Blunt Upper Abdominal Trauma: Evaluation by CT

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CT is the technique of choice for initial examination of hemodynamically stable patients after blunt abdominal trauma. It is highly sensitive, specific, and accurate for use in detecting the presence or absence of injury and defining its extent. Nonoperative management of many posttraumatic injuries, particularly in the liver, spleen, and kidney, is possible in part because of the diagnostic usefulness of CT. CT can be used effectively to visualize the progression of liver and spleen injuries in those patients chosen for conservative management. CT helps in treatment decisions in patients with renal injury by defining the character and extent and distinguishing minor from severe renal trauma. Posttraumatic injuries to the pancreas, bowel, and mesentery can be detected with CT. In these areas, however, signs may be subtle, and a significant injury may be missed on an initial examination.

Trauma is the third leading cause of death in the United States and the leading cause of death in persons less than 40 years old [1, 2]. It is currently one of America's costliest health problems [3, 4]. Two important advances in the treatment of trauma patients in the past decade have been the creation and development of the Emergency Medical Service system and the widespread use of CT to examine patients [2]. The Emergency Medical Service system defines the level of trauma care available at individual hospitals and identifies dedicated trauma centers (levels I and II centers) for designated geographic areas. Referring trauma victims to such centers for treatment results in reduced morbidity and mortality rates [2]. CT has become an integral part of the clinical evaluation of traumatized patients because of its high sensitivity, specificity, and accuracy in detecting the presence and extent of injury to the head, abdomen, chest, pelvis, and skeleton [2, 5-11].

CT examination of the abdomen has largely replaced other imaging techniques in the evaluation of hemodynamically stable patients. It is performed in patients in whom the abdomen cannot be evaluated adequately by clinical examination because of altered mental status (e.g., ethanol or drug abuse, head injury), in those in whom findings on clinical abdominal examination are equivocal, and in those with significant pelvic fractures or history of multiple operations [2, 5, 6, 8, 9, 12]. CT is not performed in hemodynamically unstable patients and in patients with obvious signs of peritonitis who require immediate surgery. For rapid evaluation of the extent of abdominal injury, diagnostic peritoneal lavage (DPL) can be performed either immediately before or during exploratory surgery.

DPL is very sensitive for detecting hemorrhage, is quick and simple to perform, and does not require sophisticated equipment. However, the test cannot differentiate consequential from significant bleeding [2, 13], resulting in unnecessary laparotomies in 6-25% of cases [6, 7, 14]. DPL also cannot show the location or extent of injury. Furthermore, it does not show injuries of the retroperitoneum, and thus is insensitive to trauma to the pancreas, the kidneys, and the retroperitoneal portion of the duodenum. Traumatic cannula insertion, rents in the peritoneal membrane that allow blood from a retroperitoneal injury to enter the abdominal cavity, and pelvic fractures can result in false-positive examinations [7, 15].

CT has replaced DPL in many centers for the initial evaluation of suspected abdominal injury in stable patients [2, 7,
Although many studies [5, 9, 11] have confirmed the value of CT compared with DPL, these results are somewhat controversial. Other reports [2, 16–19] show CT to be less valuable than DPL, particularly in injuries to the bowel or mesentery, and both CT and DPL may be warranted in such cases. DPL is best performed after CT to avoid interpretive errors because of fluid and free air introduced by the lavage procedure. Important diagnostic information may still be obtained from CT after DPL by accounting for these factors [18, 20].

The use of CT in the examination of patients with blunt abdominal trauma, along with a trend toward nonoperative management of many abdominal injuries, has decreased the need for exploratory surgery and reduced the frequency of nontherapeutic laparotomies [2, 6, 7, 9]. In fact, the trend toward conservative and nonoperative treatment of many liver, spleen, and kidney injuries is due in part to the ability of CT not only to define injury but also to exclude significant injury, thereby avoiding unnecessary surgery. The final decision to operate should be based on CT findings in conjunction with the entire clinical picture and judgment of the attending trauma surgeon [2, 21]. In this article, we review the CT findings in patients with blunt upper abdominal trauma and the impact of these findings on treatment.

**Technique**

Proper technique is critical for accurate abdominal CT examination of patients with blunt abdominal trauma. To opacify bowel, the patient is given approximately 500 ml of oral contrast medium (1–3% solution of diatrizoate sodium or diatrizoate meglumine/diatrizoate sodium) orally or via nasogastric tube approximately 30–45 min before CT and an additional 250 ml just before scanning. To avoid imaging artifacts, the patient's arms are placed above the abdomen if possible and monitoring devices, tubes, and wires are positioned out of the scan plane. If a nasogastric tube is in the stomach, it is partially withdrawn so that the tip is positioned within the distal esophagus and repositioned after the examination is completed. A large field of view decreases artifacts from structures that cannot be removed from the scan field. Restraints or sedation may be necessary to avoid motion artifacts in patients unable to maintain the proper position. Fast scans (<2 sec) may be performed with many scanners to minimize motion artifacts.

Kelly et al. [22] recommended performing an unenhanced study before the contrast-enhanced study to visualize hyperdense hematomas that may become isodense after IV contrast administration. In their study, however, all significant visceral injuries were seen on contrast-enhanced examinations. Only minor injuries that did not lead to a change in treatment were seen exclusively on unenhanced studies. Missing an isodense hematoma can be avoided by using adequate volumes of contrast material and by recognizing the irregular contour of the clot at its interface with the organ in question. Therefore, most authors do not do a preliminary unenhanced examination [5, 6, 9, 21, 23, 24].

IV contrast material can be given as an initial bolus of approximately 50 ml at a rate of 2–3 ml/sec, followed by a rapid infusion at 1 ml/sec. Alternatively, a single sustained bolus of contrast material at a rate of 1–3 ml/sec may be administered, particularly if dynamic scanning capability is available. The dose is altered for children to 2–3 ml/kg body weight. A mechanical injector is useful for regulating the flow of contrast material, and dynamic scanning techniques are used to decrease examination time in this group of patients in whom expediency can be critical to successful treatment. Scans are usually taken at 1-cm intervals from the dome of the diaphragm through the abdomen and at 1.5- to 2.0-cm intervals through the pelvis. Patients are monitored throughout the examination, and emergent resuscitation equipment should be readily available. In addition to soft-tissue window settings, lung window settings are obtained for evaluation of the lower chest for significant injuries such as pneumothorax, lung parenchymal injuries, or free peritoneal air indicating hollow viscus injury, and bone window settings are used for bony fractures [5]. It is also useful to view images directly on the console video monitor, so that window and level settings can be manipulated to appreciate subtle but potentially significant findings. After the study, oral contrast material can be withdrawn from the stomach via a nasogastric tube if indicated.

**CT Findings and Management Decisions in Blunt Abdominal Trauma**

Many trauma patients have multiorgan injuries. Therefore, a thorough evaluation of all abdominal components is warranted in each case.

**Hemoperitoneum**

Hemoperitoneum is easily seen on CT and may be the only or most obvious sign of abdominal injury. Its presence should prompt a thorough search for injury to visceral organs. Hemoperitoneum is differentiated from other fluid because of increased attenuation, averaging 45 H and always greater than 30 H if less than 48 hr old [25]. Hemoperitoneum tends to be identified near the source of bleeding, spreading throughout the abdominal cavity and into the pelvis along pathways common to all abdominal fluid collections, as described by Meyers [26]. Free collections of intraperitoneal blood are most often seen in the Morrison pouch, the most dependent peritoneal recess in the upper abdomen, and are frequently seen in the peripancreatic space and the right paracolic gutter. The pelvis is the most dependent portion of the peritoneal cavity, and large collections of blood may be present in the pelvis even when little blood is seen in the abdominal recesses [25].

Federle and Jeffrey [25] used CT to quantify hemoperitoneum into small, moderate, and large collections. They attempted to correlate estimates of the amount of hemorrhage with severity of visceral organ injury and outcome from either
operative or nonoperative treatment. Kearney et al. [18], however, using Federle and Jeffrey's classification, did not find quantification of hemoperitoneum useful in predicting the need for surgery. CT is useful, however, for detecting the resolution of hemoperitoneum [25, 27].

Clotted blood has higher attenuation (>60 H) than does free blood [25]. A localized collection of clotted blood, the "sentinel clot," is an accurate sign of injury to an adjacent organ [28]. This sign may help in detecting subtle bowel, mesenteric, or splenic lesions.

The presence of hemoperitoneum on a single CT study does not indicate that active bleeding is present. Jeffrey et al. [29], using dynamic scanning techniques, recently described CT signs of active intraabdominal arterial bleeding. Most frequently seen is a focal high-density area of 80–130 H (higher attenuation than free or clotted blood) that is isodense with adjacent major arteries (Fig. 1). Seen less frequently, a diffuse high-density area may simulate extravasation of oral contrast material from perforated bowel, although other signs of bowel perforation are not present. In most patients with active intraabdominal bleeding, CT is rarely performed because of hemodynamic instability. Occasionally, however, a patient with active abdominal hemorrhage may become hemodynamically stable and then undergo CT. Detection of hemorrhage is then of vital importance, so that proper, potentially life-saving treatment can be instituted quickly.

Signs of hypovolemic shock on CT include a small aorta, a collapsed inferior vena cava, marked enhancement of the kidneys, and initially diminished density of spleen compared with liver after contrast enhancement [30–33]. Taylor and Rosenfield [34] described a hypoperfusion complex in children that consists of marked, diffuse dilatation of the intestine by fluid; abnormally intense contrast enhancement of the bowel wall, mesentery, kidneys, and/or pancreas; decreased caliber of the aorta and inferior vena cava; and significant abdominal fluid.

**Spleen**

The spleen is the most frequently injured organ in patients with blunt abdominal trauma [5]. CT is extremely sensitive and specific in determining the presence and extent of splenic injury in the traumatized patient, and the CT features of splenic trauma have been well described [2, 35]. Subcapsular hematomas appear as crescentic fluid collections that flatten or indent the splenic margin (Fig. 2). Initially, hematomas may be isodense with splenic parenchyma on contrast-enhanced scans, particularly if adequate volumes of contrast material are not given [20, 35]. Intrasplenic hematomas are seen on CT as rounded low-density areas (Fig. 3). Lacerations appear as linear low-density areas within the spleen (Fig. 2). Multiple lacerations may have the appearance of a fragmented or

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**Fig. 1.—Renal fracture in 20-year-old man involved in motor vehicle accident. Enhanced CT scan shows kidney has been completely separated into two perfused poles by a severe laceration. Hematoma is seen between two poles. Focal areas of extremely high attenuation represent active bleeding. Patient died on day of admission.**

**Fig. 2.—Spleenic laceration with subcapsular and perisplenic hematoma in 36-year-old woman with hypotension after a fall 1 week before admission. Enhanced CT scan shows an irregular, linear, low-density laceration (arrow) traversing spleen. Lateral contour of spleen is indented from subcapsular hematoma. Density of clotted blood (arrowhead) is increased when compared with nonclotted portion of hematoma. Large volume of hemoperitoneum in right perihpatic space and surrounding left lobe of liver also is seen. CT findings were confirmed at surgery. A splenectomy was performed, and hemoperitoneum was evacuated.**

**Fig. 3.—Injury of liver and spleen in 60-year-old woman after a motor vehicle accident. Enhanced CT scan shows low-density spleenic hematoma posteriorly. Spleen also contains multiple lacerations (arrow). Perisplenic and perihpatic blood and liver laceration also are present. Exploratory laparotomy confirmed CT findings.**

**Fig. 4.—Shattered spleen in 26-year-old woman after motor vehicle accident. Enhanced CT scan shows multiple lacerations and fragmentation of spleen. Large hemoperitoneum also is present, surrounding both spleen and liver. Hemoperitoneum extended into pelvis. Exploratory laparotomy confirmed CT findings.**
shattered spleen (Fig. 4). Unenhancing portions of the spleen should suggest injury or thrombosis of the artery to the affected segment.

Disruption of the splenic capsule results in visible hemoperitoneum in up to 95% of patients with splenic injury [35]. Perisplenic clot also is associated with splenic injury. Both hemoperitoneum and perisplenic clot may be present in cases of splenic injury without evidence of a splenic laceration on CT. Therefore, presence of either should prompt a search for splenic injury. Occasionally, splenic injury may manifest as heterogeneous parenchyma with a mottled irregular enhancement [35]. This finding is almost always associated with peritoneal blood and perisplenic clot and by itself is merely suggestive of splenic injury. The spleen may also transiently appear inhomogeneous during the early capillary phase of a contrast-enhanced dynamic CT study.

Certain findings on CT may result in a false-positive diagnosis of splenic injury. Splenic lobulations and congenital clefts, and a prominent left hepatic lobe extending across the midline to lie immediately adjacent to the spleen, may simulate a splenic laceration [36]. Streak and motion artifacts can also result in incorrect diagnoses. The spleen may seem to enlarge on serial CT scans after blunt abdominal trauma [37]. This is a result of initial splenic contraction from adrenergic stimulation at the time of acute injury, which resolves with time and volume replacement.

Although rare, delayed splenic rupture has been reported in patients in whom an initial CT scan after injury showed no evidence of splenic abnormality [34, 38–40]. Suboptimal contrast enhancement techniques may be partially responsible for this missed diagnosis [41]. Subtle inhomogeneities of the splenic parenchyma and minimal thickening of the laterocoronal fascia and the left anterior renal fascia may be the only signs initially seen in some cases of delayed splenic rupture [40].

King and Shumacker [42] first reported overwhelming sepsis in five children after splenectomy, two of whom died. Other reports followed, confirming the increased risk of late sepsis after splenectomy in both children and adults [43]. This observation has encouraged nonoperative management and splenic salvage procedures in appropriate patients [2, 43–45]. The role of CT in selecting between conservative and operative treatment of splenic injuries remains unclear. Mirvis et al. [46], using a CT classification of four grades of splenic injury, found that although patients with severe splenic injury generally required laparotomy, eight of 23 such patients were treated successfully without surgery, and four of 15 patients with minor injury, initially treated conservatively, eventually required celiotomy. Buntain et al. [10] had more success in predicting outcome of splenic injury by using a CT classification that, in addition to grading splenic trauma, used modifiers for other intraabdominal and extraabdominal injuries. In their series, only patients with minor injuries were selected for nonoperative management, and all others had laparotomy. Resciniti et al. [47] devised a numeric CT scoring system that graded severity of splenic injury on a scale of 1–3 and scored 1 point each for the presence of perisplenic fluid, abdominal intraperitoneal fluid, and pelvic intraperitoneal fluid. Questionable observations received 0.5 points. In their series, no patient with a score lower than 2.5 who was initially managed nonoperatively required celiotomy. Umlas and Cronan [48] applied the grading systems of Buntain et al. and Resciniti et al. to determine whether the outcome of nonsurgical management could be predicted on the basis of CT findings. They found that these systems were not completely reliable. In particular, delayed splenic rupture remains a distinct problem in a small percentage of patients in whom the spleen is normal or shows only a limited injury on the initial CT scan [48, 49]. On the other hand, Brick et al. [21] have shown that moderate or severe splenic injury in children or injury associated with a moderate or large amount of hemoperitoneum may be treated successfully without surgery. At this time, although CT is extremely useful in characterizing initial injury and following the evolution of splenic trauma, the final decision on whether to operate or not should be made by the trauma surgeon on the basis of clinical factors and not entirely on the CT findings.

Liver

The liver is preceded only by the spleen in frequency of injury from abdominal trauma. In 22–61% of patients with hepatic injuries, significant damage is obvious, and because of shock or peritonitis such patients have immediate surgery without preliminary imaging studies. As with splenic trauma, CT has proved to be highly sensitive, specific, and accurate in defining and characterizing hepatic injury and associated hemoperitoneum in hemodynamically stable patients [5, 11, 27, 50]. In all reported series, the right hepatic lobe is injured more frequently, probably because of its larger size and proximity to the lower ribs [21, 50, 51].

The CT findings in hepatic injury are similar to those seen in the spleen; they include contusions (the mildest injury), subcapsular hematomas, intraparenchymal hematomas, and single or multiple lacerations and fractures through the hepatic parenchyma [7, 27, 50] (Figs. 3 and 5). Lack of enhancement of fractures indicates loss of vascular supply with the potential for hepatic necrosis. Periportal tracking (areas of perivascular low-attenuation surrounding portal subsegmental portal venous branches) also has been described as a sign of hepatic injury on CT and may be the only finding [51] (Fig. 6). Although Macrander et al. [51] presume that such tracking is a sign of blood, Cox et al. [52] ascribe the finding to distension of periportal lymphatics because of associated hypotension and subsequent large fluid volume replacement in traumatized patients with no other evidence of abdominal trauma. Hepatic subcapsular and parenchymal gas seen on CT 2–3 days after hepatic trauma may be due to hepatic necrosis and may not be related to infection [53].

The liver has a remarkable ability to heal even after severe injury. Therefore, nonoperative management of such injuries in hemodynamically stable patients is now accepted. Unlike the spleen, the liver does not exhibit delayed rupture. Attempting to define the role of CT in management decisions, Moon and Federle [50] and Meyer et al. [54] reported that limited hepatic injury without evidence of active bleeding and with little or no hemoperitoneum could be managed successfully without surgery. More recently, it has been shown that stable
patients with severe hepatic injuries and significant hemoperitoneum also may be treated nonoperatively without significant sequelae [21, 27, 55]. Jeffrey [49] states that CT staging of blunt hepatic injuries has little discriminatory value in predicting outcome of stable patients, as nearly all have an excellent prognosis. Other abdominal injuries may, however, require laparotomy.

Management decisions in the setting of hepatic injury should be based on clinical factors, and CT should be used to depict the injury and detect healing and resorption of hemoperitoneum. Peritoneal blood is normally resorbed and therefore significantly reduced or absent within 1 week on follow-up CT scans [27]. Otherwise, continued hemorrhage should be suspected. Subcapsular hematoma usually resolves within 6–8 weeks [56]. Intraparenchymal hematomas heal much more slowly and may persist for several years, as bile in the hematoma delays clot resorption and adversely affects parenchymal healing [56]. Persistent intraparenchymal hematoma appears as a collection with a high attenuation (30–50 H). A water-density posttraumatic cyst or biloma may result. Lacerations, conversely, appear to heal more rapidly, and significant healing is seen on serial CT examinations over a 3-week period [27]. Clearly, any patient selected for conservative therapy requires continued hemodynamic monitoring and laboratory assessment; transfusion as needed; and the availability of nursing, surgical, and imaging facilities if hemodynamic instability develops [27, 55].

Kidney

Renal injuries after blunt abdominal trauma can be categorized as minor, intermediate, and severe [57–60]. Most renal injuries (75–85%) are minor and include contusions, intrarenal hematomas, small subcapsular hematomas, small lacerations that do not communicate with the collecting system, and small segmental infarcts. Patients are usually hemodynamically stable, have microscopic hematuria, and are treated conservatively. Intermediate injuries, which account for approximately 10% of renal trauma, include deep lacerations that communicate with the collecting system and result in urine extravasation. Treatment of such injuries is somewhat controversial; some advocate conservative management unless severe bleeding or clinical deterioration ensues; others advocate early surgery to avoid complications [58–60]. The remaining 5% of renal injuries are severe, including shattered kidneys, renal pedicle injuries, and avulsion and laceration of the renal pelvis. These catastrophic injuries require immediate surgery.

Of all imaging techniques, CT most accurately depicts the character and extent of renal injury, best displays perirenal hematomas and extravasation of urine, best distinguishes between the categories of renal trauma, and, therefore, is most useful in case management [57, 58, 61, 62]. CT also detects associated injuries within the perirenal cavity and retroperitoneum that may influence management. In a stable patient with a suspected isolated renal injury, excretory urography will usually suffice as an initial examination [58, 62, 63]. Normal findings on excretory urography exclude significant renal injury. However, evidence of significant renal trauma on excretory urography often requires further evaluation with CT.

The appearance of renal injuries on enhanced CT has been well documented [57–60, 62]. Contusion, the mildest renal injury, results in edema and extravasation of small amounts of blood and urine into the interstitial space [58, 62]. Contusion may be subtle and missed on contrast-enhanced CT. When present, it appears as poorly defined areas of decreased enhancement. Lang et al. [62] described the appearance of a small collection of contrast medium in the renal interstitium on delayed scans as a sign of contusion. Contusions usually resolve within 1 week.

Intrarenal hematomas appear as areas of decreased enhancement that may be poorly defined or well margined. Subcapsular hematomas are confined by the renal capsule, are often lenticular, and may flatten the renal border. An apparent low-attenuation region around the surface of the kidney may be caused by respiratory motion during the scan and can result in a false diagnosis of subcapsular hematoma [60]. In such cases, a similar appearance is noted anterior to the abdominal wall.

Lacerations appear as focal parenchymal injuries with decreased enhancement. If they involve the collecting system, contrast-laden urine extravasates and is easily seen on CT (Fig. 7). A significant perirenal hematoma is usually present with severe lacerations. Because of fascial fusions in the retroperitoneum, hematomas due to or associated with renal
trauma tend not to cross the midline; the presence of such a hematoma should prompt a search for injury to the aorta, its branches, or other midline structures [57]. Lacerations that completely transect the kidney into two separate poles are often called fractures (Fig. 1). Lacerations usually occur parallel to the main vascular structures, preserving them, and parenchymal enhancement is observed. The margins of lacerated fragments may have an inhomogeneous, mottled appearance, possibly the result of vasospasm. The shattered kidney contains multiple lacerations, some of which may shear across vascular planes and produce devascularized fragments with nonenhancing parenchyma. A section through the hilar lip of the kidney may appear as a fracture, but its characteristic posterolateral location should prevent confusion.

A segmental renal infarct may result from injury to an intrarenal or polar arterial branch [60] and appears as a wedge-shaped or hemispheric area of nonperfusion with the apex pointing toward the renal hilum (Fig. 8). A thin enhancing rim may be seen [62]. Eventually a deep scar forms in the area of infarction.

Laceration of the renal pelvis or avulsion of the ureteropelvic junction causes extravasation of contrast-laden urine. Extravasation without evident renal injury should raise suspicion of such injuries of the renal pelvis [60].

In many cases an injury of the renal pedicle resulting in arterial or venous occlusion can be clearly documented on CT because the kidney does not enhance (Fig. 8). A cortical rim of enhancement may be present as a result of collateral blood flow from the capsular arteries. An abrupt cutoff of the contrast-enhanced renal artery is seen occasionally [64]. The reliability of CT in detecting injuries of the renal pedicle is in dispute. Sclafani et al. [57] consider CT the method of choice and confirmatory angiography unnecessary. Lupetin et al. [64], using CT, diagnosed renal artery occlusion in all seven patients in their series. Lang et al. [62], on the other hand, found CT less reliable in the detection of trauma to the renal artery, as the diagnosis was missed on CT in five of seven patients in their series. Injury to the renal vein after blunt trauma is missed more often than injury to the artery; in addition to lack of enhancement, the kidney may appear enlarged, the rim enhancement may be thicker, and thrombus in the vein may be seen [58].

Pancreas

Pancreatic injuries, including pancreatic duct disruption, fractures, contusions, and traumatic pancreatitis, represent 3–12% of all abdominal injuries from blunt trauma. They are clinically important, however, because death occurs in 16–20% of cases of pancreatic trauma, and major posttraumatic complications (pseudocyst, abscess, hemorrhage, acute recurring pancreatitis, and fistulae) occur in one of three survivors [17, 65, 66]. Delay in diagnosis leads to an increase in the mortality and morbidity rate. The typical clinical findings of upper abdominal pain, leukocytosis, and increased serum amylase may not be apparent for one or more days after acute pancreatic trauma. In addition, an increase in the serum amylase level after trauma may be present without pancreatic injury [67].

Pancreatic injury may be difficult to diagnose on CT [17, 65]. Little evidence of pancreatic injury may appear on CT examinations performed soon after the traumatic event [65]. Pancreatic duct disruption is the most significant pancreatic injury. Although this abnormality cannot be seen directly on CT, associated injury to the pancreas may be detected. Fracture of the pancreas, depicted as a clear separation or low-density line through the long axis, occurs most commonly in the neck of the pancreas as a result of compression of the organ against the spine [67] (Fig. 9). Thickening of the left
anterior renal fascia, although not specific for pancreatic injury, is frequently present and should raise the possibility of pancreatic injury [65]. Other signs include focal or diffuse enlargement of the organ, areas of decreased attenuation, and peripancreatic edema and fluid collections [17, 65, 67]. If the possibility of pancreatic trauma persists despite initially normal CT findings, a second CT examination in 12–24 hr may be warranted, because signs of injury can be delayed. ERCP, which directly visualizes the pancreatic duct, may also be necessary for further evaluation when CT findings are equivocal or CT is technically inadequate [65]. Immediate surgery is the recommended treatment for pancreatic fracture.

Bowel and Mesentery

Bowel and mesentery injuries are reported to occur in 5% of blunt trauma cases [68]. As these injuries are most commonly seen in restrained motor vehicle accident victims, the incidence may rise as seat belt usage increases [16]. Early diagnosis is important. In patients with duodenal perforation, surgery performed within 24 hr of injury has a 5% mortality rate, whereas delayed diagnosis and treatment leads to a mortality rate of 65% [68, 69]. Unfortunately, clinical signs initially may be subtle or absent.

CT signs of bowel and mesenteric injury include extraluminal air, extravasation of oral contrast material, peritoneal or retroperitoneal fluid, thickened bowel wall, high-density clot (sentinel clot) adjacent to the involved bowel, and focal mesenteric infiltration [16, 68]. Free air in either the peritoneal cavity or the retroperitoneum from injury to the retroperitoneal duodenum, small bowel, or colon is a relatively specific sign of bowel perforation but is seen in only half of cases [68, 69] (Fig. 10A). The volume of air may be quite small and subtle. Wide window or lung settings will aid in detection. The most common location in which to detect free intraperitoneal air is the subdiaphragmatic area, anterior to the liver. Extraluminal air also may be present within the leaves of the mesentery or in the retroperitoneum, particularly in the anterior pararenal space. Occasionally, pneumoperitoneum results from pneumomediastinum, pneumothorax, bladder rupture, or previous peritoneal lavage and is not related to bowel trauma [17, 70]. Extravasation of oral contrast material from the bowel lumen is a specific sign of bowel perforation (Fig. 11). Unfortunately, its presence is shown on CT in only a minority of cases. Intraabdominal fluid, although seen in nearly all cases of bowel or mesenteric injury, is not a specific indicator. Moderate or large amounts of fluid are associated with significant bowel or mesenteric trauma. If no associated solid visceral injury is noted, bowel or mesenteric injury should be suspected [16, 68]. Focal mesenteric infiltration is also a frequently seen but nonspecific sign. A localized high-attenuation mesenteric hematoma or intramural hematoma can help localize the site of injury [28, 71] (Fig. 10B). Thickened bowel is seen in about 75% of cases with transmural laceration. Therefore, its absence does not exclude bowel injury [68].

Although Rizzo et al. [68] report high sensitivity in detecting bowel and mesentery injuries, other authors indicate that this diagnosis may be difficult with CT [2, 17, 33, 72]. This difficulty may be due in part to the subtlety of the findings and the fact that presentation of signs and symptoms may be delayed. The initial CT examination may be done before the clinical signs are manifest [17, 33, 68]. The coordinated use of CT and peritoneal lavage for diagnosis of bowel and mesenteric injuries has been suggested [16, 18].

Miscellaneous Abdominal Trauma

Galbladder injury after blunt abdominal trauma is uncommon, occurring in 2–3% of cases [73, 74]. Laceration or perforation, complete avulsion, or intramural contusion can

Fig. 10.—Perforated jejunum in 37-year-old man injured in motor vehicle accident. A, Enhanced CT scan shows free intraperitoneal air due to jejunal perforation anterior to liver. Wide window settings are used to accentuate display of free air. B, CT scan at level caudal to A shows localized high-attenuation hematoma adjacent to mildly dilated loop of bowel denoting site of injury. Free intraperitoneal blood also is seen in both right and left paracolic gutters. Exploratory laparotomy revealed a perforated jejunum, torn mesentery, and ischemic ileum.

Fig. 11.—Perforated duodenum in 38-year-old man hit by a train. CT scan shows extravasation of oral contrast material from duodenum at site of injury (arrow). Free peritoneal fluid is noted in Morison pouch. Diffuse mesenteric edema also is present. CT findings were confirmed at exploratory laparotomy.
occur. On CT, the gallbladder may contain high-density hemorrage with associated peritoneal blood; low-density fluid associated with bile leakage also may be present [73, 74]. Hemobilia is likely if high-attenuation material is seen in the gallbladder, and other causes of increased density, such as stones, contrast material, and milk-of-calcium bile, can be excluded [75]. Diaphragmatic rupture occurs in 1–2% of patients after blunt abdominal trauma and almost always affects the left side [76, 77]. This injury is difficult to diagnose with any imaging technique and is often missed on CT [76]. Herniation of abdominal contents through the diaphragm may be seen occasionally [77] (Fig. 12).

Traumatic adrenal hemorrhage occurs in up to 25% of patients after severe trauma [78, 79]. In 85% of cases hemorrhage is right-sided and in 20% of cases it is bilateral. On CT, adrenal hemorrhage appears as a hyperdense mass (50–75 HU) with streaky infiltration into the periadrenal fat and thickening at the adjacent diaphragmatic crus [78]. Abnormalities in the subcutaneous fat of the abdominal wall at the site of trauma also may be seen [79].

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