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# From esophagus to rectum: a comprehensive review of alimentary tract perforations at computed tomography

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## Abstract

Gastrointestinal (GI) tract perforation is a life-threatening condition that can occur at any site along the alimentary tract. Early perforation detection and intervention significantly improves patient outcome. With a high sensitivity for pneumoperitoneum, computed tomography (CT) is widely accepted as the diagnostic modality of choice when a perforated hollow viscus is suspected. While confirming the presence of a perforation is critical, clinical management and surgical technique also depend on localizing the perforation site. CT is accurate in detecting the site of perforation, with segmental bowel wall thickening, focal bowel wall defect, or bubbles of extraluminal gas concentrated in close proximity to the bowel wall shown to be the most specific findings. In this article, we will present the causes for perforation at each site throughout the GI tract and review the patterns that can lead to prospective diagnosis and perforation site localization utilizing CT images of surgically proven cases.

**Key words:** Gastrointestinal—Perforation—Computed tomography

Gastrointestinal (GI) tract perforation is a life-threatening condition that can occur at any site along the alimentary tract. The standard management is prompt surgical intervention, with patient morbidity and mortality rising significantly when diagnosis and treatment are delayed [1]. With delayed management, sepsis and multi-organ failure result in nearly 75% of perforation cases and the mortality rate approaches 30% [1–3]. In contrast, early perforation detection and intervention significantly improves patient outcome. With a high sensitivity for pneumoperitoneum, computed tomography (CT) is widely accepted as the diagnostic modality of choice when a perforated hollow viscus is suspected [4–6].

Direct findings on CT which confirm the presence of a perforation include focal bowel wall discontinuity, extraluminal gas, and extraluminal enteric contrast (when administered). Indirect signs of bowel perforation on CT include segmental bowel wall thickening, abnormal bowel wall enhancement, perivisceral fat stranding or fluid, and abscess [4, 7–12].

While confirming the presence of a perforation is critical, clinical management and surgical technique also depend on localizing the perforation site. CT is accurate in detecting the site of perforation in about 85% of cases [4, 7, 13]. If free intraperitoneal gas is found only in the upper abdomen, a proximal GI perforation is more likely. In contrast, when free intraperitoneal gas is only identified within the pelvis, the perforation site is likely to be colon or, less frequently, small bowel [7, 14]. If the gas is isolated to the extraperitoneum, a retroperitoneal perforation is more likely, including the second or third segments of the duodenum, ascending or descending colon, or distal third of the rectum. To further pinpoint the site of perforation, the presence of any of the following three CT findings has been shown to be the most reliable; segmental bowel wall thickening, focal bowel wall defect, or bubbles of extraluminal gas concentrated in close proximity to the bowel wall (Fig. 1) [4]. In this article, we will present the causes for perforation at each site throughout the GI tract and review the patterns that can lead to prospective diagnosis and perforation site localization utilizing CT images of surgically proven cases (Table 1).

## CT technique

At our institution, when an abnormality of the alimentary tract is suspected clinically, we obtain contiguous

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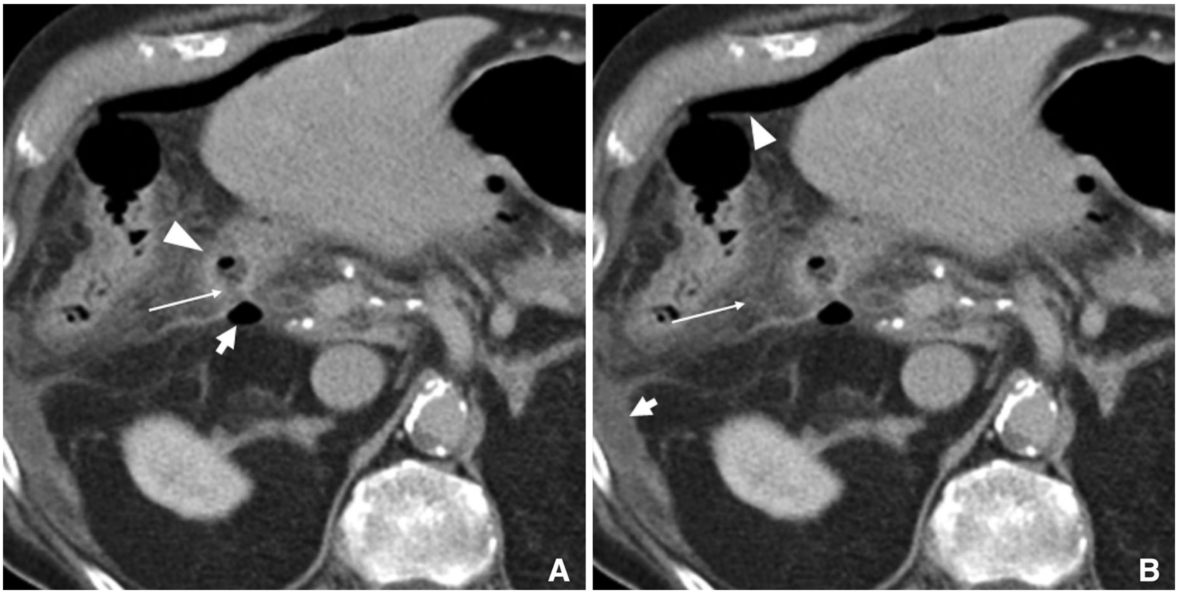


**Fig. 1.** **A** The three CT findings proven reliable in localizing a perforation site: (1) Segmental bowel wall thickening (*arrowhead*), (2) Focal bowel wall defect (*long arrow*), and (3) Concentrated extraluminal gas (*short arrow*). **B** The same image demonstrates CT findings contributory in diagnosing a bowel perforation, however, not shown to be consistently accurate in localizing a perforation site: (1) Subdiaphragmatic gas (*arrowhead*), (2) Perivisceral fat stranding (*long arrow*), and (3) Free intraperitoneal fluid (*short arrow*).

**Table 1.** Extraluminal air quantity and location by perforation site

| Perforation site | Free air quantity | Air location |
|---|---|---|
| Esophagus | Variable | Posterior mediastinum |
| Stomach/duodenal bulb | Large | Upper abdomen/intraperitoneal |
| Retroperitoneal duodenum | Variable | Retroperitoneal/right anterior pararenal space |
| Small bowel | Small | Intermesenteric/intraperitoneal |
| Appendix | Small | Periappendiceal |
| Colon | Variable | Variable (dependent on site of perforation), Intra- and/or retro-peritoneal |

axial images from the thoracic inlet through the upper abdomen to evaluate the esophagus or from the lung bases through the ischial tuberosities to evaluate the subdiaphragmatic GI tract. Intravenous contrast injection with a low osmolarity contrast medium is performed unless a contraindication exists. 5 mm maximum axial slice thickness images are acquired in the portal venous phase at a 60 s delay. Coronal and sagittal multiplanar reformatted images are routinely obtained. CT image interrogation with wide window settings (bone and lung windows) is complementary to conventional abdominal windows for detecting extraluminal gas [15, 16].

### *Oral contrast*

When administering oral contrast in a case of suspected bowel perforation, dilute water-soluble iodinated contrast (not barium-based contrast) should be administered. Extravasated ingested contrast material is a direct sign of bowel perforation, and when present, has a high specificity for localizing the perforation site. However, patients with peritoneal symptoms tend to poorly tolerate enteric contrast and waiting for intraluminal contrast opacification can delay emergent management. The sensitivity of extravasation of enteric contrast material varies from 19% to 42% [4, 17–19]. The relatively low observation is believed to be due to the rapid sealing of a large percentage of perforation sites and the supine positioning used for CT, which is unlikely to show extravasation of an anterior perforation. Therefore, enteric contrast can be helpful in identifying a site of perforation; however, it is most often noncontributory, and the absence of visible extravasation does not exclude a perforation.

## Esophagus

Esophageal perforation often presents acutely with nonspecific thoracic manifestations including, but not limited to, chest pain, odynophagia, vomiting, and shock. Therefore, CT is the most common modality utilized in detecting esophageal perforation in the emergent setting, and has been shown to be complimentary to

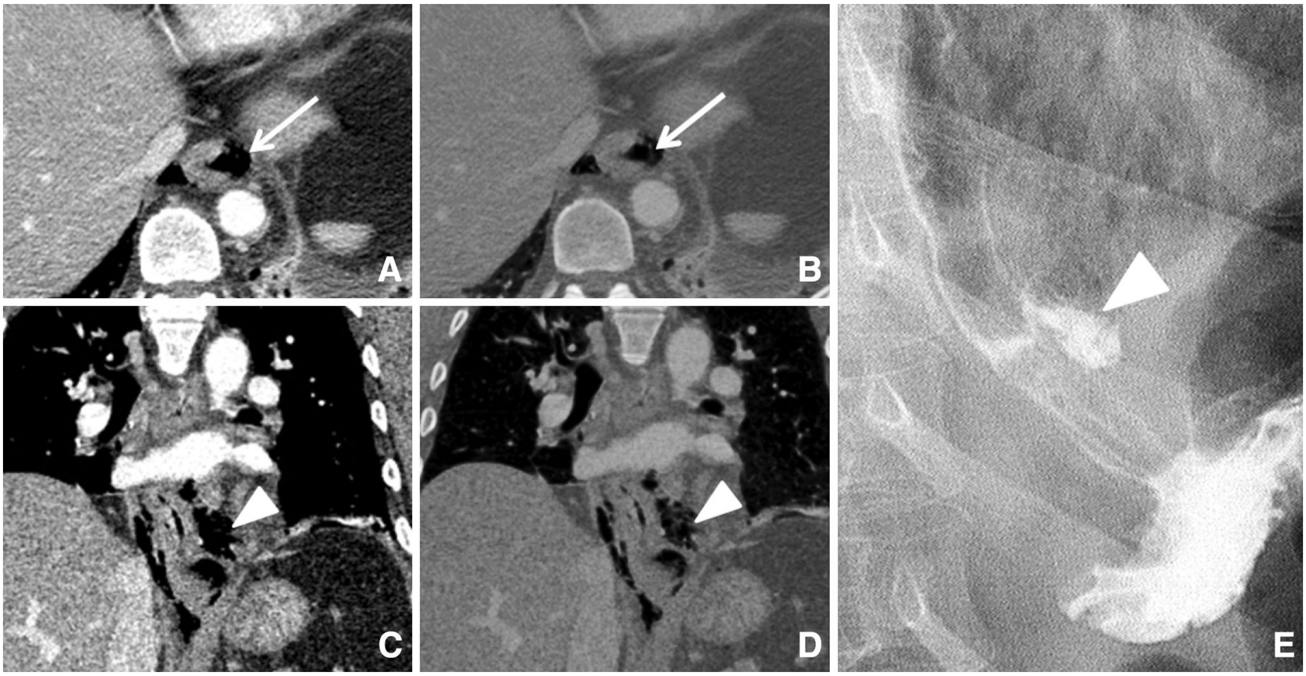


**Fig. 2.** Spontaneous: Boerhaave syndrome. **A**–**D** Axial and coronal soft tissue and bone algorithm images demonstrate a focal wall defect along the left side of the esophagus (*arrows*) and regional pneumomediastinum (*arrowheads*). **E** Subsequent esophagram confirms the perforation with extravasation of enteric contrast (*arrowhead*).

conventional esophagography and direct visualization in delineating the perforation location and underlying etiology [20–22]. As with elsewhere in the GI tract, delay in diagnosis accounts for the highest morbidity and mortality. Therefore, prompt detection and management is critical. The more common etiologies include spontaneous rupture (Boerhaave syndrome), foreign body ingestion, tumor, trauma, and iatrogenic causes.

### *Boerhaave syndrome*

With Boerhaave syndrome, spontaneous emetogenic perforation results from the rapid increase in intraluminal pressure encountered with vomiting in the setting of incomplete cricopharyngeal relaxation [20]. The most common rupture location is the distal left posterior wall, which classically presents with pneumomediastinum and left pleural effusion [20]. At CT, the esophageal wall defect may be detectable. Left-sided mediastinal gas and fluid and a left pleural effusion are often visualized (Fig. 2).

### *Foreign body*

Foreign bodies can result in perforation through penetration injury in the setting of sharp object ingestion or via pressure necrosis when a foreign body becomes lodged against the thin esophageal wall. Food bolus (usually meat) is the most commonly encountered esophageal impaction (Fig. 3) [20, 23, 24]. An underlying abnormality such as stricture is often discovered at the time of retrieval [20, 25]. Bones from fish or chicken account for the second most common esophageal foreign body (Fig. 4) [20, 26]. When the history suggests this type of foreign body, barium studies are discouraged as they may obscure visualization at the time of endoscopic examination and retrieval attempt [20, 24, 27].

### *Tumor*

Perforation of esophageal carcinoma is a rare complication that most often results from palliative measures such as radiation therapy, instrumentation at the time of stent placement, or via pressure necrosis from a previously placed stent [28, 29]. Esophagorespiratory fistulas are a known complication that can result from transmural disruption from an esophageal carcinoma or lung primary. The diagnosis may first be suggested in the setting of lung abscesses or recurrent pneumonias developing in this patient population [29]. At CT, a bronchoesophageal fistula may be visualized as a direct air-filled communication between the structures (Fig. 5). To maximize survival, the diagnosis of esophagopulmonary fistula must be established before the onset of resultant lung infections [29].

### *Trauma*

Esophageal perforation from external blunt trauma or a penetrating injury is rare, likely due to the small size and

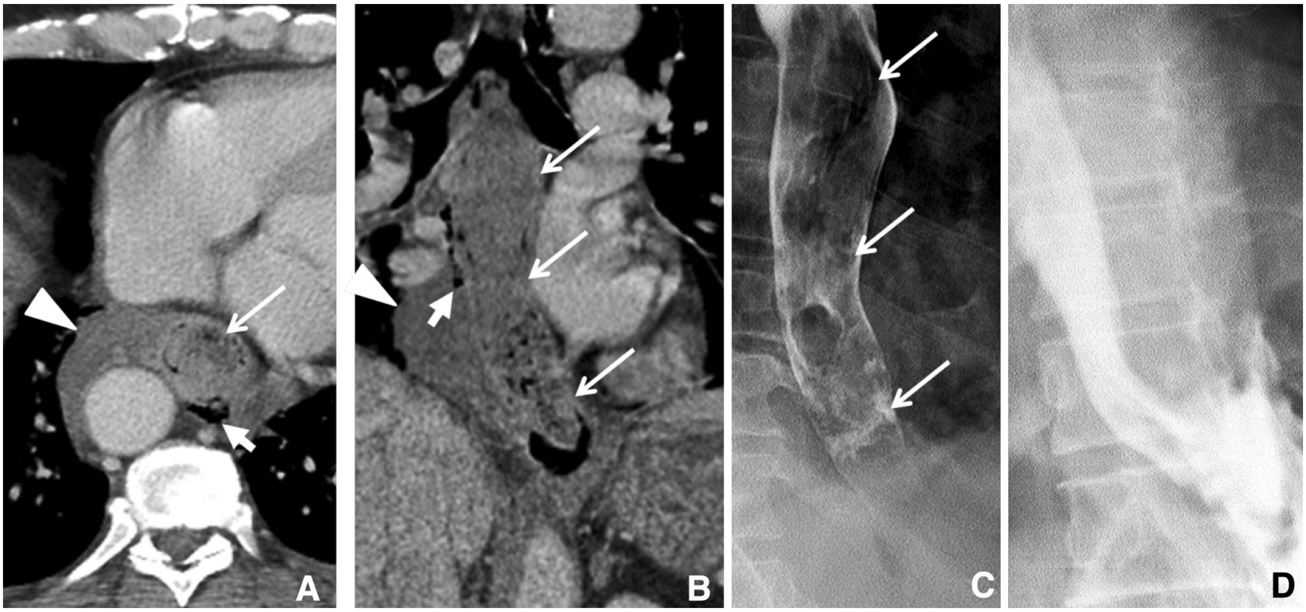

**Fig. 3.** Foreign body: food impaction. **A**, **B** Axial and coronal CT images demonstrate debris distending the esophagus (*long arrows*), with extraluminal paraesophageal fluid (*arrowheads*) and gas (*short arrows*). **C** Contrast ingested during esophagram fails to pass the debris/obstruction (*arrows*). **D** Post endoscopy and disimpaction; contrast readily flows into the stomach.

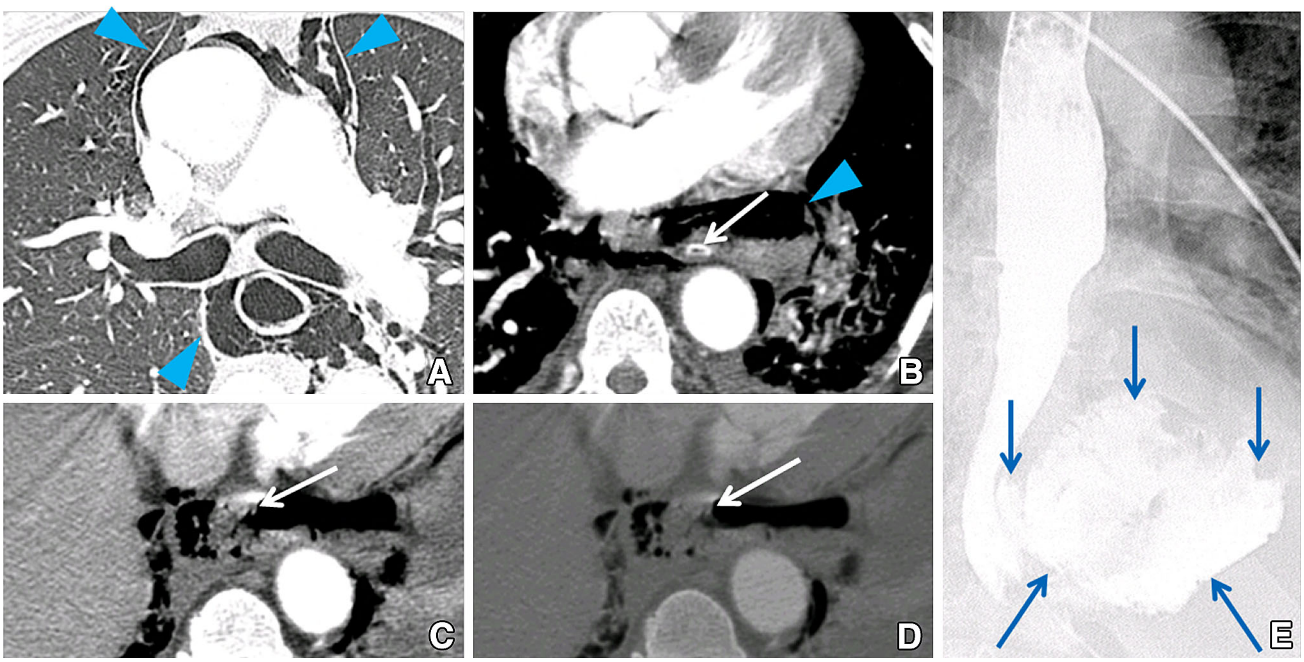

**Fig. 4.** Foreign body: fish bone. **A** Axial lung algorithm image shows extensive pneumomediastinum (*blue arrowheads*). **B** A loculated retrocardiac collection (*blue arrowhead*) containing a linear radiopaque density (*arrow*), confirmed to be a fish bone. **C**, **D** Soft tissue and bone algorithm images show an esophageal wall defect (*arrows*) in communication with the collection. **E** Esophagram confirms retrocardiac extravasation (*arrows*).

protected posterior position of the esophagus. Esophagography with water-soluble contrast is an effective imaging study in diagnosing an esophageal tear. However, the presenting symptoms of a traumatic esophageal injury are nonspecific and frequently attributed to more commonly encountered injuries [30]. Therefore, CT findings are often the first indication of a traumatic esophageal injury. An esophageal mural defect with

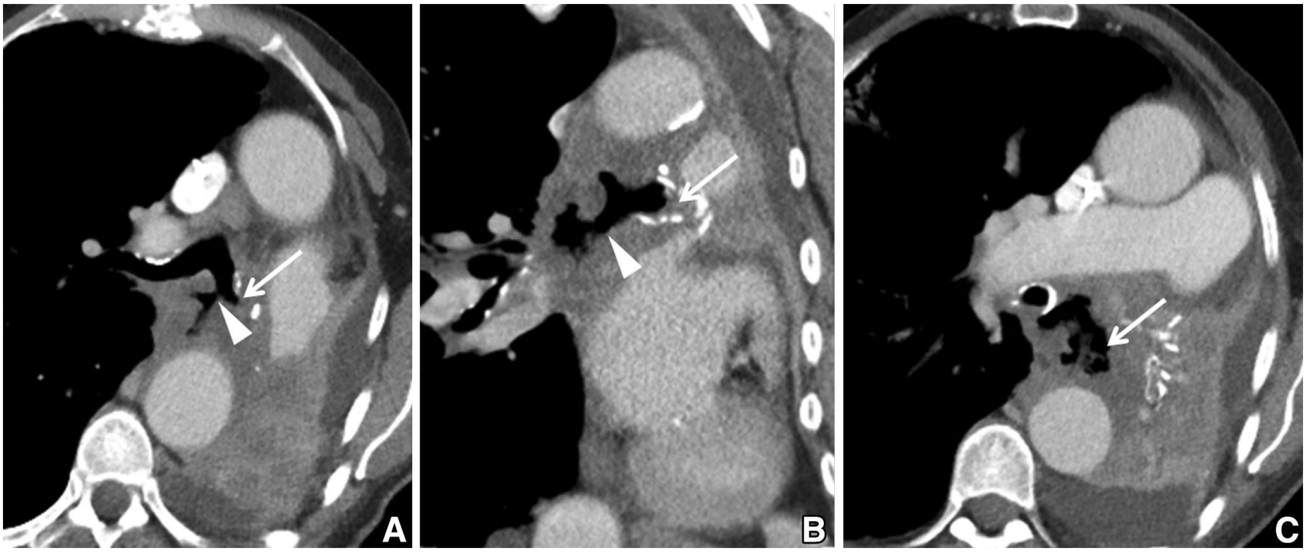


**Fig. 5.** Tumor: lung carcinoma with erosion into the esophagus; esophagobronchial fistula. **A**, **B** Axial and coronal CT images demonstrate left lower lobe bronchial narrowing (*arrows*) and lobar collapse, along with fistulous communication to the esophagus (*arrowheads*) in a patient with recurrent lung carcinoma. **C** The esophageal wall disruption led to a contained extraluminal gas collection within the posterior mediastinum (*arrow*).

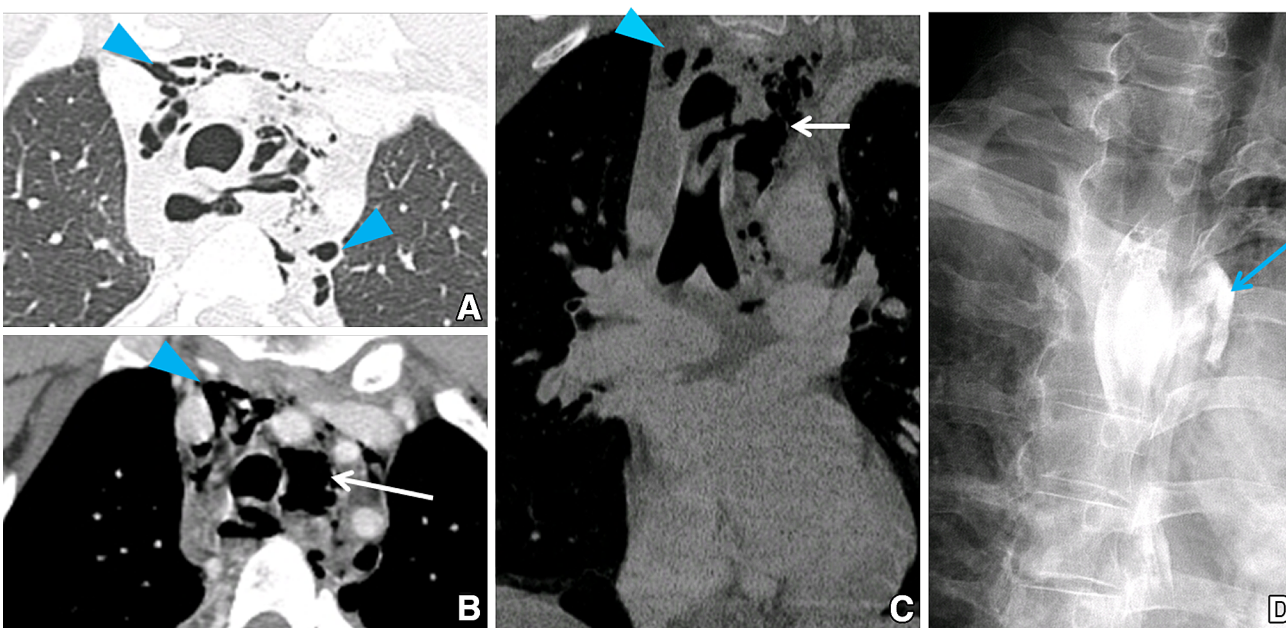


**Fig. 6.** Trauma: MVC. **A**–**C** Axial lung and soft tissue algorithm and coronal bone algorithm images show extensive pneumomediastinum (*blue arrowheads*) and a loculated collection in communication with the left wall of the upper esophagus (*white arrows*). **D** Esophagram confirms esophageal perforation (*arrow*).

posterior pneumomediastinum is diagnostic (Fig. 6). When not attributable to another cause, subcutaneous cervical gas or posterior pneumomediastinum should raise suspicion for esophageal perforation and guide further work up to include esophagography and/or direct inspection.

### *Iatrogenic*

Traumatic esophageal perforation is much more likely to result from iatrogenic causes [31]. Specifically, intraluminal trauma from therapeutic endoscopic procedures such as stricture dilatation and stent placement has the

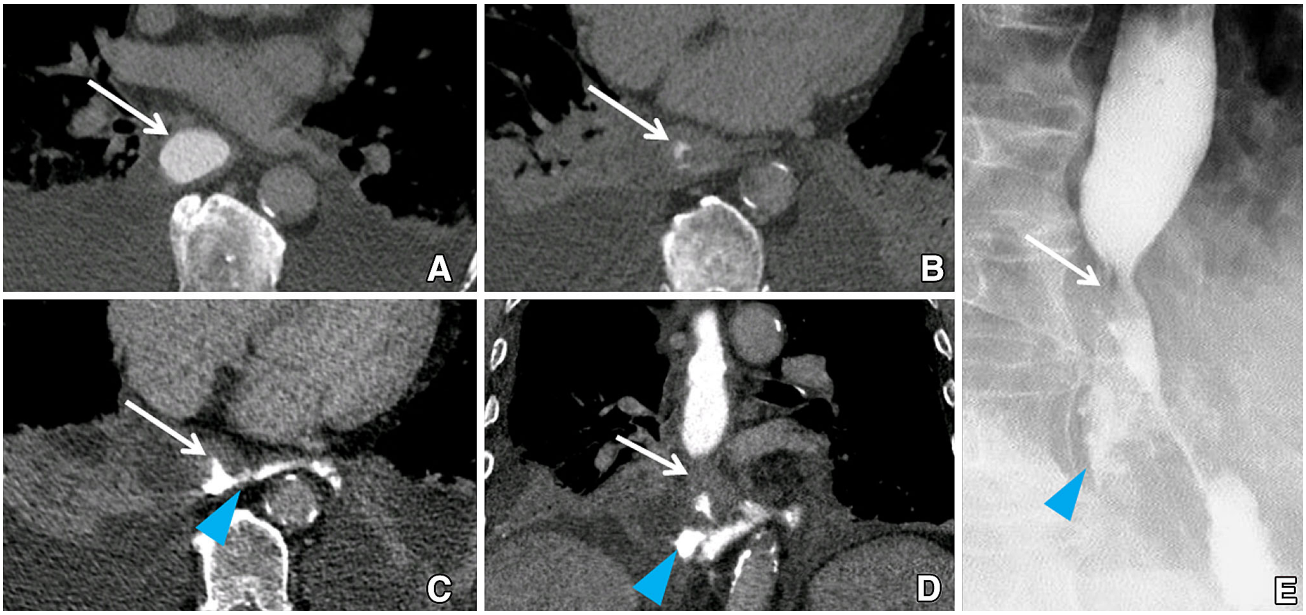


**Fig. 7.** Iatrogenic: EGD balloon dilatation attempt of an esophageal stricture. **A–C** Superior to inferior axial images show esophageal dilatation, stricture, and posterior wall disruption, respectively (*white arrows*) with extravasation of oral contrast (*blue arrowhead*). **D**, **E** Coronal image and subsequent esophagram demonstrate the stricture (*white arrows*) and ingested contrast pooling in the posterior mediastinum (*blue arrowheads*).

highest association. Effective management depends on an early clinical suspicion and accurate interpretation of diagnostic imaging [31]. The CT features will be similar to those described with trauma above, however, with the additional history of a recent esophageal procedure (Fig. 7).

## Stomach/duodenum

The primary etiologies leading to gastroduodenal perforation include ulcerative disease, blunt or penetrating trauma, malignancy, and iatrogenic causes [7, 9]. Gastric and duodenal perforations are discussed together in this section due to the similar causative pathology, clinical presentation, and management options. The imaging features can also overlap; however, there are some key differences which will be discussed below.

### *Ulcerative disease*

Pharmaceutical advancements (mainly the introduction proton pump inhibitors) along with an increased recognition of the importance of treating Helicobacter pylori infection have led to a considerable decrease in the incidence of peptic ulcer disease over the past three decades [1, 32]. Nevertheless, peptic ulcer disease remains the most common cause for gastroduodenal perforation [1]. Peptic ulcer perforation is most commonly found in the gastric antrum or duodenal bulb, with the duodenal ulcer perforation risk estimated at 5%–10% [1, 7]. At CT imaging, an ulceration or focal wall defect may be visible (Figs. 8, 9). Pneumoperitoneum is the most sensitive finding and can be extensive. However, the absence of extraluminal gas does not exclude gastroduodenal ulcer perforation, particularly at the onset of symptoms [7, 33]. Localized extraluminal gas in contact with the stomach or the duodenum is specific for localizing the perforation site to the adjacent viscus. Gastric and proximal duodenal perforations rarely result in air trapped within the mesenteric root or sigmoid recess, which would therefore strongly favor a perforation of the colon or distal small bowel [7, 14]. As the duodenum distal to the bulb is retroperitoneal, extraluminal gas in the right anterior pararenal space is a reliable CT finding for diagnosing a distal duodenal perforation. Sensitive, though less specific findings overlap with perforations elsewhere and include focal bowel wall thickening, perigastric or periduodenal fluid, and adjacent mesenteric fat stranding [7, 10]. Most patients with a perforated ulcer are managed surgically by suturing the perforation and preoperative confirmation of the ulcer location can impact surgical technique [1, 32, 34, 35]. While not common at our institution, a spontaneously sealed duodenal ulcer may occasionally be managed nonoperatively [7, 36].

Marginal ulceration occurring after Roux-en-Y gastrojejunostomy is a known and relatively common late complication of the operation. As with peptic ulcer disease, medical management is often sufficient. However, when perforation of a marginal ulcer occurs, the impact can be devastating. The reported incidence is ~1% of the

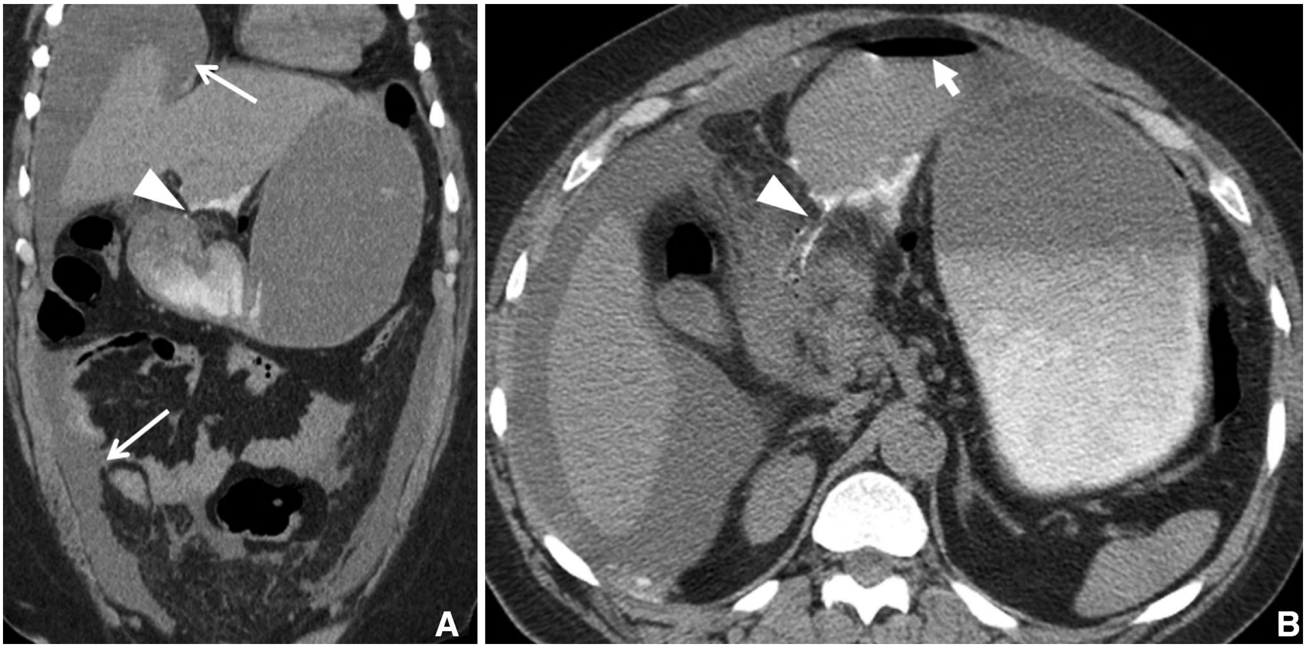


**Fig. 8.** Ulcerative disease: gastric ulcer. **A**, **B** Coronal and axial images show a thickened gastric antrum with extravasation of enteric contrast (*arrowheads*). There is extensive free fluid (*long arrows*) and a small amount of pneumoperitoneum (*short arrow*).

patients undergoing laparoscopic gastric bypass, and the perforation occurs on average 1.5 years after the operation [37]. On CT imaging, the salient findings are similar to peptic ulcer disease described above, however, will be located at the gastrojejunostomy anastomotic site (Fig. 10) [37].

## *Trauma*

With a thick muscular wall and protected location, the stomach is relatively resistant to external trauma. Penetrating injuries are more likely than blunt trauma to lead to gastric perforation, and the presence of a distended stomach increases the risk of rupture from either mechanism [1, 38]. CT features may show disruption of the gastric wall with perigastric fluid (Fig. 11). A large amount of gas may be released into the peritoneal space. With penetrating injuries, a wound track extending to the stomach may be evident (Fig. 12). Gastric trauma is often associated with concomitant left hemidiaphragmatic injury. When present, contamination of the chest cavity from spillage of gastric contents can place the patient at increased risk for subsequent empyema.

The retroperitoneal position of the duodenum provides protection from most penetrating injuries. However, with fixed attachments and proximity to the vertebral column, the descending and horizontal segments are at a relatively high risk for perforation in the setting of blunt trauma (Fig. 13) [7].

## *Tumor*

GI tract tumors are more likely to perforate as a consequence of trauma or iatrogenic injuries [39–45]. When spontaneous perforation occurs, the instigating factor tends to be underlying ischemia and necrosis (Fig. 14) [39–45]. Importantly, bowel perforation occasionally occurs proximal to the tumor secondary to the increased intraluminal pressure resulting from bowel obstruction or in the setting of a mucin-producing neoplasm [43]. Perforation of gastric tumors is rare, with a reported incidence of 0.4%–6.0%, and predominately occurs in malignant tumors at advanced stages (T3 or higher) [43, 44]. Therefore, when presenting as a perforation, CT imaging features to suggest an underlying malignancy are also often evident and include irregular thickening and enhancement of the gastric wall, perivisceral soft-tissue extension, peritoneal spread of disease, and lymphadenopathy [43]. When gastric carcinoma perforation occurs at an earlier stage, the sensitivity for CT identifying the malignancy is limited. However, in an elderly patient with a perforated deep ulcer on imaging, malignancy should be suspected [43, 46, 47].

## *Iatrogenic*

Any object placed into the GI tract has the potential to result in perforation [48–50]. Diagnostic and therapeutic techniques such as esophagogastroduodenoscopy (EGD) and endoscopic retrograde cholangiopancreatography

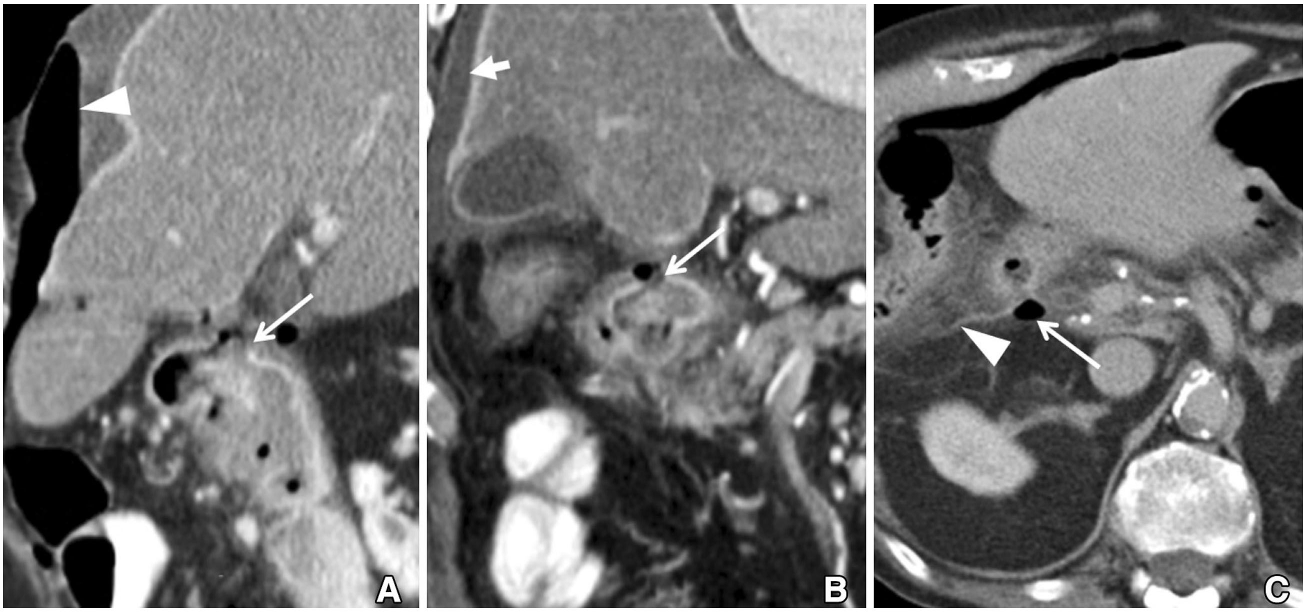


**Fig. 9.** Ulcerative disease: duodenal ulcer (same patient as Fig. 1). **A**, **B** Sagittal and coronal zoomed in images show a focal defect along the superior wall of the duodenal bulb (*long arrows*). Note the subdiaphragmatic intraperitoneal gas (*arrowhead*) and fluid (*short arrow*). **C** There is a concentrated gas bubble adjacent to the defect (*long arrow*) as well as perivisceral fat stranding (*arrowhead*).

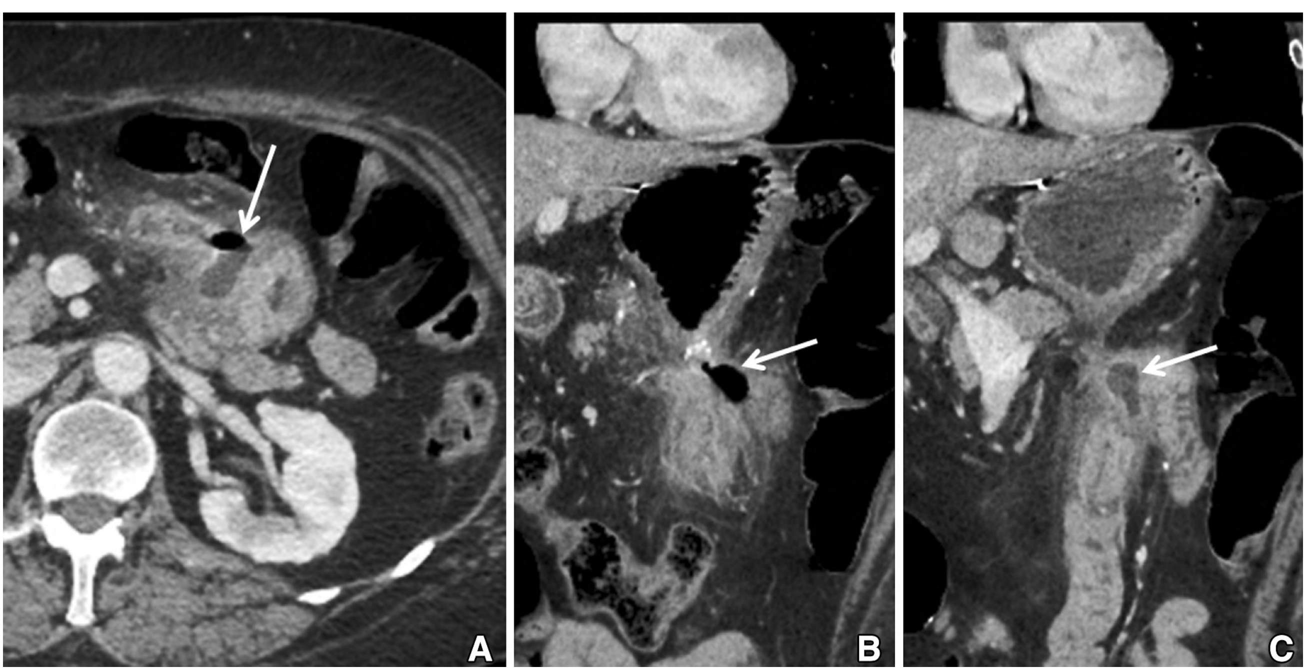


**Fig. 10.** Ulcerative disease: gastrojejunostomy with marginal ulceration. **A** Axial and **B**, **C** coronal images demonstrate a focal defect with adjacent extraluminal collection at the gastrojejunostomy anastomosis (*arrows*) in a patient 1 year post-gastric bypass. This history and imaging appearance was suspicious for, and confirmed at surgery to be, a contained perforation of a marginal ulcer.

(ERCP) are safe in the majority of patients, with reported perforation rates of 0.03%–0.3% [49, 50]. With EGD, the esophagus is the most common perforation site (51%), followed by the duodenum (32%), jejunum (6%), and stomach (3%) [50]. The thick, muscular gastric wall is felt to be protective. With ERCP, the retroperitoneal duodenum is by far the most frequent bowel perforation site, and is more common when a

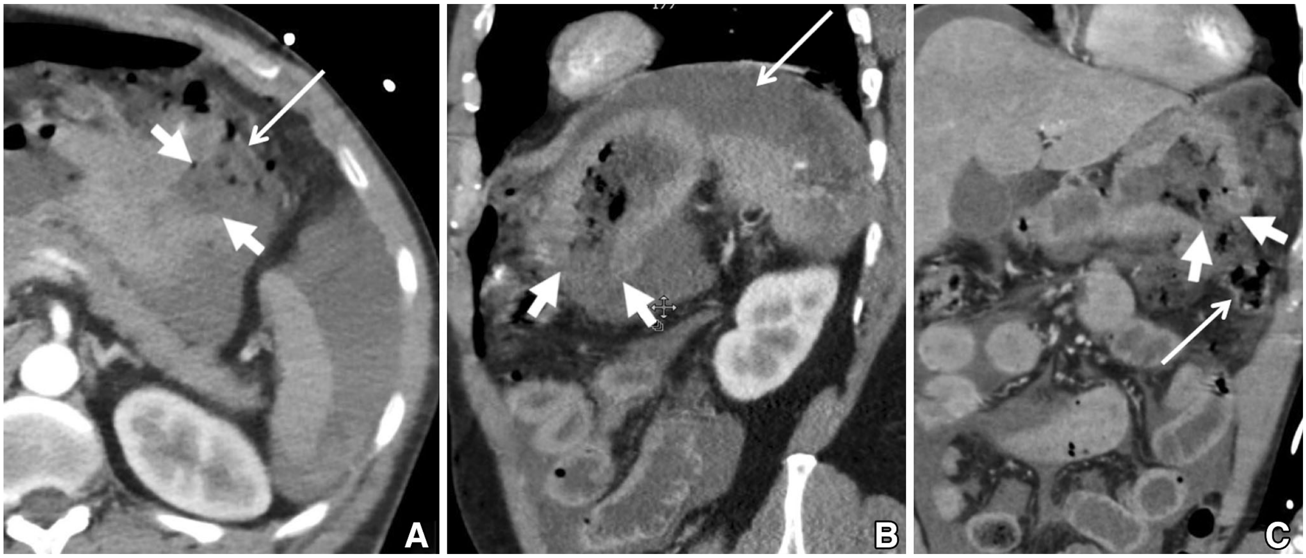


**Fig. 11.** Trauma: motorcycle accident with gastric rupture. **A**–**C** Axial, sagittal, and coronal images of the abdomen show a large rent involving the greater curvature of the stomach (margins outlined by the *short arrows*), with associated extraluminal fluid and gas (*long arrows*).

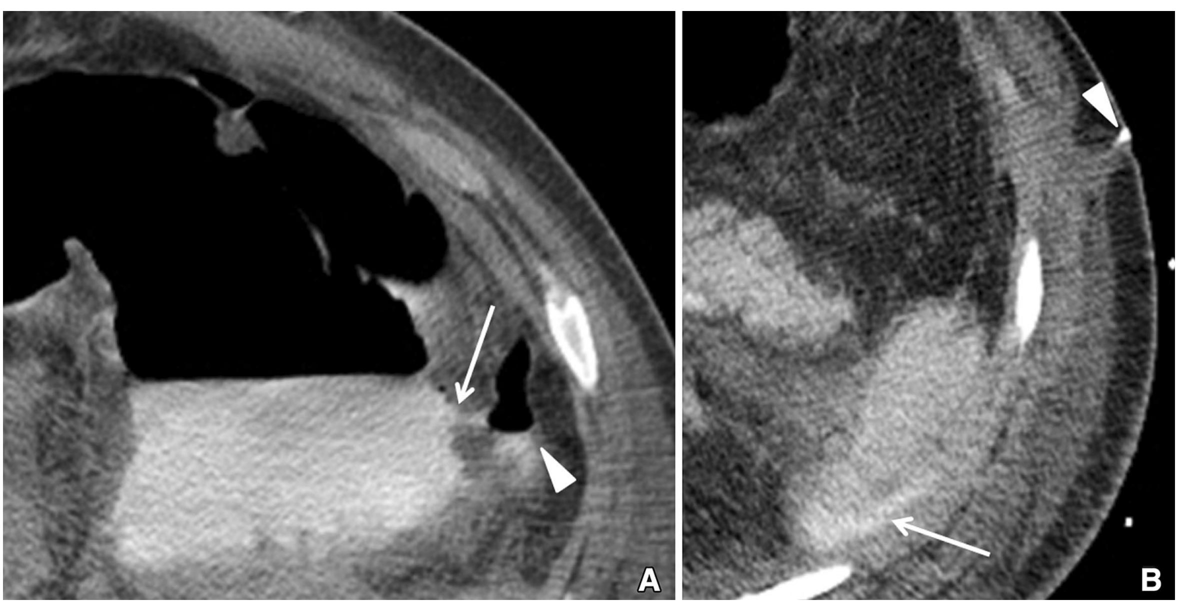


**Fig. 12.** Trauma: gastric stab wound with an unknown object. **A** There is a focal defect along the lateral wall of the stomach (*arrow*), with associated extravasation of ingested contrast and gas (*arrowhead*). **B** Axial image more inferiorly demonstrates pooling of extravasated contrast along the inferior margin of the spleen (*arrow*) and a tiny subcutaneous foreign body along the trajectory of the stab wound (*arrowhead*).

sphincterotomy is performed (Fig. 15) [49]. Unfortunately, as with other etiologies, the morbidity and mortality rates for iatrogenic gastroduodenal perforation are high. CT imaging plays a crucial role in patients with suspected iatrogenic perforation. In a Mayo Clinic study of 72 EGD perforations, the only factors determined to be predictive of which patients were more likely to fail nonoperative management were the post-procedure CT findings of free fluid or contrast extravasation [50].

## Small bowel

Perforation of the jejunum or ileum tends to present with nonspecific clinical symptoms and therefore the diagnosis is most often made at the time of CT imaging. Etiologies for small bowel perforation include inflammatory, infectious, and ischemic conditions, small bowel diverticulitis, mechanical obstruction, trauma, malignancy, iatrogenic causes, and foreign bodies [51].

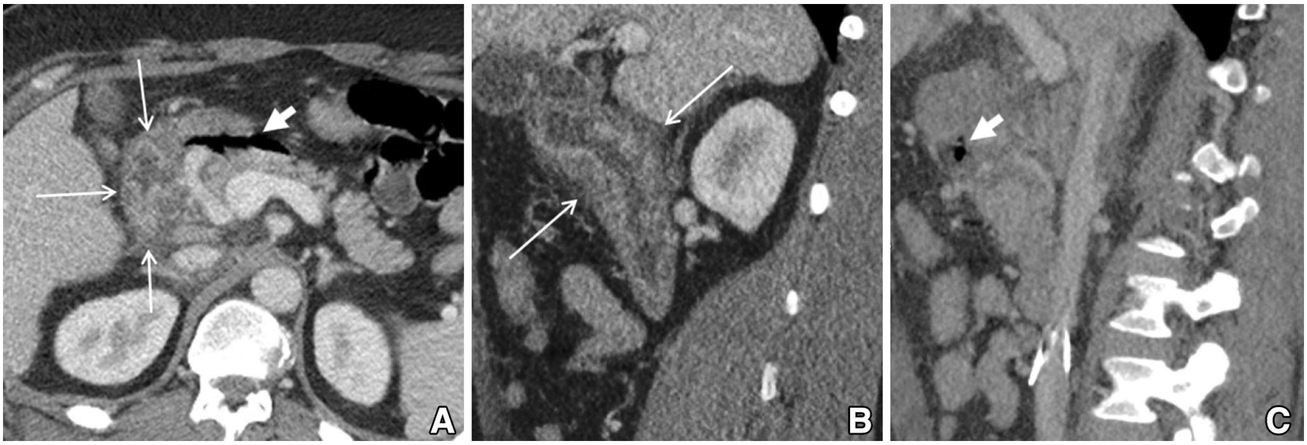


**Fig. 13.** Trauma: motor vehicle accident with duodenal perforation. **A** Axial image showing thickening of the descending segment of the duodenum (*long arrows*), with retroperitoneal gas extending along the anterior margin of the pancreas (*short arrow*). **B**, **C** Coronal images showing the second part of the duodenum to be thickened (*long arrows*), with adjacent extraluminal gas (*short arrow*).

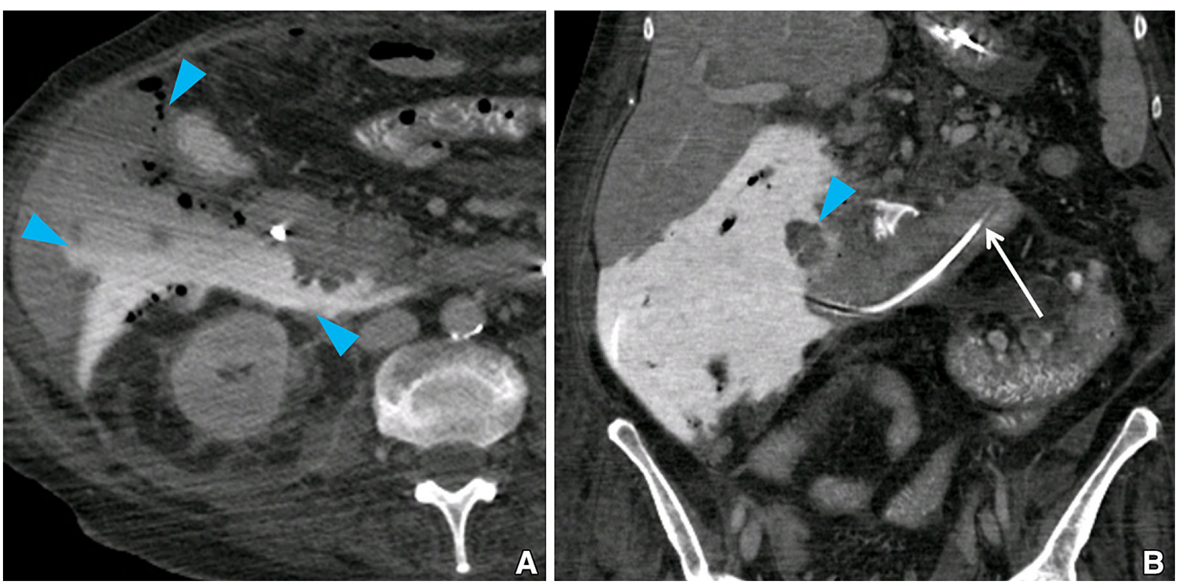


**Fig. 14.** Tumor: periampullary duodenal mass. **A** Enteric contrast spills into the hepatorenal space and extends posterior to the third portion of the duodenum (*arrowheads*). **B** The periampullary mass is suggested on this image (*arrowhead*) and subsequently confirmed endoscopically. A feeding tube extends past the mass, to the ligament of Trietz (*arrow*).

## *Inflammatory*

Crohn disease is a common inflammatory condition to affect small bowel and can rarely lead to free perforation from the colon (1.6%) or small bowel (0.7%) [52]. While the ileum is the most commonly inflamed segment of bowel in Crohn patients, the most frequent site for small bowel perforation is less clear, with some studies claiming jejunum and others claiming ileum as the most common culprit [52, 53]. More common than free perforation, Crohn disease leads to sinus tracts, fistulas, and contained perforations sealed off by inter-loop adhesions, leading to localized phlegmonous changes and abscess formation. Rarely, perforation can be the presenting finding in a patient otherwise undiagnosed as having Crohn disease [54]. CT plays a critical role in this population, identifying the signs of small bowel perforation as well as the imaging features suggestive of Crohn disease as the underlying etiology (Fig. 16) [55].

## *Ischemic*

Small bowel perforation can result from the inflammation and subsequent necrosis that develops in the setting

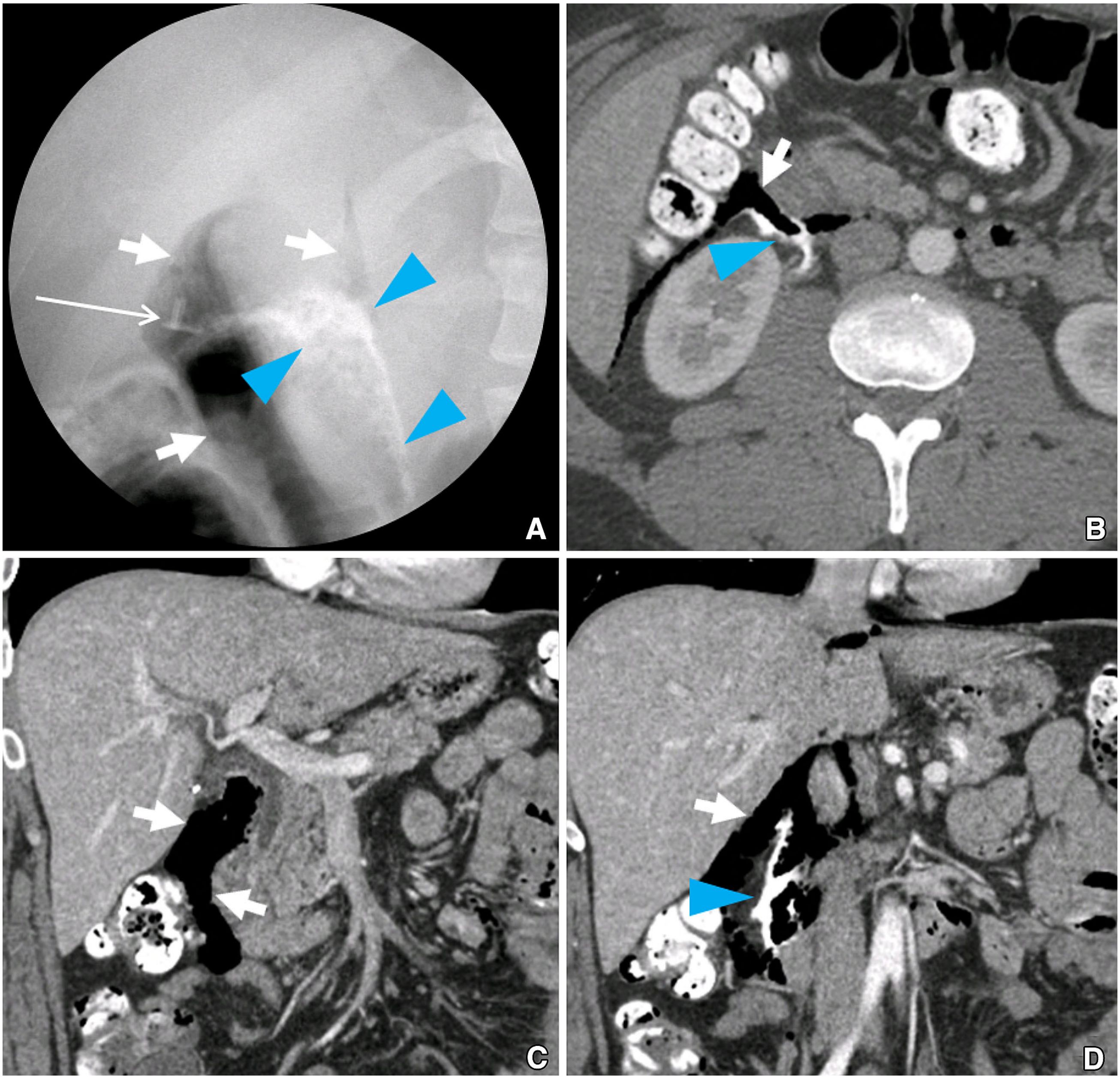


**Fig. 15.** Iatrogenic. Duodenal perforation during ERCP sphincterotomy for extraction of a common bile duct stone. **A** ERCP fluoroscopic image of the right upper quadrant in the AP projection post-sphincterotomy demonstrates an irregular collection of contrast (*arrowheads*). The lack of outlined mucosal folds and peculiar configuration favors an extraluminal location. In addition, there are adjacent vertically oriented collections of air that fail to conform to bowel, in keeping with extraluminal air (*short arrows*). Cholecystectomy clips are present (*long arrow*). Subsequent CT with axial (**B**) and coronal (**C**, **D**) images confirming the perforation by documenting extraluminal gas (*arrows*) and contrast (*arrowheads*).

of mesenteric ischemia. Underlying causes include bowel strangulation, obstruction, large vessel occlusion, or vasculitis. With vasculitides, small systemic visceral vessels may be involved and not directly demonstrable by CT [16, 56]. However, mural and perivisceral changes at CT can be suggestive of underlying ischemia, including bowel wall thickening, mural hypoperfusion, and localized mesenteric fluid (Fig. 17) [16, 56, 57]. Specific, though often late, findings of bowel infarction include a lack of bowel wall enhancement, gas within the mesenteric venous system, and bowel wall pneumatosis [16, 56, 57].

## *Trauma*

Encompassing more surface area within the peritoneal cavity than any other organ, small bowel has a high

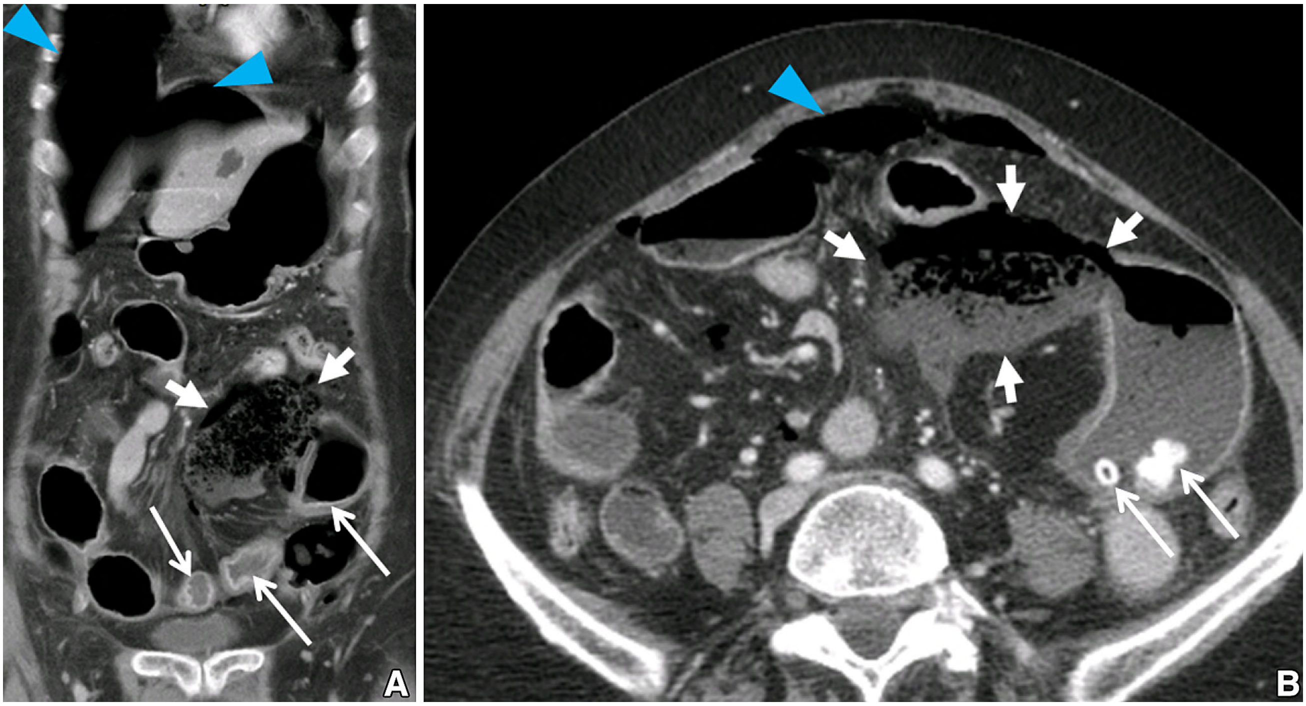


**Fig. 16.** Inflammatory: Crohn disease. **A** Coronal image showing mucosal hyperenhancement of a segment of small bowel, in keeping with active inflammation (*long arrows*). A large amount of sub-diaphragmatic gas is noted (*blue arrowheads*) as is a complex loculated collection/abscess in the left lower quadrant (*short arrows*). **B** There is a chronically distended loop of bowel in the left lower quadrant containing enterolith (*long arrows*). The distention resulted from chronic delayed transit through the stenotic, and now actively inflamed, distal segment of bowel shown in **A**. The superimposed active inflammation likely led to a complete obstruction and subsequent proximal perforation as confirmed by the focal defect along the medial wall in communication with the abscess (*short arrows*). Free air is noted anteriorly (*blue arrowhead*).

propensity for injury in the setting of penetrating abdominal trauma. 80% of gunshot wounds and 30% of stab wounds that disrupt the peritoneum lead to small bowel injury [1, 58]. Delaying surgical management or wound exploration to obtain a CT in these patients is controversial. When a CT is obtained, free intraperitoneal gas alone is not diagnostic of bowel injury as air can be introduced into the peritoneal cavity by the mechanism of injury. A wound track extending to an injured segment of bowel has been shown to be the most sensitive CT finding (Fig. 18) [16, 59].

In contrast, small bowel perforation from blunt abdominal trauma is an infrequent complication. When perforation results from blunt trauma, abdominal CT has a sensitivity of 64% and accuracy of 82% in detecting the site of perforation [16, 60]. Even in the absence of the direct CT signs of GI tract perforation discussed earlier, infiltration of the mesentery and/or a moderate to large volume of intraperitoneal fluid (in the absence of a solid organ injury) should raise concern for an occult bowel injury [16, 60, 61].

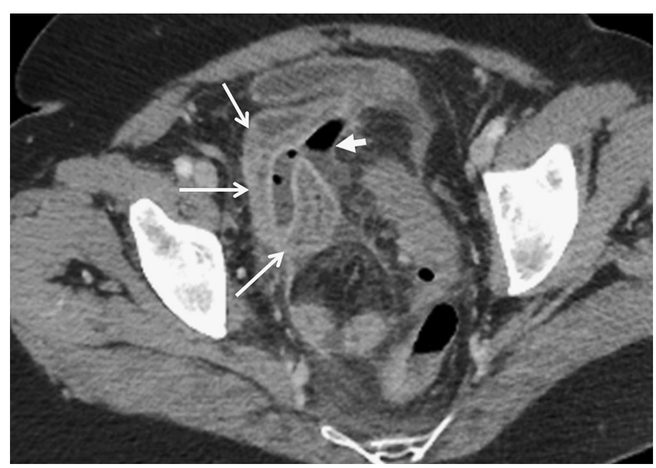

**Fig. 17.** Ischemic: vasculitis. Mucosal hyperenhancement and wall thickening of a segment of small bowel (*long arrows*), confirmed to be ischemic at surgery. Note the adjacent extraluminal gas and fluid (*short arrow*). Segmental bowel wall thickening and concentrated extraluminal gas is specific for this to be the perforation site.

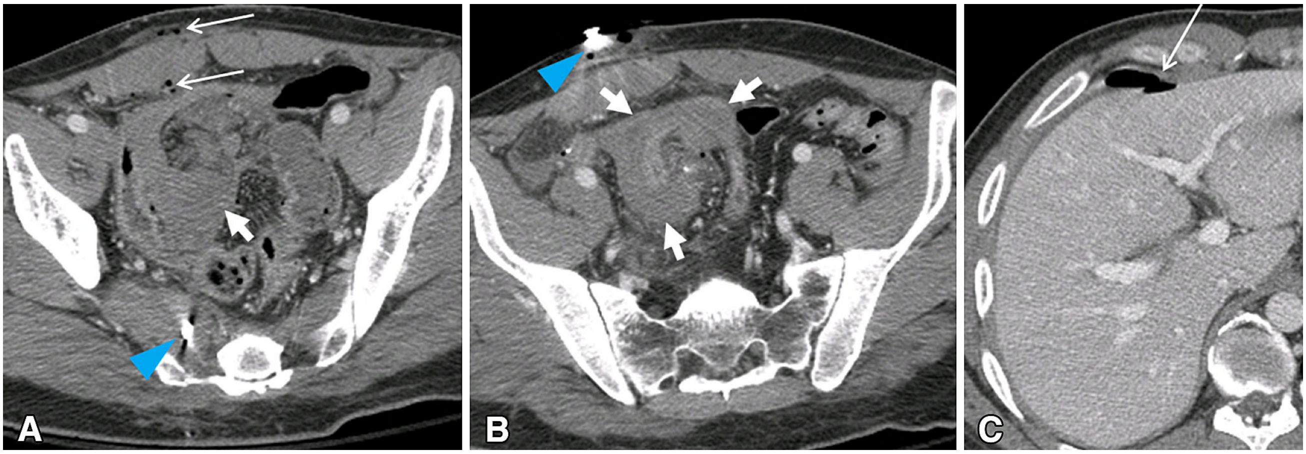


**Fig. 18.** Trauma: bullet. **A**, **B** Inferior to superior axial images showing locules of gas along a bullet track (*long arrows*) that traveled anterior to posterior, crossing small bowel and mesentery before becoming lodged within the right presacral musculature (*arrowhead*). A hematoma/complex fluid collection surrounds a small bowel loop with irregular appearing walls (*short arrows*). **C** Axial image through the level of the liver showing free intraperitoneal fluid and air (*arrow*).

## *Tumor*

Small bowel perforation from an underlying malignancy most often results from GI lymphoma, and while lymphoma can arise anywhere within the alimentary tact, the vast majority of GI lymphoma perforations occur within the small bowel [16, 39, 41, 43, 62]. Bowel perforation from GI lymphoma is more common in the setting of T-cell lymphoma, post-transplant lymphoproliferative disorder, and after chemotherapy or radiation treatment [63–67].

At CT, the signs of perforation can be subtle, with only a small amount of extraluminal gas or fluid. The characteristic bowel appearance of a circumferentially thickened segment with aneurysmal dilatation of the lumen can suggest the underlying etiology [66]. The presence of multifocal bowel involvement, lymphadenopathy, and hepatosplenomegaly can be additional clues in suggesting GI lymphoma [43].

Gastrointestinal stromal tumors (GISTs) are most commonly located in the stomach or small bowel and rarely spontaneously rupture [40–43]. At CT, ruptured GISTs tend to appear heterogeneous in attenuation, with a lamellated pattern thought to reflect areas of hemorrhage or necrotic degeneration [43]. Ascites is uncommon for GISTs. Therefore, when otherwise unexplained, a patient with a GIST who develops ascites should raise suspicion for tumor rupture (Fig. 19) [40, 43]. Risk factors for GIST rupture include a large size, exophytic configuration, large internal cystic or necrotic component, and a rapid growth rate [42, 43].

Perforation of a small bowel metastasis most often results from lung carcinoma [43]. The CT appearance is often nonspecific, though the presence of an intraluminal polypoid mass or wall thickening with variable patterns of contrast enhancement in the setting of a known primary malignancy should raise suspicion [43, 68].

## *Iatrogenic*

Bowel injury at the time of laparoscopic abdominal surgery most commonly affects the small bowel and is usually identified and corrected at the time of injury [16]. When iatrogenic bowel injury is unrecognized intraoperatively, there is a high post-operative morbidity rate. The CT appearance can be challenging, as intraperitoneal gas is not unexpected in the recently post-laparoscopy state. Oral contrast can be useful, as extraluminal ingested contrast in the setting of an intact anastomotic site suggests the diagnosis of accidental bowel injury [16].

## *Foreign body*

Intuitively, ingested foreign bodies are more likely to lead to small bowel perforation when sharp or shaped in a manner that predisposes to failed passage (long, nonflexible, > 3 cm in diameter). Fish bones and chicken bones are the most common inadvertently ingested foreign bodies to cause perforation (Fig. 20). Foreign body perforations rarely result in a large amount of free intraperitoneal gas, as the bowel insult tends to be gradual, and the injured site concurrently covers with a fibrinous exudate [16]. Concentrated extraluminal gas locules within the mesentery and infiltration of fat near a thickened bowel segment are the most common CT findings (Fig. 21) [16]. Identifying the foreign body confirms the diagnosis, and is more common with foreign bodies of radiodense material such as metal or calcium [16, 69, 70]. In cases of metal foreign bodies, a bone window setting may be useful in identifying the object [16].

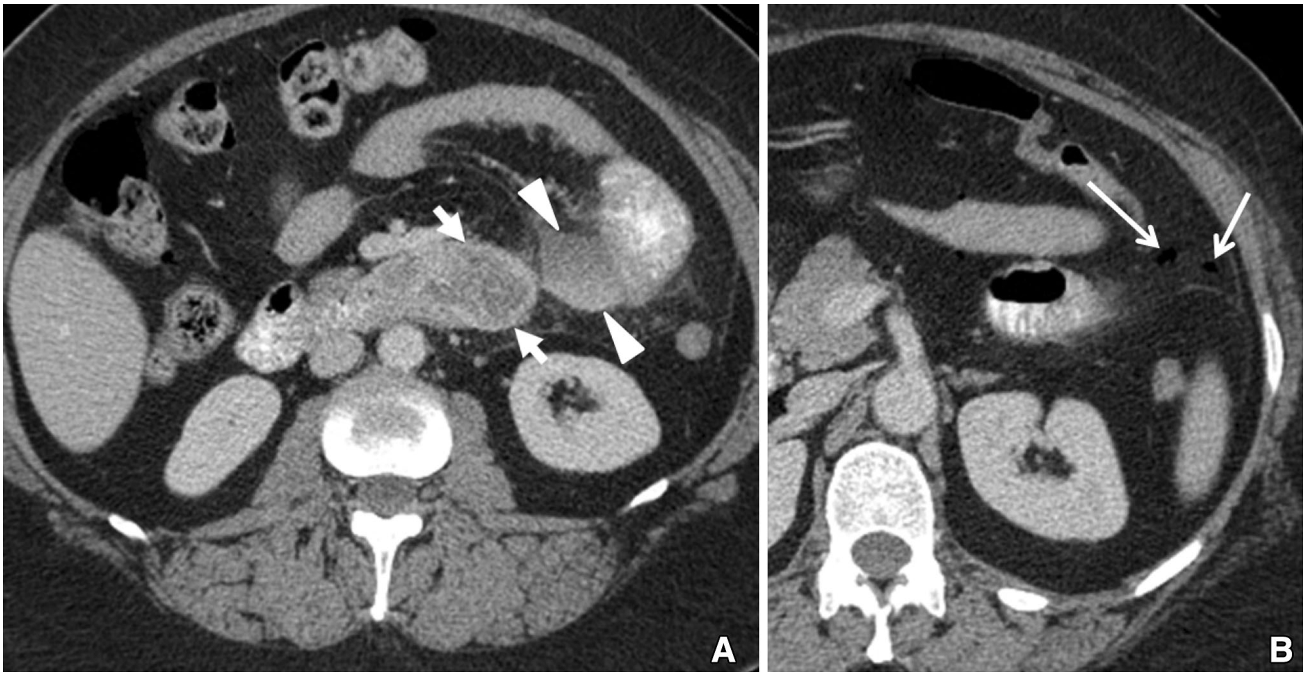


**Fig. 19.** Tumor: gastrointestinal stromal tumor (GIST). **A** Axial images showing a heterogeneous attenuation mass in the proximal jejunum (*short arrows*), confirmed surgically to represent a GIST. Note the adjacent extraluminal fluid collection (*arrowheads*). **B** Just superiorly, there are locules of intraperitoneal gas within the left hemiabdomen (*long arrows*).


**Fig. 20.** Foreign body: fish bone. **A**–**D** Sequential axial images showing a thickened loop of small bowel in the left lower quadrant with locules of extraluminal gas along the mesenteric margin (*white arrows*). In **B**, there is a linear radiopaque density within the inflamed small bowel loop (*blue arrowhead*), confirmed at surgery to be a fish bone.

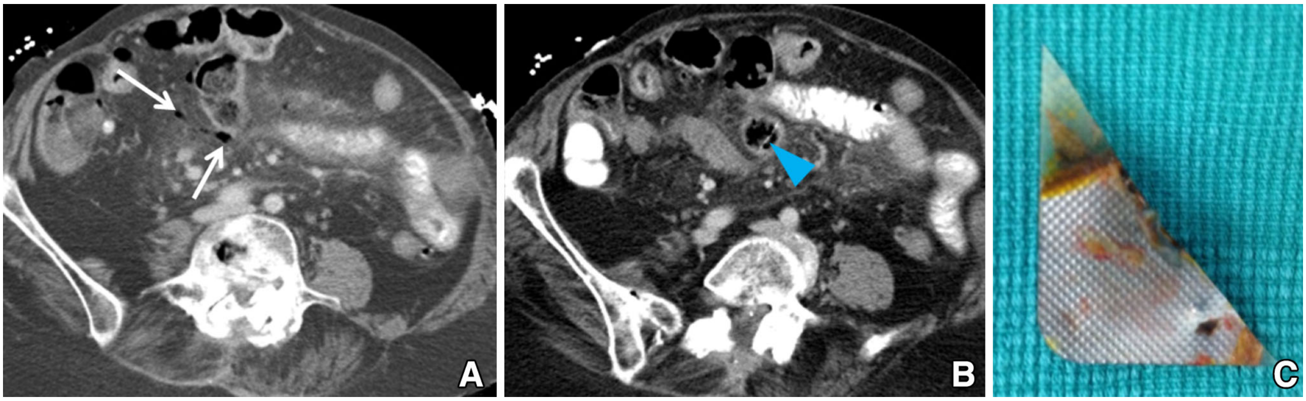


**Fig. 21.** Foreign body: corner from medication packaging. **A** Axial imaging showing a few locules of mesenteric gas (*arrows*). **B** Just inferiorly, there is a mildly thickened segment of small bowel, with an intraluminal linear opacity extending into the anterior left wall (*arrowhead*). **C** At surgery, the perforation was confirmed to be secondary to the corner of a medication package, inadvertently ingested while taking the medication.

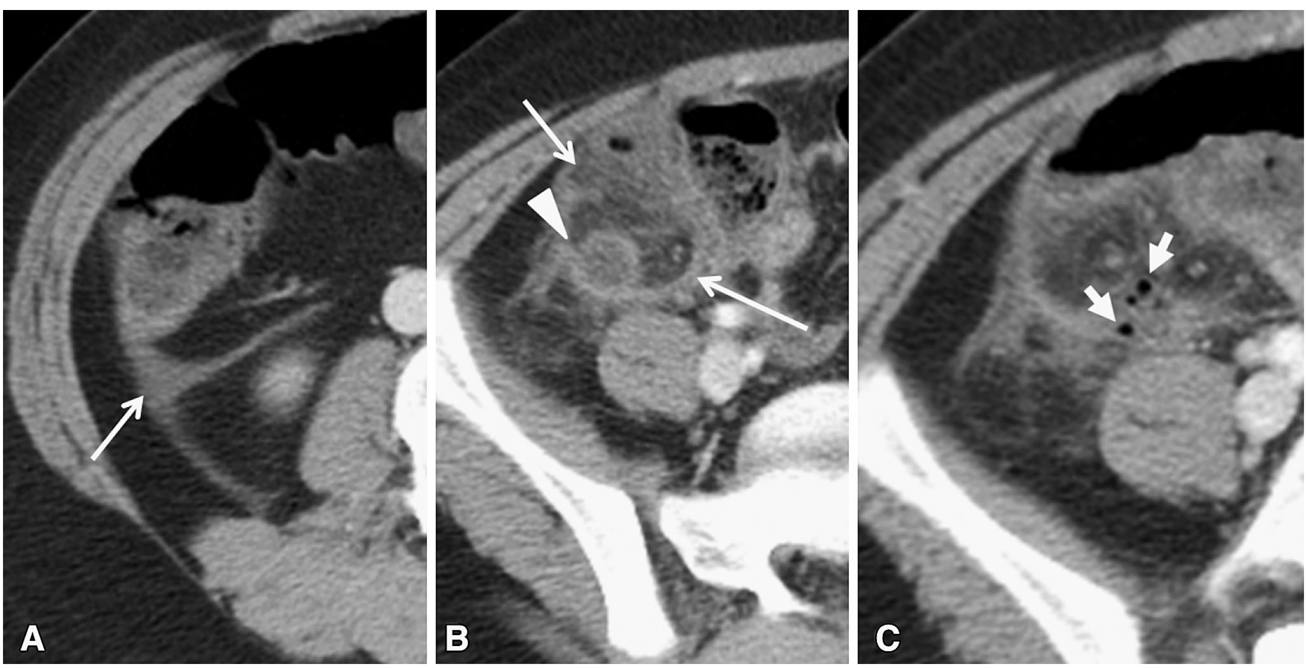


**Fig. 22.** Inflammation: perforated appendicitis. **A** Fluid tracks along the right paracolic gutter (*arrow*). **B** The appendix is dilated (*arrowhead*), with periappendiceal fat stranding and fluid (*arrows*). **C** Just inferiorly, there is an extraluminal collection with gas bubbles (*short arrows*).

# Appendix

## *Appendicitis*

CT has a high sensitivity and specificity for detecting and diagnosing acute appendicitis [71–77]. Unfortunately, the data are inconsistent as to the effectiveness for CT to prospectively detect appendiceal perforation, particularly in an early stage [71, 78–82]. The presence of an abscess, extraluminal gas, or ileus strongly correlates with appendiceal perforation (Fig. 22) [71]. However, with early or micro-perforation, these definitive findings are uncommon, and tend to be subtle if present. Periappendiceal stranding and fluid can be encountered with the perforated or nonperforated appendix and an enhancement defect in the appendiceal wall has been shown to have low sensitivity and specificity for appendiceal perforation [71]. Despite these limitations, determining whether or not the appendix has ruptured has important prognostic and management implications. In the setting of perforation, morbidity and mortality are higher, and


**Fig. 23.** Tumor: appendiceal mucinous neoplasm. **A** Coronal image showing a normal base of the appendix (*arrowhead*), with abrupt dilatation of the mid and distal appendix to over 4 cm (*arrows*). **B–D** Axial images showing extensive intraperitoneal gelatinous ascites, in keeping with pseudomyxoma peritonei. The mucocele is outlined by mural calcification (*long arrows*), with a focal defect corresponding to the rupture site (*short arrow*).

conservative preoperative management, including intravenous antibiotics or abscess drainage, is often indicated to reduce the extent of subsequent surgery [71, 83, 84].

### *Tumor*

Appendiceal mucinous neoplasms (neoplastic mucoceles) can spread to the peritoneum as pseudomyxoma peritonei through extraluminal invasive carcinomas or ruptured adenomas [85]. At CT, cystic dilatation of the appendix with a luminal diameter greater than 1.3 cm, along with the presence of mural calcification, suggests a mucocele (Fig. 23) [43]. There is overlap in distinguishing between benign and low-grade malignant processes at both imaging and pathology [85]. At CT, enhancing appendiceal wall nodularity favors the presence of an invasive mucinous cystadenocarcinoma [43, 86].

## Colon

### *Tumor*

Colon adenocarcinoma can lead to perforation via two mechanisms: (1) necrosis at the site of the mass and (2) a functional closed-loop obstruction between the mass and

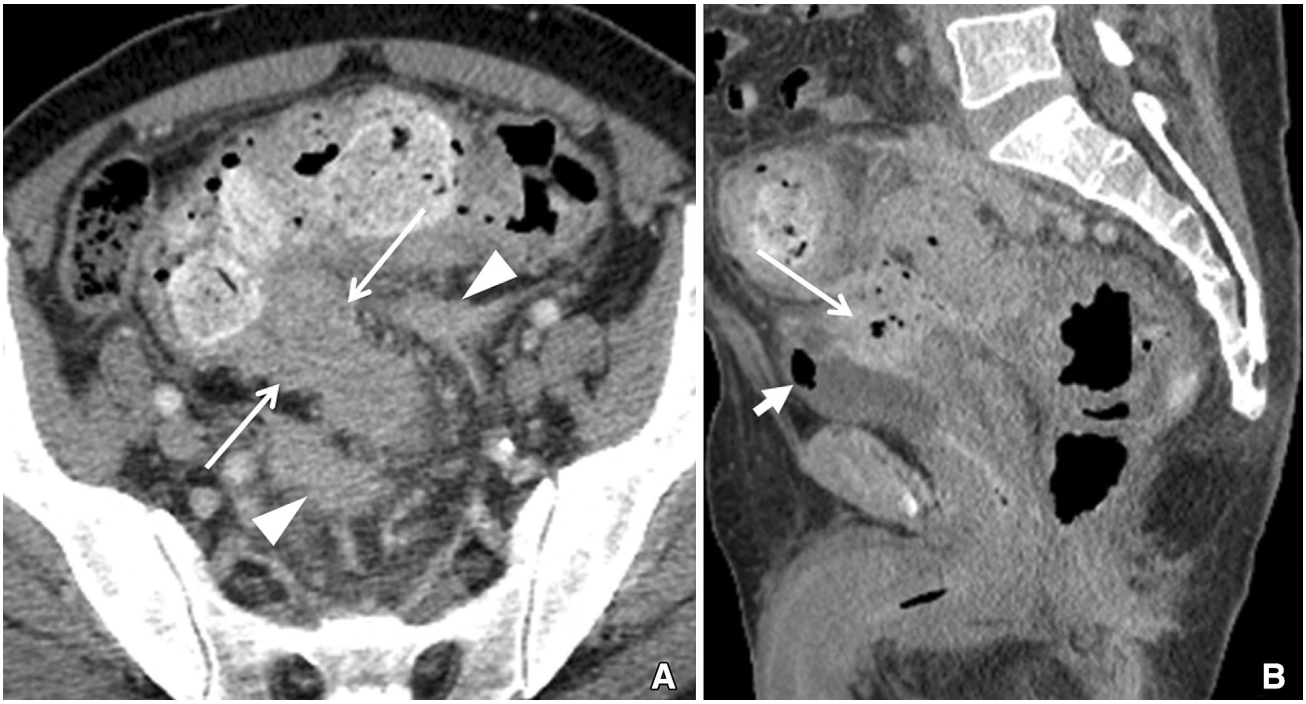


**Fig. 24.** Tumor: colon adenocarcinoma. **A** Thickened segment of sigmoid colon (*arrows*) with nodular soft tissue attenuation spread to the pericolonic fat (*arrowheads*). **B** Thick-walled extraluminal collection (*long arrow*) extends antero-inferior from the mass and abuts the bladder. Gas is noted within the bladder nondependently (*short arrow*). This was confirmed at surgery to be a sigmoid adenocarcinoma with contained perforation and fistualization to the bladder.

a competent ileocecal valve, resulting in colonic perforation proximal to the mass [43, 87, 88]. The most commonly involved segments to perforate include the sigmoid colon and cecum [43, 87, 89]. At CT, extraluminal gas can be extensive. Identifying signs of perforation in the setting of irregular colonic wall thickening and infiltrative pericolonic soft tissue can favor the diagnosis (Fig. 24) [7, 43].

Self-expanding metal stents are increasingly being used in the setting of malignant colorectal obstruction as a bridge to scheduled surgery or as palliative option in patients with advanced stage disease [90]. Perforation is a potential complication that can occur days to months after stent placement, and is more common in patients previously treated with chemotherapy [90]. CT imaging tends to be straightforward, with visualization of the stent extending through the site of colonic wall disruption (Fig. 25).

## *Diverticulitis*

Perforated diverticulitis represents the most serious complication of diverticular disease and can occur at any site along the colon [91]. In Western countries, diverticular disease, as well as diverticular perforation, most commonly arises along the sigmoid colon [92]. At CT, diverticulitis appears as segmental wall thickening and pericolonic fat stranding in the setting of underlying diverticular disease [92]. CT has a high sensitivity for detecting complications secondary to diverticulitis including abscess formation and focal-contained perforations. Contained perforations present as small extraluminal pockets of gas. Less often, diffuse pneumoperitoneum and even retroperitoneal and mediastinal gas can occur via subperitoneal communications (Fig. 26) [93].

## *Iatrogenic*

Colonoscopic perforation is a rare procedural complication; however, as with most other etiologies for bowel perforation, has a high rate of morbidity and mortality [94]. Colonoscopy being performed in patients with multiple comorbidities or for therapeutic purposes is at increased risk for perforation [94–96]. Plain radiography or CT may be ordered when colonoscopic perforation is suspected. The presence of extraluminal gas can be confirmatory (Fig. 27). However, patients are often managed based on the presence or absence of generalized peritonitis even without radiologic evidence of perforation [94]. At colonoscopy, barotrauma from pneumatic distention is the attributed etiology for most right-sided colonic tears. In contrast, most left-sided perforations

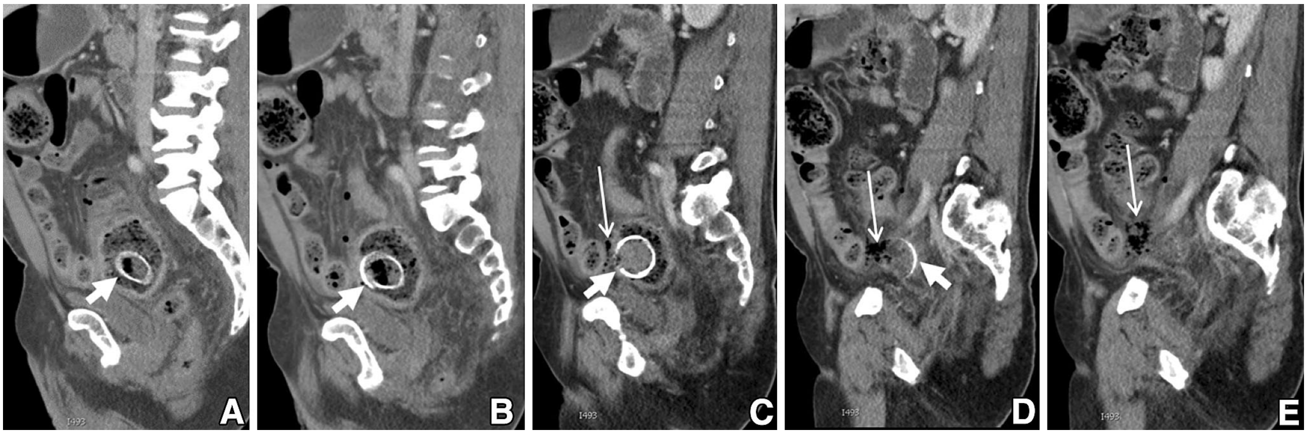


**Fig. 25.** Tumor: rectal carcinoma with metal stent complicated by perforation. **A**–**E** Sequential sagittal images showing the self-expanding metal stent (*short arrows*) to extend through the anterior wall of the sigmoid colon, with resultant concentrated extraluminal gas (*long arrows*).

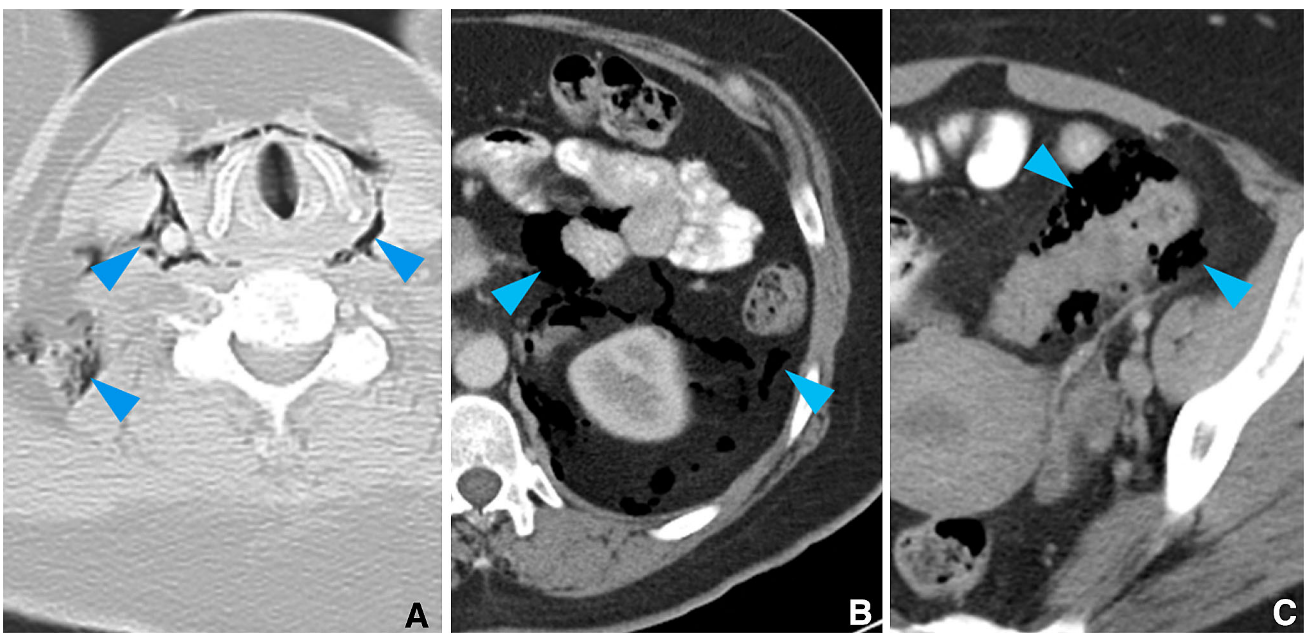


**Fig. 26.** Diverticulitis: sigmoid colon. **A** Gas tracks to the level of the thoracic inlet (*arrowheads*). **B** Gas tracks along the left retroperitoneum (*arrowheads*). **C** The air originated at the level of the sigmoid colon, where a thickened segment contains diverticula and is surrounded by extraluminal gas (*arrowheads*). The sigmoid colon is intraperitoneal, however, the subperitoneal space serves as a common pathway for extraperitoneal communication. The mediastinal gas dissects superiorly from retroperitoneal communications.

result from direct mechanical trauma from the endoscope, in which the perforation site is typically along the anti-mesenteric colonic wall [94, 97, 98].

Note that post-polypectomy syndrome, a transmural injury at the site of an excised polyp, mimics perforation by presenting with similar clinical signs and symptoms of peritonitis [94, 99]. CT scan may reveal focal mural thickening with pericolonic fluid and stranding at the polypectomy site, however, no pneumoperitoneum will be evident [94, 97].

## *Foreign body*

Colorectal foreign bodies can result from antegrade passage of ingested objects or retrograde insertion during acts of sexual stimulation or assault. The foreign body can usually be diagnosed with plain radiography and removed transanally via manual manipulation [100]. When peritoneal symptoms are present or if the foreign body is not readily reducible, CT can be complimentary in diagnosing the exact

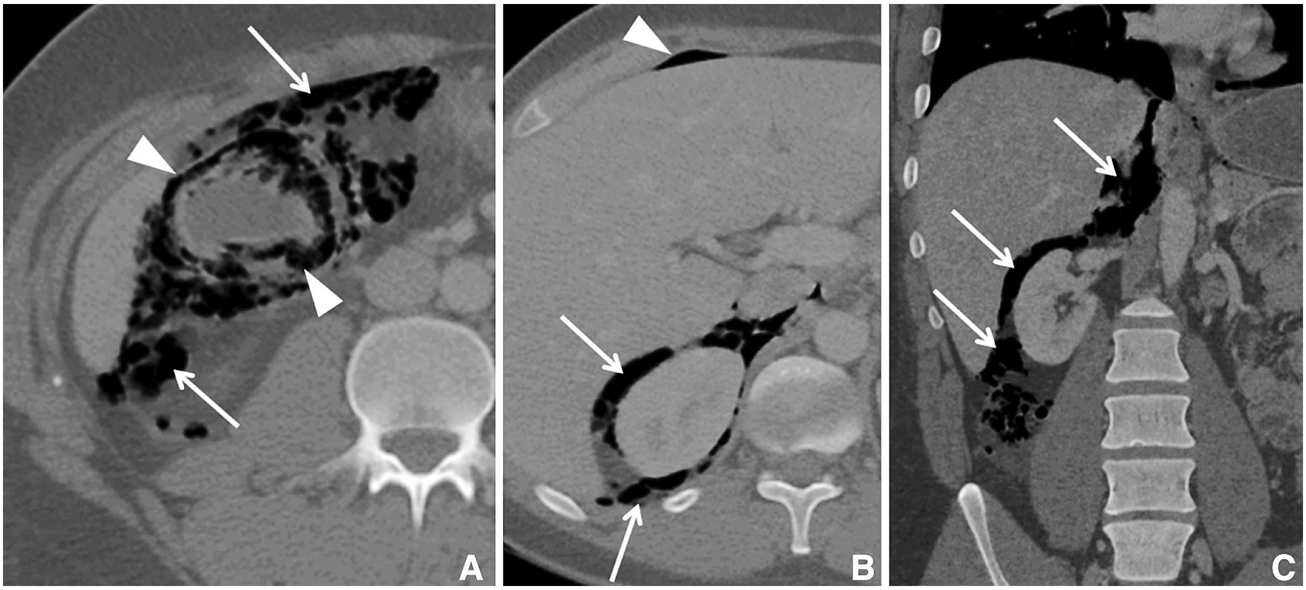


**Fig. 27.** Iatrogenic: perforation after colonoscopy. **A** Pneumatosis coli (*arrowheads*) and pericolonic gas surround the ascending colon (*arrows*). This presumably corresponds to the perforation level. **B**, **C** Axial and coronal images showing air tracking along the right pararenal spaces (*white arrows*) and a small amount of intraperitoneal gas collects anterior to the liver (*arrowhead*). Barotrauma from pneumatic distention was the attributed etiology. As the patient lacked symptoms of peritonitis, conservative management was elected.

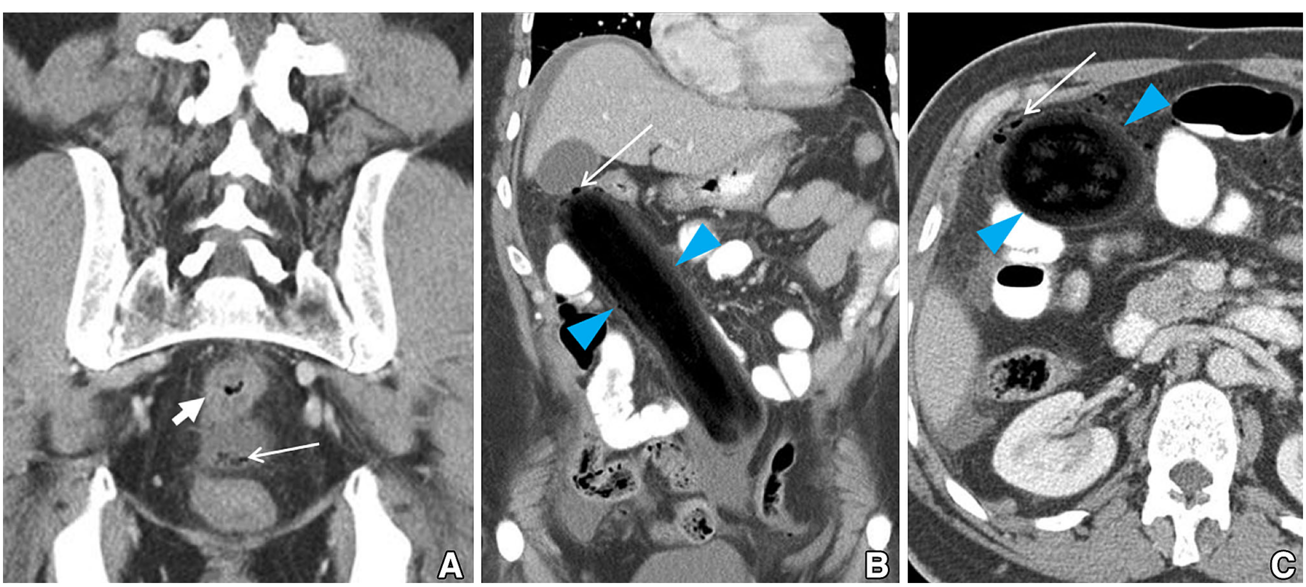


**Fig. 28.** Foreign body: intraperitoneal zucchini. **A** Coronal image showing a thickened segment of the rectosigmoid colon (*short arrow*), with an adjacent collection of fluid containing locules of gas (*long arrow*). **B**, **C** Coronal and axial images show a large, predominately air density, foreign body freely positioned within the peritoneal cavity (*arrowheads*) with adjacent locules of gas (*long arrows*). This corresponded to a rectally inserted zucchini that had perforated through the bowel wall. Reproduced with permission, courtesy of Dr. Frank Gaillard, Radiopaedia.org.

position of the foreign body and evaluating for perforation. At CT, perforation can be confirmed by bowel wall disruption and the extraluminal position of the object (Fig. 28). Perforations are often treated by surgical repair and may require proximal loop colostomy [101].

**Table 2.** Etiologies and CT imaging features for alimentary tract perforations

| Etiology | Characteristic CT features | Location-specific considerations |
|---|---|---|
| Spontaneous/ Boerhaave syndrome | Esophageal wall disruption<br>Pneumomediastinum<br>Left pleural effusion | n/a |
| Foreign body | Radiopaque density (bone window may be complimentary in detecting)<br>Extraluminal gas<br>Bowel wall disruption | *Esophagus* An underlying stricture often exists in the setting of food bolus impaction<br>Barium esophagram may obscure a radiopaque foreign body such as a bone<br>*Small bowel* Often clinically unsuspected. Minimal extraluminal gas<br>*Colon* CT can confirm perforation by demonstrating an extraluminal position of the object |
| Tumor | Irregular bowel wall thickening and enhancement<br>Perivisceral soft-tissue extension<br>Peritoneal spread of disease<br>Solid organ metastases or lymphadenopathy | *Esophagus* Primary perforation is more common from palliative measures<br>Esophagorespiratory fistulas can occur from an esophageal or lung primary<br>*Stomach* Adenocarcinoma may show deep ulceration<br>*Small Bowel* Lymphoma may show a dilated lumen<br>Perforated GIST is often heterogeneous<br>*Appendix* Mucinous neoplasm rupture can lead to pseudomyxoma peritonei<br>*Colon* Adenocarcinoma can perforate at the tumor or proximally (due to closed loop obstruction) |
| Trauma | Bowel wall disruption<br>Pneumoperitoneum<br>Intraperitoneal bowel contents<br>Weapon track (in penetrating trauma) leading to the injured site | *Esophagus* Must be considered in the setting of posterior mediastinal gas that is otherwise unexplained<br>*Stomach* Relatively protected by thick rugal folds<br>*Small Bowel* The most commonly injured organ in the setting of penetrating trauma<br>*Colon* The second most commonly injured organ in the setting of penetrating trauma |
| Iatrogenic | Leakage of oral contrast<br>Pneumoperitioneum<br>Bowel wall disruption | *Esophagus* More common after therapeutic procedures<br>*Stomach* Less commonly injured due to the thick, muscular wall<br>*Duodenum* Commonly injured site during EGD or ERCP<br>*Small Bowel* Most common location for inadvertent bowel injury during surgery<br>*Colon* At colonoscopy, right-sided perforation is most often barotrauma, left-sided perforation is more likely to be traumatic from the endoscope |
| Infectious/ inflammatory[a]/ ischemic | Mural thickening<br>Perivisceral fat stranding<br>May see underlying pathology (diverticulum, ulcer, occluded vessel, etc.) | *Stomach* Ulcerative disease, intraperitoneal gas<br>*Duodenum* Retroperitoneal gas if distal to the bulb<br>*Small Bowel* Contained perforation leading to abscess is not uncommon with Crohn disease<br>*Appendix* Periappendiceal stranding and fluid can be encountered with the perforated or nonperforated appendix |

[a] Inflammatory includes ulcerative disease, inflammatory bowel disease, diverticulitis, appendicitis

# Conclusion

CT is an excellent resource in detecting and localizing a GI tract perforation site at any location from the esophagus to the rectum (Table 2). Early detection of a perforation has critical implications for patient morbidity and mortality. Preoperatively diagnosing the site and cause for the perforation is important for surgical planning. A focal bowel wall defect is a highly specific CT finding, though has a limited sensitivity. In challenging cases, localize the gas as predominately intraperitoneal or extraperitoneal. Then, search for a focal defect, concentrated extraluminal gas, and/or segmental bowel wall thickening to further localize the perforation origin.

*Conflict of interest*. None.

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