INTRODUCTION
Computed tomography (CT) is a useful tool for emergency cases because it facilitates an accurate and reproducible diagnosis. Emergency cases have various causes, and CT helps to identify characteristics such as abnormal gas in the abdomen and pelvis. Although radiography can detect large amounts of abnormal gas, it cannot evaluate the distribution and amount of the gas in detail. CT has the highest accuracy among the imaging modalities for detection of abnormal gas in the abdomen and pelvis.\(^1\) Abnormal gas can be more easily observed in the lung or bone window settings compared to the soft tissue window setting. CT often provides key imaging findings for correct diagnosis. Hence, through this study, we aimed to describe various CT presentations of abnormal gas in the abdomen and pelvis.

GAS IN VESSELS
Portal venous and mesenteric venous gas are clinically important, because they are commonly caused by serious and potentially fatal conditions including bowel ischaemia, bowel obstruction, bowel perforation and sepsis.\(^1\) However, several non-life-threatening causes have also been reported.\(^1\)

Portal venous gas appears as areas of tubular or branched air attenuation in the portal vein and its branches on CT (Fig. 3a). It typically extends to within 2 cm of the liver capsule because of the centrifugal blood flow to the hepatic periphery.\(^5\) Importantly, pneumobilia, which refers to accumulation of gas in the biliary system, can also be observed as intrahepatic gas. It is important to distinguish between portal venous gas and pneumobilia because of the difference in their clinical significance. Pneumobilia is not clinically significant in most cases. Pneumobilia is located centrally and does not extend to within 2 cm of the liver capsule because of the centripetal biliary flow to the hepatic hilum (Fig. 3b).\(^5\) Common causes of pneumobilia include biliary-enteric surgical anastomosis and sphincter of Oddi dysfunction. Mesenteric venous gas can be found with portal venous gas, because gas from the necrotic bowel can pass through the intestinal wall and travel via the small mesenteric veins and either the superior or inferior mesenteric vein to the portal vein.\(^5\) Mesenteric venous gas appears as an area of tubular or branched air attenuation in the mesenteric border of the bowel (Fig. 4).

Abnormal gas in the aorta can be a sign of a life-threatening condition. However, it is also observed in patients with an intracoronary balloon pump (IABP) (Fig. 5). It is a long, thin balloon that controls blood flow by changing its size according to the cardiac cycle.\(^6\) An IABP is visualised as a structure with regular air attenuation in the caudal direction on coronal or sagittal CT (Fig. 5b). The distance between the air attenuation is determined by the length of the cardiac cycle and the speed of the CT gantry.\(^6\) It is important to recognise the typical IABP imaging findings to avoid misinterpretation of life-threatening abnormal gas in the aorta.

GAS IN THE PERITONEAL OR RETROPERITONEAL CAVITY
Pneumoperitoneum and pneumoretroperitoneum
The presence of gas within the peritoneal cavity (pneumoperitoneum) and the retroperitoneal space (pneumoretroperitoneum) is a

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crucial imaging finding for gastrointestinal perforation. The direct imaging finding of gastrointestinal perforation is bowel wall discontinuity (Fig. 6b). There are several findings supporting the correct diagnosis of gastrointestinal perforation, including pneumoperitoneum/pneumoretroperitoneum, surrounding fat stranding, focal bowel wall thickening, extraluminal fluid and extraluminal abscess formation.\(^\text{4}\) The most common causes of gastric and duodenal perforation are peptic ulcer (Fig. 6) and malignancy.

Pneumoperitoneum may be detected owing to reasons other than gastrointestinal perforation, including postoperative state or peritoneal dialysis. However, these typically have no symptoms. Pneumoperitoneum due to open laparotomy decreases over time. However, it can remain for up to two weeks.\(^\text{4}\)
In patients with peritoneal dialysis, pneumoperitoneum can occur owing to catheter insertion or inappropriate exchange technique for a bag or extension tube, and its incidence rate has been reported to range between 4% and 34%.[7] Therefore, it is important to review the patient’s treatment history to avoid misinterpreting pneumoperitoneum due to postoperative state and peritoneal dialysis as life-threatening pneumoperitoneum. The common causes of pneumoretroperitoneum include duodenal or rectal perforation and extensions from pneumomediastinum. The common causes of pneumoperitoneum and pneumoretroperitoneum are different, but both are potentially serious signs.

Abscess
An abscess may form because of inflammation in the peritoneal or retroperitoneal cavity. Common causes of an intra-abdominal abscess include surgical trauma, anastomotic leaks, perforation of a peptic ulcer, perforated appendicitis or diverticulitis, and pelvic inflammatory disease.[8] An abscess is demonstrated as a low-attenuation central necrotic component with an enhancing wall that can be irregular and thick on contrast-enhanced CT. Abnormal gas is often contained in an abscess when gas-producing bacteria are the cause of the abscess (Fig. 7).

Walled-off pancreatic necrosis
Walled-off pancreatic necrosis (WOPN) is a late complication of necrotising pancreatitis, as defined in the revised Atlanta
Postoperative pancreatic fistula

Postoperative pancreatic fistula (POPF) is one of the most serious complications after pancreatic resection. It is defined as an abnormal communication between the pancreatic ductal system and another epithelial surface containing pancreas-derived, enzyme-rich fluid. The incidence of POPF ranges between 3% and 45% of pancreatic operations at high-volume centres. For diagnosis, any measurable volume of drain fluid on or after postoperative day 3 with amylase levels > 3 times the upper limit of normal amylase for each specific institution is the necessary threshold, and this condition is defined as biochemical leak (BL) in the latest guidelines. BL is not considered a true pancreatic fistula or an actual complication and implies no deviation in the normal postoperative pathway. Clinically significant POPF is defined as a condition that requires persisting peripancreatic drainage or other treatment in addition to BL. On CT, fluid collection around the pancreatic stump or anastomosis is an indicator of an underlying POPF (Fig. 9). Gas can be observed within the fluid collection on CT owing to anastomosis with the jejunum or infection (Fig. 9). Demonstrating the communication between the fluid collection and the pancreatic duct is especially useful for imaging diagnosis of POPF (Fig. 9b).

GAS IN HOLLOW ORGANS

Pneumatosis intestinalis

Pneumatosis intestinalis is defined as the presence of gas in the bowel wall owing to various causes. It occurs as a primary (idiopathic) form or secondary form in 15% and 85% of cases, respectively. It can be found with portal venous gas and mesenteric venous gas, rendering them related phenomena. Pneumatosis intestinalis is commonly caused by fatal diseases including bowel necrosis, bowel obstruction and bowel perforation. Nevertheless, it has been reported in various pathological conditions including inflammatory bowel disease and chronic pulmonary disease, with corticosteroids or molecular targeted drugs, and trauma that can show better clinical outcomes (so-called benign pneumatosis intestinalis). Three patterns of pneumatosis on CT have been described: a circumferential form in the bowel wall (Fig. 10), a linear pattern in which the gas has a curvilinear or a crescent shape (Fig. 10), and a bubble-like or cystic pattern characterised by separate bubbles of gas with a cystic appearance (Figs. 10 & 11). These can all be observed at the same time (Fig. 10). It is not possible to judge the presence or absence of necrosis only by the shape of the gas. It should be evaluated for bowel necrosis along with the patient’s condition and blood test results. Among benign pneumatosis intestinalis, a disease in which multiple gas cysts form in the bowel walls is classified as an independent disease called pneumatosis cystoides intestinalis (Fig. 11). Although the prognosis is good, it may be associated with pneumoperitoneum. Thus, it is important to differentiate it from bowel perforation.

EMPHYSEMATOUS INFECTIONS

Emphysematous infections of the abdomen and pelvis are life-threatening conditions that require aggressive medical and often surgical management. They are rare and typically caused by gas-forming microbes. Underlying diabetes mellitus is a well-known risk factor for emphysematous infections. The clinical outcome will largely depend on whether early diagnosis and treatment are achieved. Thus, it is important to reach the correct diagnosis via imaging.
Emphysematous cholecystitis
Emphysematous cholecystitis is a rare form of acute cholecystitis. Vascular compromise of the cystic artery is thought to play a significant role in the evolution of the emphysematous form. The overall mortality rate of patients with emphysematous cholecystitis has been reported as 15%. Emphysematous cholecystitis is characterised by the presence of air within the gallbladder lumen or wall in the absence of abnormal communication between the biliary system and gastrointestinal tract, and CT is the most sensitive and specific imaging modality (Fig. 12).^{22,13}

Emphysematous pyelonephritis
Emphysematous pyelonephritis has been defined as a necrotising infection of the renal parenchyma and perirenal tissue, with abnormal gas in these areas (Fig. 13).^{2,12,13} Obstruction of the urinary collecting system due to urinary stones or urothelial neoplasm is commonly observed. It is important to assess the imaging features, including parenchymal destruction with gas, fluid content, and the extent of gas or abscess on CT.^{12,13}

Gastrointestinal Fistulas
Gastrointestinal fistulas should be considered for possible non-infectious conditions of abnormal gas. The common causes
of gastrointestinal fistulas include diverticulitis, inflammatory bowel disease, malignancy, surgical complications, post-radiation therapy and trauma.\textsuperscript{[2,14,15]} Cholecystoenteric fistula is a rare complication of acute cholecystitis. The most common cholecystoenteric fistula is the cholecystoduodenal fistula, followed by the cholecystocolic fistula.\textsuperscript{[14]} CT can allow direct visualisation of a fistula between the gallbladder and the duodenum or colon (Fig. 14b). Pneumobilia and gas in the gallbladder may also be present (Fig. 14). Colovesical fistula is a rare complication of diverticular disease, especially between the urinary bladder and sigmoid colon.\textsuperscript{[15]} Fistulas can be directly demonstrated on CT, and abnormal gas in the bladder or local...
colonic and bladder wall thickening can also be observed (Fig. 15).

CONCLUSION

CT imaging can play a crucial role in various emergency cases with characteristic abnormal gas in the abdomen and pelvis. Contrast-enhanced CT is useful for improved diagnosis of the site of abnormal gas. Most cases are urgent; therefore, it is important for clinicians to be familiar with their characteristic radiologic features to arrive at the correct diagnosis.

REFERENCES

SINGAPORE MEDICAL COUNCIL CATEGORY 3B CME PROGRAMME
(Code SMJ 202206B)

Question 1. Regarding portal venous gas:
(a) It is commonly caused by serious and potentially fatal conditions.
(b) The distribution of portal venous gas is the same as that of pneumobilia.
(c) Mesenteric gas cannot be found with portal venous gas.
(d) It typically extends to within 2 cm of the liver capsule.

Question 2. Regarding pneumoperitoneum and pneumoretroperitoneum:
(a) Pneumoperitoneum is only found in gastrointestinal perforations.
(b) Pneumoperitoneum can remain for up to two months after open laparotomy.
(c) They have some common causes.
(d) Both are crucial imaging findings for gastrointestinal perforation.

Question 3. Regarding pneumatosis intestinalis:
(a) The idiopathic form is more common than the secondary form.
(b) It is possible to judge the presence or absence of necrosis by the shape of the gas.
(c) It can be found with portal venous gas and mesenteric venous gas.
(d) Pneumatosis cystoides intestinalis may be associated with pneumoperitoneum.

Question 4. Regarding emphysematous infections:
(a) They are life-threatening.
(b) Obstruction of the urinary collecting system due to urinary stones or urothelial neoplasm is common.
(c) Ultrasonography is the most sensitive and specific imaging modality for emphysematous cholecystitis.
(d) Underlying diabetes mellitus is a well-known risk factor for emphysematous infections.

Question 5. Regarding gastrointestinal fistulas:
(a) Pneumobilia and gas in the gallbladder are not present with cholecystoduodenal fistula.
(b) Colovesical fistula is a common complication of diverticular disease.
(c) Cholecystoduodenal fistula is the most common cholecystenteric fistula.
(d) Computed tomography does not allow direct visualisation of a fistula between the gallbladder and the duodenum.

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