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PICTORIAL ESSAY

Scary gas: a spectrum of soft tissue gas encountered in the axial body (part II)

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Abstract Ectopic gas in the mediastinum, subperitoneal abdomen, and superficial soft tissues is concerning and can be seen in the setting of trauma, iatrogenic injuries, infection, and inflammation. It can spread along different dissection pathways and may present remotely from the involved organ as described in part one. Recognition of ectopic gas on imaging and differentiating it from other causes of benign gas is very important as these conditions associated with ectopic gas can lead to rapid patient deterioration and usually require urgent surgery. In part two, the different causes of ectopic and benign gas in the torso are reviewed as well as the imaging features that can help to narrow the differential diagnosis.

Keywords Tracheobronchial injury · Esophageal rupture · Macklin effect · Subperitoneal bowel perforation · Emphysematous infection · Necrotizing infection

Introduction

The possible dissection pathways for gas within the torso reviewed in Part I help explain where dissecting soft tissue gas may arise. The next question is whether or not this gas is a surgical or medical emergency. Ectopic gas naturally leads to concern for potentially fatal diagnoses that require immediate surgery. Benign types of soft tissue gas, in contrast, do not require surgery. Since clinical manifestations may be remote from the gas' origin, the radiologist might be the first to suggest a source of dissecting gas. The combination of clinical history and imaging clues is crucial to the correct diagnosis and management of soft tissue gas.

In this manuscript, we will discuss of the types and diagnostic clues to ectopic soft tissue gas that might be seen in the torso. Narrowing the differential is difficult yet essential for guiding patient management.

Scary causes of mediastinal gas and mimics

Pneumomediastinum may arise from a source within the mediastinum or may dissect centrally from other sites, including from the lungs (Table 1).

Tracheobronchial injury

Tracheobronchial injury occurs in less than 1% of blunt chest trauma or following penetrating chest or neck trauma [1, 2]. While less common than bronchial injury, tracheal injury has higher morbidity and mortality [1]. Blunt force trauma ruptures the membranous portion of mediastinal trachea and bronchi, while penetrating injuries more likely disrupt the anterior cervical trachea, including the tracheal cartilage or ligaments between cartilaginous rings [1]. Imaging signs of tracheal rupture include deep cervical air and pneumomediastinum, a tracheal wall defect or deformity, or herniation or over-distension of the endotracheal balloon [1] (Fig. 1). Unlike bronchial rupture, tracheal rupture has a low rate of pneumothorax.

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Table 1 Differential diagnosis of pneumomediastinum

Gas type	Originate in mediastinum	Dissect from elsewhere
Scary gas	Disruption of mucosal barrier: •Laryngeal or tracheobronchial perforation •Pharyngoesophageal perforation/ Boerhaave's syndrome	•Necrotizing mediastinitis or non-necrotizing infection with gas-forming organism from extremity, groin, abdomen, or cervical origin
Benign gas	Gas-containing diverticulum: •Tracheal diverticulum •Laryngocele/pharyngocele/Zenker's diverticulum/esophageal diverticulum	•Macklin effect/spontaneous pneumomediastinum •Sterile gas from cervical, thoracoabdominal, or pelvic source •Intravenous gas

Like mediastinal tracheal injuries, bronchial injuries most commonly follow blunt trauma [2]. Imaging signs of bronchial rupture are nonspecific but include pneumomediastinum, subcutaneous gas, atelectasis, and pneumothorax that persist despite chest tube drainage [3]. The *fallen lung sign* refers to collapse of the lung into the dependent chest due to loss of bronchial support at the hilum and implies complete bronchial disruption. By computed tomography (CT), pulmonary vessels in the affected lung have an abnormal posterior course [3]. Other CT findings include bronchial wall discontinuity or asymmetric bronchial enlargement [4] (Fig. 2).

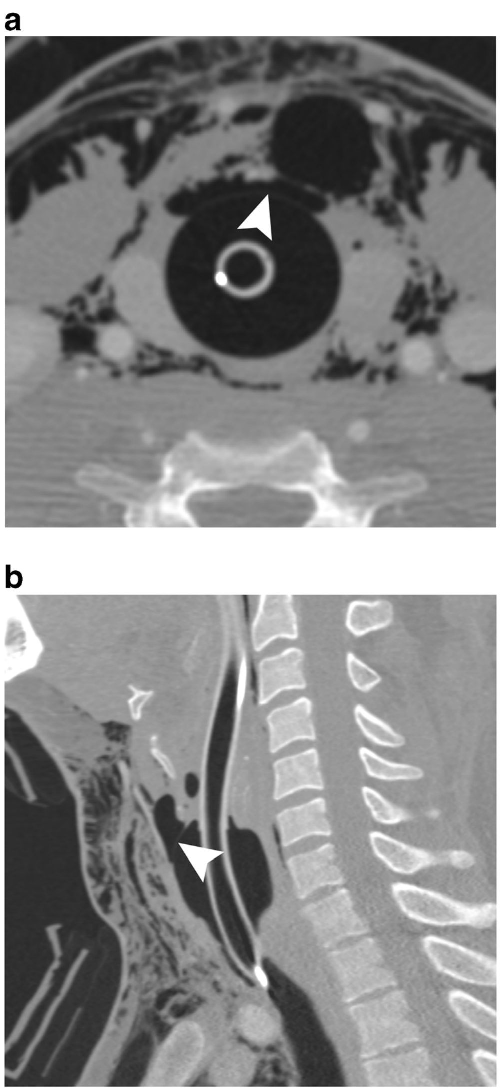

Fig. 1 Tracheal rupture in a 31-year-old man after wakeboard accident. **a** Axial and **b** sagittal CT images of the lower neck demonstrate overdistension of the endotracheal tube balloon, reaching 3 cm in diameter. The anterior wall of the endotracheal balloon (*arrowhead*) covers the traumatic defect in the anterior wall of the trachea

The site of airway injury may be detectable on CT, particularly with multiplanar reformations and minimum intensity projections, and is usually confirmed by bronchoscopy. Long-term complications, including hemoptysis or airway obstruction, are usually preventable with primary surgery [4].

A benign mimic of airway injury is a tracheal diverticulum. This benign entity is most often seen at the right posterolateral corner of the trachea at the level of the cervical-thoracic junction [5]. The rounded gas collection may be single or multilobulated, and the diverticulum neck may be very thin or even undetectable by CT (Fig. 3).

Esophageal rupture

Esophageal rupture may result spontaneously during retching (also known as Boerhaave's syndrome) or foreign body impaction, iatrogenically, during endoscopy, or rarely from blunt or penetrating trauma. Indirect findings suspicious for perforation include esophageal thickening, periesophageal fluid or fat infiltration, extraluminal air, and pleural effusion, often left-sided [6, 7] (Fig. 4). CT is sensitive for detection of esophageal perforation [7]. The location of the extraluminal fluid and gas correlates well with location of the defect, but the actual hole in the esophagus is uncommonly identified directly on CT. Fluoroscopic esophagram with water-soluble oral contrast is traditionally performed to confirm esophageal perforation or rupture, to locate the defect, and to differentiate a contained perforation from one in continuity with the pleural space. An alternative to conventional fluoroscopy may be CT esophagography, where water-soluble contrast is swallowed

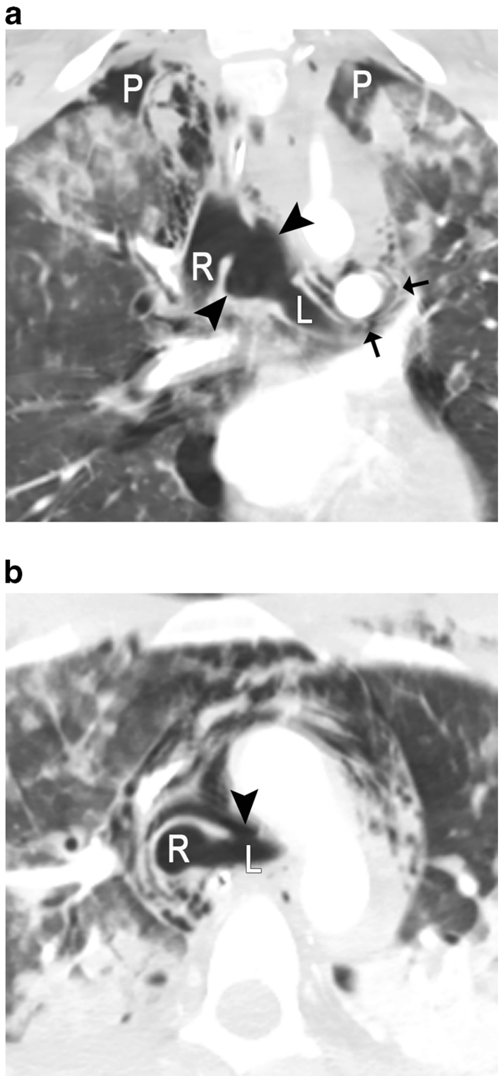

Fig. 2 Bronchial rupture in a 19-year-old man after skateboard crash. **a** Coronal and **b** axial CT images of the chest demonstrate bronchial wall discontinuity and focal enlargement (*arrowheads*) of the left main stem bronchus (*L*), consistent with bronchial rupture. Associated findings include pneumomediastinum surrounding the left main pulmonary artery (*arrows*) and bilateral pneumothoraces (*P*). The right main stem bronchus (*R*) remains intact

or injected via enteric tube in the upper esophagus immediately before CT of the chest [8] (Fig. 4).

Macklin effect

Alveolar rupture is the most common cause of benign pneumomediastinum. Terminal alveolar rupture caused by sudden increase in intra-alveolar pressure results in interstitial gas, which tracks centrally along the bronchovascular bundle into the mediastinum [9]. This phenomenon, called *Macklin*

Fig. 3 Tracheal diverticulum incidentally detected in a 38-year-old woman. Axial CT image at the level of the thoracic inlet demonstrates lobulated gas collection at the right posterolateral aspect of the trachea, diagnostic of a tracheal diverticulum. The neck of this diverticulum (*arrow*) is too small to be detectable on CT

effect, may occur spontaneously or in the setting of blunt trauma or mechanical ventilation [9]. Pneumomediastinum is found in 10% of severe blunt chest trauma patients, and Macklin effect is the presumed cause in 39% (far exceeding the rate of blunt tracheobronchial or esophageal injuries) [10]. Macklin effect from barotrauma is detected in 4–15% of patients on mechanical ventilation for respiratory failure [11].

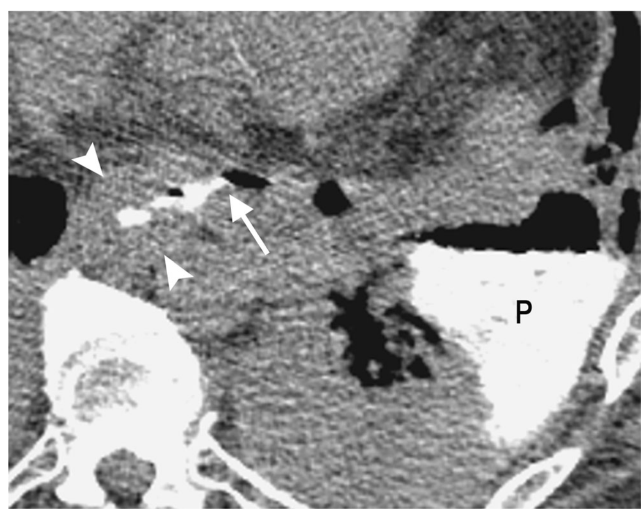

Fig. 4 Spontaneous esophageal rupture (Boerhaave's syndrome) in a 69-year-old man with chest pain after retching. Axial CT esophagogram image of the lower chest with only oral contrast demonstrates thickening of the lower esophageal wall (*arrowheads*). Leaked oral contrast is seen within a tract (*arrow*) between the left lateral esophageal wall and the left pleural space, resulting in contrast-containing left hydropneumothorax (*P*)

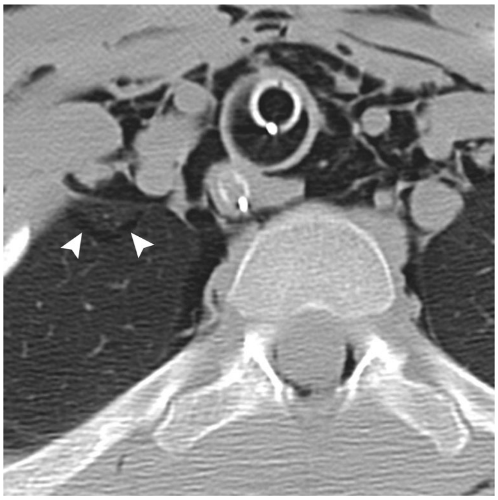

Fig. 5 Pulmonary interstitial emphysema in a 20-year-old man status post motor vehicle crash. Axial CT image of the lung apices demonstrates linear interstitial gas collections (*arrowheads*) in the right lung upper lobe characteristic of pulmonary interstitial emphysema (PIE). Pneumomediastinum, cervical soft tissue gas, intraspinal gas, and subcutaneous gas were all attributed to the PIE

Spontaneous pneumomediastinum (SPM) or *Hamman's syndrome* is Macklin effect in the absence of trauma or mechanical ventilation, although a triggering event is recalled in 20–80%, including coughing, emesis, exertion, childbirth, and cocaine inhalation [12, 13]. Underlying lung disease, including interstitial lung disease, emphysema, and bronchiectasis, predisposes to SPM [12, 14]. Regardless of inciting cause of Macklin effect, positive pressure ventilation may promote dissection of gas from the mediastinum into the retroperitoneum, peritoneal cavity, cervical soft tissues, and subcutaneous tissues [11].

Pneumomediastinum from Macklin effect is frequently over-evaluated and over-treated. The condition is self-limited and rarely recurs [14]. The radiographic findings—pneumomediastinum and subcutaneous gas—are nonspecific. Multidetector CT of the chest has the highest sensitivity for detecting SPM and potentially allows differentiation of SPM from secondary pneumomediastinum. Gas in the middle mediastinum is found in nearly all cases of SPM but overlaps with secondary pneumomediastinum. CT findings that favor SPM include air in the anterior mediastinum and pulmonary interstitial emphysema (PIE) [15]. PIE is identified on CT as gas outlining interstitial and bronchovascular structures (Fig. 5) [16]. Esophagram and endoscopy are rarely necessary in cases of SPM [12, 13]. CT findings concerning for secondary pneumomediastinum, requiring further work-up, include subdiaphragmatic air, hydropneumothorax, pulmonary consolidation, mediastinal fluid, or pneumopericardium [15].

Necrotizing mediastinitis

Of gas dissecting into the mediastinum, the most feared is necrotizing mediastinitis. Necrotizing mediastinitis may complicate any necrotizing soft tissue infection but is most often of

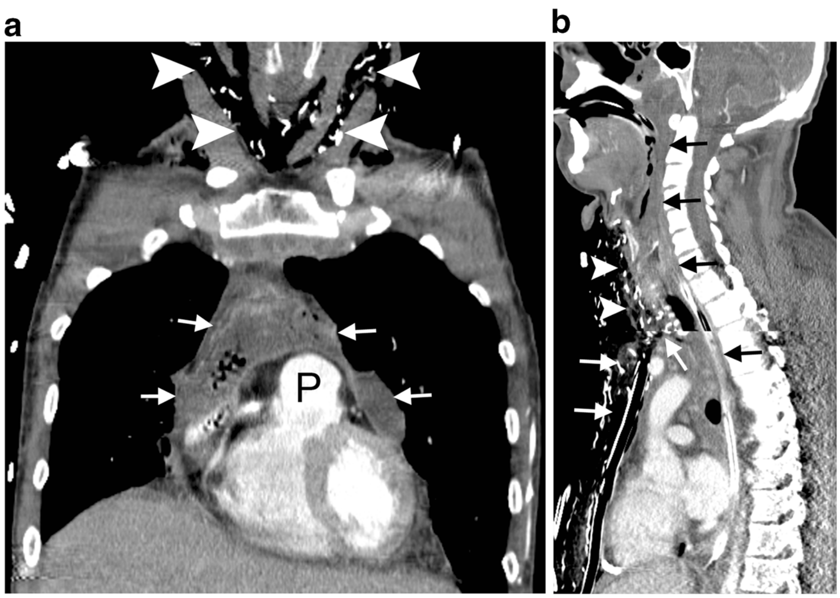

Fig. 6 Necrotizing mediastinitis in a 36-year-old man with necrotizing soft tissue infection originating from a dental source. **a** Chest CT was performed after patient had undergone emergent debridement of necrotizing infection in the superficial space of the anterior neck (packing material in surgical wound indicated by *arrowheads*). Coronal CT image through the anterior chest shows mediastinal spread via the perivisceral space with mixed gas and fluid collection (*white arrows*) above the heart and pulmonary outflow tract (*P*). **b** After sternotomy and further mediastinal debridement, fused midline sagittal CT images of the neck and chest show the surgical packing material in the superficial and anterior perivisceral spaces (*white arrowheads* and *arrows*, respectively). Although generalized anasarca also involves the prevertebral soft tissues, there was no frank infection of the danger zone (*black arrows*) in this patient

Table 2 Differential diagnosis of subperitoneal gas

Gas type	Originate in subperitoneum	Dissect from elsewhere
Scary gas	Disruption of mucosal barrier •Duodenum –Trauma –ERCP –Penetrating ulcer –Duodenal diverticulitis •Right colon/left colon/rectum –Trauma –Ischemia/infarct –Inflammatory bowel disease –Colonoscopy –Neoplasm –Diverticulitis –Pathologic causes of pneumatosis Pancreatic infection •Emphysematous pancreatitis •Abscess/infected pseudocyst Genitourinary tract infection •Emphysematous pyelonephritis or pyelitis •Emphysematous cystitis	•Necrotizing soft tissue infection or non-necrotizing infection with gas-forming organism from extremity, groin, chest, or cervical origin
Benign gas	•Benign cystic pneumatosis intestinalis •Duodenal diverticulum •Pancreatic pseudocyst with spontaneous or iatrogenic enteric fistula	•Sterile gas from cervical, thoracoabdominal, or pelvic source

cervical or buccal origin dissecting inferiorly along the cervical fascial planes, most often within the superficial space, the

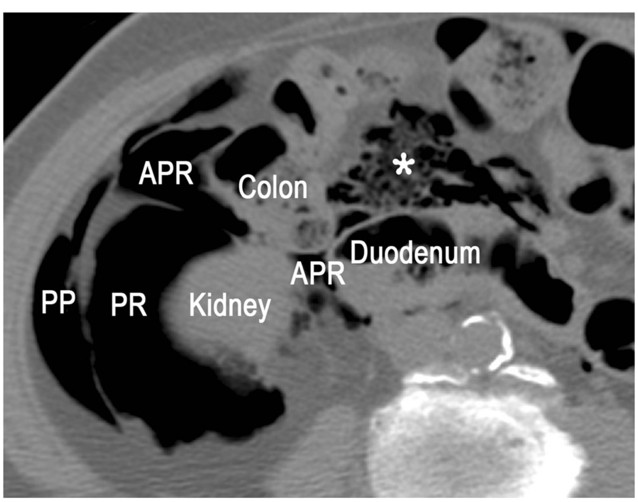

Fig. 7 Iatrogenic subperitoneal duodenal perforation in a 62-year-old woman following ERCP. Axial CT image of the abdomen demonstrates gas in the anterior pararenal space (*APR*) due to extraluminal leakage of bowel contents from the perforated duodenum. Gas tracks into the perivascular mesentery (*asterisk*), the right perirenal space (*PR*), and the right properitoneal space (*PP*)

Fig. 8 Duodenal transection in a 62-year-old woman status post motor vehicle crash. Axial contrast-enhanced CT image of the abdomen demonstrates disruption and loss of continuity of the second part of the duodenum (*arrow*), proximal to the ampulla. There is associated retroperitoneal hematoma (*asterisk*) and free intraperitoneal air (*arrowheads*) indicating duodenal perforation with tear of the posterior parietal peritoneum overlying the anterior duodenal wall. Hepatic laceration (*open arrow*) and pancreatic head contusion (*curved arrow*) are also present. Surgical exploration revealed complete transection of the second part of the duodenum without injury to the common bile duct or the pancreatic duct

Fig. 9 Perforated duodenal diverticulitis in an 88-year-old man. Contrast-enhanced axial CT image shows a known duodenal diverticulum (*D*) arising from the third portion of the duodenum. New free air and inflammatory stranding are seen adjacent to the diverticulum in the anterior pararenal space (*white arrow*) and tracking into the perivascular mesenteric root (*black arrow*). This perforation was managed nonoperatively

danger zone, or the perivisceral space (Fig. 6). Less commonly, a subperitoneal necrotizing process might dissect superiorly. The extent of gas and of fluid or fat stranding indicates the extent of infection until proven otherwise by surgical debridement.

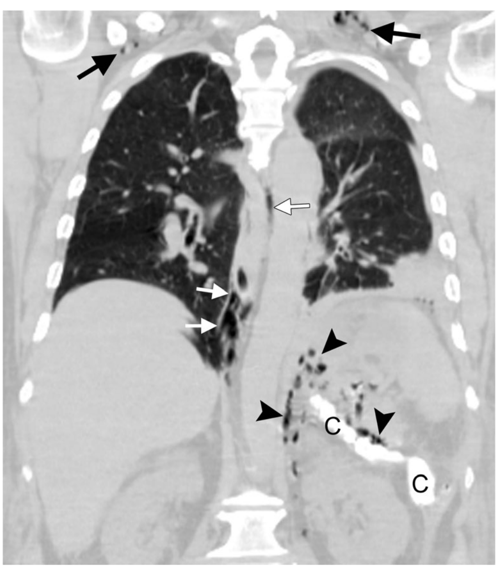

Fig. 10 Pneumomediastinum and cervical gas from perforated diverticulitis of the proximal descending colon in a 54-year-old man. Coronal CT image of the chest and abdomen with rectal contrast, shown in lung windows, demonstrates colonic contrast (*C*) leaking from a perforation of the proximal descending colon into the retroperitoneum. Adjacent retroperitoneal gas (*black arrowheads*) tracked along the aorta and esophagus into the mediastinum (*white arrows*) and to the superficial tissues of the neck and axilla (*black arrows*). Two negative esophagrams had been performed (for evaluation of pneumomediastinum) before surgery confirmed perforated diverticulitis with gross retroperitoneal contamination

Scary causes of subperitoneal gas and mimics

Dissecting subperitoneal gas may arise from perforation of subperitoneal bowel (duodenum, right and left colon, and rectum) or infection of retroperitoneal solid organs (pancreas, kidneys) with gas-forming organisms. Retroperitoneal contamination tends to be less clinically conspicuous than

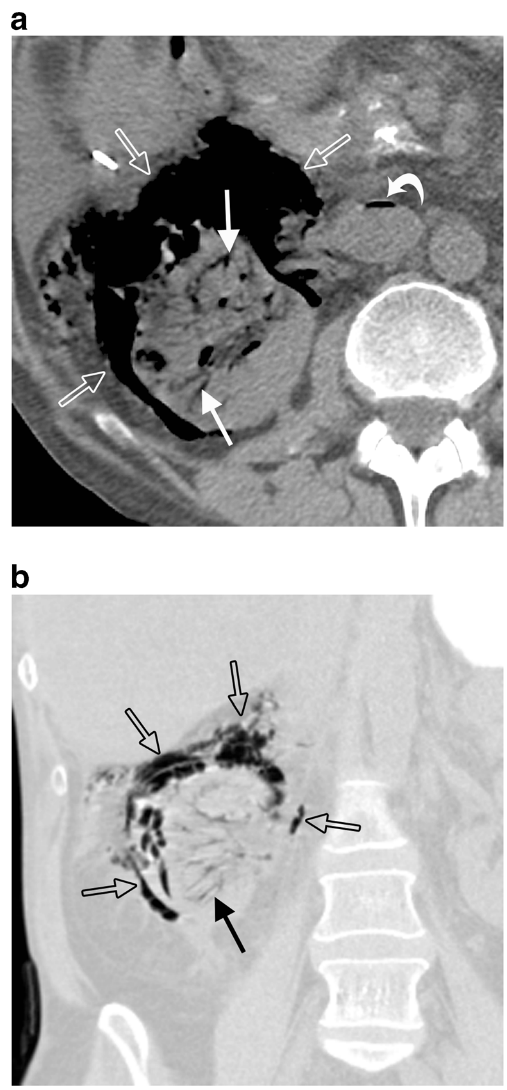

Fig. 11 Emphysematous pyelonephritis in a 49-year-old woman with history of diabetes mellitus and on immunosuppression for orthotopic liver transplant. **a** Axial and **b** coronal noncontrast CT images through the right kidney in soft tissue and lung windows, respectively, show striations of gas within the renal parenchyma (*closed arrows*), consistent with emphysematous pyelonephritis. The gas dissects into the perirenal space (*open arrows*). There is also gas within the IVC (*curved arrow*)

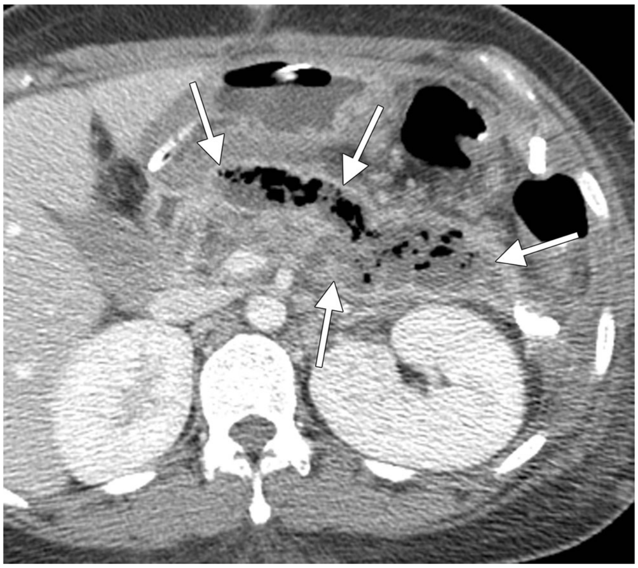

Fig. 12 Infected pancreatic collection in a 34-year-old woman with known necrotizing pancreatitis. Axial contrast-enhanced CT image of the upper abdomen demonstrates gas (*arrows*) within the preexisting necrotic fluid collection filling the pancreatic bed. This fluid-gas collection was drained, with subsequent culture showing a mixed microbial infection including *Streptococcus* species, *Staphylococcus*, anaerobes, and *Klebsiella*

intraperitoneal perforation, potentially delaying diagnosis. Etiologies of subperitoneal gas are summarized in Table 2.

Subperitoneal bowel perforation

Duodenal perforation may result from trauma, endoscopic retrograde cholangiopancreatography (ERCP), or penetrating ulcer. Perforation can result in retroperitoneal gas, intraperitoneal gas, or both (Figs. 7 and 8). Retroperitoneal perforation requires a higher level of suspicion to detect, aided by CT [17]. Retroperitoneal duodenal perforation may be confined to the right anterior pararenal space despite communication of this space across midline [18]. A potential mimic of duodenal perforation is duodenal diverticulitis, which by CT has a duodenal diverticulum accompanied by wall thickening, stranding of the adjacent mesenteric or retroperitoneal fat, and occasionally subperitoneal (but not intraperitoneal) free air (Fig. 9) [19].

Retroperitoneal colonic perforation may cause subperitoneal or intraperitoneal free air [18]. Etiologies include trauma, iatrogenia, ischemia, inflammatory bowel disease, diverticulitis, infection, or neoplasm. Subperitoneal gas may dissect widely, particularly when aided by bowel peristalsis, to present with crepitus or pneumomediastinum (Fig. 10).

Emphysematous infection

Emphysematous pyelonephritis is an acute, necrotizing infection of the proximal renal collecting system and/or renal parenchyma, usually seen in diabetics or an obstructed urinary tract (Fig. 11). The most common organisms are *Escherichia coli* and *Klebsiella pneumoniae* [20]. The infection may remain localized to the collecting system (*emphysematous pyelitis*) or kidney (*emphysematous pyelonephritis*) or may perforate the renal capsule into the perirenal space, the pararenal space, and subcutaneous tissues distant from the kidney. Prognosis worsens with increased extent of involvement [20].

Complications of acute pancreatitis include emphysematous pancreatitis and gas-containing fluid collections (Fig. 12). Emphysematous pancreatitis is a rare and potentially lethal form of necrotizing pancreatitis superinfected most often with *E. coli* and sometimes with additional organisms [21]. Pancreatic necrosis can also be infected without the formation of gas. In both cases, treatment is surgical debridement with similar prognosis, though emphysematous pancreatitis may have more locoregional complications [21]. Gas may also develop within a peripancreatic abscess [22].

Table 3 Differential diagnosis of superficial soft tissue gas

Gas type	Originate in superficial tissues	Dissect from elsewhere
Scary gas	•Necrotizing soft tissue infection –Necrotizing fasciitis –Myonecrosis –Gangrenous or crepitant cellulitis –Fournier's gangrene •Non-necrotizing soft tissue infection with gas-forming organism •Abscess	•Necrotizing soft tissue infection or non-necrotizing infection with gas-forming organism spreading from deeper spaces of torso or from extremities
Benign gas	•Direct inoculation (trauma, surgery, subcutaneous medicinal injection, drug use)	•Sterile gas from deeper spaces of torso or from extremities –Mechanical dissection –Injection of pressurized gas

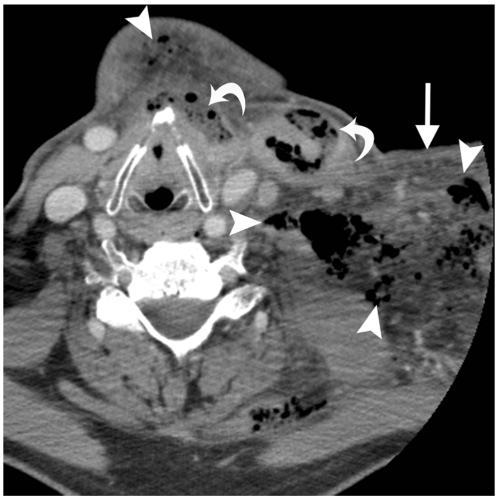

Fig. 13 Necrotizing soft tissue infection descending from dental source into neck and left supraclavicular fossa of a 62-year-old man. On this axial contrast-enhanced CT image from the lower neck, gas and fluid collections surrounded by fat stranding reflect areas of necrosis and inflammation of supraclavicular fat (*arrowheads*) and myonecrosis of sternocleidomastoid and platysma (*curved arrows*). Skin thickening (*arrow*) may indicate cellulitis or skin necrosis. Despite the administration of contrast, it is difficult to determine if these tissues are still enhancing or infarcted, but extensive necrosis was found at surgery

Benign gas may be seen within a peripancreatic fluid collection that communicates with bowel through a pancreatic-enteric fistula, internal pseudocyst drainage, or prior pancreaticojejunostomy [22]. Spontaneous pancreatic-enteric fistulization may or may not effectively decompress the pseudocyst.

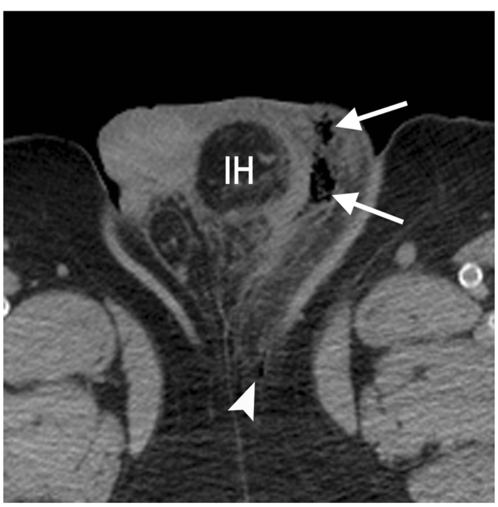

Fig. 14 Fournier's gangrene in a diabetic 59-year-old man presenting with clinical signs of sepsis following several days of left scrotal swelling and erythema. Axial noncontrast CT image through the scrotum demonstrates gas (*arrows*) and fat stranding within the scrotum, surrounding (but sparing) a fat-containing inguinal hernia (*IH*). The inflammation and gas also extend toward the perineum (*arrowhead*). Necrosis of the perineum and scrotal tissues, consistent with Fournier's gangrene, was found at surgery

Scary causes of superficial soft tissue gas and mimics

Superficial gas may arise in situ or may dissect from distant sources (Table 3).

Necrotizing soft tissue infection

Superficial dissecting gas in the torso, as in the extremities, is concerning for necrotizing soft tissue infection (NSTI) if the patient appears toxic and has local signs of infection. NSTI collectively describes a heterogeneous group of infections involving necrosis of fascia (*necrotizing fasciitis*), muscle (*myonecrosis*), subcutaneous fat, and/or skin (*gangrenous* or *crepitant cellulitis*) (Fig. 13). *Fournier's gangrene* is a subtype of NSTI arising in the perineal region (Fig. 14). Organisms include *Clostridium* species, beta-hemolytic group A *streptococcus*, and mixed infections with synergistic aerobic and anaerobic organisms [23].

If performed, CT may reveal abnormal soft tissue enhancement and thickening due to inflammation and ischemia, muscle necrosis, fluid collections, or gas along tissue planes [24] (Fig. 13). These signs, however, are neither sensitive nor specific. Necrosis of the skin or subcutaneous tissues without muscular involvement may be difficult to identify on CT, while soft tissue thickening and fluid collections are also found in non-necrotizing infections [25]. Gas is a late imaging finding of NSTI, and its absence should not exclude the diagnosis. High clinical suspicion necessitates aggressive debridement, and emergent surgery should not be delayed by extensive imaging or equivocal results.

Direct Inoculation

Subcutaneous gas may result from direct inoculation, such as during penetrating trauma, surgery, or subcutaneous injection, or may dissect from remote sources. In the head and neck region, dissecting soft tissue gas can result from fractures involving the paranasal sinuses [26]. Infection can be excluded by history and lack of local inflammation.

Conclusion

Aerodigestive tract perforation and necrotizing and emphysematous infections may cause dissecting gas, usually accompanied by inflammatory fluid and clinical signs of infection. However, a high index of suspicion is necessary for early detection, particularly in the subperitoneum. It is also important to recognize that dissecting gas can result from benign sources such as Macklin effect. When clinical, imaging, or laboratory findings are concerning, surgical exploration is generally warranted.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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