Ajay Singh
Editor

Emergency Radiology

Imaging of Acute Pathologies

Second Edition

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Preface

The practice of emergency radiology has evolved rapidly over the last two decades, playing an important part in the triage of emergency room patients. Plain radiography and CT imaging are the most commonly used imaging modalities in managing emergency conditions in the more than 115,000 patients visiting the emergency room. Ultrasound, MR, and nuclear medicine imaging, although less often used, play crucial roles in managing specific conditions.

This textbook of emergency radiology represents the state-of-the-art radiology practice in the management of emergency room patients by leading experts in the field. The chapters are based on different organ systems, with few chapters being imaging modality based.

I would like to take this opportunity to thank the publishers for the privilege of editing the second edition of the textbook and Mohammad Mansouri for diligently working to make this edition possible. I must thank the authors of the book chapters for sharing their expertise and case material in preparing the manuscript.

Boston, MA, USA — Ajay Singh, MD

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Imaging of Acute Aortic Conditions

1

Jeanette Chun, Mohammad Mansouri, and Ajay Singh

Introduction

Acute aortic conditions include, but are not limited to, aortic rupture, aortic dissection, intramural hematoma, and penetrating aortic ulcer. Prompt diagnosis of these conditions is essential for managing these conditions. Because these conditions often have similar symptoms, namely, chest and abdominal pain, the imaging characteristics are key to prompt and accurate diagnosis.

Abdominal Aortic Aneurysm and Aortic Rupture

Abdominal aortic aneurysm (AAA) is seen in 5–10% of elderly male smokers. Most AAAs are true aneurysms and involve all three layers of the aortic wall. The two most common etiologies of AAA are degenerative and inflammatory (Tables 1.1 and 1.2).

The most significant complication of AAA is aortic rupture. The mortality rate for ruptured AAA is 50%; thus, an accurate diagnosis is essential for prompt surgical intervention. The risk of rupture is proportional to the maximum cross-sectional diameter, with 1%/year risk for aneurysms measuring 5–5.9 cm. The risk of rupture increases up to 20%/year for an aneurysm measuring greater than 7 cm in diameter. Although AAAs are less common in females (M:F = 4:1), they are more likely to rupture when compared to males.

Ultrasound is the most commonly used imaging modality to screen for AAA and has been shown to reduce mortality. The imaging criteria to diagnose AAA include aortic caliber of more than 3 cm and an aortic caliber of more than 1.5 times the expected diameter of the abdominal aorta (Fig. 1.1). The aortic caliber is measured perpendicular to the long axis of the aorta, from outer wall to outer wall. Although ultrasound is highly sensitive in making the diagnosis of abdominal aortic aneurysm, it is not as reliable as CT in diagnosing aortic rupture. However, the demonstration of normal caliber of abdominal aorta by ultrasound makes aortic rupture an unlikely possibility.

Most aortic aneurysms rupture involves the middle third of the aneurysm, through the posterolateral wall and into the retroperitoneum (Fig. 1.2a). However, intraperitoneal rupture and rupture into the bowel (usually the duodenum) and very rarely into the IVC may occur (Fig. 1.2b, c).

Risk Factors for Aortic Rupture

Progressive aneurysmal dilatation of the aorta with increased wall tension is directly related to the risk of rupture (Fig. 1.3). The decreased proportion of thrombus-to-lumen ratio is also thought to play a part, as a larger thrombus better protects against rupture by providing protection against the high aortic pressures [1]. In addition, discontinuity in aortic wall calcification is associated with an increased risk of rupture [2].

Imaging

The imaging modality of choice is a contrast-enhanced multidetector CT (MDCT). The CT can demonstrate an AAA with surrounding retroperitoneal hemorrhage into psoas compartment, pararenal space, and perirenal space. A contrast-enhanced

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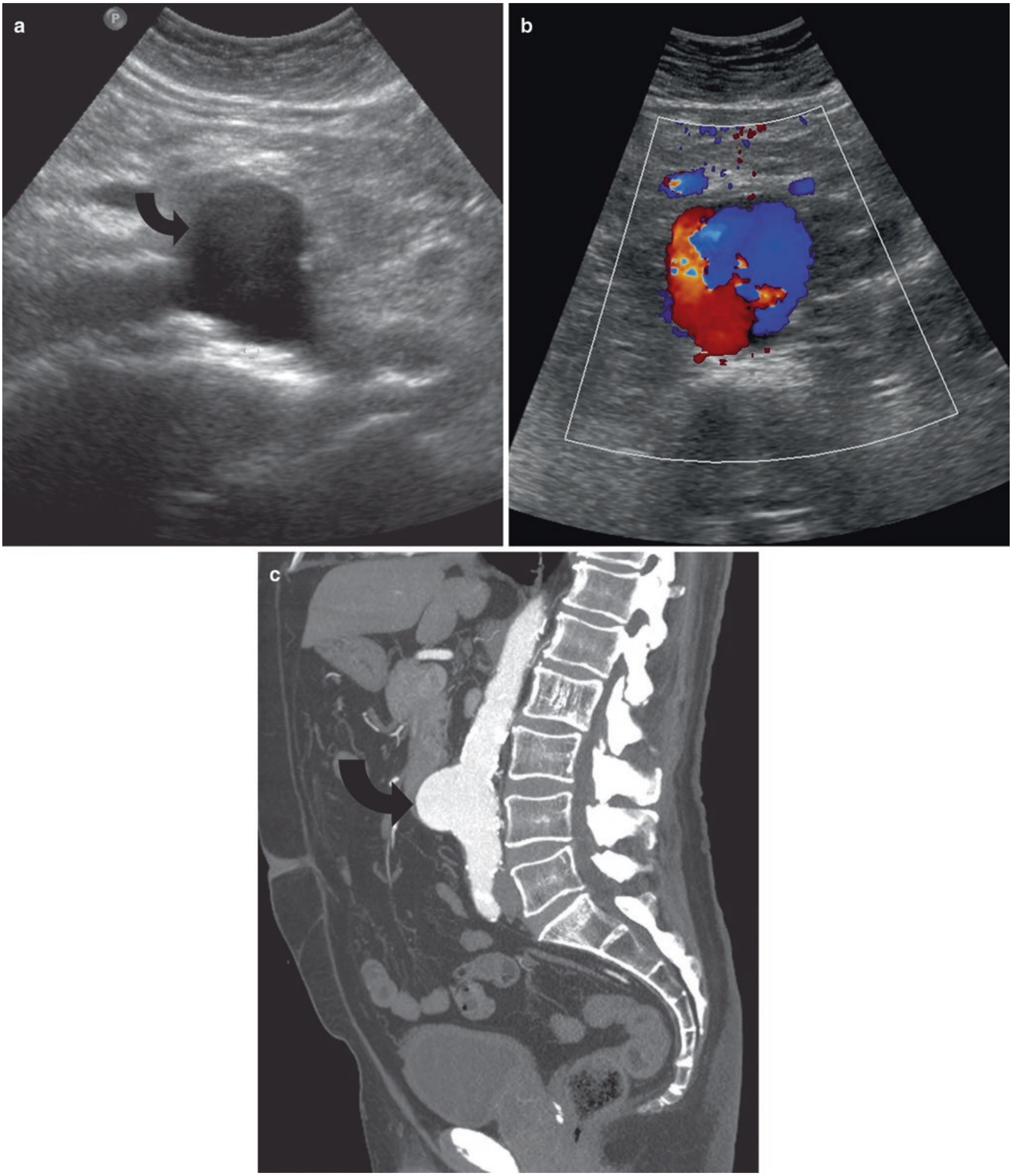


Fig. 1.1 Saccular abdominal aortic aneurysm. (**a**, **b**) US demonstrate a saccular infrarenal aortic aneurysm (*curved arrow*) with yin-yang sign on color Doppler imaging. (**c**) Sagittal reformation demonstrates the saccular infrarenal abdominal aortic aneurysm (*curved arrow*)

Table 1.1 Causes of abdominal aortic aneurysm

Degenerative (most common)
Inflammatory (5–10% of all)
Mycotic
Syndromes: Marfan's syndrome, Ehlers–Danlos syndrome
Vasculitis: Takayasu's disease, Behcet's disease
Traumatic

Table 1.2 Normal caliber of aorta and other arteries

Vascular structure	Normal average diameter (cm)
Aortic sinuses	2.9
Ascending aorta	3
Mid-transverse arc	2.5
Mid descending	2.5
At diaphragm	2.4
Main pulmonary artery	2.7
Infrarenal	2
Common iliac	1
Common femoral	0.9
Popliteal	0.7

Table 1.3 CT findings of aortic rupture

1. Active extravasation of contrast
2. Retroperitoneal hematoma around the aortic aneurysm
3. Periaortic stranding
4. Draped aorta sign
5. Hyperdense crescent sign
6. Tangential calcium sign
7. Discontinuity of intimal calcification

CT provides additional information about the aortic size, presence or absence of active extravasation, and anatomic relationships (Table 1.3). A hyperdense crescent sign and draped aorta sign are indicators of contained aortic leak or impending rupture. Focal discontinuity of intimal calcification is also a secondary sign of aortic rupture.

Hyperdense Crescent Sign

Hyperdense crescent sign is seen as a well-defined peripheral, high-density, crescent configuration within a thrombus where there is internal dissection of hemorrhage into the thrombus and ultimately reaching the aortic wall. It is a sign of acute or impending rupture (Fig. 1.4a) [1].

Draped Aorta Sign

Draped aorta sign indicates a contained aortic rupture and shows posterior aortic wall not identifiable as a separate structure and draping over the adjacent vertebral bodies (Fig. 1.4b, c). If rupture should occur, the most common sign of aneurysmal rupture is a retroperitoneal hematoma adjacent to the aneurysm.

Tangential Calcium Sign

The intimal calcification in the aorta points away from the circumference of the aneurysm (Fig. 1.4d).

Mycotic Aneurysm

One of the less frequent etiologies of AAA is mycotic aneurysm, which constitutes 1–3% of aortic aneurysms. However, mycotic aneurysm is known to more commonly involve aorta than any other artery. Staphylococcus and Streptococcus species are the most common pathogens of mycotic aneurysm. The cases of mycotic aneurysm due to Salmonella species are more common in East Asia and demonstrate an early tendency to rupture.

The typical imaging features of mycotic aneurysm (Fig. 1.4e) include rapidly increasing caliber of a saccular aortic aneurysm with wall irregularity, periaortic edema and soft tissue mass, and the presence of gas. Periaortic soft tissue stranding and soft tissue mass are the most common features seen on imaging of mycotic aneurysm. Calcifications and thrombus are uncommon in a mycotic aneurysm. The lack of calcification in the aortic wall is due to the nonatherosclerotic origin of the aneurysm.

Traumatic Aortic Transection

Traumatic aortic transection is usually caused by rapid deceleration injury, resulting from shearing forces. It involves a tear in all layers of the aortic wall and usually occurs in the aortic arch, most commonly between the origin of left subclavian artery and ligamentum arteriosum. CT is the imaging modality of choice, and findings include periaortic hematomas, mediastinal hematoma, pseudoaneurysm, and change in aortic diameter. Transection of aorta has irregular margins with acute angles relative to the aorta (Fig. 1.5).

Aortic Dissection

Aortic dissection is the most common acute presentation involving the aorta [3]. It usually originates with a tear in the intima, which causes high-pressure blood to enter and dissect the aortic wall (Table 1.4) (Fig. 1.6). Based on the period from onset of symptoms to clinical presentation, aortic dis-

Table 1.4 Factors predisposing to aortic dissection

Hypertension (most common)
Syndromes
Marfan's syndrome
Turner syndrome
Noonan syndrome
Ehlers–Danlos syndrome
Coarctation, bicuspid aortic valve
Cocaine use
Pregnancy
Trauma

section is classified as: hyperacute (symptom onset to 24 h), acute (2–7 days), subacute (8–30 days), and chronic (>30 days).

The most commonly used classification for aortic dissection is the Stanford classification system.

1. *Type A aortic dissection:* Regardless of origin and extent of dissection, a Type A aortic dissection involves the ascending aorta (Fig. 1.7) [4]. The potential for complications with Type A dissection necessitates urgent surgical intervention [4]. The complications include dissection into the pericardium resulting in cardiac tamponade, dissection into the coronary arteries resulting in occlusion, and aortic insufficiency with involvement of the valve [4].
2. *Type B aortic dissection:* The aortic dissection originates past the left subclavian artery [5]. Unlike Type A dissection, the Type B dissections are usually medically treated.

Imaging

The goals of imaging in aortic dissection include identification of:

1. Site of intimal tear site
2. Extent of dissection (for classification)
3. Cardiac involvement (pericardial, myocardial, and valvular)
4. Aortic rupture
5. Major branch-vessel involvement

The imaging modality of choice to evaluate aortic dissection is MDCT. It allows accurate assessment of the extent of the disease, including the origin of the dissection, involvement of the visceral branches, and presence of a false lumen [3, 4]. The most characteristic findings of aortic dissection include an intimal flap and two distinct lumens. Secondary findings include intimal displacement of calcified wall, delayed enhancement of false lumen, pericardial or mediastinal hematoma, and ischemia or infarction of distal organs supplied by the false lumen [4].

True Versus False Lumen

Once the recognition of an aortic dissection is made, it is important to distinguish between the true and false lumen for treatment purposes, especially endovascular repair. Lepage et al. evaluated signs to distinguish between the true and false lumen and determined two consistent signs: beak sign and larger cross-sectional area of false lumen as the best indicators. The beak sign is present in the false lumen and consists of an acute angle between the dissection flap and the aortic wall [5]. The larger caliber lumen is generally the false lumen and is most commonly present anteriorly, to the right side in the ascending aorta (Figs. 1.7, 1.8, and 1.9). In the descending thoracic aorta, the false lumen is most often seen posteriorly and to the left. Cobwebs are seen in the false lumen while aortic wall calcifications are usually seen around true lumen. The true lumen may show systolic expansion and diastolic collapse during the cardiac cycle.

Intramural Hematoma

Intramural hematoma is a hematoma that has dissected through the media without an originating intimal tear (Figs. 1.10 and 1.11). The intramural hematoma may represent hemorrhage of the vasa vasorum (nutrient vessels for the vessel wall) that has dissected through the media [6]. It can be seen in hypertensive and can also be seen after blunt trauma. It can progress to rupture of the aortic wall or aortic dissection.

Unlike mural thrombus, intramural hematoma is deep to the intimal calcification and does not demonstrate the continuous flow seen with aortic dissection. Intramural hematoma can be diagnosed on CT, transesophageal echocardiography, and MRI. Since there is no intimal disruption, it cannot be diagnosed on conventional aortography. Aneurysmal dilatation, focal contrast enhancement, and intramural thickness >16 mm on CT scan indicate poor prognosis. The treatment of intramural hematoma is similar to aortic dissection.

Endoleak

Endoleak is extravasation of blood out of the endovascular stent but within the aneurysmal sac. The aneurysmal sac may enlarge and may ultimately rupture over time, especially in the setting of hypertension. CT scan is the imaging modality of choice in the detection of endoleak (Fig. 1.12).

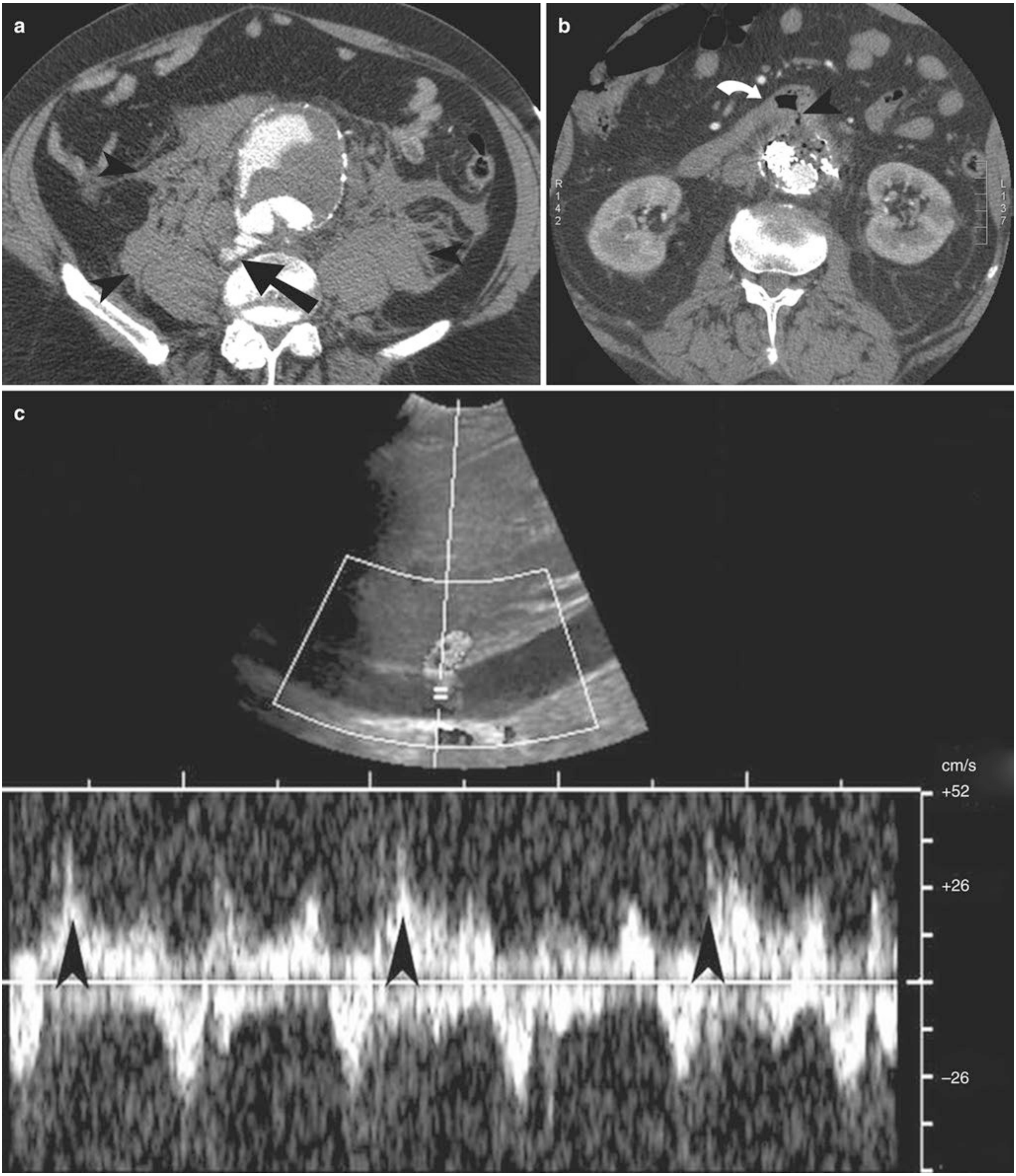


Fig. 1.2 Abdominal aortic aneurysm rupture, aorto-enteric and aortocaval fistula. (**a**) Contrast-enhanced CT scan study of the lower abdomen demonstrates active extravasation of contrast (*arrow*) from infrarenal abdominal aortic aneurysm. There is retroperitoneal hemorrhage (*arrowheads*) identified around the aortic aneurysm. (**b**) Aorto-enteric fistula. Contrast-enhanced CT scan study demonstrates communication (*arrowhead*) of the third portion of the duodenum (*arrow*) with the infrarenal abdominal aortic aneurysm sac. The patient had recently undergone endovascular stent placement. (**c**) Aortocaval fistula. Doppler US shows the combination of arterial and venous spectral waveform in the inferior vena cava lumen, in a patient with aortocaval fistula

Fig. 1.3 Aortic pseudoaneurysm CTA in a 73-year-old female demonstrates a large saccular pseudoaneurysm (*arrows*) arising from the aortic arch

Five types of endoleak are:

Type I: Incomplete seal between graft and vessel wall in (a) proximal or (b) distal anchors.
Type II: Most common type. Retrograde blood flow into the sac from aortic branch vessels.
Type III: Relatively uncommon type. Due to separation or tear of graft material.
Type IV: Due to porosity of stent-graft material and have no CT findings.
Type V: Continued expansion of the aneurysm sac without radiographic identification of a leak.

Penetrating Ulcer

Penetrating ulcer is characterized by atherosclerotic ulceration that has penetrated through the elastic lamina and formed a hematoma in the media. On CT scan, it is seen as an ulcer with focal hematoma and adjacent arterial wall thickening (Fig. 1.13) [7, 8]. Unlike penetrating ulcer, an atherosclerotic plaque with ulceration does not extend beyond the intima and is not associated with intramural hematoma.

Penetrating ulcer and aortic dissection are characterized by disruption of the intima, while aortic rupture is characterized by disruption of the aortic wall.

CT is the key diagnostic modality in the emergency room evaluation of acute aortic syndromes and allows different pathologies to be diagnosed for proper triage as well as treatment (Table 1.5).

Table 1.5 CT findings in acute aortic conditions

Condition	CT findings
Aortic dissection	1. Intimal flap 2. Two distinct lumens 3. Displacement of intimal calcification 4. Delayed enhancement of false lumen 5. Infarction of distal organs
Intramural hematoma	1. Thickening of aortic wall 2. Hyperdense crescent on unenhanced CT
Penetrating ulcer	1. Ulcer with focal hematoma 2. Adjacent arterial wall thickening

Teaching Points

- Most common cause of abdominal aortic aneurysm are degenerative and inflammatory.
- The imaging criteria to diagnose AAA include aortic caliber of more than 3 cm and an aortic caliber of more than 1.5 times the expected diameter of the abdominal aorta.
- There is increased risk of rupture with increasing caliber of the aneurysm and reduced thrombus-to-lumen ratio.
- Hyperdense crescent sign and draped aorta sign are indicators of contained aortic leak or impending rupture.
- The most common imaging features of mycotic aneurysm are periaortic soft tissue stranding and soft tissue mass.
- Type A aortic dissection involves the ascending aorta and is surgically managed.
- Type B aortic dissection originates past the left subclavian artery and is usually medically managed.
- Beak sign and larger cross-sectional area of lumen are indicators of false lumen.
- Intramural hematoma represents hemorrhage of the vasa vasorum and is not associated with intimal discontinuity (unlike penetrating ulcer).

Questions

1. What is the most common cause of abdominal aortic aneurysm?
   (a) Inflammatory
   (b) Marfan's syndrome
   (c) Degenerative
   (d) Traumatic

Answer: C

2. Which of the following is the imaging criteria to diagnose abdominal aortic aneurysm?

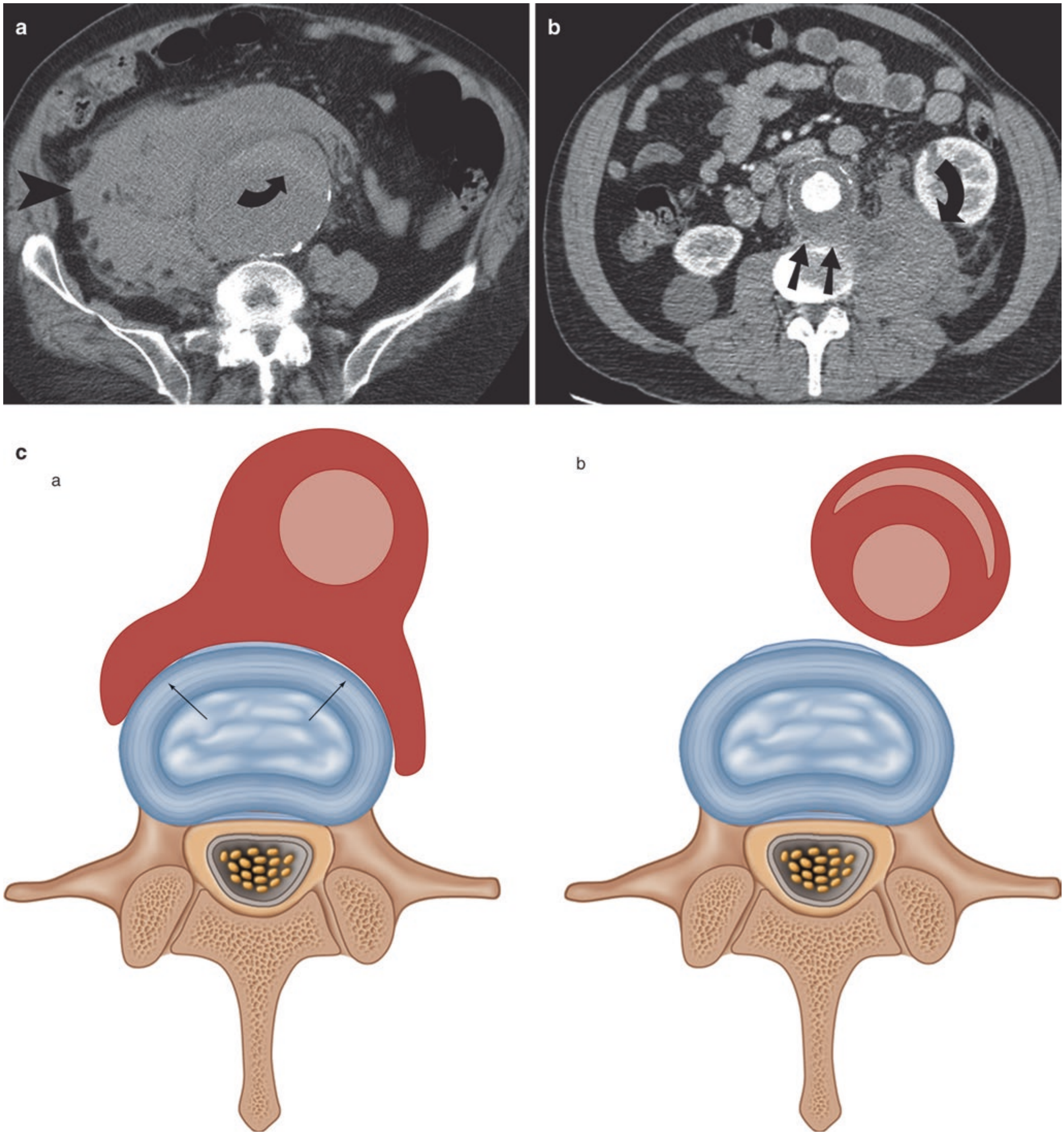
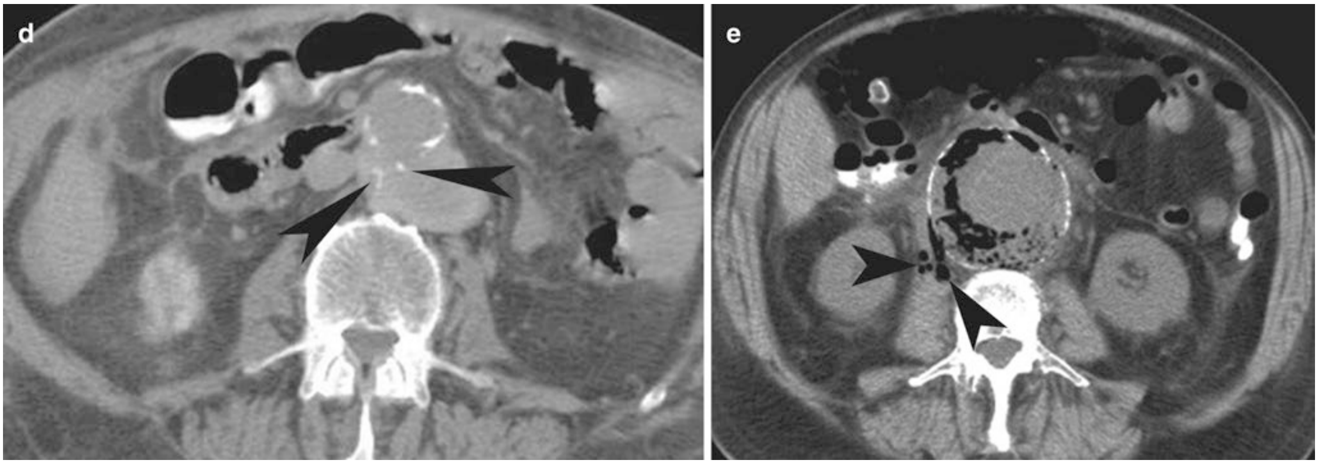


Fig. 1.4 CT features of abdominal aortic aneurysm rupture. (**a**) Hyperdense crescent sign. Noncontrast CT demonstrates large retroperitoneal hematoma (*arrowhead*) from the ruptured aortic aneurysm. A hyperdense crescent (*curved arrow*) is present in the anterior wall of the infrarenal abdominal aortic aneurysm. (**b**) Draped aorta sign. Contrast-enhanced CT demonstrates draping of the posterior wall of the aorta (*straight arrows*) on the anterior aspect of the lumbar spine. There is large retroperitoneal hematoma (*curved arrow*) identified in the psoas compartment and left posterior pararenal space. (**c**) Schematic representation of the *draped aorta sign* (*a*) and *hyperdense crescent sign* (*b*). Draped aorta sign is characterized by draping of deficient aortic wall on the anterior aspect of the vertebral body. Hyperdense crescent sign is characterized by the presence of a high-density sickle-shaped blood clot in the aortic wall. (**d**) Tangential calcium sign in a patient with contained aortic leak. Noncontrast CT demonstrates intimal calcifications (*arrowheads*) displaced from their expected location and pointing away from the aortic circumference. (**e**) Rupture of mycotic aneurysm. Noncontrast CT demonstrates air in the wall of the aortic aneurysm, secondary to clostridial infection. Breech in the aortic wall is indicated by the presence of air (*arrowheads*) outside the aortic adventitia



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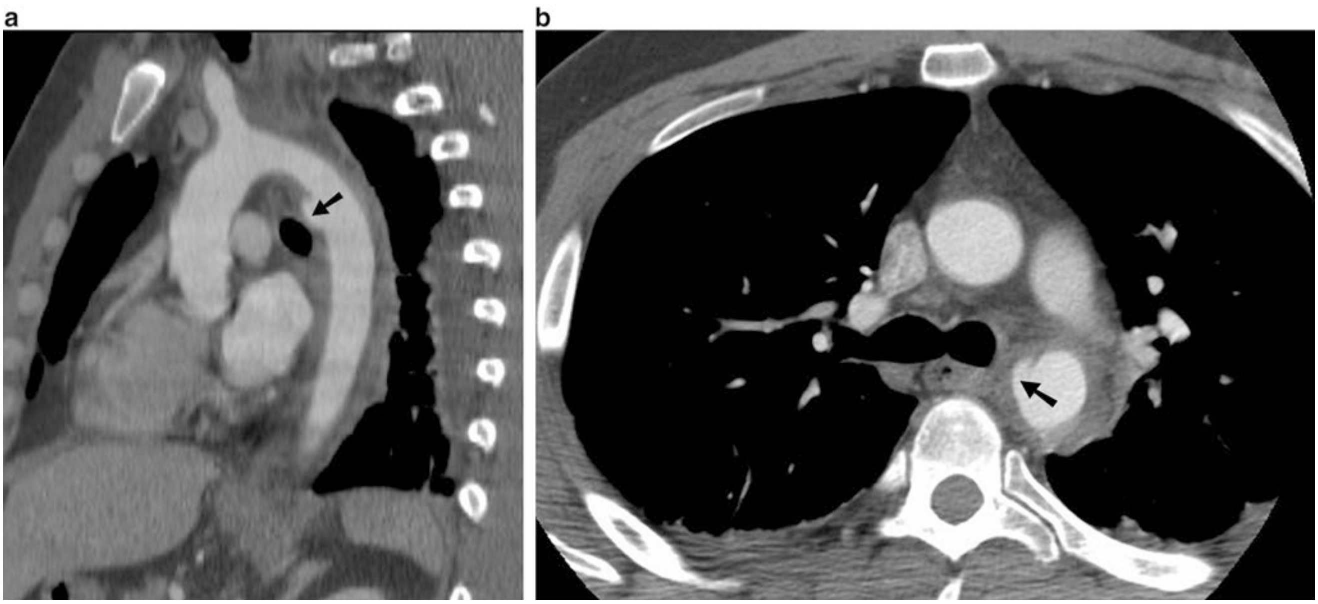

Fig. 1.5 Aortic transection. Sagittal (**a**) and axial CT (**b**) demonstrates outpouching (*arrow*) of the aorta and surrounding hemorrhage, at the junction of aortic arch and descending thoracic aorta

(a) Caliber >1.5 times the expected
(b) Active extravasation
(c) Hyperdense crescent sign
(d) Draped Aorta Sign

Answer: A

3. What is the most common predisposing factor to aortic dissection?
   (a) Drug abuse
   (b) Coarctation
   (c) Trauma
   (d) Hypertension

Answer: D

4. Which of the following is an indicator of false lumen?
   (a) Acute angle between the dissection flap and aortic wall
   (b) Smaller lumen
   (c) Posterior location in the ascending aorta
   (d) Aortic wall calcifications around the lumen

Answer: A

5. Aortic wall irregularity and surrounding edema are the imaging features of which of the following aortic pathology?
   (a) Aortic rupture
   (b) Mycotic aneurysm
   (c) Aortic dissection

Fig. 1.6 Postoperative changes in a patient with Type A aortic dissection. 3-D CT image demonstrates ascending aortic graft (*arrow*) which was placed to surgically managed Type A aortic dissection. The dissection flap (*arrowheads*) is visible in the aortic arch, descending thoracic aorta, and abdominal aorta

Fig. 1.7 Type A aortic dissection. Contrast-enhanced CT scan study of the chest demonstrates aortic dissection involving the ascending as well as the descending thoracic aorta. The true lumen can be identified by the smaller caliber (*arrows*) and higher acute aortic density. The beak sign (*arrowheads*) is identified in the false lumen

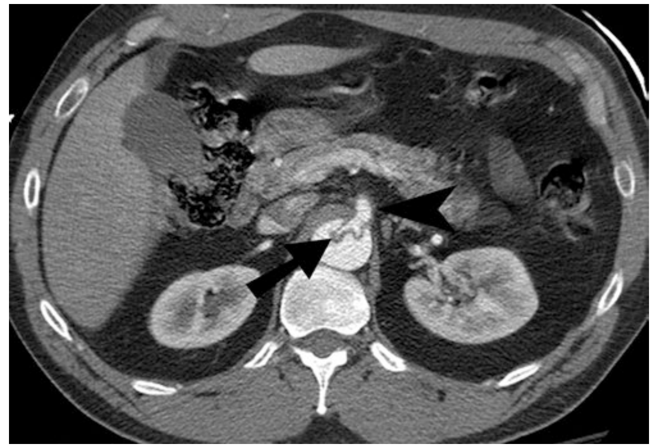

Fig. 1.8 Aortic dissection involving the abdominal aorta. Contrast-enhanced CT scan study demonstrates small caliber of the true lumen (*arrow*) supplying the superior mesenteric artery (*arrowhead*)

Fig. 1.9 Type B aortic dissection on MR angiogram. Gadolinium-enhanced MR angiogram demonstrates the dissection flap (*arrowheads*) present in the descending thoracic aorta

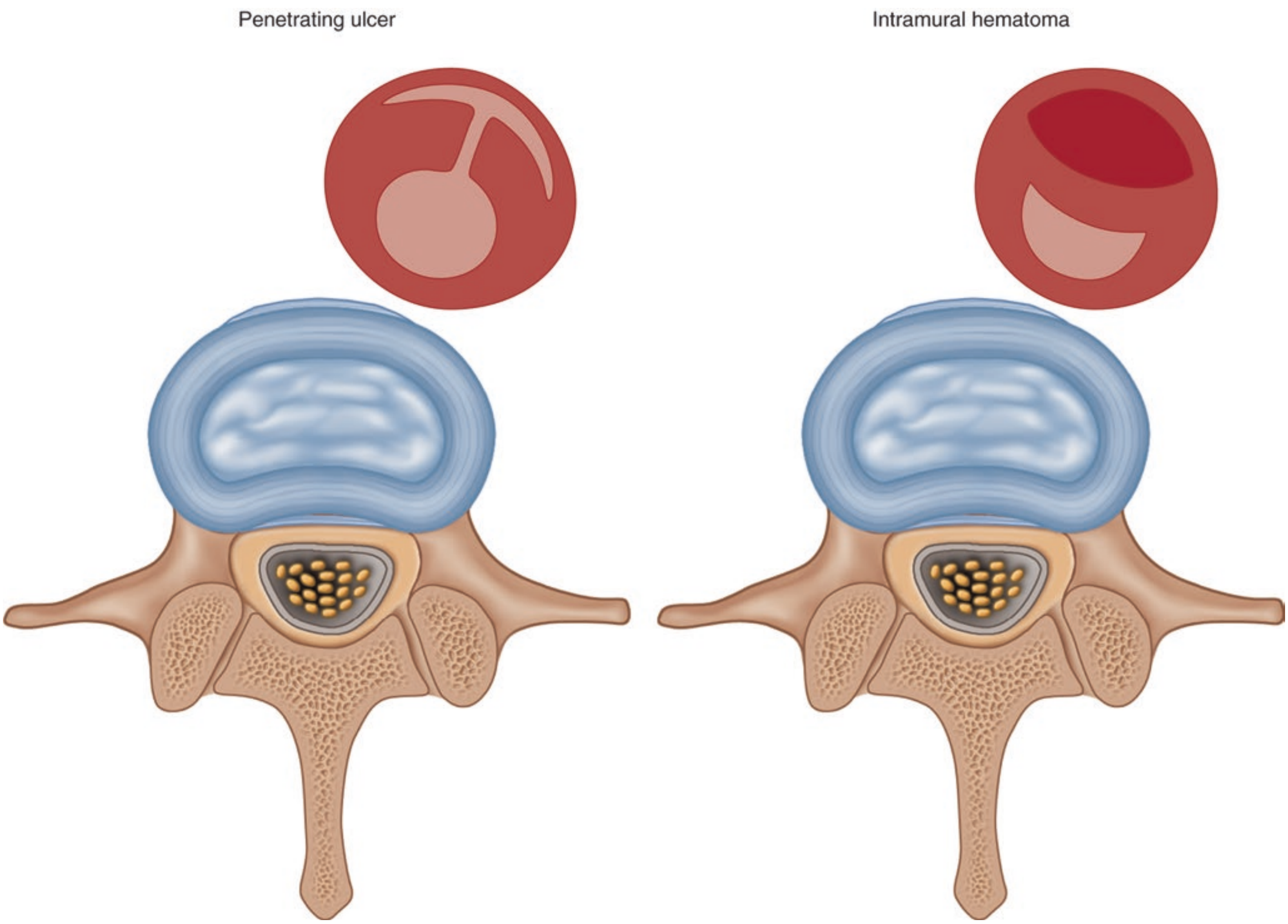

Fig. 1.10 Schematic representation of penetrating ulcer and intramural hematoma. Penetrating ulcer is characterized by communication of the arterial lumen with the hematoma located in the media. Intramural hematoma is characterized by lack of direct communication of the arterial lumen with the hematoma in the media

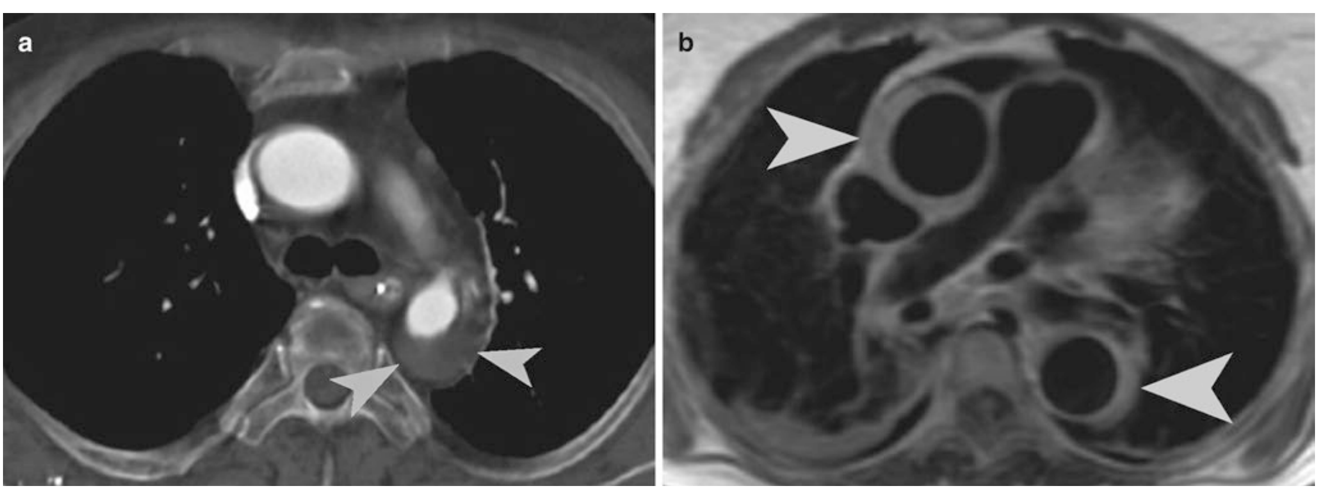

Fig. 1.11 Intramural hematoma. (**a**) Contrast-enhanced CT demonstrates asymmetric aortic wall thickening, consistent with intramural hematoma (*arrowheads*) in the descending thoracic aorta. (**b**) Noncontrast axial T1-weighted MR shows intramural hematoma (*arrowheads*) causing asymmetric aortic wall thickening in the ascending and descending thoracic aorta

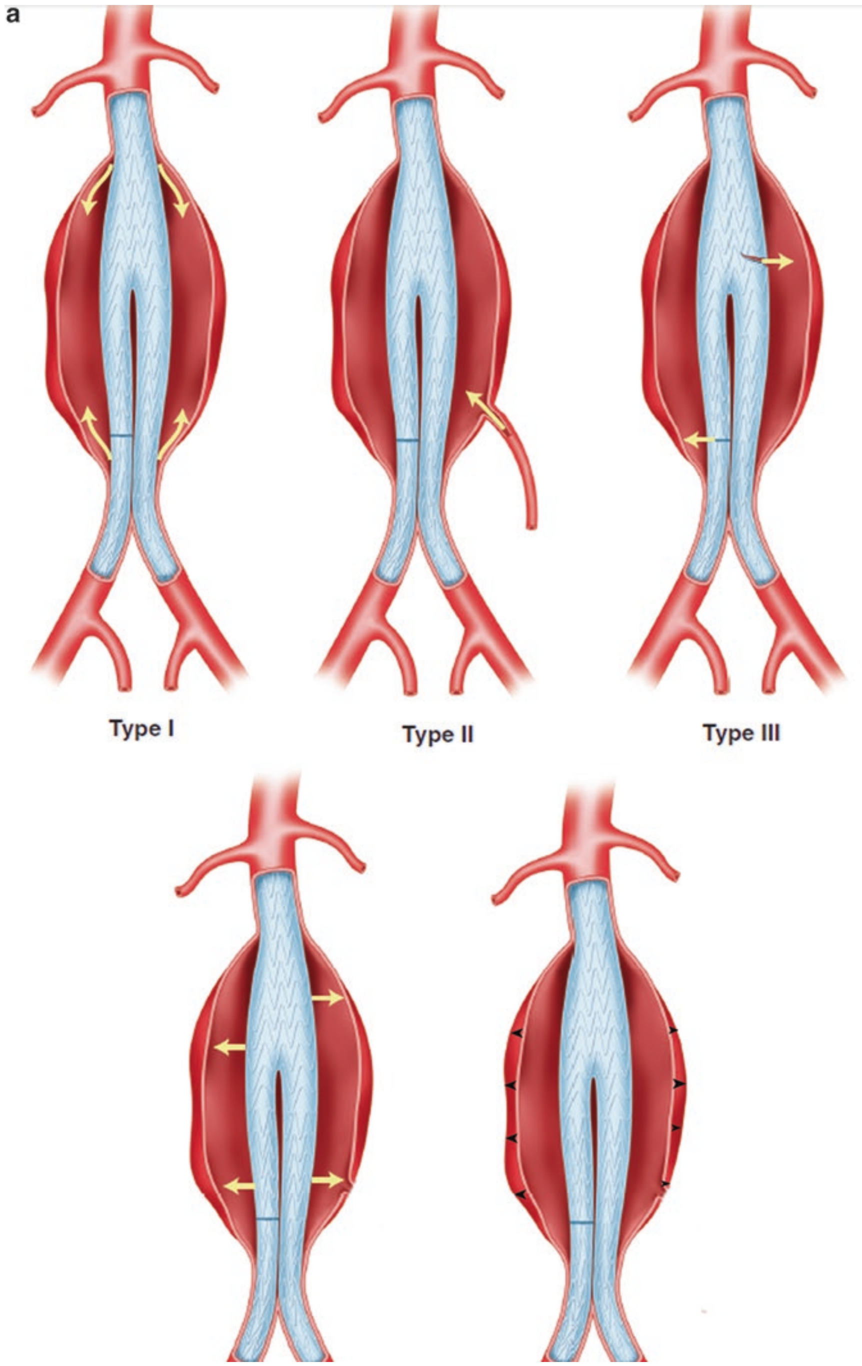

Fig. 1.12 Endoleak. (**a**) Schematic representation of endoleak types. (**b**) US demonstrates type 1b endoleak (*arrowheads*), outside the endograft. (**c**) Axial CT image demonstrates a type 2 endoleak (*arrowhead*), being fed by inferior mesenteric artery (*arrow*)

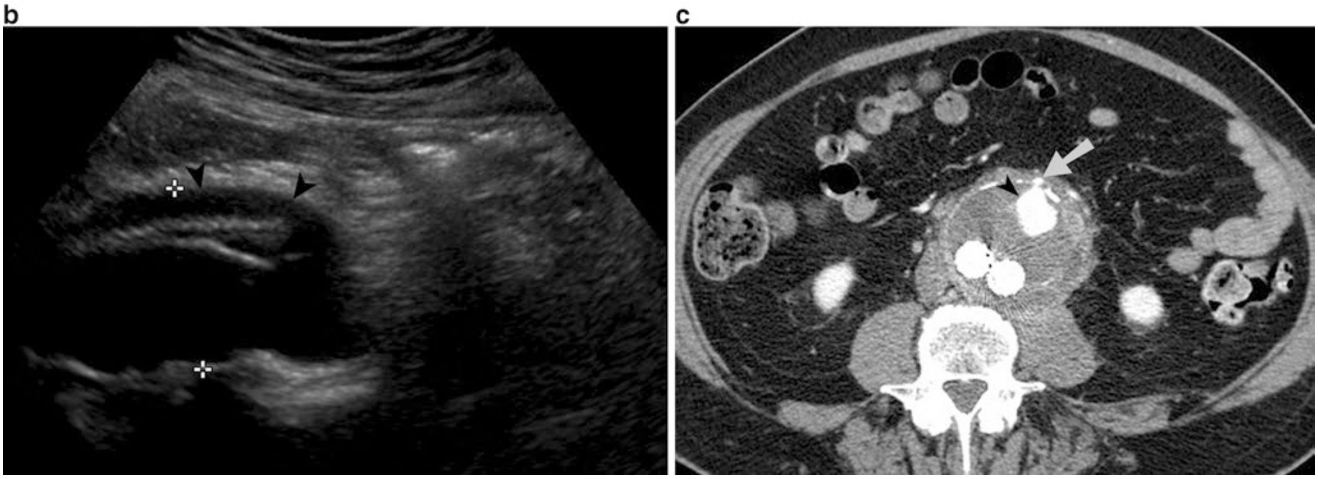

Fig. 1.12 (continued)

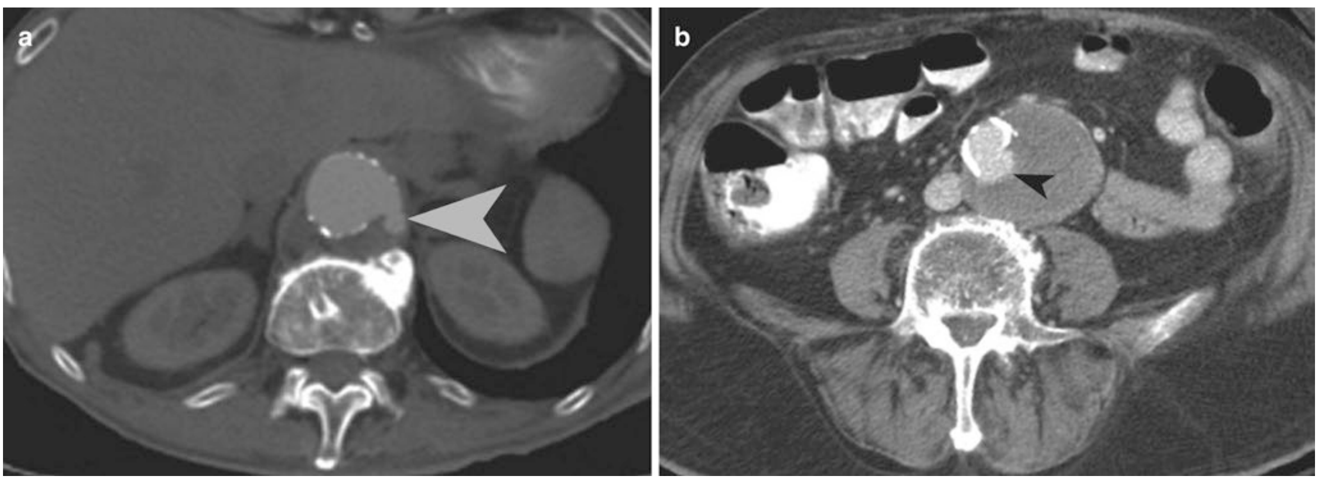

Fig. 1.13 Aortic ulcer. (**a**, **b**) Contrast-enhanced CT scan study of the abdomen demonstrates abdominal aortic aneurysm with an aortic ulcer (*arrowheads*) along with intramural hemorrhage

(d) Intramural hematoma

Answer: B

6. CTA of an elderly man with acute chest pain in depicted on Fig. 1.14. Which of the following is a possible cause of the patient's chest pain?
   (a) Hematoma
   (b) Aneurysm
   (c) Endoleak
   (d) Penetrating ulcer

   Answer: D

7. Which of the following is the CT (Fig. 1.15) diagnosis of patient involved in motor vehicle collision?
   (a) Transection
   (b) Endoleak
   (c) Hematoma
   (d) Aneurysm

   Answer: A

8. What is the finding depicted on angiography (Fig. 1.16) in a patient with chest pain?
   (a) Aneurysm
   (b) Endoleak
   (c) Aortic pseudoaneurysm
   (d) Hematoma

   Answer: C

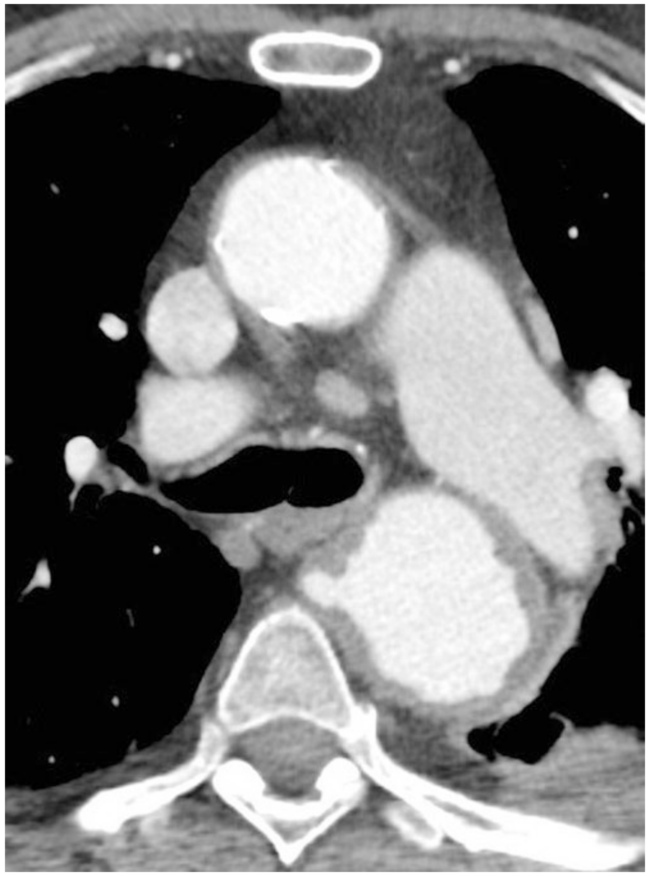

Fig. 1.14

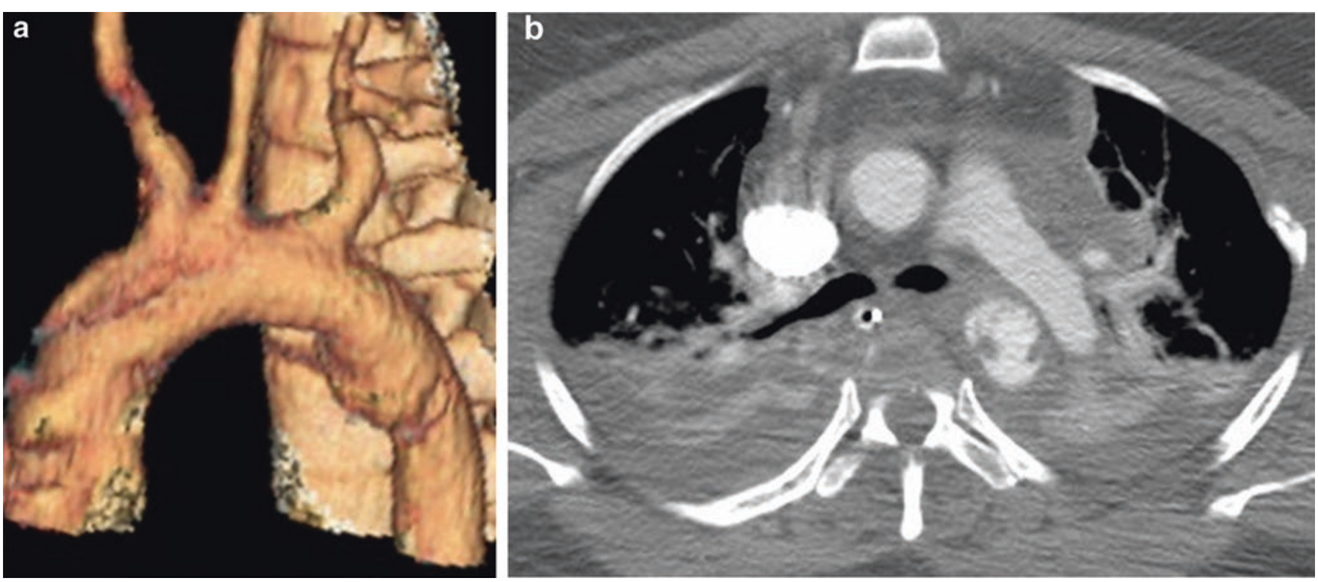

Fig. 1.15

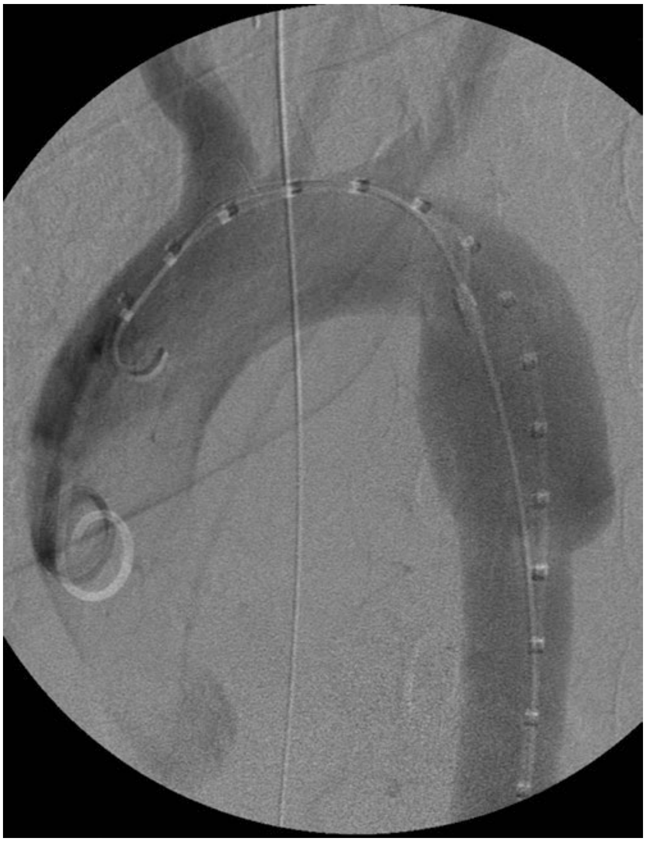

Fig. 1.16

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Emergencies of the Biliary Tract

2

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Introduction

Gallstones are seen in 10–15% of the population, most commonly in middle-aged and elderly females. While majority of gallstones have cholesterol as the main component, a minority of stones are constituted by calcium bilirubinate and are called pigment stones. Ten to twenty percent of the gallstones contain enough calcium to be visible on plain radiograph (Fig. 2.1a). The stones are most commonly multiple and sometimes faceted. A triradiate collection of nitrogen gas within the fissures inside the gallstone produces Mercedes-Benz sign (Fig. 2.1b, c).

Typically, gallstones are seen as echogenic foci with clean distal acoustic shadowing (Fig. 2.1d). Stones larger than 2 mm should produce a shadow regardless of their composition. Mobility of stones and posterior acoustic shadowing helps to differentiate cholelithiasis from other gallbladder abnormalities including polyps, masses, and sludge. *Wall echo shadow sign* refers to the parallel echogenic lines produced by a combination of the gallbladder wall, echogenic stone, and associated distal acoustic shadowing (Fig. 2.1e). The hypoechoic line seen between the two echogenic lines represents interposed bile. This sign is seen in gallbladder filled with either a single large gallstone or multiple small gallstones.

Ultrasound has higher sensitivity than CT in diagnosing gallstones (96% in ultrasound versus 75% in CT) and is therefore the screening modality of choice. On sonography, highest possible frequency transducer should be used with the focal zone placed at the level of the stone. Although ultrasound remains the exam of choice for suspected cholecystitis, there are ever more cases of acute cholecystitis being detected today with CT in the evaluation of abdominal pain than in the past.

On T2-weighted MRI, gallstones are seen as signal voids in the high-signal intensity bile (Fig. 2.2). On T1-weighted images signal intensity depends on stone composition. Blood clot, gas bubbles, and tumor can mimic gallstones on MRI.

Majority of the patients with gallstones are asymptomatic. Sometimes the gallstone can cause transient gallbladder outflow obstruction, leading to biliary colic. Biliary colic patients present with transient pain for 1–3 h with nausea and vomiting. The symptoms subside when the gallstone falls back into the gallbladder or passes distally into the biliary tree.

Acute Cholecystitis

Acute cholecystitis usually is caused by the gallstone obstruction of the cystic duct or the gallbladder neck (one-third of cases). Acute cholecystitis without stones (5–10% of cases) can be seen in patients with adenomyomatosis, gallbladder polyp, and malignant neoplasm [1, 2]. The predisposing factors for acute acalculous cholecystitis include history of trauma, mechanical ventilation, hyperalimentation, postoperative/postpartum state, diabetes mellitus, vascular insufficiency, prolonged fasting, and burns [2].

The clinical presentation includes right upper quadrant pain for more than 6 h (vs. biliary colic), nausea, vomiting, and fever in a patient with history of gallstones. No clinical or lab finding provides high enough positive predictive value in making the diagnosis of acute cholecystitis.

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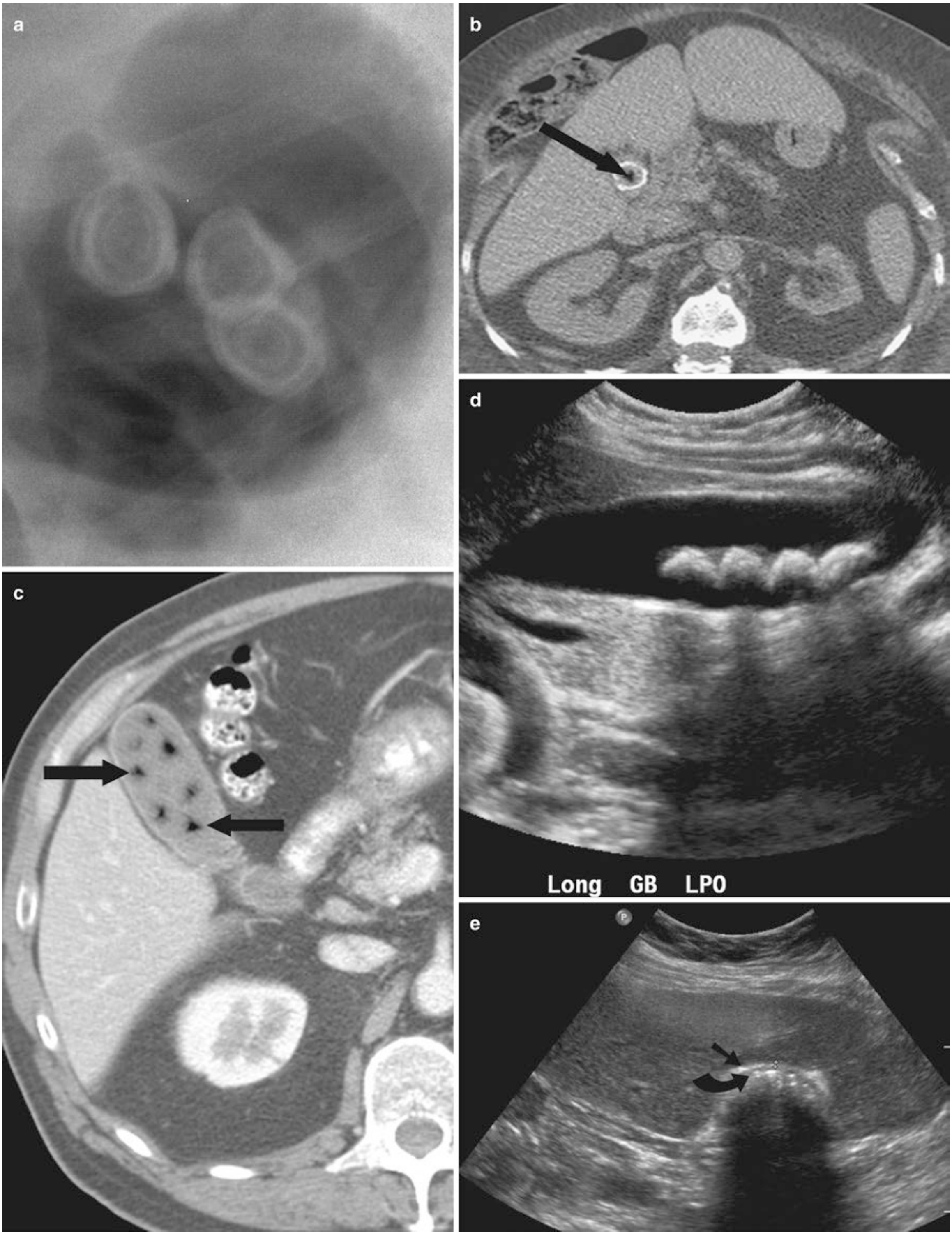

Fig. 2.1 Imaging appearance of gallstones on plain radiograph and ultrasound. (**a**) Plain radiograph demonstrates laminated radiopaque gallstones in the *right upper quadrant*. Up to a fifth of the gallstones can be seen on plain radiograph of the abdomen. (**b**, **c**) Noncontrast CT of the gallbladder shows gallstones with Mercedes-Benz sign (*arrows*). Mercedes-Benz sign is due to nitrogen collection in triradiate configuration, within fissures of a gallstone. (**d**) Ultrasound shows multiple echogenic gallstones with distal acoustic shadowing, within the gallbladder lumen. (**e**) Ultrasound shows wall echo shadow sign in a patient with multiple gallstones and chronic cholecystitis. The outer echogenic line (*straight arrow*) represents the gallbladder wall, while the inner echogenic line (*curved arrow*) represents the outer edge of gallstones