Diseases of the Abdomen and Pelvis

Diagnostic Imaging and Interventional Techniques
DISEASES OF THE ABDOMEN AND PELVIS

DIAGNOSTIC IMAGING AND INTERVENTIONAL TECHNIQUES

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Preface

The International Diagnostic Course in Davos (IDKD) offers a unique learning experience for imaging specialists in training as well as for experienced radiologists and clinicians wishing to be updated on the current state of the art and the latest developments in the fields of imaging and image-guided interventions.

This annual course is focused on organ systems and diseases rather than on modalities. This year’s program deals with diseases of the abdomen and pelvis. During the course, the topics are discussed in group seminars and in plenary sessions with lectures by world-renowned experts and teachers. While the seminars present state-of-the-art summaries, the lectures are oriented towards future developments.

Accordingly, this Syllabus represents a condensed version of the contents presented under the 20 topics dealing with imaging and interventional therapies in abdominal and pelvic diseases. The topics encompass all the relevant imaging modalities including conventional X-rays, computed tomography, nuclear medicine, ultrasound and magnetic resonance angiography, as well as image-guided interventional techniques.

The Syllabus is designed to be an ‘aide-mémoire’ for the course participants so that they can fully concentrate on the lecture and participate in the discussions without the need of taking notes.

Additional information can be found on the IDKD website: www.idkd.ch

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SEMINARS
Emergency Radiology of the Abdomen: The Acute Abdomen

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Introduction

The term ‘acute abdomen’ defines a clinical syndrome characterized by an history of hitherto undiagnosed abdominal pain lasting less than one week. A large number of disorders, ranging from benign, self-limited diseases to conditions that require immediate surgery, can cause acute abdominal pain. Eight conditions account for over 90% of patients who are referred to hospital and are seen on surgical wards with acute abdominal pain: acute appendicitis, acute cholecystitis, small bowel obstruction, urinary colic, perforated peptic ulcer, acute pancreatitis, acute diverticular disease, and non-specific, non-surgical abdominal pain (‘dyspepsia’, ‘constipation’).

Imaging Techniques

Clinical assessment of acute abdomen is often difficult because of the often non-specific findings of physical examination and laboratory investigations. In many centers plain radiographs of the abdomen, despite significant diagnostic limitations, serve as the initial radiological approach. Two views are usually taken, one supine and one erect. If the patient is unable to stand, a left lateral decubitus view is performed. For a systematic film analysis it is helpful to follow the mnemonic ‘gas, mass, stones and bones’ for the detection of (1) signs of mechanical bowel obstruction or paralytic ileus; (2) gas outside the bowel lumen in the peritoneal cavity (pneumoperitoneum), retroperitoneum, bowel wall, portal veins, or biliary tract; (3) mass or fluid collections, displacement of organs or bowel loops; (4) abnormal calcifications and/or calculi; (5) skeletal pathology.

The need for plain abdominal radiographs has declined due to the impact of cross-sectional imaging. The traditional indications for plain abdominal radiography – pneumoperitoneum, bowel obstruction, and the search for ureteral calculi – are better evaluated by unenhanced helical computed tomography (CT). The major obstacles to replacing plain abdominal radiography with unenhanced CT are its higher cost, more limited availability, and higher radiation dose.

Although ultrasonography (US) has gained widespread acceptance for evaluating the gallbladder in affected patients and the pelvis in children and women of reproductive age, CT is considered to be one of the most valued tools for triaging patients with acute abdominal pain. This is because it can provide a global perspective of the gastrointestinal (GI) tract, mesenteries, peritoneum, and retroperitoneum, inhibited by the presence of bowel gas and fat. Over recent years, most emergency centers have been equipped with newer helical CT scanners that permit imaging procedures to be performed in less time, with greater accuracy, and with less patient discomfort. The introduction of multidetector CT (MDCT) technology, with advances in contrast dynamics and high-resolution volumetric data acquisition, has further enhanced the utility of CT in abdominal imaging. Image interpretation with helical CT and particularly with MDCT is primarily performed at a workstation by manually paging or continuously scrolling up and down through the stack of reconstructed images. Additionally, multiplanar reformation (MPR) using coronal, sagittal, and curved planes, has evolved as a routine supplement to the axial images.

Three-dimensional volume rendered and maximum intensity projection (MIP) images are also easily produced from MDCT data sets. Inquiry about the site of abdominal pain facilitates the choice of imaging technique. For practical reasons, it is helpful to discuss the imaging strategies for acute pain localized in an abdominal quadrant separately from acute abdomen with diffuse pain and acute abdomen with flank or epigastric pain.

Acute Pain in an Abdominal Quadrant

Acute abdomen with pain localized in an abdominal quadrant can be classified as pain in the right upper, left upper, right lower, and left lower abdominal quadrant.
**Right Upper Quadrant**

Acute cholecystitis is by far the most common disease in the right upper quadrant. Other important diseases that resemble acute cholecystitis are pyogenic or amebic liver abscess, spontaneous rupture of a hepatic neoplasm (usually hepatocellular adenoma or carcinoma), hepatitis, and myocardial infarction.

US is the preferred imaging method for evaluating patients with acute right upper abdominal pain. It is a reliable technique for establishing the diagnosis of acute calculous cholecystitis. The primary criterion is the detection of gallstones. Secondary signs include the sonographic Murphy sign, gallbladder wall thickening by 3 mm or more, and pericholecystic fluid. Typically, a calculus obstructs the cystic duct in acute calculous cholecystitis. The trapped concentrated bile irritates the gallbladder wall, causing increased secretion, which in turn leads to distension and edema of the wall. Rising intraluminal pressure compresses the vessels, resulting in thrombosis, ischemia, and subsequent necrosis and perforation of the wall. Gallbladder perforation and complicating pericholecystic abscesses typically occur adjacent to the gallbladder fundus because of the sparse blood supply. CT may be useful for confirmation of the sonographic diagnosis. Emphysematous cholecystitis is a rare complication of acute cholecystitis and is associated with diabetes mellitus. US or CT demonstration of gas in the wall and/or lumen of the gallbladder imply underlying gangrenous changes (Fig. 1). Acalculous acute cholecystitis accounts for approximately only 5% of cases of acute cholecystitis. It is especially common in intensive care unit patients. Prolonged bile stasis results in increased viscosity of the bile that ultimately leads to functional cystic duct obstruction.

US and CT are both accurate techniques for diagnosing liver abscesses. US usually reveals a round or oval hypoechoic mass with low-level internal echoes. Although the lesion may mimic a solid hepatic mass, the presence of through transmission is a clue to its cystic nature. Normally, pyogenic liver abscesses are the result of seeding from appendicitis or diverticulitis, or direct extension from cholecystitis or cholangitis. Amebic abscesses result from primary colonic involvement with seeding through the portal vein. In most cases, pyogenic and amebic abscesses are indistinguishable by US appearance. The CT appearances of pyogenic and amebic abscesses also show substantial overlap. Amebic abscesses are low attenuation cystic masses. An enhancing wall and a peripheral zone of edema surrounding the abscess are common but not universally present. Extrahepatic extension of the amebic abscess with involvement of chest wall, pleura, or adjacent viscera is a frequent finding. Whereas amebic abscesses are usually solitary and unilocular, pyogenic abscesses may be multiple or multiloculated and may demonstrate an irregular contour.

Spontaneous rupture of a hepatocellular carcinoma and subsequent hemoperitoneum represent a frequent complication found in countries with a high incidence of this tumor, but uncommon in Western countries. Subcapsular localization and tumor necrosis have been implicated in pathogenesis. US, and especially CT, are the most useful techniques for diagnosing a ruptured he-
patocellular carcinoma, which appears as a peripheral or subcapsular mass. Spontaneous hemorrhage within a hepaticocellular adenoma occurs most commonly in women taking oral contraceptives. Capsular rupture with subsequent hemoperitoneum is an uncommon complication. On CT, high-density intraperitoneal fluid confirms the diagnosis of hemoperitoneum, and extravasation of contrast material is indicative of active bleeding.

**Left Upper Quadrant**

Acute abdomen with left upper quadrant pain is not frequent. Splenic infarction, splenic abscess, gastritis, and gastric or duodenal ulcer are the most important causes. US is usually used for screening, and CT enables accurate further evaluation. The diagnosis of gastric pathology is established by endoscopy, with imaging playing a minor role.

Common causes of splenic infarction include bacterial endocarditis, portal hypertension, and underlying splenomegaly. Pancreatitis that extends into the splenic hilum can also result in infarction. Splenic infarction may be focal or global. Typical focal splenic infarcts appear as peripheral wedge-shaped defects, hypoechoic at US and hypodense at CT, respectively. Most splenic abscesses are associated with hematogenous dissemination of infection, such as bacterial endocarditis or tuberculosis. Intravenous drug abusers are predominantly affected. Both US and CT are sensitive, but specificity is low. On US, most abscesses appear as hypo- or anechoic, poorly defined lesions; on CT, they typically appear as rounded, low-density lesions with rim enhancement.

**Right Lower Quadrant**

Acute appendicitis is not only the most frequent cause of acute right lower quadrant pain, but also the most commonly encountered cause of acute abdomen. Other diseases manifesting acute right lower quadrant pain include acute terminal ileitis (Crohn’s disease), acute typhlitis, right sided colonic diverticulitis and, in women, pelvic inflammatory disease, complications of ovarian cyst (hemorrhage, torsion and leak), endometriosis, or ectopic pregnancy.

Most patients with typical clinical findings of acute appendicitis undergo immediate surgery without preoperative imaging. Since diagnosis is uncertain in up to one third of patients because of atypical symptoms, many centers today request appendiceal imaging for clinically equivocal patients. Although plain radiography continues to play a role in evaluating patients with acute right lower quadrant pain, its role is quite limited. Less than 50% of patients with appendicitis show an abnormality on plain radiographs. The most specific finding is the presence of an appendicolith, which is usually calcified, solitary, and rounded.

US has become an important imaging option in the evaluation of suspected acute appendicitis, particularly in children, pregnant women, and women of reproductive age. The prime sonographic criterion is the demonstration of a swollen, non-compressible appendix greater than 7 mm in diameter with a target configuration (Fig. 2). Generally, the normal appendix cannot be defined with US, thus, clear visualization of the appendix is suggestive of inflammation.

Advantages of US include lack of ionizing radiation, relatively low cost, and widespread availability. On the other hand, US requires considerable skill and is difficult to perform in obese patients, patients with severe pain, and patients likely to have a complicating periappendiceal abscess. When the sonographic findings are unclear, CT can provide a rapid and definitive diagnosis.

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**Fig. 2.** A 25-year-old man presented with acute abdominal pain in the right lower abdominal quadrant. Physical examination and laboratory tests revealing elevated white blood cell counts, raised the suspicion of acute appendicitis. Longitudinal (a) and perpendicular (b) graded compression US shows an enlarged appendix ( cursors, diameter > 10 mm) with edematous thickening of the appendiceal wall, confirming the diagnosis of acute appendicitis.
CT has emerged in many centers as the primary imaging modality for patients with suspected acute appendicitis due to its exceptional accuracy. In the case of mild disease, the findings include a dilated, fluid-filled appendix with a calcified appendicolith or inflammatory changes of the mesenteric fat (Fig. 3). An inflammatory mass or an abscess may develop with disease progression and perforation.

Diverticulitis rarely manifests itself as a right-sided condition. Right-sided colonic diverticula are often congenital, solitary and true diverticula, unlike sigmoid diverticula. The normal appendix should be visible in right-sided diverticulitis. If the appendix cannot be identified, right-sided omental infarction or epiploic appendagitis must be considered in the differential diagnosis.

**Left Lower Quadrant**

Diverticulitis is the most common cause of acute abdominal pain in the left lower quadrant. Diverticulitis occurs in up to 25% of patients with known diverticulosis and typically involves the sigmoid colon. CT has replaced barium enema examinations because it is very sensitive and approaches 100% specificity and accuracy in the diagnosis or exclusion of diverticulitis. CT is also very useful in establishing the presence of pericolic complications and differentiating sigmoid diverticulitis from carcinoma — a major differential diagnostic consideration.

Superimposed on diverticulosis, the CT diagnosis of acute diverticulitis is based on the identification of segmental colonic wall thickening and pericolic inflammatory changes, such as fat stranding, inflammatory mass, gas bubbles, abscess, or free fluid (Fig. 4). Occasionally, patients with diverticulitis may manifest pneumaturia because of a complicating enterovesical fistula.

**Acute Abdomen with Diffuse Pain**

Any disorder that irritates a large portion of the GI tract and/or the peritoneum will cause diffuse abdominal pain. The most common disorder is gastroenterocolitis. Other important disorders are bowel obstruction, ischemic bowel disease, and GI tract perforation.

**Bowel Obstruction**

Bowel obstruction is a frequent cause of abdominal pain and accounts for approximately 20% of surgical admissions for acute abdominal conditions. The small bowel is involved in 60-80% of cases. Frequent causes of small bowel obstruction are adhesions resulting from prior surgery, hernias, and neoplasms. In the large bowel, mechanical obstruction is commonly due to diverticular disease or colorectal carcinoma. 5-10% of cases of large bowel obstruction are caused by volvulus, which is most commonly in the sigmoid, followed by the cecum.

The diagnosis of bowel obstruction is established on clinical grounds and usually confirmed with plain abdominal radiographs. Because of the diagnostic limitations of plain films, CT is increasingly used to establish the diagnosis, identify the site, level, and cause of obstruction and determine the presence or absence of associated bowel ischemia. CT can be useful for differentiating between simple and closed loop obstruction. Closed loop obstruction is a form of mechanical bowel obstruction in which two points along the course of the bowel are obstructed at a single site. It is usually secondary to an adhesive band or a hernia. A closed loop tends to involve the mesentery and is prone to produce a volvulus, thus representing the most...
common cause of strangulation. However, only volvulus of the large bowel is associated with classic features on plain abdominal radiographs. The sigmoid volvulus produces a distended loop, with the twisted mesenteric root pointing to the origin of the volvulus, i.e., to the sigmoid.

CT is particularly reliable in higher grades of bowel obstruction. It has proved useful for characterizing bowel obstruction from various causes, including adhesions, hernia, neoplasm, extrinsic compression, inflammatory bowel disease, radiation enteropathy, intussusception, gallstone ileus, or volvulus. The essential CT finding of bowel obstruction is the delineation of a transition zone between the dilated and decompressed bowel. Careful inspection of the transition zone and luminal contents usually reveals the underlying cause of obstruction. However, the presumed point of transition from dilated to non-dilated bowel can be difficult to determine in the axial plane. MDCT facilitates this task by providing the radiologist with a volumetric data set that can be viewed in the axial, sagittal, or coronal plane or any combination of the three. These MPR views centered on the anticipated transition point help to determine the site, level, and cause of obstruction.

Mechanical obstruction has to be differentiated from paralytic ileus. Numerous causes exist for both diffuse and localized paralytic ileus. Paralytic ileus is a common problem after abdominal surgery. It may be secondary to ischemic conditions, inflammatory or infectious disease, abnormal electrolyte, metabolite, drug or hormonal levels, or innervation defects. A massively dilated colon with a thickened wall ("thumbprinting") caused by wall edema and inflammation is seen with toxic megacolon in pseudomembranous colitis. Toxic megacolon is the radiological manifestation of a paralytic ileus.

**Ischemic Bowel Disease**

Arterial or venous occlusion or thrombosis and hypoperfusion are predominant causes of bowel ischemia. Usually, a combination of these factors is observed. The predominance of one factor determines the outcome and the findings on CT. Diminished bowel wall enhancement is the only direct sign of vascular impairment of the bowel and has been reported in predominantly arterial disease, such as infarction, as well as in predominantly venous diseases, such as strangulation. Other CT findings are direct visualization of the thrombus in the superior mesenteric artery or vein. Bowel distention and bowel wall edema are nonspecific findings and can be seen with inflammatory or infectious causes. Bowel distention reflects the interruption of peristaltic activity in ischemic segments.

In closed loop bowel obstruction the closed loop can become strangulated, i.e., ischemic, although the progression of a closed loop obstruction to a strangulated one is not inevitable. The reported prevalence of strangulating obstruction ranges from 5-40%. Strangulation is a predominantly venous disease. The most frequent abnormality seen on CT is bowel wall thickening. The thickened bowel wall is sometimes associated with the target sign, alternating layers of high and low attenuation within the thickened bowel wall, which results from submucosal edema and hemorrhage. The bowel segment proximal to an obstruction can become ischemic due to severe bowel distention. CT findings that suggest subsequent infarction include non-enhancement of the bowel wall, gas in the bowel wall, mesenteric or portal veins, edema/hemorrhage in the mesentery adjacent to thickened and/or dilated bowel loops, and ascites (Fig. 5).

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**Fig. 5.** 76-year-old man with acute diffuse abdominal pain and with a history of abdominal surgery performed five weeks previously. **a** Transverse MDCT demonstrates mesenteric edema and infarction of the distal ileum (arrowhead) with intramural gas. **b** Transverse MD-CT at a level below depicts thickening of the bowel wall with irregular mucosal enhancement (arrow) indicative of bowel ischemia. Intraoperatively, a strangulating small bowel volvulus secondary to adhesion of the distal ileum was identified.
GI Tract Perforation

Pneumoperitoneum usually starts with localized pain and culminates in diffuse pain after peritonitis has developed. It may result from a variety of causes. Gastroduodenal perforation associated with peptic ulcer or necrotic neoplasm has become less frequent in the last few decades due to earlier diagnosis and improved therapy. At the same time, the incidence of gastroduodenal perforations resulting from endoscopic instrumentation has increased. Perforation of the small bowel is relatively uncommon. Spontaneous rupture of the large bowel is more frequent and can occur in a markedly dilated colon proximal to an obstructing lesion (tumor, volvulus) or when the bowel wall is friable (ischemic or ulcerative colitis, necrotic neoplasm). Over the last decades, fiberoptic endoscopy has been increasingly performed for evaluation and biopsy of colorectal lesions, as well as for polypectomy; these procedures cause perforation in 0.5-3% of patients.

Pneumoperitoneum can be recognized by the presence of subdiaphragmatic gas on an erect chest radiograph or an erect or left lateral decubitus radiograph of the abdomen. An abundant pneumoperitoneum is indicative of a perforation complicating large bowel obstruction, and moderate quantities of free gas are seen in the perforation of the stomach. Only small quantities of gas escape with perforation of the small bowel, because the small bowel does not usually contain gas. Detection of subtle pneumoperitoneum is often difficult. CT is far more sensitive than conventional radiography for the detection of a small pneumoperitoneum, and it has thus become the modality of choice in cases that are unclear on a conventional radiograph. To enhance the sensitivity of CT for extraluminal gas, the images are also viewed at ‘lung window’ settings. On CT, small amounts of gas around the stomach and the liver are seen mainly after gastroduodenal or small bowel perforation.

Retroperitoneal perforations (duodenal loop beyond the bulbar segment, appendix, posterior aspect of ascending and descending colon, rectum below the peritoneal reflection) tend to be contained locally and remain clinically silent for several hours or days. Retroperitoneal gas has a mottled appearance and may extend along the psoas muscles. In contrast to intraperitoneal gas, retroperitoneal gas does not move freely when the patient’s position is changed from supine to upright for plain abdominal radiographs.

Acute Abdomen with Flank or Epigastric Pain

Acute flank or epigastric pain is commonly a manifestation of retroperitoneal pathology, especially urinary colic, acute pancreatitis, or leaking abdominal aortic aneurysm.

Urinary Colic

For several decades, intravenous urography has been the primary imaging technique used in patients with flank pain thought to be caused by urinary colic. Abdominal radiograph and US are considered useful for those patients with contraindications to irradiation or contrast media. However, because of the low sensitivity of abdominal radiographs and US for urinary tract calculi, the role of unenhanced CT has grown rapidly. On CT, virtually all ureteral stones are radiopaque, regardless of their chemical composition. Uric acid stones have attenuation values of 300-500 Hounsfield units (HU), and calcium-based stones have attenuation values > 1,000 HU. In addition to the direct demonstration of a ureteral stone, secondary signs of ureterolithiasis may be seen, including hydrourter, hydronephrosis, perinephric stranding, and renal enlargement (Fig. 6). Perinephric stranding and edema result from reabsorbed urine infiltrating the perinephric space along the bridging septa of Kunin. The more extensive the perinephric edema as shown on unenhanced CT, the higher the degree of urinary tract obstruction. Focal periureteral stranding resulting from local inflammatory reaction or irritation and induced by the passage of a stone helps localize subtle calculi. MDCT is
favored over single-detector CT because it provides coronal MPRs, which often portray the urinary tract more effectively than axial images.

When no stone is detected, a search for an alternative diagnosis should be performed. Non-calculus urinary tract abnormalities causing symptoms of colic include acute pyelonephritis, renal cell carcinoma, acute renal vein thrombosis and renal infarction. Extrarenal diseases, such as appendicitis, diverticulitis, small bowel obstruction, pancreatitis, and retroperitoneal hemorrhage may also simulate acute urinary colic. Occasionally, repeating the CT examination with intravenous, oral, or rectally administered contrast material may be required.

Acute Pancreatitis

Acute pancreatitis is an important disease causing epigastric pain. US is helpful for the demonstration of gallstones as a cause of acute pancreatitis and for the follow-up of known fluid collections. CT has become the imaging modality of choice to stage the extent of disease and to detect complications because CT findings correlate well with the clinical severity of acute pancreatitis. Pancreatic enlargement due to interstitial parenchymal edema may progress to pancreatic exudate collecting in the anterior pararenal space, the transverse mesocolon, the mesenteric root, and the lesser sac. The pancreatic parenchyma may undergo necrosis or hemorrhage. Severe pancreatitis is often complicated by thrombosis of the splenic and portal vein.

Acute pancreatic and peripancreatic fluid collections may evolve into pseudocysts. Pseudocysts exhibit defined capsules. A pseudocyst can erode peripancreatic vessels, resulting in bleeding or formation of a pseudoaneurysm. Larger aneurysms can be diagnosed by CT or sonographically with Doppler; angiography may be necessary to diagnose small pseudoaneurysms (<1 cm).

Leaking Aneurysm of Abdominal Aorta or Iliac Artery

One of the most life-threatening alternative diagnoses in acute flank pain is a leaking aneurysm of the abdominal aorta or iliac artery. When a patient with suspected rupture of an abdominal aortic aneurysm is hemodynamically unstable, US is the initial imaging technique used. The examination can be performed rapidly using portable equipment in the emergency room. However, the diagnosis of para-aortic hemorrhage by US is poor.

In hemodynamically stable patients non-contrast-enhanced CT is the initial imaging test of choice. Non-contrast CT can almost always demonstrate a para-aortic hematoma if present and may show additional findings helpful in establishing the diagnosis, such as a high-attenuating crescent sign. If the non-contrast CT findings are equivocal or if endoluminal stent graft repair of the aorta is planned, contrast-enhanced CT should be performed.

Conclusions

The practice of radiology in imaging patients with acute abdomen has changed dramatically in the last few years. The time-honored plain abdominal radiographs have been largely replaced with US and CT. In particular, helical CT and more recently, MDCT permit the examination to be performed in less time, with greater diagnostic accuracy, and with less patient discomfort. The topographic classification of pain (i.e., localized pain in one of the four abdominal quadrants, diffuse abdominal pain and flank or epigastric pain) facilitates finding the answer to specific questions. Therefore, close co-operation with the referring physician prior to imaging remains essential for rapid and accurate diagnosis.

Suggested Reading

Mindelzun RE, Jeffrey RB (1997) Unenhanced helical CT for evaluating acute abdominal pain: a little more cost, a lot more information. Radiology 205:43-47
Introduction

Trauma has become a significant health problem, in part due to high velocity transportation and the use of penetrating weapons, especially firearms. Not only the young, but also the elderly and pregnant women are affected. Improvements for those affected include more rapid rescue, better organization of trauma centers, and advances in treatment. There are three recent trends: the increased tendency for non-operative care, the resulting increased need for accurate non-invasive imaging diagnosis, and a desire for cost-effective use of imaging. One aspect of the trend towards non-operative care is the desire to avoid non-therapeutic surgery; this is possible if imaging can identify those patients who require surgery. Another aspect is the realization that non-operative care can result in better long-term outcome, such as salvaging splenic and renal function. Lastly, imaging evaluation with a high negative predictive value may allow for discharge of trauma victims directly from the Emergency Department, avoiding hospital admission for observation.

CT versus Ultrasound

Controversy exists about the appropriate use of CT versus ultrasound (US). Each has advantages and disadvantages [1-3]. In general, CT has been shown to have the best statistical accuracy for detecting, characterizing and excluding injuries. If the volume of trauma justifies it, CT can be located in the trauma suite such that even unstable patients can be examined quickly and without compromise. This has been done in our institution and there is heavy reliance on CT for rapid accurate diagnosis, avoiding diagnostic peritoneal lavage and non-therapeutic laparotomies. CT is more reliable at excluding injury in those who may be discharged home, avoiding observation in hospital.

However CT may be overused – in one study only three of 100 patients had an alteration in clinical management after follow-up CT [4]. Sonography can detect significant injuries that can be treated; conversely, low risk patients with normal sonograms may be observed and possibly avoid CT [2, 3]. One of the strengths of US is its ability to detect peritoneal fluid, a significant but non-specific finding indicative of abdominal injury. However, abnormal US often requires further evaluation by CT. In a large study, US had 86% sensitivity and 98% specificity, with 43 false negative and 23 indeterminate studies, including six splenic, one liver, one renal, one pancreatic and one bowel injury [3]. Although the incidence of significant injury in the absence of free intraperitoneal fluid is low, it does occur. A multi-institutional study found a 28% incidence of splenic and hepatic injury in patients with no or minimal free fluid on CT [5]. In patients with seat belt marks, where bowel and mesenteric injury are common, US has been reported to miss up to 78% of significant injuries [6].

The advent of multidetector CT (MDCT) for trauma has allowed some improvements, although routine trauma CT of the abdomen has changed little. Use of MDCT allows for more rapid acquisition of high quality images of multiple body parts, such as examination of the head, neck, chest, abdomen and pelvis. It allows for better reformatting of images, with either thinner slice reconstructions, or other planes. In addition, if clinical circumstances warrant, a CT angiogram can be performed immediately followed by routine trauma imaging.

In traumatized pregnant women, US should be the first examination. It can evaluate the pregnancy, documenting fetal viability. US is nearly as accurate in detecting abnormal fluid in pregnant, as in non-pregnant patients [7]. If US shows fluid or other injury, CT is justified to obtain the best evaluation (Fig. 1). The best outcome for the fetus is assured by the best care of the mother. The radiation risk is reasonable if there is life-threatening injury, necessitating prompt diagnosis and treatment [8].

Urinary Tract

Installation of CT in the Trauma unit, and nearly universal use of CT, has altered our assessment of urinary tract trauma. While significant hematuria has been shown to be the best indicator of urinary tract injury, presently the decision to perform CT has little to do with presence or
absence of hematuria. CT is a primary investigation, after standard radiographs, for those patients with significant mechanism of injury or any signs or symptoms of significant injury. While intravenous urography (IVU) can detect renal injuries, it is less sensitive than CT, not accurate for grading the renal injury and cannot assess other organ systems (Fig. 2). US has a limited ability to evaluate renal injury [9]. Although screening US has value in trauma in general, it has severe limitations in detecting genitourinary (GU) injury. Free intraperitoneal fluid may not result from renal injury; although it may from bladder rupture, US cannot diagnose bladder injury. In a study of 4,320 trauma patients who had undergone US, 33 of 99 patients with urologic injury had false negative US. The sensitivity was only 56% for those with isolated urologic injury [10]. US is also not capable of grading renal injuries.

CT has excellent negative predictive value for renal injury. Presence and type of renal injury can be accurately indicated [11]. Renal contusion demonstrates ill-defined
regions of diminished enhancement. Segmental renal infarction is identified as a wedge shaped, well-defined area of non-enhancement, and renal artery occlusion can be accurately diagnosed by its complete lack of enhancement or excretion by the kidney, usually with little to no associated hematoma. Angiography is thus not needed, and conservative therapy is now most often used. Most renal injuries are lacerations, with simple laceration limited to the cortex, and deep laceration extending into the collecting system, which may show extravasation. Scans delayed between 2 and 10 minutes aid in demonstrating or excluding extravasation (Fig. 3), although in most cases small amounts of extravasation will resolve with conservative therapy. Subcapsular hematoma is delimited by the renal cortex and may deform the renal surface; perinephric hematoma extends from the renal surface to fill Gerota’s space, but does not deform renal contours, although it may displace the kidney. CT is excellent at demonstrating the extent of hematoma, and evaluating enlargement on follow-up scans [11]. Renal fracture indicates a single complete fracture plane, often extending through the collecting system; multiple planes of disruption are seen with shattered kidney. CT can also diagnose ureteropelvic junction (UPJ) avulsion or ureteral injury, demonstrating lack of opacification of the ureter, retroperitoneal water attenuation collections adjacent to pelvis or ureter, and possibly extravasation of contrast on delay scans [11].

Although the American Association for Surgery of Trauma (AAST) Organ Injury Severity Scale for the kidney includes lesions with a different appearance in each category (1: contusion, small subcapsular hematoma, 2: < 1 cm laceration without extravasation, 3: > 1 cm laceration without extravasation, 4: deep laceration with extravasation or main renal artery or vein injury, 5: shattered kidney or UPJ avulsion), it has been shown to correlate with need for surgery and outcome [12].

Urethral injuries are predominantly seen in males. Anterior urethral ruptures are most commonly seen due to straddle injury. Posterior urethral ruptures most often are due to compressive force and resultant pubic bone fractures, although both anterior and posterior urethral injury can result from penetrating injury. Retrograde urethrography is the only accurate diagnostic imaging procedure. If a urethral injury is strongly suspected, a urethrogram should be performed before passage of a catheter (Fig. 4). However, in patients with moderate risk, a urethral catheter may be gently passed and the patient may go on to CT. A pericatheter urethrogram may then be performed after other injuries are stabilized. Urethral in-

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**Fig. 3.** Hematuria after fall from power line. a Initial CT shows left renal laceration with perinephric hematoma. b Delay image shows no leak from collecting system

**Fig. 4.** Blunt trauma resulted in pubic rami fractures. Retrograde urethrogram reveals type 3 posterior urethral rupture
Injuries may be classified as Type 1: posterior urethra stretched but intact, Type 2: tear of membranous urethra above urogenital diaphragm, Type 3: tear of posterior urethra above and below urogenital diaphragm, Type 4: bladder neck injury and Type 5: anterior urethral injury [13]. Although urethrography remains the standard, CT findings have been described in urethral injury, which may be useful if CT is performed as the initial study. Obscuration of normal periurethral landmarks, in particular distortion or obscuration of urogenital diaphragm fat planes and hematoma of the ischiocavernosus muscle, are commonly seen in those with urethral injury [14]. Alternatively, completely normal perineal anatomy may exclude significant injury, but further investigation is needed.

Bladder injuries, which consist of contusions and ruptures, are most commonly extraperitoneal, less commonly intraperitoneal, or are combined in about 5% of cases. They have classically been detected with standard radiographic cystography (Fig. 5). While CT with only intravenous contrast may fail to identify extravasation from a ruptured bladder, several studies have shown very high accuracy for CT cystography, which is now our standard (Fig. 6). In those with suspected bladder rupture (primarily those with gross hematuria, over 25 red blood cells per high power field [rbc/hpf] with pelvic fractures, or unexplained pelvic fluid), we perform standard CT with the bladder catheter clamped. If there is no extravasation, the bladder is drained then refilled with 300-500 cc of dilute contrast and the pelvis is rescanned. Bladder ruptures are virtually always associated with fluid or hematoma in the pelvis, but such blood or fluid may be due to splenic or other injuries, or pelvic fracture. Extravasation low in the pelvis, not outlining bowel loops (and which may extend up the retroperitoneum) indicates extraperitoneal rupture that most often can be managed conservatively. Extravasation high near the dome outlining bowel loops or extending to the gutters or higher indicates intraperitoneal rupture, and is more often managed surgically [15].

**Bowel and Mesenteric Injury**

Bowel and mesenteric injury are found in about 5% of patients having surgery for trauma, seen in 0.7% of traumatized patients [1, 16]. Mechanism of injury is direct compressive force, including from seatbelts, although deceleration may play a role. Morbidity and mortality can occur if peritonitis and resulting abscess are missed. Clinical signs and symptoms are non-specific. Although positive diagnostic peritoneal lavage (DPL) or free fluid on sonography may be due to bowel or mesenteric injury, these findings are non-specific [2].

Although some have commented on the difficulty of correct diagnosis by CT, CT is the most accurate diagnostic modality, with a reported sensitivity of 88-96% and a specificity of 80-99% [16-20]. Use of oral contrast,
and early scanning after rapid injection of high volume intravenous contrast allows detection of extravasation [21]. Active bleeding is seen as a focal collection with attenuation similar to the aorta at the same level and different from the adjacent organ. Contrast extravasation, whether intravenous contrast from a mesenteric vessel or oral contrast from the bowel lumen, is the most specific sign of mesenteric or bowel injury, but is not common – it was seen in only seven of 26 patients with bowel injury [17]. Free air is thought to be a good sign of perforated bowel, but in fact it has limited value; it is infrequently seen in those patients with bowel injury, and may in fact represent air tracking into the peritoneum from thoracic injuries. Free air was seen in only 28% of true positive CT scans, but in 2% of false positive scans [16]. The commonest finding was unexplained free fluid, even though 70% of those with only unexplained free fluid had no bowel injury. Other findings, such as focal bowel wall thickening, interloop fluid, mesenteric stranding or frank hematoma are often seen (Fig. 7). If a single finding is seen, likelihood of injury is low; a combination of findings, particularly free fluid without an obvious source in combination with focal bowel wall thickening and/or mesenteric stranding is very suggestive of bowel injury and such patients should be further explored or followed very carefully.

Oral contrast presents a risk, although low, of adverse events, including aspiration pneumonia. Given this and the low rate of visible bowel contrast leak, some have questioned the use of oral contrast to detect bowel injury. One study of 1,000 patients [22] and another of 500 [23] showed similar accuracy to previous reports with oral contrast – with a sensitivity of 82-95%, and a specificity of 99%. At our institution, the use of oral contrast has been discontinued in trauma patients with no recognized ill effect.

**Splenic Injuries**

The spleen is the most frequently injured abdominal organ in blunt trauma. There may be signs of blood loss, or left upper quadrant pain, but the diagnosis largely rests on imaging or surgical exploration. A trend towards non-operative management is supported by evidence that long-term health is better in those who have had splenic function preserved. This necessitates accurate non-invasive diagnosis, and is aided by signs predictive of success or failure of conservative management.

Splenic injuries can cause free fluid, perisplenic or elsewhere, which can readily be detected by sonography. Splenic injury may alter echo texture: lacerations may be anechoic if there is rapid bleeding, but are more commonly more echogenic than normal spleen [2]. With such findings on sonography, the decision whether to further evaluate with CT or to proceed to surgery can be made on clinical grounds (Fig. 1). Splenic injuries may be missed by sonography, particularly if not associated with free fluid. In one large study, there were 43 false negative sonograms, including six splenic ruptures that required surgery [3].

CT is quite sensitive for the detection of splenic injuries [24]. Subcapsular hematoma is seen as a crescentic low attenuation peripheral rim, and intraparenchymal hematoma is seen as a rounded area within the spleen with low attenuation and no enhancement. Lacerations are common, seen as linear or branching low attenuation lesions which often extend to the surface, often associated with perisplenic or free fluid (Fig. 1, 2). Hemoperitoneum tends to be higher attenuation close to the source of the bleeding; thus when the spleen is the source, the collection adjacent to the spleen may be higher in attenuation than elsewhere (Fig. 1), the sentinel clot sign. Lacerations may involve the vasculature. There can be devascularization of the spleen by hilar injury. There may be active extravasation into the peritoneal cavity or a confined area of extravasation – a pseudoaneurysm (Fig. 2). Both types of extravasation indicate that non-operative management may not succeed, although angiographic embolization may control the bleeding and allow splenic salvage [25].

A number of schemes have been devised to grade splenic injury on CT in an attempt to predict outcome, with variable correlation with need for surgery [1]. One of the commonest is the AAST scoring system. In a large study, failure of non-operative management correlated with splenic injury grade: less than 10% failed with grades 1 or 2, while one-third of grade 4 and three-quarters of grade 5 injuries required surgery [26]. Nevertheless, for the individual patient, occasional cases of low-grade injury suffer delayed rupture, and some high-grade injuries are successfully conservatively managed. The additional finding of traumatic pseudoaneurysm or active extravasation (which does not confer to a specific stage in the AAST scoring system) increased the likelihood of failure of non-operative management, whatever the grade [27]. No CT findings are accurate predictors of

![Fig.7. Motor vehicle collision. Focal hematoma and thickening of cecum; cecal laceration was found at surgery](image-url)
the need for intervention. Angiographic embolization has similar outcomes and less morbidity compared with surgery [28].

Hepatic Injuries

The liver is the second most frequently injured abdominal organ, accounting for about 20% of abdominal injuries [1, 24]. The right lobe is more often affected than the left, with the posterior right lobe being the most frequently injured segment. Hepatic injuries may be associated with intraperitoneal hemorrhage, but injury may be confined to the liver, or hemorrhage limited by an intact capsule. Laceration of the bare area is associated with extraperitoneal fluid [1]. US may show liver lacerations, which appear similar to splenic injuries, but US has a limited sensitivity of 67%, compared to 93% for CT [29]. This is in part because of the large size of the liver, and the difficulty in clearly imaging all portions by US.

Injuries to the liver include contusion, seen on CT as an ill-defined area of low attenuation; subcapsular hematoma, a crescentic collection limited by the capsule; and intraparenchymal hematoma, a collection of blood within a liver laceration. Laceration is the most common, with linear or branching low attenuation regions, sometimes with jagged margins, that can extend to surface or to vessels. Periportal low attenuation is usually due to edema, but it may represent blood tracking along portal veins. Rarely, this is the only sign of liver injury [1, 24]. The most severe, and rare, injury is avulsion of the hepatic pedicle [30].

Liver injuries may require surgery, but 50-90% can be managed non-operatively. The liver, with a dual blood supply, is relatively resistant to infarction, and has considerable functional reserve. No CT signs or grading schemes have been shown to be reliable predictors of which patients will require intervention. However, active extravasation may predict a need for surgery or angioembolization. The presence of hepatic arterial extravasation or extension of injury into hepatic veins correlates with the need for surgery [31]. Subclassification of extravasation can be useful: extravasation into the peritoneal cavity is highly correlated with the need for surgery, intraparenchymal extravasation with significant hemoperitoneum may require surgery, while extravasation limited within a hepatic hematoma without hemoperitoneum can usually be managed conservatively [21].

References


Introduction

Computed tomography (CT) is the established method for the imaging evaluation of traumatic injury to the abdomen and pelvis. This role has been galvanized in the era of multidetector CT (MDCT) because of the greater speed and flexibility afforded by this modality. MDCT can now image the head, entire spine and torso, often in less time than would be typical for obtaining a standard three-view radiographic trauma series (portable chest, lateral C-spine and AP pelvis). When coupled with its accuracy for detecting multisystem injuries, CT has become the indispensable means by which prompt diagnosis and triage is undertaken for the stable trauma patient. Additionally, the high quality image data sets now obtained from MDCT permit the routine use of post processing techniques such as multiplanar reformation (MPR), maximum intensity projection (MIP) and three-dimensional (3D) image display for improving evaluation and communication of diagnostic results.

MDCT Imaging Techniques

Since most traumatic injury is not isolated to a single anatomic region, abdominal and pelvic imaging is usually undertaken in the context of a complete system evaluation of the multitrauma patient that often includes imaging of the head, entire spine and torso. As previously published by several authors, following a head CT without intravenous contrast material (IVCM), scanning is performed from the circle of Willis, or alternatively, from the thoracic inlet to the symphysis pubis following the intravenous administration of nonionic IVCM (100-150 ml of 300 mg iodine/mL, Ultravist 300) using an injection rate of at least 3 cc/s. Imaging through the abdomen should be timed so that it commences during the portal venous phase of homogeneous parenchymal enhancement. Early or delayed scanning may falsely simulate injury or decrease conspicuity of true injury. At our institution, the emergency radiologist immediately reviews a trauma patient’s scans while the patient is on the CT table. When injury is present, delayed imaging is generally performed approximately 3 minutes after the initial IVCM injection, or during the pyelographic phase. Delayed imaging is not performed if no significant injury is detected, thereby reducing radiation exposure for these patients. If immediate review of the initial scan is not an option based on radiologist’s availability, or if the incidence of injury is high among a given institution’s trauma population, routine acquisition of a delayed scan in every patient may prove a more efficient means of operating procedure. An unenhanced CT is performed in patients with known renal insufficiency or severe contrast allergy, though sensitivity for detecting injury is reduced.

Oral contrast material (OCM) is not routinely used at our trauma center at the time of the initial CT evaluation. Though the use of OCM has been shown to be safe, the perception of providers at our institution is that it delays transit to CT, results in the otherwise unnecessary placement of a nasogastric tube in many patients, and owing to the speed of MDCT, is increasingly of little benefit having rarely progressed beyond the stomach to typical areas of injury by the time CT is performed in most patients. Instead, once immediate life-threatening injuries have been excluded by an initial CT scan, patients with suspected bowel injury based on clinical grounds or results of the initial scan are reimaged after administration of water soluble OCM and a relatively short time for bowel transit, usually about 1 hour.

Rectal contrast material should be administered in all patients with penetrating injuries to the abdomen or flank. Approximately 50 cc of Ultravist 300 (or any IVCM of similar iodine concentration) is injected into a liter of warm saline for use as contrast material. Adequate colonic distention generally involves administration of approximately 500 cc rectal contrast material with the patient in a left lateral decubitus position for suspected left colonic injury, or up to a liter of contrast material with the patient in a right lateral decubitus position for suspected right colonic injury. Use of intravenous, oral and rectal contrast material (i.e., triple contrast CT) has been shown to be a highly accurate means of excluding peritoneal violation in the setting of penetrating trauma to the flank. Additionally, among those patients with peritoneal violation, CT has been reported...
to accurately predict the need for laparotomy with 100% sensitivity, 96% specificity, 100% negative predictive value, and 97% accuracy.

When bladder injury is suspected, CT cystography is performed. Antegrade filling of the bladder from renal excretion of IVCM is insufficient for excluding bladder injury. Bladder contrast is easily obtained by mixing 50 cc Ultravist 300 in a liter of warm saline. Following the initial scan of the abdomen and pelvis with IVCM, the Foley catheter is unclamped, permitting complete drainage of excreted contrast material. A closed system is used to connect the liter of saline to the indwelling Foley catheter and contrast is instilled in a retrograde fashion with the saline bag approximately 40 cm above the height of the patient’s bladder (i.e., the height of the CT table). Bladder contrast is instilled until one of the following: 1) contrast flow stops, 2) 350 to 400 cc of contrast have been instilled, or 3) the patient no longer tolerates contrast instillation. Adequate retrograde distention of the bladder is critical for its proper evaluation. Furthermore, CT cystography should not be performed until after the initial CT scan through the abdomen and pelvis with IVCM. This allows easy discrimination between arterial extravasation and bladder contrast extravasation, both of which are encountered in the setting of pelvic fractures.

Splenic Injury

The spleen is the most commonly injured solid organ in the setting of blunt abdominal trauma, representing approximately 25% of all blunt injuries to the abdominal viscera. The spleen is a highly vascular organ that weighs approximately 75-100 grams in the average adult, contains approximately one unit of blood at any given time and circulates approximately 350 liters of blood per day. With greater recognition of its important immunologic roll, there has been a progressive trend toward the conservative, nonoperative management of splenic injury among hemodynamically stable patients. Today, more than half of all patients with splenic injury are managed nonoperatively.

Splenic injury may be manifest on CT as parenchymal contusion, intraparenchymal or subcapsular hematomas, intrasplenic lacerations, vascular injuries including pseudoaneurysms and arteriovenous fistulas, and active arterial hemorrhage. Parenchymal contusions are seen as poorly defined areas of decreased parenchymal enhancement. Subcapsular hematomas are generally seen as well defined elliptical or crescentic collections of blood that reside immediately below the splenic capsule, may compress the subjacent splenic parenchyma and are of lower attenuation than the enhancing splenic parenchyma. Presence of parenchymal compression helps differentiate subcapsular hematoma from perisplenic hematoma. Intrasplenic lacerations are seen as linear or complex and branching areas of low attenuation coursing through the normally enhancing splenic parenchyma, whereas intraparenchymal hematomas are seen as intrasplenic low attenuation collections. Active hemorrhage, pseudoaneurysms and arteriovenous fistulas appear as areas of increased density relative to the normally enhancing splenic parenchyma and are of similar attenuation value to an adjacent major artery, generally within 10 Hounsfield units (HU) (i.e., contrast blush [CB]). Traumatic injury may also result in segmental or complete splenic devascularization.

Relying on CT appearance alone to accurately predict those patients requiring splenectomy versus those who can be managed nonoperatively would be highly advantageous. Unfortunately, despite a number of CT grading systems, none has proven reliable in predicting outcome for nonoperative management. Using logistic regression, Schurr et al. showed that CT splenic injury grade had no predictive value for nonoperatively-managed patients. Other studies have shown that CT often underestimates the severity of splenic injury. There is also significant interobserver variability among radiologists in their grading of splenic injury. Despite these limitations, CT has nonetheless greatly facilitated the trend toward nonoperative management, if for no other reason than its contribution toward excluding other injuries that would require surgical exploratory laparotomy.

More recent radiology literature suggests that some CT findings may have strong predictive values for failed nonoperative management. These include: 1) active hemorrhage, 2) post-traumatic pseudoaneurysm, and 3) arteriovenous fistula. All three of these lesions may be seen as a ‘contrast blush’ on the initial phase of CT scanning. The latter two splenic vascular injuries cannot be further differentiated on contrast-enhanced CT. However, the latter two can be differentiated from active hemorrhage on delayed scanning, at which time the arterial attenuation ‘blush’ typically decreases to become isodense or minimally hyperdense compared to the normally enhancing splenic parenchyma. Conversely, the arterial ‘blush’ persists during delayed scanning with active hemorrhage since the contrast material has extravasated from vascular structures and therefore does not ‘wash-out’. Furthermore, whereas the splenic vascular injuries of post-traumatic pseudoaneurysm and arteriovenous fistula are always intrasplenic, active hemorrhage may be intrasplenic, subcapsular or freely intraperitoneal (Fig. 1) (Tab. 1).

Among those managed nonoperatively, the majority of failures will occur within 24 hours of admission. Gavant and colleagues reported an 82% failure rate among patients with contrast extravasation or intrasplenic vascular injury (pseudoaneurysm or arteriovenous fistula) who were managed nonoperatively. Other investigators have shown that patients with a CB by CT are 9.2 times more likely to require surgical laparotomy or angiographic embolization. In effect, a CB at CT has a high correlation with failure of nonoperative management. However, to date this finding has not been included in any of the widely used splenic injury grading criteria.