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Critical concepts in abdominal injury

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Trauma is the leading cause of death between the ages of 1 and 44 years. In all age groups, it is surpassed only by cancer and atherosclerosis in mortality [1]. The evaluation and treatment of abdominal injuries are critical components in the management of severely injured trauma patients. Because missed intra-abdominal injuries are a frequent cause of preventable trauma deaths, a high index of suspicion is warranted.

Multiple factors, including the mechanism of injury, the body region injured, the patient's hemodynamic and neurologic status, associated injuries, and institutional resources influence the diagnostic approach and the outcome of abdominal injures.

Mechanism of injury

Blunt trauma

The etiology of blunt abdominal trauma (BAT) is dependent on the environment of the receiving institution. The most common cause of BAT in metropolitan trauma centers is the motor vehicle collision (MVC), responsible for 45% to 50% of BATs. Assaults, falls, automobile–pedestrian accidents and work-related injuries are also common [2]. Abdominal injuries in blunt trauma result from compression, crushing, shearing, or deceleration mechanisms.

Fortunately, the incidence of BAT requiring celiotomy is only 6%. The most frequently injured organs are the spleen (40% to 55%), the liver (35% to 45%), and the retroperitoneum (15%) [1].

Penetrating trauma

Gunshot wounds are the most common cause (64%) of penetrating abdominal trauma, followed by stab wounds (31%) and shotgun wounds (5%) [2]. Injury

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patterns differ depending on the weapon. Stab wounds are generally less destructive and have a lower degree of morbidity and mortality than gunshot wounds and shotgun blasts. The most commonly injured organs are the liver (40%), small bowel (30%), diaphragm (20%), and colon (15%) [1]. Gunshot wounds and other projectiles have a higher degree of energy and produce fragmentation and cavitation, resulting in greater morbidity [3–5]. These mechanisms result in multiple intra-abdominal injuries of the small bowel (50%), colon (40%), liver (30%), and abdominal vascular structures (25%) [1]. For this reason, exploratory celiotomy traditionally has been warranted for gunshot wounds between the nipple line and the inguinal crease.

Diagnostic modalities

Physical examination

Blunt trauma

Although the physical examination is the first step in evaluating the need for exploratory celiotomy, it has questionable validity in BAT [6,7]. The initial examination is often unreliable when the effects of alcohol, illicit drugs, analgesics or narcotics, or a diminished level of consciousness are present. The initial abdominal examination results in a 16% false-positive rate, a 20% false-negative rate, a positive predictive value of 29% to 48%, and a negative predictive value of 50% to 74% in determining the need for celiotomy [8–12].

Penetrating trauma

The physical examination is a more reliable indicator for celiotomy in penetrating trauma. In a prospective study, Quiroz et al identified two thirds of patients requiring celiotomies on initial physical examination. The remaining patients who required celiotomy developed physical findings within 10 hours of injury [13].

Local wound exploration

In the trauma patient with a stab wound, local wound exploration is a valuable diagnostic aid. Its utility is dependent on the wound's mechanism and location. Stab wounds to the anterior abdomen (anterior costal margins to inguinal creases, between the anterior axillary lines) are a clear indication for local wound exploration, because many do not penetrate the peritoneum. Exploration requires aseptic technique and local anesthesia. The wound is enlarged as necessary so that the posterior fascia may be evaluated. If penetration occurs or is inconclusive, the wound is considered intraperitoneal [14,15]. These wounds must be evaluated further by diagnostic peritoneal lavage (DPL) or celiotomy.

The thoracoabdominal region is defined as the fourth intercostal space anteriorly and seventh intercostal space posteriorly to the inferior costal margins. Stab wounds in this area should not be explored for fear of inducing a tension pneumothorax. Diagnostic laparoscopy, thoracoscopy, or exploratory celiotomy may evaluate this injury pattern better. Exploration of flank and back wounds is more difficult, less reliable, and thus not indicated [16]. Triple contrast computed tomography (CT), using intravenous, oral, and rectal contrast, is more diagnostic for these wounds. It better enables the evaluation of the retroperitoneal structures.

Radiography

Blunt trauma

The chest radiograph is useful in the evaluation of BAT for several reasons. First, it identifies the presence of low rib fractures. This should heighten the examiner's suspicion for abdominal injuries and mandate further evaluation with an abdomen and pelvis CT. The chest film also assists in the diagnosis of diaphragmatic injuries. In such instances, the admission chest radiograph is abnormal in 85% of cases and diagnostic in 27% of cases [17]. The pelvis roentgenogram is diagnostic of pelvic fractures. Similar to low rib fractures, pelvic fractures should raise the possibility of intra-abdominal injuries, and thus warrant further evaluation with an abdominal and pelvic CT scan.

Penetrating trauma

In penetrating injuries, the chest radiograph identifies the presence of a hemothorax, a pneumothorax, and possibly a diaphragmatic injury. Although plain abdominal radiography adds little to the evaluation of BAT, in penetrating trauma it allows one to account for bullets, shrapnel, and foreign bodies. This determination becomes important intraoperatively. If all foreign bodies are not accounted for, one must consider the possibility that it is intraluminal or intravascular. Intravascular foreign bodies are a potential source of emboli, and thus all intraperitoneal foreign bodies should be accounted for at exploration.

Focused assessment with sonography for trauma

The focused assessment with sonography for trauma (FAST) examination has gained acceptance in the evaluation of abdominal trauma. Its portability, speed, noninvasiveness, and reproducibility make it an ideal diagnostic study. It is not without limitations, however. The primary disadvantage is its dependency on free intraperitoneal fluid for a positive study. Thus, hollow visceral and retroperitoneal injuries are not detected reliably by the FAST exam [18–24].

For this and other reasons, recent studies have questioned its reliability in the evaluation of BAT. Stengel et al performed a meta-analysis of 30 prospective trials evaluating ultrasonography for BAT. They concluded that the FAST exam has an unacceptably low sensitivity for the detection of intraperitoneal fluid and organ injuries. They recommend that additional diagnostic studies be undertaken in patients with clinically suspected BAT regardless of the FAST results [25].

Diagnostic peritoneal lavage

Blunt trauma

Root et al introduced the DPL in 1965 as a rapid, accurate, and inexpensive diagnostic test for the detection of intraperitoneal hemorrhage following abdominal trauma [26]. Disadvantages include the DPL's invasiveness, risk of complications over noninvasive diagnostic measures, inability to detect retroperitoneal injuries, high rate of nontherapeutic laparotomies, and low specificity.

The criteria for a positive DPL in BAT are listed in Box 1 [26]. In the hemodynamically unstable patient, a positive DPL indicates the need for an immediate celiotomy. In the hemodynamically stable patient, however, the DPL criteria are too sensitive and nonspecific. As such, a positive DPL based on aspiration of gross blood or red blood cell (RBC) count does not mandate emergency celiotomy in this patient population [9,27–31]. An abdomen and pelvis CT scan will increase the specificity for surgical injury.

Penetrating trauma

The use of DPL in stab wounds is more complicated. Following local wound exploration, the DPL indices considered positive require modification. The RBC threshold indicating the need for celiotomy is lowered to 10,000/mm^3 or 1000/mm^3, but the lower the threshold, the higher the false-positive rate [16,32,33]. Using a higher threshold will increase the number of missed injuries. The remaining DPL criteria are unchanged.

Computed tomography

Blunt trauma

The abdomen and pelvis CT is the mainstay of diagnosis for abdominal injury in the hemodynamically stable patient. Sensitivity rates between 92% and 97.6% and specificity rates as high as 98.7% can be anticipated [34,35]. The CT provides useful information as to specific organ injuries, and it is superior in diagnosing retroperitoneal and pelvic injuries. The CT scan is imperfect in identifying hollow visceral injuries. If suspected, the DPL may be a useful adjunct [36,37].

Box 1. Criteria for a positive DPL in BAT

- 10 mL of gross blood
- $\geq$ 100,000 RBC/mm^3
- $\geq$ 500 white blood cells (WBC)/mm^3
- Food particles
- Gram's stain positive

Penetrating trauma

CT has a limited role in the evaluation of penetrating abdominal trauma. Its main drawback is its lack of sensitivity in diagnosing mesenteric, hollow visceral, and diaphragmatic injuries, all of which are common in penetrating trauma [13]. In evaluating penetrating injuries to the flank and back, the triple contrast abdomen and pelvis CT is greater than 97% accurate [38–41].

Laparoscopy

Blunt trauma

The utility of diagnostic laparoscopy in BAT is a developing field. When performed in carefully selected hemodynamically stable patients, laparoscopy is safe and technically feasible. Chol et al reported reduced negative and nontherapeutic laparotomy rates in this identified population [42].

Penetrating trauma

Diagnostic laparoscopy for the evaluation of penetrating trauma is more defined. In thoracoabdominal stab wounds, laparoscopy may aid in the diagnosis of diaphragmatic and other intra-abdominal injuries, thus avoiding nontherapeutic laparotomies [42–44]. Patients with stab wounds to the anterior abdomen or with uncertain peritoneal penetration are also candidates for diagnostic laparoscopy. Gunshot wounds to the anterior abdomen with questionable tangential trajectory likewise may be assessed. Based on their experience in Memphis, Tennessee, Fabian et al concluded that diagnostic laparoscopy is a safe, efficacious means of evaluating patients with equivocal peritoneal penetration [45].

Specific injuries

Diaphragm

Early recognition of diaphragmatic trauma is critical, since the mortality of an undiagnosed injury and subsequent bowel strangulation is approximately 30% [46]. Postmortem examinations reveal an equal prevalence between the right and left sides, despite the fact that most seen clinically are left-sided [46].

Unfortunately, diagnostic modalities are insufficient. Chest radiography is abnormal in 85% of cases, yet diagnostic in only 27% of cases (Fig. 1) [17]. For those nondiagnostic cases, further evaluation is warranted by DPL, laparoscopy, thoracoscopy, or exploratory celiotomy. When DPL is used, 1000 RBC/mm^3 is indication for exploratory surgery. Despite this lower RBC criterion, DPL may fail to detect isolated diaphragmatic stab wounds [46]. In this injury pattern, laparoscopy (as previously stated) or thoracoscopy should be considered. The ability of laparoscopy to evaluate for concomitant intra-abdominal injuries makes it superior in the author's opinion.

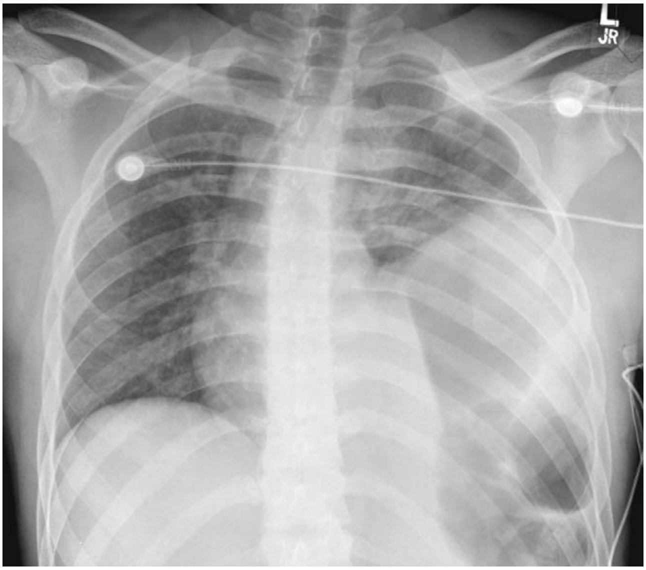

Fig. 1. Chest radiograph following a motor vehicle collision revealing a left diaphragmatic rupture.

Open or laparascopic therapeutic interventions may be performed. Most injuries, particularly penetrating, may be repaired primarily. The defect is approximated with interrupted horizontal mattress or figure-of-eight polypropylene sutures. A tube thoracostomy should be performed. If primary repair cannot be achieved with minimal tension, diaphragmatic transposition or synthetic mesh may be required.

Liver and spleen

Nonoperative management

Nonoperative management of blunt hepatic or splenic injuries is the treatment of choice in hemodynamically stable patients. High success rates are obtained independent of the injury severity based on CT scan, or the degree of hemoperitoneum [46–48]. Advantages of nonoperative management include the avoidance of a nontherapeutic celiotomy and its inherent complications, reduced transfusion requirements, and fewer intra-abdominal complications [46,48–50]. The increased risk of missed associated intra-abdominal injuries with nonoperative management has not been substantiated in the literature [51,52].

Abdominal CT is the most sensitive and specific study in identifying and assessing the injury severity to the liver or spleen (Fig. 2) [53,54]. The presence of a contrast blush on CT or ongoing hemorrhage is indication for angiography and embolization in this patient population [55,56].

Management guidelines include serial vital signs, physical examinations and laboratory values. Worsening of any of these may be indication for operative

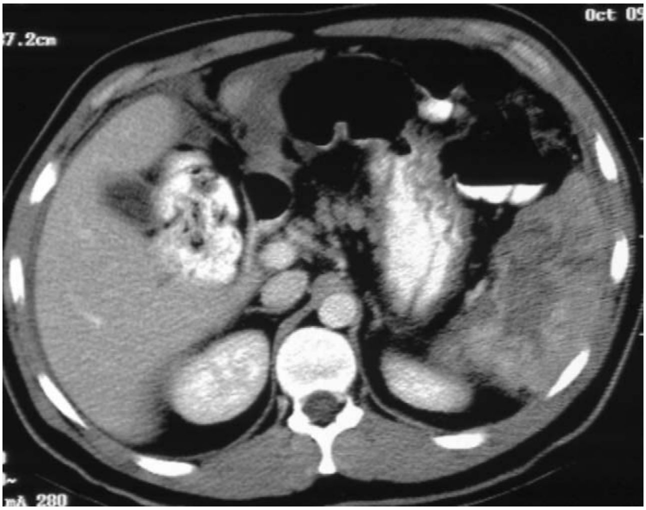

Fig. 2. CT scan of the abdomen following a motor vehicle collision, revealing a splenic injury. Patient was managed nonoperatively.

intervention. Mandatory bed rest or activity restrictions and serial CT scans have been refuted in the literature [48,53,57,58]. Resumption of normal activity is dependent on the extent and severity of the injury.

Operative management

Liver. Regardless of the mechanism of injury, the key principles in operative trauma are exposure and hemostasis. These are especially true in liver trauma. Following adequate mobilization of the liver, simple lacerations may be managed by direct pressure, electrocautery, argon beam coagulation, and topical hemostatic agents [46]. Finger fracture techniques with direct ligation of bleeding vessels are also useful.

Obtaining hemostasis is much more difficult in severe injuries. If the aforementioned techniques fail, compression of the portal triad, the Pringle maneuver, should be performed. This will control ongoing hemorrhage from the portal venous and hepatic arterial systems. If the Pringle maneuver is effective, the laceration may be approached with finger fractionation and direct ligation of the bleeding vessels. Once hemostasis is obtained, the laceration is best tamponaded with a vascularized omental flap. The use of deep hepatic sutures should be abandoned [46].

If the Pringle maneuver is ineffective, hepatic venous or retrohepatic inferior vena caval injuries should be suspected. In these instances, obtaining vascular control is challenging. Total hepatic exclusion or atriocaval shunts are options, neither of which should be undertaken lightly. Damage control techniques should receive heavy consideration in the face of such injuries [46]. This involves abdominal packing and temporary abdominal closure.

The use of postoperative angiography and embolization is helpful. In patients with active arterial extravasation, differing methods of embolization may control the source of hemorrhage. Hepatic resection is reserved for subsequent operations, at which time debridement of nonviable liver may be performed.

Spleen. The basic tenets of exposure and hemostasis are also applicable to splenic trauma. The ability to mobilize the spleen into the wound is critical (Fig. 3). This, in conjunction with the patient's physiologic status, enables the surgeon to decide on pursuing splenorrhaphy or splenectomy. If selected, splenorrhaphy techniques include electrocautery, argon beam coagulator, topical hemostatic agents, compressive mesh. and partial splenectomy [59].

Pancreas

The pancreas, by virtue of its protected retroperitoneal location, is injured relatively uncommonly. Penetrating trauma accounts for 70% to 80% of injuries, and mortality rates exceed 30% [60]. Although protective, this location makes the diagnosis and treatment of pancreatic injuries complex. Despite the liberal use of CT scans, 84% of pancreatic injuries are diagnosed intra-operatively [61]. For this reason, a high index of suspicion is critical in the management of potential pancreatic trauma.

Pancreatic duct status and injury location are important determinants in the management of pancreatic injuries. Proximal injuries are to the right of the mesenteric vessels, while distal injuries are to the left. Patton et al developed a management algorithm based on these factors (Fig. 4) [61]. Proximal injuries with or without duct involvement should be managed by closed suction drainage only.

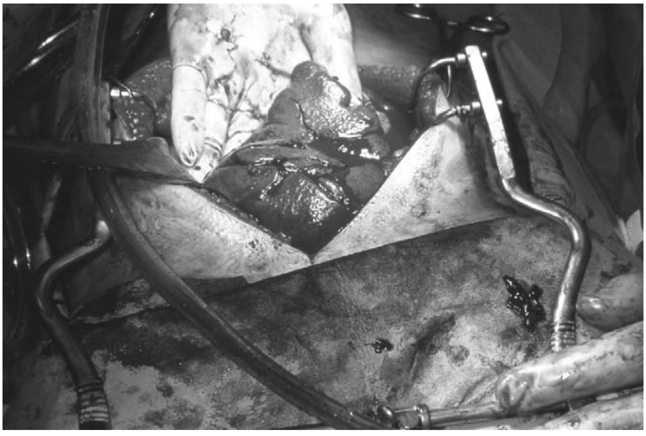

Fig. 3. The ability to mobilize the spleen into the wound is critical in the operative management of splenic trauma. Adequate exposure allows the surgeon to choose between splenorrhaphy and splenectomy.

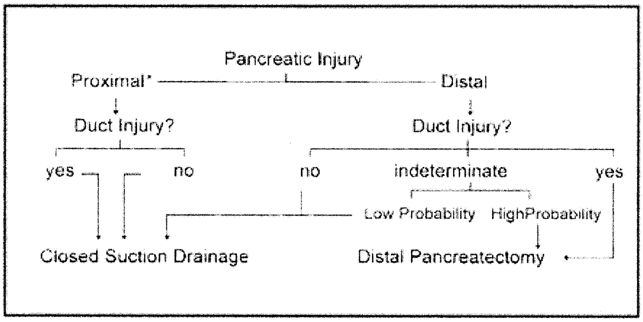

Fig. 4. Management algorithm for pancreatic injuries. Note that rare devitalizing, destructive injuries may require pancreaticoduodenectomy. (*From* Patton Jr JH, Lyden SP, Croce MA, Pritchard FE, Minard G, Kudsk KA, et al. Pancreatic trauma: a simplified management guideline. J Trauma 1997;43(2):234–41; with permission).

Similarly, distal injuries without duct disruption should be treated with closed suction drainage. Distal pancreatic trauma with duct involvement should undergo distal pancreatectomy and closed suction drainage [61]. In this study, pancreatic fistula formation was the most common morbidity, at 15%. Despite this frequency, all fistulas closed within 3 months [61].

Duodenum

Like the pancreas, the duodenum is injured infrequently, with most injuries coming from penetrating trauma. Morbidity and mortality rates associated with duodenal trauma are 60% and 15% respectively [62]. These are most commonly the result of associated injuries [63]. The primary determinant of outcome related to the duodenal injury itself is failure of repair [64]. For this reason, multiple therapeutic techniques have been developed depending on the severity of the injury [62,63].

Seventy percent to 80% of duodenal injuries are simple lacerations without significant surrounding tissue injury. These often may be repaired with conventional two-layered anastomotic techniques [65]. If the injury is severe, or the quality of repair is questionable, techniques to secure the repair are used. Duodenal decompression with tube duodenostomy or antegrade or retrograde intubation of the duodenum is advocated by many [65–67]. After 2 to 3 weeks, the tube generally may be removed safely [65].

Duodenal diverticulization is of historic note. Pyloric exclusion achieves the same effect in a less permanent and more expeditious manner [68]. This procedure isolates the duodenal repair with suture occlusion of the pylorus and a diverting gastrojejunostomy. Pyloric patency is present in 94% of patients at 3 weeks. Of concern is the risk of marginal ulceration at the gastrojejunostomy site [69,70]. Pancreaticoduodenectomy is a procedure of last resort, usually in nonreconstructable pancreatic or biliary duct trauma. The mortality in these cases is 33% [62]. In such instances, damage control surgery may be a better option.

Intramural duodenal hematomas are diagnosed most frequently by CT scan. If so, they are managed expectantly. Most will resolve spontaneously with conservative therapy [63]. If diagnosed at celiotomy, the injury is inspected and repaired if necessary.

Hollow viscus

Blunt hollow viscus injuries occur in less than 1% of trauma patients. This is contrary to penetrating trauma, where hollow visceral injuries are quite frequent. The most common site of injury is the small bowel (93%), followed by the colon/rectum (30.2%) and the stomach (4.3%) [71].

Delays in diagnosis and management result in significant morbidity and mortality [72]. These delays are caused by the lack of clinical signs in early hollow

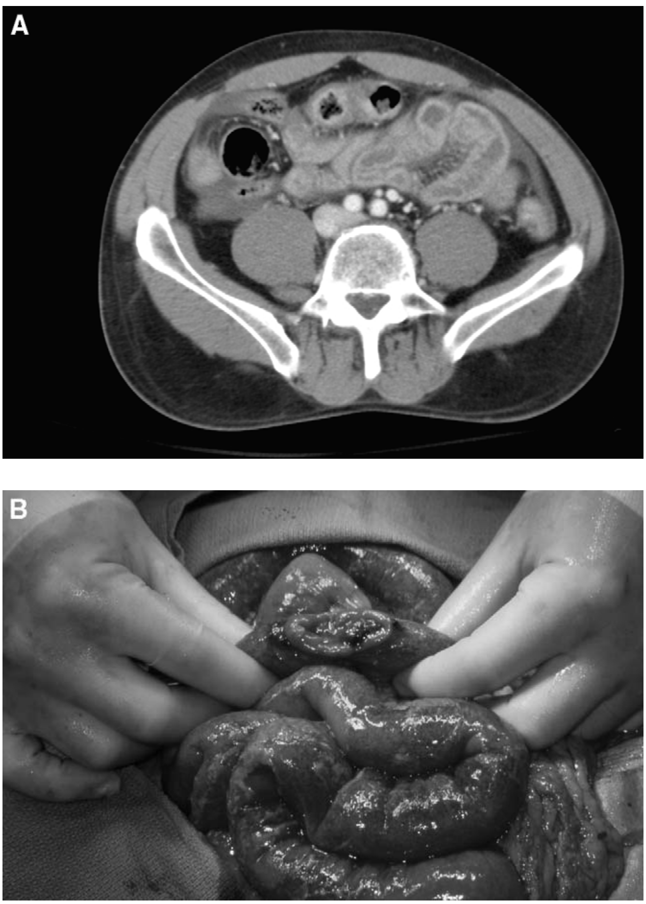

Fig. 5. (*A*) CT scan of BAT patient revealing bowel wall thickening and enhancement. (*B*) At surgery, the presence of a small bowel perforation.

visceral injuries and inadequate diagnostic algorithms [73]. Diagnostic peritoneal lavage was the primary diagnostic modality until the evolution of the CT scan. CT findings suggestive of hollow viscus injuries include discontinuity of bowel, extraluminal oral contrast material, pneumoperitoneum, intramural air, bowel wall thickening, bowel wall enhancement, mesenteric stranding, and free intraperitoneal fluid (Fig. 5) [74].

If only free intraperitoneal fluid is present, hollow visceral injury cannot be excluded. In those patients without solid organ injury, the literature is contradictory in the need for exploratory celiotomy [75–79]. Further evaluation with DPL may be of assistance in this decision, the positive criterion being WBC count of at least $500/mm^3$ [26]. If significant hemoperitoneum exists in either instance, the WBC criterion should be modified. Using a cell count ratio of greater than or equal to one, Fang et al predicted hollow viscus perforation with a sensitivity of 100% and a specificity of 97%. The cell count ratio is equal to the WBC/RBC ratio in the lavage fluid divided by the WBC/RBC ratio in the peripheral blood [80]. Another modification of the criteria was developed by Otomo et al. A positive DPL requires the standard WBC count of at least $500/mm^3$ and a positive–negative borderline adjusted to WBC greater than RBC/150, where RBC count is at least $100,000/mm^3$. If performed 3 to 18 hours after injury, this DPL criterion is 96.6% sensitive and 99.4% specific for intestinal injury [81].

Operative management

Small intestine. In small bowel injuries, the operative technique depends on the severity of injury more so than the mechanism. Small intramural or subserosal hematomas and partial-thickness lacerations may simply be inverted. Full-thickness small intestinal perforations involving less than 50% of the circumference may be repaired primarily with conventional two-layered anastomotic techniques. Similar repairs are used in full-thickness injuries involving greater than 50% of the circumference, providing the mesenteric vasculature is intact, and the intestinal lumen is not compromised. Segments of small bowel that are transected, with or without devitalization, should be resected and repaired with a primary anastomosis [82].

Large intestine. In large bowel injuries, the operative treatment is dependent on the severity of the injury and the location. Small hematomas and partial-thickness lacerations may simply be inverted. Full-thickness injuries with less than 50% circumferential involvement, without devascularization, and without peritonitis may be repaired primarily [82–88]. In injuries involving greater than 50% of the circumference, resection and anastomosis may be performed as long as the patient is hemodynamically stable, has no significant comorbidities, has minimal associated trauma, and has no evidence of peritonitis [84–87]. In these instances, a colostomy should be undertaken. If a contrast enema reveals distal colonic healing in 2 weeks, the colostomy may be closed assuming the patient is hemodynamically stable and is without sepsis [89].

Complications

The management of specific injuries, either appropriately or inappropriately, may result in an array of complications. These may include missed injuries, intra-abdominal abscesses, fistula of various types, pancreatitis, abdominal compartment syndrome, necrotizing fasciitis, and abdominal wound dehiscence. A high index of suspicion is key in diagnosing and managing such complications.

Summary

Missed intra-abdominal injuries are among the most frequent causes of potentially preventable trauma deaths. The evaluation and management of abdominal trauma is dependant on multiple factors, including mechanism of injury, location of injury, hemodynamic status of the patient, neurologic status of the patient, associated injuries, and institutional resources.

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