INJURIES TO THE LIVER, BILIARY TRACT, SPLEEN, AND DIAPHRAGM

Jon M. Burch, M.D., F.A.C.S., and Ernest E. Moore, M.D., F.A.C.S.

Injuries to the Liver

ASSESSMENT

The initial step in the management of penetrating abdominal injuries and of blunt abdominal injuries in cases when nonoperative treatment is contraindicated or has failed is exploratory laparotomy [see 7:6 Operative Exposure of Abdominal Injuries and Closure of the Abdomen].

Visualization of the right hemiliver [see Figure 1] is hindered by the posterior attachments and by the right lower costal margin. Exposure of the right hemiliver is facilitated by elevating the right costal margin with a large Richardson retractor. Further exposure can be achieved with mobilization, which requires division of the right triangular and coronary ligaments [see Figure 2]. In dividing the superior coronary ligament, care must be taken not to injure the lateral wall of the right hepatic vein; in dividing the inferior coronary ligament, care must be taken not to injure the right adrenal gland (which is vulnerable because it lies directly beneath the peritoneal reflection) or the retrohepatic vena cava. When the ligaments have been divided, the right hemiliver can be rotated medially into the surgical field. Mobilization of the left hemiliver poses no unusual problems other than the risk of injury to the left hepatic vein, the left inferior phrenic vein, and the retrohepatic vena cava.

If optimal exposure of the junction of the hepatic veins and the retrohepatic vena cava is necessary, the midline abdominal incision can be extended by means of a median sternotomy. The pericardium and the diaphragm can then be divided toward the center of the inferior vena cava. This combination of incisions provides superb exposure of the hepatic veins and the retrohepatic vena cava while avoiding injury to the phrenic nerves.

Hepatic injuries are classified according to the grading system developed by the American Association for the Surgery of Trauma Committee on Organ Injury Scaling [see Table 1 and Figure 3].

---

*Figure 1* Shown are the anatomic divisions of the liver.
grading scale ranges from I to VI, with I representing superficial lacerations and small subcapsular hematomas and VI representing avulsion of the liver from the vena cava. Isolated injuries that are not extensive (grades I to III) often require little or no treatment; however, extensive parenchymal injuries and those involving the juxtahepatic veins (grades IV and V) may require complex maneuvers for successful treatment, and hepatic avulsion (grade VI) is lethal.

Clamping of the hepatic pedicle—the Pringle maneuver—is helpful for evaluating grade IV and V hepatic injuries. This maneuver allows one to distinguish between hemorrhage from branches of the hepatic artery or the portal vein, which ceases when the clamp is applied, and hemorrhage from the hepatic veins or the retrohepatic vena cava, which does not. When performing the Pringle maneuver, we prefer to tear open the lesser omentum manually and place the clamp from the patient’s left side while guiding the posterior blade of the clamp through the foramen of Winslow with the aid of the left index finger. The advantages of this approach are the avoidance of injury to the structures within the hepatic pedicle, the assurance that the clamp will be properly placed the first time, and the inclusion of a replacing or accessory left hepatic artery between the blades of the clamp.

**MANAGEMENT OF INJURIES**

**Techniques for Temporary Control of Hemorrhage**

Temporary control of hemorrhage is essential for two reasons. First, during treatment of a major hepatic injury, ongoing hemorrhage may pose an immediate threat to the patient’s life, and temporary control gives the anesthesiologist time to restore the circulating volume before further blood loss occurs. Second, multiple bleeding sites are common with both blunt and penetrating trauma, and if the liver is not the highest priority, temporary control of hepatic bleeding allows repair of other injuries without unnecessary blood loss. The most useful techniques for the temporary control of hepatic hemorrhage are manual compression, perihepatic packing, and the Pringle maneuver.

Periodic manual compression with the addition of laparotomy pads is useful in the treatment of complex hepatic injuries to provide time for resuscitation. Hands and pads should be positioned to realign the liver in its normal anatomic position. Perihepatic packing with carefully placed laparotomy pads is capable of controlling hemorrhage from almost all hepatic injuries. The right costal margin is elevated, and the pads are strategically placed over and around the bleeding site. Additional pads may be placed between the liver and the diaphragm and between the liver and the anterior chest wall until the bleeding has been controlled. Ten to 15 pads may be required to control the hemorrhage from an extensive right lobar injury. Perihepatic packing forces the right diaphragm superiorly and impairs its motion; this may lead to increased airway pressures and decreased tidal volume. Careful consideration of the patient’s condition is necessary to determine whether the risk of these complications outweighs the risk of additional blood loss.

The Pringle maneuver is often used as an adjunct to packing
## Table 1  AAST Organ Injury Scales for Liver, Biliary Tract, Diaphragm, and Spleen

<table>
<thead>
<tr>
<th>Injured Structure</th>
<th>AAST Grade</th>
<th>Characteristics of Injury</th>
<th>AIS-90 Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liver*</td>
<td>I</td>
<td>Hematoma: subcapsular, nonexpanding, &lt; 10% surface area</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Laceration: capsular tear, nonbleeding, &lt; 1 cm parenchymal depth</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>Hematoma: subcapsular, nonexpanding, 10%–50% surface area; intraparenchymal, nonexpanding, &lt; 10 cm in diameter</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Laceration: capsular tear, active bleeding, 1–3 cm parenchymal depth, &lt; 10 cm in length</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>Hematoma: subcapsular, &gt; 50% surface area, expanding; ruptured subcapsular hematoma with active bleeding; intraparenchymal, &gt; 10 cm or expanding</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Laceration: &gt; 3 cm parenchymal depth</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>IV</td>
<td>Hematoma: ruptured intraparenchymal hematoma with active bleeding</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Laceration: parenchymal disruption involving 25%–75% of hepatic lobe or 1–3 Couinaud’s segments within a single lobe</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>Laceration: parenchymal disruption involving &gt; 75% of hepatic lobe or &gt; 3 Couinaud’s segments within a single lobe</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vascular: juxtahepatic venous injuries (i.e., injuries to retrohepatic vena cava or central major hepatic veins)</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>VI</td>
<td>Vascular: hepatic avulsion</td>
<td>5</td>
</tr>
<tr>
<td>Extrahepatic biliary tree*</td>
<td>I</td>
<td>Gallbladder contusion/hematoma</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Portal triad contusion</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>Partial gallbladder avulsion from liver bed; cystic duct intact</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Laceration or perforation of gallbladder</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>Complete gallbladder avulsion from liver bed</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cystic duct laceration</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>IV</td>
<td>Partial or complete right or left hepatic duct laceration</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Partial common hepatic duct or common bile duct laceration (&lt; 50%)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>&gt; 50% transection of common hepatic duct or common bile duct</td>
<td>3–4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Combined right and left hepatic duct injuries</td>
<td>3–4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intraduodenal or intrapancreatic bile duct injuries</td>
<td>3–4</td>
</tr>
<tr>
<td>Diaphragm†</td>
<td>I</td>
<td>Contusion</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>Laceration &lt; 2 cm</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>Laceration 2–10 cm</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>IV</td>
<td>Laceration &gt; 10 cm, with tissue loss &lt; 25 cm²</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>Laceration with tissue loss &gt; 25 cm²</td>
<td>3</td>
</tr>
<tr>
<td>Spleen*</td>
<td>I</td>
<td>Hematoma: subcapsular, nonexpanding, &lt; 10% surface area</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Laceration: capsular tear, nonbleeding, &lt; 1 cm parenchymal depth</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>Hematoma: subcapsular, nonexpanding, 10%–50% surface area; intraparenchymal, nonexpanding, &lt; 5 cm in diameter</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Laceration: capsular tear, active bleeding, 1–3 cm parenchymal depth, not involving a trabecular vessel</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>Hematoma: subcapsular, &gt; 50% surface area or expanding; ruptured subcapsular hematoma with active bleeding; intraparenchymal, &gt; 5 cm or expanding</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Laceration: &gt; 3 cm parenchymal depth or involving trabecular vessels</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>IV</td>
<td>Hematoma: ruptured intraparenchymal hematoma with active bleeding</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Laceration: laceration involving segmental or hilar vessels producing major devascularization (&gt; 25% of spleen)</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>Laceration: completely shattered spleen</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vascular: hilar vascular injury that devascularizes spleen</td>
<td>5</td>
</tr>
</tbody>
</table>

*Advance one grade for multiple injuries, up to grade III.
†Advance one grade for bilateral injuries, up to grade III.
AAST—American Association for the Surgery of Trauma
for the temporary control of hemorrhage. Over the years, the length of time for which surgeons believe a Pringle maneuver can be maintained without causing irreversible ischemic damage to the liver has increased. Several authors have documented the maintenance of a Pringle maneuver for longer than 1 hour in patients with complex injuries, without appreciable hepatic damage. When a life-threatening hepatic injury is encountered on entry into the abdomen, the Pringle maneuver should be performed immediately and perihepatic packs placed. Persistent bleeding in the face of effective inflow occlusion implies that either the retrohepatic vena cava or hepatic vein has been injured. Perihepatic packing is more likely to control bleeding from the retrohepatic vena cava.

Another technique for temporary control of hepatic hemorrhage is the application of a tourniquet or a liver clamp. Once the bleeding hemiliver is mobilized, a 2.5 cm Penrose drain is wrapped around the liver near the anatomic division between the left hemiliver and the right. The drain is stretched until hemorrhage ceases, and tension is maintained by clamping the drain. Unfortunately, tourniquets are difficult to use: they tend to slip off or tear through the parenchyma if placed over an injured area. An alternative is the use of a liver clamp; however, the application of such devices is hindered by the variability in the size and shape of the liver. We have not had consistent success with either of these methods.

Juxtahepatic venous injuries are technically challenging, difficult to control with packing, and often lethal. Complex procedures may be required for temporary control of these large veins. Of these procedures, the most important are hepatic vascular isolation with clamps, placement of the atriocaval shunt, and use of the Moore-Pilcher balloon.

Hepatic vascular isolation is accomplished by executing a Pringle maneuver, clamping the aorta at the diaphragm, and clamping the suprarenal and suprahepatic vena cava. In patients scheduled for elective procedures, this technique has enjoyed nearly uniform success, but in trauma patients, the results have been disappointing. The relative ineffectiveness of hepatic vascular isolation with clamps in this setting is presumably due to the inability of a patient in shock to tolerate an acute reduction in left ventricular filling pressure; on occasion, sudden death has occurred.
Figure 4  The Pringle maneuver controls arterial and portal vein hemorrhage from the liver. Any hemorrhage that continues must come from the hepatic veins.

on placement of the venous clamps. If, however, a trauma patient requiring hepatic vascular isolation has been maintained in a relatively normal physiologic condition, it is reasonable to consider this method.

An alternative approach to exposure of the retrohepatic vena cava and the hepatic veins has been developed in which vascular isolation of the liver is achieved by means of clamping and the suprahepatic vena cava is divided between vascular clamps [see Figure 7]. The liver and the suprahepatic vena cava are then rotated anteriorly to provide direct access to the posterior aspect of the retrohepatic vena cava. Anterior injuries of the large veins are repaired through an incision in the posterior aspect of the retrohepatic vena cava.

The atrociaval shunt was designed to achieve hepatic vascular isolation while still permitting some venous blood from below the diaphragm to flow through the shunt into the right atrium. After a few early successes, the initial enthusiasm for the atrociaval shunt declined as high mortalities associated with its use began to be reported. Surgeons' lack of familiarity with the technique; the manipulation of a cold, acidic heart; and poor patient selection have all contributed to the poor overall results. A variation on the original atrociaval shunt has been described in which a 9 mm endotracheal tube is substituted for the usual large chest tube [see Figure 8]. The balloon of the endotracheal tube makes it unnecessary to surround the suprarenal vena cava with an umbilical tape. This minor change eliminates one of the most difficult maneuvers required for the original shunt procedure: because hemorrhage must be controlled by posterior pressure on the liver during the insertion of the shunt, access to the suprarenal vena cava is severely restricted, and thus, surrounding this vessel with an umbilical tape is almost impossible. A side hole must be cut in the tube to allow blood to enter the right atrium. Care must be taken to avoid damage to the integral inflation channel for the balloon.

An alternative to the atrociaval shunt is the Moore-Pilcher balloon. This device is inserted through the femoral vein and advanced into the retrohepatic vena cava. When the balloon is properly positioned and inflated, it occludes the hepatic veins and the vena cava, thus achieving vascular isolation. The catheter itself is hollow, and appropriately placed holes below the balloon permit

Figure 5  Manual compression of large hepatic injuries temporarily controls blood loss in hypovolemic patients until the circulating blood volume can be restored.

Figure 6  Perihepatic packing is often effective in managing extensive parenchymal injuries. It has also been successfully employed for grade V juxtahepatic venous injuries.
blood to flow into the right atrium, in much the same way as the atrio caval shunt. At present, the survival rate for patients with juxtahepatic venous injuries who are treated with this device is similar to that for patients treated with the atrio caval shunt.18

Surgeons who attempt hepatic vascular isolation should be aware that none of these techniques provide complete hemostasis. Drainage from the right adrenal vein and the inferior phrenic veins and persistent hepatopetal flow resulting from unrecognized replacing or accessory left hepatic arteries contribute to this problem. The relatively small volume of blood that continues to flow after vascular isolation is readily removed by means of suction.

An adjunct to vascular isolation with clamps is venovenous bypass. This technique provides vascular decompression for the small bowel and maintains high cardiac filling pressures, which are often necessary. Venovenous bypass is accomplished by placing a catheter in the inferior vena cava via the femoral vein and a second catheter in the superior mesenteric vein [see Figure 9].22 A centrifugal pump withdraws blood from these veins and pumps it into the superior vena cava through a third catheter placed in the internal jugular vein.

Figure 7 With hepatic vascular isolation accomplished, the suprahepatic vena cava is divided between clamps, and the liver and the suprahepatic vena cava are rotated anteriorly to afford access to the posterior aspect of the retrohepatic vena cava.

Techniques for Definitive Management of Injuries

Techniques available for the definitive management of hepatic injuries range from manual compression to hepatic transplantation. Grade I or II lacerations of the hepatic parenchyma can generally be controlled with manual compression. If these injuries do not respond to manual compression, they can often be controlled with topical hemostatic measures.

The simplest of these measures is electrocauterization, which can often control small bleeding vessels near the surface of the liver (though the machine’s power output may have to be increased). Bleeding from raw surfaces of the liver that does not respond to the electrocautery may respond to the argon beam coagulator. This device imparts less heat to the surrounding hepatic tissue and creates a more consistent eschar, which enhances hemostasis. Also useful in similar situations is microcrystalline collagen in the powdered form. The powder is placed on a clean 10 × 10 cm sponge and applied directly to the oozing surface, with pressure maintained on the sponge for 5 to 10 minutes. Thrombin can also be applied topically to minor bleeding injuries by saturating either a gelatin foam sponge or a microcrystalline collagen pad and pressing it to the bleeding site.

In previous years, there was interest in the use of “bathtub” fi-
brin glue (made by mixing concentrated human fibrinogen with a solution containing bovine thrombin and calcium) to treat hepatic lacerations.23,24 This substance has now been rendered obsolete by the commercial availability of numerous glues and sealants [see Table 2].

Another relatively new hemostatic adjunct that can be highly useful in the setting of hepatic injury is recombinant activated factor VII (NovoSeven; Novo Nordisk, Copenhagen), which works by promoting coagulation at the lacerated edges of blood vessels. Many trauma surgeons have personally witnessed the abrupt cessation of hemorrhage when factor VII has been administered after other materials have failed. Although this agent seems at times to have an almost magical effect, it does not always work, and it is extremely expensive; furthermore, the only prospective study to date that addressed the use of factor VII in trauma patients reported only a modest decrease in total blood use and failed to demonstrate a survival advantage.25 For these reasons, many institutions, including ours (University of Colorado Health Sciences Center), have created protocols for the use of factor VII. At our institution, for factor VII to be used, (1) the patient must be salvageable; (2) the patient must have received at least 10 units of packed red blood cells (PRBCs) plus clotting factors; (3) surgical control of hemorrhage must be achieved; and (4) the patient must still be experiencing diffuse hemorrhage. The usual dose is 60 to 90 µg/kg, which may be repeated once. It should be kept in mind that factor VII is not a substitute for fresh frozen plasma and platelets and that adequate amounts of fibrin and platelets must be present for it to work.

Although some grade III and IV lacerations respond to topical measures, many do not. In these instances, one option is to suture the hepatic parenchyma. Although this hemostatic technique has been maligned as a cause of hepatic necrosis, it still is frequently used.3,4,10,17,26,27 Suturing of the hepatic parenchyma is often employed to control persistently bleeding lacerations less than 3 cm in depth; it is also an appropriate alternative for deeper lacerations if the patient cannot tolerate the further hemorrhage associated with hepatotomy and selective ligation. If, however, the capsule of the liver has been stripped away by the injury, this technique is far less effective.

The preferred suture material is 0 or 2-0 chromic catgut attached to a large, blunt-tipped, curved needle; the large diameter prevents the suture from pulling through Glisson’s capsule. For shallow lacerations, a simple continuous suture may be used to approximate the edges of the laceration. For deeper lacerations, interrupted horizontal mattress sutures may be placed parallel to the edges. When tying sutures, one may be sure that adequate tension has been achieved when hemorrhage ceases or the liver blanches around the suture.

Most sources of venous hemorrhage can be managed with parenchymal sutures. Even injuries to the retrohepatic vena cava and the hepatic veins have been successfully tamponaded by closing the hepatic parenchyma over the bleeding vessels.15,28 Venous hemorrhage caused by penetrating wounds traversing the central portion of the liver may be managed by closing the entrance and exit wounds with interrupted horizontal mattress sutures.
Although this measure may lead to the formation of intrahepatic hematomas that may then become infected, the risk is reasonable compared with the risks posed by an intracaval shunt or a deep hepaticotomy. Still, suturing of the hepatic parenchyma is not always successful in controlling hemorrhage, particularly hemorrhage from the larger branches of the hepatic artery. If it fails, one must acknowledge the failure promptly and remove the sutures so that the wound can be explored.

Hepatotomy with selective ligation of bleeding vessels is an important technique that is usually reserved for deep or transhepatic penetrating wounds. Most authorities prefer it to parenchymal suturing\(^{3,4,10,29,30}\); some even favor it over placement of an atrio-caval shunt for exposure and repair of juxtahepatic venous injuries.\(^{20}\) The finger-fracture technique is used to extend the length and depth of a laceration or a missile tract until the bleeding wound can be identified and controlled [see Figure 10]. It should be remembered that considerable blood loss may be incurred with the division of viable hepatic tissue in the pursuit of bleeding from deep penetrating wounds. As an alternative to finger fracture, we have begun to use the LigaSure vessel sealing system (Valleylab, Boulder, Colorado) and have observed significant

---

**Table 2** Characteristics of Selected Commercially Available Tissue Glues and Sealants

<table>
<thead>
<tr>
<th>Tisseel VH*</th>
<th>FloSeal*</th>
<th>CoSeal*</th>
<th>BioGlue†</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contents</strong></td>
<td>Human fibrinogen and thrombin; calcium chloride; bovine aprotinin</td>
<td>Bovine gelatin and thrombin</td>
<td>Polyethylene glycol</td>
</tr>
<tr>
<td><strong>Method of absorption (time)</strong></td>
<td>Fibrinolysis (10–14 days)</td>
<td>Cell-mediated inflammation (6 wk)</td>
<td>Hydrolysis (30 days)</td>
</tr>
<tr>
<td><strong>Physical properties</strong></td>
<td>Flexible and elastic</td>
<td>Granular; conforms to irregular surfaces</td>
<td>Clear hydrogel; flexible and elastic</td>
</tr>
<tr>
<td><strong>Preparation time</strong></td>
<td>7–15 min</td>
<td>1–2 min</td>
<td>1–2 min</td>
</tr>
<tr>
<td><strong>General applications</strong></td>
<td>Tissue sealing and adherence; hemostasis in venous oozing</td>
<td>Hemostasis in wet fields up to arterial pressure</td>
<td>Tissue sealing in dry fields</td>
</tr>
<tr>
<td><strong>Specific applications</strong></td>
<td>Venous oozing; sealing of staple lines; decortication; pleurodesis</td>
<td>Active bleeding</td>
<td>Sealing of small vessels and synthetic grafts; prevention of adhesion in pediatric cardiac surgical patients; sealing of large vessels</td>
</tr>
<tr>
<td><strong>Means of application</strong></td>
<td>Cannula; spray; minimally invasive surgery</td>
<td>Cannula; minimally invasive surgery; 8 cm or 10 cm bulb tip</td>
<td>Flexible cannula; spray; minimally invasive surgery</td>
</tr>
<tr>
<td><strong>Limiting factors</strong></td>
<td>Arterial pressure</td>
<td>Does not seal</td>
<td>Wet field</td>
</tr>
<tr>
<td><strong>Set times</strong></td>
<td>3 min</td>
<td>2 min</td>
<td>1 min</td>
</tr>
<tr>
<td><strong>Stability</strong></td>
<td>4 hr</td>
<td>2 hr</td>
<td>2 hr</td>
</tr>
</tbody>
</table>

---

\(^{*}\)Baxter International, Deerfield, Illinois.  
\(^{†}\)CryoLife, Inc., Kennesaw, Georgia.
Perihepatic packing is the most significant advance in the treatment of hepatic injuries to occur in the past 25 years. The practice of packing hepatic injuries is not a new one, but the concepts and techniques associated with it have changed. In the past, liver lacerations were packed with yards of gauze, and one end of the gauze strip was brought out of the abdomen through a separate stab wound; the remainder of the gauze was then teased out of the wound over a period of days. Unfortunately, this approach often led to abdominal infection and failed to control the hemorrhage, and as a result, it eventually fell from favor. The current approach is not to place packing material in the laceration itself but rather to place it over and around the injury to compress the wound by compressing the liver between the anterior chest wall, the diaphragm, and the retroperitoneum. The abdomen is closed, and the patient is taken to the surgical intensive care unit for resuscitation and correction of metabolic derangements. Within 24 hours, the patient is returned to the OR for removal of the packs.

Perihepatic packing is indicated for grade IV and V lacerations and for less severe injuries in patients who have a coagulopathy caused by associated injuries.

A technique that may be attempted if packing fails is to wrap the injured portion of the liver with a fine porous material (e.g., polyglycolic acid mesh) after the injured hemiliver has been mobilized. Using a continuous suture or a linear stapler, the surgeon constructs a tight-fitting stocking that encloses the injured hemiliver. Blood clots beneath the mesh, which results in tamponade of the hepatic injury. Although this technique is intuitively attractive, to date it has achieved only limited success.

The final alternative for patients with extensive injuries to one hemiliver is anatomic hepatic resection. In elective circumstances, anatomic hemihepatectomies can be performed with excellent results; however, in the setting of trauma, the mortality associated with this procedure exceeds 50% in most series. Consequently, hepatic resection is rarely performed in trauma patients, having been largely replaced by perihepatic packing, resectional debridement, and hepatotomy with selective ligation. Nonetheless, there are two circumstances in which anatomic resection may still be a reasonable choice. The first is prompt resection in patients with extensive injuries of the left lateral section of the liver; because hemorrhage from the left hemiliver is easily controlled with bimanual compression, the risk of uncontrolled blood loss is not as high as it is with left or right anatomic hemihepatectomies. The second is delayed anatomic hemihepatectomy in patients whose hemorrhage has been controlled but whose left or right hemiliver is nonviable as a result of ligation or thrombosis of essential blood vessels. Because of the large mass of necrotic liver tissue, there is a high risk of subsequent infection or persistent hyperinflammation, setting the stage for the multiple organ dysfunction syndrome (MODS). The necrotic hemiliver should be removed as soon as the patient’s condition permits.

Hepatic transplantation has been successful in several trauma patients with devastating hepatic injuries who required total hepatectomy. In each of these five patients, the mean anhepatic period was approximately 24 hours. All five survived the transplantation, though two died of disseminated viral infections within 2 months of the procedure. Two others were alive and well 16 and 17 months after the procedure; no follow-up was reported for the fifth patient. Hepatic transplantation represents the ultimate expression of aggressive trauma care. All other injuries must be well delineated (particularly injuries to the CNS), and the patient must have an excellent chance of survival aside from the hepatic injury. High cost and limited availability of donors restrict the performance of hepatic transplantation for trauma, but it seems probable that this procedure will continue to be performed in extraordinary circumstances.
Subcapsular Hematoma

An uncommon but troublesome hepatic injury is subcapsular hematoma, which arises when the parenchyma of the liver is disrupted by blunt trauma but Glisson’s capsule remains intact. Subcapsular hematomas range in severity from minor blisters on the surface of the liver to ruptured central hematomas accompanied by severe hemorrhage [see Table 1]. They may be recognized either at the time of the operation or in the course of CT scanning.

Regardless of how the lesion is diagnosed, subsequent decision making is often difficult. If a grade I or II subcapsular hematoma—that is, a hematoma involving less than 50% of the surface of the liver that is not expanding and is not ruptured—is discovered during an exploratory laparotomy, it should be left alone. If the hematoma is explored, hepatotomy with selective ligation may be required to control bleeding vessels. Even if hepatotomy with ligation is effective, one must still contend with diffuse hemorrhage from the large denuded surface, and packing may also be required. A hematoma that is expanding during operation (grade III) may have to be explored. Such lesions are often the result of uncontrolled arterial hemorrhage, and packing alone may not be successful. An alternative strategy is to pack the liver to control venous hemorrhage, close the abdomen, and transport the patient to the interventional radiology suite for hepatic arteriography and embolization of the bleeding vessels. Ruptured grades III and IV hematomas are treated with exploration and selective ligation, with or without packing.

Perihepatic Drainage

For years, all hepatic injuries were drained via Penrose drains brought out laterally or through the bed of the resected 12th rib; recently, the use of large sump drains and closed suction drains has become increasingly popular. Several prospective and retrospective studies have demonstrated that the use of either Penrose or sump drains carries a higher risk of intra-abdominal infection than the use of either closed suction drains or no drains at all.45-47 It is clear that if drains are to be used, closed suction devices are preferred. What remains unclear, however, is whether closed suction drains are better or worse than no drains, particularly in view of the advent of percutaneous catheter drainage. Patients who are initially treated with perihepatic packing may also require drainage; however, drainage is not indicated at the initial procedure, given that the patient will be returned to the OR within the next 48 hours.

Mortality and Complications

Overall mortality for patients with hepatic injuries is approximately 10%. The most common cause of death is exsanguination, followed by MODS and intracranial injury. Three generalizations may be made regarding the risk of death and complications: (1) both increase in proportion to the injury grade and to the complexity of repair; (2) hepatic injuries caused by blunt trauma carry a higher mortality than those caused by penetrating trauma; and (3) infectious complications occur more often with penetrating trauma.48

Postoperative hemorrhage occurs in a small percentage of patients with hepatic injuries. The source may be either a coagulopathy or a missed vascular injury (usually to an artery). In most instances of persistent postoperative hemorrhage, the patient is best served by being returned to the OR. Arteriography with embolization may be considered in selected patients. If coagula-
tion studies indicate that a coagulopathy is the likely cause of postoperative hemorrhage, there is little to be gained by reoperation until the coagulopathy is corrected.

Perihepatic infections occur in fewer than 5% of patients with significant hepatic injuries. They develop more often in patients with penetrating injuries than in patients with blunt injuries, presumably because of the greater frequency of enteric contamination. An elevated temperature and a higher than normal white blood cell count after postoperative day 3 or 4 should prompt a search for intra-abdominal infection. In the absence of pneumonia, an infected line, or urinary tract infection, an abdominal CT scan with intravenous and upper gastrointestinal contrast should be obtained. Many perihepatic infections can be treated with CT-guided drainage; however, infected hematomas and infected necrotic liver tissue cannot be expected to respond to percutaneous drainage. Right 12th rib resection remains an excellent approach for posterior infections and provides superior drainage in refractory cases.

Bilomas are loculated collections of bile that may or may not be infected. If a biloma is infected, it is essentially an abscess and should be treated as such; if it is sterile, it will eventually be resorbed. Biliary ascites is caused by disruption of a major bile duct. Reoperation after the establishment of appropriate drainage is the prudent course. Even if the source of the leaking bile can be identified, primary repair of the injured duct is unlikely to be successful. It is best to wait until a firm fistulous communication is established with adequate drainage.

Biliary fistulas occur in approximately 3% of patients with major hepatic injuries. They are usually of little consequence and generally close without specific treatment. In rare instances, a fistulous communication with intrathoracic structures forms in patients with associated diaphragmatic injuries, resulting in a bronchobiliary or pleurobiliary fistula. Because of the pressure differential between the biliary tract and the thoracic cavity, most of these fistulas must be closed operatively; however, we know of one pleurobiliary fistula that closed spontaneously after endoscopic sphincterotomy and stent placement.

Hemorrhage from hepatic injuries is often treated without identifying and controlling each bleeding vessel individually, and arterial pseudoaneurysms may develop as a consequence. As the pseudoaneurysm enlarges, it may rupture into the parenchyma of the liver, into a bile duct, or into an adjacent branch of the portal vein. Rupture into a bile duct results in hemobilia, which is characterized by intermittent episodes of right upper quadrant pain, upper GI hemorrhage, and jaundice; rupture into a portal vein may result in portal vein hypertension with bleeding varices. Both of these complications are exceedingly rare and are best managed with hepatic arteriography and embolization.

Injuries to the Bile Ducts and Gallbladder

Injuries to the extrahepatic bile ducts [see Table 1] can be caused by either penetrating or blunt trauma; however, they are rare in either case.49-53 The diagnosis is usually made by noting the accumulation of bile in the upper quadrant during laparotomy for treatment of associated injuries. Treatment of common bile duct (CBD) injuries after external trauma is complicated by the small size and thin wall of the normal duct, which render primary repair almost impossible except when the laceration is small and there is no tissue loss. When there is tissue loss or the laceration is larger than 25% to 50% of the diameter of the duct, the best treatment option is a Roux-en-Y choledochojunostomy [see 5:22 Procedures for Benign and Malignant Biliary Tract Disease].54-57 Treatment of injuries to the left or right hepatic duct is even more difficult—so much so that we question whether repair should even be attempted under emergency conditions. If only one hepatic duct is injured, a reasonable approach is to ligate it and deal with any infections or atrophy of the hemiliver rather than to attempt repair.58 If both ducts are injured, each should be intubated with a small catheter brought through the abdominal wall. Once the patient has recovered sufficiently, delayed repair is performed under elective conditions. Injuries to the intrapancreatic portion of the CBD are treated by dividing the duct at the superior border of the pancreas, ligating the distal portion, and performing a Roux-en-Y choledochojunostomy.

The Roux-en-Y choledochojunostomy is done in a single layer with interrupted 5-0 absorbable monofilament sutures. To prevent ischemia and possible stenosis, no circumferential dissection of the duct is performed. A round patch of approximately the same diameter as the CBD is removed from the seromuscular layer of the small bowel, but the mucosa and submucosa are only perforated, not resected. The posterior row of sutures is placed first, with full-thickness bites taken through both the duct and the small bowel. The anterior row is then completed. Finally, three or four 3-0 polypropylene sutures are placed to secure the small bowel around the anastomosis to the connective tissue of the porta hepatitis. The only purpose for these sutures is to spare the fragile anastomosis any potential tension. No T tubes or stents are employed. Closed suction drainage is added in the case of injuries to the intrapancreatic portion of the duct or at the surgeon's discretion.

Injuries to the gallbladder [see Table 1] are treated by means of either lateral repair with absorbable sutures or cholecystectomy [see 5:21 Cholecystectomy and Common Bile Duct Exploration]; the decision between the two approaches depends on which is easier in a given situation. Cholecystostomy is rarely, if ever, indicated.

Injuries to the Spleen

Splenic injuries [see Table 1] are treated operatively by means of splenic repair (splenorrhaphy), partial splenectomy, or resection, depending on the extent of the injury and the condition of the patient.57,58 The continued enthusiasm for nonoperative management of splenic injuries is driven, in part, by concern about the rare but often fatal complication known as overwhelming postsplenectomy infection (OPSI). OPSI is caused by encapsulated bacteria (e.g., Streptococcus pneumoniae, Haemophilus influenzae, and Neisseria meningitidis) and is very resistant to treatment: mortality may exceed 50%. OPSI occurs most often in young children and immunocompromised adults and is uncommon in otherwise healthy adults. For this reason, splenic salvage is attempted more vigorously in pediatric patients than in adult ones [see Discussion, Nonoperative Management of Blunt Hepatic and Splenic Injuries, below].

To ensure safe removal or repair, the spleen should be mobilized to the point where it can be brought to the surface of the abdominal wall without tension. To this end, the soft tissue attachments between the spleen and the splenic flexure of the colon must be divided. Next, an incision is made in the peritoneum and the endoabdominal fascia, beginning at the inferior pole, 1 to 2 cm lateral to the posterior peritoneal reflection of the spleen, and continuing posteriorly and superiorly until the esophagus is encountered [see Figure 12a]. Care must be taken not to pull on the spleen, so that it will not tear at the posterior peritoneal reflection, causing significant hemorrhage. Instead, the spleen should be rotated counterclockwise, with posterior pressure applied to expose the
peritoneal reflection. It is often helpful to rotate the operating table 20° to the patient's right so that the weight of the abdominal viscera facilitates their retraction. A plane is thus established between the spleen and pancreas and Gerota's fascia that can be extended to the aorta [see Figure 12b]. With this step, mobilization is complete, and the spleen can be repaired or removed without any need to struggle to achieve adequate exposure.

Splenectomy [see 5:25 Splenectomy] is the usual treatment for hilar injuries or a pulverized splenic parenchyma. It is also indicated for lesser splenic injuries in patients who have multiple abdominal injuries and a coagulopathy, and it is frequently necessary in patients in whom splenic salvage attempts have failed. Partial splenectomy is suitable for patients in whom only a portion of the spleen (usually the superior or inferior half) has been destroyed. Once the damaged portion has been removed, the same methods used to control hemorrhage from hepatic parenchyma can be used to control hemorrhage from splenic parenchyma [see Figure 13]. When horizontal mattress sutures are placed across a raw edge, gentle compression of the parenchyma by an assistant facilitates hemostasis; when the sutures are tied and compression is released, the spleen will expand slightly and tighten the sutures further. Drains are never used after completion of the repair or resection.

If splenectomy is performed, vaccines effective against the encapsulated bacteria are administered. The pneumococcal vaccine is routinely given, and vaccines effective against *H. influenzae* and *N. meningitidis* should also be given if available.

Injuries to the Diaphragm

In cases of blunt trauma to the diaphragm, the injury is on the left side 75% of the time, presumably because the liver diffuses some of the energy on the right side. With both blunt and penetrating injuries [see Table 1], the diagnosis is suggested by an abnormality of the diaphragmatic shadow on chest x-ray. Many of these abnormalities are subtle, particularly with penetrating injuries, and further diagnostic evaluation may be warranted. The typical injury from blunt trauma is a tear in the central tendon; often, the tear is quite large. Regardless of the cause, acute injuries are repaired through an abdominal incision. Because of the concave shape of the diaphragm and the overlying anterior ribs, anterior diaphragmatic injuries may be difficult to suture. Repair is greatly facilitated by using a long Allis clamp to grasp part of the injury and evert the diaphragm. Lacerations are repaired with continuous No. 1 monofilament nonabsorbable sutures. Occasionally, with large avulsions or gunshot wounds accompanied by extensive tissue loss, polypropylene mesh is required to bridge the defect.

The explosive growth of laparoscopic procedures has led to the application of this technology for both diagnostic and therapeutic purposes in trauma patients. In a number of patients with low anterior thoracic stab wounds who otherwise were not candidates for a laparotomy, small diaphragmatic lacerations have been identified and repaired with laparoscopy and stapling.

**Discussion**

Nonoperative Treatment of Blunt Hepatic and Splenic Injury

Only a few years ago, blunt and penetrating hepatic and splenic injuries were managed in a similar fashion on the basis of a positive diagnostic peritoneal lavage or the probability of peritoneal penetration: a laparotomy was performed, and the injured organs were identified and treated. Currently, although penetrating abdominal injuries are still treated in the same way, nearly all children and 50% to 80% of adults with blunt hepatic and splenic injuries are treated without laparotomy.95-68 This remarkable change was made possible by the development of the high-speed helical CT scanner, the replacement of diagnostic peritoneal lavage by ultrasonography, and the growth of interventional radiology.

The diagnosis of blunt abdominal trauma is suspected on the basis of the mechanism of injury and the presence of associated injuries (e.g., right or left lower rib fractures). Ultrasonographic examination of the abdomen may reveal a fluid stripe in Morrison’s pouch, the left upper quadrant, or the pelvis, which suggests a hemoperitoneum. This observation prompts a CT scan of the abdomen, which establishes the presence or absence of injuries to the liver or the spleen and, to some degree, serves as a means of grading the severity of organ injury. Patients may be observed either in the SICU or on the ward, depending on the apparent severity of the parenchymal injury on the CT scan, the presence and extent of any associated injuries, and the overall hemodynamic status.95,70

The primary requirement for nonoperative therapy is hemodynamic stability.63-72 To confirm stability, frequent assessment of vital signs and monitoring of the hematocrit are necessary. Continued hemorrhage occurs in 1% to 4% of patients.65,66,68-73 Hypotension may develop, usually within the first 24 hours after hepatic injury but sometimes several days later, especially when splenic injury is present.71,72 It is often an indication that operative intervention is necessary. A persistently falling hematocrit should be treated with PRBC transfusions. If the hematocrit con-
tines to fall after two or three units of PRBCs, embolization of the liver in the interventional radiology suite should be considered. Out of concern over the risk of delayed hemorrhage or other complications, follow-up CT scans have often been recommended; unfortunately, there is no consensus as to when or even whether they should be obtained. Given that patients with grade I or II hepatic or splenic injuries rarely show progression of the lesion or other complications on routine follow-up CT scans, it is reasonable to omit such scans if patients’ hematocrits remain stable and they are otherwise well. Patients with more extensive injuries often have a less predictable course, and CT scanning may be necessary to evaluate possible complications. Routine scanning before discharge, however, is unwarranted. On the other hand, patients who participate in vigorous or contact sports should have CT documentation of virtually complete healing before resuming those activities.

A more convenient and less expensive alternative to follow-up CT scanning is ultrasonographic monitoring of lesions. Ultrasonographic monitoring is particularly useful for following up splenic injuries; however, it may not be useful for following up hepatic injuries, because the technology currently available is incapable of reliably imaging the entire liver.

Other complications of nonoperative therapy for blunt hepatic and splenic injuries occur in 2% to 5% of patients; these include missed abdominal injuries, parenchymal infarction, infection, and bile leakage (a complication associated solely with hepatic injuries). Aseptic infarcts, infected hematomas, and bile collections are suspected on the basis of a clinical picture suggestive of infection and confirmed by CT-guided aspiration. Aseptic infarction usually does not necessitate operative intervention. Fluid collections are drained, with the method depending on the viscosity of the fluid: CT-guided drainage may be effective in treating thin collections, but operative intervention is required for thicker collections, those with solid components, and those for which percutaneous drainage was attempted without success. Extrahepatic bile collections should be treated with percutaneous drainage under CT guidance. Most biliary fistulas close spontaneously; endoscopic stent placement may hasten closure in recalcitrant cases.

Intrahepatic collections of blood and bile are managed expectantly. Complete absorption of large intrahepatic collections may take several months. If a collection becomes infected, CT-guided aspiration is performed and drainage obtained as described.

Missed enteric and retroperitoneal injuries are another cause of failed nonoperative treatment. Such injuries are present in 1% to 4% of patients in whom nonoperative treatment is attempted. High-quality images and expert interpretation minimize the number of missed injuries on CT scans but cannot eliminate them entirely. Therefore, patients must be watched carefully for the development of peritoneal irritation and other signs of intra-abdominal pathology.

References

35. Pougetti RS, Moore EE, Moore FA, et al: Balloon tamponade for bilobar transfusing
hepatic gunshot wounds. J Trauma 33:694, 1992

Acknowledgments

Figure 1 Tom Moore.
Figures 2, 7, and 9 Thom Graves.
Figure 3 Marcia Kammerer.
Figures 4 through 6, 8, and 10 through 13 Susan Brust, C.M.I.
Table 2 Information provided by Baxter International, Deerfield, Illinois.