Blunt Abdominal Trauma

16

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Learning Objectives

- Recognize that most solid organ injury following blunt trauma can be managed nonoperatively.
- Understand that hemodynamic stability is the primary determinant for nonoperative management.
- Recognize that the patient with abdominal solid organ injury necessitating laparotomy after blunt trauma is generally hemodynamically unstable.

16.1 Introduction

Mechanisms of blunt abdominal injury include fall, motor vehicle crash, motorcycle or bicycle crash, sporting mishap, and assault. Forces producing injury include compression, crush, rotational shear, deceleration, or sudden increase in pressure. Deceleration forces may tear organs or vascular pedicles. A sudden increase in luminal pressure can lead to perforation of a hollow viscus. Possible cavity hemorrhage or abdominal sepsis demands expedient diagnosis and treatment of intra-abdominal injuries to avoid preventable morbidity or death [1, 2].

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16.2 Clinical Evaluation

Knowledge of the mechanism of injury is essential to determine the likelihood of an intra-abdominal injury. The force involved and vector of injury (where the abdomen absorbs the force) dictate injury patterns. Importantly, physical examination of the abdomen following blunt force trauma is often unreliable. Frequent confounders that limit findings with physical examination include altered level of consciousness (substance use or traumatic brain injury), distracting pain, usually from associated orthopedic injuries, and spinal cord injury. Although adjunctive diagnostic testing is essential in the evaluation of blunt abdominal trauma, careful, repeated physical examination of the patient is critical for early diagnosis of intra-abdominal injury. Evaluation on primary survey may detect signs of hypoperfusion (obtundation, cool skin temperature, mottling, diminished pulse volume, or delayed capillary refill), which should prompt a rapid search for a source of blood loss. Blood in the peritoneum often does not produce peritoneal signs, and massive hemoperitoneum may be present without abdominal distension. On the other hand, evaluation of the abdomen may reveal

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distension or signs of peritoneal irritation (usually associated with hollow viscus injury). Clinical findings associated with intra-abdominal injury that require laparotomy include significant chest injury, elevated base deficit, complex pelvis fracture, and any episode of hypotension. If the patient is a restrained victim in a motor vehicle crash with a visible contusion on the abdomen from a lap belt (lap belt mark), or a lumbar vertebral body fracture (Chance fracture), an associated hollow viscus injury should be suspected.

16.3 Diagnostic Testing

Determine the hemodynamic status of the patient. Follow the history and trend in vital signs, rather than developing a management plan based on a single value. Adjunctive diagnostic testing in the setting of blunt force abdominal trauma depends largely on these data. In the hypotensive patient, or the patient who requires ongoing fluid infusions to achieve normal hemodynamics, rapid evaluation of the abdomen as a source of hemorrhage is accomplished using focused abdominal by sonography for trauma (FAST) or diagnostic peritoneal aspiration (DPA) while the patient is in the trauma resuscitation bay. In the hemodynamically normal patient without immediate need for operation, computed tomography (CT) is the investigation of choice (Fig. 16.1).

16.3.1 Focused Assessment by Sonography for Trauma

The FAST exam can identify free fluid in the abdominal cavity, which in the setting of blunt force trauma should be considered blood. FAST can be performed rapidly at bedside without the need for transportation outside the trauma bay. It is non-invasive, widely available, inexpensive, and may be repeated as often as necessary. However, sensitivity and specificity are generally low (60%–85%), and it is not accurate for the detection and anatomic characterization of solid

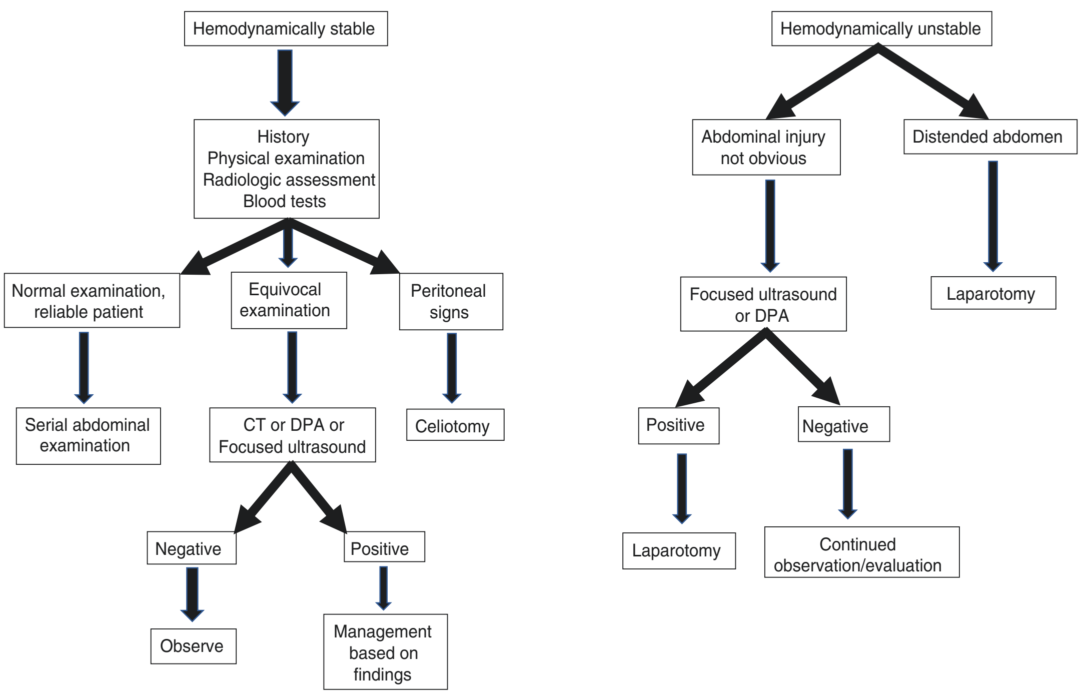

Fig. 16.1 Algorithm for the management of blunt abdominal trauma (From: Corcos A, Six C, Britt LD, Peitzman AB. Abdominal trauma. In Peitzman AB, Yealy DM, Fabian TC, Schwab CW, Guyette FX, Seamon MJ, Zuckerbraun BS, (eds). The Trauma Manual, fifth edition. Wolters-Kluwer, Philadelphia, 2020, page 426)

organ injury. FAST is most valuable when positive for free fluid in the hemodynamically unstable patient. In this setting, FAST quickly identifies the abdominal cavity as the source of hemorrhage, prompting rapid transfer to the operating room for exploratory laparotomy. On the other hand, with a false negative rate as high as 40%, a negative FAST does not exclude abdominal cavity hemorrhage. In this case, a more definitive diagnostic test, CT or DPA based on hemodynamic characteristics, should be considered with high energy physical trauma [3]. Other limitations to FAST include inability to distinguish fluids (i.e., ascites vs. succus entericus vs. blood), variability in examiner proficiency, requirement for specialized training and continuing competency, and difficulty in interpreting findings in the obese patient or the patient with extensive subcutaneous emphysema. Place a 3–5.0 MHz transducer in the subxiphoid region in the sagittal plane to view the pericardial space and set the machine gain. Sagittal views of Morison's pouch and the splenorenal recess are performed, followed by a pelvic transverse view. Free fluid appears anechoic (black) compared with the surrounding structures. The chest can also be assessed using the ultrasound.

16.3.2 Diagnostic Peritoneal Aspiration (DPA)

Surgeon-performed FAST has supplanted diagnostic peritoneal lavage (DPL) as a tool to determine the presence of hemoperitoneum after blunt force trauma. DPA, however, remains an important adjunctive test during the resuscitative phase of care. This is a simple and rapid, although invasive, technique to diagnose hemoperitoneum. A peritoneal dialysis catheter is introduced into the abdominal cavity through a small infraumbilical incision and connected to a 10 mL syringe for aspiration (supraumbilical with an associated pelvic fracture). The subcutaneous tissues are dissected bluntly along the umbilical stalk to the level of the fascia. With upward traction, a dialysis catheter with a trocar is introduced by puncture into the abdominal cavity. The catheter is directed into the pelvis. Any quantity of blood is considered positive for hemoperitoneum. Level III evidence reports sensitivity of 89% for DPA compared to 50% for FAST exam [3]. DPA should be performed when a FAST exam is negative, equivocal, or unreliable but high suspicion for abdominal cavity hemorrhage persists, or in the patient with persistently abnormal hemodynamics or transient response to resuscitation.

16.3.3 Computed Tomography (CT)

CT is an accurate diagnostic modality (92–98%) for intra-abdominal organ evaluation and should be obtained in any hemodynamically stable patient suspected of intra-abdominal injury. Hollow viscus, diaphragm, and pancreatic injuries are most likely to be missed by CT. CT is specific for solid organ injury, distinguishes intra-abdominal free fluid from blood, and identifies even small amounts of air in the peritoneum or retroperitoneum. For maximum specificity, CT should be obtained with intravenous (IV) contrast, imaging from the top of the diaphragm through the bony pelvis. Avoid omitting IV contrast because of an elevated creatine or glomerular filtration rate. Recent studies confirm that even in patients perceived to be at the highest risk for post-contrast acute kidney injury (AKI), administration of IV contrast is not an independent risk factor for AKI, dialysis, or mortality [4]. Limitations to CT include cost, exposure to radiation, need for transportation outside the trauma bay, and the need for specialized non-trauma team personnel.

16.4 Conduct of the Exploratory Laparotomy for Trauma

Because of refinements in diagnostic capabilities, the trauma laparotomy is now more selectively applied, reducing the frequency of nontherapeutic explorations. Indications for immediate exploratory laparotomy following blunt trauma are based on physical exam findings or clinical signs and symptoms appreciated during the primary or secondary survey including peritoneal irritation, hypotension with a distended abdomen, or positive FAST/DPA. Findings on CT scan obtained in the hemodynamically stable patient who requires operative repair should follow a similar approach with expeditious transportation to the operating room (OR) and initial exploration.

16.4.1 General Considerations and Setup

Once the decision is made to operate, rapidly transport the patient directly to the OR with appropriate airway support personnel, trauma team surgeons, and trauma team nursing staff in attendance. This is a direct transfer to the OR, not the preoperative holding area. If possible and practical, informed consent is obtained from the patient or a relative before laparotomy; the operation should proceed without delay in life-threatening circumstances. In the patient with high suspicion of a vascular injury or pelvic fracture, perform the laparotomy in a hybrid operating room. This allows immediate angiography, embolization, and endovascular techniques in the polytrauma patient. Adequate intravenous circulatory access and arterial lines for blood pressure transduction are placed as necessary in the OR. Do not delay control of cavitary bleeding with attempts at fluid resuscitation. The trauma patient who has been hypotensive should have femoral arterial access secured to facilitate later deployment of the REBOA (Resuscitative Endovascular Occlusion of the Aorta) catheter. Broad-spectrum antibiotic coverage to include gram-negative and anaerobic organisms is administered (an extended spectrum penicillin or a third-generation cephalosporin). Chest tubes placed during the resuscitative phase of care are placed to underwater seal during transport and to suction drainage on arrival in the OR; do not clamp the chest tubes. Collection canisters are positioned where readily visible so blood loss from the thoracic cavity can be monitored. Nasogastric or orogastric tubes and a bladder catheter are inserted prior to laparotomy. However, no procedure should be performed in such a way as to delay control of bleeding and contamination.

Transfer the patient to the operating table with appropriate cervical spine and thoracolumbar spine precautions. Patients immobilized on a rigid backboard, however, should be logrolled and remove the board before beginning the operation to prevent decubitus ulcers. Sequential compression devices are used for hemodynamically stable patients. Make a rapid infusion system and cell-saver system available in the trauma OR and primed for infusion of blood-bank products and cell-saved blood. Ensure that packed RBC units are in the OR and plasma and platelet products are available for any patient with active hemorrhage. In the exsanguinating patient, the massive transfusion protocol (MTP) should be activated to alert the on-site blood bank to the need for blood products. If the patient meets criteria for tranexamic acid (TXA) infusion or the initial bolus was given in the trauma bay or by pre-hospital transport, communicate this information to the anesthesia team so that the process can be initiated or continued. If time allows, shave the patient prior to the skin incision. The sterile preparation should include the entire anterolateral neck (sandbags may replace the anterior portion of the immobilization collar), entire chest and abdomen, both groins and thighs (Fig. 16.2).

16.4.2 Initial Priorities

The exploratory laparotomy for trauma is a structured operative procedure with two primary goals—stop bleeding and control gastrointestinal (GI) contamination. A generous midline incision is generally used. Adequate exposure is critical; self-retaining retractor systems and headlights are invaluable. Upon entry into the peritoneal cavity, control bleeding by scooping free blood and clots, rather than using a suction device. Next, rapidly pack all four quadrants with opened laparotomy pads, typically three to four per quadrant. With blunt injury, the most likely sources of bleeding are the liver, spleen, and mesentery.

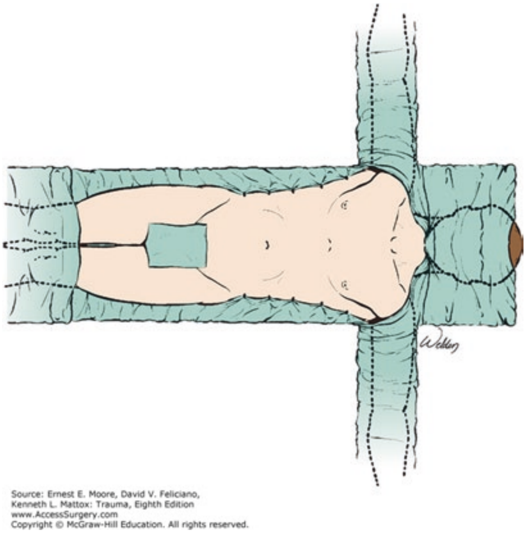

Fig. 16.2 Position and preparation for exploratory laparotomy of the trauma patient. (From: Salotto J, Jurkovich GJ. Trauma laparotomy. In Moore EE, Feliciano DV, Mattox KL, (eds) Trauma. eighth edition. McGraw-Hill, New York, 2017, page 524)

Pack the upper quadrants and quickly clamp actively bleeding mesenteric vessels. If this does not subdue active bleeding, the source of ongoing hemorrhage should be readily apparent and becomes the highest priority. For rapid contamination control, Babcock or Allis clamps can temporarily occlude bowel lacerations prior to suture repair or segmental resection using a bowel stapler. Once active bleeding is controlled and GI injury temporarily contained, step back and assess the patient's hemodynamic status, units of blood products infused, acid-base status, temperature, coagulation, obvious abdominal and known or suspected nonabdominal injuries. Based on this information, a decision is made whether to proceed with further systematic exploration and definitive repair of all injuries or to abbreviate the operation along guidelines that dictate damage control surgery (see Chap. 26).

16.4.3 Systematic Exploration

This stage of the operation involves a systematic evaluation of the entire abdominal cavity after hemorrhage and contamination have been definitively addressed. Start with the liver and spleen, as these solid organs are most often involved in blunt trauma. This is followed by each hemidiaphragm, the anterior stomach, and the omentum. Elevate the omentum and deliver the transverse colon to allow easy evisceration of the entire small bowel, facilitating hand-over-hand palpation and close inspection of the entire jejunum, ileum, and mesentery from the ligament of Treitz to the cecum. The cecum and ascending colon, transverse colon and its mesentery, descending colon, sigmoid colon and its mesentery, as well as the intraperitoneal portion of the rectum are then thoroughly inspected and palpated. Return the small bowel and omentum to the abdominal cavity and enter the lesser sac by dividing the gastro-omental attachment. This allows inspection of the pancreas, proximal duodenum, and posterior stomach. Perform a Kocher maneuver to visualize the entire duodenum if evidence of injury.

Next, retroperitoneal hematomas are assessed for the need to explore. The retroperitoneum, for the purposes of traumatic injuries and exploration, is divided into three zones or regions (Fig. 16.3). In the central region (**zone 1**), resides the abdominal aorta, celiac axis, mesenteric vasculature, vena cava, proximal renal vasculature, portions of the duodenum, and pancreas. The lateral retroperitoneum (**zone 2**) encompasses the distal renal vasculature, kidneys, adrenals, urinary collecting system, proximal ureters, and portions of the ascending and descending colon. The pelvic retroperitoneum (**zone 3**) contains the distal ureters, iliac vasculature, bladder, extraperitoneal rectum, and bony pelvis. Management of retroperitoneal hematomas is dictated by mechanism of injury and zone. All penetrating injuries of the retroperitoneum are explored. Retroperitoneal hematomas resulting from blunt force trauma are approached on a more selective basis. All zone 1 hematomas should be explored since injury to vasculature or organs in this region will generally require surgical repair. When a large or expanding zone 1 retroperitoneal hematoma is found, place a REBOA catheter prior to entering the hematoma. For zone 2 retroperitoneal hematomas resulting from blunt trauma,

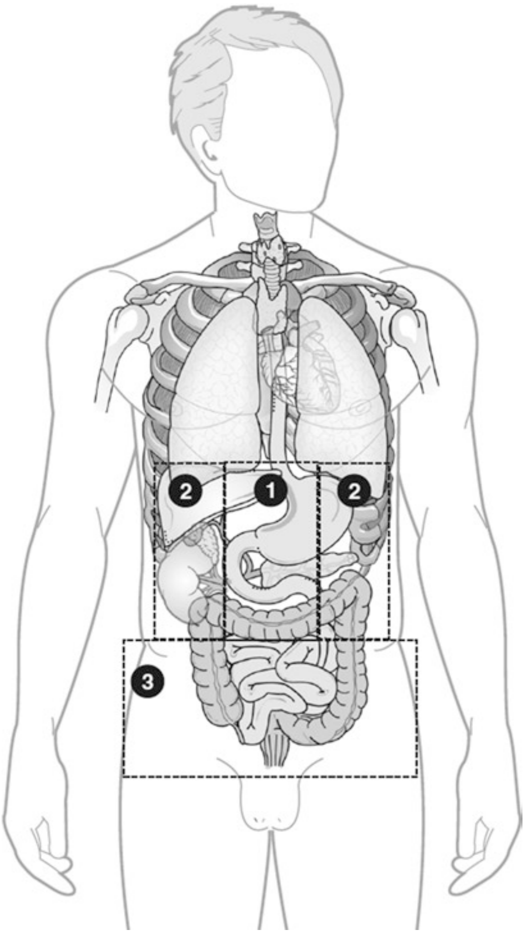

Fig. 16.3 Zones of the retroperitoneum (From: Corcos A, Six C, Britt LD, Peitzman AB. Abdominal trauma. In Peitzman AB, Yealy DM, Fabian TC, Schwab CW, Guyette FX, Seamon MJ, Zuckerbraun BS, (eds). The Trauma Manual, fifth edition. Wolters-Kluwer, Philadelphia, 2020, page 460)

only pulsatile or expanding hematomas undergo exploration. Gross extravasation of urine, identified pre-operatively or intra-operatively (see Chap. 22), also necessitates exploration. Most renal organ injuries, however, can be managed nonoperatively, and preserving Gerota's fascia is of value if no vascular injury is suspected. Lateral hematomas along the peritoneal reflection of the ascending or descending colon should be universally investigated as they may disclose a posterior colon injury. With blunt trauma, exploration of a zone 3 pelvic hematoma generally is avoided. This finding most likely represents venous or bony bleeding associated with a pelvic bone fracture; application of an external compression device, with or without extraperitoneal pelvic packing, would be the preferred intervention (see Chaps. 9 and 19). The exception is the zone 3 hematoma from blunt injury that is pulsatile or visibly expanding suggesting a vascular injury. In this situation, deployment of the REBOA catheter may be life-saving prior to angiography and embolization or direct control of a vascular injury.

16.5 Specific Organ Injury

16.5.1 Diaphragm

Diaphragm injury from blunt force trauma most often result from motor vehicle collisions and falls. Rupture occurs with a sudden and severe increase in the intra-abdominal pressure, the left side being more vulnerable than the right. Chest radiograph is the usual initial screening modality. Its diagnostic accuracy is poor but may be improved by the placement of a radiopaque nasogastric tube if the stomach has already undergone herniation into the thoracic space. CT has a low sensitivity (63%) but high specificity (100%) for blunt injury rupture. Thus, it is helpful when positive (i.e., evidence of visceral herniation), but negative or equivocal findings on CT, when suspicion is high, are best treated as false negatives. Diagnostic laparoscopy has emerged as the modality of choice for acute diaphragmatic injury.

In the acute setting, diaphragmatic injuries are best repaired primarily with a heavy, nonabsorbable suture. At times, large lateral defects require reattachment of the diaphragm to another rib. Rarely, blunt force ruptures result in significant tissue destruction, necessitating repair with a synthetic mesh. In the event of gross contamination, endogenous tissue, such as latissimus dorsi, tensor fascia lata, or omentum, should be used instead of mesh for the definitive repair. Biologic tissue grafts offer questionable durability and are best avoided. Outcomes for diaphragmatic injuries treated early are good with mortality and morbidity related to associated injuries.

16.5.2 Hollow Viscus

Gastric injury secondary to blunt trauma is rare. Shear injury from seat belts or direct blows to the epigastrium are the common causes. Gastric lacerations should be repaired primarily after debridement of non-viable edges, in either a single layer with non-absorbable suture or with a standard two-layer closure. Primary repairs seldom compromise the gastric lumen, and major resections are rarely required.

Small bowel wounds are the most common hollow viscus injury [5]. As with other hollow viscus injuries, all small bowel perforations are treated operatively. The majority of small bowel injuries resulting from blunt force are diagnosed directly or indirectly by CT in the absence of peritonitis on physical exam. With modern multidetector CT scanners, accuracy in diagnosing bowel and mesenteric injuries has improved significantly. Extraluminal gas is detectable in only half of patients with hollow viscus injury; images require scrutiny for indirect findings such as bowel wall edema, free fluid, or mesenteric stranding. Diagnostic laparoscopy is a valuable adjunct to CT in these situations. In addition to a complete perforation, surgically important injuries include seromuscular tears, active mesenteric bleeding, or mesenteric injury associated with bowel ischemia.

If small bowel viability is in question at laparotomy, a segmental resection should be performed. Isolated small bowel enterotomies that are viable can be closed primarily in a single layer provided the closure does not narrow the lumen by 50% or more. Non-viable edges may require debridement prior to closure. Multiple contiguous small bowel enterotomies or an intestinal injury on the mesenteric border with associated mesenteric hematoma are best managed with segmental resection and primary anastomosis. The operative goal is to reestablish intestinal continuity without substantial narrowing of the intestinal lumen, along with closure of any associated mesenteric defeat. The application of a non-crushing bowel clamp can minimize ongoing contamination while the repair is performed. Either hand-sewn or stapled anastomosis is acceptable. In the immediate postoperative period, gastric decompression is prudent.

Blunt colon injury occurs in less than 1% of patients with blunt force trauma. It can occur with sudden deceleration shear forces, such as seat belts or direct blows, that result in bowel wall contusions or serosal tears with associated mesenteric hematomas. These carry a significant risk of ischemic bowel necrosis. The right colon is more commonly injured. CT offers high sensitivity and specificity, whether IV contrast only or with "triple-contrast" (oral, rectal, and intravenous). Current evidence-based recommendations support primary repair of colonic injury in two layers for most non-destructive colon wounds and segmental resection with primary anastomosis for more destructive wounds. Resection with fecal diversion should be reserved for destructive wounds in patients with multiple comorbidities, severe associated injuries, hemorrhage requiring transfusion of six or more units of blood, or damage control laparotomy.

Blunt force rectal injury is usually associated with pelvic fracture. Digital rectal exam (DRE) can reveal blood and should be routine in patients with a pelvic fracture. Proctosigmoidoscopy is recommended whenever there is a high suspicion for rectal injury and absolutely indicated when DRE is positive. Intraperitoneal rectal injuries are managed along similar guidelines as colon. Extraperitoneal rectal injuries are usually managed with proximal fecal diversion to avoid pelvic sepsis [6]. Presacral drainage through an incision in the perineum, midway between the anus and coccyx, should be considered, for destructive wounds within the lower third of the rectum.

Primary closure of the skin incision with colon injuries is associated with a high incidence of wound infections. These can result in fascial dehiscence or necrotizing fasciitis. Leave the skin wound open with colon injuries complicated by fecal contamination to reduce wound infection and fascial dehiscence. Some report good results with delayed primary closure at post-op day four as an alternative to healing by secondary intention. Inadequate empiric antibiotic coverage is an independent risk factor for abdominal sepsis in patients with colon injuries. Coverage should target both aerobic and anaerobic organisms, i.e., a second-generation cephalosporin or cefazolin plus metronidazole, with even broader coverage at institutions that have identified significant resistance.

16.5.3 Duodenum and Pancreas

With a common blood supply, there is a high incidence of concomitant injuries to the pancreas and the duodenum. As they are relatively well protected in the central retroperitoneum, associated intraperitoneal organ injuries are the rule (>3 on average). Blunt force injury to these intimately associated organs occurs most often from a crushing force to the upper abdomen that compresses them between the rigid spine and an external object (e.g., steering wheel, handlebar, or blunt weapon). Preoperative diagnosis is difficult, and management is challenging. Concomitant major vascular injury (aorta, portal vein, or inferior vena cava) is associated with 12% of blunt force pancreatic injuries and is the leading cause of death. Early death from pancreatic or duodenal injury is from this associated vascular injury. Morbidity and late mortality are from the duodenal or pancreatic injury, particularly if diagnosis and treatment are delayed.

16.5.3.1 Duodenum

The anatomy of the duodenum is complex. It extends for 25 cm from the pylorus to the ligament of Treitz and is commonly divided anatomically into 4 portions. **D1** (superior) lies within the peritoneum, while **D2** (descending) enters the retroperitoneum and contains the orifices of the bile and pancreatic ducts. **D3** (transverse) travels medially over the IVC and aorta from the ampulla of Vater to the superior mesenteric vessels, which traverse anteriorly. **D4** (ascending) begins at the mesenteric vessels ending at the jejunum to the left of the lumbar vertebral column. Bile, pancreatic secretions, and gastric secretions flow through the duodenum at rates of one to two liters per day each, making injuries and leaks difficult to control.

Suspicion for duodenal injury must be based on the mechanism of injury. Findings on physical exam are nonspecific and subtle. Retroperitoneal air or obliteration of the right psoas margin may be seen on radiograph or CT. Periduodenal hematomas on CT should prompt an oral contrast study, either by CT or plain radiographs (UGI series), done first with water-soluble contrast followed by barium if negative. The diagnosis of duodenal injury is often made at laparotomy for associated injuries. Adequate exposure of the duodenum is vital to avoid missed injury. As described above, entering the lesser sac and performing a wide Kocher maneuver are essential. Bile staining, air in the retroperitoneum, or central retroperitoneal hematoma mandate a thorough exploration.

In children, *intramural duodenal hematoma* is a common compression injury that can occur in isolation (classically from a bicycle handlebar, although 50% are related to abuse and assault). These present as a “coiled spring” or “stack of coins” appearance on an UGI series or CT. This occurs less often in adults as an isolated injury. Nonoperative treatment with nasogastric tube (NGT) decompression of the stomach and IV alimentation is often successful, but operative decompression should be considered if the obstruction has not resolved after 2–3 weeks. Follow-up gastrografin images should be obtained weekly until outlet obstruction resolves. In adults, intramural hematomas found at trauma laparotomy need careful consideration. Incising the serosa to drain the hematoma is an option; avoid converting a contained injury into a full-thickness laceration. An alternative is to place a feeding jejunostomy tube for enteral nutrition and plan for prolonged NGT decompression.

Full-thickness duodenal perforations require operative repair with many options depending on injury severity. Simple lacerations or perforations less than 50% of the circumference can be closed primarily with one or two layers in a transverse fashion that avoids luminal narrowing. More extensive perforations will require complex repairs, duodenal decompression with or without pyloric exclusion, and wide drainage. When primary closure would compromise luminal integrity, jejunal or omental patching is effective and safe. Complete transections require repair by end-to-end primary anastomosis following debridement. Achieving this without tension can be a challenge and is facilitated by de-rotation of D3 and D4 [7]. With injuries where anastomosis is hindered by proximity to the superior mesenteric vessels, side-to-side duodenojejunostomy at D2 with a closed end distally is the best option. Roux-en-Y techniques are required when end-to-end anastomoses cannot be accomplished without tension. As a general approach, the simplest repair of the duodenal injury is usually best.

The duodenum should be decompressed after repair of an injury. Nasogastric decompression, at times with the tube advanced into the proximal duodenum, is generally effective. Further techniques of duodenal decompression remain controversial. An additional lateral tube duodenostomy is not supported. Decompression via retrograde jejunostomy drainage has been advocated. Pyloric exclusion with oversew of the pylorus from within the stomach and creation of a gastrojejunostomy as diversion has been utilized. Recent data, however, question the need for pyloric exclusion in the management of most duodenal injuries [8]. Truncal vagotomy to prevent marginal ulceration is not indicated as the pylorus will open within a few weeks. Finally, an antegrade feeding jejunostomy can provide enteral nutrition which is superior to IV alimentation. All anastomoses and complex repairs also require closed suction tube drainage to ensure that any postoperative leaks become controlled fistulae.

Mortality rates with duodenal injuries are less than 10% when treated early but increase to as high as 40% when the diagnosis is delayed more than 24 h. Complications occur in 40% of patients with anastomotic dehiscence and resultant sepsis accounting for nearly half of all deaths.

16.5.3.2 Pancreas

The pancreas is almost entirely retroperitoneal with the head lying to the right of midline at the level of the second lumbar vertebra. The body of the pancreas crosses the midline with the tail ending in the hilum of the spleen at the level of L1. The superior mesenteric vessels lie posteriorly in a groove at the neck of the pancreas. The main pancreatic duct of Wirsung typically runs the length of the pancreas with an accessory duct (Santorini) branching from it within the parenchyma, emptying separately into the duodenum. Twenty percent of individuals have an accessory duct that drains into the main pancreatic duct, and 8% have it as the sole drainage of the pancreas into the duodenum.

In hemodynamically stable patients, the diagnosis of blunt force pancreatic injury is made primarily by CT with a sensitivity of only 60–70% [9]. Integrity of the main pancreatic duct is the most important diagnostic question. Injury to the main duct is the principle determinant of morbidity; delay in diagnosis is associated with an increase in complications [10]. A high index of suspicion for ductal disruption, based on mechanism of injury or indirect signs on CT, is of paramount importance. Physical exam is often unreliable, and signs and symptoms may be subtle or only apparent several hours after injury. Hyperamylasemia is neither sensitive nor specific on initial presentation even in the presence of complete pancreatic duct transection.

As with duodenum injury, associated injuries generally prompt surgical exploration; a thorough inspection of the lesser sac will reveal the pancreatic injury. Close visual inspection and bimanual palpation of the pancreas are essential. This approach requires dividing the gastrocolic ligament, opening the retroperitoneum widely, and performing a full Kocher maneuver. This can be accomplished by careful mobilization of the spleen and tail of the pancreas out of its retroperitoneal location as a single unit, based on their shared blood supply. Intraoperative pancreatography performed through the ampulla of Vater (via a duodenotomy) or through the distal main pancreatic duct (via amputation of the tail of the pancreas) has been described to assess the integrity of the main pancreatic duct; we do not advocate this approach. Bimanual palpation of the substance of the gland is preferred to distinguish transection from contusion without the morbidity of unnecessary duodenotomy or splenectomy.

In the patient without immediate indication for laparotomy, repeat CT during a course of observation is often warranted, particularly when symptoms persist, or hyperamylasemia develops. Endoscopic retrograde cholangiopancreatography (ERCP) is the most sensitive technique short of operative exploration to diagnose pancreatic ductal injury; it may be useful in patients with equivocal CT findings who otherwise meet criteria for observation. Clearly, the logistics of obtaining ERCP during the resuscitative phase of care limits its utility. ERCP and stent placement are utilized far more commonly for treatment of complications rather than in diagnosis of pancreatic injury. The role of magnetic resonance cholangiopancreatography (MRCP) in trauma has not been fully delineated.

Nonoperative management of documented pancreatic injury remains controversial; this approach is more common in children. Suspected pancreatic grade 3–5 injuries should be surgically explored. The status of the pancreatic duct, the location of the injury (proximal vs distal), and the patient's overall clinical status dictate selection of treatment options that adhere to the following important principles: control of hemorrhage, debridement of devitalized tissue, maximum preservation of viable pancreatic parenchymal, wide drainage of secretions with closed suction drains, and strategies for enteric feeding to optimize postoperative nutrition including feeding jejunostomy if necessary. As a rule, restrictive management protocols, such as external drainage and limited pancreatectomy, result in lower mortality and morbidity than more complex procedures that involve extensive resections and pancreatoenteric anastomoses.

At laparotomy, pancreatic contusions and capsular lacerations without injury to the main duct (AAST grade I or II) are best managed by debridement of devitalized tissue and wide external drainage alone [11]. Do not suture the injured capsule or parenchyma as this may result in a pseudocyst. The goal in this scenario is to ensure that any pancreatic fistula that develops be well controlled as these typically close without further intervention. Pancreatic injuries that include the main duct are addressed according to location. Most blunt force main duct transections occur in the body of the gland to the left of the SMA (AAST grade III) and are managed effectively by distal pancreatectomy, preferably with splenic salvage if the patient's hemodynamic status allows. Pancreatic transection to the right of the SMA or massive disruption of the pancreatic head (AAST grade IV and V) is more complicated to manage and more common with penetrating injury. There are no universally recommended approaches. Options include wide drainage of the area to promote a controlled fistula or complex procedures such as on-lay pancreaticojejunostomy or pancreaticoduodenectomy. Simple drainage alone is safest as a controlled pancreatic fistula is easier to deal with and less morbid than the complications arising from more aggressive approaches. Severe injury to both the head of the pancreas and the duodenum may require pancreaticoduodenectomy; however, this is rare. Indications are limited to resections required to control exsanguinating hemorrhage from adjacent vasculature or resection that essentially completes the damage resulting from the severity of the injury. When required, a staged approach is best with the reconstruction phase delayed for 24–48 hours to facilitate creation of multiple anastomoses (Fig. 16.4).

Pancreatic fistula and abscess are the most common postoperative complications (up to 25%). A pancreatic fistula is defined as 100 mL per day output for greater than 2 weeks (minor) or greater than 1 month (major). Most will resolve spontaneously with less than 7% requiring further operative intervention. Pancreatic duct injury and associated colon injuries are independent predictors of abscess formation, most of which can be drained percutaneously. Postoperative pancreatitis complicates 5% of cases. Pancreatic pseudocysts occur in roughly 3% of cases and often related to missed or inadequately treated ductal injuries. Postoperative hemorrhage occurs in 10%, ideally managed with angioembolization.

Overall mortality ranges from 12% to 32% with pancreatic related mortality ranging from 1.6% to 3%. Early deaths are most often from associated vascular injuries while late deaths are often due to delayed diagnosis or treatment of the pancreatic injury.

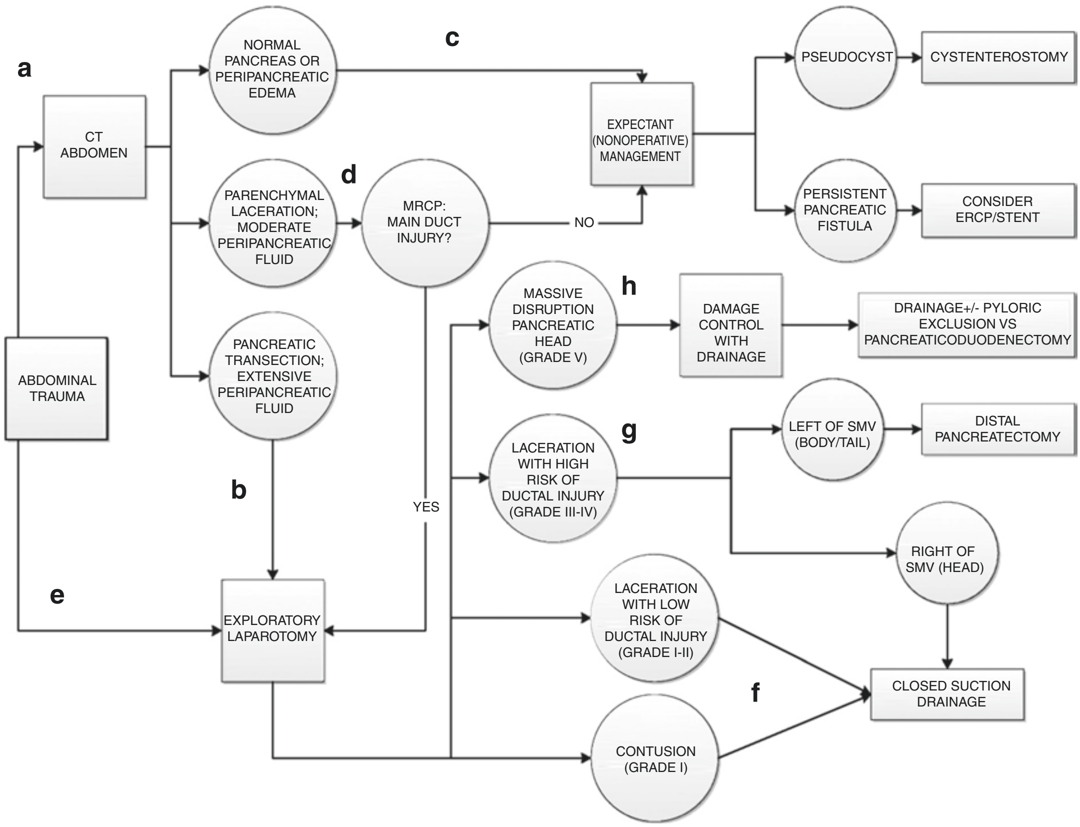

Fig. 16.4 Western Trauma Association algorithm for the management of pancreatic injury (From Biffl WL, Moore EE. Croce M, et al. Western Trauma Association critical decisions in trauma: management of pancreatic injuries. J Trauma Acute Care Surg 2013: 75: 941–946)

16.5.4 Spleen

Blunt splenic injury typically occurs from compression or deceleration forces. The spleen is bounded by the stomach, left hemidiaphragm, left kidney, chest wall, and colonic flexure. The peritoneal attachments define the spleen's relationship to these adjacent organs: gastrosplenic ligament, splenorenal ligament, splenophrenic ligament, splenocolic ligament, and pancreaticosplenic attachments. The spleen receives 5% of cardiac output, primarily through the splenic artery, which courses superior and anterior to the splenic vein in a groove along the superior edge of the pancreas. Along its course, it supplies portions of the stomach and pancreas. The splenic artery bifurcates as an end-artery into superior and inferior polar arteries.

In the hemodynamically unstable patient with blunt injury, ultrasound (or DPA) obtained during the primary survey may reveal hemoperitoneum, and the diagnosis of splenic injury is made subsequently at surgical exploration. In stable patients, the physical exam is insensitive and nonspecific. CT scan with IV contrast of the abdomen should be obtained to define any injuries and allow delineation by AAST grade. On occasion, when hemoperitoneum irritates the diaphragm, the patient may complain of referred pain to the left shoulder (Kehr's sign). Twenty-five percent of patients with left lower rib fractures [9–12] will have an associated splenic injury; this finding on chest radiograph should serve as a marker.

Management of splenic injury depends primarily on the hemodynamic status of the patient at presentation (Fig. 16.5). The hemodynami-

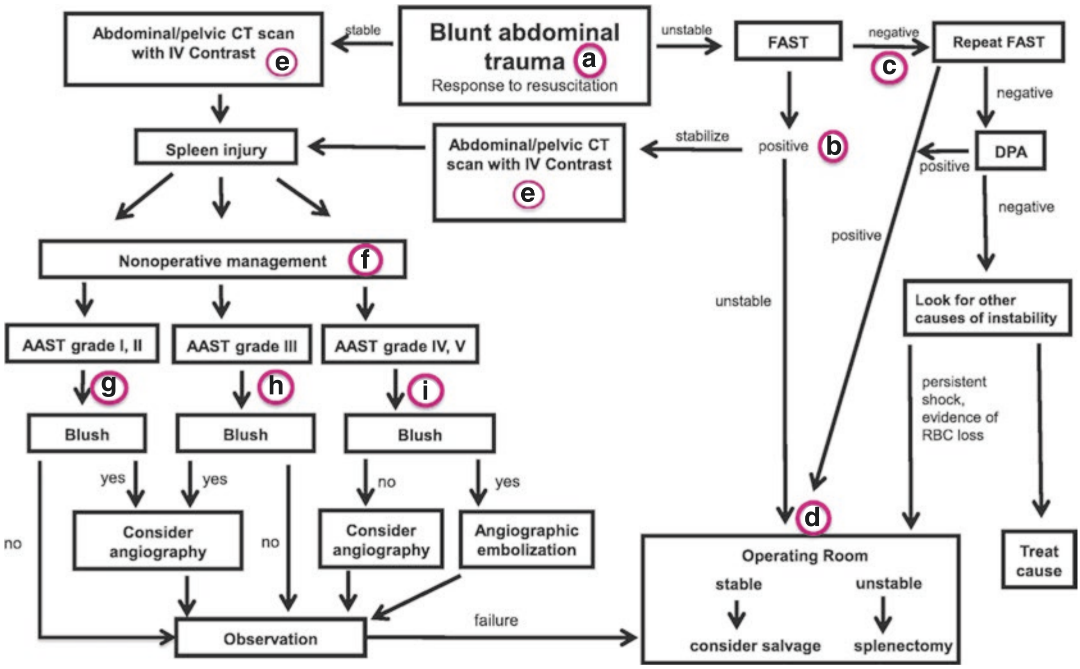

Fig. 16.5 Western Trauma Association algorithm for the management of adult blunt splenic injury (From: Rowell SE, Biffl WL, Brasel K, et al. Western Trauma Association Critical Decisions in Trauma: Management of adult blunt splenic trauma –2016 updates. J Trauma Acute Care Surg 2017; 82: 787–793)

cally unstable patient with splenic injury requires operative intervention, usually resulting in splenectomy [12].

The ubiquity of CT and an understanding of the importance of splenic function have resulted in the preservation of 60–80% of injured spleens in hemodynamically stable adult patients. In children, nonoperative management (NOM) is successful in over 90% of splenic injury. Children who present in shock, however, still warrant operative management.

Failure of NOM correlates most significantly with grade of injury. According to the multi-institutional study by the Eastern Association for the Surgery of Trauma (EAST), 61.5% of adult patients with blunt splenic injury were initially observed. Of these, 11% failed observation with 61% of failures occurring within 24 h and 90% within 72 h [13, 14]. Failure of NOM by grade was as follows: grade I–5%, grade II–10%, grade III–20%, grade IV–33%, and grade V–75%. In this study, NOM failure also correlated with the quantity of hemoperitoneum. Longitudinal studies from the National Trauma Data Bank also report failure rates of 40% to 50% for grades IV and V. Other factors which increase the likelihood of failure of observation are vascular blush or large pseudoaneurysm on CT, large hemoperitoneum, and high injury severity score (ISS).

The patient with splenic injury treated nonoperatively should be observed in a monitored unit with immediate access to CT, blood and blood components, a surgeon, and an OR. Changes in physical examination, hemodynamic stability, or ongoing blood or fluid requirements indicate the need for laparotomy. Serial hemoglobin levels should be monitored until stable, and the patient should be placed at bed rest during this interval. A follow-up CT scan at 48 h for medium and high grade injuries is recommended based on a high yield of pseudoaneurysm formation, which may require further intervention. Follow-up imaging in children has not shown clear benefits. Splenic artery embolization (SAE) has been shown to significantly improve splenic salvage rates in adults when used in cases of active extravasation or pseudoaneurysm on CT and empirically in grade IV and V injuries, even in the absence of active extravasation.

At laparotomy for splenectomy, mobilize the spleen entirely to visualize the injury. Start with the operator's nondominant hand providing medial traction to the spleen to facilitate division of the avascular splenorenal and splenophrenic ligament; avoid injury to the splenic capsule (Fig. 16.6). As the organ is further freed from its peritoneal attachments, stay in the plane posterior to the pancreas. At this point, the hilum of the spleen can be controlled with manual compression. The gastrosplenic ligament and short gastric vessels are then divided by suture ligation near the spleen to avoid injury to or late necrosis of the gastric wall. The spleen can now be delivered into the operative field to allow surgical control of the splenic vessels. Vascular staplers, suture ligation, or ligation between clamps are all acceptable. Drainage of the splenic fossa is associated with an increased incidence of subphrenic abscess and should be avoided, except when concern exists for an injury to the tail of the pancreas.

Non-bleeding injuries encountered during laparotomy for associated injuries may occasionally be treated with splenic salvage techniques (splenorrhaphy). Grade I injuries typically require no treatment or simple topical hemostatic agents with or without electrocautery. Grade II or III non-bleeding injuries can be suture repaired with Teflon pledgets or wrapped in an absorbable mesh. Grade IV and V injuries, even if not actively bleeding at exploration, are best treated with splenectomy. When considering splenorrhaphy, remember that one-third of the splenic mass must be functional to maintain immunocompetence. With the emergence and evolution of nonoperative management protocols, splenorrhaphy has become rare.

Rates of re-bleeding following both splenectomy and splenorrhaphy are low. Postoperative pulmonary complications are common. Left subphrenic abscess occurs in less than 10% of postoperative patients; more common with concomitant bowel injury. Thrombocytosis occurs commonly following splenectomy and usually requires no treatment. Platelet counts typically peak by postoperative day 10 and take several weeks to abate. Complications of SAE include re-bleeding (requiring splenectomy or repeat embolization), splenic or pancreatic necrosis, iatrogenic vascular injury, hematoma at the catheter insertion site, and contrast reactions/nephropathy.

Overwhelming post splenectomy infection (OPSI), a rapidly fatal septicemia following splenectomy, is a greater risk to children than adults with an overall incidence of less than 0.5% per year. The most common organisms are the encapsulated bacteria: *Haemophilus influenza, meningococcus, Streptococcus pneumoniae, as well as Staphylococcus aureus, and Escherichia coli*. Following splenectomy, vaccines for pneumococcus (Pneumovax), H. influenzae, and meningococcus should be administered. The timing of injection is controversial with some authors recommending waiting 3–4 weeks after surgery as the patient may be too immunosuppressed in the immediate post-injury period to benefit from vaccination. However, most centers vaccinate patients in the early postoperative period before the patient may be lost to follow-up. Patients who have undergone splenectomy should have a clear understanding of the concerns regarding OPSI. They are typically recommended to start penicillin therapy with the development of any mild infection.

16.5.5 Liver

The liver is the most commonly injured intra-abdominal organ with overall mortality rates approaching 10%. The patients with blunt injury to the liver generally present in one of two conditions. The vast majority of these patients are hemodynamically stable or fluid responsive and will undergo CT and planned nonoperative management. However, a small portion of patients with blunt hepatic injury present with significant hypotension (due to high grade liver or juxtahepatic venous injury); prompt laparotomy is required. Thus, major injuries in unstable patients will be diagnosed at laparotomy. The decision-

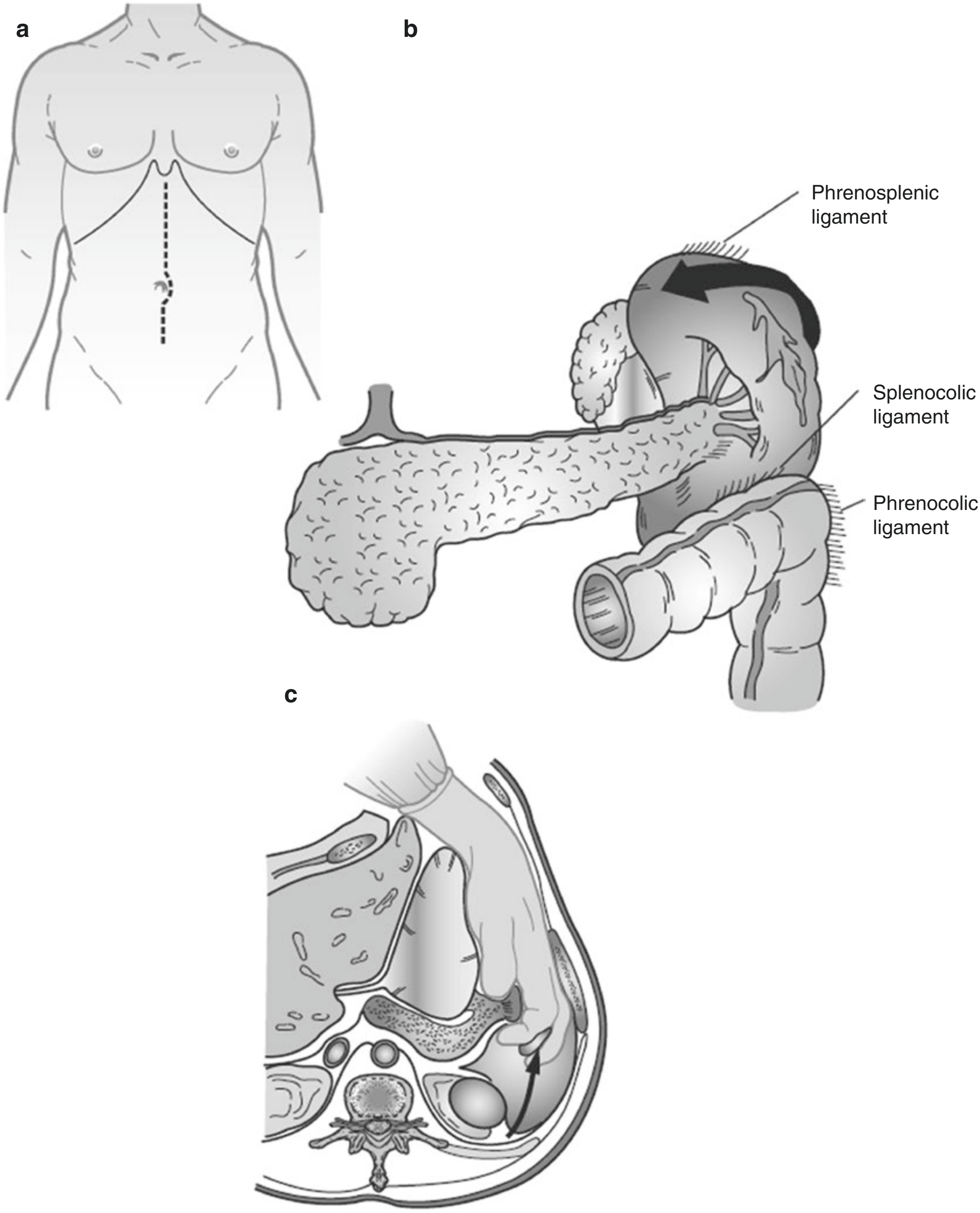

Fig. 16.6 Laparotomy for splenectomy. A. Midline incision B. Phrenosplenic, splenocolic, and phrenocolic ligaments c. Mobilization of the spleen (From: Corcos A, Six C, Britt LD, Peitzman AB. Abdominal trauma. In Peitzman AB, Yealy DM, Fabian TC, Schwab CW, Guyette FX, Seamon MJ, Zuckerbraun BS, (eds). The Trauma Manual, fifth edition. Wolters-Kluwer, Philadelphia, 2020, page 451)

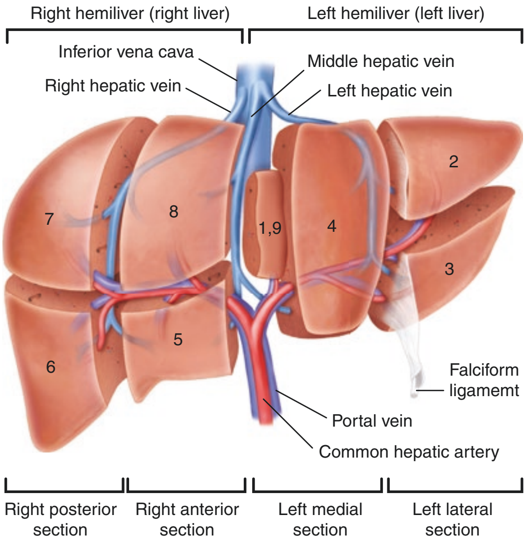

Fig. 16.7 Hepatic segmental and vascular anatomy (From: Corcos A, Six C, Britt LD, Peitzman AB. Abdominal trauma. In Peitzman AB, Yealy DM, Fabian TC, Schwab CW, Guyette FX, Seamon MJ, Zuckerbraun BS, (eds). The Trauma Manual, fifth edition. Wolters-Kluwer, Philadelphia, 2020, page 453)

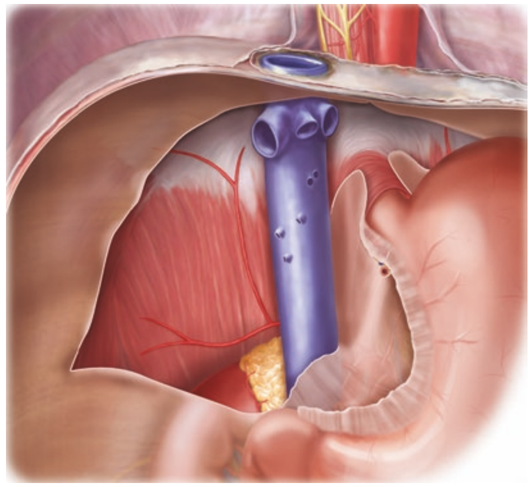

Fig. 16.8 Anatomy of the retrohepatic vena cava. Note the 3 major hepatic veins and the multiple short hepatic veins. (From: Corcos A, Six C, Britt LD, Peitzman AB. Abdominal trauma. In Peitzman AB, Yealy DM, Fabian TC, Schwab CW, Guyette FX, Seamon MJ, Zuckerbraun BS, (eds). The Trauma Manual, fifth edition. Wolters-Kluwer, Philadelphia, 2020, page 453)

tree with blunt hepatic injury is based on hemodynamic status. If the patient is stable enough for CT, they will generally be successfully managed nonoperatively, irrespective of the grade of hepatic injury. However, 10–25% will require an intervention: angioembolization for bleeding or pseudoaneurysm; ERCP and stent for bile leak; or percutaneous drain for abscess or biloma [15–17].

An understanding of hepatic anatomy is essential when approaching these injuries at surgery for hemorrhage control. A sagittal plane running from the IVC to the gallbladder fossa separates the right and left lobes (Cantlie's line). The segmental anatomy of the liver is shown in Fig. 16.7. The portal triad, containing the portal vein, hepatic artery, and common bile duct, is encased within a tough extension of Glisson's capsule and runs centrally within the segments of the liver. Right and left hepatic arteries usually arise from the common hepatic artery. Anomalies are frequent and include the right hepatic artery originating from the SMA and the left hepatic artery originating from the left gastric artery. The major hepatic veins run between segments of the liver and are not protected by an investing sheath, making them particularly vulnerable to injuries that require operative control of hemorrhage. (Fig. 16.8) The right and left hepatic veins drain directly into the IVC just below the hiatus and have short extrahepatic courses. The middle hepatic vein also drains directly to the IVC in 15% of patients but usually joins the left hepatic vein within the liver parenchyma. The retrohepatic IVC is approximately 10 cm in length and has multiple "short" hepatic veins that enter the cava directly. These average 5–7 in number and may be as large as 1 cm in diameter. This area is difficult to access, and injury here is difficult to control carrying a high mortality [18–20].

Adequate mobilization of the liver requires division of the ligamentous attachments. The falciform ligament divides the left lateral segments (II and III) from the medial segment of the left lobe (IV). The coronary ligaments attach the liver to the diaphragm by anterior and posterior leaflets and are avascular, as are their lateral extensions, the left and right triangular ligaments. Division of these ligamentous attachments exposes the “bare” area of the liver which is without a capsule and contains the short hepatic veins and cava. Injury to the diaphragm, phrenic veins, and hepatic veins must be avoided when mobilizing the liver.

As mentioned, the majority of patients with blunt injury to the liver who do not have other intra-abdominal injuries requiring laparotomy can be treated with NOM regardless of AAST grade. (Fig. 16.9) In addition, the presence of hemoperitoneum on CT scan does not mandate laparotomy. Grade 4 and 5 injuries are more likely to develop a complication which requires an intervention; bleeding, bile leak, abscess, biloma, or hemobilia. The criteria for NOM of blunt liver injury include the following: hemodynamic stability, absence of peritoneal signs, lack of continued need for transfusion for the hepatic injury, and bleeding amenable to angioembolization.

There is little support for frequent hemoglobin sampling, bed rest, or prolonged intensive care unit monitoring in NOM of blunt liver injury. Similarly, reimaging the asymptomatic patient by CT scan is not necessary. Early repeat imaging is reserved for changes in clinical status (abdominal pain, fever, abnormal LFTs). Evolution of injury on CT, hemodynamic instability, or continued blood product requirement should prompt immediate laparotomy or angiographic intervention.

If the patient is hemodynamically unstable or has indications for laparotomy, operative management is required. The operative approach to major hepatic injury is systematic and logical along the following management principles: manual compression to resuscitate, division of ligamentous attachments for adequate exposure, packing that reconstructs hepatic anatomy, inflow occlusion (Pringle maneuver) if necessary for

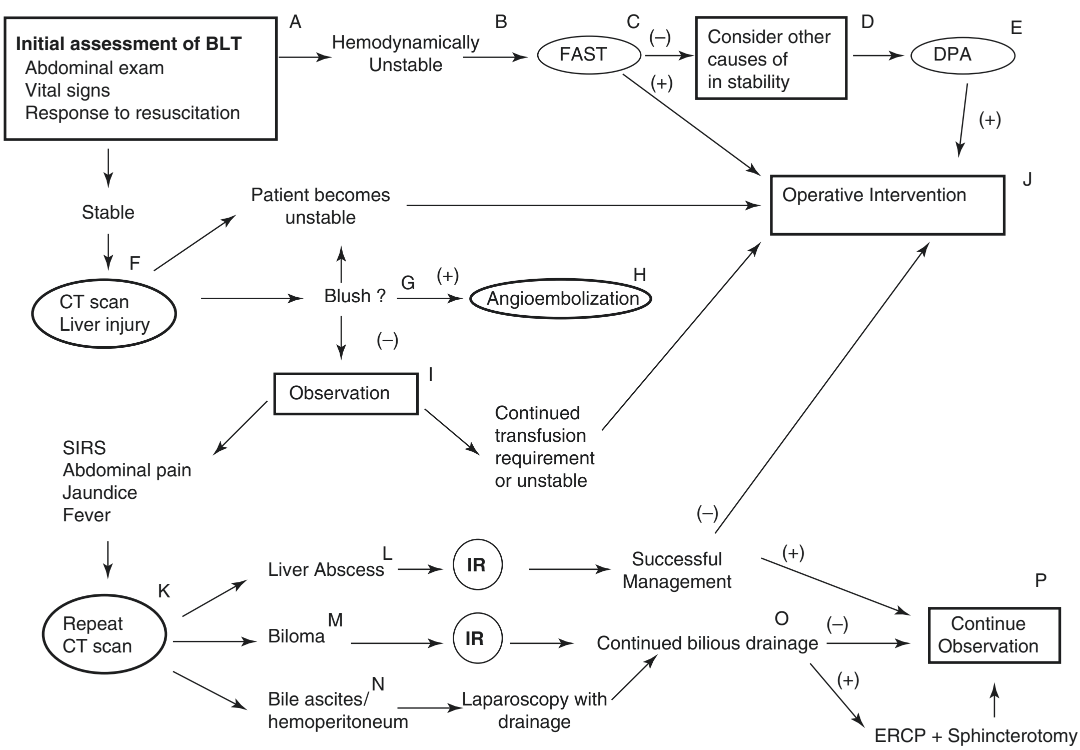

Fig. 16.9 Western Trauma Association algorithm for the nonoperative management of blunt hepatic injury. (From: Kozar, R.A., Moore, F.A., Moore, E.E., et al., Western Trauma Association critical decisions in trauma: nonoperative management of adult blunt hepatic trauma. J Trauma, 2009. 67 [6]: p. 1144–8)

ongoing bleeding, individual vessel ligation when possible, mobilization of the liver to midline when necessary, and adherence to damage control principles (Fig. 16.10).

In the case of failed NOM when an approach to the liver is the recognized goal, a bilateral subcostal incision will offer excellent exposure. When already at laparotomy via the typical long midline incision for trauma, a transverse extension laterally to the right will facilitate optimal exposure to the entire right upper quadrant. On rare occasion, an extension of the midline incision to sternotomy is needed for complex suprahepatic IVC injury. Use of a self-retaining retractor to lift the upper edges of the wound cephalad and anteriorly is critical. Thoracotomy is rarely useful. Low grade, non-bleeding injuries encountered at laparotomy for other injuries can be managed with simple techniques (electrocautery, simple suture, or topical hemostatic agents).

Complex liver injuries can produce exsanguinating hemorrhage; the only essential goal at the first operation is to stop the bleeding. Ultimate operative goals include controlling bile leak,

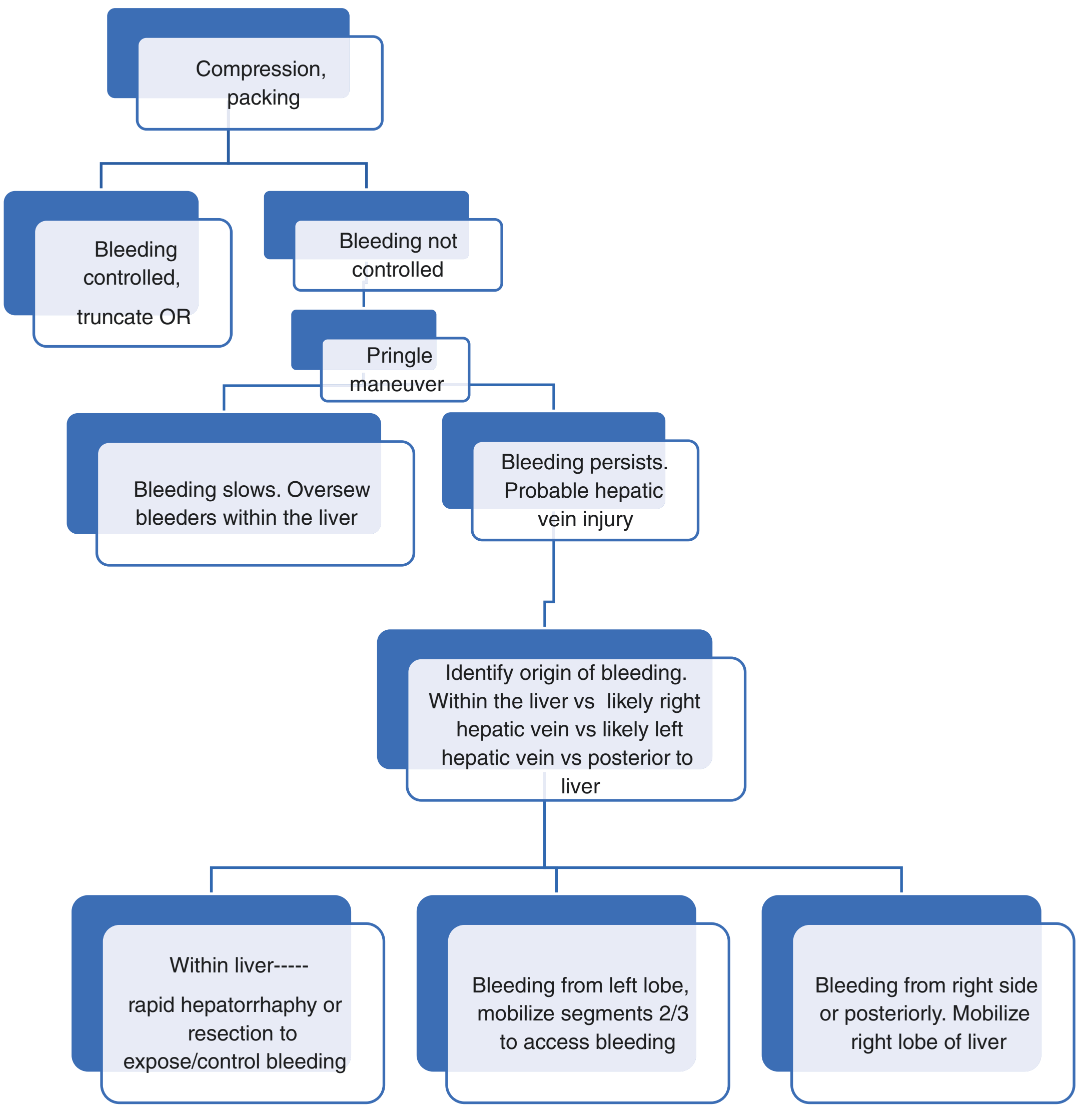

Fig. 16.10 Flowchart for the operative management of major hepatic injury

debridement of non-viable liver, and drainage, but these operations are most frequently staged.

To begin, temporary tamponade of the bleeding by two-handed manual compression of the entire liver (**push**) immediately after entering the abdomen allows anesthesiology to resuscitate the patient and the surgeon to formulate an operative plan. Next, **pack** the liver to control hemorrhage as blood flow to the liver is largely a low-pressure system. Packing the liver, however, must be performed correctly. Restore normal anatomy by compressing the left lobe back into the right lobe while simultaneously directing the liver posteriorly to tamponade any posterior venous bleeding. Stuffing packs into the liver laceration will distract the injury and exacerbate bleeding. If packing successfully stops the bleeding in a hemodynamically unstable patient, truncate the first operation and plan return to the operating room in 36–48 hours to remove the packs and reassess.

If packing does not control the bleeding, occlude the portal triad within an atraumatic clamp (**Pringle** maneuver); this is both diagnostic and therapeutic. If the Pringle maneuver substantially slows the bleeding, the source is either hepatic artery or portal vein branches; rapid hemorrhage control within the laceration can be accomplished with hepatorrhaphy and individual vessel ligation. Mass parenchymal suturing can lead to tissue necrosis and is discouraged. Incise Glisson's capsule with electrocautery; approach the injury within the liver by the finger fracture technique. With gentle traction on the liver edges, isolate injured vessels and bile ducts between right-angled or tonsil clamps and ligate with 2–0 silk sutures, or even more rapidly with vascular staplers. Intermittent application of the Pringle maneuver (10–15 min on, 5 min off) produces less hepatic ischemia than continuous clamping. Packing the liver defect with viable omentum is not recommended as a reliable hemostatic technique.

If bleeding persists with the porta hepatis occluded, the source is injury to the IVC, a major hepatic vein or the short hepatic veins. If the origin is within the laceration of the liver, a direct approach is preferred. If the bleeding is extrahepatic, the origin can usually be located to either over the dome of the liver, suggesting a middle or left hepatic vein injury, or posterior to the liver, suggesting an IVC, right hepatic vein, or short hepatic vein injury. This determination guides which lobe to mobilize. Remember, the entire liver can be made a midline structure with mobilization.

Liver resections for traumatic injuries are typically non-anatomic and can be performed rapidly with vascular staplers. Often, these are completion resections along injury planes. On occasion, this may be required to expose hepatic vein injuries that can then be ligated or repaired expeditiously. The Aquamantys Bipolar Sealer device is an invaluable adjunct to the Argon Beam Coagulator in managing exposed liver parenchyma following resection or individual vessel ligation.

With major hepatic resection, an intraoperative cholangiogram via the cystic duct (necessitating cholecystectomy) will help define biliary anatomy. Injection of saline through the cystic duct will help identified bile leaks that require ligation to avoid postoperative complications. These maneuvers are often performed at planned returns to the operating room following hemorrhage control rather than the index laparotomy. Closed suction drainage of grade III to V injuries is preferred. Drains are not necessary for grade I and II injuries if bleeding and bile leakage are controlled.

Hepatic vascular isolation with occlusion of the suprahepatic and infrahepatic vena cava, as well as application of the Pringle maneuver, may be required for major retrohepatic venous injuries. Complex retrohepatic vascular injury may require repair in an avascular field on venovenous bypass with total hepatic vascular isolation. Thoracotomy or atrial–caval shunting is rarely helpful. Survival depends on prompt recognition, adequate exposure, and rapid access to a bypass circuit.

Mortality correlates with degree of injury. Although overall mortality for liver injury is 10%, mortality rates for high grade liver injury and retrohepatic caval injury remain well over 50% at most centers. Intrahepatic or perihepatic abscess or biloma occurs in up to 40% of patients and can usually be managed with percutaneous drainage. Meticulous control of bleeding, ligation of bile ducts, adequate debridement, and closed suction drainage are essential to avoid abscess formation. Biliary fistula (>50 mL/day for more than 2 weeks) usually resolves nonoperatively if external drainage of the leak is adequate and distal obstruction is not present. With a high output bile leak (>300 mL/day), further evaluation with a radionucleotide scan, a fistulogram, ERCP, or a transhepatic cholangiogram may be necessary. Major ductal injury can be stented to facilitate healing of the injury or as a guide if operative repair is required. Endoscopic sphincterotomy or trans-ampullary stenting may facilitate resolution of the biliary leak. Hemobilia is a rare complication that may occur days or weeks after injury. The classic presentation is right upper quadrant pain, jaundice, and hemorrhage with only one-third of patients presenting with all three. Treatment is angioembolization.

16.6 Conclusion

Blunt abdominal injury often occurs in the polytrauma patient. As physical examination is unreliable in their diagnosis, adjunctive techniques are vital; FAST, CT, and DPA. Hypotensive patients with blunt abdominal injury require prompt hemorrhage control and at times, invoking damage control approaches.

Key Concepts

- Blunt abdominal injury most commonly injures solid organs.
- The majority of solid organ injury is low grade and can be managed nonoperatively. High grade solid organ injury tends to produce hypotension on presentation and operative decision-making is difficult and technically challenging.
- Blunt hollow viscus injury is less common and difficult to diagnose clinically.
- Adjunctive diagnostic techniques are important.

Take Home Messages

- Understand injury patterns to suspect blunt abdominal injuries.
- Physical exam is insensitive in the diagnosis of blunt abdominal injury.
- 85% of blunt injuries to the liver and over 65% of splenic injuries can be managed nonoperatively.
- The high grade solid organ injuries produce active bleeding and generally require urgent operation. Damage control is useful in this setting.

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