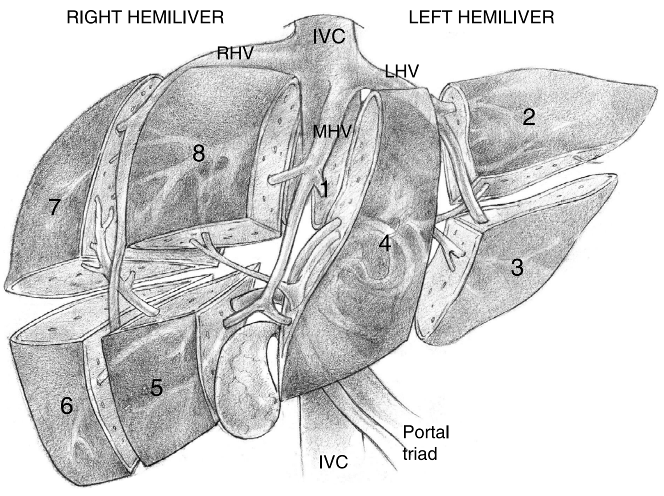

Figure 1. Hepatic anatomy. Segments of the liver are numbered. RHV indicates right hepatic vein; LHV, left hepatic vein; MHV, middle hepatic vein.

This is not ideal and should only be done until a clamp can be more properly placed. The second technique achieves intrapericardal control of the IVC. The central pericardium can be opened, and the IVC can be clamped as it enters the right atrium (Fig. 2) (see Figures, Supplemental Digital Content 1–3, http://links.lww.com/TA/A168, http://links.lww.com/TA/A169, and http://links.lww.com/TA/A170).

In slightly more controlled circumstances, the preferred method to control the suprahepatic IVC is to encircle it above the liver in a horizontal fashion inside the abdomen, just below the diaphragm. At this point, the retroperitoneum courses posteriorly over the caudate lobe and then the vena cava then turns superiorly to cover the esophagus. At its most posterior and superior reflection, this peritoneum is opened as described in Figure 3. The point of entry is between the right crus of the diaphragm and the caudate lobe as it wraps around the IVC (see Figures, Supplemental Digital Content 4–7, http://links.lww.com/TA/A171, http://links.lww.com/TA/A172, http://links.lww.com/TA/A173, and http://links.lww.com/TA/A174).

THE OPERATION

At least one central line with a large bore introducer placed in the neck (if possible) along with several peripheral IVs are required. Once the liver injury at laparotomy has been identified, femoral vein lines should be clamped and no longer used for high-volume infusion. To the extent possible, the central venous pressure should be kept as low as possible to avoid edema and subsequent unnecessary bleeding of the liver parenchyma. A cell saver and rapid transfusion device should be in the room and primed before surgery. Twenty-five percent of the cardiac output is to the liver; exsanguination can occur rapidly if the team is not prepared for the blood loss associated with major liver injury. If severe liver injury is expected, it can be helpful (although uncommonly needed) to percutaneously place bypass cannulae in the left femoral vein and the right internal jugular vein in case total liver isolation (or even the rare event of liver removal) should be necessary. This allows total interruption of the liver inflow (the portal flow can also be shunted into the circuit with a cannula into the portal vein directly or through the inferior mesenteric vein) and outflow while still maintaining the patient's hemodynamics.[32–35]

Injury to the Hilar Structures

Bile Duct

Never place sutures blindly in the porta hepatis because iatrogenic injury to the bile ducts/vascular structures may result.

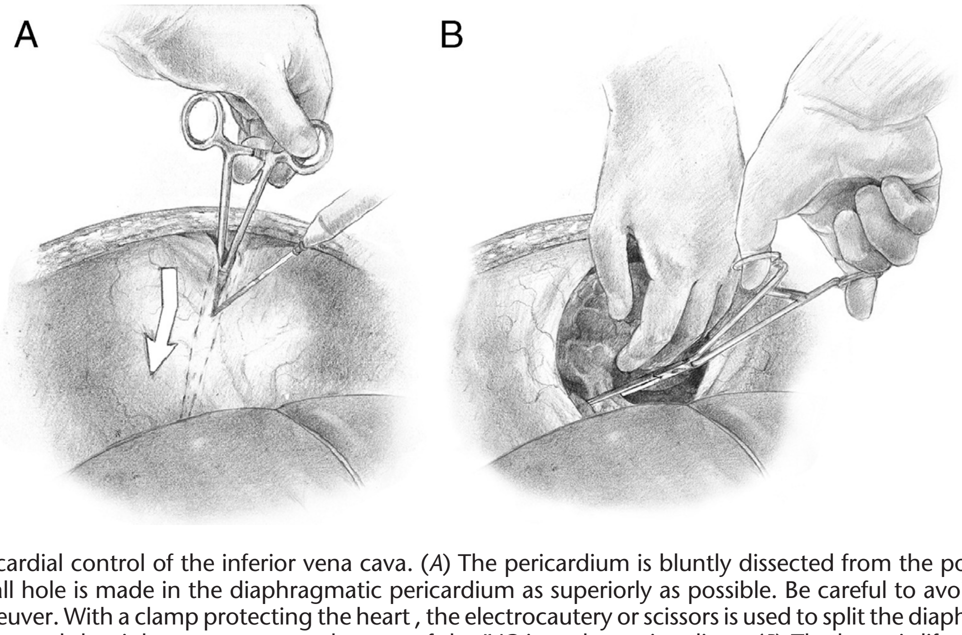

Figure 2. Intrapericardial control of the inferior vena cava. (*A*) The pericardium is bluntly dissected from the posterior aspect of the sternum. A small hole is made in the diaphragmatic pericardium as superiorly as possible. Be careful to avoid injury to the heart with this maneuver. With a clamp protecting the heart , the electrocautery or scissors is used to split the diaphragm/pericardium posteriorly. Curve toward the right as you approach entry of the IVC into the pericardium. (*B*) The heart is lifted cephalad and anteriorly; a vascular clamp is placed on the IVC. The IVC should be clamped at an angle to ensure clamping of the entire vein; an angled Potts or IVC clamp is best. An umbilical tape may be used to stabilize the clamp on the IVC as the operation proceeds.

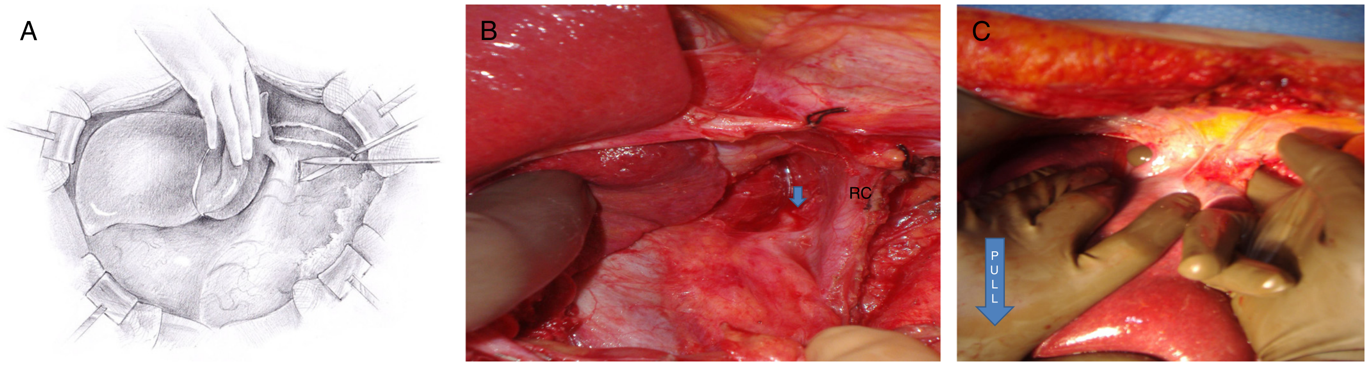

Figure 3. Suprahepatic control of the inferior vena cava. (*A*, *B*) The left lateral segment is taken down with the electrocautery, avoiding injury to the left hepatic vein or phrenic vein. The left lateral segment and liver are retracted to the right. The nadir of the peritoneum between the right crus of the diaphragm and the caudate lobe over the IVC will be visible and palpable. With the scissors in a longitudinal plane (not perpendicular), incise the peritoneum and gently spread. (*B*) Arrow points to appropriate plane between the right crus of the diaphragm (RC) and the caudate lobe as it wraps around the IVC. (*C*) With the left hand pulling the mobilized liver hard caudally (shown by arrow), the right index/middle finger is placed in the opening in the retroperitoneum and then passes behind the suprahepatic vena cava. The initial direction is back to the spine and then from left to right. It is critical to follow the curve of the liver from left to right because the easiest route behind the IVC is into the chest. Approximation of right to left index finger allows a clamp to then safely be placed on the suprahepatic IVC.

Late biliary complications can be corrected endoscopically or surgically in almost all cases and should not be the primary focus in surgery for liver trauma. The one exception is in the setting of transection of the common bile duct. In the setting of blunt trauma, this tends to occur at the superior border of the pancreas. As an isolated injury in the stable patient, and with appropriate expertise, common bile duct injury can be definitely reconstructed with a Roux-en-Y hepaticojejunostomy. Primary repair or anastomosis of a major injury to the common bile duct will generally stricture and is not recommended. In the patient with multiple injuries or the surgeon inexperienced with such problems, external drainage with a drain placed in the proximal duct may be the best temporizing option.

Hepatic Artery

Injury to the hepatic artery should be repaired primarily if possible. If this is not possible, ligation of the artery can be done but an effort should be made to ligate only the artery bleeding. If the entire hepatic artery must be ligated, the more proximal, the better. If the right hepatic artery is ligated, cholecystectomy is required. Although the hepatic parenchyma will generally sustain hepatic artery ligation, this is not true for the biliary system; the patients are at risk for postoperative intrahepatic biloma and abscess formation.

Portal Vein

Injury to the portal vein should be repaired primarily. In general, portal vein ligation should not be performed because liver necrosis will often occur. Packing and repeat surgery or liver resection are preferable to portal vein ligation.

Hepatic Parenchymal Injury

Key principles in the management of these injuries include (1) thorough knowledge of hepatic anatomy, (2) adequate exposure, (3) the most experienced second pair of hands available at your hospital, (4) good anesthesia support, (5) adequate supradiaphragmatic IV access and a rapid infusion device, and (6) being a minimalist. If simple maneuvers control the bleeding liver in the unstable patient, pack the liver and truncate the operation. The trauma laparotomy will nearly always start with a midline incision. Adequate exposure is achieved with a self-retaining retractor system. Retraction in both cephalad and anterior directions is critical for optimal exposure; attempt to lift the ribcage off the table with the retractor. With a complex right lobe injury or retrohepatic IVC injury, a right extension of the midline incision is often necessary. Injury to the left hemiliver or middle/left hepatic veins can generally be controlled through a midline incision alone.[3,33–37] If exposure is compromised by a midline access, do not hesitate to extend the incision in either direction subcostally for exposure; adequate exposure is essential in dealing with these difficult injuries. Almost all liver injuries can be exposed and treated with these permutations off the midline incision. On very rare occasion, a sternotomy will be needed to see a complex suprahepatic IVC injury; thoracotomy is rarely a useful maneuver. A second pair of experienced hands (another surgeon) is generally necessary with these complex liver injuries. You need the best help available at your hospital. How the assistant handles/rotates the liver, compresses the liver to staunch bleeding, and exposes the bleeding liver surface or the retrohepatic IVC to the primary surgeon are mandatory for optimal outcome.

Fractures into the parenchyma of the liver should first be treated with compression. Small bleeders along the fractured surface can be coagulated or sutured (not with large liver sutures). Vessels within the liver grow larger the deeper into the parenchyma one goes. It has been the practice of trauma surgeons for years to avoid entering the liver to suture vascular injuries, opting instead for reapproximating the liver with large deep sutures, hoping that the subsequent pressure will tamponade the bleeding. While this may work in many situations and at times be lifesaving, this is not ideal. These large liver sutures close the surface over what is often deep substantial hepatic injury, which can lead to late bleeding, abscess formation, intrahepatic hematomas/bilomas, or late biliary complications. The preferred method for deep injury is either liver resection or deepening the fracture and directly and precisely suturing the bleeding. In the situation where large liver sutures have been placed, a postoperative computed tomographic scan is recommended to fully assess the extent of the liver injury and possible need for a secondary more definitive management.

For severe fractures, do not spend a great deal of time trying to repair these, provided that, if resected, a large enough fragment of liver would remain to sustain the patient. When the underlying liver is normal, regeneration will take place in a stable noninfected recovering patient. Anatomic or nonanatomic lobectomy can be completed rapidly with the stapling devices. Portal bundles within the liver parenchyma and the major hepatic vein are divided with a vascular stapler. Generally, the resection is a completion of what was started by a massive liver injury.

Total hepatic resection can be done under the most extreme circumstances (e.g., total hepatic avulsion or total crush injury to the liver); however, it is much better tolerated in children than adults. When this maneuver is performed, it is with the anticipation that a liver transplant could be offered as a salvage operation. When total hepatic resection is performed, the portal and systemic venous systems must be decompressed. If this takes place in a transplant center where a liver is available (admittedly a rare occurrence), the patient can be placed on venovenous bypass until the liver is available. (We have performed five liver transplants for trauma within 27 years, with 60% long-term survivors.) When this is not the case, it is advisable to leave the retrohepatic vena cava intact (replacing it with a synthetic graft if required) along with portal venous drainage.

Drainage of the portal circulation can be accomplished by either an end-to-side portocaval shunt or by sewing the portal vein to either the right hepatic vein or the junction of the middle and left hepatic veins (after removal of the liver). It is advisable to place a space holder (e.g., breast implant) in the right upper quadrant to prevent loss of domain that quickly occurs. During the anhepatic phase, the patient will require constant intravenous drips of fresh-frozen plasma and glucose.

The approach to the bleeding liver should be systematic and logical. On entry into the abdomen and identification of the liver injury, pack/compress the liver. How this is accomplished is critical. Do not place packs in the cracks within the liver because this worsens the liver injury and exacerbates the bleeding. Proper technique is as follows. The surgeon places his hands on either lateral edge of the liver and compresses it back to normal anatomy; reapproximate the right lobe and left lobe of the liver (see Figure, Supplemental Digital Content 8, http://links.lww.com/TA/A175). Simultaneously, direct the liver posteriorly; this helps tamponade posterior venous bleeding. This initial maneuver provides time for anesthesia to resuscitate the patient. Packing of the liver is with the same goals: to restore the hepatic parenchyma back to normal anatomy. Packing the right upper quadrant too tightly can compress the IVC and impede venous return to the heart.

If packing fails to control the bleeding parenchyma, the next step is the Pringle maneuver;[38] this is both diagnostic and therapeutic. When the bleeding continues despite the clamp on the porta hepatis, this represents back-bleeding from the main and short hepatic veins. Thus, response to the Pringle maneuver—control or lack of control of bleeding—defines the anatomic injury (portal triad vs. hepatic veins) and dictates the next step in management of the liver injury. The Pringle is commonly applied by placing an atraumatic clamp across the hilar structures. However, the authors prefer double-looping a wide vessel loop around the hilar structures, pulling up hard on the vessel loop, and clamping the vessel loop just anterior to the hilar structures with a large right angle clamp.

Intermittent clamping of the porta hepatis is preferred (on for 10–15 minutes and off for 5 minutes) as opposed to continuous clamping.[9,34,37] Data suggest that this decreases the degree of the ischemia/perfusion injury to the liver from portal clamping. In the face of severe hypotension, a Pringle is often not necessary because the bleeding is often reduced from the hypotension alone. The Pringle should be applied only as long as absolutely necessary to control major bleeding.

If the Pringle maneuver subdues the bleeding from the liver parenchyma, a controlled search to oversew bleeding sites should quickly be completed. This is accomplished through the laceration in the liver, often extending the injury for adequate control of hemorrhage. This can be accomplished by the finger fracture technique or even more rapidly with the stapling devices.[9,39–41]

If bleeding persists with the porta hepatis occluded, the major bleeding is from the short or major hepatic veins. The origin of the bleeding must quickly be determined for expeditious exposure and control of hemorrhage. The vast majority of major hepatic venous injuries are intraparenchymal (Buckman Type A), in association with extensive parenchymal disruption, and can be controlled with reestablishment of containment of the liver parenchyma (remember these are low-pressure vessels) or direct approach through the liver injury[9,12] (see Figure, Supplemental Digital Content 9, http://links.lww.com/TA/A176). However, remember that "injudicious surgical disruption of containment structures during attempts to mobilize the liver and expose venous injuries for direct repair may result in massive and uncontrollable free bleeding."[12, p 980] Judgment, knowledge of the anatomy, and technical expertise are critical in determining the correct approach. Perhaps the most difficult to treat is the middle hepatic vein because major liver trauma often traverses the midline of the liver. The middle hepatic vein runs from behind the gallbladder superiorly to the vena cava. When the liver is fractured, the main vein can be torn or, more commonly, the small branches are avulsed, leaving multiple side holes that can both bleed and serve as an entrance for air emboli. The middle hepatic vein can almost always be ligated/oversewn without consequence. The short hepatic veins can be approached similarly or with mobilization of the liver from caudal to cephalad. The small short hepatic veins must also be controlled with clips or ties. Medium/large clips are not generally recommended because they tend to be dislodged; instead, microclips, ties, or sutures are preferred.

Less commonly, the hepatic venous injury is extrahepatic (Buckman Type B), at times, with a large defect in the IVC (see Figure, Supplemental Digital Content 10, http://links.lww.com/TA/A177). Quickly determine whether the blood seems to be originating behind the liver (right or short hepatic veins) or more cephalad (middle and left hepatic veins). Expeditious mobilization of the appropriate hemiliver provides adequate exposure. A side-biting clamp (Satinsky) will often suffice for control of the bleeding from the IVC. If this is insufficient, complete occlusion above and below the injury with vascular clamps will usually suffice. The authors essentially never use the atriocaval shunt. If this level of compromise has occurred, veno-veno bypass is the preferred method of control but is almost never required. If needed, make the liver a midline structure; remember that the liver can be fully mobilized anteriorly, into the midline if needed—this will provide full exposure of the IVC. Speed and good help are essential in dealing with these injuries, which can bleed massively.

Definitive operative management of an injury to the liver must arrest hemorrhage, control bile leak, debride nonviable tissue, and drain the area. However, damage control should be invoked in the hemodynamically unstable patient with major liver injury. In this situation, the only goal at the first operation is control of hemorrhage. Once surgical bleeding has been controlled, the operation is truncated, the abdomen is packed with temporary abdominal closure, and the patient is transferred to the intensive care unit for further resuscitation. It is critical that the operation be terminated only when control of "surgical bleeding" is clearly accomplished and what remains is oozing (medical bleeding) caused by hypothermia and coagulopathy. Control of hemorrhage as quickly as possible is critical.

Aids for Parenchymal Transection and Hemostasis

Stapling Devices

The stapling devices have greatly reduced transection time in hepatic surgery and are equally useful in the setting of trauma. Crushing staples are best and are fitted with the vascular loads. The capsule of the liver along the intended cutting plane is scored first with the electrocautery, then the liver parenchyma is crushed and stapled with the stapler (Fig. 4).

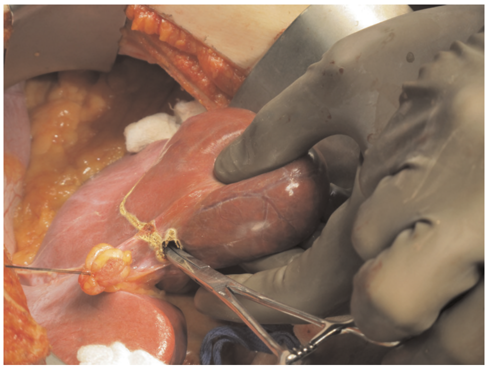

Figure 4. Liver resection with the stapler. The resection line has been marked, coming through the capsule of the liver with the electrocautery. A clamp is passed into the hepatic parenchyma to develop the plane for placement of the stapler in preparation to fire the stapler or the small limb of the stapler may be passed directly into the plane of resection.

There are a few caveats to using the stapler, however,

1. Once the parenchymal transection is begun with the stapler, it is difficult to stop because there will always be bleeding along the staple line (which is best controlled with bimanual compression until the transection is complete).
2. Place the smaller blade of the stapler into the parenchyma.
3. The scrub nurse must be familiar with changing the stapler cartridge. When necessary, use two staplers and two scrub nurses.
4. The staplers do not know what they are stapling. The surgeon must be certain what is between the jaws of the stapler as it will staple everything, including the hilar structures and hepatic veins. A rapid hepatic lobectomy, generally nonanatomic, can be performed with the staplers. Remember the location of the middle hepatic vein running within the main portal fissure. Inadvertent injury to the middle hepatic vein will add another major bleeding site. Make certain that the resection line is off center (Cantlie's line), toward the lobe being resected, relative to the middle hepatic vein.
5. When placing the stapler into the liver, the stapler should pass easily into the parenchyma. When it meets resistance, the stapler is either going through the capsule of the liver or into an intrahepatic vascular structure. When this occurs, the stapler should be redirected either deeper or more superficially in the liver. A Kelly clamp can be used to pass into the liver along the intended transection plane as a guide before placing the larger blades of the stapler.

Instruments and Other Techniques

The argon beam coagulator (ABC) is a useful tool for surface injuries to the liver and for subcapsular hematomas. Ligasure or Enseal is useful for dividing the liver under controlled circumstances. Salient Surgical Technology devices (formerly TissueLink) are useful tools for dissection of the liver and for hemostasis on the intrahepatic tissue. The bipolar device (the Aquamantis) is useful for hemostasis alone and is quick. However, none is useful for large parenchymal injuries, especially in cracks and crevices that can occur in liver trauma. None of these devices should be used on or near the main hepatic ducts because significant thermal injury will occur. If the patient is stable and has undergone any significant resection, the raw liver surface should be treated with one of these devices to minimize the risk of postoperative bleeding and biliary leaks. Similarly, thrombin-activated factors are useful for sealing small bile leaks and for stopping minor bleeding.

Aortic clamping should never be done for isolated hepatic trauma. It affords the surgeon nothing and deprives the other abdominal viscera of inflow.

Completion cholangiogram. If there is any question about a biliary injury or leak, a cholangiogram should be performed (assuming that the patient is stable). Saline can be intermittently injected via the cystic duct remnant (cholecystectomy performed) to identify and oversew leaking bile ducts. This defines the biliary anatomy and prevents postoperative bile leak. Often, this is at the second operation following damage control at the first procedure.

The successful treatment of hepatic injuries is, in large part, dependent on the surgeon's knowledge of hepatic anatomy and comfort operating on the liver. It is beneficial for the trauma surgeon to assist hepatobiliary surgeons in hepatic resections when possible; it is also helpful to assist transplant surgeons both in organ recovery and in transplantation. Finally, assisting in living donor liver transplantation exposes the surgeon to more intrahepatic anatomy than any other surgical procedure.

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