Imaging the ICU Patient

Florian Falter
Nicholas J. Screaton
Editors

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To our long-suffering wives, Christi and Maura: Thank you for your patience! Our apologies for the months of abandonment! To Róisín, Aoife, and Orla: Daddy loves you.

Preface

The vast majority of intensive care patients will have at least one form of radiological investigation during their stay on an intensive care unit. Whether it is a bedside chest X-ray or a magnetic resonance angiography, both intensivists and radiologists need to have a thorough understanding of the indication, the strengths and limitations of the available techniques, and the practicalities of carrying out an investigation on an intensive care patient. Despite the high level of necessary interaction between both specialties, it sometimes appears that they are speaking different languages!

This book is a collaboration between the two specialties with the aim of demystifying the process of deciding when to investigate and how to investigate. With a symptom-orientated approach, it addresses imaging techniques as well as patient safety issues. This book is aimed at clinicians from both disciplines.

We hope this publication will lead to a better understanding of the concerns radiologists and intensivists have and thus improve communication between the two.

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Part I
Imaging Modalities

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Chapter 1
Radiography

Nicholas Hilliard

Techniques

Plain radiography continues to be the most common mode of imaging in medical practice, with over 22 million examinations in the UK alone during 2010. Understanding practicalities of usage and the influence of method acquisition on image interpretation is crucial for effective patient management.

The most frequent imaging test requested on any ICU is the mobile chest x-ray (CXR) (Fig. 1.1). In the outpatient setting the standard postero-anterior (PA) CXR is performed with the patient standing facing away from the x-ray tube at a distance of approximately 180 cm. On the ICU, achieving a PA CXR is practically impossible due to patient immobility, space limitation and decreased power of mobile x-ray units. As a compromise, an antero-posterior (AP) CXR can be performed with the patient sat upright and facing the x-ray tube. If the patient is unable to be positioned upright, as often is the case in ICU, a supine film can be acquired with the tube above the patient at a distance of approximately 100 cm. Both these CXR acquisitions are of technically inferior quality to the PA CXR, and bring caveats in interpretation.

Other radiographic techniques are occasionally employed on ICU. These might include abdominal or extremity radiographs. An abdominal x-ray (AXR) is only occasionally performed, having been shown as ineffective in comparison with computed tomography (CT) (Fig. 1.2a, b). Extremity radiographs may occasionally be indicated in trauma or orthopedic patients; in these situations it should be remembered that two views of a bone or joint are almost always necessary. Pathology can easily be hidden on single views, particularly in the ICU setting where there may be overlying artifacts such as lines, drains and monitoring equipment or difficulty obtaining optimum patient positioning.

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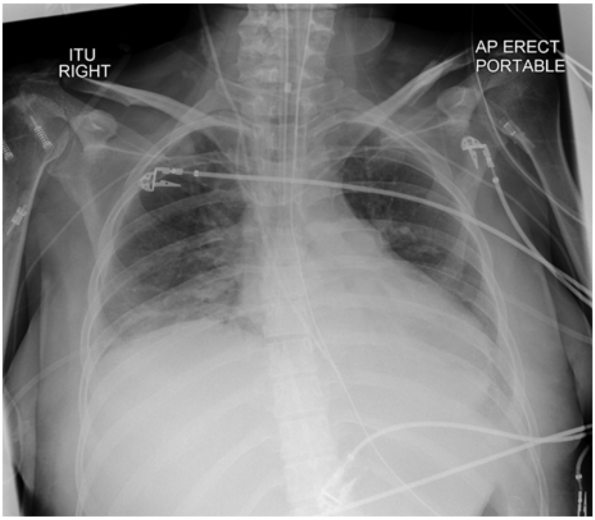

Fig. 1.1 CXR of patient on ICU, with multiple lines evident. Careful attention needs to be paid to line placement on each radiograph. The left peripherally inserted central cannula that has misdirected into the right IJV. This line had been in good position on previous radiographs

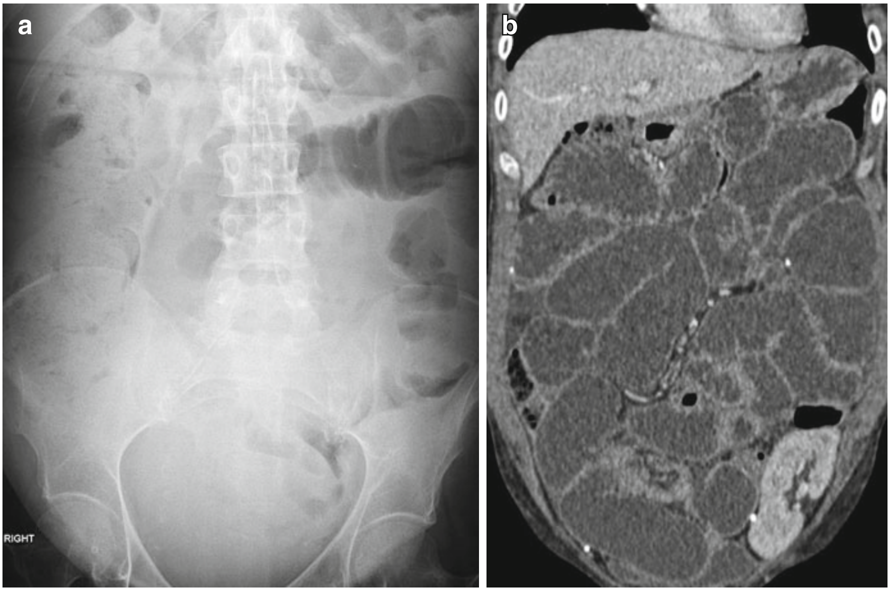

Fig. 1.2 An AXR (**a**) with coronal reformat of a CT (**b**). A single, short loop of small bowel is dilated on the AXR. CT performed the same day reveals multiple, fluid filled, dilated loops of small bowel, a finding that could not be definitively stated from the AXR. Notice also the renal transplant in the left iliac fossa

Strengths

The main advantages of the radiographic imaging of ICU patients stem from its portability. A mobile radiograph can be performed relatively quickly, without the need for potentially risky transfers to other locations in the hospital. An unstable

Table 1.1 Effective radiation doses of various radiographic examinations

Investigation	Effective dose (mSv) (as per Mettler et al. *Radiology* 2008)
PA CXR	0.02
AXR	0.7
XR wrist	0.001
CT head	2
CT chest	7
CT abdomen and pelvis (single phase)	14
CT pulmonary angiogram	15

patient can be imaged 'in-situ' with only a short hiatus in normal clinical care as the film is taken. In comparison with CT, plain radiography also has low radiation dose (Table 1.1). Mobile CXR has been shown to be useful in detecting pathology that influences clinical management, such as locating newly placed lines and tubes, or investigation of acute change in respiratory parameters caused by pulmonary parenchymal or pleural disease.

Limitations

This portability also gives rise to the practical limitations in the diagnostic quality of mobile radiography. As previously discussed, most ICU CXRs are performed AP, semi-erect or supine. This causes artifacts that can complicate interpretation.

In contrast to a PA film, an AP or supine projection causes apparent enlargement of the heart size and mediastinal width. This is due to an increase in divergence of the X-ray beams before they reach the radiographic plate. In a supine film, this effect is magnified due to the increased proximity of the X-ray tube to the plate. Hence, when examining the mediastinal contour, there should be careful consideration of the mode of image acquisition.

Furthermore, the positioning and situation of the patient when imaged can have a great impact on quality and interpretation. Confounders include:

- Rotation: a patient slumped or positioned to one side may not directly face the X-ray beam. This will cause rotation of mediastinal structures, such that one side may be more prominent than the other. An example might be an apparent difference in size of the hila. This factor can be assessed by considering the position of the medial clavicles; they should be symmetrically distant from the center of the film (Fig. 1.3).
- Inspiration: the normal PA CXR is taken on full inspiration. ICU patients may not be in a position where respiration can be controlled. The radiographer will attempt to acquire an inspiratory image; however, this is not always successful. Expiratory films can be distinguished by a decrease in size of the lungs and raising of the hemidiaphragm (Fig. 1.4a, b). Introduced artifacts with an expiratory radiograph include an apparent increase in size of the mediastinal structures and increased lung opacity. This can be occasionally confused with interstitial disease or other pathology.

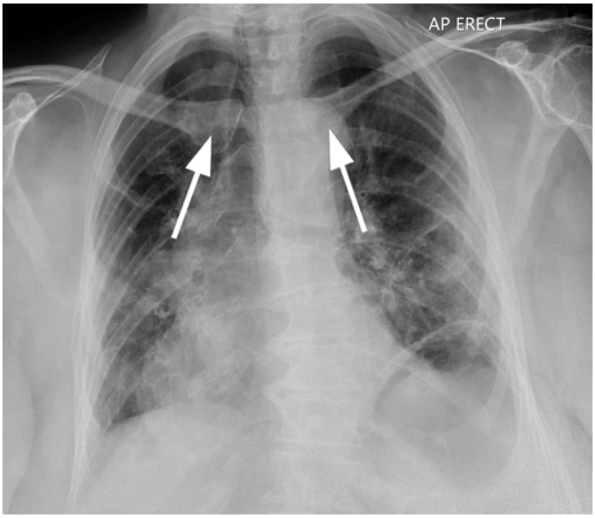

Fig. 1.3 To establish rotation assess the position of the clavicular heads; if they are of unequal distance from the midline the radiograph is rotated. *White arrows* indicate the heads of the clavicles in this example of a rotated film, notice how the majority of the mediastinum is projected over the right hemithorax

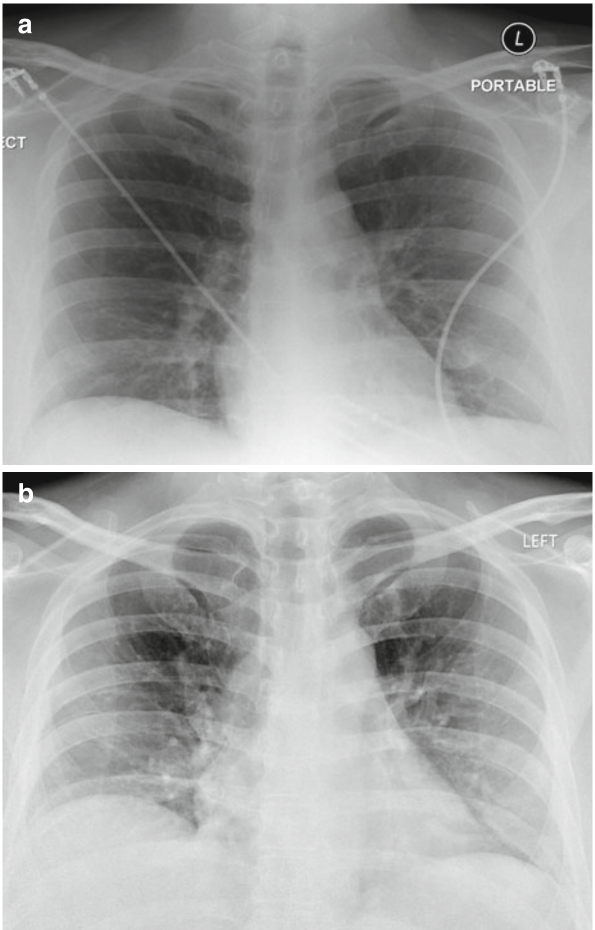

Fig. 1.4 These two radiographs were taken a short time interval apart: (**a**) is during inspiration, and (**b**) is during expiration. When viewing the expiratory radiograph there is an apparent increase in cardiac size with hazy opacification of the lung bases. Adequate inspiration is judged by visualisation of the fifth to seventh anterior rib intersecting the diaphragm in the mid-clavicular line

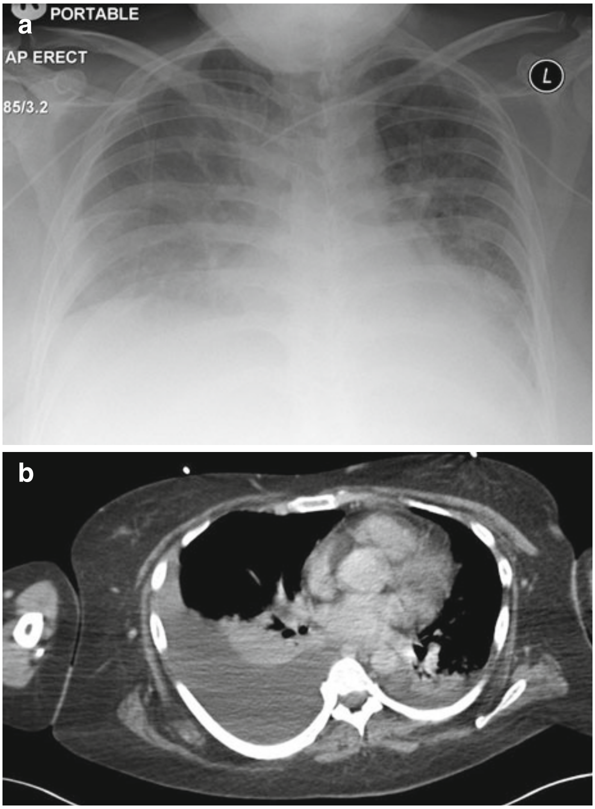

Fig. 1.5 CXR (**a**) and axial CT through the lung bases (**b**) obtained the same day. Although stated to be erect, the radiograph does not demonstrate the moderately large right pleural effusion demonstrated by CT. It is likely the CXR was taken semi-erect and the patient had been moved from a supine position, with not enough time left for the fluid to redistribute

- The semi erect and supine radiograph: these can cause an alteration in distribution of pathology. For example, a pleural effusion will collect in the most dependent portion of pleural cavity. In normal circumstances, an erect CXR will demonstrate fluid collecting in the costophrenic angle. When the patient is recumbent this fluid will track along the posterior aspect of the pleural cavity, layering out behind the lung. On supine CXR this fluid will give a hazy increased density to the affected hemithorax, but the classical features of pleural effusion may be absent, even in large volume effusions (see Fig. 1.5a, b). This effect will also apply to pneumothoraces.
- Patient artifacts: When sat out of bed or sitting as upright as possible in bed the posture of ICU patients is often poor. Slumped patients' heads can superimpose and make interpretation of the mediastinum or the lung apices impossible (Fig. 1.6).
- Artifacts external to the patient and thoracic cavity: usually external tubes and equipment are obvious. Occasionally, they can precipitate worries regarding an unusual radiographic appearance, particularly if causing an asymmetric opacity (Fig. 1.7). Examining the patient should provide reassurance.

Relative to CT, the CXR is a blunt tool for interrogation of thoracic structures. A CXR is almost always appropriate as a first line investigation, but if there is clinical suspicion for chest disease there should be a low threshold for CT, even when the CXR

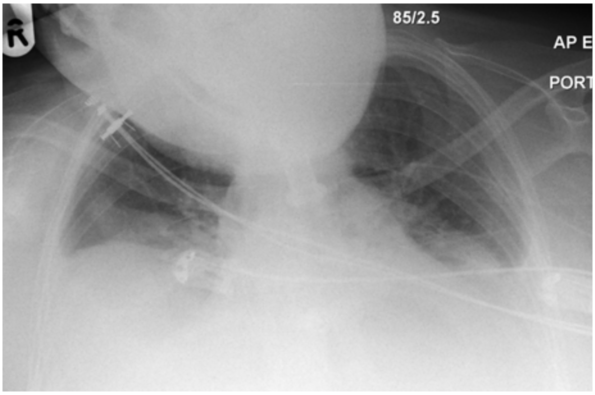

Fig. 1.6 In this radiograph very little information can be obtained on the lung apices and mediastinum, due to the difficulties in positioning the patient

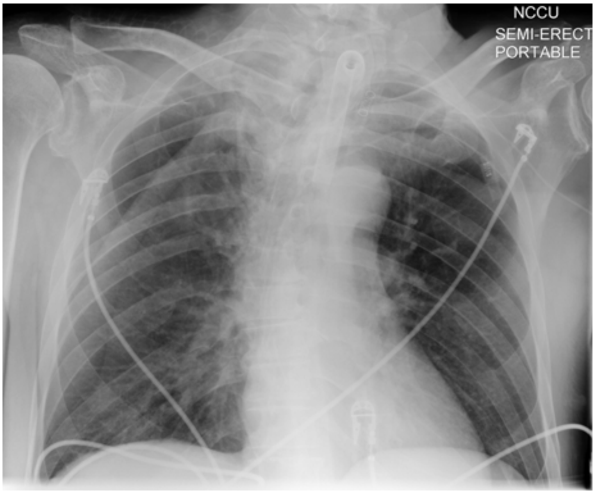

Fig. 1.7 A prominent skin fold is projected across the left hemithorax, which could be mistaken for the lung edge of a pneumothorax, if the clear lung markings lateral to the fold are not appreciated

appears normal. In comparison with CXR, additional findings can be demonstrated on CT in 52–69 % of patients, with one series judging 30 % of these to be significant.

The AXR is infrequently performed due to its many limitations in comparison with CT. Dilated bowel loops may not be visualized if fluid filled, and when seen a cause cannot usually be ascertained (Fig. 1.2a, b). Very little information on integrity of solid organs or vasculature is obtained. Detection of perforated viscus can be difficult with AXR, even when there is a large amount of free air, and the site is rarely seen. An erect CXR is a better tool for perforation, and an experimental study demonstrated that as little as 1 ml of free air injected into a volunteer could be detected. Similar to the supine CXR, an AXR is subject to problems of magnification, as the mobile X-ray tube has to be positioned close to the patient.

When extremity radiographs are used to follow-up orthopedic or trauma patients, the indication should be considered when evaluating film quality. A radiograph to examine for fracture at a critical site will need to be of higher standard than one to demonstrate metalwork position. Similarly, if osteomyelitis is a serious consideration it should be remembered that radiographs are of low sensitivity and do not demonstrate classical features until 1–2 weeks into the disease process.

Finally, when placing requests for any radiological investigation, it is noted that the usefulness of the final radiological report will be reduced if insufficient or misleading clinical information is given.

Preparation and Practical Issues

Little special preparation is required for most radiographs, other than full consideration of the patient position. As discussed, the quality of a mobile CXR suffers a step-wise decline from the 'ideal' PA CXR as the patient becomes more horizontal. Before requesting, and during set up for acquisition, there should be an attempt to optimize the position to the best achievable within the limitations of the patient condition. Improved sensitivity for detection of free air below the diaphragm requires the patient to be erect for 10 minutes before taking the X-Ray.

Indications

It has been the standard in some ICUs to perform a routine daily CXR. However, recent meta-analyses have questioned whether routine chest radiography usefully contributes to patient management or confers any benefits in mortality or ICU length of stay, suggesting that it might be safe to reserve CXR for situations with a relevant clinical indication. Adopting this on demand approach can help to reduce the number of unnecessary CXR and reduce costs significantly. There are many circumstances where a CXR is considered appropriate, the broad categories of which are detailed in Table 1.2.

As discussed, an AXR is often inadequate in comparison with CT. There are a few indications where acquiring an AXR is helpful. These include:

- Patients with abdominal signs but who are too unstable for transfer to the CT department. Due to the poor sensitivity, this could be considered a 'stop-gap' in imaging, until the patient can proceed either to surgery or for CT once stabilized. Occasionally, diagnostic information may be elaborated, such as clear small bowel obstruction or sigmoid volvulus (Fig. 1.8). Portable ultrasound may also be useful in the unstable patient.

Table 1.2 Broad indications for chest radiography

New admissions to the ICU
Clinical suspicion of cardio-respiratory disease
Unexpected deterioration in patient condition
Placement/change in position of support devices such as lines or endotracheal tubes

Fig. 1.8 AXR of classical sigmoid volvulus. A large dilated viscus can be seen projected out the pelvis, with dilatation of the proximal large bowel and lack of air in the rectum

- Follow-up of ingested foreign bodies and approximating location of implanted devices or lines. An AXR will provide a crude location, although overlapping structures can be misleading.
- Follow-up of nephrolithiasis.
- Delayed films following orally ingested contrast medium to establish passage through the small and large bowel.

Extremity radiographs might be performed in suspicion of fracture or follow up of orthopedic operations.

Cautions/Contraindications

The radiation dose from a plain radiograph of the chest or extremity is negligible, so there should not be hesitation in performing these studies if a valid clinical reason is found. AXR have a higher dose and the diagnostic yield is often limited, usually requiring subsequent CT for further evaluation. Thus, AXR should only be performed in specific settings, or where CT cannot be accessed.

Caution should be taken in positioning the patient for the radiograph; a poor quality supine CXR is better than an accidently extubated patient.

Teaching Points

1. Approach the chest radiograph in a logical fashion, including systematic assessment of lungs, mediastinum, soft tissues, thoracic cage and all visible lines, tubes, and devices. Most causes of hypoxemia will be apparent on plain film.
2. It is important to remember that the film is likely to have been taken in the supine position and that this will alter the appearances of a pneumothorax or pleural collection. The standard PA chest radiograph is difficult to take in the ICU patient and is replaced by an anteroposterior (AP) radiograph. These radiographs have a shorter patient-to-film distance of 40 in. (vs. 72 in. of the PA radiograph) and are obtained in the supine or sitting position, given the difficulty in maneuvering a critically ill patient.
3. The main difference between an AP and PA Chest X-ray is magnification of the anterior structures, i.e., mediastinum and heart. If the X-ray is not taken in deep inspiration and the lungs are poorly expanded abnormalities at the lung bases and effusions are more difficult to identify.

Chapter 2
Ultrasound

Nicholas Hilliard

Introduction

Ultrasound has part of the medical diagnostic toolkit for the past 60 years. Technological advances have allowed ultrasound equipment to become smaller without compromising image quality. With greater access to portable sonography, ultrasound is increasingly utilized in the intensive care unit (ICU), particularly in patients who might be too unstable to be moved into the radiology department. It has thus become essential in patient diagnosis and treatment. Recognizing this value, there have been efforts to train intensivists, surgeons and emergency physicians in the use of ultrasound. Both performing and requesting ultrasound requires knowledge of the possible benefits and pitfalls. Understanding these allows correct application of the modality and avoids misdirection and delays in clinical decision-making.

Technique

Modern ultrasound machines all work using the same fundamental physical principles. The most important component is the probe, which contains a piezoelectric emitter. These have the ability to both transmit and receive sound waves. By emission of a sound wave, and calculation of the time taken for reflection, the ultrasound machine can establish the depth of the reflective structure. The strength of the reflection is represented on screen by the brightness.

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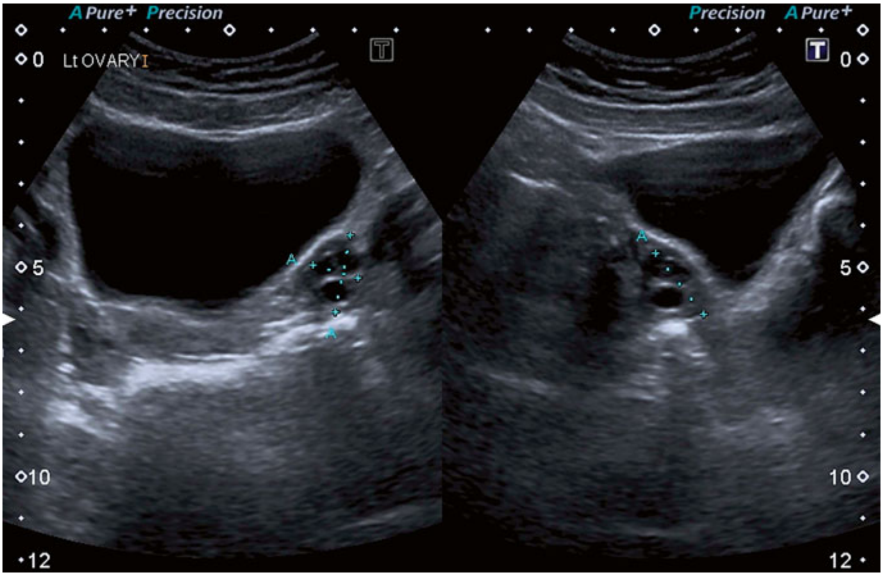


Fig. 2.1 Measurement of the ovary, with a sonographic window provided by the full bladder

As sound passes through tissue it is absorbed, scattered in random directions, and occasionally reflected back towards the probe. Only sound returning to the probe provides the information to build the image on screen. This results in limitation of the depth that can be visualized, as the returned signal decreases with increased distance between the probe and the structure of interest.

The type of tissue examined affects the image. Water is easily traversed by sound, which allows increased penetration into the body. Sometimes this is beneficially used to interrogate deeper structures, such as visualizing pelvic structures through a full bladder (Fig. 2.1). Fat has the opposite effect and tends to attenuate sound, reducing penetration. This causes a double confounder in overweight patients; the structures of interest are both deeper, and masked by a layer of fat. Densely calcified structures, such as bone, cannot be penetrated and cast a black acoustic shadow. Ultrasound has only limited ability to cross air, hence the requirement for application of a gel to the probe.

Different types of probes operate at different frequencies. The human ear can detect sound from 20 to 20,000 Hz. Routinely used ultrasound probes are found with a range of operating frequencies, typically from 3.5 MHz to 11+MHz (11,000,000 Hz). Higher frequency probes produce higher quality images but are unable to penetrate deep into the body. Thus, there is a trade off between depth of visualization and image detail. The workhorse abdominal imaging probe operates at around 3.5 MHz.

Normal imaging is performed using the setting termed M-mode (Fig. 2.2a), which gives a real-time two-dimensional representation of the tissue examined. Doppler imaging allows information on the direction of flow of blood within a

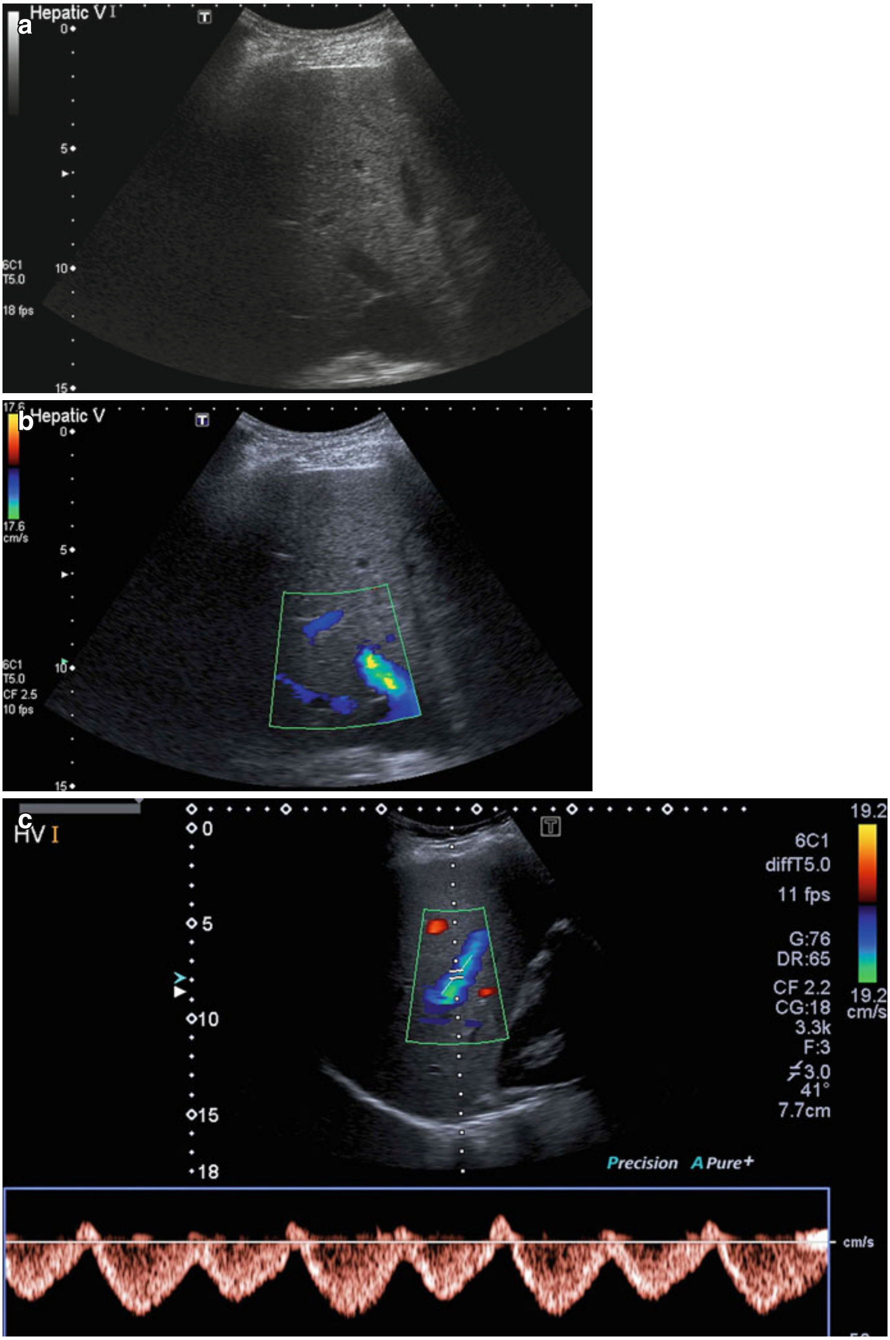


Fig. 2.2 (**a–c**) Images of the hepatic veins. (**a**) Uses M-mode to give an anatomical overview. (**b**) Is a Doppler image, with *blue colours* indicating flow away from the probe. (**c**) Shows the phasic pulse wave Doppler signal often shown by the hepatic veins

tissue; by convention, red is towards the probe and blue is away (Fig. 2.2b). Pulse wave and continuous wave Doppler enable the analysis of vascular flow within a small, user-defined area of interest inside a vessel, to give information on waveform, velocity and direction (Fig. 2.2c). Both of these additional modes consume capacity within the probe, further limiting the useful working depth of a probe.

Strengths

While some ultrasound machines can be bulky, portable versions are becoming more commonplace, and diagnostic quality images can now be produced using a machine the size of a laptop. Once in place at the bedside, the image acquisition is through a maneuverable and lightweight probe. Diagnosis of an unstable patient in the safety of the ICU is an important benefit of ultrasound. Some studies have found value in routine ultrasound of all ICU patients. Use of ultrasound has been shown to diagnose previously unknown pathology and potentially avoid the need for more complex investigations, such as CT, which involve transfer.

There are theoretical risks of tissue heating from prolonged ultrasound examination at one site, but under normal circumstances ultrasound is a completely safe investigative procedure. This allows repetition of examination; if clinical need dictates, pathology can be reassessed at short intervals.

Ultrasound provides functional, morphological as well as physiological information. Assessment of vascular flow is often important (Fig. 2.3). While cross sectional modalities may typically only indicate vascular patency, ultrasound can ascertain flow direction, velocity and waveform.

Image guided intervention has made a number of bedside procedures safer. A skilled operator can use ultrasound to track placement of a needle in any plane that can be visualized by the probe (Fig. 2.4). Sites can be targeted easily using ultrasound by choice of the most direct route, avoiding vascular and other structures. At the same time the success of the intervention can be controlled. Ultrasound guided procedures in the ICU regularly include vascular cannulation, fluid aspiration, drain placement or tissue biopsy.

Limitations

The limitations of ultrasound result from the transcutaneous method of image acquisition. It is mainly physical factors that limit the view obtained. The most common examples are:

- Patient body habitus – overweight patients can be extremely difficult to scan. As already discussed, fat has a negative effect on image quality (Fig. 2.5a, b). When considering the value of an ultrasound request, or report, this should always be born in mind.

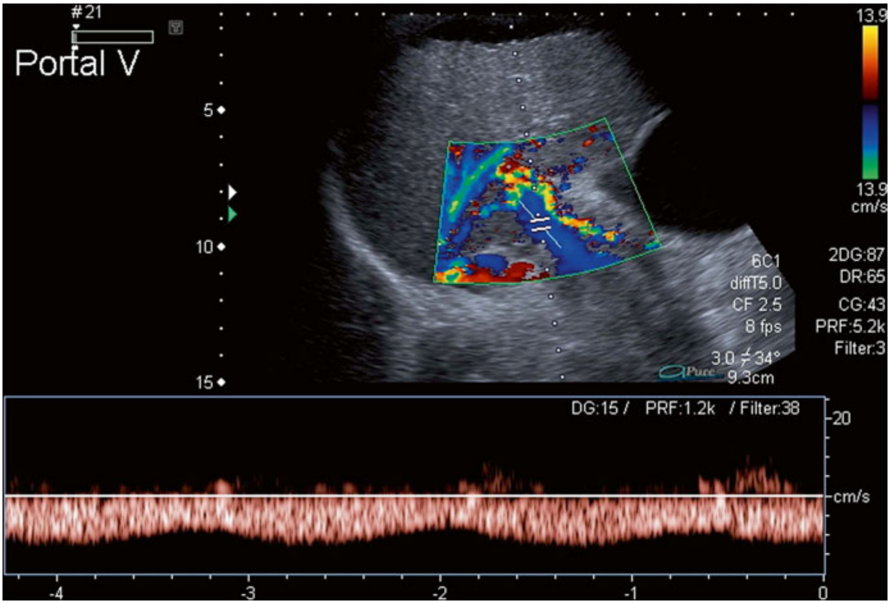
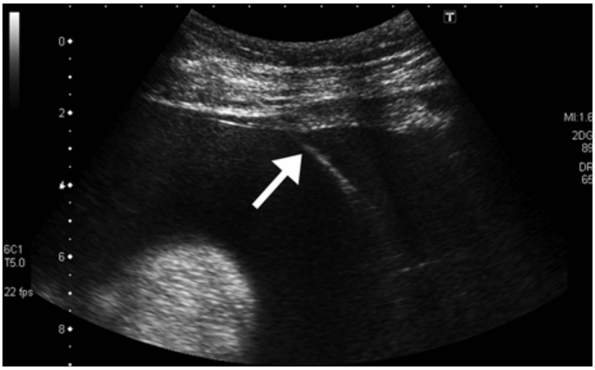


Fig. 2.3 Pulse wave Doppler image of the portal vein, showing flow away from the liver (hepatofugal), in a patient with decompensated cirrhosis

Fig. 2.4 Ultrasound guided insertion of an ascitic drain; the *white arrow* indicates the needle inserted into the ascites, to allow passage of a guide-wire



- Patient mobility – the highest quality ultrasound images are obtained in a mobile, cooperative patient. This may include turning the patient to give access to the site where the tissue of interest is closest (e.g., posteriorly for the kidneys). Suspended respiration removes respiratory motion artifact, and a deep breath may move subdiaphramatic organs below the shadows cast by the ribs. Neither turning, nor respiratory control, may be possible in critically ill or injured ICU patients. Easy to perform US guided procedures might become impossible to do in immobile patients; e.g., pleural effusions tend to collect posteriorly in the supine patient, making it difficult to reach them and leading to false negative results.

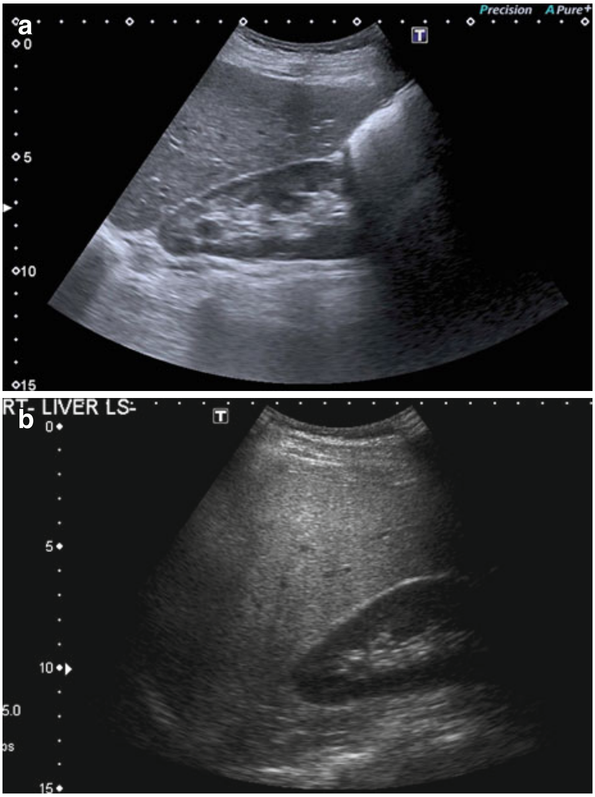


Fig. 2.5 (**a**) Illustrates the normal relationship between kidney and liver, with the liver parenchyma slightly more echogenic than the renal cortex. (**b**) Is a patient with hepatic steatosis; the liver is markedly echogenic. The absorption of the sound wave results in poor visualisation of the deeper aspects of the liver

- Patient pain – as the method of image acquisition involves direct pressure of the probe on the skin, patients who have pain at the site of interest may find the examination difficult to tolerate. Often, the highest quality images can only be found through tissue compression, which may be impossible in the uncomfortable patient.
- Air and bone cannot be imaged through – the ribs commonly partially obscure the liver, spleen and kidneys. Gas filled bowel may obstruct views of all of the abdominal and pelvic organs.
- Dressings and wounds may limit access – surgical dressings or wounds can prohibit the use of an ultrasound probe in certain areas. If available and feasible alternative imaging methods will have to be discussed for these patients.

Preparation and Practical Issues

Positioning the patient for good access prior to performing an ultrasound scan can save time as well as producing superior images. For instance, if there is a high clinical suspicion of pleural effusion, positioning the patient for easy access to the most dependent

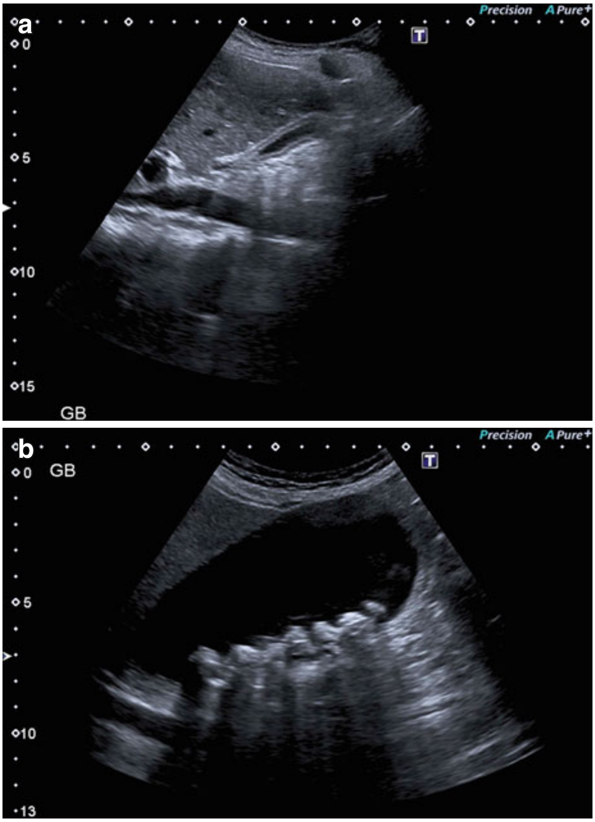


Fig. 2.6 (**a**) Non-fasting causes the gallbladder to contract, giving inaccurate wall thickness measurements and reducing sensitivity for gallstones. (**b**) A patient fasted 4 h, with a well distended gallbladder containing multiple shadowing calculi

part of the thorax is more likely to facilitate a high quality examination and an intervention carried out safely. Similarly, the number and position of abdominal drains or stoma should be considered before requesting a diagnostic abdominal ultrasound.

Other considerations involve studies where gallbladder pathology is a consideration. To maximize the diagnostic yield the patient should ideally be fasted for 4–6 h.

If the site of interest is causing discomfort, ensuring good patient analgesia and possibly sedation prior to the scan can also improve diagnostic accuracy (Fig. 2.6a, b).

In case of an US guided intervention the patient's clotting status and the need for anticoagulation should be reviewed.

Indications

Bearing in mind the physical limitations to the technique and the potential obstacles put up by patient factors there are virtually no areas of the body that are not amenable to some sort of ultrasound examination. Table 2.1 lists the scans regularly performed on ICU patients as well as the clinical questions they can attempt to answer.

Table 2.1 Areas commonly accessed by ultrasound

Organ	Common pathology seen with US
Heart	Valvular pathology
	Function
	Morphological defects
Lungs	Pleural effusion
	Consolidation
Liver	Biliary pathology
	Abscess
	Tumour
	Blood flow
Spleen	Rupture
	Intrinsic lesions
Pancreas	Tumour
	Inflammation
Kidneys	Obstruction
	Abscess
	Tumour
	Blood flow
Bowel	Wall thickening
	Intussusception
	Appendicitis
Abdominal cavity	Ascites
	Collection
	Hernia
Pelvic organs	Ovarian pathology
	Pregnancy
Vessels	Thrombus
	Aneurysm
	Dissection
Skin	Abscess
	Tumour

As ultrasound imaging is becoming more and more accessible and a large number of 'front line' clinicians are trained in using it various imaging protocols have emerged, particularly in Intensive Care and Emergency Medicine. Three point-of-care protocols have been globally endorsed and have become part of the standard toolkit available when dealing with critically ill patients:

- Focused Echo Evaluation in Life support (FEEL)
- Focused Assessment Transthoracic Echocardiography (FATE)
- Focused Assessment Sonography in Trauma (FAST)

Table 2.2 provides an overview over these protocols.

Table 2.2 Focused ultrasound in critically ill patients

	FEEL	FATE	FAST
Views	Parasternal long axis Parasternal short axis Apical four chamber Subcostal	Parasternal long axis Parasternal short axis Apical four chamber Subcostal Pleural	Subcostal Right upper quadrant Left upper quadrant Pelvis
Pathology	Pericardial collection Cardiac contractions Ventricular function	Pericardial collection Ventricular function Ventricular dimensions Volume status	Free intra-abdominal or pericardial fluid

Cautions/Contraindications

Operator dependency is a term often used in reference to ultrasound. Images available on PACS following an ultrasound have limited value for further interpretation and drawing conclusions from them can be misleading. The accuracy of an ultrasound report relies on the skill and experience of the operator.

When examining critically ill patients it is highly desirable that the referrer is present during the scan. The sonographer can then directly target their examination with the benefit of accurate, up-to-date clinical information, enabling a discussion about any findings. This helps to:

- establish a high level of confidence in the findings.
- prompt planning of alternative imaging when an examination was technically difficult or the results were ambiguous.

Teaching Points

1. Bedside ultrasound is widely available and is often the first-line imaging modality in unstable patients.
2. It can serve as a diagnostic modality but can also guide interventional procedures as well as document their usefulness.
3. Ultrasound has limitations due to technical factors (penetration depth, tissue) and patient factors (positioning, wounds and dressings, body habitus).
4. FEEL, FATE and FAST are three recognized imaging protocols to assess critically ill patients.

Chapter 3
Computed Tomography

Helen Stunell

Introduction

CT scanning is used more and more in complex critically ill patients with multiple, complex medical issues. Bedside imaging like ultrasound or plain film is often not sufficient to discriminate between various differential diagnoses. Early studies after the broader introduction of CT technology in the 1980s demonstrated that up to 75 % of chest CTs showed new, clinically useful information, translating into a change of patient management in up to 40 %.

Technique

Computed Tomography was first used in clinical practice in the early 1970s at which time each axial image took several minutes to acquire and even longer to reconstruct, thus severely limiting its practical application in clinical medicine. Subsequent technological improvement over several decades resulted in the development of spiral or helical CT. This technique allows the continuous revolution of the x-ray unit around the patient as they move through the gantry, resulting in the acquisition of a volume of data, which can be reconstructed in the sagittal and coronal planes as well as the conventional transverse plane. This also resulted in significant reduction in image acquisition time, facilitating widespread integration of CT into everyday clinical practice. Since the late 1990s the focus has been the development of Multidetector CT (MDCT) whereby multiple slices are simultaneously acquired,

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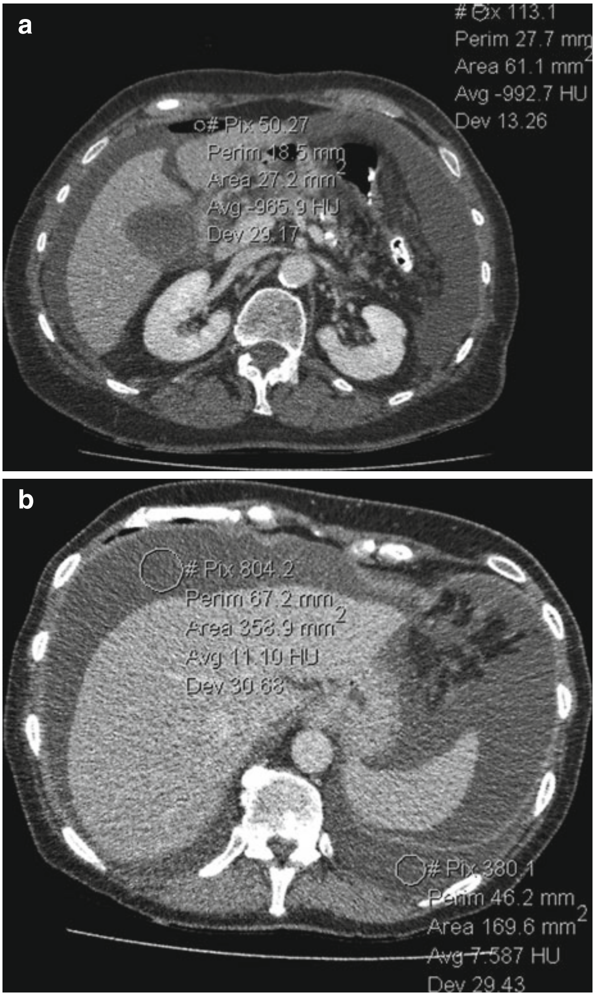

Fig. 3.1 (**a**) Axial image from a CT in an 85 year old female with severe upper abdominal pain and peritonitis in whom chest and plain abdominal radiographs were normal. This shows a shallow collection of air anterior to the liver surface in the right upper quadrant, outside the confines of the colonic lumen. The average attenuation value was −965 Hounsfield units (HU), comparable to the attenuation value of air outside the patient at the top right periphery of the image which averaged −992 HU. (**b**) Axial CT image through the upper abdomen in a 66 year old female patient with a history of metastatic ovarian carcinoma and peritoneal carcinomatosis. There is extensive free fluid surrounding the liver and spleen as well as a large volume of fluid in the left pleural space. The average attenuation value of the fluid ranged from 7 to 11 HU, consistent with malignant ascites and malignant pleural effusion

further reducing image acquisition time and motion artifact, thus improving image quality.

CT images consist of a matrix of picture elements called "pixels." Each pixel represents a volume of tissue known as a "voxel." The term Hounsfield unit represents the amount of attenuation of the X-ray beam within voxels, which is influenced by tissue composition. Hounsfield units range from −1,000 (air) (Fig. 3.1a) to + 1,000, with water being defined as 0 (Fig. 3.1b). CT is exquisitely sensitive in differentiating tissues of different attenuations. However in order to optimize interpretation a number of standard settings (lung, soft tissue, bone) are available (Fig. 3.2a, b). Further interaction with window width and window level can be manually performed. Windowing allows customizing the visualization of soft tissues, such as brain, or dense structures, such as bone. A narrow window width

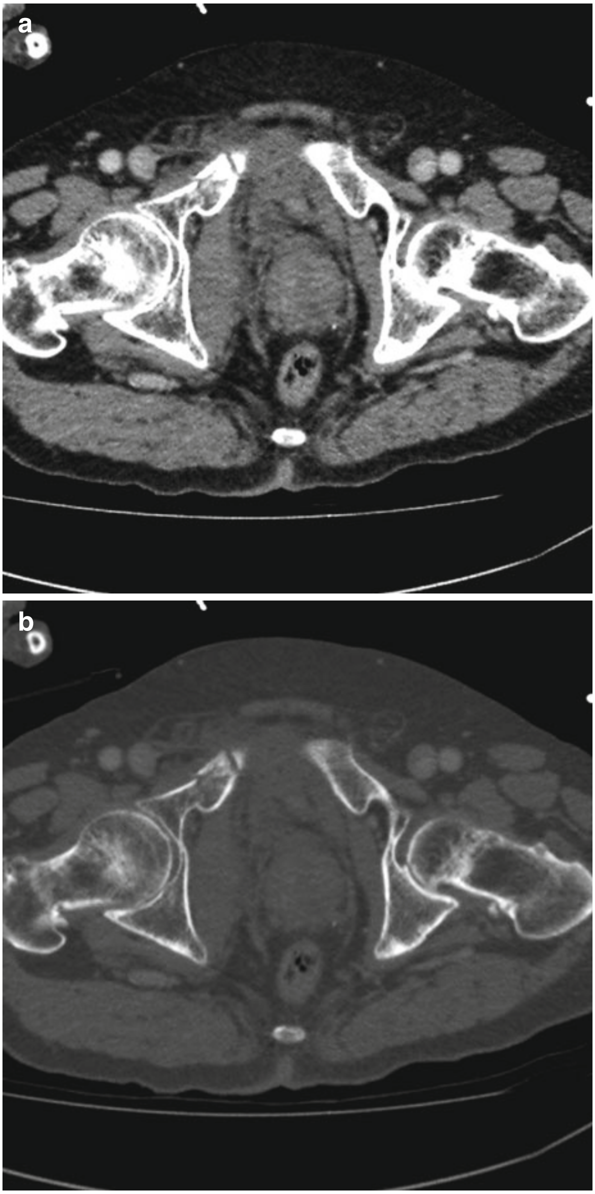

Fig. 3.2 Axial CT images at the level of the pubic rami in a 76 year old male patient who sustained blunt pelvic trauma viewed on (**a**) a soft tissue window and (**b**) a bone window, reveal right sided pubic rami fractures. The fractures are much better delineated on appropriate windowing (**b**), optimised for detection of osseous fractures and osseous destructive lesions

means that the gray scale can detect subtle differences in density but in a narrow range, with a small transition zone of white to black. This is used to display soft tissues within organs containing different structures of similar density. Conversely, a wide window width implies that the gray scale has a broad transition between black and white and is used to simultaneously review tissues with a large variation in attenuation

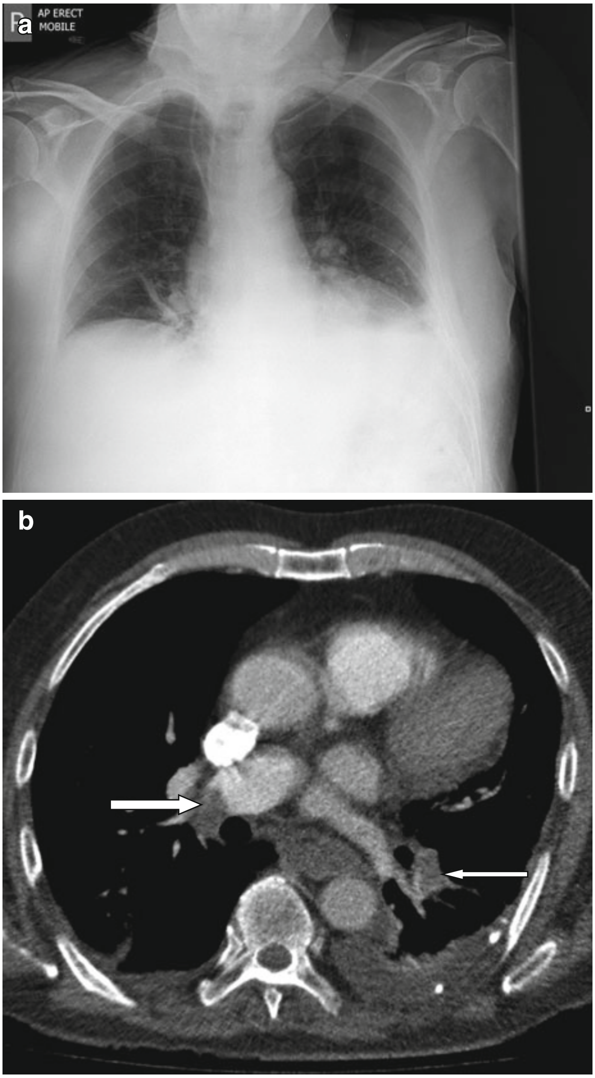

Fig. 3.3 (**a**) Chest x-ray in a 73 year old male patient re-admitted 2 weeks following radical prostatectomy with shortness of breath, low-grade pyrexia and an elevated white cell count, thought clinically to represent a post-operative pneumonia. X-ray showed patchy atelectasis in the right middle lobe with left lower lobe consolidation. He failed to improve clinically despite 48 h of intravenous antibiotics and a CT pulmonary angiogram was subsequently performed. (**b**) CT pulmonary angiogram in the same patient demonstrates filling defects within the right main and left lower lobe pulmonary arterial branches (*arrows*) consistent with acute pulmonary embolus in addition to bibasal consolidation and effusion

Indications

CT is a valuable technique in all body systems:

- Chest – it may be indicated in problem solving abnormalities identified on plain film particularly where there is a discrepancy between the clinical and imaging findings, for example in the post-operative patient in whom chest x-ray frequently demonstrates bibasal infective consolidation and effusion but who are at high risk for concurrent venous thromboembolism (Fig. 3.3a, b), in the immunocompromised patient subgroup including those with chronic illness in whom there is an increased risk of atypical respiratory tract infection such as TB (Fig. 3.4a–c),

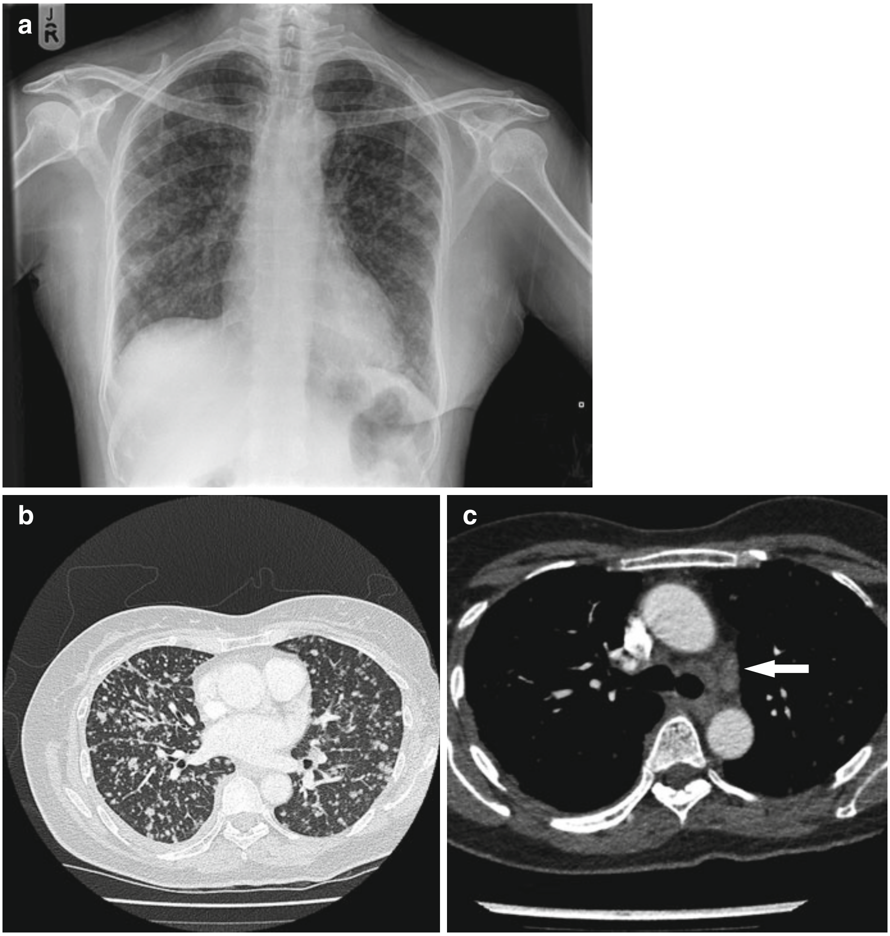

Fig. 3.4 (**a**) Chest x-ray in a 53 year old female patient who presented with a 1 month history of cough and weight loss on a background of HIV positivity shows multiple bilateral nodules measuring up to 5 mm in diameter. The differential was between miliary TB and miliary metastases. (**b**, **c**) Further evaluation with CT of the chest, abdomen and pelvis was performed. This confirms the presence of widespread nodular infiltrates throughout both lungs (left-hand pane, lung window) in addition to mediastinal lymphadenopathy (right-hand pane, soft tissue window, *arrow*) without evidence of primary thoracic or abdominal malignancy. The CT appearances were highly suggestive of disseminated TB which was subsequently confirmed clinically

fungal infection and cavitating infection. CT can be a critical adjunct to the chest x-ray in these select subgroups of patients, without which important underlying or co-existing pathology would have a delayed clinical diagnosis.

- Cardiac CT – uses ECG gating to acquire and reconstruct imaging data at specific phases of the cardiac cycle (typically during diastole). This enables in most cases motion free images of the coronary arteries to be produced permitting exclusion of obstructive coronary disease or evaluation of aortic disease such as dissection.

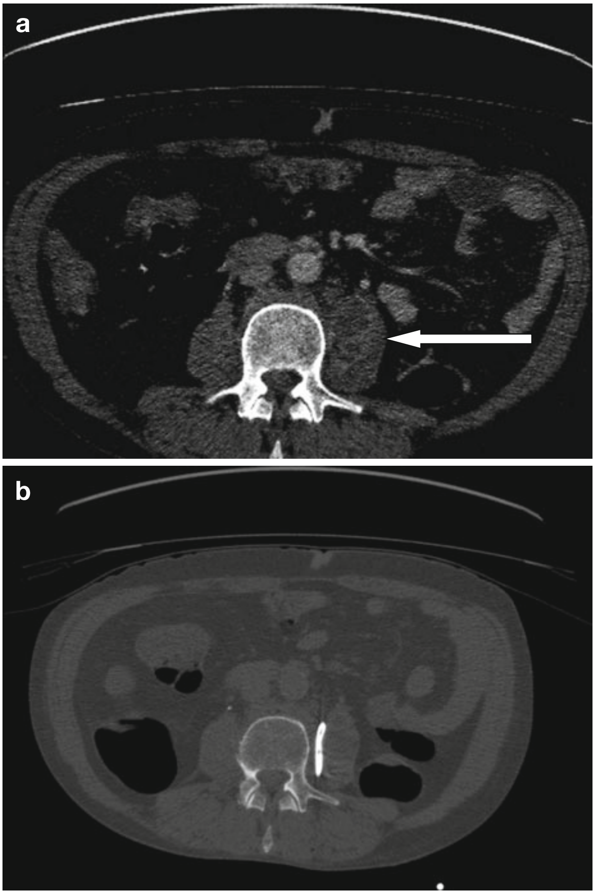

Fig. 3.5 (**a**) Axial CT image in a 54 year old male patient who presented with left sided back pain and fever. Plain x-rays of the abdomen and lumbar spine were normal and CT was subsequently performed to assess for possible diverticulitis. This demonstrated loss of disc space at the level of L2/L3 with end plate irregularity at these levels suggestive of discitis with an associated left sided psoas abscess as shown (*arrow*). (**b**) Axial CT in the same patient windowed to show final position of percutaneous drainage catheter with side holes coiled within left psoas abscess, inserted successfully under CT guidance with the patient in the prone position

- Abdomen and pelvis – CT is sensitive in detecting fluid collections, visceral perforation and ischemia. It is particularly useful in the retroperitoneum where ultrasound can be difficult (Fig. 3.5a, b). CT is considered the modality of choice for the assessment of the majority of intra-abdominal pathologies ranging from cases of suspected bowel ischemia (Fig. 3.6), post-operative sepsis (Fig. 3.7a, b) and evaluation of solid organ injury following blunt (Fig. 3.8a, b) and penetrating abdominal trauma.
- Head – Despite the superior soft tissue differentiation provided by magnetic resonance imaging of the brain (Fig. 3.9a–c), CT has remained the first line investigation for the evaluation of a wide range of intracranial pathology including hemorrhage, acute stroke (Fig. 3.10) and raised intracranial pressure in ICU patients. This is mostly due to the easier availability of CT and the substantial logistic difficulties associated with providing the necessary level of care and monitoring for ICU patients in the MRI scanner (see Chap. 13). Modern scanners have the ability to perform dynamic cerebral perfusion studies, which allow the evaluation of regional blood flow within the brain in cases of suspected acute CVA, guiding the clinical decision-making about thrombolytic therapy.

Fig. 3.6 Coronal reformatted image from an arterial phase CT in a 48 year old male on post-operative Day 5 following laparotomy and small bowel resection for small bowel ischaemia secondary to mesenteric venous thrombosis. His serum Lactate level began to rise slowly and he was experiencing increasing abdominal pain. Repeat CT shows a grossly abnormal loop of ileum in the right lower quadrant (*arrow*) with hyperenhancing mucosa suggestive of recurrent ischaemia

- CT also provides a platform for image guided interventions, such as biopsy and drainage, in the chest, abdomen or pelvis and may act as a 'roadmap' for vascular intervention (Figs. 3.5b and 3.7b, c).

Strengths

For the intensive care patient the strengths of modern multidetector CT lie in its ready availability both within and out of hours, rapid acquisition time (seconds), and relative lack of expense. This is in addition to its physical attributes:

- cross-sectional imaging which overcomes the superimposition limitation of plain films;
- excellent contrast and spatial resolution;
- ability to provide multiplanar reconstructions;
- delineate arterial and venous anatomy using intravenous enhancement with multiple phases of contrast.

Limitations

The major limitation of CT is the requirement to transfer a critically ill patient with their support equipment, monitoring and personnel to the Radiology department (see Chap. 11). In unstable, critically ill patients the potential gain of establishing a

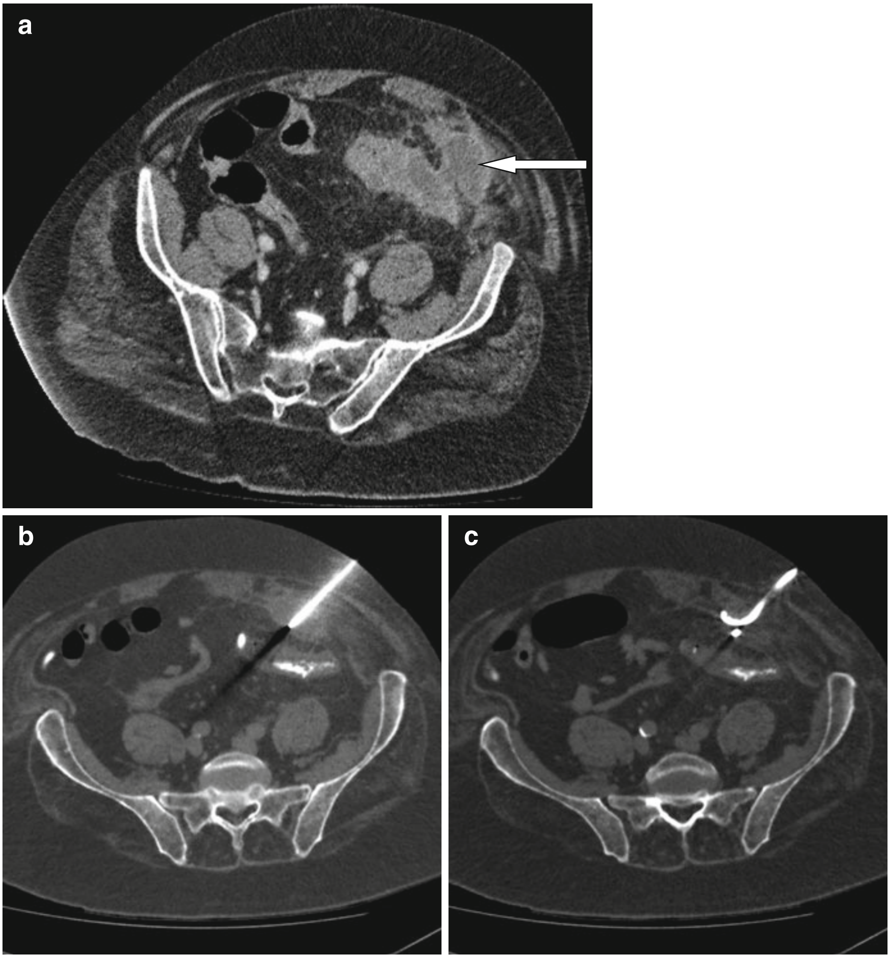

Fig. 3.7 (**a**) Axial contrast enhanced CT image through the pelvis in a 75 year old male patient with left sided abdominal pain and sepsis demonstrates a grossly thick-walled sigmoid colon with an intramural abscess (*arrow*) tracking towards the anterior abdominal wall. The appearances were due to a diverticular abscess. Percutaneous drainage was subsequently performed. (**b**, **c**) Demonstrating percutaneous needle placement to gain access to the abscess cavity (**b**) and subsequent satisfactory final position of the drain coiled within the abscess (**c**) performed under CT guidance

more accurate or confident diagnosis with the help of a CT scan must be weighed carefully against the risk associated with transfer, the potential for contrast-induced nephropathy (see Chap. 12) as well as potential harm from radiation.

CT is less sensitive and specific than MRI in the assessment of neurological disease particularly in the posterior fossa. However in the critically ill patient the relatively safe patient environment commonly leads to CT being used as the first line modality.

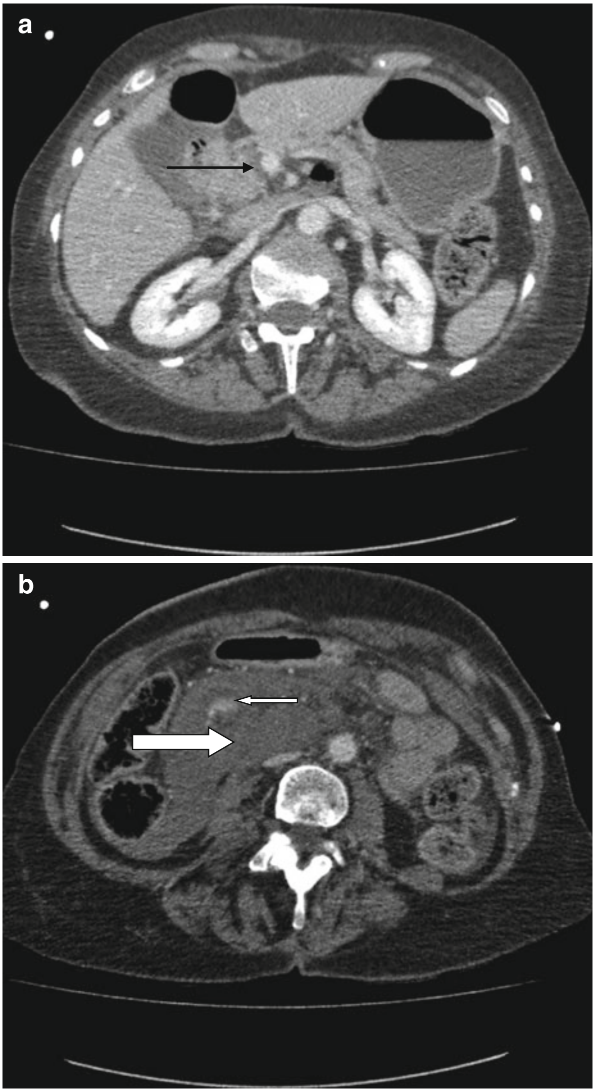

Fig. 3.8 (**a**) Axial contrast enhanced CT through the upper abdomen at the level of the pancreas in a 70 year old female patient who was a restrained front seat passenger involved in a road traffic collision at 70 mph. This demonstrates a low attenuation linear cleft in the head of pancreas (*arrow*), transecting the gland, consistent with a pancreatic laceration. (**b**) Axial CT image form the same study at a more caudal level demonstrates extensive haematoma within the mesentery on the right side of the abdomen (*large arrow*) with a focal actively bleeding vessel (*small arrow*) resulting from a tear in a mesenteric venous branch

Radiation risk, particularly in young or pregnant patients, and contrast contraindications, particularly in the setting of renal failure, are important considerations and both use of radiation and contrast medium should be minimized or avoided where appropriate. However it is commonly the case in the ICU setting that the benefits of CT to establish and accurate diagnosis are greater than the risks so these factors need to be seen as relative not absolute contraindications.

While obese patients are challenging to image given their ability to attenuate the x-rays and limited size of the bore of the CT machine, modern scanners have also grown in size and power to cope with the obesity epidemic. Close discussion with

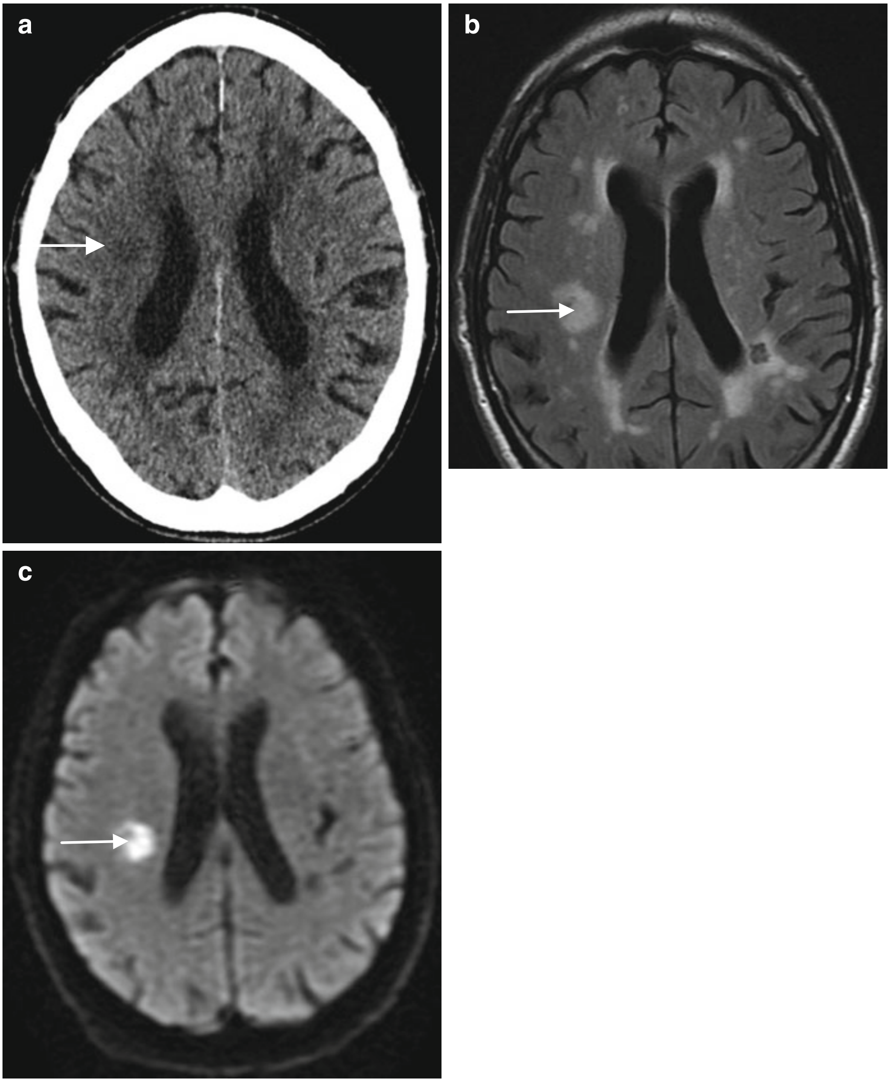

Fig. 3.9 (**a**) Non contrast CT of the brain in a 76 year old male patient with left sided weakness demonstrates a subtle focal area of low attenuation (*arrow*) in the periventricular deep white matter of the posterior right frontal lobe on a background of chronic small vessel ischaemia. MRI was subsequently performed. (**b**, **c**) Axial T2 FLAIR (**b**) demonstrates an area of high signal abnormality (*arrow*) in the right cerebral hemisphere corresponding with the subtle area of abnormality visualised on CT. Note the additional areas of high signal surrounding the ventricles, thought to represent chronic deep white matter ischaemic change. Diffusion weighted imaging (**c**), optimised for detection of acute ischaemia, demonstrates only a single focus of marked corresponding high signal in keeping with acute infarction in this region

Fig. 3.10 Non contrast CT brain in an 89 year old female patient found collapsed with right hemiplegia demonstrates extensive low attenuation throughout the left cerebral hemisphere in the left middle cerebral artery vascular territory. The appearances are those of an extensive left middle cerebral artery infarct

the imaging department is essential in morbidly obese patients to ensure that the scanner is able to tolerate the patient's weight and girth.

Teaching Points

1. Modern CT technology allows images to be displayed in the conventional transverse plane as well as in a coronal and sagital plane. 3D reconstructions allow exquisite anatomical overview.
2. Multiple phase contrast gives very good delineation of venous and arterial phase images.
3. CT is available 24/7, image acquisition time is short.
4. The need for a quick and definite diagnosis often outweighs any concerns about transferring a critically ill patient to the radiology suite or about giving contrast medium.

Chapter 4
Magnetic Resonance Imaging

Edmund M. Godfrey

Introduction

Magnetic Resonance Imaging (MRI) is constantly evolving and improving. Magnetic Resonance (MR) images show excellent soft tissue detail and can provide considerable functional information not available using other imaging techniques, for example measurement of dynamic blood flow.

The key advantage of MRI is that there is no requirement for ionizing radiation. It is the modality of choice for studying brain, muscle and nerve tissue. MR images show much greater contrast between different tissues and hence better characterization than computerized tomography (CT) images. While indications for MRI in the critical care patient are limited, MR images of the brain and spinal cord are increasingly used for critically ill patients with neurological problems.

Technique

Magnetic resonance imaging relies on three factors: a powerful static magnetic field, varying electromagnetic field gradients and pulsed radiofrequency (RF) waves. The gradient and RF fields are only present within, or very close to, the magnet and during scanning. The static field is present at all times. Each of these has implications for both the patient and the attending medical and nursing staff (see Chap. 13).

Tesla (T) is a measure of magnetic field strength. The static magnetic field at the Earth's surface varies between 25–60 μT at inhabited latitudes. By comparison, clinical MRI typically operates at 0.5–3 T, describing the field strength in the central

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bore of the scanner. The vast majority of hospitals use high field strength, superconducting (1.5 T or greater) closed imaging systems.

Small time-varying gradient fields are super-imposed on the static field but are only switched on for very short periods. They are used to localize the MR signals with spatial information to generate the image. RF coils are used to both transmit the pulsed RF field and detect RF signals emitted by the patient.

MRI technology relies on the fact the protons oscillate when they are placed in a magnetic field. They absorb energy at the frequency of the oscillation. After absorption the nuclei reradiate the energy as they return to their initial state of equilibrium. This reradiation is observed as the MRI signal. Two physical processes dictate the nucleus' return to its initial state:

1. relaxation of the component of magnetization parallel to the magnetic field
2. relaxation of the component of magnetization perpendicular to the magnetic field.

T1 is equal to the time it takes the first process to complete; T2 corresponds to the time taken by the second process.

A wide variety of imaging sequences are used depending on the clinical context. These include standard T1 and T2-weighted sequences, FLAIR (fluid attenuated inversion recovery), contrast enhanced sequences and diffusion weighted imaging sequences.

The way that the different sequences produce signals from different tissues is an interesting topic but a long and complicated one. For practical purposes, it is far more useful to understand the different sequences in terms of the signal intensity that they produce in different tissues.

For an example in a patient with terminal ileal Crohn's disease the involved segment of bowel is thickened, edematous and hyperemic. MR sequences can be acquired in any order, although in general the contrast-enhanced images are obtained at the end of the examination. On T2-weighted sequences fluid has a high signal and appears white (Fig. 4.1), which makes them particularly suited to identify areas of abnormal fluid or edema.

Fluid in the small bowel lumen and the urinary bladder is high signal. Gas in the stomach is low signal (black). Fat in the subcutaneous and intra-abdominal compartments is high signal, whereas soft tissues such as liver and muscle are varying degrees of intermediate signal (grey).

It can be very useful to remove the high signal caused by fatty tissue from an image, a process called "fat saturation". This is particularly important when looking for abnormal fluid on T2-weighted images. Figure 4.2 demonstrates how the abnormal intermediate signal within the thickened terminal ileal wall is much more conspicuous when fat signal is removed. In this case it also provides vital diagnostic information: the mural intermediate signal seen in Fig. 4.1 could be due to fat (secondary to chronic inflammation) or edema (acute inflammation). Figure 4.2

Fig. 4.1 Coronal T2-weighted image of a patient with Crohn's terminal ileitis

demonstrates that is due to edema and therefore strongly supports acute rather than chronic inflammation.

T1-weighted images are equally widely used and differ from T2-weighted images most obviously by the fact that fluid or water is low signal. On conventional T1-weighted sequences, fat is high signal, just as it is in T2-weighted sequences. Figure 4.3 is a conventional T1-weighted axial image of a patient with hydrocephalus secondary to a colloid cyst (the circular structure at the center of the image). The fluid within the ventricles is low signal and the subcutaneous fat is high signal. The colloid cyst is intermediate signal as is the brain parenchyma.

T1-weighted imaging can also be used with fat saturation, as is demonstrated in Fig. 4.4.

On fat saturated T1-weighted images, relatively few substances are high signal. Gadolinium based contrast agents will cause the T1 signal of the tissues around them to increase dramatically, allowing structures with an increased vascularity or

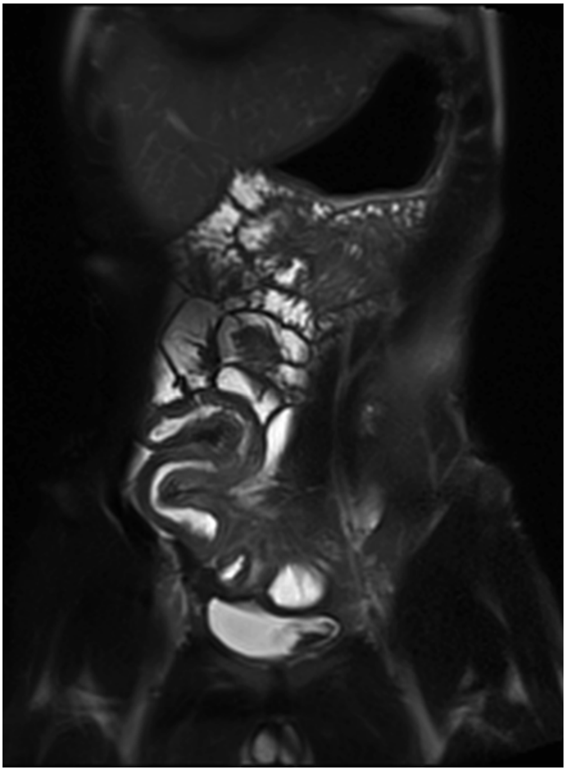

Fig. 4.2 Coronal T2-weighted fat saturated image of a patient with Crohn's terminal ileitis

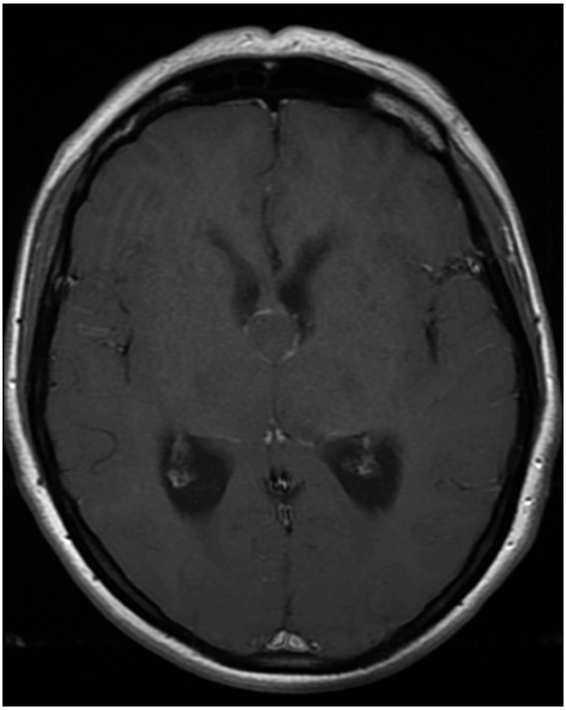

Fig. 4.3 T1-weighted axial image of a patient with a colloid cyst of the third ventricle

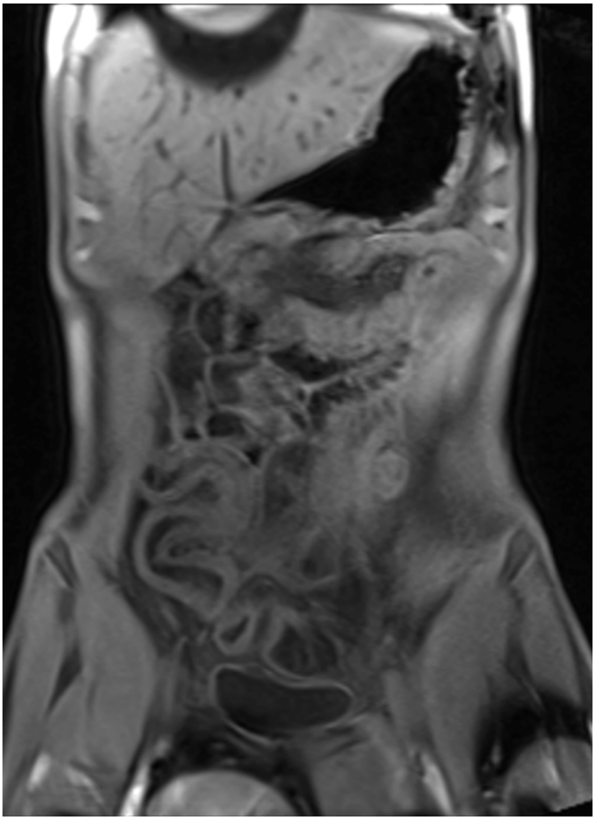

Fig. 4.4 Coronal T1-weighted fat saturated image of a patient with Crohn's terminal ileitis

vascular permeability to be highlighted. Given that many neoplastic or inflammatory processes involve an increase in vascularity or vascular permeability, contrast-enhanced images are widely used in all types of cross-sectional imaging. Contrast enhanced MRI images are almost always T1-weighted (as contrast medium reduces, rather than increases, the signal of tissues on T2-weighted imaging), but they may be either conventional or fat saturated. Figure 4.5 is an example of a contrast enhanced T1-weighted fat saturated image.

The involved segment of bowel in Fig. 4.5 is hyperenhancing (enhances more than adjacent loops of bowel) consistent with acute inflammation, supporting the diagnosis of active Crohn's disease.

Although the most frequently used sequences can be thought of in terms of T1 versus T2-weighting, with and without fat saturation or contrast enhancement, this is only the tip of the MR iceberg. There are many additional sequences that are technically extremely demanding. Examples of these sequences include FLAIR (fluid attenuated inversion recovery) and FIESTA (fast imaging employing steady state acquisition).

Figure 4.6 is a FLAIR image of the same patient as seen in Fig. 4.3. The fluid in the ventricles is low signal, and the subcutaneous fat is high signal, so one might assume that this is a conventional T1-weighted sequence. Comparing Fig. 4.6 with Fig. 4.7, a T2-weighted image of the same patient, is useful as it shows that the two

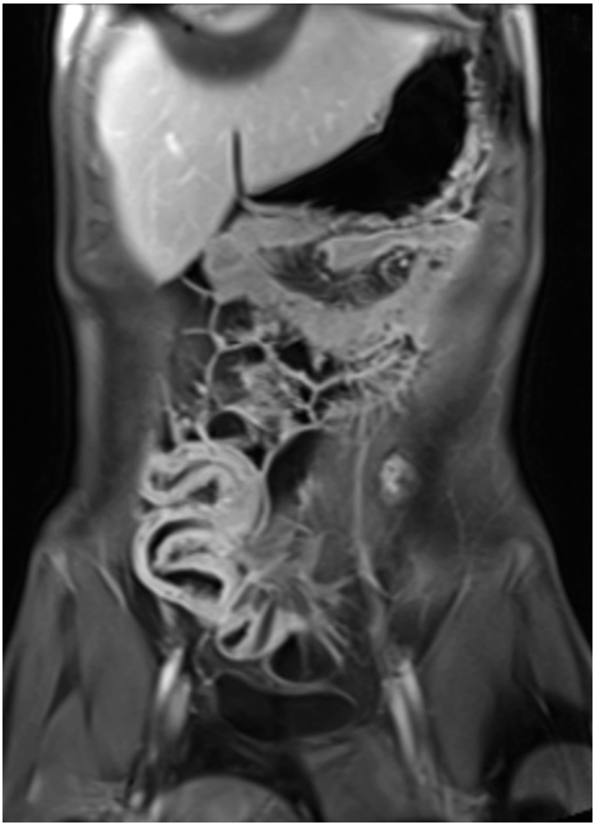

Fig. 4.5 Coronal contrast enhanced T1-weighted fat saturated image of a patient with Crohn's terminal ileitis

images are very similar with the exception of the signal of the cerebrospinal fluid in the ventricles. The grey matter in both images has a higher signal than the white matter, and the colloid cyst is hyperintense in both; compare this with Fig. 4.3. The reason for this is the fact that FLAIR is essentially a T2-weighted image with signal from simple fluid removed.

FIESTA is another sequence that is widely used but does not confirm to the usual behavior of the sequences described above. As you would expect from the name of the sequence, it is very fast to acquire. The high temporal resolution makes it excellent for imaging moving structures such as the heart of the bowel. The signal derived from tissues is dependent on the T2 to T1 ratio, which can make things quite complicated.

Although this FIESTA image shown in Fig. 4.8 looks superficially similar to the T2-weighted image shown in Fig. 4.1 the key difference is the low signal line at areas where there is an interface between fluid and fat, such as around the segment of abnormal terminal ileum.

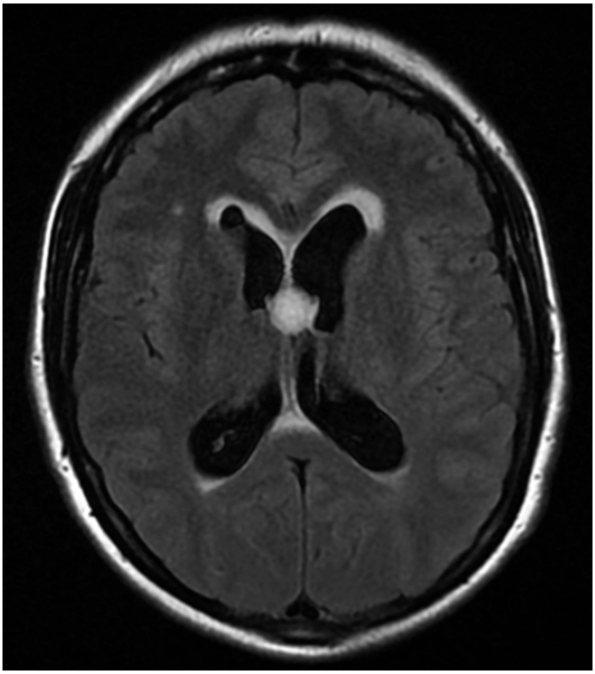

Fig. 4.6 Axial FLAIR image of a patient with a colloid cyst of the third ventricle

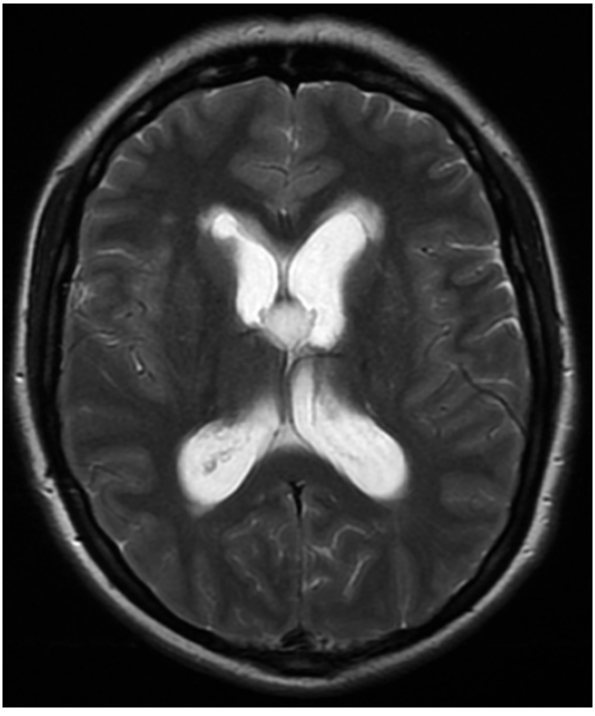

Fig. 4.7 T2-weighted axial image of a patient with a colloid cyst of the third ventricle

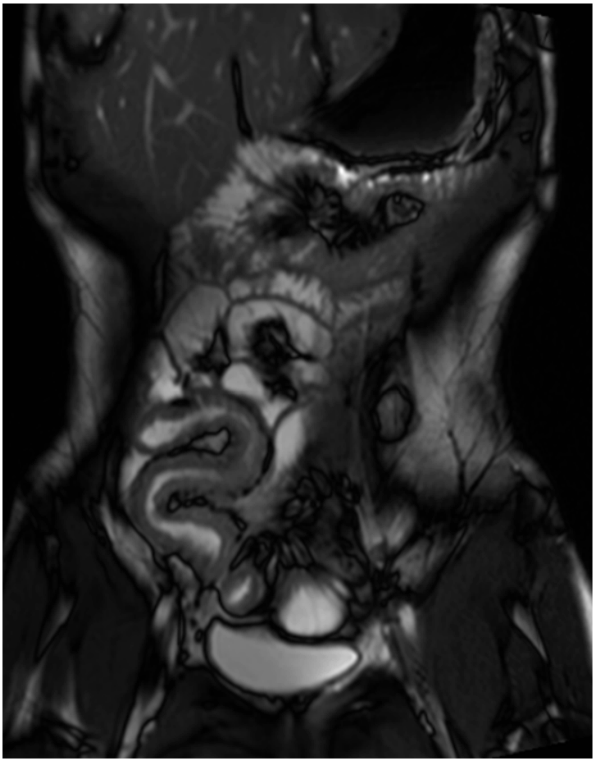

Fig. 4.8 Coronal FIESTA image of a patient with Crohn's terminal ileitis

Strengths

In critical care, the reason that MRI is used despite all the complexities involved is because it offers unparalleled soft tissue imaging. There are several important diagnoses that can only be made using MRI. These include: spinal cord injury without radiographic abnormality (SCIWORA), ligamentous spinal injury, characterization of congenital heart disease, early diagnosis of hypoxic-ischemic brain injury, assessing the prognosis of brain injury, and determining the extent of residual brain tumor following debulking surgery.

The following images provide an illustrative case where MRI was required to make a diagnosis. Figure 4.9 is an unenhanced axial CT image of a patient that had been admitted to ITU following treatment for profound hypernatremia. Figure 4.10 is an axial T2-weighted image of the same patient, and Fig. 4.11 is a similar image from a normal patient for comparison. The high signal in the pons seen in Fig. 4.10 allows the diagnosis of central pontine myelinolysis to be made.

For some patients, the ability to obtain images without the use of ionizing radiation is a reason to use MRI rather than CT. This consideration most frequently arises in the context of abdominal or pelvic imaging during pregnancy, for example in suspected appendicitis. Finally, MRI can provide functional information that would

Fig. 4.9 Unenhanced axial CT image of the posterior fossa in a patient recently treated for profound hyponatraemia

Fig. 4.10 Axial T2-weighted image of the posterior fossa in a patient recently treated for profound hyponatraemia

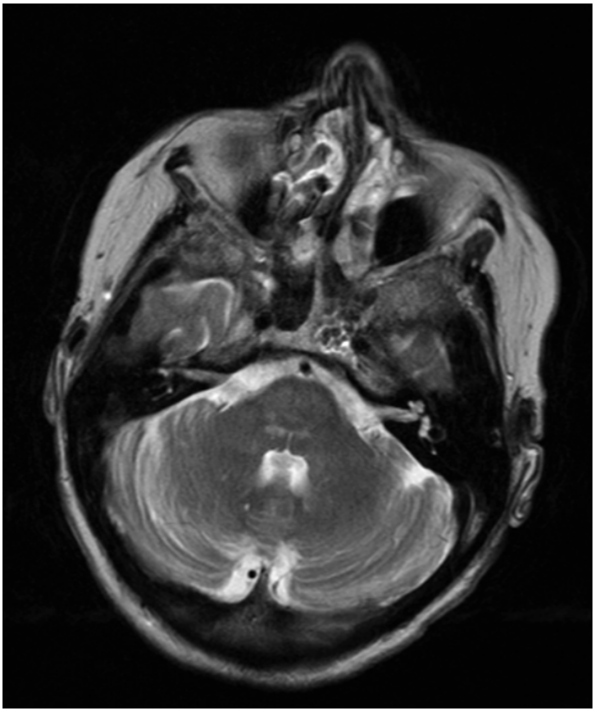

Fig. 4.11 Axial T2-weighted image of the posterior fossa in a normal patient for comparison

be impossible to obtain with other techniques. A good example of this is in the assessment of congenital heart disease, where it can be used to obtain not only structural images but also functional data such as the ejection fraction or dynamic blood flow measurements.

Limitations

Imaging ICU patients with MRI is limited chiefly by the practical issues of transfer and keeping the patient safe in the scanner as well as by the availability of what is a limited resource.

In some patients, the technique is absolutely contraindicated due to implanted devices (Table 4.1). Specialized equipment such as MRI compatible ventilators, monitors or syringe drivers are required. The technique is inherently slower than other imaging modalities such as CT. Most MR examinations will take 30 min for an outpatient, but for an intubated patient requiring what is essentially mobile intensive care, the whole process can take several hours.

For most types of MR imaging systems, the patient is completely enclosed. This makes clinical assessment and adjustment of lines impossible unless imaging is interrupted.

Table 4.1 Screening questions before MRI scanning

Cardiac pacemakers or implantable defibrillators
Heart valve replacement
Cochlear implants
Cerebral aneurysm clips
Implanted neurological stimulator
Joint prostheses or bone fixation
Shrapnel
Tattoos, body piercings, permanent metallic eye make up
Implanted infusion devices
Skin patches for drug treatment (HRT, nicotine, pain relief, contraceptive)

Table 4.2 Typical indications for MRI in ICU patients

Brain	Assessing the cause of come when other imaging ins normal
	Assessing extent of residual tumor after debulking
	Early diagnosis of neonatal hypoxic-ischemic injury
Spine	Suspected Cauda Equina
	Suspected ligamentous spinal injury
	Suspected SCIWORA
Other	Characterization of congenital heart disease
	Abdominopelvic imaging in pregnant patients

Preparation and Practical Issues

The first step is usually a discussion between clinician and radiologist to discuss the merits of alternative imaging techniques, timing and availability once any contraindications for MRI have been excluded. The staff transferring the patient should be screened to ensure that it is safe for them to enter the MR room. The MR radiography staff should explain the dangers inherent. This is particularly important for ITU staff who may be less familiar with the relevant safety issues.

The indications for MRI have been growing in parallel with its increasing availability and are summarized in Table 4.2.

Cautions/Contraindications

Most implantable electronic devices are MRI incompatible. These include most pacemakers and implantable cardiac defibrillators, spinal cord stimulators, cochlear implants etc. Some modern cardiac pacemakers are MRI compatible up to 1.5 T, but imaging these patients is still laborious, requiring pre and post imaging assessment by a cardiac technician and monitoring throughout.

Cerebral aneurysm clips vary in their compatibility with MRI, and written confirmation that they are safe from the patient’s neurosurgeon is usually required prior to imaging. The presence of orthopedic implants such as joint prostheses or fixation devices is not a contraindication to MRI and is rarely an issue if the implant has been in situ for at least 6 weeks. Metallic implants can cause imaging problems, particularly of the tissues in their immediate vicinity. The safety of other implanted metallic objects such as shrapnel varies according to their composition, size and location and an assessment has to be made on a case-by-case basis.

Caution is required in MR imaging during pregnancy, with the need for imaging balanced against the risks. The use of gadolinium-based contrast agents is avoided unless absolutely necessary in pregnancy. The use of gadolinium-based contrast agents is contraindicated in patients with significant renal impairment, as there is a risk of nephrogenic systemic fibrosis. The use in patients with liver disease and after liver transplantation is still subject to debate and uncertainty.

Teaching Points

1. MRI does not involve iodizing radiation but relies on the oscillation of protons when introduced into a magnetic field.
2. MRI shows excellent tissue detail and can provide functional information.
3. It is indicated when other imaging modalities do not provide sufficient detail and tissue resolution.
4. The use of MRI in critically ill patients is limited because of the potential risks involved in transferring patients into the scanning suite of up to several hours.

Chapter 5
Angiography

Nadeem Shaida

Introduction

This technique dates as far back as 1927, when Egas Moniz performed the first cerebral angiogram at the University of Lisbon. The first aortogram was performed at the same university in 1929. Since the introduction of the Seldinger technique angiography has become one of the most important diagnostic and, more recently, interventional procedures. Critically ill patients regularly find themselves requiring angiography, particularly in the cardiac and the neurological ICU.

Technique

Most angiographic procedures require vascular access initially via a needle, targeting a catheter or wire to the site of interest and performing a diagnostic or interventional procedure, usually with the help of contrast agents. For all structures apart from the heart, image acquisition involves Digital Subtraction Angiography (DSA) whereby a series of "mask" images are acquired initially prior to instillation of contrast medium. Once contrast is added bones and other structures are "subtracted," giving a clear view of contrast filled blood vessel only (Fig. 5.1a–c). The images can be viewed in either native or "subtracted" format. Further post processing techniques such as "road mapping", where the visualized vessel acts as a map during live fluoroscopy screening of a wire or catheter, can be easily performed on most modern fluoroscopy systems.

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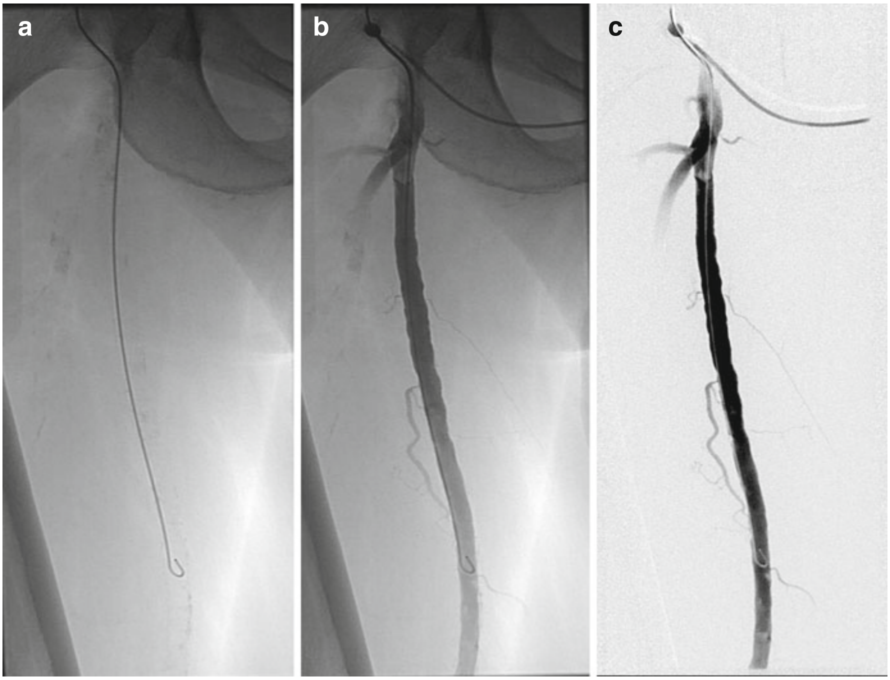

Fig. 5.1 Digital subtraction angiography. A mask image (**a**) is obtained, contrast medium administered (**b**) and a subtracted image (**c**) produced to highlight (in this case) the superficial femoral artery

Indications

It can be difficult and potentially not without risk to transfer a critically ill patient out of the ICU into the imaging suite. However, there are situations where angiography not only offers a superior diagnostic tool but can facilitate life-saving interventions.

Identification and Treatment of Arterial Hemorrhage

Many of the interventional procedures performed on critically ill patients relate to identifying areas of active bleeding. It is important to appreciate that unless the patient is actively bleeding at the time of angiogram, it is very difficult to identify an abnormal area. The cardinal angiographic findings that suggest recent or active bleeding are contrast extravasation, pseudoaneurysm formation or abnormal "cut-off" of a vessel, which abruptly terminates in a non-anatomical fashion. From the angiographer's point of view, timely transfer at the time of suspected hemorrhage is preferable. Having said that, it is possible to identify bleeding points in the abdomen with blood loss of as low

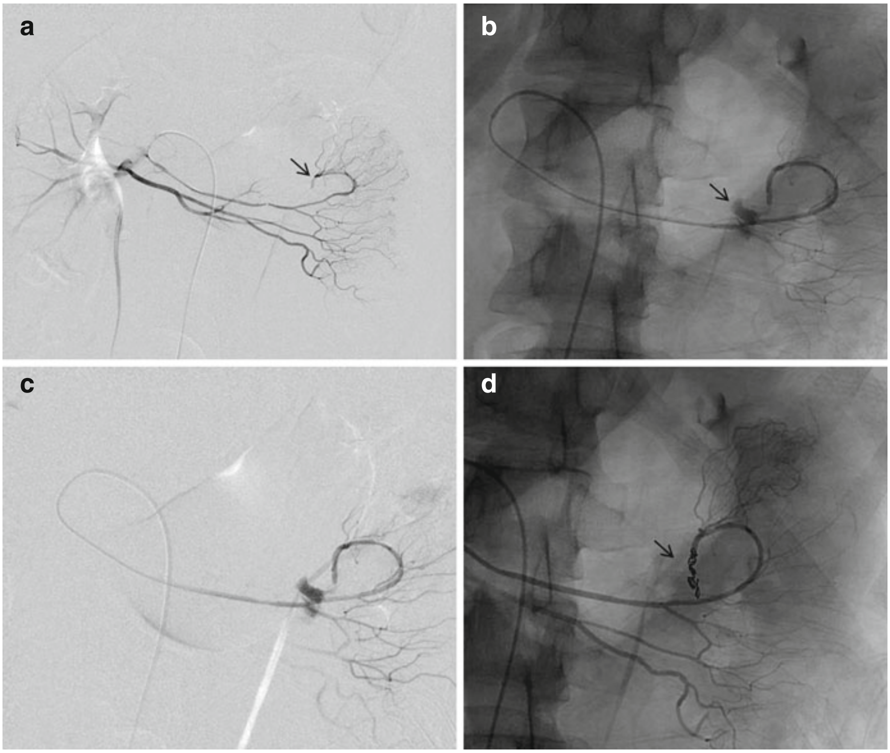

Fig. 5.2 Unstable trauma patient. Initial angiogram (**a**) from the proximal superior mesenteric artery (SMA) shows abnormal cutoff of a peripheral branch (*arrow*). Following super-selective catheterisation of the peripheral branch with a microcatheter, unsubtracted and subtracted (**b**, **c**) angiograms demonstrate contrast extravasation (*arrow*) in keeping with active arterial bleeding. This was embolised (**d**) using multiple microcoils (*arrow*) with a good embolic result

as 0.5–1 ml/min. Once a bleeding point is found, it may be possible to treat it by embolizing the feeding artery (Fig. 5.2a–d). A variety of embolic agents including liquids, glues, foams, particles, coils and plugs are available with varying properties and indications. Angiography is commonly employed for bleeding complications within the lungs, the GI tract or in the case of pelvic or visceral hemorrhage. It is important to realize that angiography is only one of a number of available diagnostic options and other imaging modalities such as CT angiography (CTA) may be more appropriate in the first instance. In some situations, non-radiological investigations such as endoscopy may be indicated before an invasive imaging test.

Nonarterial Hemorrhage

Control of variceal bleeding and portal hypertension may be achieved by means of insertion of a transjugular intrahepatic portosystemic shunt (TIPSS procedure) to reduce portal venous pressure. Such procedures are technically challenging and may also require varix embolisation as part of the procedure.

Non-hemorrhage Control Procedures

These procedures include insertion and removal of IVC filters to prevent pulmonary emboli, nephrostomy insertion in patients with obstructed kidneys and difficult intravascular access procedures in patients where commonly used vessels are no longer patent. In addition to those the intensivist is likely to encounter patients who have undergone major endovascular procedures such as endovascular aortic aneurysm repair (EVAR) as well as those who have undergone neurological interventions such as carotid artery stenting and more recently, catheter directed intra-arterial thrombolysis for acute stroke.

Removal of Intravascular Foreign Bodies

The need to remove items such as retained wire or catheter fragments is fortunately rarely required and is usually performed by “snaring” the fragment and pulling it out under fluoroscopic guidance.

Strengths

The main strength of angiography relates to the fact that it is the gold standard investigation for intravascular pathology. Multiple alternative non-invasive modalities such as Duplex ultrasound, Magnetic Resonance Angiography (MRA), and CTA exist and in many cases may be a useful adjunct or precursor to angiography. The key advantage of angiography is the ability to treat the encountered pathology at the same time as performing the diagnostic test. Often the treatment provided is a less invasive alternative to a surgical or medical treatment option.

Limitations

Angiographic procedures have to be performed outside the ICU, in the angiography suite or ideally in a hybrid operating theatre, which combines a fixed fluoroscopy unit with operating theatre conditions. The considerations relating to transfer and treating a critically ill patient outside the intensive care environment are discussed in separate chapters (see Chaps. 9 and 11).

Angiographic procedures require contrast medium to be administered. Modern non-ionic, low or iso-osmolar contrast agents are safer than older agents in terms of contrast medium reactions; however such agents are still nephrotoxic. Chapter 12 describes the issues related to application of contrast in critically ill patients in more detail. If the risk of contrast induced nephropathy is a major concern alternative non-iodinated contrast agents such as carbon dioxide may be considered.

The diagnostic quality of abdominal and thoracic images in particular is highly dependent on the patient being able to hold their breath. It may be difficult to assess the vasculature if this is not the case thereby potentially obscuring subtle hemorrhage. If the patient is ventilated it is usually possible to breath hold whilst diagnostic images are obtained. This can pose more of a problem in uncooperative patients and the need for intubation and ventilation in order to increase the diagnostic accuracy of the angiography should be discussed between the radiologists and intensivists prior to the patient leaving the ICU.

Special Considerations

On a number of occasions angiographic procedures afford special considerations that might have implications on various aspects of caring for ICU patients:

- Blood pressure control – in some specialized situations it may be desirable to lower blood pressure during various stages of the procedure, for example when deploying a thoracic aortic stent graft. The need for hypotension has to be discussed prior to the procedure and it must be taken into account that some patients might not be able to tolerate reduction of end organ perfusion.
- Additional procedures – many endovascular procedures will require invasive blood pressure monitoring. Others such as extended thoraco-abdominal stent grafts usually require the insertion of a spinal fluid drain in an attempt to reduce the risk of spinal ischaemia.
- Positioning – during most interventional procedures the patient will be lying supine for groin, neck or arm access, although occasionally some other position may be required, e.g. prone or lateral position is more suitable than a supine one for nephrostomy insertion. This can have implications on trauma patients and requires even more careful placement of monitoring and infusion lines or ventilator tubing.
- Clotting – it is not uncommon for ICU patients to either be anticoagulated or have impaired clotting or platelet function. Intensivists and radiologists have to discuss the need to correct the patient's clotting function before establishing arterial access. Typically a vascular access sheath of varying size (Fig. 5.3) is inserted into the common femoral artery (CFA) but sometimes elsewhere such as the brachial or radial artery. At the end of the procedure the sheath should be removed and the arteriotomy closed either by direct pressure or by use of one of a number of commercially available closure devices. This is followed by strict bed rest, which may include a period of time where the patient is lying completely flat. This can be difficult to achieve and might require additional sedation after the procedure.

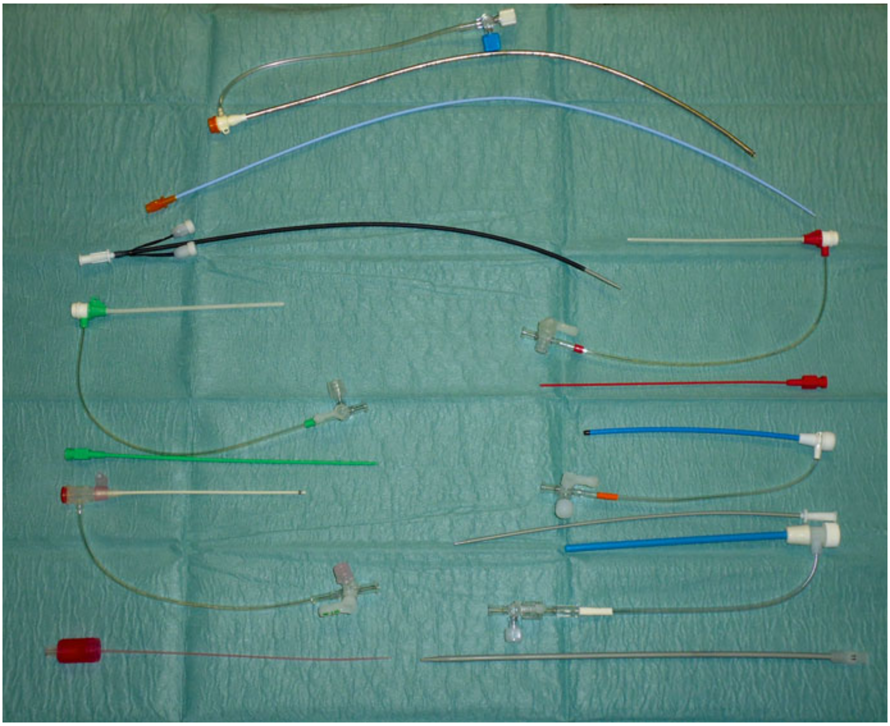

Fig. 5.3 Variety of vascular sheaths designed to provide haemostatic access to a vessel. Catheters and wires are manipulated through such access sheaths

Complications

Complications include hemorrhage which can be life threatening particularly from high CFA punctures which can cause clinically occult retroperitoneal hemorrhage. Other complications to be aware of include local hematoma, pseudoaneurysm formation, arterial dissection, which can occlude the access artery and arteriovenous fistula formation. Ideally, the patient's clotting should be corrected prior to performing the procedure. However, in many situations this is not possible. In these cases, the vascular access sheath is often left in situ, to be removed later when the clotting has normalized. It is imperative that the sheath is removed by a member of staff who is proficient in the procedure in order to reduce the complication rate.

Teaching Points

1. Angiography is performed for a number of life-saving indications such as the identification of bleeding sites with the option of embolization and endovascular aortic repair.
2. The patient position during the procedure has to be discussed between the referring clinician and the radiologist.
3. Patients should ideally have a normal coagulation profile prior to an angiographic procedure, although this is not always possible.

Part II
Referrals and Reviewing Images

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Chapter 6
Imaging Referrals in their Legal Context

Katie Howard

Introduction

> Referrer: "Medical doctor, dentist, or other health professional who is entitled to refer individuals for medical exposures to a practitioner, in accordance with national requirements." (ICRP, 2009. Education and Training in Radiological Protection for Diagnostic and Interventional Procedures. ICRP Publication 113. Ann. ICRP 39)

The "referrer" or "prescriber" of ionising radiation clearly has a part to play in the management of a patient's radiation safety. Their role, its responsibilities and obligations, is set out, to a greater or lesser extent, in national regulations. These regulations find their roots in the recommendations of the International Commission on Radiological Protection (ICRP), specifically the recommendations from 1990, 1996 and 2007.

International Commission on Radiological Protection (ICRP) Recommendations

Significant updates to the ICRP's recommendations, incorporating newer epidemiological evidence, were made in 1990 (Publication 60), with details of how this applies in a medical context given in 1996 (Publication 73) and again in 2007 (Publication 103). The publications deal with a full range of aspects of radiological protection, and include the needs and responsibilities of the referrer or prescriber of medical examinations using ionising radiations. The key principles of radiological

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protection coming from these recommendations are the need for justification, optimisation and limitation of radiation doses. It is in the need for justification that the referrer has an important role. While it is not the job of the referrer to justify an examination – this task belongs to a specialist practitioner such as a radiologist – it is imperative that the information on which the specialist relies to make this judgement is provided by the referrer. This information must therefore be provided with sufficient detail for the practitioner to make a judgement on the justification of each individual exposure.

Furthermore, the ICRP recommend that "radiation detriment should be explicitly included" when considering medical exposures using ionising radiation. This means that the referrer should have an awareness of the radiation dose delivered by the exposure, the level of detriment and the alternative procedures that are available with their relative merits. There is specific advice concerning radiation exposure of the female abdomen; this should be avoided "unless there are strong clinical indications" and the ICRP recommend that information on possible pregnancy be gathered from the patient herself.

The Commission is clear that the managers of institutions using ionising radiation have responsibility for controlling radiation exposures but note that operationally these duties (although not the overall responsibility) may be delegated. Under these recommendations there is leeway for nation states to give more or less instruction on how the management structures should be organised and how roles should be defined.

Further explanatory advice is given in later publications of the ICRP, including the Supporting Guidance of 2001. This document states that "benefit to patients from medical uses of radiation has been established beyond doubt" but goes on to discuss the need for individual justification of examinations. While in other publications the responsibility for justification is laid almost wholly with the radiation practitioner, this publication calls on the referrer to "justify the examination before referring a patient to the radiologist or nuclear medicine physician." With both the referrer and the practitioner making an individual assessment of each case, unnecessary examinations should be minimised. In referring the patient, the referrer must remember to provide sufficient information on which the practitioner can draw. Of course, should insufficient information be provided, the referrer should find that the request is refused or delayed while more information is requested of them. An examination is only justifiable if the outcome "influences the management of the patient" and may also be useful if it "boosts confidence in a diagnosis." This means, for example, there is no value in referring a patient for an examination if there has been insufficient time since the previous imaging for the disease to have progressed or resolved. The referrer is not expected to keep up-to-date with all available imaging techniques, but is recommended to use criteria based on "clinical experience and epidemiology." The Commission advises that the World Health Organisation, the International Atomic Energy Agency, the Commission (ICRP) and the European Union, may provide such criteria. The main issue of concern when referring for imaging with ionising radiation should be whether the same information can be obtained from non-ionising imaging modalities (ultrasound, magnetic resonance imaging). The Commission does accept, however, that practical considerations can

Table 6.1 Examples of unjustifiable examinations

Examination	Unjustifiable indications
Chest radiography	At hospital admission or before surgery "in the absence of symptoms indicating cardiac or pulmonary involvement"
Skull radiography	Asymptomatic subjects of accidents
Lower sacro-lumbal radiography	Stable degenerative condition of the spine in the 5th or later decade of life
Medico-legal work outside standard referral criteria	When the examination is not expected to provide useful information on the individual's health, nor does it support criminal investigations.
Medical screening of asymptomatic populations	When expected advantages for the individuals or population are insufficient to compensate for economic and societal (including radiation detriment) costs.

Based from ICRP Supporting Guidance 2 and ICRP Publication 103

be taken into account in this respect (local availability of relevant equipment, cost, waiting times, "organisational difficulties").

Advice on a few occasions when imaging can be avoided are given in Table 6.1; this collection of examinations can all be summed up in a reminder that patients should only be referred for examinations that are expected to affect the management of the patient. Additionally, repetition of examinations can be avoided by checking for previous similar examinations. To facilitate this there needs to be appropriate sharing of information between health-care providers. While the framework for this sharing may be outside the remit of the referrer, the referrer could have considerable influence here.

The Commission advises on a number of areas where special consideration should be given to referrals for ionising radiation. Referrers are advised to give extra consideration to medico-legal examinations (e.g., insurance companies requesting evidence of the health of their policy holders) since these examinations are not requested for the sake of any medical benefit to the individual. Special consideration is further expected for higher dose examinations (such as those using computed tomography), for examinations of pregnant women (when the abdomen is in or near the exposed area) and for examinations of children. Furthermore, the Commission advises that the pregnancy status of a woman should be determined before completing diagnostic studies; of relevance to the decision to continue with the examination are whether or not the fetus would be in the primary exposed area and the expected dose from the examination. If the examination is distal from the fetus, the examination can continue (e.g., chest or extremity radiographs). It is of note that it is rare for the radiation risk of the examination to outweigh the risks of a delayed diagnosis.

Training

ICRP Publication 105, 2007, and Publication 113, 2009, give advice on the training required by those involved in medical work with ionising radiation. Publication 105 records three categories of physicians in need of training: physicians in

Table 6.2 Training requirements for referrers

Training area	Level
Radiological quantities and units	L
Principle and process of justification	M
Fundamentals of radiobiology, biological effects of radiation	L
Risks of cancer and hereditary disease	M
Risk of deterministic effects	L
General principles of RP including optimisation	L
Operational RP	L
Particular patient RP aspects	L
Particular staff RP aspects	L
Typical doses from diagnostic procedures	M
Risks from fetal exposure	L
National regulations and international standards	L
Suggested number of training hours	5–10

Data from ICRP 113

Levels of required knowledge and understanding: L = low, a general awareness and an understanding of the principles, M = medium, a basic understanding sufficient to inform work practices, H = high, able to educate others. Note: the high level of training is only required by specialists in the field of ionizing radiation (such as radiologists)

RP radiological protection

medical radiation specialties, other physicians using ionising radiation modalities, and physicians that prescribe medical procedures that use ionising radiation. This training should be provided at an "appropriate" level for each category and should be delivered at medical schools, during residencies and in "focused specific courses"; it should also be evaluated to confirm successful completion of the training. The Commission emphasise the need for resources for education and training of future staff who "request or partake in radiological practices in medicine," noting that training should be provided for new staff and as updates for existing staff. The recommendation to include radiological protection training for all physicians within their medical degree reflects an acknowledgment that all medical professionals are likely to have cause to refer for examinations using ionising radiation.

The recommended training requirements for referrers are given in Table 6.2. Particular attention is noted for the need to emphasise the special differences for paediatrics and more generally, for an acquaintance with referral criteria for the examinations that they are expecting to request. The ICRP recommends using (up-to-date versions of) guidelines produced by radiology societies. A lower level, more targeted training including radiation hazards is recommended for staff, such as nurse practitioners in casualty departments, who refer for a limited range of examinations with a limited range of indications. Of course, in countries where nurse practitioners have a greater scope for referrals, their training should be equivalent to the training of other referring health professionals.

Commercial considerations of referrals for radiological examinations are also discussed. The Commission records its disapproval of systems where commercial considerations can affect referral rates as this is likely to lead to clinically unjustified examinations.

The training of healthcare professionals in radiological protection remains a topic of live debate and a draft ICRP document was circulated for consultation in 2010 on "Radiological Protection Education and Training for Healthcare Staff and Students."

Incorporation of ICRP Recommendations in the European Union (Council Directive 97/43/Euratom on Health Protection of Individuals Against the Dangers of Ionizing Radiation in Relation to Medical Exposure)

This European Union (EU) Council Directive 97/43/Euratom (henceforth referred to as the Directive) is based closely on ICRP Publications 60 and 73, with the definition of a prescriber matching that of a referrer in ICRP publication 113 exactly.[1] The Directive states that the "responsibilities for administering medical exposures need to be set out." Training of referrers is not explicitly included or excluded, with the Directive requiring "appropriate training of the staff involved" in medical work with ionising radiation although Article 7 of the Directive does not specify referrers as a group requiring training. As regards justification, the prescriber and practitioner are explicitly required to check medical records, "where practicable," to guard against unnecessary exposures and both parties are required to be involved in the process of justification to an "appropriate level" and to check the pregnancy status of the patient requiring medical exposure. Importantly, the Directive requires Member States to ensure that referral criteria for medical exposures (including information on radiation dose) are available to all referrers. In 2000, the European Commission published "Radiation Protection 118: Referral Guidelines for Imaging" which draws heavily on the (since superseded) fourth edition of the UK's Royal College of Radiologists referral criteria guidelines (1998). While various professional bodies have produced such referral criteria, the need for comprehensive internationally recognised criteria remains present and is the subject of both a 2011 European Commission tender for a "study on the implementation of Council Directive 97/43/Euratom – requirements concerning referral criteria for medical imaging in the European Union" and of a World Health Organisation meeting in March 2010 that called for global referral guidelines to be produced for medical imaging.

[1] EU Directives are legally binding acts of the EU that require Member States to achieve stated objectives but leave Member States to decide and legislate on the measures to be implemented to achieve these objectives.

United Kingdom

The UK's Ionising Radiations (Medical Exposures) Regulations, 2000 (IRMER) follow a similar definition of a referrer as the ICRP Recommendations and EU Directive, with the clarification that entitlement to refer is conferred in the "Employer's procedures"; these Employers Procedures are the specific documents required by the regulations to lay down the management of the medical use of radiation in the organisation. The amendment regulations, "The Ionising Radiation (Medical Exposure) (Amendment) Regulations 2006" give a further clarification, defining referrers as "registered health professionals" and these registered health professionals as persons who are members of professions that are regulated by a body included in Section 25(3) of the National Health Service Reform and Health Care Professions Act 2002.

As stipulated in the 97/43/Euratom Directive, the UK regulations establish that the employer (of staff who carry out medical exposures using ionising radiations) shall establish "recommendations concerning referral criteria" with information on radiation doses and shall make these criteria available to the referrer. This wording retains a certain amount of flexibility. In practice, such employers generally cite the Royal College of Radiologist's (RCR) referral criteria; these criteria are regularly updated and are now available in digital versions as "iRefer" to enable comprehensive access for referrers. The RCR guidelines consist of tables of clinical conditions with possible imaging techniques with a grading of radiation dose and advice on the recommended approach to take with a grade given to the quality of the supporting evidence for that advice; the guidelines also suggest that the referrer ask a number of pertinent questions when making a referral (Table 6.3).

Drawing directly from the ICRP and EU documents, the UK legislation requires the referrer to provide the practitioner with "sufficient medical data" to enable the practitioner to decide if the examination is justified. There is also a clarification, confirming that where an individual holds multiple roles under the regulations (as occurs, for instance, in a dental practice where the dentist may be employer, referrer, practitioner and operator concurrently) the individual must comply with duties conferred on holders of each of these roles. Employers are required to identify the individuals who are "entitled to act as referrer or practitioner or operator"; this is interpreted by UK employers variously as named individuals or groups of individuals listed by their position within the organisation.

Table 6.3 Important questions to be asked before an image referral

Has it been done already?	
Do I need it?	i.e., will it affect the management of the patient?
Do I need it now?	i.e., could imaging less often give the disease chance to progress or resolve between exposures?
Is this the best investigation?	This may require discussion with an imaging specialist
Have I explained the problem?	
Are too many investigations being performed?	

Spain

In Spain the European Directive is directly transferred into Spanish law. The role of the referrer is noted in the process of justification of individual examinations. To this end, the referrer is required to obtain information from previous imaging. Of note in the Spanish legislation is that it is also incumbent on the patient to inform the referrer of previous imaging that they have undergone, that "La Dirección General de Salud Pública y Consumo" (the body responsible for public health) shall ensure that recommendations on referral criteria for typical examinations are made available (with reference radiation doses) and that these criteria are included in the local quality assurance programmes. As elsewhere, referrers are required to pay special attention to the justification of examinations with no direct health benefit to the individual (such as medico-legal examinations).

Ireland

Radiation protection legislation likewise comes from the European Directive. It is governed under the European Communities (Medical Ionising Radiation Protection) Regulations, 2002, which follow a similar pattern to the other EC countries. Prescribers of medical uses of ionising radiation must be registered under Section 26 of the Medical Practitioners Act, 1978 or Section 26 of the Dentists Act, 1985. Prescribers (and Practitioners, responsible for justifying the examination) are required to check, "where practicable," earlier diagnostic information and medical records for the purpose of establishing if the examination is necessary. All referrals must be made in writing and include the reasoning behind the request. The Practitioner has a duty to make recommendations for referral criteria. It is a requirement that the Prescriber, Practitioner and the radiographer check and record the pregnancy status of female patients of childbearing age.

Incorporation of ICRP Recommendations in National Legislation Outside the EU

United States of America

In the United States of America, the National Council on Radiation Protection and Measurements (NCRP) provides non-mandatory guidance for individual states. Legislation is at the state, not federal, level and there is some variation in approach. The Conference of Radiation Control Program Directors (CRCPD) works to foster consistent approaches to radiation protection between states and encourage high standards. The American College of Radiology (ACR) have produced Appropriateness Criteria® as an online database (available at:

http://www.acr.org/Quality-Safety/Appropriateness-Criteria). The ACR have taken a slightly different approach to the RCR: clinical conditions are listed with the possible imaging methods with an appropriateness rating (and some comments and a radiation dose rating) for each imaging method.

In the State of Minnesota, for example, Chapter 4732 gives the State Rule (carrying the force of a law) on "ordering of diagnostic radiographic or therapeutic procedures." Referrals ("orders") can be made only by a "licensed practitioner of the healing arts, a certified clinical nurse specialist, certified nurse midwife, certified nurse practitioner, or physician assistant" and any physician's assistant must have a written agreement from the physician detailing their eligibility to make referrals. Furthermore, examinations cannot be completed unless the referral has come from one of these groups and the referral is available at the time of the examination. Referrals must include patient identification, referrer's identification, clinical indication, anatomy to be examined and the required examination. Special dispensation is given to the limited examinations in use in dental radiology and the difference in referral criteria for screening examinations.

Australia

Australia now has a uniform approach to radiation protection across all states and territories. The Codes of Practice produced by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) use "must" for statutory requirements and "should" for areas of best practice. Medical uses of ionising radiation are covered in Radiation Protection Series no. 14. Like the European Directive, this document is similarly based on ICRP Publication 60. Again the definition of a referrer follows the example set by the ICRP. The Code of Practice states that no radiological examination (excluding health screening programmes, research projects and emergency radiological procedures) can be approved without a written (electronic or paper) referral. This referral must include "adequate patient identifying information," specify the clinical question that the diagnosis should aim to answer (or the condition that the therapy intends to treat) and provide the referrer's own contact details to enable consultation with the practitioner.

Furthermore, there is a requirement that the "Responsible Person" (the individual with ultimate management responsibility for the radiation work) ensures that there are systems for the practitioner to communicate with the referrer following interventional radiological procedures with regard to the possible occurrence of deterministic effects. In cases where a radiological procedure is expected to deliver over 1 mSv to an embryo or fetus and is considered necessary for a pregnant woman, the risks must be explained to the pregnant woman and the referrer before completing the procedure. Importantly this implies that the pregnancy status of the patient is established and that an indication of expected dose to the embryo or fetus is available.

Teaching Points

1. Referrals can only be made by certain professional groups. There is variation in the limitations on the individuals permitted to make referrals and these are generally health professionals with some national recognition (for example by registration).
2. These referrers must provide sufficient information with the referral to allow the practitioner to make a decision on the justification of the examination and to allow the operator to identify the patient.
3. It is best practice, and in some cases mandatory, that referral criteria are provided to referrers, including an indication of radiation dose. Referrers must use these criteria and should insist that they are made available if not provided.

Chapter 7
Image Review and Reporting

Peter Beddy

Introduction

The clinicians requesting imaging as well as the radiologist have a duty towards the patient to maximize the diagnostic yield from any examination. In order to achieve this they don't only have to make sure that the right imaging modality is chosen but also that the resulting images are available in best possible format.

Medical Imaging Displays

Medical imaging can be reviewed on a multitude of devices ranging from a diagnostic monitor to a tablet computer. Generally viewing devices are classified under three types:

1. Primary diagnostic monitors are used for the interpretation of medical images and have very high-resolution displays. The recommended resolution is greater than three megapixels, especially if used to report a large volume of radiographs.
2. Clinical review monitors are used to review medical images in key clinical areas where a level of primary diagnosis may be carried out, such as in the Emergency Department or Orthopaedic Outpatient Department. These monitors should have a resolution of greater than two megapixels. In high use areas, like an Intensive Care Unit, where the clinical team will review a large volume of radiographs, a high-resolution monitor is essential.

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3. General PC monitors are where clinical teams review the majority of images in hospitals. They are not designed for diagnostic purposes and should only ever be used for clinical review in conjunction with the official radiology report.

Viewing Conditions

Medical imaging should be reviewed in a quiet room where the ambient light can be controlled. There can be a significant reduction in image quality from reflections on the display surface, depending on the ambient light. The American Association of Physicists in Medicine (AAPM) recommends an ambient light level of between 2 and 60 lux depending on the type of imaging that is being reviewed (2–10 lux for radiographs, 15–60 lux for cross sectional imaging). On a practical level, 2 lux is about equivalent to twilight and 60 lux is similar to low level lighting in at home.

It is important to regularly clean the monitors and remind colleagues that they are not to touch screens. Diagnostic and clinical review monitors often have multiple screen functions, which allow the reader to simultaneous review current and prior examinations. It is good medical practice to always review prior imaging when available.

Imaging Review

Radiological images are taken in order to contribute to the understanding of the patients condition and relate all findings, anticipated or unexpected, to their clinical condition. They require specialist interpretation through a reporter who also has the technical knowledge to understand the limitations of the various techniques and knows how these shortfalls can affect diagnostic accuracy.

Radiographs

The majority of radiographs require no image processing or manipulation to review. All Picture Archiving and Communication Systems (PACS) monitors have basic controls to alter the brightness of the image and to alter the image size and orientation. Some more advanced systems may have filters, which allow optimization of a certain part of the image. For example, a lung filter can improve the visualization of the lung parenchyma on a chest radiograph. The image controls for a PACS system may not be immediately obvious and a tutorial from your hospital's PACS manager can be invaluable.

Ultrasound

Ultrasound is a relatively subjective imaging modality as the technician or radiologist who acquires the study only takes representative images of the organs. Ultrasound images require little manipulation to review them. The study is displayed as a sequence of still greyscale images, although some system will acquire short cine loops. The examination may also include colour Doppler images or Power Doppler images which can show flow within blood vessels or organs. Aside from applications in echocardiography, Doppler imaging is commonly employed in the liver to assess portal vein flow or in head and neck imaging to assess the patency of the carotid arteries. Doppler imaging is often complimented by a Doppler recording of the waveform of the vessel that is interrogated. The Doppler imaging can usually only be manipulated at the time of acquisition and not when it is reviewed at a later time. As with any imaging modality, it is essential to review ultrasound images with the report of the examination.

Computed Tomography

Most Computed Tomography (CT) is acquired on a Multidetector CT (MDCT) scanner. MDCT has revolutionized patient imaging and has changed imaging review into a multiplane three-dimensional (3D) imaging experience. In MDCT, images are acquired as a volume of very thin slices (less than 1 mm) and then reconstructed into thicker imaging slices (e.g., 5 mm axial slices). The final MDCT study will usually contain multiple individual series. The different series may include images performed at different phases of intravenous contrast medium enhancement, sagittal and coronal reconstructions and images with different window presets (discussed next).

The CT images are acquired by calculating the relative x-ray attenuation of the tissue that is imaged. The attenuation is represented by the Hounsfield unit (Hu). Tissues that absorb a large quantity of x-rays have a high Hu (e.g., bone Hu = +1,000) and tissues that absorb fewer x-rays have a lower Hu (e.g., air Hu = −1,000). Water is chosen as the null point on the Hounsfield scale and has a Hu of 0. The Hu of certain tissues can be measured with the region of interest (ROI) tool on a PACS monitor. For example, simple intra-abdominal fluid has a Hu of 0, whereas intra-abdominal blood might have a Hu of 60. CT images can be manipulated or windowed depending on the organ of interest. If the lung parenchyma is being reviewed, the windows are set to the lung preset, which optimizes visualization of the lung architecture. If the thoracic spine is the area of interest, the windows are set to the bone present. All display monitors will have window presets available to manipulate the images.

Magnetic Resonance Imaging

Magnetic Resonance Imaging (MRI) is a technique where spinning hydrogen protons are imaged. Although it is a cross sectional imaging modality like CT, the images are acquired by a completely different technique. The imaging is performed in any plane and exquisite soft tissue detail can be depicted. Any MRI series will have several series, including a variety of T1-weighted and T2 weighted sequences. Intravenous contrast medium may also be administered. Techniques such as diffusion weighted MRI are frequently used to image the brain. There are no linear units such as Hu in MRI and window presets are not required.

Advanced Image Processing

Cross-sectional imaging data sets can be manipulated to review the images in a more than one plane or in three dimensions. Four principal post-processing techniques are employed, multiplanar reconstructions (MPR), maximum intensity projection (MIP), surface shaded display (SSD) and volume rendered (VR). The radiographer or technician will commonly perform these reconstructions, however most workstations are capable of manipulating the images. In order to perform these reconstructions, the thinnest slices or source imaging should be available. MPR allows the image to be viewed in any plane chosen. Frequently the three planes (axial, sagittal and coronal) are shown together but any imaging plane can be chosen. Most cross sectional imaging series will include standard MPR datasets (coronal and sagittal planes). MIP displays the highest attenuation voxels in an image only (voxel is the smallest box shaped part of the 3D volume dataset), therefore allowing visualization of structures not in a single plane, such as vessels. MIP imaging is very helpful in vessel imaging and colour display can be added to simulate real anatomical detail. SSD gives 3D representations of the anatomy in gray scale but is prone to artefacts. VR allows visualization of the vessels distinct from the surrounding anatomy. VR manipulation can be very time consuming as extensive post processing is required however some state of the art PACS systems have automated software to do this function.

Reporting

A radiological report is not a tool that provides the referrer with a finished dataset. It is a clinical opinion, which given by a specialist based on the clinical information they have been provided with and their expertise in interpreting obtained images.

A number of essential steps constitute the process of producing a radiological report:

- Referral – the referring clinician needs to provide the relevant information that led to the imaging request and will be relevant to the interpretation of the images. The radiologist should be familiar with the clinical picture and with all the supporting information given.
- Observation – Radiologists are observers! With the appropriate knowledge and in the right conditions four observations can be found:
  - Normal findings
  - Unequivocally abnormal findings
  - Findings that may be normal or abnormal
  - Normal variants
- Analysis – the observed findings have to be linked to other patient specific and clinical information. When available, previous imaging has to be reviewed and further information might have to be requested from the referring clinician. When put together, the information gained from the imaging examination plus the patient information provided will allow a clinically relevant opinion and advice to be given.
- Communication – The report will include a summary of the clinical details provided, a description of the findings and an interpretation of the findings with a conclusion. There has to be a reliable flow of communication between the referrer and the radiologist in order to discuss findings, to better understand their implications and to provide further clinical information that might influence interpretation.

Teaching Points

1. High-resolution displays are mandatory when reporting radiological examinations. PC monitors can only be used to review images in conjunction with the written radiologist's report.
2. Monitors need to be maintained regularly, the ambient viewing conditions have to be optimal.
3. When reviewing examinations, technical knowledge of the various modalities is important to manipulate the images obtained understand their limitations.
4. When reporting an examination it is important to have the relevant clinical information and to have an easy channel of communication between the referrer and the radiologist.

Chapter 8
Picture Archiving and Communication System (PACS)

Yu Xuan Kitzing

Introduction

With advancement in computer technology, medical images can be stored, transferred and accessed through the Picture Archival and Communication System (PACS). In most hospitals, it has replaced the conventional film filing rooms and light-box film reading. A typical PACS has four components: The modalities for image acquisition, a dedicated network for data transfer, workstations for image reporting and reviewing and an archive allowing storage and near real time image retrieval. Image data acquired through various modalities are sent via high-speed network connection to a storage server, which in turn connects to the archival storage media, the clinical and reporting workstations and the server for remote access. The network is interfaced with HIS (Hospital Information System) via RIS (Radiology Information System) to ensure the integration of the imaging system with the hospital database.

Requirements

Successful implementation of PACS is dependent on several factors:

- Digital acquisition – to enable the digital transfer of the images, the acquisition at each imaging modality also needs to be digitalized. CT, MRI and US images are intrinsically digital. Radiography, which makes up the bulk of the daily imaging work, is also now increasingly being acquired digitally rather than via old style screen-film exposure.

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- Standardization of image data – in order to make images interchangeable between different imaging devices, across modalities and different manufacturers, a universally accepted data standard is required. The Digital Imaging and Communications in Medicine (DICOM) standard was introduced in 1993 and has a near universal acceptance amongst manufacturers. DICOM dictates the storage, the handling and the transmission of the image data. An important feature of DICOM is the incorporation of patient identification within the file, so that the images cannot be separated from the patient identity.
- Image transfer – PACS requires a Local Area Network (LAN) connecting imaging devices, servers and workstations. The speed of the LAN generally depends on wire used. However, the faster the images are available, the more user-friendly the system and the higher the acceptance. Remote image review at a tertiary center or the use of teleradiology providers depends on links provided by telecommunications companies. If appropriate access regulation, encryption and authentication are established an internet based link can be used.
- Integration – PACS is interfaced with a Radiology Information System (RIS), which is in turn interfaced with the hospital database network. RIS organizes the work-list of the requested examinations, queries the demographic data from the hospital database and directly provides the patient identifiers to PACS. Completed reports in RIS are sent to PACS and are available alongside the images at the viewing stations. The interface prevents the errors associated with manual data entry and ensures that all the studies of a specific patient are grouped under the same identifier.
- Security and confidentiality – these have to be in place to prevent unauthorized access to confidential patient information. In LANs these processes include restricted password access, user education and mandatory password change on a regular basis. Where the network has an interface to non-clinical networks or the internet, protection to prevent unauthorized access from outside of the network needs to be established. Security relating to the data transmission is supported by encryption and authentication. Encryption ensures the data is coded and can only be de-coded by the intended recipient. Authentication allows the network server to verify the identity of the accessing user.
- Image backup – archive systems are required to provide the means to recover images in case of a disaster or a system error. There are a number of different systems and concepts available. However, many hospitals are moving to Cloud based PACS due to the enormous volume of images.

Advantages

The benefits of PACS relate to the ease and convenience of use and the accuracy of data transmission. Particularly in busy and acute areas like Intensive Care or the Emergency Department going back to working without digital imaging access is unthinkable.

The rapid access allows the radiologists and the clinicians to review urgent studies in a timely manner and avoids unnecessary delay in clinical decision making. It is possible to view images simultaneously throughout the hospital. This allows multiple clinical teams to have access to complex patients' data, further avoiding potentially detrimental delays in planning therapeutic interventions.

Storage in an electronic archive ensures that the image data is not misplaced and that no (often junior) member of the medical team needs to be dispatched on an onerous trawl through the hospital in search of films. The availability of the patient's imaging history allows the radiologists and the clinicians to identify clinically significant acute changes and to prevent duplication of investigations.

Digital images can be transferred accurately and rapidly from one site to other, if necessary even across geographic barriers. Sharing image data when a patient moves between different hospitals and seeking subspecialty radiology expertise at a remote hospital have become commonplace. Teleradiology is also used to address workforce issues with the provision of off-site radiology service at all hours.

Teaching Points

1. PACS have all but replaced film globally.
2. Once set up and integrated into the hospital IT system PACS offers numerous advantages, such as rapid access to current and past investigations, easy consultation with other clinicians through the ability to view images simultaneously at different locations or obtaining a specialist opinion by transferring data to a remote hospital.

Part III
The Intensivist's Concerns

Rolf Dembinski, MD
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Chapter 9
The Ideal Radiology Suite

Joanna Simpson and Florian Falter

Introduction

In the advent of increasingly more complex patients and the availability of more sophisticated imaging, transfers to the radiology department have become regular occurrences. The radiology department is a potentially dangerous place for the critically ill patient. It is desirable that patients are only moved to radiology when they are stable, however the suspected cause of instability can regularly require immediate diagnosis to enable targeted treatment.

Designing a Radiology Suite

Published guidelines and statements for the management of anesthetized patients in non-operating room or remote locations should be applied and considered when designing a radiology suite. In view of the fact that potentially unstable patients require imaging, it is imperative that advice is taken from intensive care physicians and anesthesiologists early on in the process. Table 9.1 shows the key points that have to be considered.

A good relationship and close co-operation between the departments of radiology and intensive care is essential to design the best environment for good working practices:

- Both departments should identify a person who can be involved in design planning and negotiations
- There should be liaison over the production of local protocols
- An agreed plan for the management of unexpected emergencies in the radiology department has to be developed by members of both departments.

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Table 9.1 Key points to consider when designing a radiology suite

The radiology department is a remote location, unfamiliar to intensive care staff
Critical care patients are transported on large beds often with a lot of surrounding equipment and require plenty of space for maneuvering
Ready access to resuscitation equipment that is maintained and checked regularly is mandatory
Necessity for dedicated holding bay, large enough to accommodate the patient with all accompanying equipment and, if necessary, all personnel required for a resuscitation event
The same monitoring that is required for the transfer (see Chap. 11) needs to be easily visible during imaging

Practical Issues for the ICU Team in the Radiology Suite

Understanding the challenges that meet the transferring team when looking after critically ill patients in remote and unfamiliar locations is key to achieving the best possible patient safety under these circumstances.

Unfamiliar Environment

The main safety issues with imaging patients from intensive care units are that they are often unstable before transfer and the journey to the radiology department can worsen this instability. In extreme circumstances, this may require patients to be re-stabilized on arrival in the radiology department before transfer into the imaging room and onto the radiology table. Intensive care staff are having to work under stressful conditions in an environment they are not used to. The radiology department should be able to carry a minimal stock of drugs and equipment commonly used in intensive care therapy to avoid members of the team having to shuttle back and forth to the ICU should the transfer bags become depleted. The difficulties the intensive care team is facing in such situations can be compounded by limited access to the patient, especially during the imaging procedure (see Chap. 10).

Maneuverability

Ideally the radiology suite is next door to the intensive care unit or at least on the same floor connected with a wide corridor and doors to allow for the passage of beds and equipment. When designing the floor plan of a radiology department, attention must be paid to allowing adequate space for the arrival of patients from the intensive care unit (Fig. 9.1). Beds are large and often equipment is stacked around them, increasing the area required to move around and gain access to the patient. Ideally access should be via a separate entrance to ambulant patients to avoid congestion and to protect the dignity of the critical care patient passing through waiting areas. Procedure rooms and holding bays must be large enough to maneuver the bed and all equipment easily as well as accommodating the personnel required.

Fig. 9.1 A well configured imaging room allowing plenty of space for patient bed, equipment and staff to the side of the imaging table

Resuscitation

On occasions it might become necessary to resuscitate a critically ill patient on arrival or even during the imaging procedure. In the latter case the patient should be removed from the imaging room as soon as is safely possible. Ideally the holding bay used for resuscitation is close to the entrance of the radiology department and close to the most commonly used imaging rooms. It is mandatory that a resuscitation trolley, which has to be checked on a daily basis, is in easy access and rooms should allow space for this should it be required. Radiology staff should be familiar with the principles of resuscitation.

Medical Gases

The waiting areas and the radiology suites should be equipped with piped medical gas supplies of oxygen and air. The oxygen comes from either a Vacuum Insulated Evaporator, in which oxygen is produced from the fractional distillation of liquid air, or an oxygen manifold. It travels along copper pipes to wall mounted or ceiling mounted sockets and exits via a non-interchangeable screw thread (NIST) or a diameter index safety system (DISS) ensuring correct connection of the hose assembly. Ceiling mounted pipes situated next to the CT/MRI scanner allow connection of portable ventilators easily without long connections and circuits that can easily get disconnected or increase the dead space for the patient. This removes the risk of oxygen in the cylinders being fully consumed. However, it should be remembered that oxygen failure can occur and oxygen cylinders should be available in emergency situations.

Patient Access

Access to the patient is very limited while they are in the scanner. With patients often intubated, ventilated and paralyzed, there is a loss of verbal and non-verbal cues. Monitoring of these patients has to be adequate and accurate. It is imperative that patients are placed on the scanner table carefully and all lines and circuits are able to stretch when the table moves through the scanner. All monitoring and vital connections must be visible from the control room (Fig. 9.2). If that is not directly possible closed circuits cameras (CCTV) that transmit views of the patient and the monitoring equipment to the control room have to be used.

Fig. 9.2 All monitoring, vital equipment and connections have to be visible from the control room

Monitoring

It is essential that the standard of care and monitoring is as high as that applied in the controlled operating theatre or intensive care environment (see Chap. 11). All monitoring should comply with practice guidelines published by societies such as the American Society of Anesthesiologists (ASA) or the Association of Anaesthetists of Great Britain and Ireland (AAGBI). The fourth National Audit Project (NAP4) "Major complications of airway management" was published in March 2011 and raised particular concerns about complications of airway management in the intensive care unit and the emergency department, leading to serious consequences in up to 60 % of cases. Common factors in both the intensive care unit and emergency department included unrecognized esophageal intubation or unrecognized displacement of tracheal or tracheostomy tubes after patient movement, intervention, or during transport. Particular attention has to be to be paid to airway management and continuous capnography is mandatory at all times in all intubated and ventilated patients.

Patient Specific Factors

Radiology tables are hard and unconscious or sedated patients are unable to move position. Particular attention should be paid to padding of pressure areas, especially during long imaging or interventional procedures. Blankets or warming devices should be used to prevent hypothermia and hearing protection should be used for patients having MRI scans.

Manual handling devices such as sliding aids need to be available to protect staff.

Teaching Points

1. Designing and maintaining a radiology suite that is frequently used by ICU patients requires dedicated input from radiology and intensive care staff.
2. Ideally the radiology suite provides similar access to the patient and monitoring as the Intensive Care Unit.
3. Patient specific factors such as duration of the procedure, temperature of the room or manual handling need to be taken into consideration when planning an examination.
4. Resuscitation equipment and drugs stored in the radiology suite must be checked daily.

Chapter 10
Patient Preparation

Najwan Abu Al-Saad and Hervé Schlotterbeck

Introduction

Transport of the critically ill patient is an inevitable and frequent part of critical care practice. The reasons for this are manifold; however, a visit to the radiology department for specialist investigation and/or intervention is probably the most frequent.

The increased risk to patient safety combined with the frequency with which transfers occur has led to the development of local and national guidelines regarding the necessary procedures and precautions that need to be considered before and during patient transfer to minimise the risk of patient harm. The American College of Critical Care Medicine recommends that "a patient should not be transported before airway stabilization if it is judged likely that airway intervention will be needed" during the transfer. The potential risks and complications of inducing anaesthesia, performing tracheal intubation and instituting invasive ventilation in a critically ill patient in an emergency situation are plenty even when tackled in the relative comfort of an ICU. However, to do so in less familiar and more isolated surroundings merely adds layers of technical difficulty and stress and unduly amplifies the risk of possible complications.

The decision to secure a patient's airway before embarking on transfer to the radiology suite should be made based on three considerations:

- Procedural factors
- Patient factors
- Organisational and human factors.

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In the context of the critically ill patient, it should be emphasised that the only satisfactory method of airway stabilisation is endotracheal intubation. Other methods, such as the use of supraglottic airway devices or simple airway adjuncts are usually only appropriate as rescue techniques to maintain oxygenation in an emergency situation such as failed endotracheal intubation.

Procedural Factors

The majority of investigations and procedures performed in the radiology department will require the patient to be both supine and still for a variable length of time. This requires a patient with an adequate

- level of consciousness and cognitive function to preserve airway patency and protective airway reflexes as well as to comply with lying still and supine on the scanning table and
- cardio-respiratory reserve to physically lie flat without undue breathlessness and distress.

If outpatients regularly find it difficult to lie flat and still for a protracted period of time on a scanning table, critically ill patients are even less likely to tolerate such a procedure easily. The changes in respiratory mechanics in supine position are well known, and are likely to be affected further by sedation. The supine position leads to:

- reduction in Functional Residual Capacity (FRC) and oxygen reserves
- increased basal atelectasis as closing capacity encroaches above FRC
- reduction in chest wall compliance, reducing total lung compliance with subsequently reduced tidal volume.

In the critically ill these factors can conspire to increase the work of breathing, manifested by an increased respiratory rate / tidal volume ratio, hypoxemia and hypercarbia, dyspnoea, respiratory distress adversely affecting the already delicate balance between reduced oxygen delivery and increased oxygen consumption. Other factors such as agitation and tachycardia contribute further to increased oxygen consumption.

One way to predict if an unintubated patient has adequate reserve to tolerate lying supine, particularly for shorter investigations, is to test this prior to leaving the department. This can be done while organising the transfer. Although this is not a guaranteed reflection of exactly how the patient will react during the procedure, it helps guiding the decision if the patient experiences difficulty on the ICU.

Ease of getting to the patient is an additional factor to consider. Although access to a patient during a CT scan is limited and far from ideal, in the event of an emergency it is possible to interrupt the scan, enter the scanning room and gain direct access to the patient relatively quickly. It is quite different in the MRI suite (see Chap. 13) or during interventions where the logistics in safely gaining access to the patient can be significantly more cumbersome and time consuming. The type of procedure may therefore influence the decision to electively sedate and intubate a patient prior to transfer.

Issues such as pain or discomfort, bleeding or other procedural risks and maintenance of body temperature need to be considered. Advance communication with the radiology team about anticipated problems, duration and access requirements is key aid to planning and decision-making. Avoidance of all sedation, while clearly preferable if feasible, needs to be balanced against the patient's comfort as well as the quality of the imaging study.

Patient Factors

Several patient-related factors contribute to the decision whether to establish a secure airway prior to leaving for the radiology suite:

- anticipated airway problems
- risk of aspiration
- anticipated tolerance of sedation
- need for respiratory support like continuous positive airway pressure (CPAP) or non-invasive ventilation (NIV).

Airway

Thorough airway assessment prior to the transfer is mandatory, regardless whether the patient is intubated or not. Knowledge of previous difficult intubations or of issues with mouth opening, neck extension, TMJ function or dentition is valuable. Any airway intervention perceived as difficult in the relative comfort of the operating room or the intensive care unit is likely to become very challenging in case of an emergency in the unfamiliar and less well equipped radiology suite. If difficulties with airway management are anticipated the threshold for intubating prior to transfer should be significantly lower.

Aspiration

For a variety of reasons critically ill patients are at a higher risk for aspiration of gastric contents into the lung. A number of factors can potentially increase the already elevated risk of aspiration:

- altered neurological status and sedation can impair protective reflexes and subsequently allow anything from clinically inapparent microaspiration to massive ingestion of gastric contents into the lung

- need for potentially significant volumes of oral or enteral contrast prior to the imaging procedure
- obesity carries a higher risk of aspiration in addition to the more pronounced effects of being in a supine position.

Sedation

Anxiety, delirium or cognitive dysfunction is common in critically ill patients. Non-pharmacological methods such as simple reassurance can be helpful in the ICU. During transfer and particularly during the imaging procedure they are unfortunately of very limited use. For this reason the requirement for sedation and analgesia is increased. The effect of sedation agents is often difficult to predict in ICU patients, making the balance between a satisfactory level of sedation and patient safety very challenging.

If tracheal intubation is deemed highly undesirably a "look and see" approach to the transfer and the imaging procedure can be considered under certain circumstances:

- the patient has minimal risk factors
- light sedation provided by a experienced clinician
- the complications of unintended over-sedation are deemed unlikely and
- should they occur, there is no known or anticipated difficulty in oxygenation, airway maintenance, laryngoscopy and endotracheal intubation. This includes knowing that patient access is easy to achieve and necessary drugs, equipment and personnel are readily available.

This approach should only be adopted in special circumstances and after careful weighing of risks and benefits.

Human and Organisational Factors

Non-technical factors are a less predictable part of the decision-making process, but awareness of their potential impact is likely to contribute to increasing the overall safety of a procedure.

The perceived level of difficulty of airway management is susceptible to both inter-and intra-individual variations. The clinician in charge of the patient during the transfer and the radiological procedure has to determine what they consider safe. This is particularly important out of normal working hours when back up from colleagues, senior or otherwise, may be less readily available. Senior clinicians should restrict themselves to advising junior colleagues rather than making decisions on their behalf or 'persuading' them into doing something against their better clinical judgement.

Organisational factors – such as the actual distance of the critical care area from the radiology department, time of day, the presence and availability of back up from colleagues in the event of an emergency – influence the clinical decision. Such factors can become more important when it is unclear whether to intubate the patient or not.

Teaching Points

1. Establishing a secure airway has highest priority when planning to transfer a critically ill patient.
2. The decision how to manage the airway has to be guided by procedural, patient and institutional factors.
3. The clinician in charge of the transfer has to be allowed to determine what they consider to be safe and act accordingly.

Chapter 11
Transfer of the Critical Care Patient

Darcy Pearson and Rolf Dembinski

Introduction

The decision to transfer a patient from the intensive care unit should never be taken lightly. All bedside imaging options should be explored first before embarking on the trip to the radiology department. Despite the potential problems, if approached diligently transfers can be conducted safely.

Physiological Effects and Potential Risks to Patients During Transfer

During transfer postural changes and inertial forces can have a detrimental effect on physiology, primarily affecting the respiratory and cardiovascular systems.

Respiratory Effects

Adopting a supine position can reduce ventilatory compliance and increase both the work of breathing and the respiratory oxygen consumption thus potentially worsening hypoxemia. In addition, by exacerbating atelectasis, the upward displacement of

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the diaphragm can generate ventilation-perfusion mismatch and increase the shunt fraction. Any change of position in invasively ventilated patients can precipitate coughing and ventilator asynchrony. Access to the patient in order to perform endobronchial suctioning can be difficult, therefore atelectasis and airway obstruction due to retained secretions are more likely. As a consequence oxygen requirements and the need for positive end-expiratory pressure tend to increase, as do the need for sedation and neuromuscular blockade. If it is necessary to change the mode of invasive ventilation to enable transfer, it is recommended that a trial of appropriate duration is undertaken before departure to determine whether gas exchange is significantly compromised.

Cardiovascular Effects

Changing the position of the patient and the inertial effects of the extracellular fluid during acceleration and deceleration often leads to hemodynamic instability. These effects are exacerbated in hypovolemia. Therefore before departure intravenous access should be secured and fluid responsiveness should be assessed to minimise variations in blood pressure.

Equipment and Management Issues

The development of new medical problems during transfer can rarely be predicted and management may be suboptimal due to limited resources and possible lack of senior medical support. Displacement of indwelling medical apparatus is a particular issue during the movement of patients between beds or trolleys and the radiology department may not be set up for urgent clinical procedures such as re-insertion of central venous or arterial catheters.

In an audit of 100 critical care patients undergoing inter-hospital transfer the incidence of adverse events was 34 % and the majority of these were attributed to avoidable technical issues such as shortage of oxygen. An analysis of data submitted to the Australian Incident Monitoring Study in Intensive Care demonstrated that 61 % of 191 incidents involving intra-hospital transfer were related to suboptimal clinical management. This included events such as accidental extubation, accidental disconnection or dislodgment of intravascular catheters, inadequate monitoring and incorrect stabilisation of injuries. 39 % of incidents related to equipment failure including battery failure, ventilator malfunction and a lack of emergency drugs. Significant physiological deteriorations including hypoxia, hypoventilation, hypotension and cardiac arrest occurred in 15 % of the patients suffering adverse incidents. In 4 % the hospital stay was prolonged and in 2 % the incident was felt to have contributed to the death of the patient.

Equipment

Transfer equipment that has been checked and deemed functional should be available at any time of day or night in critical care to prevent delays if an urgent need for transfer arises. To ensure the quality of this process many institutions perform daily inspections using checklists as they would do for resuscitation equipment. The transfer team must perform a final check of any apparatus being used before departure and if a fault cannot be remedied quickly the equipment should be replaced. In the ideal situation the level of monitoring and treatment during transfer should be the same as that deemed clinically necessary in critical care. Most portable monitors are able to display a variety of parameters such as end-tidal CO_2, pulse oximetry, non-invasive and invasive blood pressure, central venous pressure, cardiac output and intra-cranial pressure. This means that compromises in patient monitoring during transit can be minimised.

The level of support required by the patient will influence both the equipment needed and the expertise of the accompanying personnel. For patients not requiring ventilatory or haemodynamic support the minimal level of monitoring includes pulse oximetry, regular non-invasive blood pressure measurement and ECG. Patients whose stability depends on multi-organ support will need additional equipment determined on a case-by-case basis. In Europe it is recommended that all hospitals responsible for the transfer of critical care patients have access to equipment that conforms to the European Committee for Standardisation specifications and can be secured to a transfer trolley in order to prevent it becoming a projectile.

It is recommended that a systems-based ABCDE approach is used to structure the collection of transfer equipment. Table 11.1 gives an overview of equipment commonly included in the transfer kit.

It is important that the transfer team have the facilities to be self-sufficient throughout the transfer however the availability of equipment such as a resuscitation trolley, defibrillator and emergency drugs in the radiology department improves safety and can provide a valuable backup (see also Chap. 9). Once the patient has arrived in radiology, transferring to the mains electricity and oxygen supply conserves portable supplies and enables recharging. While it is preferable to minimise the time spent away from the intensive care, a suitably equipped waiting area with an oxygen supply and wall mounted suction should be available to prolong the endurance of portable equipment if a delay in the radiology department is unavoidable.

Personnel

All members of the transfer team should have undergone formal training and should not be expected to practice at a level exceeding their experience and competence. At least two members of staff are required for transfer and must have attained basic

Table 11.1 Commonly used transfer equipment

Airway	End-tidal carbon dioxide monitor
	Laryngoscopes, blades and spare batteries
	Endotracheal tubes of appropriate sizes
	Water soluble lubricant
	Securing tape or ties for the endotracheal tube
	Guedel, nasopharyngeal airways
	Facemasks
	Bougie
	Stethoscope
	Portable suction with suction catheters and Yankauer sucker
	Nasogastric tubes
	Emergency airway (laryngeal mask, cricothyroidotomy needle)
Breathing	Oxygen cylinder with both a Schrader valve and a pin indexed flow meter
	Reservoir mask
	Oxygen tubing
	Portable ventilator
	Breathing circuit and HME filter
	A self-inflating bag and Water's circuit
	Pulse oximetry
	Large bore cannula with three-way tap for intercostal decompression
Circulation	Cardiac monitor with adhesive electrodes
	Intravenous fluids, giving set
	Venous cannulae, dressings, saline flush
	Syringes, hypodermic needles
	Non-invasive blood pressure monitor
	Invasive blood pressure monitor, pressure bag, transducer, arterial cannulae
	Sterile gauze
	Adhesive tape
	Vasopressors/inotropes
	Emergency/cardiac arrest medications
Neurology	Sedation
	Hypertonic saline/mannitol
	Intra-cranial pressure monitor
	Anti-convulsive medication
	Pen-torch
Miscellaneous	Thermometer/temperature probe
	Blood glucose monitor
	Regular medications such as insulin, antibiotics, diuretics

This list is by no means exhaustive and should be tailored to individual patient's needs

competencies including a practicing knowledge of advanced life support, competence to use and interpret monitoring, an awareness of their limitations and good insight as to when to seek senior support. Additional competencies should include adequate knowledge of the pathophysiology and pharmacology of critical illness and transfer, the ability to plan a safe transfer and the ability to initiate treatment if complications arise.

The level of patient care dictates the skill-mix and experience of the team members. Experienced nursing staff can often accompany stable, self-ventilating patients. Unstable, ventilated or patients at risk of complications have to be escorted by medical staff with anesthetic or critical care experience. Patients who are managed in tertiary centres and are dependent on complex interventions such as extracorporeal membrane oxygenation must be attended by clinicians with the experience to manage complications related to this level of support. Transfer of these challenging patients often requires two physicians or one physician supported by a technical assistant such a perfusionist. Both must be familiar with the device with which the patient is supported.

Optimisation

To identify and avoid adverse events the patient should be assessed thoroughly prior to departure and optimised medically (see Chap. 10). This may involve securing the airway, inserting a nasogastric tube or urinary catheter, ensuring adequate venous access and treating any clinical problems such as dysrhythmias. In all but the most urgent of clinical scenarios, medical conditions should be treated adequately before setting off. If clinical urgency dictates that the patient should be transferred before outstanding medical issues are resolved, those accompanying the patient should be competent to commence treatment during the transfer.

Avoiding and Managing Complications During Transfer

Ensuring the safe transfer of critically unwell patients can be complex and stressful for all members of the team, particularly the team leader who must be continually vigilant. Even in the most urgent of clinical scenarios where there is pressure to expedite the transfer, it is important that the team continues to care for the patient in a methodical and safe manner. Cautiously pre-empting and preventing complications will save more time and be safer than attempting to rectify adverse events after they have occurred. All members of the transfer team, irrespective of seniority must be the patient's advocate and have the courage to halt proceedings and communicate any issues they have noticed.

Communication between nurses, radiology staff and the clinicians responsible for the patient is the most valuable tool in preventing complications. Communication with the receiving department allows them to prepare for the needs of the transfer team and schedule other cases. The routine workload of the imaging department may have been interrupted by the need to scan an intensive care patient so they should be kept informed of any delays in arrival to prevent wastage of valuable scanning time. Conversely delays to imaging of a critically ill, potentially unstable, patient by prolonged waiting outside the radiology suite should be avoided.

Displacement

Preventing the displacement of endotracheal tubes, monitoring apparatus, indwelling catheters, infusion lines and therapeutic devices requires constant vigilance. If patients are managed well, dislodgment of devices is an avoidable complication. Usually patients who are clinically less stable require more intervention and equipment than fitter patients and the consequences of accidental displacement tend to be more serious. Before departure, the endotracheal tube, lines and drains should be secured appropriately. Re-insertion can be challenging even in a controlled environment such as the ICU and may be impossible during transfer or in the radiology department. If vital equipment does become accidentally displaced action should be taken to minimise harm to the patient and it may be necessary to abandon the scan or procedure.

Equipment Failure

Equipment malfunction is both common and unpredictable and failure to manage the situation well can have disastrous clinical consequences. A self-inflating bag, oxygen supply and replacement infusion pumps should be taken on all transfers of critical care patients requiring ventilatory and inotropic support. Most radiological investigations necessitate intra- rather than inter-hospital transfer, therefore a replacement device can usually be provided without excessive delay.

Communication and Documentation

Communication within the transfer team is vital in ensuring that all members understand their role and also how the team leader aims to conduct the transfer. Before departure the team should have a final opportunity to clarify any details with the team leader and voice any concerns so that they can be addressed. The staff in the destination department should be made aware of the complexity of the case and the estimated time of arrival to ensure that they are prepared and delays are minimised. At all times it should be possible to contact the senior clinician with overall responsibility for the patient for advice or to attend if complications have developed.

Thorough documentation of events should continue throughout the transfer. Important information includes the names of team members, the timing of clinical events, clinical observations and all therapeutic interventions, particularly respiratory and haemodynamic support.

Teaching Points

1. All bedside imaging options should be exhausted before considering transfer of a critically ill patient out of the ICU to the Imaging Department.
2. The patient should be medically optimized as much as possible before transfer.
3. Transfer equipment and staff need to be appropriate for the patient's condition and must be prepared to deal with unexpected complications.
4. Excellent communication between the ICU and the Radiology team is essential.

Chapter 12
Contrast Media

Lina Glőckner and Rolf Dembinski

Introduction

The use of contrast media can often improve diagnostic yield and accuracy of imaging procedures. Contrast agents are generally regarded as safe, however the incidence of adverse effects increases with the level of patient's physiological impairment. Therefore, the risks and benefits of using contrast have to be weighed carefully in patients requiring intensive care treatment.

Radiographic Contrast Agents

These agents are used to enhance x-ray based imaging techniques such as computed tomography (CT) or plain film, aiming to produce additional information about anatomy and morphology of internal body structures. Radiographic contrast agents can absorb x-rays either to a greater or to a lesser extent than the surrounding tissues. Accordingly, they are divided into x-ray positive and negative agents. Enhanced CT, cerebral or coronary angiography are typical investigations using contrast media in intensive care patients. Figure 12.1 provides an overview over commonly used contrast agents.

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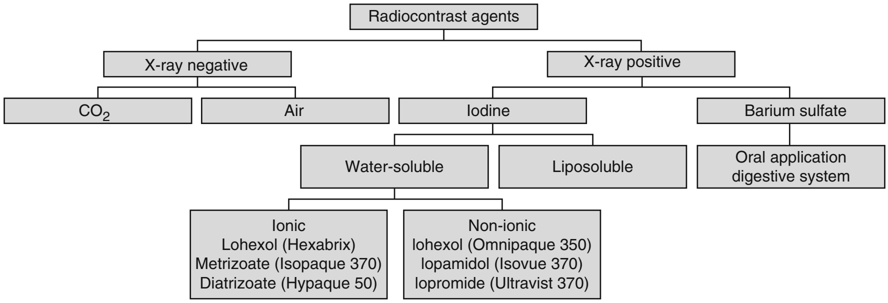

Fig. 12.1 Commonly used radiographic contrast agents

X-Ray Positive: Barium and Iodine-Containing Agents

The use of barium sulfate is restricted to opacification of the gastro-intestinal tract for fluoroscopic examinations. Particularly when used in combination with a negative contrast agent (double contrast) it can give exquisite mucosal detail.

A suspension of barium sulfate particles with water, thickener and declumping agents is swallowed, given via a naso-gastric tube or administered as an enema. Due to the fact that barium is insoluble in water it cannot be absorbed or metabolized and must be eliminated with feces. Barium sulfate is contraindicated in cases of suspected perforation. Leakage out of the gastrointestinal lumen can cause severe inflammatory reactions and necrosis of surrounding tissues.

In clinical practice barium sulfate has been almost completely replaced by water- or fat-soluble iodine based agents.

Iodinated contrast media are usually classified as

- Ionic – due to higher osmolality these have more side effects and can lead to a higher frequency of contrast induced nephropathy and local phlebitis;
- Nonionic – have lower osmolality and tend to be less toxic as they don't dissociate into charged molecules.

Both types of iodinated contrast agents are primarily used intravenously but can equally be administered via intraarterial, intrathecal, intravesical, oral or rectal access. They are mainly intended to visualize vascular trees but can also be used to enhance imaging of the urinary and intestinal tract or the uterus and fallopian tubes.

In the advent of high resolution CT and MRI the use of gasses such as air, CO_2 or Xenon as negative contrast agents has mostly been superseded.

Adverse Effects

The iodinated contrast agents in use today are mostly well tolerated. However, anaphylactoid reactions and contrast-induced nephropathy remain of concern,

Table 12.1 Conditions associated with an increased incidence of acute adverse contrast reactions

Previous reaction to contrast
Asthma
Known food or drug allergies, hayfever
Advanced age

Table 12.2 Categories acute adverse contrast reactions

Mild	Nausea	Altered taste	Sweats
	Vomiting	Itching	Rash
	Cough	Pallor	Hives
	Warmth	Flushing	Nasal stuffiness
	Headache	Chills	Facial swelling
	Dizziness	Shaking	Anxiety
Moderate	Tachycardia	Dyspnea	
	Bradycardia	Bronchospasm	
	Hypertension	Laryngeal edema	
	Diffuse erythema	Mild hypotension	
Severe	Unresponsiveness	Convulsions	
	Cardiorespiratory collapse	Profound hypotension	
	Arrhythmias	Rapidly progressing laryngeal edema	

particularly in critically ill patients. The incidence of adverse events occurring after intravenous administration of contrast has dramatically decreased since switching from ionic high-osmolality (HOCM) to nonionic low-osmolality contrast media (LOCM).

Generally, adverse effects are mild and only require observation and reassurance. Supportive measures may become necessary occasionally. Severe, life-threatening reactions still occur randomly. It is important to note that the majority of severe adverse effects happen in the first 20 min after contrast administration.

HOCM generate acute adverse events in 5–15 % of all patients. The use of LOCM is associated with an incidence of 0.2–0.7 % of adverse events. Serious acute reactions are very rare and occur after 0.01–0.02 % of intravascular injections.

Table 12.1 gives an overview of conditions associated with an increased rate of acute adverse reactions to contrast. Premedicating patients with these conditions with steroids and/or a H_1 receptor blocker might help decreasing the incidence even further although data is limited.

Table 12.2 provides a summary of the categories of reactions to contrast media.

Anaphylactic Reactions

Anaphylactic reactions are potentially life threatening severe reactions, which occur within minutes after the administration of contrast. These anaphylactic reactions are caused by an IgE- mediated Type I immune response (immediate hypersensitivity) through an antigen-antibody reaction. As little as 1 ml of contrast can lead to an anaphylactic reaction resulting in acute bronchospasm, hypotension and severe urticaria. The principles of treating anaphylactic reactions are the stabilization of the patient's airway and cardiac function following the advanced life support algorithm.

Delayed reactions can occur 30 min or later after the administration of contrast agents. They manifest in flu-like symptoms and may include fever, chills, nausea, vomiting, abdominal pain, fatigue and congestion. They usually only require supportive management and resolve spontaneously.

Anaphylactoid Reactions

Anaphylactoid reactions are similar in presentation to anaphylactic reactions, but are not caused by an IgE-mediated immune response. Symptoms range from urticaria and itching to bronchospasm and facial or laryngeal edema

Extravasation

Tissue damage caused by extravasation of contrast media is due to an inflammatory reaction caused by the direct toxic effect of the agent. Because of the high osmolality extravasation of ionic contrast agents is more likely to cause severe tissue damage than nonionic media. Despite the majority of ICU patients having central venous access, the high viscosity of contrast agents might make the placement of a peripheral venous line necessary to achieve an adequate flow rate. Sedated, intubated and ventilated patients are at a higher risk of extravasation remaining undetected, as they will not be able to complain of pain. A high index of suspicion is required when faced with a swollen limb after contrast injection.

There is no clear evidence how to best treat extravasation of contrast. The general principles are:

- stop infusion immediately
- aspiration of agent if possible
- remove needle or peripheral access
- elevated position
- effective pain-therapy
- complete documentation
- prophylaxis of infection
- close observation and follow- up care.

Depending on the site and the size of the leak clinicians need to keep in mind that a compartment syndrome can develop if enough contrast has been injected into the tissue. A surgical consultation is indicated if

Table 12.3 Risk factors for developing CIN

Impaired renal function
Serum creatinine >1.2 mg/dl
Decreased creatinine clearance
Dehydration
Aggressive use of diuretics
Diabetes mellitus together with impaired renal function (serum creatinine >2 mg/dl)
Heart failure
NYHA III or greater
EF < 40 %
Hypertension
Proteinuria, paraproteinuria, plasmocytoma
Nephrotoxic medication such as
Vancomycin, aminoglycocides
Non-steroidal anti-inflammatory drugs
ACE inhibitors
Old age
Intra-arterial contrast administration
Contrast load >2 ml/kg bodyweight
Repeat contrast exposure

- the swelling progresses after the infusion has been stopped,
- there is evidence of altered peripheral perfusion,
- the sensation in the affected limb changes
- the skin in the affected limb ulcerates or blisters.

Contrast Induced Nephropathy (CIN)

CIN is a common cause of health care acquired renal failure, which may require renal replacement therapy and can cause prolonged intensive care and hospital length of stay. Despite the absence of agreed criteria, it is generally accepted that a serum creatinine rise of ≥25 % from baseline within 3 days of intravenous administration of contrast can be considered as CIN in the absence of an alternative etiology. Contrast enhanced CT and angiography have seen a huge increase in the last decades. The magnitude of the potential problem becomes apparent if one considers that an estimated 80 million CT scans and one million angiographies are performed annually in the US alone. This equates to around 35 million doses of contrast medium.

The etiology of CIN is not completely understood. Altered renal blood flow, activation of the tubuloglomerular feedback response, regional hypoxia, cytotoxic effects on renal epithelial cells, generation of reactive oxygen species and increased adenosine and endothelin production have been discussed as potential mechanisms.

A number of risk factors for developing CIN have been identified (Table 12.3). The majority of these are frequently encountered in patients requiring intensive care treatment. Whereas CIN is uncommon in non-critically ill patients the incidence increases with the numbers of risk factors, particularly in the presence of renal impairment.

Alternative imaging methods not requiring contrast media should be considered in patients at risk of developing CIN, especially in those with renal impairment. If no alternative is available the need for contrast administration has to be reviewed carefully as the potential risk can outweigh any benefits in this patient group. The Cigarroa quotient – (Contrast medium (ml) × serum creatinine (mg/dl))/body weight (kg) – provides a tool to estimate a patients risk. A quotient >5 is associated with an increased risk.

Prevention

A number of different prophylactic strategies to prevent CIN from occurring have been trialed. They are aimed at preserving renal perfusion, reducing cytotoxicity, medullary hypoxemia and enhancing contrast elimination:

- Hydration – plays the biggest part in preventing CIN. Renal perfusion is decreased for up to 20 h post contrast administration. Expansion of intravascular volume helps maintain renal blood flow and decreases cytotoxicity by bringing the high osmolality of contrast agents closer to the physiological range. Normal saline has been shown to be superior to other fluids. In addition to the above effects delivery of sodium to the distal nephron prevents activation of the renin-angiotensin system, thereby maintaining increased renal blood flow. The CIN Consensus Working Panel found that commencing volume expansion of 1–1.5 ml/kg/h 6 h prior to the intervention and continuing for 6–24 h post procedure decreases the incidence of CIN in patients at risk. Although a target urine output of around 150 ml/h has been suggested in the past this was not found to be useful in guiding fluid therapy. Patients with heart failure pose a particular challenge and require careful hemodynamic monitoring while being placed on hydration therapy. A number of these patients might not tolerate the high volume load. In these cases the need for an investigation and the risk of renal failure requiring renal replacement therapy (RRT) have to be weighted carefully.
- N-acetylcysteine (NAC) – is an anti-oxidant and free radical scavenger. However, several trials designed to confirm the benefit of NAC in patients with chronic renal insufficiency undergoing angiography produced conflicting results. A meta- analysis of eight prospective studies comprising 1,023 patients concluded that NAC provides no additional benefit to a uniform 24-h hydration protocol. Although the Working Panel is currently not able to give a definite recommendation, the use of NAC to prevent CIN is common in clinical practice due to its low cost and its lack of adverse effects. NAC is generally administered orally, 600 mg twice daily 24 h before and on the day of the procedure.
- Duiretics – were studied based on the hypothesis that inducing and maintaining forced diuresis as well as inhibiting energy consuming active transport in the ascending medullary limb post-contrast diuresis would prevent CIN. However, the use of furosemide and mannitol has been shown to worsen CIN through dehydration. Their use is presently being discouraged.

Table 12.4 Commonly used measures to reduce incidence of developing CIN

Do	Make sure that the patient is well hydrated
	NaCl 0.9 % 1–1.5 ml/kg/h starting 6 h before contrast
	If tolerated NaCl 0.9 % up to 24 h post contrast administration
	Use low- or iso-osmolar contrast media
	Stop administration of nephrotoxic drugs for at least 24 h
	Consider alternative imaging techniques, which do not require iodinated CM
Don't	Give high osmolar contrast media
	Administer large doses of contrast media
	Administer mannitol and diuretics, particularly loop diuretics
	Perform multiple studies with CM within a short time

- Statins - are widely used for their cholesterol-lowering effect and cholesterol-independent actions such as improving endothelial function as well as decreasing inflammation and oxidative stress. There is currently no recommendation to routinely start statins prior to procedures involving contrast as most of the data stems from cardiac patients already on them undergoing percutaneous cardiac interventions.
- Renal Replacement Therapy (RRT) – Contrast agents are not protein bound small molecules and therefore easy to clear from the bloodstream by RRT. However, the hypothesis that routine hemodialysis might prevent CIN by removing contrast media from the circulation was not confirmed in clinical trials. Patients in severe heart failure might benefit from early RRT if the increased osmotic load leads to pulmonary edema and anasarca.

Table 12.4 gives an overview over the most commonly used measures aimed at avoiding CIN.

MRI Contrast Agents

MRI contrast agents either reduce the T1 relaxation time by increasing the signal intensity on T1 weighted images, thus appearing bright or they produce spin relaxation effects, resulting in shorter T1 and T2 relaxation times and a dark appearance.

MRI contrast agents are generally tolerated very well. The overall incidence of all acute adverse reactions ranges from 0.07 to 2.4 %. Most of these reactions are mild in nature, including nausea, headache, paresthesias, dizziness or itching. Life-threatening anaphylactoid or anaphylactic reactions are extremely rare (0.001–0.01 %).

However, there is growing evidence that gadolinium-based agents are associated with an increased risk of developing nephrogenic systemic fibrosis (NSF) in patients with severely impaired renal function, hepato-renal syndrome or in the peri-operative phase after liver transplantation. NSF is characterized by extreme thickening and hardening of the skin and development of fibrotic nodules and plaques. It can also involve lungs, esophagus, heart and skeletal muscles. Signs and symptoms develop rapidly.

Gadolinium based contrast is now contraindicated in patients whose glomerular filtration rate is less than 30 ml/min/m^2.

Teaching Points

1. The sicker the patient, the higher is the incidence of adverse effects related to contrast application.
2. Contrast associated complications have decreased in the advent of low-osmolality contrast media.
3. Contrast induced nephropathy remains one of the most common health care induced forms of kidney injury. Adhering to a few basic principles can reduce the incidence of CIN.
4. Although MRI contrast media are generally tolerated very well, Gadolinium has recently been associated with Nephrogenic Systemic Fibrosis in patients with severely impaired renal function.

Chapter 13
MRI Practicalities

Claire Sandberg and Christiana C. Burt

Introduction

The use of magnetic resonance (MR) imaging is rapidly increasing in clinical practice. At the same time research continues into the risks of exposure to magnetic fields and guidelines are continually being updated. There are specific equipment, monitoring and safety considerations for a critically ill patient in the MR environment. These differ from other areas of the radiology suite. Practical steps should be taken to minimize the risks to both the patient and to staff.

MRI Specific Hazards

As seen in Chap. 4 there are three types of magnetic fields present: a strong static field, gradient (fast switching) fields and pulsed radiofrequency (RF) fields.

Static Magnetic Field

The field extending outside of the central bore is known as the "fringe field" and is dependent on the design of the magnet. If the superconducting magnet is actively

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shielded the extent of the fringe field will be reduced. Of particular interest is the 5 Gauss (1 Tesla = 10,000 Gauss) contour line. Prior to passing the 5 Gauss line all personnel should be screened and all equipment subject to assessment for MR suitability.

Physical movement within the static magnetic field can affect

- the semicircular canals causing vertigo,
- the retina causing visual disturbance and
- the production of saliva causing a metallic taste in the mouth.

These effects can be alleviated in part by moving more slowly. There is no current evidence that exposure to a static magnetic field up to a strength of 8T produces either serious or permanent ill health effects. Regulatory agencies caution strongly that this reassurance is based on very limited evidence.

Ferromagnetic Attraction

Within the 5 Gauss line, as the magnetic field increases, ferromagnetic objects will exhibit both attraction to the magnet and torque (a tendency to rotate to align with the magnetic field). Any ferromagnetic object will act as a missile (the "projectile effect") with larger objects, such as an oxygen tank, presenting the risk of crush injury. Small ferromagnetic fragments within the body may move and cause injury. This is particularly relevant where metal fragments are present in the eye or cerebrovascular clips are in place. Implanted prostheses are often made from titanium and thus non-ferromagnetic. If prosthetic material is ferromagnetic but is firmly anchored, such as at a hip or knee joint, it does not pose a hazard but will distort the MR image. If there is reason to suspect that any potentially hazardous ferromagnetic material is present but the patient is unable to confirm or deny it, as often is the case in the critically ill, a plain x-ray can help to confirm any suspicions.

Historically the presence of an implanted cardiac pacemaker, defibrillator or other programmable device was an absolute contraindication to MRI scanning, and this is largely still the case. However, as the technology of these devices has developed, certain models have become available that are MR *conditional* (discussed next), i.e., they can be scanned under strictly controlled conditions. The main risks lie in malfunction or movement of the implanted device, which can occur at very low field strengths.

All MR units should have access to regularly updated web-based information listing implantable medical devices and their compatibility or otherwise with MRI. A key MR suite safety measure is to ensure that no person passes the 5 Gauss line without first undergoing a check for MR incompatible implanted devices or other contraindications to MRI.

Gradient Magnetic Field

The fast switching gradient fields cause a rapidly varying magnetic field, which can interfere with the electrocardiogram (ECG). If the intensity of the gradient fields increases they may become sufficient to cause involuntary muscle contraction, vertigo and, in the extreme, ventricular fibrillation (VF). The induction of VF would be as a result of induced flow potentials within the heart causing an increase in the likelihood of re-entrant arrhythmia. Those patients already susceptible to re-entrant arrhythmia may be at increased risk when exposed to gradient and static magnetic fields.

Temperature and RF Electromagnetic Field Heating

The ambient temperature within the scan room is usually cooler than that on the Intensive Care Unit (ICU). The pulses emitted transmit energy into the patient's body and consequently have a heating effect. The RF power deposited into the patient is measured per kilogram of body tissue and is known as the Specific Absorption Rate (SAR). Using the patient's body weight the SAR is calculated before each scan and is limited by both national and international guidelines. High levels of SAR cause increases in body temperature. Monitoring equipment and metal implants may preferentially take up RF energy, which can cause excessive heating and may result in burns. There are also case reports that eyeliner tattoos may result in image artifacts, burns, swelling and puffiness. The team should ensure that monitoring cables are MR compatible and not in close contact with one another or the patient's skin and are not looped. Where multiple monitoring devices are in use, this is best addressed before arriving at the MRI suite. Core body temperature should be monitored during scanning, particularly in those with impaired thermoregulation.

Contrast Agents

Intravenous chelates of the paramagnetic substance gadolinium are often administered in MRI to highlight pathology and vascular structures. The contrast medium shortens the relaxation times of nearby protons and gives a high signal on T1 weighted images only. Gadolinium is excreted by the renal system and should be given with caution to those with renal impairment. Such patients should be discussed with the radiology department prior to imaging. Side effects are usually mild. For further information see Chap. 12.

Quench

The superconducting magnets used to maintain a field strength of 1.5T or more require cooling with cryogens. Modern MRI systems use liquid helium as the cryogen. If the helium boils off rapidly it is known as "quench" and will be accompanied by immediate loss of superconductivity and thus switching off of the magnetic field. The risk lies not directly with the helium but with the potential for the helium to displace oxygen within the scan room if it is not adequately vented. Quench may occur inadvertently, or be activated deliberately to power down the magnet or in response to an emergency such as fire. Intensivists who work in the MR suite should be familiar with the emergency procedure in the event of quench occurring.

Acoustic Noise

The vibration of electromagnetic coils generates the switching gradient fields. It is this vibration that generates the high level acoustic noise in the scanner. This is typically in excess of 100 dB and thus well above the safe level of 80 dB. Hearing loss in both staff and patients is a real risk. Acoustic protection should be provided for all. As higher strength magnets and stronger faster switching gradient fields are used the noise levels within the MR scanner are likely to increase.

The rapid changes of electromagnetic field gradients can occasionally cause stimulation of peripheral nerves. The effect of this very variable but can be painful.

Managing the Critical Care Patient in the MR Scanner

The intensivist accompanying a critically ill patient to the MRI suite must be mindful of the dangers posed to themselves and their team as well as their patient. There are a number of factors to consider and it is recommended that physicians undergo specific MRI training before accompanying patients to the scanner.

There are three key points to consider with regard to monitoring a critical care patient in an MRI system:

- special monitoring equipment is essential
- the MR environment itself can interfere with monitoring devices
- patient factors.

Table 13.1 Commonly encountered equipment issues

Pulse oximetry	MR safe pulse oximeters have fibreoptic probe connections Standard probes can cause burns from induced currents
ECG	MR safe ECG electrodes must be placed in a narrow triangle on the patient's chest in order to produce a high amplitude signal ECG leads should be as short as possible, braided, have high impedance and use fibreoptics for transmission
Ventilator	It is preferable to have bedside ventilators that can be made MR conditional, allowing the patient uninterrupted benefit from best available mode of ventilation
Endotracheal tube	Because the metal spring in it may distort the image the pilot balloon should be taped as far away as possible from the area investigated and not be in contact with the patient's skin

Equipment Considerations

There are three standard terms that are used to identify the safety of equipment in the MR environment. These terms are MR *safe*, MR *unsafe* and MR *conditional*:

- MR *safe* equipment poses no threat to patient or personnel in the MR scan room provided that its instructions for use are correctly followed. This label does, however, not guarantee that the equipment will not degrade the MR images or function effectively.
- MR *unsafe* equipment is hazardous in all MR environments.
- MR *conditional* equipment poses no known hazard in a specified MR environment when used under specified conditions. The specified MR environment is defined by parameters such as main magnetic and RF field strengths.

The intensivist should be familiar with MR conditional and MR safe monitoring equipment and satisfied that all the equipment accompanying the patient into the scan room is safe. Table 13.1 summarizes the most commonly encountered equipment issues.

MR Environmental Interference

MRI scanner rooms are RF shielded both to protect that which is outside the room from the RF energy produced by the scanner and to prevent electromagnetic signals from the external environment interfering with MR signal detection. The RF shield is a layer of thin copper or aluminum sheet. The doors and windows are an integral part of this lining and so the door must be closed during scanning. Monitoring cables and medical gas supplies which pass into the shielded room must be made of non-conducting materials and travel through dedicated waveguides so the shield is

Table 13.2 Common problems seen when scanning ICU patients in the MRI suite

Access	Difficult access once patient is positioned in the magnet's core (see Chap. 11)
	Scanning should not be interrupted once started
	All lines need to be in appropriate position and well secured
Monitoring lines	Capnography trace can be up to 20 s delayed
	Long lines more likely to have damped trace
Noise	Visual alarms must be employed as noise levels and the requirement for hearing protection render audible monitor alarms ineffective within the scan room
	In the control room it is advisable to have both audible and visual alarms activated
ECG	Current induced by the magnetic field in the ECG leads can cause spikes
	The magnetic field generates current flow in the aorta, which can produce ST segment changes
	RF interference may cause persistent alarm activation
Infusions	All unnecessary infusions should be disconnected
	MR unsafe pumps are likely to malfunction or deliver incorrect doses
	Length of lines can cause delay in drug bolus delivery
	Length of lines poses increased risk of disconnection or pressure sensor malfunction on infusion pumps
Intravascular monitoring and other indwelling lines	Pulmonary artery catheters with a thermistor have to be removed
	MR unsafe pressure transducers and lines have to be passed through waveguide
	Temporary endocardial and epicardial pacing wires present a theoretical risk of micro-shock and RF heating of cardiac structures and should be removed prior to scanning

not breached. This includes gas and drug delivery pipes. Cables that carry power or signals must be fibreoptic or pass through low-pass electrical filters. A number of professional bodies, such as The Association of Anaesthetists of Great Britain and Ireland (AAGBI), recommends that all monitoring devices are placed in the control room outside the MR scan room. Table 13.2 provides a list of common problems that need to be considered by the intensive care team in the MRI scanner.

Patient Factors

Apart from safety and logistic concerns associated with transferring a critically ill patient from the safety of the ICU to the less familiar environment of the radiology suite, there are several patient factors that need considering in addition to making sure that there are no dangers to the patient resulting from ferromagnetic attraction. These concerns mainly center around image quality, pregnancy and emergency situations (Table 13.3).

Table 13.3 Patient factors to consider during MRI scanning

Image distortion	Ventilation with 100 % oxygen can produce artifact in some MRI sequences. High oxygen requirements should be discussed with the radiologists when planning the procedure
	Movement degrades the quality of images. As MRI scans can take up to 2 h the need for sedation and/or intubation needs to be assessed before transfer (see Chap. 11)
Pregnancy	No current evidence that exposure to the magnetic fields adversely affects pregnancy outcome
	Concern over fetal noise exposure and potential teratogenic effect of exposure to excessive heat
	Gadolinium-based contrast agents is avoided unless absolutely necessary
Emergencies	Emergency situations cannot be safely and effectively managed within the scan room and the 5 Gauss line.
	Resuscitation and emergency team members should be restricted from entering the scan room and the patient be moved to a designated place within the radiology suite

Teaching Points

1. There are different types of magnetic fields with different effects on the human body and on equipment.
2. Ferromagnetic attraction poses a big risk to patient, staff and equipment.
3. Noise protection and issues of thermoregulation need to be considered in addition to standard patient monitoring.
4. Ideally only MR safe equipment should be used. However, in certain circumstances MR conditional equipment can be acceptable. Good communication between radiology and ICU staff is important.
5. It is crucial that radiology staff are made aware of any patient factors that might prohibit MRI.

Part IV
Neurological Imaging

Peter Schmidt, MD

Chapter 14
Stroke

Peter Schmidt

Clinical Problem

A 62 year-old male life-long smoker with controlled systemic hypertension is admitted to ICU following apparently uncomplicated triple vessel CABG. He is hemodynamically stable, with no signs of mediastinal bleeding, arterial blood gases are normal on FIO2 0.4. Sedation is discontinued 2 h after arrival on the ICU. The bedside nurse notices a weakness in the right arm and leg on waking. As the patient is maintaining his airway and respiratory effort he is extubated following which an expressive dysphasia becomes apparent.

Given the hemiparesis and dysphasia a left hemisphere stroke is suspected and urgent brain CT is arranged to characterize.

The term "stroke" describes a sudden loss of neurologic function of indeterminate cause. This results from an ischemic infarct in around 80 % of cases and cerebral hemorrhage in 15–20 %. Less common causes of stroke include metabolic disorders such as hypoglycemia and electrophysiological disturbances such as seizures. Ischemic or hemorrhagic stroke results in high mortality and in significant long-term morbidity.

Spontaneous (non traumatic) cerebral hemorrhage in the older patient (>60 years) is typically caused by hypertension, hemorrhagic infarction or cerebral amyloid angiopathy. In contrast in patients <60 years old cerebral hemorrhage is more frequently the result of a vascular malformation (aneurysm, arteriovenous malformation, cavernous or venous angioma, dural arteriovenous fistula), venous thrombosis, arterial dissection or an inflammatory vasculopathy.

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The principal cause of ischemic stroke is thromboembolic disease due to atherosclerosis or embolism. Non-atherosclerotic causes of ischemic stroke include metabolic/toxic events, migraine or vasculopathies (e.g., vasospasm).

Differentiation of ischemic from hemorrhagic stroke is pivotal to planning therapy. Since thrombolytic therapy for ischemic stroke has proven efficacy and a limited time window of maximally 4.5 h after the event urgent imaging to determine the nature of a stroke is important to direct appropriate management.

The treatment goals are fundamentally different for both types of stroke:

- In hemorrhagic stroke, the primary aim is stopping the bleeding by neurosurgical or endovascular procedures and controlling the intracranial pressure.
- In ischemic stroke the therapeutic objective is to restore normal blood flow immediately as “time is brain”: every minute in which a large vessel ischemic stroke is untreated, the average patient loses 1.9 million neurons, 13.8 billion synapses, and 12 km (7 miles) of axonal fibers. Each hour in which treatment fails to occur, the brain loses as many neurons as it does in almost 3.6 years of normal aging. Restoring the blood flow in order to save the “tissue at risk” can be achieved either by administering thrombolytics or by endovascular procedures and mechanical recanalization.

Recombinant tissue plasminogen activator (rtPA) administered intravenously within in the first 4.5 h after an ischemic stroke improves outcome without affecting mortality. Intra-arterial fibrinolysis via a catheter placed in the occluded vessel has also been found to improve outcome in patients with acute ischemic stroke. In cases with a large thrombotic load intravenous thrombolysis often has only limited success. This has led to increased interest in thrombectomy and thromboaspiration in specific cases.

Imaging Techniques

As clinical features can be non-specific imaging is central to the evaluation process. There are several imaging techniques available for the assessment of stroke, including computed tomography (CT), magnetic resonance imaging (MRI), angiography of the cervical and cerebral vessels by CT angiography (CTA) or MRI angiography (MRA), catheter angiography, cerebral brain perfusion imaging by CT or MRI and finally diffusion imaging performed by MRI.

In most centers initial stroke imaging is performed with CT, which is usually readily available and offers short scan times of 5–10 min. MRI provides a more hostile environment for a critically ill patient and scanning time is about 20–40 min. However, some centers have adopted initial stroke imaging with MRI as their standard practice.

Table 14.1 shows the sensitivity and specificity of CT and MRI in ischemic and hemorrhagic stroke in emergency situations. Performance is similar in hemorrhagic stroke but MRI has a higher sensitivity in ischemic stroke.

Table 14.1 Accuracy of CT and MRI in stroke diagnosis

Sensitivity for diagnosing **ischemic stroke** in the emergency situations	Sensitivity for diagnosing **hemorrhagic stroke** in the emergency situation:
CT scans (*without* contrast enhancement)	CT scans (*without* contrast enhancement)
Sensitivity = 16 %	Sensitivity = 89 %
Specificity = 96 %	Specificity = 100 %
MRI scan	MRI scan
Sensitivity = 83 %	Sensitivity = 81 %
Specificity = 98 %	Specificity = 100 %

Usually an unenhanced brain CT is enough to differentiate between ischemic and hemorrhagic stroke. Because of its higher density compared to normal brain tissue, it is easy to detect blood within the parenchyma. In the absence of hemorrhage a clinical stroke is considered ischemic. The radiologist can make an accurate diagnosis with the knowledge of specific CT- or MRI- features. If the patient is within the time window (i.e., <4.5 h since the onset of symptoms), thrombolytic therapy may be appropriate in the absence of hemorrhage. If the time window is longer or unclear (e.g., sedated patient or wake-up stroke) or thrombolysis is contraindicated an endovascular approach might be considered. This may require additional imaging – usually CT- or MR-angiography – and, where possible, a CT- or MR- perfusion scan.

MR and CT findings of ischemic stroke change rapidly within the first week following the ischemic insult due to the underlying cellular changes (Fig. 14.1). It is, therefore, important to know the time course of symptoms when interpreting the images. Cerebral infarction can be classified as:

Hyperacute infarction	0–6 h
Acute infarction	6–36 h
Early subacute infarction	36 h–5 days
Late subacute infarction	5–14 days
Chronic infarction	>2 weeks

Unenhanced Brain CT

On unenhanced brain CT signs that typically appear 2–6 h after the onset of symptoms include (Fig. 14.2a, b):

- Hyper-attenuation of arteries due to fresh thrombus
- Loss of differentiation between gray and white matter in the basal ganglia, insula and cortex
- Effacement of the cortical sucli due to localized mass effect
- Focal hypoattenuation resulting in regional density differences and asymmetry.

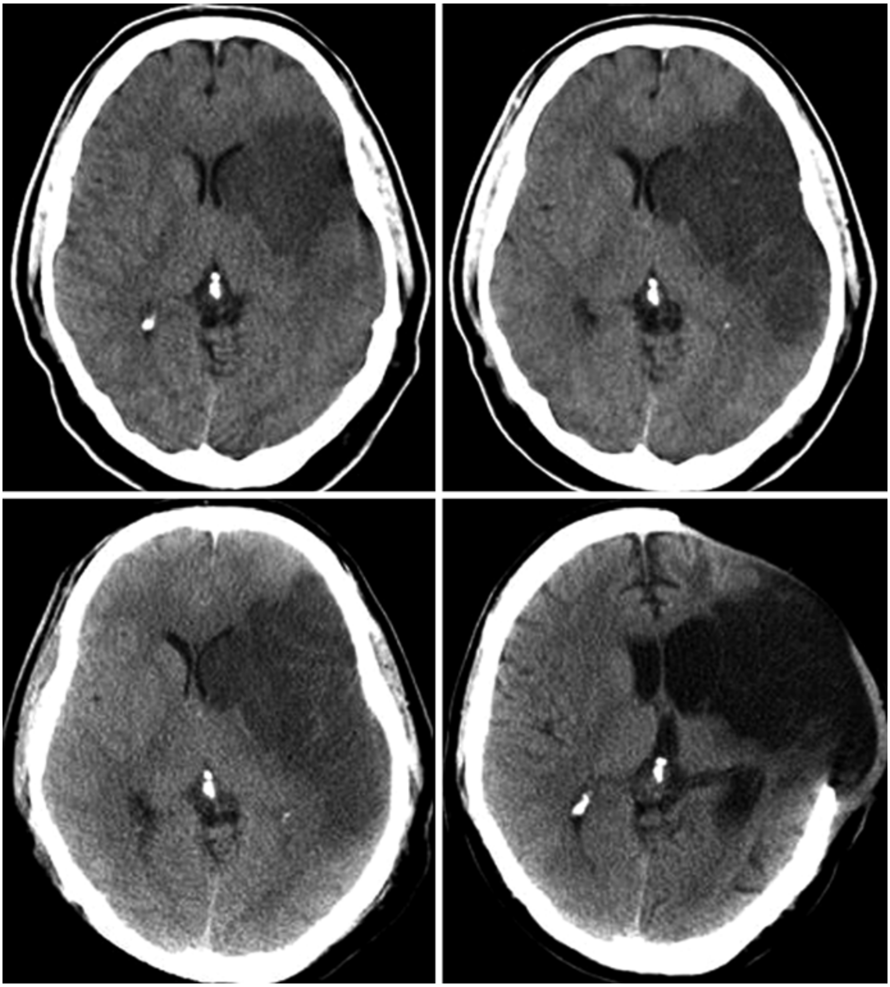

Fig. 14.1 Typical time course of a left sided ischemic stroke with hemicraniectomy

Unenhanced Brain MRI

MRI is more sensitive to early ischemic injury. The early signs include (Fig. 14.3a–c):

- Absent flow void signal of the culprit vessel in T2 WI due to low blood flow or occlusion
- Arterial high signal in T1 WI due to low blood flow
- High signal intensity in DWI images in combination with signal reduction on ADC-maps due to decreased motion of protons
- Subtle sulcal effacement in T1-WI due to cytotoxic edema
- Hyperintense signal in T2-WI due to vasogenic and cytotoxic edema

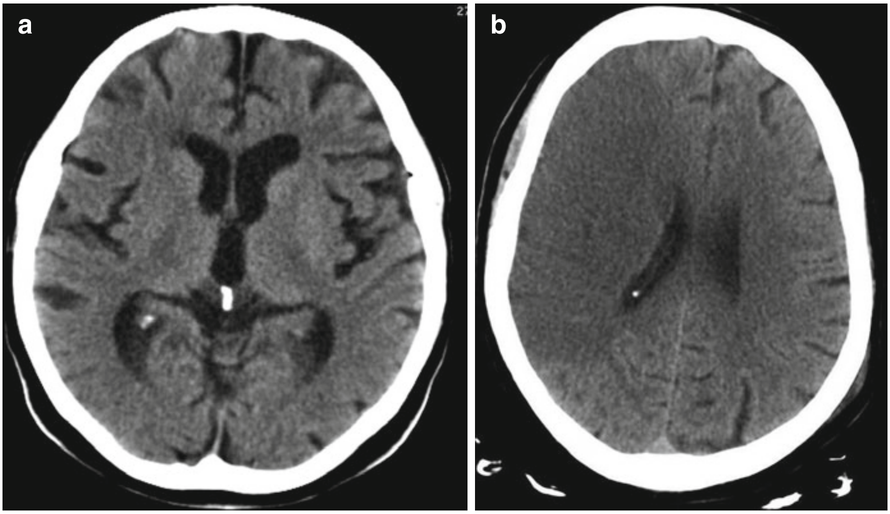

Fig. 14.2 Unenhanced CT scans. (**a**) Normal brain. (**b**) Ischemic infarction of the right hemisphere

Angiography

Figures 14.4a, b and 14.5a–d show images of cerebral angiography performed non-invasively with CT or MRI (CTA, MRA). Identifying occluded or stenosed vessels confirms the ischemic nature of a stroke and is crucial in determining appropriateness of thrombolytic therapy or mechanical recanalization. MRI can confirm or exclude arterial dissection as a cause for the ischemic stroke. Both CTA and MRA allow estimation of the amount of thrombotic material and thus guide the interventional radiologist in planning any potential mechanical recanalization. Invasive catheter angiography is only necessary as part of a therapeutic, interventional procedure.

Perfusion Imaging

Perfusion CT and MRI imaging (Fig. 14.6a, b) detects cerebral blood flow (CBF) at capillary level, which normally is in the order of 30–50 ml/100 g/min in healthy brain tissue. This technique has the advantage of being able to further characterize the ischemic injury into four subcategories:

Core infarct = dead tissue	CBF < 10 ml/100 g/min
Ischemic penumbra = brain at risk	CBF 10–20 ml/100 g/min
Oligemia = brain not at acute risk	CBF 30–50 ml/100 g/min
Normal brain	CBF > 50 ml/100 g/min

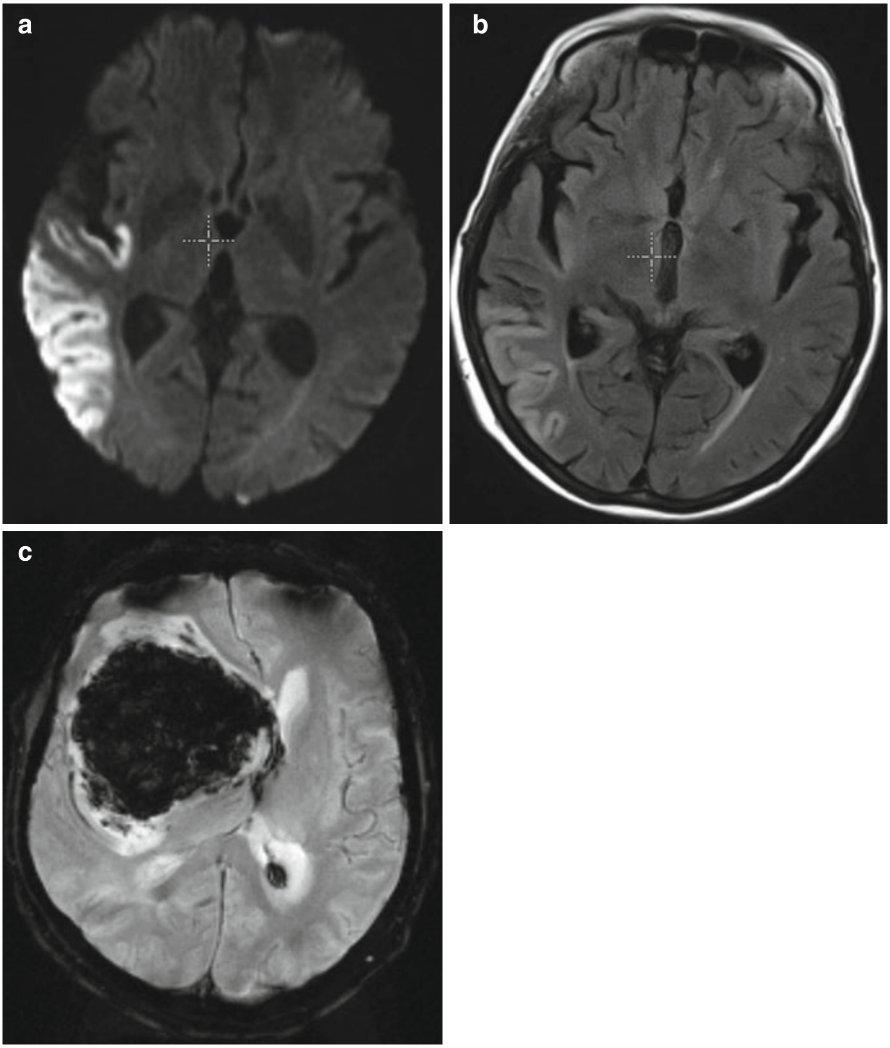

Fig. 14.3 (**a**) Ischemic stroke in DWI-Imaging. (**b**) Ischemic stroke in FLAIR Imaging. (**c**) In comparison hemorrhagic stroke in t2* weighted image

Thrombolytic therapy or mechanical recanalizing may be an option if the mismatch between core infract and penumbra is >20 % and all other treatment criteria are met (<4.5 h duration, no hemorrhage, infarct less 30 % of a vascular distribution).

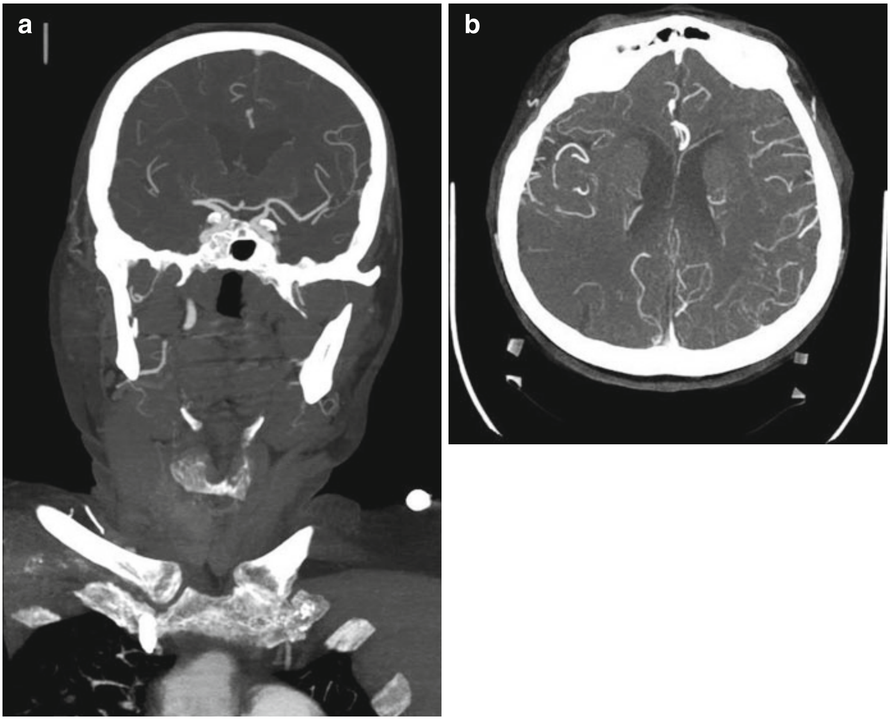

Fig. 14.4 CT Angiogram. (**a**) Coronal section showing an occlusion of the right MCA. (**b**) Transverse section with hypoattenuation of brain parenchyma of the right parieto-occipital region

Diffusion Imaging

Diffusion weighted imaging (DWI) can only be performed by MRI. It is based on the principle that the failure of the membrane pumps after about 5 min of hypoxia results in cytotoxic cell edema and unrestricted to free diffusion. The main advantage of DWI is the ability to visualize ischemic infarction in the posterior cranial fossa where CT is limited due to beam hardening artifacts from the petrous temporal bone. Another important advantage is the high spatial resolution compared to perfusion imaging, allowing ischemic regions as small as 1–2 mm in diameter to be visualized (Fig. 14.7). Finally, in contrast to perfusion imaging, no contrast media are required.

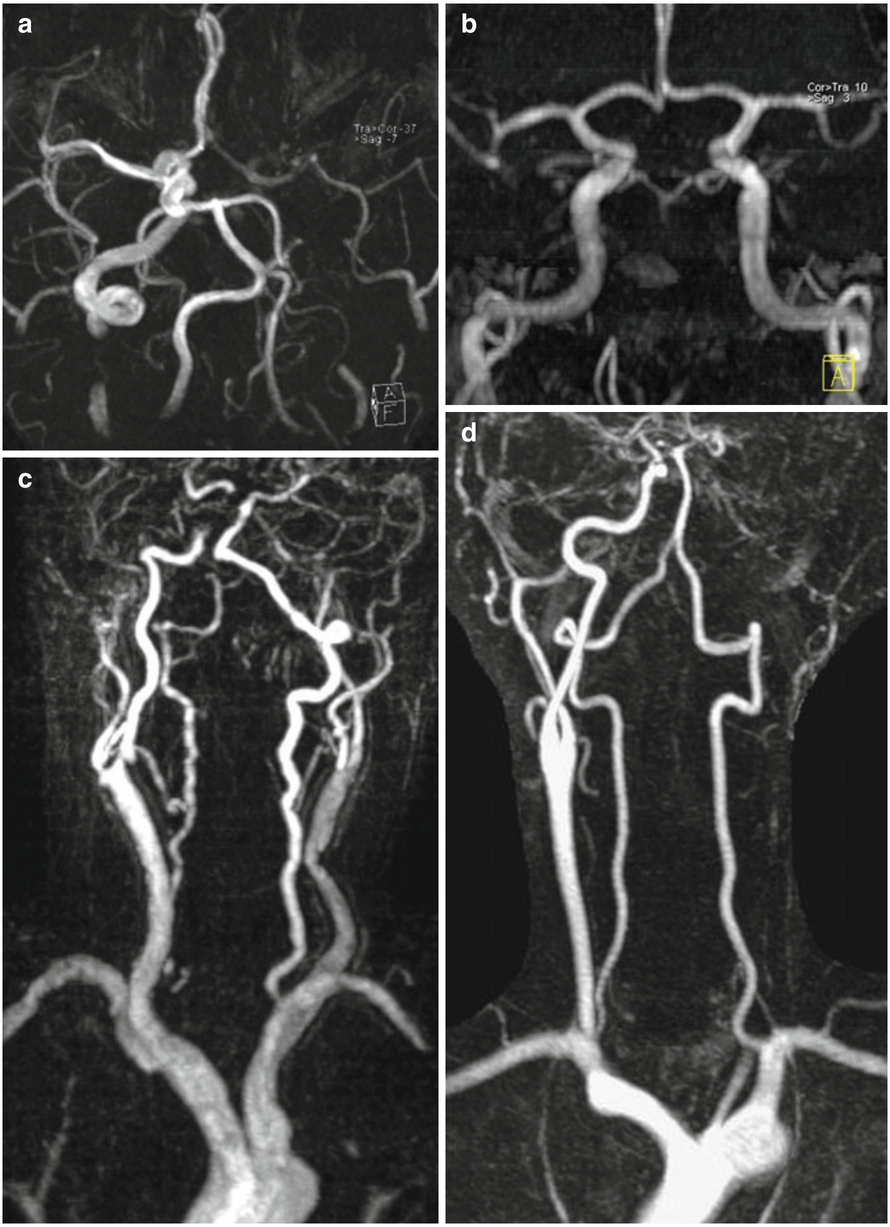

Fig. 14.5 MR angiography. (**a**) Internal carotid artery occlusion on *left side*. (**b**) Basilar artery occlusion. (**c**) Dissection of left internal carotid artery. (**d**) Carotid artery occlusion on left side

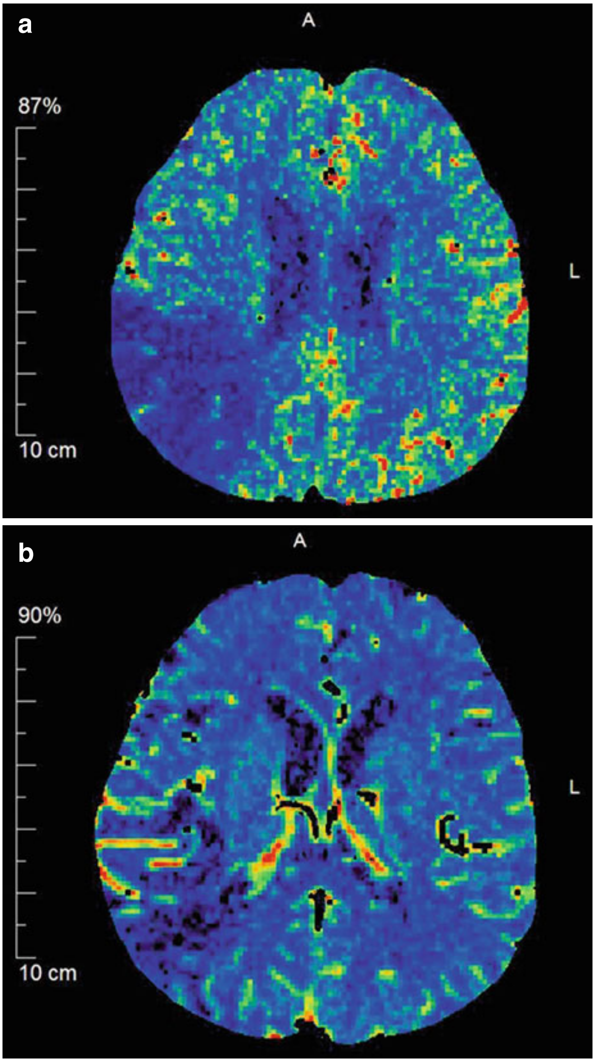

Fig. 14.6 CT perfusion maps depicting a perfusion deficit of the right parieto-occipital region with a significant missmatch between reduced Cerebral Blood Flow (**a**) and reduced Cerebral Blood Volume (**b**), showing the infarct core. Recanalization therapy should be considered in this case

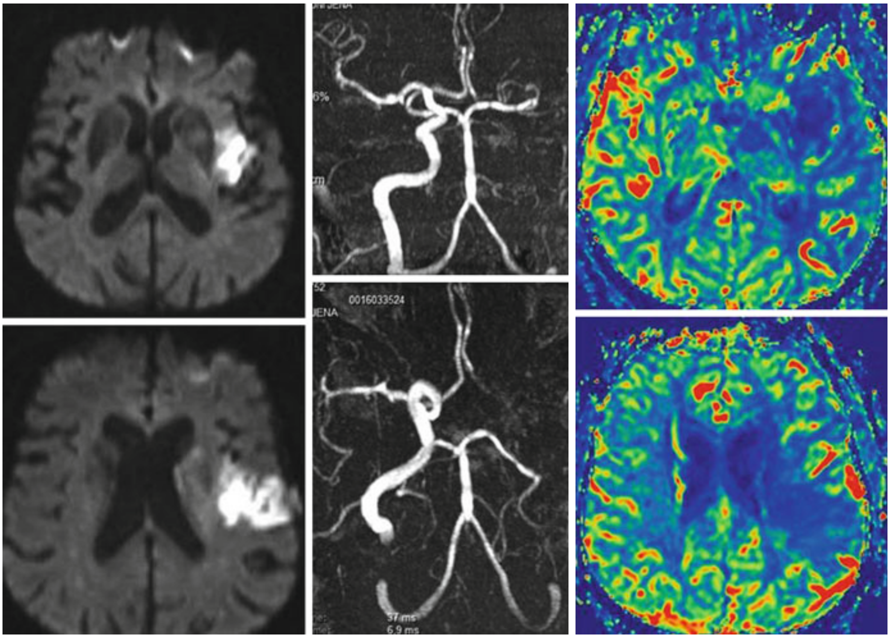

Fig. 14.7 Typical set of MRI images of an ischemic infarct of the left middle cerebral artery (MCA) territory: signal increase on the DWI images (*left panel*); corresponding MR angiography showing an occlusion of the left MCA (*middle panel*); perfusion deficits in the left MCA territory (*right panel*)

Teaching Points

1. CT scan can rule out a intracerebral hemorrhage and, if the patient is within the 4.5 h time window, thrombolytic therapy can be initiated
2. If time of onset of stroke is not clear an MRI can more precisely age ischemic stroke and gives better determination of the extent of the stroke.
3. Compared to CT, MRI takes substantial longer time (3–6 times) and requires the patient to remain motionless during examination

Chapter 15
Infections of the Central Nervous System

Tilak Das

Clinical Problem

A 46-year-old patient is brought to the Emergency Department (ED) with a 1-day history of headache, neck pain and vomiting. Her General Practitioner had prescribed her antibiotics for a diagnosis of otitis media after she complained of earache 4 days previously. In the ED, she is found to have a fever and is confused, unable to follow commands. The patient deteriorates rapidly and has a seizure, culminating in a low GCS requiring intubation and admission to the ICU. Blood cultures are taken and the patient is started on antimicrobial treatment for a presumed diagnosis of meningitis.

Although there has been a decline in mortality rate from neurological infectious diseases globally, early detection, accurate diagnosis and prompt treatment remain critical to reducing morbidity and mortality. Immunocompromised patients, whether related to treatment for malignancy, inflammatory disorders or to HIV infection, are at high risk of CNS infection. Neurosurgical units regularly see patients following neurosurgical procedures and at risk of post-operative infection or following the treatment of brain abscesses.

Imaging Techniques

The role of imaging in the assessment of CNS infections includes evaluating the characteristics and extent of pathology, providing a diagnosis in the context of known clinical information, assessing progress with treatment, defining the surgical approach when necessary and excluding alternative pathologies. Magnetic

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Resonance Imaging (MRI) is the modality of choice due to its superior tissue contrast, multiplanar imaging, sensitivity to enhancement and potential to obtain functional data such as diffusivity, perfusion and metabolic information. However, Computed Tomography (CT) continues to play an important role as it is often used as the first-line modality for brain imaging in emergency situations.

A pragmatic approach to the evaluation of CNS infections is to assess the pattern of changes demonstrated on imaging to narrow the differential diagnosis. This includes categorizing into extra-axial abnormalities (epidural abscess, subdural empyema and meningitis), ring-enhancing lesions, parenchymal changes (temporal lobe encephalitis and white matter lesions) and basal ganglia lesions.

Extra-Axial Infection

Epidural and Subdural Empyema

An epidural abscess or empyema is an infected collection in the potential space between the periosteum of the calvarium and the dura mater, while a subdural empyema is an infected collection between the dura and pia mater. Both are relatively uncommon. However, due to the lack of septations in the subdural space, subdural empyema can spread quickly and should be treated as a neurosurgical emergency requiring prompt drainage.

Organisms usually reach the epidural space by direct extension from an adjacent focus of infection (such as paranasal sinuses, mastoid air cells or orbit) or direct inoculation during trauma or surgery. Subdural empyema can occur due to direct extension of infection, via retrograde thrombophlebitis of emissary veins, following surgery and as a complication of meningitis.

CT is a reasonably accurate and cost-effective screening tool for detecting low attenuation epidural or subdural collections. However, Gadolinium-enhanced MR is more sensitive for small, early collections and identifying associated brain complications.

An epidural collection is typically lentiform, iso- or slightly hyperdense relative to CSF on CT, iso- or hypointense on T1-weighted MRI and hyperintense on FLAIR and T2-weighted MRI (Fig. 15.1a, b). A subdural empyema can be lentiform or crescentic, does not cross the midline and has similar signal characteristics to an epidural abscess (hypodense on CT, low on T1-weighted and high on T2-weighted MRI) with peripheral enhancement (Fig. 15.2a–c). Administration of contrast medium usually demonstrates thick peripheral enhancement of the dural surface. Occasionally effusions develop a fibrin network or membranes that enhance making the distinction from empyema more difficult. Multi-planar reformations from thin-slice CT images or MRI in the coronal or sagittal planes are useful to delineate paratentorial or subtemporal collections.

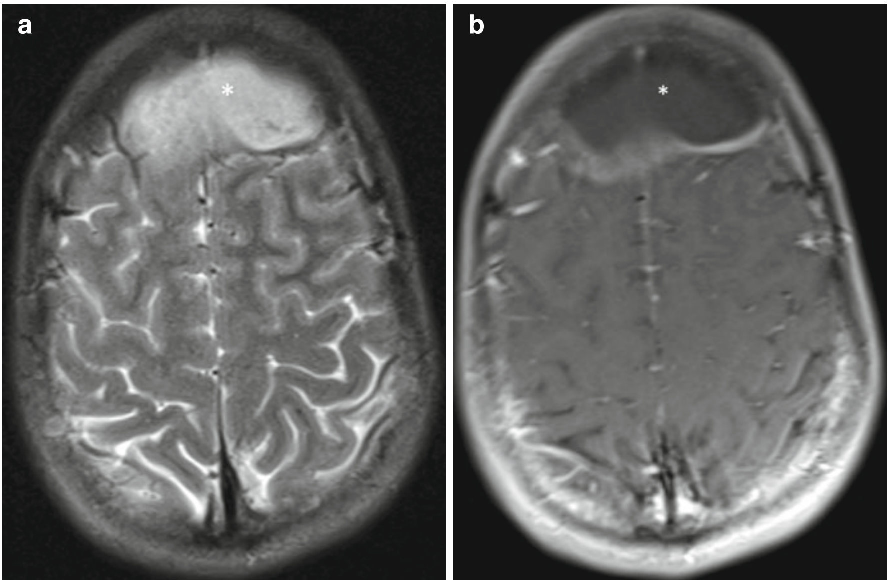

Fig. 15.1 Epidural collection in a 19-year old male. A lentiform collection (*) crosses the midline, displacing the falx cerebri posteriorly. The collection is hyperintense on T2 (**a**), hypointense with thick peripheral enhancement on post-contrast T1 (**b**)

Both CT and MRI may demonstrate an associated cause such as sinonasal or mastoid opacification.

Meningitis

Meningitis has infectious and non-infectious causes. Infectious meningitis may be caused by a wide variety of organisms, most frequently through hematogenous spread. Other routes include direct extension from an extra-cranial source or rarely by direct inoculation following trauma. Non-infectious causes that should be considered comprise a wide differential including carcinomatosis, drug-induced meningitis, chemical meningitis, sarcoidosis and collagen vascular disorders. Given its rapid and fulminant course bacterial meningitis is the most likely cause in the critically ill patient.

The role of imaging in meningitis is not to make the initial diagnosis but to rule out mimics and assess for complications. Although imaging findings are not usually specific to a causative organism, imaging can be helpful to classify a detected lesion into infectious or inflammatory versus neoplastic disease.

Lumbar puncture (LP) should not be delayed until after imaging has taken place. Signs of possible raised intracranial pressure for which CT is recommended prior to LP are outlined in Table 15.1.

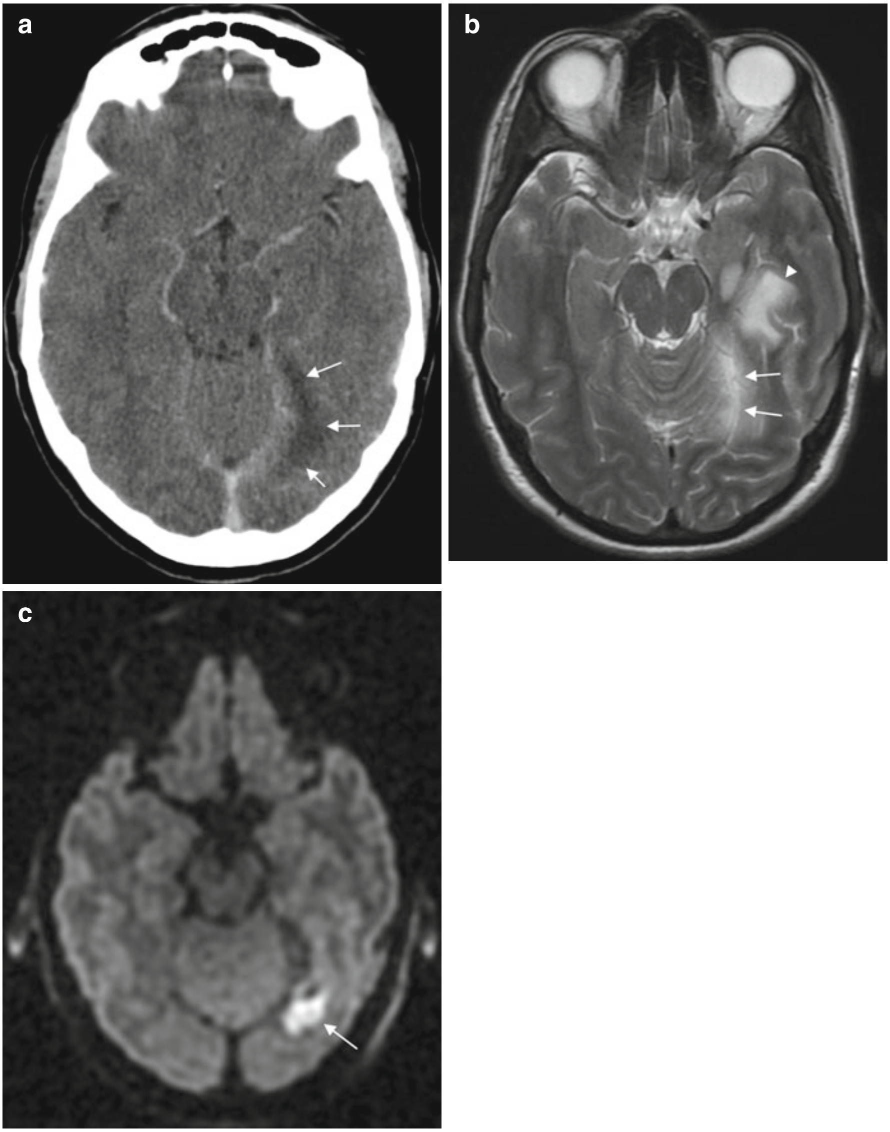

Fig. 15.2 Subdural empyema in a 34-year-old patient. The subdural empyema (*arrows*) is hypodense on CT (**a**), hyperintense on T2 (**b**) and hyperintense on diffusion-weighted imaging consistent with infection (**c**). The associated parenchymal T2 hyperintensity (**b**, *arrowhead*) is due to cerebritis

MRI is more sensitive to meningeal enhancement than CT. In the early stages of the disease, both CT and MRI may be normal. The hallmark of meningitis from any cause is contrast enhancement of the meninges, which can be classified into two patterns:

Table 15.1 Guidelines suggesting CT prior to LP to exclude imaging evidence of raised intracranial pressure

Infectious Diseases Society of America (IDSA) guidelines 2004	National Institute for Health and Care Excellence Guidelines 2010
Immunocompromised state (eg, HIV infection, immunosuppressive therapy, solid organ or hematopoietic stem cell transplantation)	Reduced or fluctuating level of consciousness (Glasgow Coma Scale score less than 9 or a drop of 3 or more)
History of CNS disease (mass lesion, stroke, or focal infection)	Relative bradycardia and hypertension
Abnormal level of consciousness	Abnormal posture or posturing
Focal neurologic deficit	Focal neurological signs
Papilloedema	Papilloedema, abnormal 'doll's eye' movements
New onset seizure (within 1 week of presentation)	Unequal, dilated or poorly responsive pupils

- Leptomeningeal enhancement of the pia-arachnoid layers, with a serpentine or gyriform appearance that follows the pial surface of the brain, filling the subarachnoid spaces of sulci and cisterns
- Pachymeningeal enhancement of the dura-arachnoid layers, parallel to the calvarium, or of dural reflections (falx cerebri, falx cerebelli, tentorium cerebelli and cavernous sinus).

Infectious meningitis is generally associated with leptomeningeal enhancement (Fig. 15.3a–c). Enhancement from viral and bacterial meningitis is typically thin and linear, whilst fungal meningitis tends to be nodular and thicker. Cranial nerve enhancement, which is always abnormal, can be associated with viral meningitis or neoplastic disease such as lymphoma and leukemia.

Pachymeningeal enhancement is seen transiently in post-operative patients, secondary to intracranial hypotension (rarely following lumbar puncture), or due to granulomatous disease or malignancy such as metastatic breast and prostate cancer and secondary CNS lymphoma.

Thick leptomeningeal enhancement in the basal cisterns, as opposed to leptomeningeal enhancement in the convexities, is more likely seen in chronic meningitides such as tuberculous or fungal meningitis (Fig. 15.4). This is thought to be due to a thick, gelatinous exudate found in the basal cisterns. It is also demonstrated as hyperdensity in the basal cisterns on unenhanced CT. The triad of basal meningeal enhancement plus the associated complications of hydrocephalus and infarcts is specific for tuberculous meningitis.

Complications of Meningitis

Up to 50 % of adults with bacterial meningitis develop complications such as hydrocephalus, subdural effusions, subdural/epidural empyema, cerebritis, abscess formation and arteriopathy or venous thrombosis with associated infarction. Cerebrovascular complications are common, occurring in approximately one third of patients.

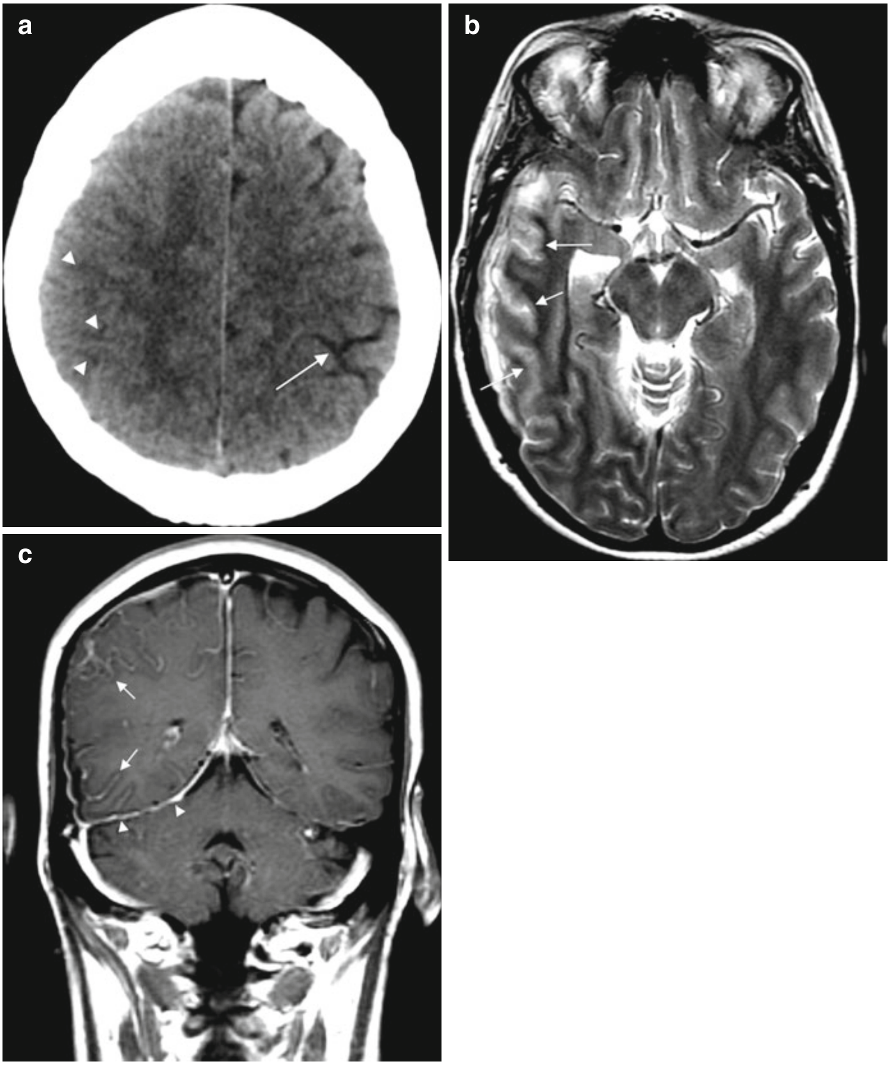

Fig. 15.3 Meningitis in a 50-year-old patient. CT (**a**) demonstrates subtle sulcal effacement (*arrowheads*) on the right compared to the left (*arrow*). The T2-weighted image (**b**) demonstrates cortical swelling and hyperintensity in the affected lobes (*arrows*). The T1 post-contrast image (**c**) shows leptomeningeal enhancement (*arrows*) and pachymeningeal enhancement (*arrowheads*)

A hydrocephalus may be communicating, due to reduced absorption of CSF in meningitis or obstructive, due to the formation of adhesions and loculations, particularly in the cerebral aqueduct. Both CT and MRI are sensitive to changes in the size of the ventricles, best seen at the temporal horns or third ventricle.

Basal meningitis can lead to spasm or occlusion of small perforating vessels with subsequent infarction of the basal ganglia, or of large arteries, causing large cortical/subcortical infarcts (see also Chap. 14).

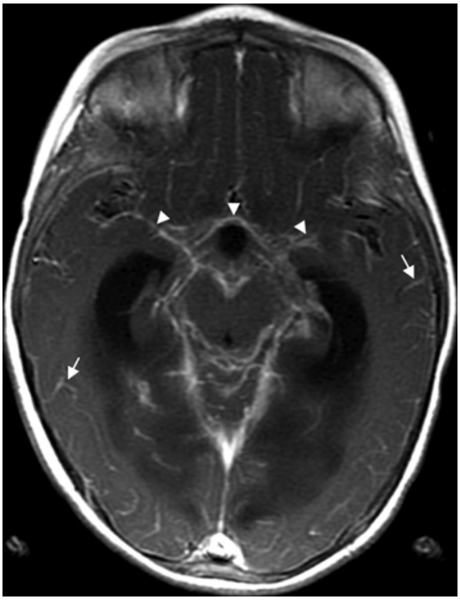

Fig. 15.4 Basilar meningitis in TB, extensive leptomeningeal enhancement in a 4-year-old child with tuberculous meningitis. The T1 post-contrast images show thick leptomeningeal enhancement around the basal cisterns and Sylvian fissures (*arrowheads*) and leptomeningeal enhancement in the convexity sulci throughout the brain (*arrows*)

Cortical infarction disrupts the pia, a normal barrier to the spread of infection, enabling the development of cerebritis and abscess formation. Infection may also spread via retrograde thrombophlebitis. Cerebritis can be difficult to differentiate from infarction and a focus of infarction can develop into cerebritis. However, the two can be distinguished with time as cerebritis evolves into an abscess, whilst signal change from infarction persists in the affected vascular territory.

Ring-Enhancing Lesions

The spectrum of differential diagnoses for ring-enhancing lesions in the brain is enormous. It includes abscesses, tumors and primary CNS lymphoma, radiation necrosis, subacute infarction or hematoma and atypical infections such as tuberculosis, fungal or parasitic infections. Atypical infections are an important consideration in the immunocompromised patient.

Cerebritis and Pyogenic Abscess

Sources of infection leading to abscess formation include direct spread from local infection (otomastoiditis, sinusitis, dental abscess), hematogenous spread from a distant source (e.g. bacterial endocarditis, IV drug use, intra-abdominal infection), trauma and neurosurgical complication.

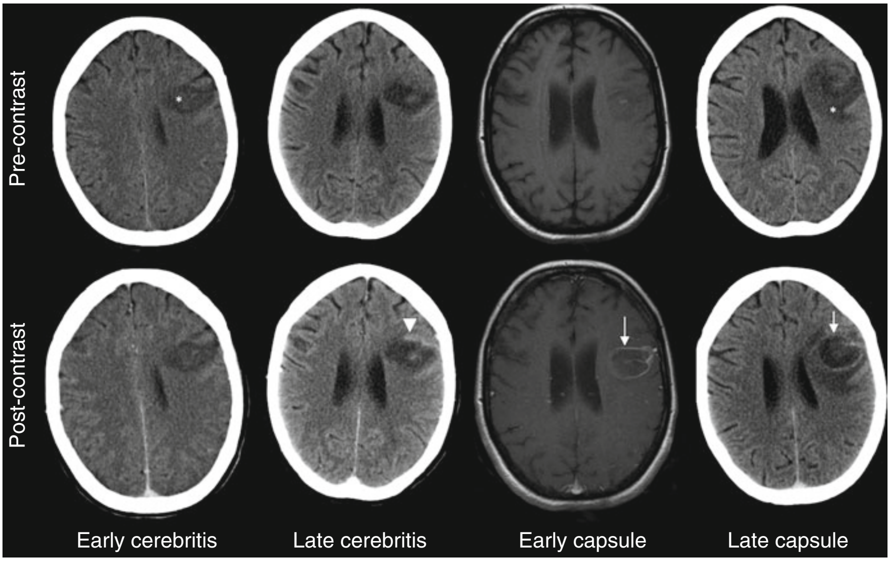

Fig. 15.5 Stages of abscess formation. CT and MR examinations of one patient showing the evolution of cerebritis into abscess over time. *Top row* – unenhanced images; *Bottom row* – post-contrast images. Non- or poorly enhancing hypodensity (*) represents early cerebritis. In late cerebritis, there is some ring-like enhancement (*arrowhead*). The enhancing capsule is evident in the early capsule phase (*arrow*) with hyperintense contents of the lesion. On CT, there is oedema surrounding the lesion (*) as well as persistent ring-enhancement (*arrow*) in the late capsule phase

The formation of cerebral abscess occurs in stages:

1. Early cerebritis – is a poorly defined focal parenchymal infection associated with edema, presence of polymorphonuclear leukocytes and petechial hemorrhage. On CT this may be visible as hypodensity, on MRI as T1 hypointensity, T2 hyperintensity and subtle mass effect. Contrast enhancement is variable and patchy (Fig. 15.5).
2. Late cerebritis (4 days to 2 weeks) – the central necrotic foci coalesce and a rim of mononuclear inflammatory cells and fibroblasts surrounds the necrotic center. The imaging shows ring-like or nodular enhancement around the hypodense or T1 hypointense core.
3. Early and late capsule phases – a well-defined capsule forms around a purulent or necrotic core. The capsule matures with increasing collagen content with a zone of surrounding reactive gliosis and edema. In the capsular phase, CT and MRI demonstrate the characteristic imaging features of a cerebral abscess (Table 15.2).

In immunocompromised patients the impaired immune response may result in the lack of surrounding edema and ring-enhancement.

Diffusion-weighted imaging offers additional information in differentiating abscess from neoplasm. The necrotic center of a primary or secondary tumor

Table 15.2 Imaging features of cerebral abscesses

Central fluid	Hypodense on CT
	Hypointense to white matter and hyperintense to CSF on T1
	Hyperintense to parenchyma on T2
Surrounding oedema	Hypointense to parenchyma on T1
	Hyperintense to parenchyma on T2
Surrounding rim	Hypointense on unenhanced T2

usually exhibits high diffusivity whereas an abscess generally exhibits restricted diffusion. Diffusion-weighted imaging can be useful for monitoring the response to treatment, with resolution of restricted diffusion corresponding to successful treatment and the re-appearance of restriction suggesting treatment failure.

The complications of cerebral abscesses include mass effect, often due to the surrounding edema, meningitis, extra-axial effusion or empyema and rupture into the ventricle resulting in ventriculitis, which portends a poorer prognosis.

Tuberculoma

Following hematogenous dissemination of primary tuberculous infection, small tubercles may form within brain parenchyma. Without rupturing into the subarachnoid space they grow to form tuberculomas walled off from surrounding brain parenchyma. They can be solitary or multiple and occur anywhere in the brain. Approximately 10 % of cases are associated with concurrent TB meningitis, where tuberculomas form following the extension of CSF disease into the parenchyma via the cortical veins or perivascular spaces. Imaging appearances of tuberculomas vary according to their pathological content. Initial granulomatous reaction forms a non-caseating granuloma that subsequently develops central caseating necrosis, initially solid and later liquefied. Non-caseating tuberculomas are hypodense on CT, T1 hypointense and T2 hyperintense. Caseating lesions are T1 iso- to hypointense compared to grey matter with a slightly T1 hyperintense rim. Solid tuberculomas are generally T2 hypointense while liquefaction leads to T2 hyperintensity. Tuberculomas demonstrate intense nodular and ring-like enhancement (Fig. 15.6a, b). Even though non-caseating and liquefied caseating tuberculomas may be difficult to differentiate from pyogenic abscesses or other ring-enhancing lesions the presence of central T2 hypointensity in a ring-enhancing lesion and in the appropriate clinical context should raise the possibility of tuberculoma.

Fungal Infection

The radiological appearance of fungal CNS infections is non-specific but they must be considered as a differential diagnosis when ring-enhancing lesions are seen. Knowledge of a patient's immune status can help to narrow the differential.

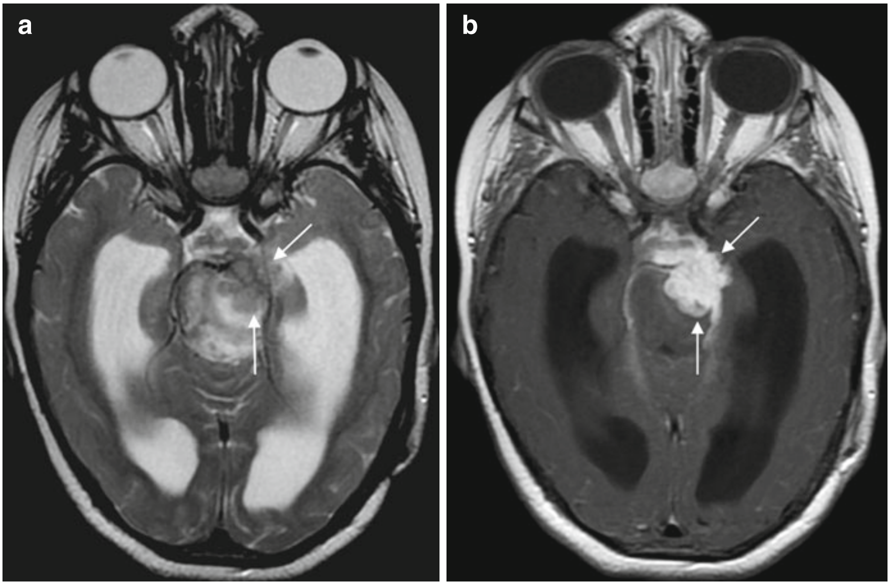

Fig. 15.6 Multiple parenchymal lesions in the left side of the brainstem after treatment for TB meningitis, consistent with tuberculomas. These are (**a**) hypointense on T2-weighted images (*arrows*) and (**b**) avidly enhancing (*arrows*)

Aspergillus and Candida mainly affect immunocompromised hosts, while Cryptococcus, Coccidioides, Histoplasma and Blastomyces can affect the immunocompetent. Geographic considerations may narrow the differential further.

CNS manifestations of fungal infection include meningitis and parenchymal lesions such as granulomata, cerebritis and abscesses. Fungal meningitis tends to appear as nodular, basal leptomeningeal enhancement. The appearances of granulomata, cerebritis and abscesses are non-specific and similar to their bacterial counterparts.

There are a few features that may suggest a fungal etiology. Fungal abscesses may lack enhancement in immunocompromised patients and are more commonly associated with hemorrhagic foci. Hematological spread causes appearances at multiple sites, often situated at the grey-white matter junction. They may involve the basal ganglia, normally spared in bacterial infection. Fungal infection can spread from infected paranasal sinuses, which would be non-specifically opacified or hyperdense on CT but more specifically T1 and T2-hypointense on MRI. Relative T2 hypointensity of the granuloma has been shown in Aspergillomas.

Toxoplasma

Immunocompetent individuals are usually asymptomatic following acute infection with Toxoplasma gondii. However, once ingested the organisms remain dormant in multiple organ systems and latent infection can be re-activated when the immune

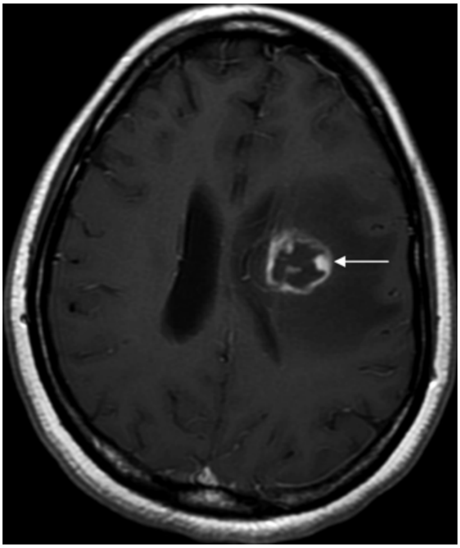

Fig. 15.7 Toxoplasmosis in a patient with AIDS. T1 post-contrast image of a ring-enhancing lesion and surrounding oedema demonstrating the 'eccentric target sign' (*arrow*)

system is compromised. CNS toxoplasmosis is the most common cause of a cerebral space-occupying lesion in AIDS. Toxoplasma lesions are often seen at multiple sites and have a predilection for the basal ganglia, thalamus and grey-white matter junction. Lesions demonstrate ring, or less commonly nodular, enhancement with a hypodense or a T1-hypointense center and surrounding T2 hyperintense edema. The enhancing ring does not correspond to a capsule but to an "intermediate zone" of inflammation. The pathognomonic "eccentric target sign" is seen in less than 30 % of cases. It consists of an eccentric nodule of enhancement within an enhancing ring (Fig. 15.7).

An important differential consideration is the primary CNS lymphoma. It can also present with periventricular, multifocal ring-enhancing lesions and has indistinguishable clinical features. Additional MRI sequences including DWI, perfusion and spectroscopy have been used to differentiate the two but are not entirely specific. Empiric treatment for toxoplasma followed by serial imaging to assess the response is often used initially. A lack of response (expected within 2–4 weeks although full resolution may take up to 6 months) indicates the need for biopsy in order to differentiate between concurrent infection, resistant toxoplasma or lymphoma.

Diffuse Parenchymal Abnormality

MR imaging is sensitive to the presence of diffuse or ill-defined brain parenchymal signal abnormality but rather non-specific. There are some features that help narrowing down the differential diagnosis. The most important pattern to recognize is that of temporal lobe changes suspicious for encephalitis from a herpes simplex virus (HSV) infection.

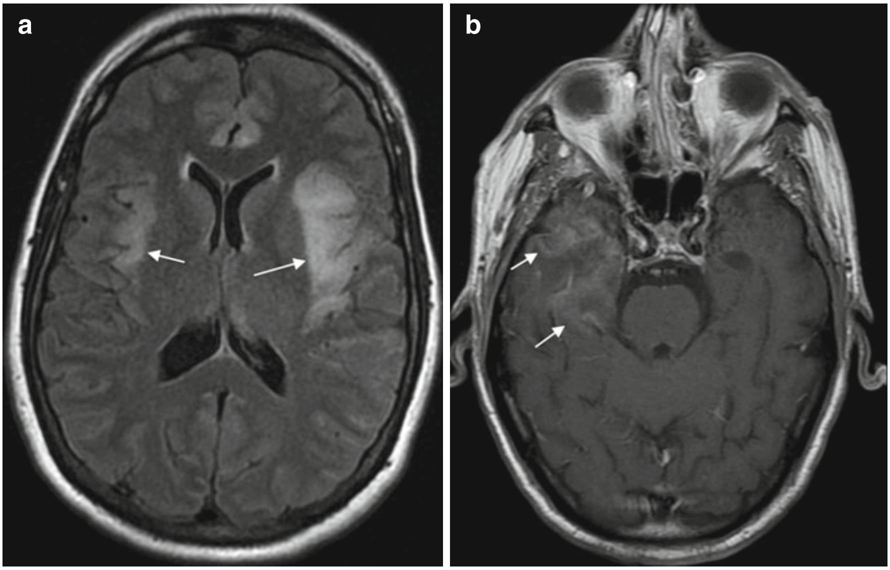

Fig. 15.8 Herpes Simplex Encephalitis. FLAIR image (**a**) showing asymmetric hyperintensity in the medial temporal lobes, inferior temporal lobes, insular regions and anterior cingulate cortex bilaterally (*arrows*). T1 post-contrast (**b**) of a different case demonstrating patchy enhancement in the right temporal lobe (*arrows*)

Herpes Simplex Encephalitis

Encephalitis is typically associated with changes in consciousness. There are numerous etiologies for infectious encephalitis including viral, bacterial and spirochetal infection. Viral encephalitides will generally appear as scattered or confluent areas of T2 hyperintensity, T1 iso- or hypointensity and variable mass effect. Foci of increased signal may be due to subacute focal hemorrhage. Contrast enhancement is variable and there may be a patchy pattern of restricted diffusion.

Herpes simplex encephalitis (HSE) is the most common cause of encephalitis, with Herpes Simplex Virus type 1 (HSV-1) responsible for 95 % of cases. Mortality is as high as 50–70 % without treatment and early diagnosis and commencement of treatment is critical. Imaging findings are characteristic in location. Most cases start with unilateral signal change and 85 % will become bilateral but asymmetric within 2 weeks.

HSE is a necrotizing hemorrhagic encephalitis, typically with asymmetric involvement of the temporal and inferior frontal lobes bilaterally and less commonly of the insula and cingulate gyri (Fig. 15.8a, b). Signal changes on MRI, which is more sensitive than CT, include cortical and white matter hyperintensity on T2-weighted or FLAIR sequences associated with cortical swelling, T1-hypointensity and restricted diffusion. Contrast enhancement is variable. Hemorrhagic changes in the form of focal increased susceptibility on gradient echo (T2*) may be demonstrated.

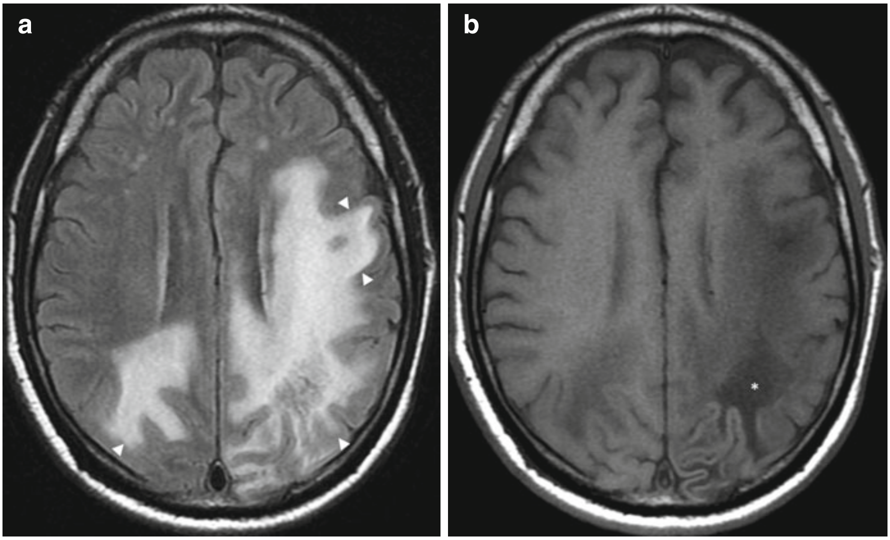

Fig. 15.9 Progressive multifocal leukoencephalopathy (PML) in an immunocompromised patient known to harbour JC Virus. (**a**) FLAIR image with extensive high signal abnormality in the left cerebral hemisphere involving sub-cortical U-fibers (*arrowheads*). (**b**) T1-weighted unenhanced image with profound hypointensity (*) often seen in this condition

Progressive Multifocal Leukoencephalopathy

Progressive multifocal leukoencephalopathy (PML) is a rare, opportunistic, severe demyelinating disease caused by reactivation of latent JC polyomavirus (JCV). Antibodies to the virus can be found in 86 % of adults. Similar to other opportunistic infections, the widespread use of highly active antiretroviral therapy (HAART) in AIDS has led to a decrease in the incidence of PML. Recently however, the increasing use of natalizumab in the treatment of multiple sclerosis and Crohn's disease has led to an increase in the incidence of associated PML.

Typical imaging features include unilateral or asymmetric multifocal areas of T2 hyperintensity in the white matter, involving subcortical U-fibers (peripheral white matter) with little mass effect (Fig. 15.9a, b). There is often marked T1 hypointensity corresponding to hypodensity on CT. There may be faint and peripheral contrast enhancement within the lesions. These features help to differentiate PML from other white matter diseases such as HIV encephalitis (often a concurrent risk in the same patient), in which white matter signal changes tend to be symmetric, more anterior and spare the subcortical white matter.

Cryptococcus

Cryptococcus neoformans is the most common fungus to involve the CNS and the most common fungal infection in AIDS patients. Cryptococcus usually manifests as basal meningitis. Parenchymal disease caused by direct extension of

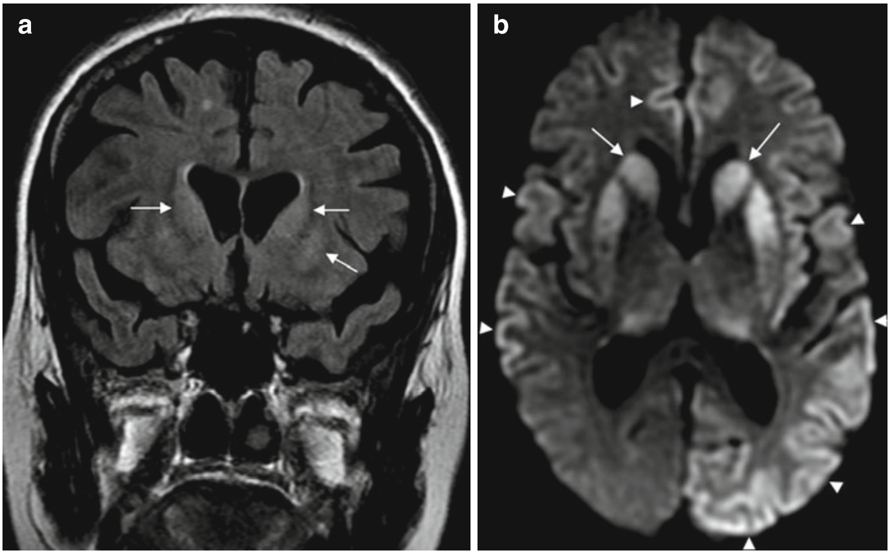

Fig. 15.10 Creutzfeld-Jacob Disease (CJD). (**a**) Subtle hyperintensity in the basal ganglia on a coronal FLAIR image (*arrows*). (**b**) Marked hyperintensity on DWI in the basal ganglia (*arrows*) and extensive areas of cortex throughout the cerebral hemispheres (*arrowheads*)

the infection from the subarachnoid spaces includes the formation of granulomas (cryptococcomas) and dilated perivascular spaces, known as "gelatinous pseudocysts" formed by mucoid material from microorganisms spreading along perforating vessels. They occur primarily in the midbrain and basal ganglia and rarely enhance.

Creutzfeld-Jacob Disease

The very low incidence of Creutzfeld-Jacob Disease (CJD) and variability in its clinical presentation can lead to patients with this slow but progressive dementia to be referred to the critical care unit. The classic triad of progressive dementia, myoclonic jerks and periodic sharp-wave EEG tracing may be lacking in up to 25 % of patients. MRI, in particular DWI and FLAIR sequences, is sensitive and specific for abnormalities from sporadic CJD. Characteristic findings are of FLAIR hyperintensity and restricted diffusion in the basal ganglia and cortex, which can be asymmetric and distributed throughout the cerebrum (Fig. 15.10a, b).

Teaching Points

1. CT and MRI are useful in the initial detection of CNS infectious pathology, although MRI is generally more sensitive and the preferred modality for imaging.
2. A narrower differential diagnosis can be generated from an understanding of the pattern of abnormality on imaging.
3. Specific features on imaging can help establish the diagnosis of common and critical infections, such as pyogenic abscess and herpes encephalitis.
4. CT prior to LP is only necessary in the presence of specific ‘red flag’ features.

Chapter 16
Seizures

Tomasz Matys and Daniel J. Scoffings

Clinical Problem

A 49-year old woman presented to the Emergency Department with confusion, severe headache and altered mentation. She had received a cadaveric renal transplant 2 years earlier and was immunosuppressed with tacrolimus. She was hypertensive at 210/105 mmHg and she was tachycardic at 105 bpm. She was febrile at 38.3 °C and had reduced air entry at the right base with consolidation on chest radiograph suggestive of pneumonia. While in the Emergency Department she suffered a generalized seizure. Initially a head CT was performed and was reported as normal. Due to high suspicion of posterior reversible encephalopathy syndrome secondary to tacrolimus a MRI was requested. This confirmed mild bilateral cortical vasogenic edema in occipital lobes. The patient was admitted to ICU for blood pressure control, treatment of pneumonia, and seizure monitoring. Treatment with tacrolimus was temporarily withheld. The neurological symptoms improved and MRI performed 4 days later demonstrated complete resolution of bilateral occipital lobe changes.

Seizures are defined as abnormal excessive or synchronous neuronal activity that interferes with normal brain function. They can manifest as convulsive or non-convulsive phenomena. Seizures occur in 3.3 % patients in ICU and approximately 90 % of these cases present as generalized tonic-clonic convulsions or status epilepticus. Non-convulsive seizures are less common. However, as they may present non-specifically as altered mental status, obtundation or coma, they are difficult to recognize and their frequency is likely to be underestimated.

Seizures may be caused by a variety of neuropathological processes, which are summarized in Table 16.1. Neuroimaging can play a crucial role in their initial diagnosis. Unenhanced computed tomography in particular plays a crucial role in

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Table 16.1 Common causes of seizures secondary to intracranial pathology

Neurovascular	Ischemic stroke
	Hemorrhage (traumatic or non-traumatic)
	Subarachnoid
	Intracerebral (hemorrhagic stroke, contusion)
	Subdural
	Arteriovenous malformation
	Cortical vein thrombosis
	Dural venous sinus thrombosis
	Posterior reversible encephalopathy syndrome (PRES)
	Hypoxic ischemic encephalopathy
Infection	Meningitis
	Encephalitis
	Brain abscess
	Ventriculitis
Tumors	Primary brain tumors (especially cortically-based)
	Metastases
Autoimmune and inflammatory	Antibody-mediated encephalitis
	Acute disseminated encephalomyelitis (ADEM)
	Multiple sclerosis
	Vasculitis
Other	Primary epilepsy
	Seizures post neurosurgical procedures

the early detection of intracranial complications. New onset of seizures, change in the seizure pattern, or refractory epilepsy should be considered as indication for neuroimaging, especially if accompanied by additional changes in neurological status or a new focal deficit. New seizures occurring in patients admitted to ICU following neurosurgery should always be seen as a potential harbinger of complications and urgent imaging should be requested to exclude a postsurgical intracranial catastrophe.

In patients admitted to ICU with no previous history of neurological disease the majority of seizures are secondary to systemic or metabolic factors associated with critical illness or its treatment. Precipitating factors include hypoxia, hypoglycemia, sepsis, fever, drug toxicity (bronchodilators, antibiotics, antidepressants or antipsychotics), substance abuse (amphetamine, cocaine) or drug withdrawal (alcohol, opioids, benzodiazepines), as well as electrolyte imbalance (such as hyponatremia, hypocalcemia, hypophosphatemia, or acidosis). With few exceptions, these conditions do not have specific imaging appearances and are diagnosed and managed based on history, clinical and biochemical findings. However, neuroimaging may be required to exclude intracranial complications arising de novo, most often of neurovascular origin.

Lastly, prolonged seizure activity causes profound metabolic stress to the brain. That may exacerbate an existing injury, and imaging may be required to assess for consequences such as cerebral edema or encephalopathy.

Imaging Techniques

Owing to its speed and availability unenhanced computed tomography (CT) is the mainstay of acute neuroimaging in ICU. The main advantage of unenhanced CT is in the detection of acute hemorrhage, hemorrhagic transformation of an ischemic infarct, or a new intraaxial or extraaxial hemorrhage. Even inexperienced observers readily appreciate a large bleed. Small intracerebral hemorrhages in the posterior fossa and adjacent to the skull may be difficult to detect because of partial volume averaging and beam-hardening artifacts from adjacent bone.

In addition to the detection of hemorrhage, CT allows the assessment of the ventricles and extraaxial fluid spaces, as well as of the effacement of cortical sulci and basal cisterns suggestive of diffuse cerebral edema and increased intracranial pressure. Although non-specific, prominence of extraaxial fluid spaces and ventricles in disproportion to the patient's age, as well as cerebellar atrophy, may provide clues of possible chronic alcohol abuse as a seizure precipitant. CT allows assessment of vasogenic edema accompanying intracranial lesions, of the degree of exerted mass effect and midline shift or of uncal herniation. The usefulness of CT in the detection of acute cerebral ischemia presenting as subtle hypoattenuation and loss of grey-white matter differentiation is limited and is strongly dependent on the observer's experience. Established ischemia is easier to appreciate but care should be taken not to misinterpret this as edema if the grey matter is spared. CT can depict advanced global hypoxic ischemic brain injury leading to effacement of cortical sulci and loss of grey-white matter differentiation.

Contrast-enhanced CT may be helpful in the monitoring of intracerebral abscesses, ventriculitis, or intracranial infection. CT angiography is useful in evaluating the patency of intracranial arteries, cerebral ischemia and vasospasm. CT venography has a role to play in the assessment of the patency of the dural venous sinuses.

Due to the practical limitations (see Chap. 4) Magnetic Resonance Imaging of ICU patients is usually reserved for cases in which CT fails to detect the cause of seizures, or if further characterization of abnormal CT findings is needed. The main advantages of MRI stem from its unsurpassed ability to detect changes in brain parenchyma, and to partially categorize them. MRI is more sensitive than CT in the detection of posterior fossa and pituitary abnormalities, as well as pachymeningeal and leptomeningeal enhancement. MR angiography and venography have similar sensitivity to their CT counterparts but are less practical for obvious reasons.

Cortical Vein Thrombosis and Dural Venous Sinus Thrombosis

Cortical vein thrombosis is an uncommon condition presenting with seizures followed by a focal cortical deficit, secondary to cortical venous infarction. The isolated form of this condition (ICVT) is rare, although its frequency is probably underestimated due to the inherent difficulty in establishing the diagnosis. More often, cortical vein thrombosis occurs in combination (CCVT) with superior sagittal sinus thrombosis due to retrograde thrombus propagation and is accompanied by clinical features such as headache, increased intracranial pressure and papilledema. Predisposing factors include hypercoagulable states, head trauma, parameningeal or meningeal infections, pregnancy and the puerperium, dehydration, nephrotic syndrome, and malignancy.

Imaging findings in ICVT on unenhanced CT include isolated, often hemorrhagic cortical infarction (Fig. 16.1a). The thrombosed cortical vein may be visible as a hyperdense, serpentine structure on the brain surface (the "cord sign," Fig. 16.1b). On MRI, a gradient recalled T2*-weighted sequence is the most sensitive modality and demonstrates low signal intensity in the thrombosed vein (Fig. 16.1c, d). CT venography and MR venography have low sensitivity in detecting cortical vein thrombosis.

Cortical vein thrombosis combined with sagittal sinus involvement (CCVT) should be suspected if there is hyperdensity in the sagittal sinus on unenhanced CT in addition to the above features. As the process is more widespread, multiple cerebral infarcts may be present. The frontal and parietal veins are the most commonly affected. On MRI there is low signal in the sagittal sinus on gradient-recalled echo T2* with "blooming" artifact, and T1 and T2 signal changes depending on the age of the thrombus. Venographic imaging is helpful as the lack of opacification or flow signal in the superior sagittal sinus is unlikely to be an anatomic variant and so indicates occlusion. The main diagnostic pitfall of CTV is the misinterpretation of hyperdense thrombus as normal contrast opacification; an unenhanced CT should always be obtained for reference.

Posterior Reversible Encephalopathy Syndrome

Posterior reversible encephalopathy syndrome (PRES) is a neurotoxic state affecting vascular watershed/junctional zones with a predilection for the posterior circulation, causing a unique pattern of vasogenic cerebral edema. Clinical symptoms include headache, altered mental state, and visual disturbances often associated with seizures or status epilepticus. Cases of PRES were originally described in the context of hypertension (hence the term "hypertensive encephalopathy"), pregnancy, and immunosuppression. It is now recognized to be associated with many different pathological processes (Table 16.2). The underlying pathophysiological cause of PRES is not fully established but it is thought to involve endothelial injury, failure of vascular autoregulation mechanisms, cerebral hyperperfusion or hypoperfusion.

Unenhanced CT may be normal but changes of subcortical low attenuation vasogenic edema can be seen in more severe cases (Fig. 16.2a). Generally, MRI is preferred to CT for the detection of PRES. The typical, parieto-occipital pattern of PRES on MRI consists of symmetrical, T1-hypointense, T2-hyperintense cortical and subcortical regions of vasogenic edema in the posterior circulation (Fig. 16.2b, c). The parieto-occipital white matter is affected in approximately 97 % cases. PRES

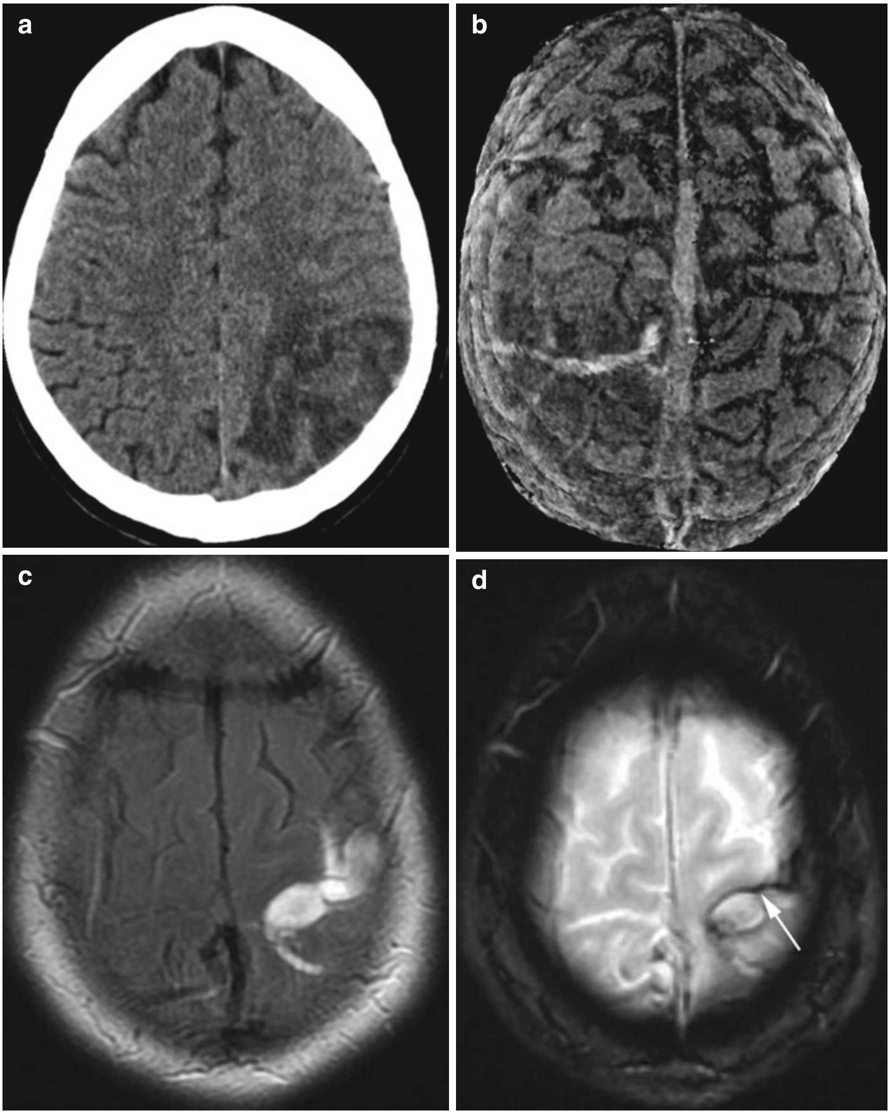

Fig. 16.1 Cortical vein thrombosis. (**a**) CT demonstrates a cortically based infarction in the left parietal lobe. (**b**) 3D reconstruction shows a hyperdense, thrombosed cortical vein ("cord sign") which is difficult to appreciate on axial images. FLAIR (**c**) and gradient recalled echo (**d**) (T2*) images in a different patient demonstrate FLAIR hyperintensity in the region of the left precentral gyrus; T2* images show low signal in the thrombosed cortical vein (*arrow*)

can also affect the basal ganglia and deep white matter. Involvement of the brain stem and cerebellum can cause an obstructive hydrocephalus.

The main differential diagnosis is ischemic stroke. Diffusion weighted imaging can help differentiate PRES from ischaemia. Angiographic studies may demonstrate

Table 16.2 Risk factors for developing PRES

Preeclampsia/eclampsia
Immunosuppression with cyclosporin or tacrolimus after bone marrow or solid organ transplantation
High-dose multidrug cancer chemotherapy
Autoimmune diseases
Nephrotic state
Thrombotic microangiopathies
Sepsis
Shock
Moderate to severe hypertension

diffuse vasoconstriction or focal areas of vasoconstriction and vasodilatation with a "string of beads" appearance due to vasospasm or vasculopathy. Characteristically, imaging changes and clinical symptoms are fully or near fully reversible after normalization of blood pressure or cessation of other causative factors.

Antibody-Mediated Encephalitis

Antibody mediated encephalitis is a rare condition primarily affecting the hippocampus and limbic region ("limbic encephalitis"). Patients typically present with amnesia, confusion, seizures and personality changes or psychosis. It can be associated with a variety of antibodies directed at neuronal cell surface proteins or intracellular targets. The presence of these antibodies is frequently associated with malignancy, particularly in small cell lung carcinoma, breast and testicular cancers, as well as thymoma. Encephalopathy with NMDA receptor antibodies was first identified in young women with ovarian teratomas.

Seizures are a major feature of encephalitis associated with antibodies directed against VGKC, NMDA and GABA-B receptors, as well as with high titers of GAD65. Of note, a growing body of evidence suggests that some of the autoantibodies may play a role in chronic epilepsy without manifesting limbic encephalitis symptoms.

MRI can be normal in up to 45 % of patients. If present, imaging findings include unilateral or bilateral temporal lobe FLAIR hyperintensity (Fig. 16.3a, b). NMDA receptor antibodies may cause a more diffuse process extending beyond the temporal region. In later stages the process may evolve into mesial temporal sclerosis leading to chronic temporal lobe epilepsy. Suspicion of antibody-mediated encephalitis should prompt a thorough search for an underlying malignancy, which may include pelvic or testicular ultrasound, mammography, CT, and PET.

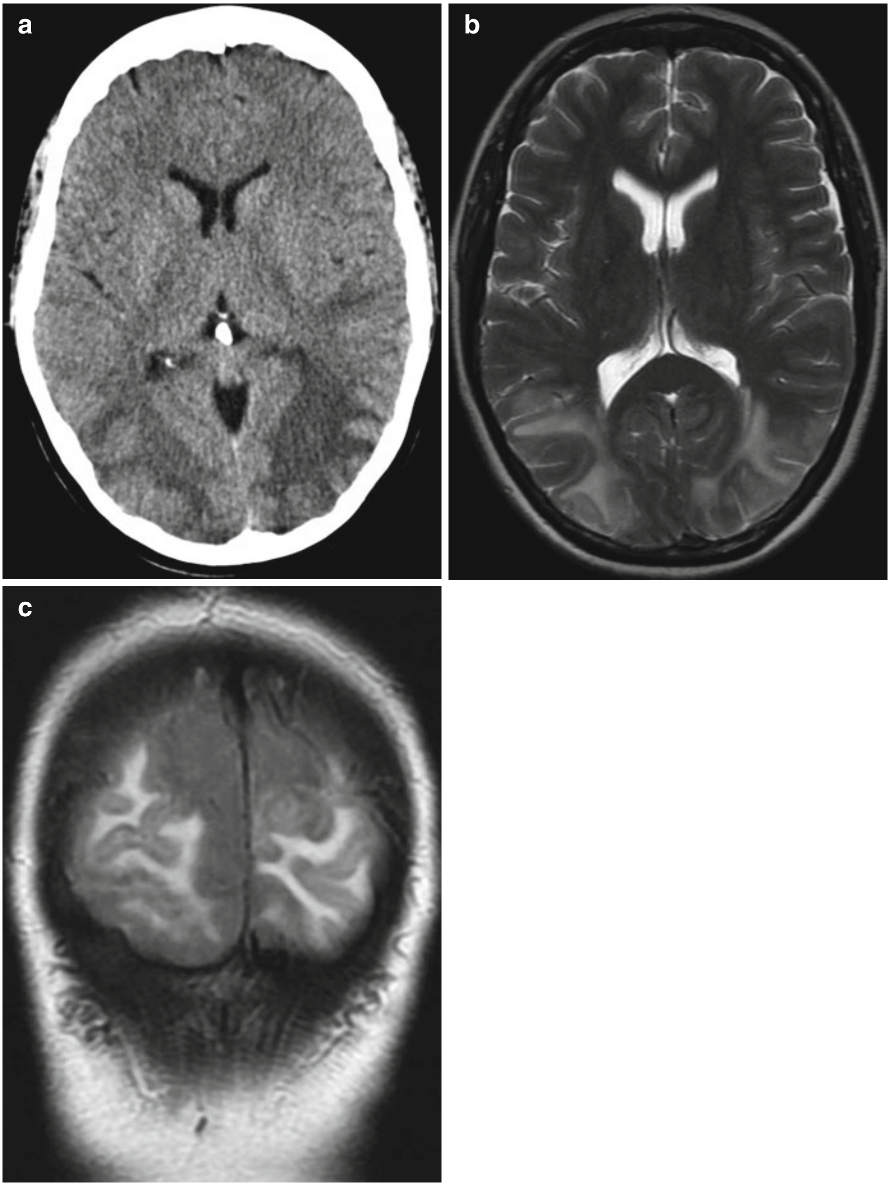

Fig. 16.2 Posterior reversible encephalopathy syndrome. (**a**) CT demonstrates bilateral areas of cortical and subcortical low attenuation in occipital lobes; corresponding T2-weighted (**b**) and coronal FLAIR (**c**) images of the most typical distribution

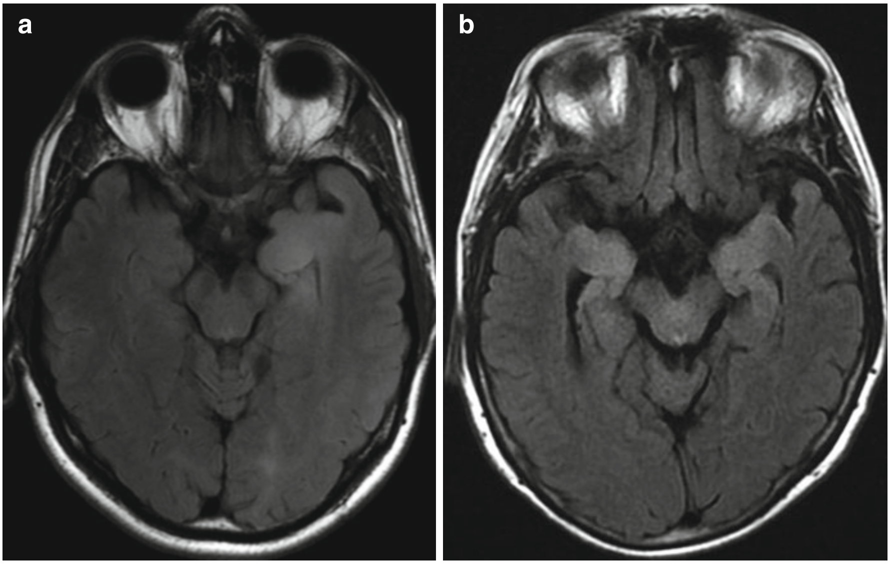

Fig. 16.3 Antibody-mediated encephalitis. (**a**) Unilateral high signal intensity in a patient with NMDA-receptor mediated encephalitis on a background of ovarian teratoma. (**b**) Bilateral changes in a patient with potassium channel antibodies

Transient Postictal Changes

Seizure activity causes many pathophysiological changes in the brain including hyperperfusion and increased blood-brain barrier permeability with the development of focal cytotoxic or vasogenic edema. On CT this manifests as focal gyral swelling, effacement of cortical sulci, as well as a region of low attenuation in the area of epileptogenic discharge. On MRI several characteristic postictal imaging patterns have been described depending on the location of the seizure focus and the underlying cause (Fig. 16.4a–c):

- A hippocampal pattern can be seen in temporal lobe epilepsy as restricted diffusion and enlargement of the hippocampus, usually unilateral and involving the side of seizure focus but can be bilateral. In some cases this may develop into hippocampal atrophy.
- A cortical pattern can be seen following hypoxia or hypoperfusion and is characterized by restricted gyral diffusion in the cortex corresponding to the seizure focus as well as functionally connected regions such as the ipsilateral posterior thalamus and the contralateral cerebellar hemisphere (crossed cerebellar diaschisis).
- The third pattern can be associated with bitemporal seizures, seizures related to metabolic factors, as well as antiepileptic drug withdrawal, and manifests as restricted diffusion in the splenium of corpus callosum.

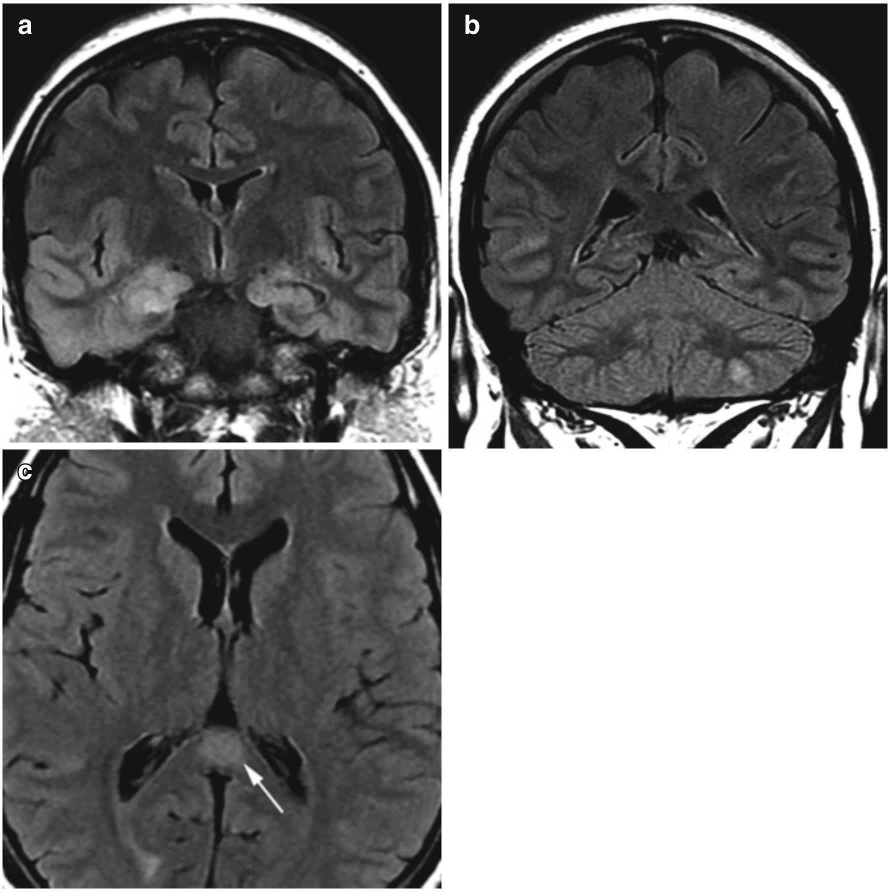

Fig. 16.4 Transient postictal changes. (**a**) Coronal FLAIR images demonstrate bilateral high signal in temporal lobes, more pronounced on the right with associated swelling of the hippocampus. (**b**) Cortically based high signal in contralateral cerebellar hemisphere, likely due to a crossed cerebellar diaschisis. (**c**) FLAIR images in a different patient demonstrating a postictal lesion in the splenium of a corpus callosum (*arrow*)

Awareness of the above imaging findings is important to avoid diagnostic error. Unenhanced CT findings of cortical and subcortical low attenuation can be misinterpreted as ischemic stroke. Cases in which thrombolytic therapy was erroneously administered have been described. MRI appearances may be misleading due to diffusion restriction in the region of seizure-associated cytotoxic edema mimicking an ischemic infarct. CT perfusion or MRI perfusion imaging may be helpful to differentiate these conditions by demonstrating increased blood flow in the region affected by seizures, in contrast to hypoperfusion in ischemia. Depending on the location there may be an overlap of postictal MRI changes with those seen in PRES, limbic encephalitis, and herpes encephalitis. As these conditions are typically associated with seizures, it may be difficult to know if imaging changes represent the cause, or the result of epileptic discharge.

Teaching Points

1. Seizures may be seen in critically ill patients with or without preexisting intracranial pathology.
2. New onset seizures, change in the seizure pattern, and refractory epilepsy should be considered as indications for neuroimaging, especially if associated with changes in neurological status or a new focal deficit.
3. The suggested first line investigation is an unenhanced CT, which allows exclusion of hemorrhage and gross structural changes.
4. MRI has an advantage in evaluating the brain parenchyma and plays a crucial role in the diagnosis of posterior reversible encephalopathy syndrome and encephalitis as the cause of seizures.
5. Postictal imaging findings need to be differentiated from ischemic stroke, posterior reversible encephalopathy syndrome, and encephalitis.

Chapter 17
Altered Level of Consciousness

Christoph Terborg and Roland Brüning

Clinical Problem

A 28-year-old, previously fit and well female had been admitted to the ICU 3 days ago after a complicated birth of twin babies. She suffered severe post-partum haemorrhage, had to be massively transfused before she eventually had to undergo a hysterectomy in order to control the bleeding. Once she had been stabilised and no further intervention was necessary she was extubated on day 2. She became hypercapnic post extubation and was supported with non-invasive ventilation. On crude examination she appeared neurologically intact and was drowsy but rousable. Before discharge to the High Dependency Unit she suddenly became unresponsive and did not show adequate reaction to painful stimuli. Her pupils were equal in size but reacting sluggishly to light; her vital signs remained unchanged.

The term "decreased level of consciousness" describes an impaired level of perception beginning with slowness and drowsiness, which can rapidly deteriorate to coma. Consciousness depends on both an intact brain stem as well as cortical and subcortical structures. A decreased level of consciousness can be the result of a wide range of cerebral and extra-cerebral processes, affecting these structures either directly or indirectly.

An altered level of consciousness often indicates a serious and potentially life-threatening disease. Since the causes are diverse and he clinical signs are non-specific a systematic approach to diagnosis and treatment is mandatory.

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Initial Clinical Evaluation

The physical examination of an unconscious patient requires the standard review of airway, breathing and circulation. Immediate resuscitation has to be initiated if required. Once cardiorespiratory stability is established an extended physical examination should be performed. Laboratory investigations and radiological examinations may be required to further evaluate underlying etiology. Where possible witnesses and relatives should asked in order to clarify the past medical history and the circumstances leading to the acute picture. The neurological examination should determine where on the Glasgow-Coma-Scale (GCS) the patient scores.

Symptoms such as neck stiffness indicate meningitis or subarachnoid haemorrhage, however meningism may be absent in comatose patients with these conditions. In suspected infra-tentorial CNS lesions cranial nerve examination with an emphasis on gaze, pupils and their reaction to light is important. Motor system evaluation should include muscle tone, strength and symmetry including reaction to painful stimuli. Sensory testing often consists of a rudimentary assessment of reaction to painful stimuli. Increased deep tendon reflexes and Babinski's reflex may indicate central motor lesions. The assessment of a complete neurological examination is limited in a non-cooperative patient; in sedated, ventilated and paralyzed patients it is impossible.

Differential Diagnosis

The temporal evolution of an altered level of consciousness (acute onset, chronic progressive, relapsing-remitting) and a careful neurological examination provide important informations to the location of the lesion and the probable pathophysiology. This knowledge enables target-oriented radiological imaging and interventions.

Traumatic Brain Injury

Traumatic brain injury is discussed in detail in Chap. 40. Loss of consciousness is often associated with amnesia, which might be retrograde, anterograde, or both. Clinical examination should assess for visible injuries of the skull, face and back as well as neurological deficits like impaired consciousness, hemiparesis, hemihypesthesia, unequal pupils, or signs of spinal cord injury. If a patient is comatose and/or sedated and ventilated but not paralyzed the examination is restricted to brainstem reflexes, motor tone, the reaction to painful stimuli, tendon reflexes and Babinski's sign.

A CT scan of the head should be performed routinely if GCS is <15. Clinicians need to keep in mind that the size of lesions caused by traumatic brain injury may increase within the first hours, possibly making follow-up, or even serial CT-scans necessary in some cases. A MRI of the head is usually not required in the acute phase of traumatic brain injury.

Cerebrovascular Disorders

Cerebrovascular disorders are the most common causes of acute changes in levels of consciousness. Patients usually have acute neurological deficits and may have a drop in their GCS. If a patient presents with an acute stroke, cerebral imaging needs to be undertaken as soon as possible, since intravenous thrombolytic therapy should only be administered within the first 4.5 h after symptom onset after an ischemic stroke. Stroke is described in more detail in Chap. 14.

CT has limited value as a tool in the diagnosis of early infarction as it may not show an ischemic demarcation. Ischemic infarction of the brain stem can be detected with higher sensitivity by diffusion-weighted MRI imaging. However, this might not be feasible in emergency situations.

Brain edema can transform large infarcts following occlusion of the middle cerebral artery (MCA) or the distal internal carotid artery into space-occupying lesions within 2–10 days. Patients may suffer from increased intracranial pressure with headache, vomiting, and secondary deterioration in their level of consciousness. A large trepanation may be made in selected patients within the first 48 h to prevent a malignant cerebral edema and a transtentorial or transfalcine herniation (Fig. 17.1a–b). A large infratentorial infarct with secondary brain edema may cause a hydrocephalus through obstruction of the fourth ventricle and the aqueductus cerebri, leading to a subsequently reduced level of consciousness (Fig. 17.1c–d).

Spontaneous intra-cerebral hemorrhage is the cause of 10–15 % of strokes. Compared to ischemic strokes it carries a poorer prognosis, and the 3-month mortality is reported to be up to 40 %. Neurological symptoms depend on the site and size of the bleeding. Intracranial hypertension occurs when the hemorrhage exceeds a critical volume. The clinical signs are non-specific and urgent imaging with CT or MRI is required when the index of suspicion is high (Fig. 17.2a–c).

In case of subarachnoid hemorrhage cerebral aneurysms or vascular malformations must be excluded (Fig. 17.2d–f). CT angiography (CTA) or MR angiography (MRA) should be considered as first diagnostic step. However, invasive angiography is still the gold standard in cases of subarachnoid hemorrhage, as CTA or MRA may miss small aneurysms of the basal cerebral arteries.

Atypical spontaneous intracerebral hemorrhage can be caused by cerebral sinus thrombosis. The bleeding is localized near the occluded vein. Venous angiography with contrast CT or MR-angiography is the imaging modality of choice to detect sinus thrombosis. Catheter angiography is only required in indeterminate cases.

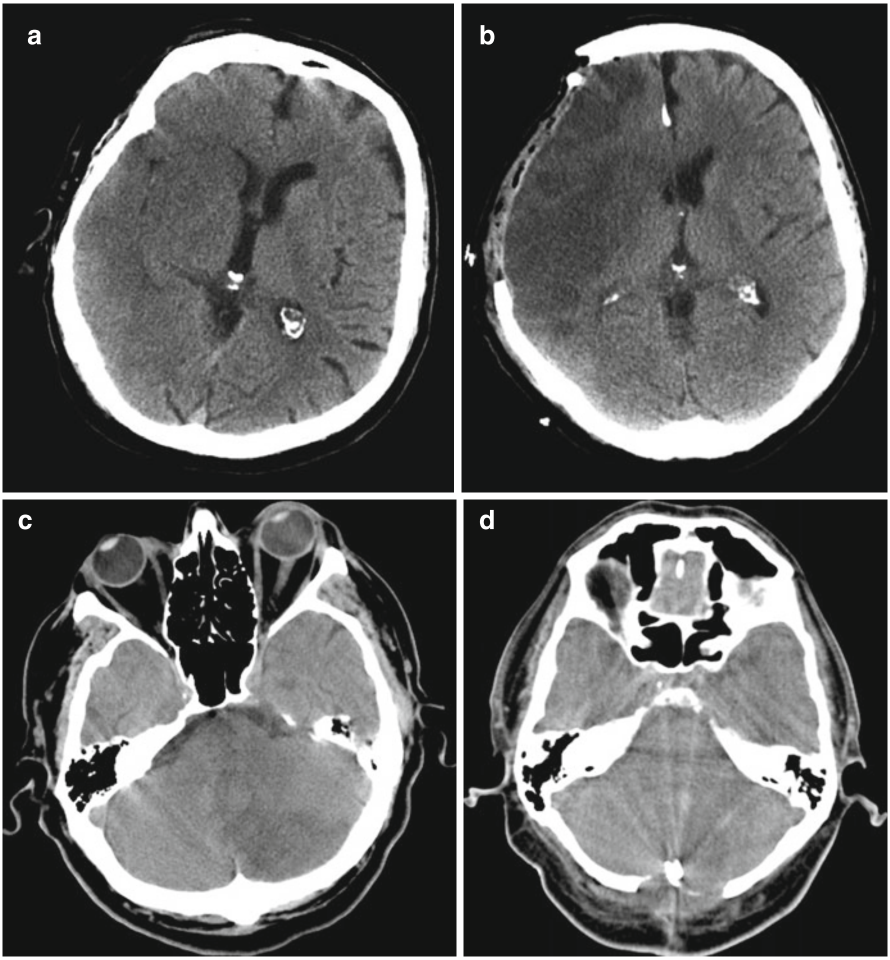


Fig. 17.1 Space-occupying MCA-infarction before (**a**) and after osteoclastic trepanation (**b**); space-occupying PICA-infarction at onset (**c**) and after suboccipital craniectomy (**d**)

Meningitis, Encephalitis and Sequelae from Infective Endocarditis

Infections of the meninges or the CNS due to bacterial, viral, fungal or parasitic microorganisms may present with broad array of unspecific symptoms including fever, altered level of consciousness and focal neurological deficits. These conditions are potentially life-threatening, but if the diagnosis is made early successful antimicrobial treatment is often possible. Infections of the central nervous system are described in more detail in Chap. 15.

Acute bacterial meningitis constitutes a neurological emergency requiring rapid antibiotic treatment. Patients present with fever and severe headache, the neurologic examination usually reveals meningeal signs such as neck stiffness. Low GCS and confusion or agitation are further non-specific, but nevertheless alarming symptoms. The CT-scan may reveal diffuse brain edema, parenchymal involvement in

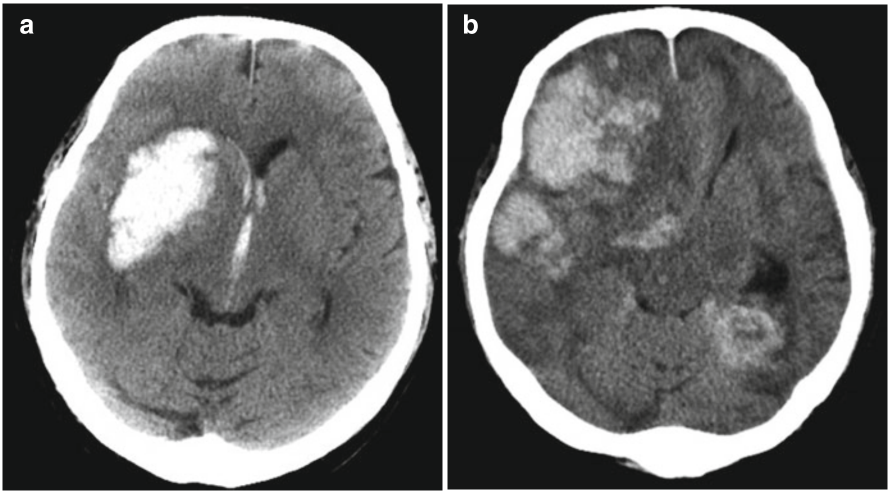
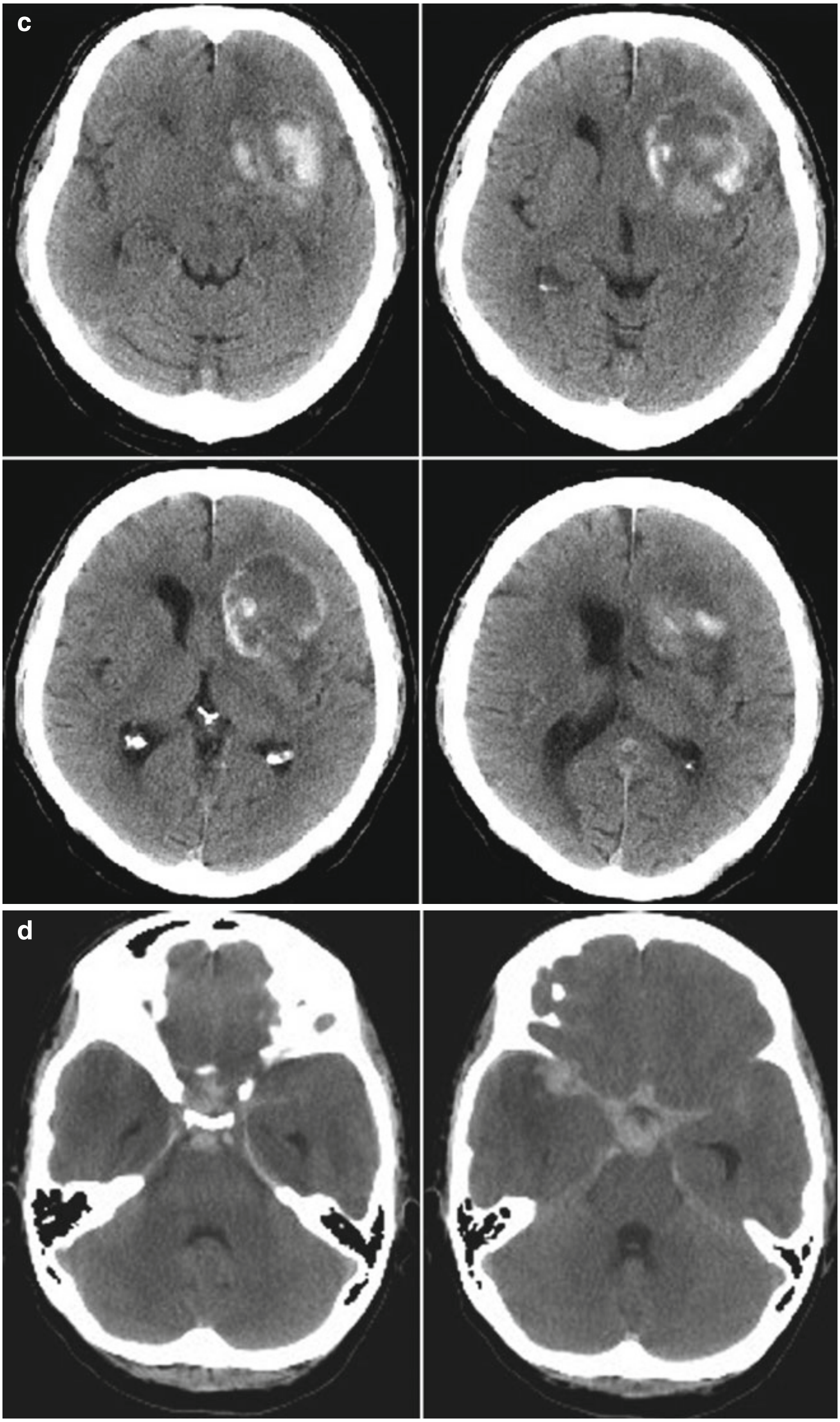


Fig. 17.2 Unenhanced CT images of spontaneous intracerebral haemorrhage. (**a**) Due to hypertension; (**b**) due to a coagulation disorder; (**c**) tumor hemorrhage (nativ and with contrast media); (**d**, **e**) subarachnoid hemorrhage due to an aneurysm of the right middle cerebral artery; (**f**) CT Angiogram showing the aneurysm



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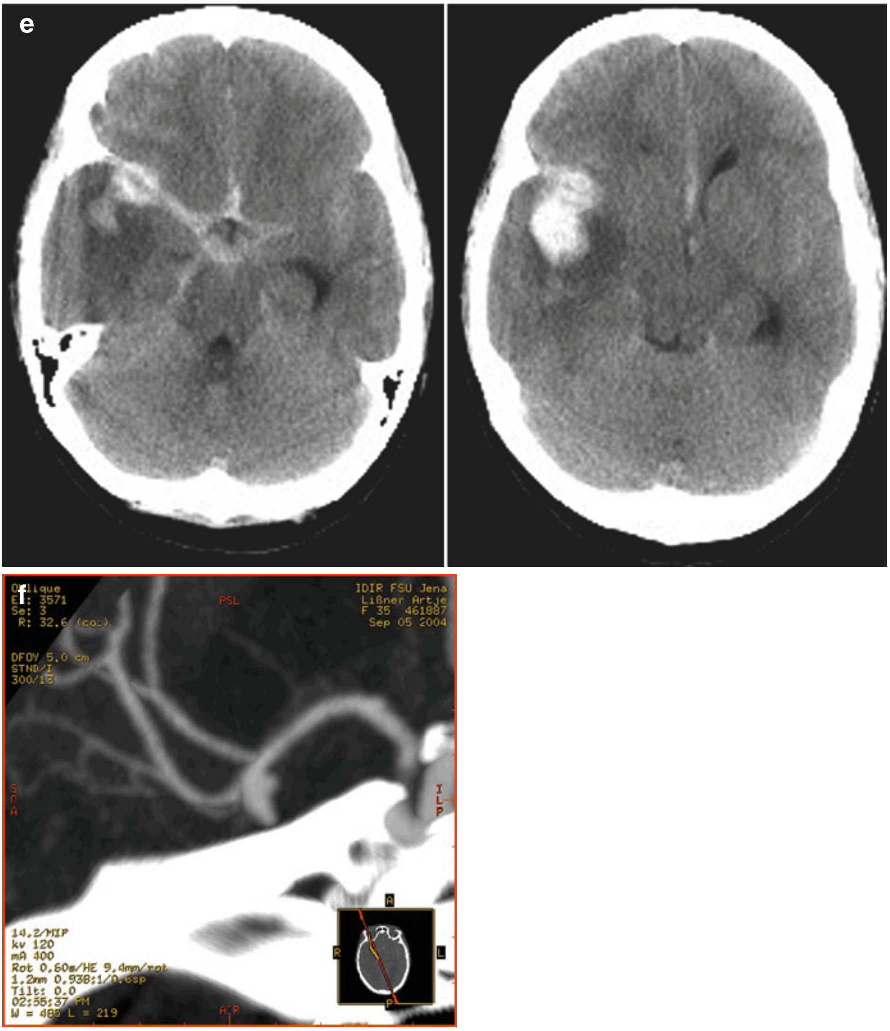

Fig. 17.2 (continued)

cases of meningoencephalitis, malresorptive hydrocephalus, and on rare occasions, ischemic stroke due to cerebral vasculitis, which is a typical complication of the disease (Fig. 17.3a–d). A lumbar puncture may be performed after a mass effect has been excluded by CT imaging.

Thrombotic or bacterial emboli causing ischemic stroke, meningitis, or embolic encephalitis are regularly seen as complication of infective endocarditis (IE). As in other central nervous infective processes the symptoms are unspecific and include seizures, focal neurological signs and a decreased level of consciousness. In the course of the disease brain abscesses may develop in isolated cases. If the diagnosis of infective endocarditis is established, the embolic source must be identified and treatment must be initiated at once. MRI involving unenhanced and contrast enhanced images is superior to CT for the detection of cerebral emboli, and MRA may reveal mycotic aneurysms.

Encephalopathies

A decreased level of consciousness secondary to metabolic disorder or intoxication is a common occurrence in intensive care. Metabolic or toxic encephalopathies are usually associated with stupor, coma and seizures. Focal neurological signs are

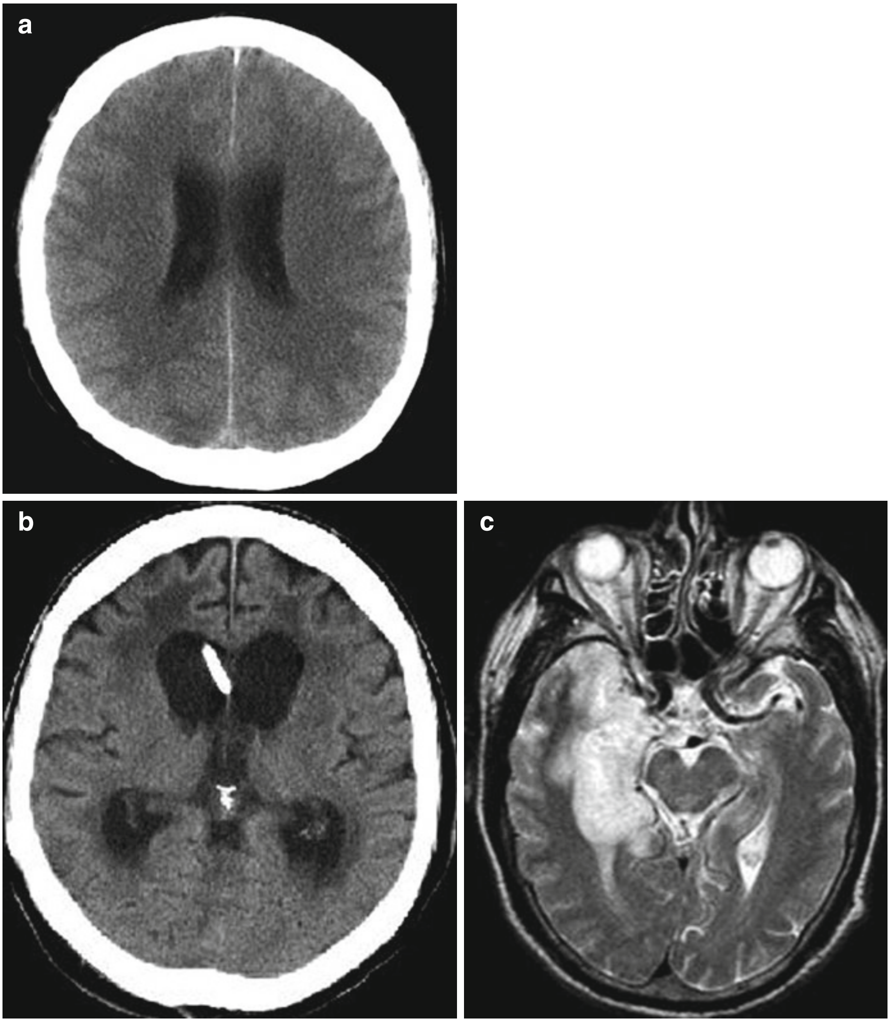

Fig. 17.3 CT of a patient with bacterial meningitis. (**a**) Diffuse brain edema. (**b**) Hydrocephalus. (**c**) Herpes simplex-encephalitis with temporal lobe involvement in T2 weighted MRI imaging. (**d**) Multiple cerebral emboli complicating bacterial endocarditis in diffusion weighted imaging MRI

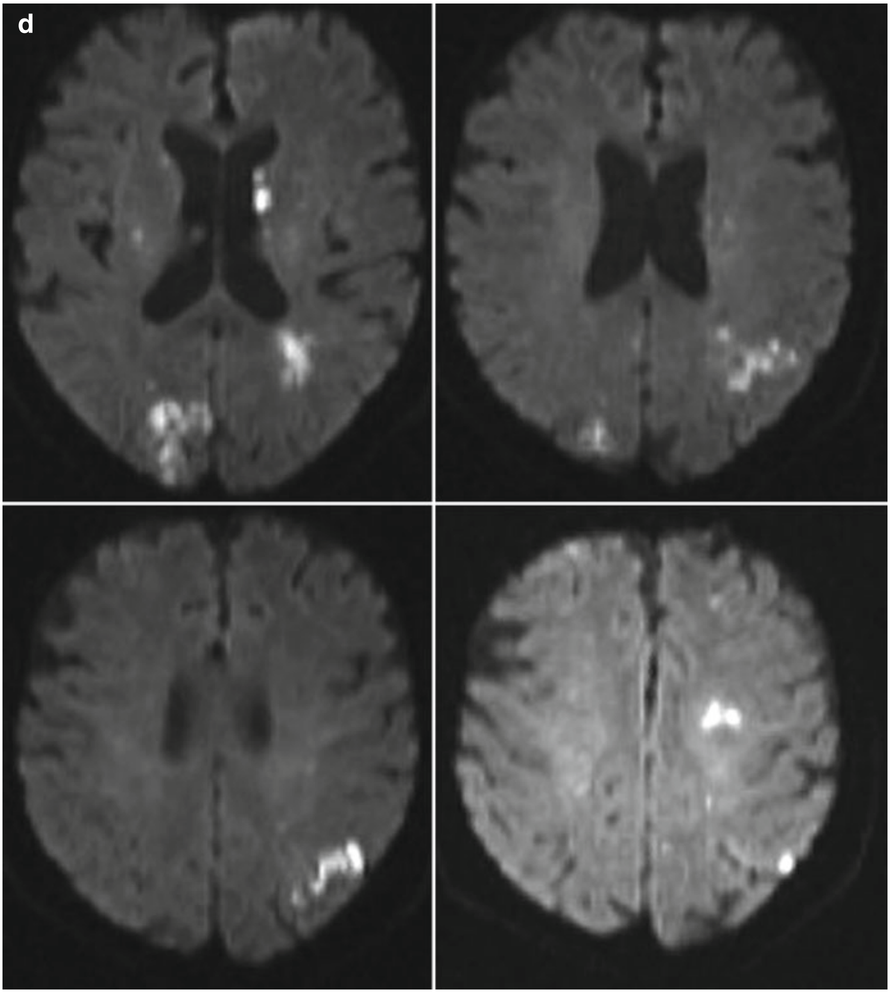

Fig. 17.3 (continued)

uncommon, and symptoms often resolve if the metabolic disorders are appropriately treated. The diagnosis can often be made by taking a careful history, the exclusion of focal neurological signs and laboratory tests. Neuroimaging usually is unremarkable, but is mandatory to exclude other causes of reduced level of consciousness in the absence of an obvious metabolic cause.

Hypoxic encephalopathy after cardiac arrest may be detected by CT but often only shows only a transient cerebral edema and remains otherwise unequivocal. MRI is more sensitive to ischemic lesions. DWI-weighted images can show cytotoxic lesions located in regions with a high metabolic demand, particularly the cerebral gray matter (Fig. 17.4a–b).

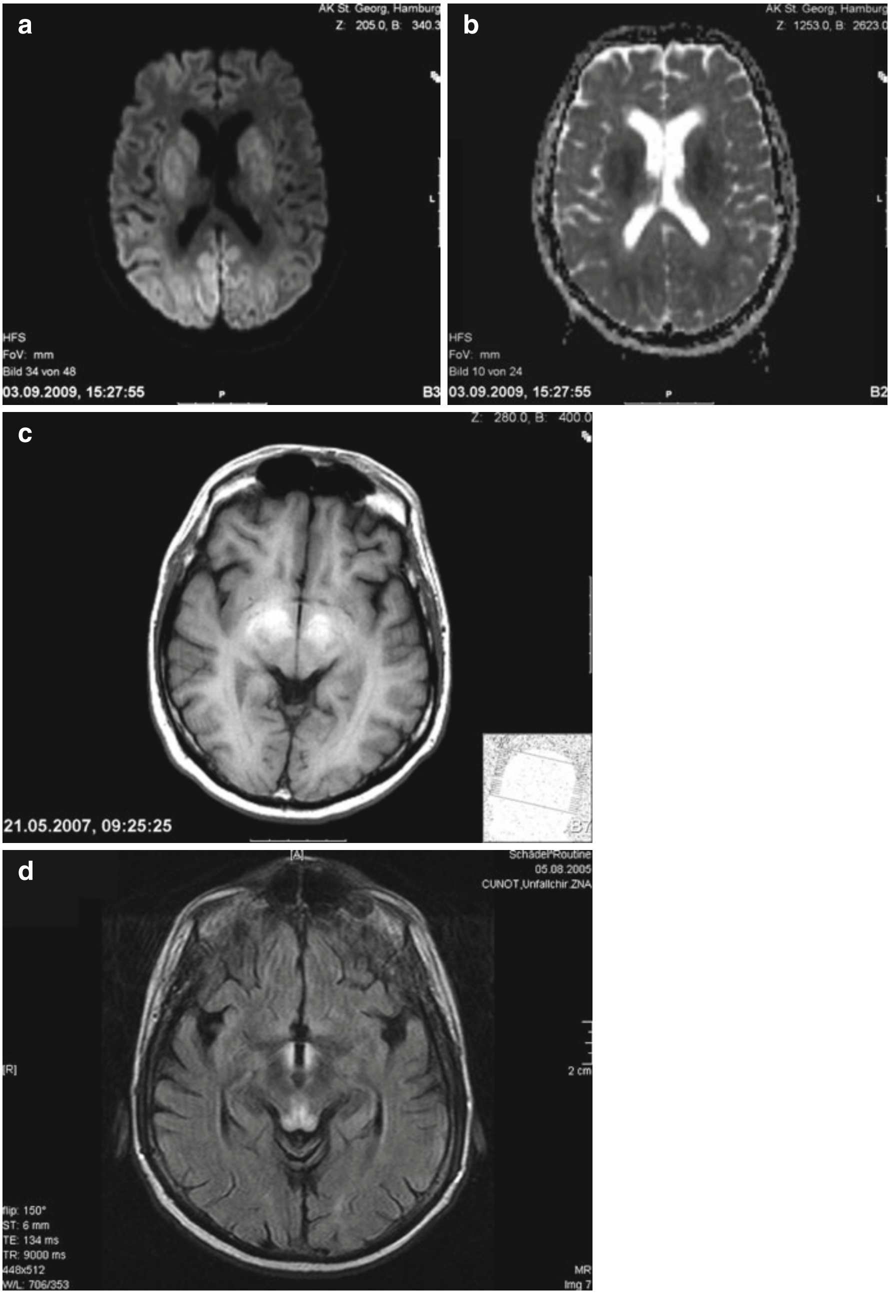

Fig. 17.4 Cytotoxic edema in cerebral grey matter. DWI images (**a**) and corresponding ADC (**b**) map in a patient with hypoxic encephalopathy after cardiac arrest. (**c**) T1-weighted MRI in a case of hepatic encephalopathy. (**d**) FLAIR images of Wernicke's encephalopathy

Whereas neuroimaging of encephalopathies due to electrolyte disturbance is often unremarkable, hepatic encephalopathy may show T1-hyperintense lesions typically located in the basal ganglia (Fig. 17.4c). In septic encephalopathy the MRI may show signs of a reversible posterior encephalopathy due to an interstitial cerebral edema predominately located in the posterior parts of the brain. In patients with Wernicke's encephalopathy after chronic alcohol abuse, FLAIR and especially thin section T2-weighted MRI may show typical lesions in both mamillary bodies, the thalami and the periaqueductal grey matter of the midbrain (Fig. 17.4d). MRI may also reveal central pontine myelinolysis with hyperintensities in the central pons on T2-weighted images in patients with alcoholism or sodium disturbances.

Teaching Points

1. In patients with reduced conscious level of uncertain nature, CT can be used as an emergency tool, but cerebral MRI is superior to CT for the characterisation and is the preferred modality when available.
2. In patients with a decreased level of consciousness due to metabolic disorders, neuroimaging may be used to exclude common causes of structural brain injury

Chapter 18
Brain Death

Ruth Thiex and Sebastian Schulz-Stübner

The concept of brain death evolved when developments in critical care in the second half of the 20th century made it possible to sustain the cardiorespiratory functions of the body in the absence of brain function. In 1995, the American Academy of Neurology (AAN) published guidelines defining the medical standards for the determination of brain death and revised them in 2010. There is no published report of recovery of neurologic function after the diagnosis of brain death has been made according to these practice standards.

Brain death is defined as the complete and irreversible loss of all brain functions, including those of the brainstem. The mandatory diagnostic criteria for legal definition and declaration of brain death vary worldwide, even within different countries of the European Union or between States within the US, based on statutory tradition. Only very few countries do not accept brain death as a legal definition of death.

In adults, the most common causes of brain death are severe head injury and subarachnoid hemorrhage.

Clinical Examination

The gold standard for the determination of brain death is a series of neurologic tests, which may only be carried out if a number of prerequisites are met:

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Table 18.1 Clinical criteria for brainstem death

Coma	No motor response to painful stimuli (e.g., pressure on supraorbital nerve, painful stimulus to nail bed or sternum)
Absent brainstem reflexes	Pupils mid-size or dilated, no response to bright light
	No oculocephalic reflex (no grimacing nor eye opening with deep pressure on both condyles of the temporomandibular joint)
	No corneal reflex when wiping the cornea with cotton wool
	No oculovestibular response toward the side of the cold stimulus when ice water is injected into the external ear canal
	No cough reflex on bronchial suctioning
	No gag reflex on stimulation of the posterior pharynx
Apnea	No respiratory effort when patient is disconnected from the ventilator and CO_2 is allowed to at least 20 mmHg above baseline

- The cause of coma is known with a high degree of certainty and is demonstrably irreversible. That implies that the clinical or neuroimaging evidence of a central nervous system catastrophe is consistent with irreversible loss of brain function.
- Medical conditions that may confound clinical assessment, such as hypothermia, severe hypotension or severe electrolyte, acid-base and endocrine disturbances must be corrected.
- Drug intoxication, poisoning or neuromuscular blocking agents have to be ruled out.

The diagnosis of brain death is primarily clinical. No other tests are required if the full clinical examination including the brainstem reflexes and apnea test is conclusively performed.

The three cardinal findings in brain death are coma, absence of brainstem reflexes, and apnea (Table 18.1).

Confirmatory Tests

The role of confirmatory tests differs among countries but they generally are indicated when a specific part of the clinical examination cannot be performed or is deemed unreliable (Table 18.2).

In the United States, the choice of tests is left to the discretion of the physician. Confirmatory tests demonstrate either extinct brain function (electroencephalography, evoked potentials) or cessation of cerebral blood flow (cerebral angiography, radionuclide angiography, cerebral perfusion scintigraphy).

Cerebral Angiography

Four-vessel cerebral angiography has traditionally been the gold standard for documenting cessation of cerebral blood flow. The arterial circulatory arrest within the cranium develops in a distal-to-proximal direction as intracranial hypertension progresses. Thus, the level of contrast stop descends from the subarachnoid to the

Table 18.2 Conditions that may interfere with the clinical diagnosis of brain death and may require ancillary tests

Severe facial or cervical spine trauma confounding cranial nerve assessment
Preexisting pupillary abnormalities
Toxic levels of CNS-depressant drugs or neuromuscular blockage agents
Severe chronic pulmonary disease or obesity resulting in chronic retention of carbon dioxide

cervical levels (Fig. 18.1a–g). Cerebral angiography is conclusive if the flow in the posterior circulation ceases at the foramen magnum and at the petrosal portion of the carotid artery in the anterior circulation. The external carotid circulation generally is patent, and filling of the superior sagittal sinus may be delayed.

There have been a number of case reports about clinically brain-dead patients where angiography demonstrated persistent filling of intracerebral arteries. The phenomenon of persistent cerebral blood flow can be found when intracranial pressure has not exceeded cerebral perfusion pressure yet. The progressive deterioration of cerebral circulation until its complete arrest has been documented with serial angiography over a period of about 45 min. Isolated venous sinus visualization is not uncommon and occurs in up to 57 % of brain-dead patients. It represents trivial blood flow and confirms brain death. Persistent arterial flow does not exclude brain death, but the diagnosis should be confirmed either by means of repeated studies or other tests.

CT Angiography

Although conventional angiography remains the standard imaging method for cerebral circulatory arrest, CTA is emerging as an alternative. Conventional angiography is highly sensitive, but invasive, expensive and time-consuming. It exposes potential donor organs to toxic contrast material, and it requires an experienced neuroradiologist, potentially leading to delays. CTA confers a number of advantages such as lower invasiveness, wider availability and less operator dependence. It has been shown to have a sensitivity of 69.7–95 % compared with conventional angiography in a number of studies. However, a recent publication described residual contrast enhancement in pericallosal arteries and horizontal portions of the middle cerebral artery and/or the internal cerebral veins in up to 25 % of the clinically brain-dead patients. This mandates repetitive CTAs and increases the time window between clinical brain death and radiographic confirmation. Currently there is no international consensus about the use of CTA for the detection of cerebral circulatory arrest.

Transcranial Doppler Ultrasonography

The velocity waveform of the basal cerebral arteries changes in a characteristic way as circulatory arrest evolves. Four steps can be distinguished (Fig. 18.2a–c):

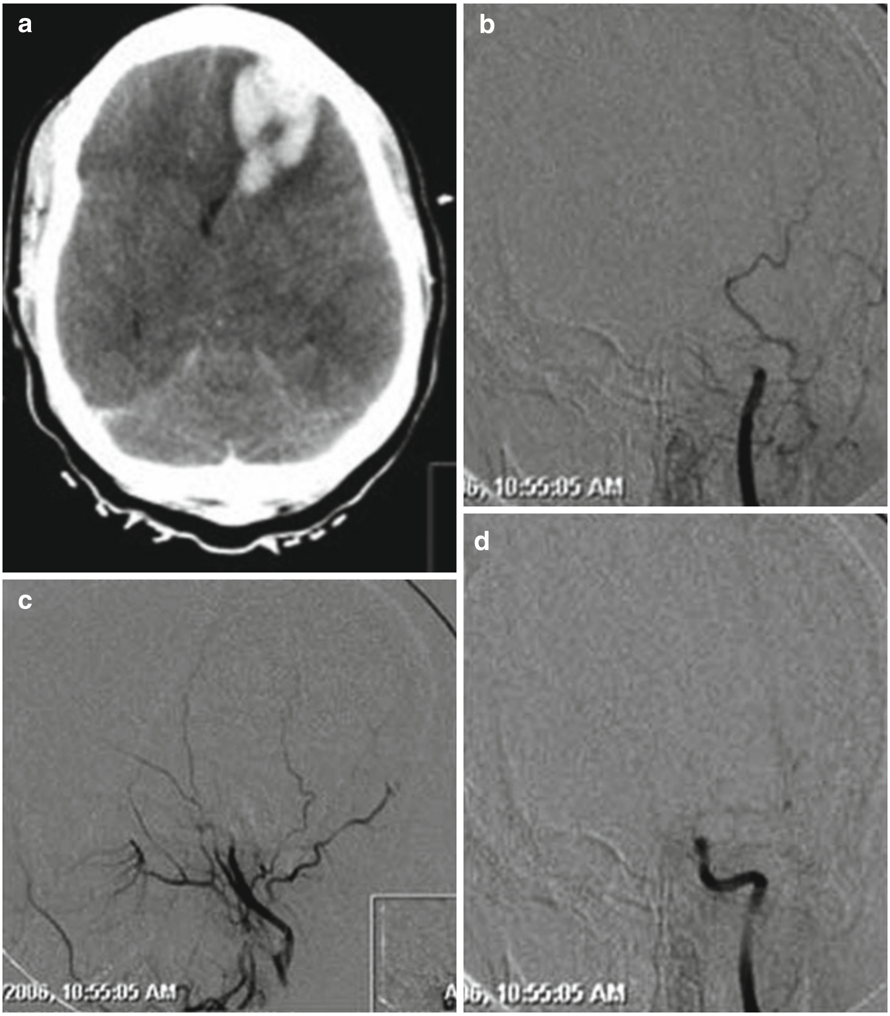

Fig. 18.1 Non-contrast computed tomography scan of the head (**a**) in an anonymous young female who was found comatose and tested positive for multiple drugs with evidence of a space-occupying left frontal lobar hemorrhage and diffuse brain edema. Cerebral angiography was pursued to rule out an underlying vascular anomaly. Left common carotid artery injection demonstrated cessation of flow distal to the supraclinoid segment of the left internal carotid artery in frontal (**b**, arterial phase; **d**, late capillary phase) and lateral plane (**c**, arterial phase; **e**, late capillary phase) leading to contrast stasis in the extradural segments of the left internal carotid artery. The left external carotid artery branches well opacified. Circulatory arrest at the foramen magnum was confirmed for the left vertebral artery (**f**, arterial phase; **g**, capillary phase) given the lack of opacification of any intradural segment of the left vertebral artery (Images courtesy of Darren B. Orbach, Interventional Neuroradiology, Boston Children's Hospital)

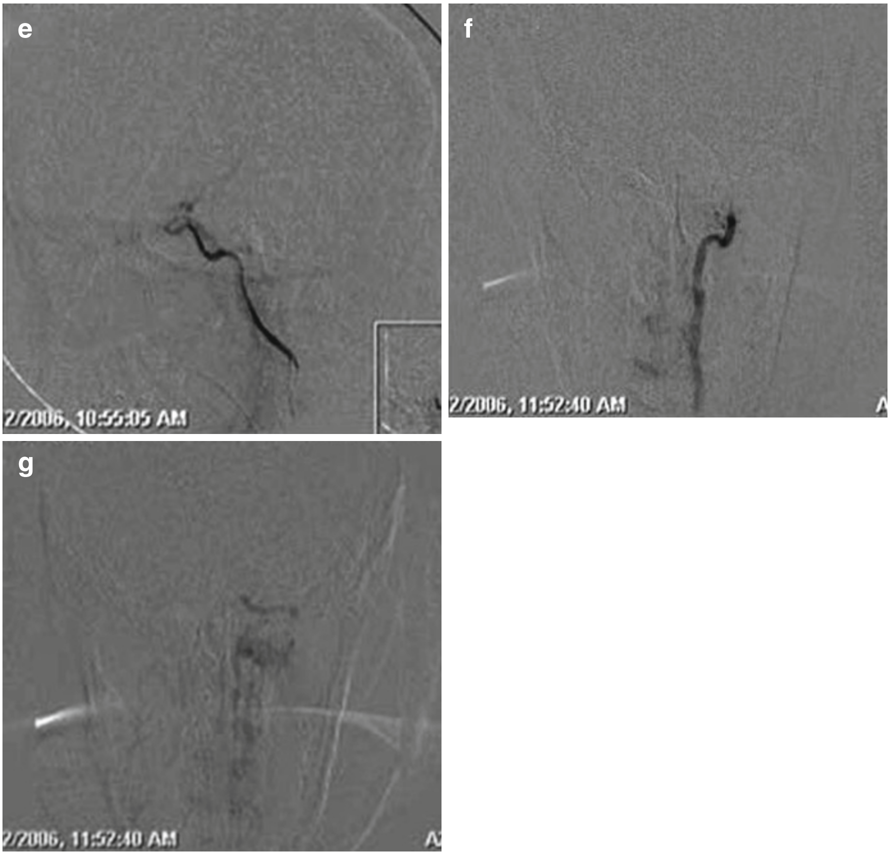

Fig. 18.1 (continued)

- Stage 1, *systolic peaks* – With increasing pulsatility, the flow velocity approaches zero at the end of diastole; therefore, only forward flow can be seen in systole.
- Stage 2, *oscillating flow* – Cerebral perfusion has ceased when forward and reverse flow is almost equal. This correlates with the angiographic appearance of cerebral circulatory arrest.
- Stages 3, *systolic spikes* – The hallmark of the third stage are *systolic spikes* as blood velocity decreases and intracranial pressure increases.
- Stage 4, *no signal* – No intracranial flow can be detected. This final stage mandates referencing with insonation of the extracranial internal carotid and vertebral arteries to rule out transmission problems.

Before using transcranial Doppler (TCD), the absence of brainstem reflexes should be ascertained as flow arrest in the middle cerebral arteries has been shown to precede the complete loss of brainstem function. The Task Force Group on

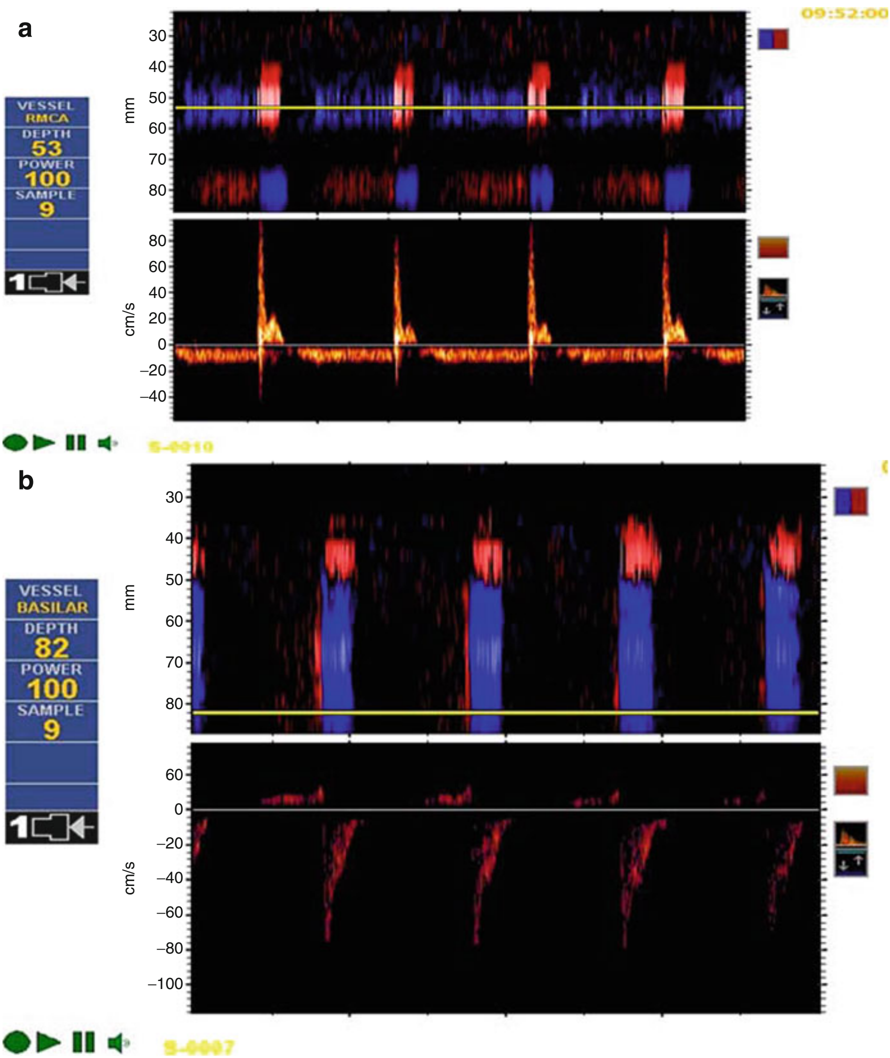

Fig. 18.2 A 54 year-old female patient with intracerebral hemorrhage from large right frontal AVM. Following staged embolization, the patient became unresponsive, hypotensive and progressed to deep coma with fixed and dilated pupils. Computed tomography of the head revealed rehemorrhage and contrast extravasation indicating a small perforation secondary to guide wire manipulation. The initial ICP readings were 40–50 mmHg despite the administration of mannitol, barbiturates and hypertonic saline. Doppler spectral wave forms and color M-mode display of the right middle cerebral artery (**a**) indicated antegrade flow in systole and retrograde flow in diastole or oscillating flow. TCD reading from the basilar artery (**b**) demonstrated oscillating flow. Recording of the left extracranial internal carotid artery (**c**) with spectrum analysis indicating systolic peaks (Images courtesy of Colleen Douville, Swedish Neuroscience Institute, Seattle)

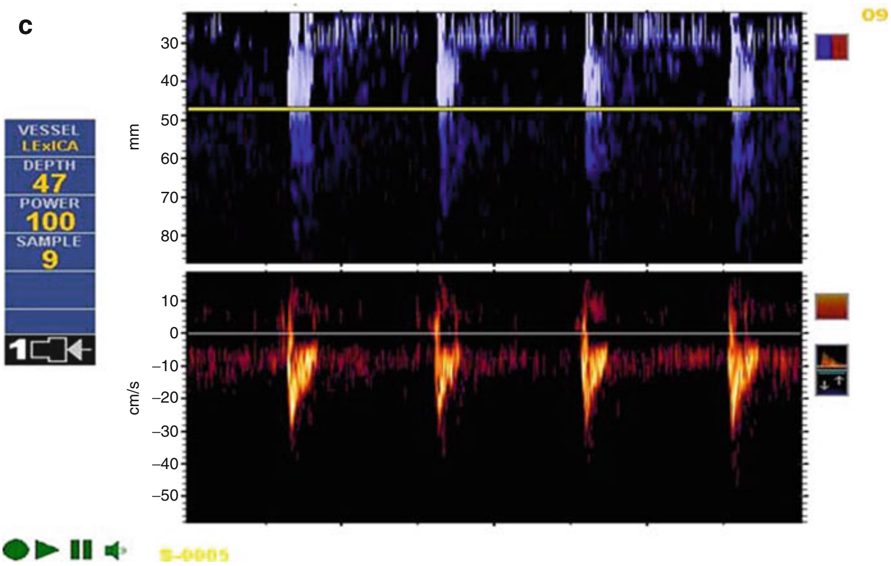

Fig. 18.2 (continued)

Cerebral Death of the Neurosonology Research Group of the World Federation of Neurology states that cerebral circulatory arrest can be confirmed if the extra- and intracranial Doppler findings have been documented bilaterally on two examinations at an interval of at least 30 min (Table 18.3).

The availability at the bedside and its non-invasive nature render TCD advantageous over cerebral angiogram as a confirmatory test. However, despite its high sensitivity of 95 % and specificity of 99 %, the widespread use of TCD is limited by its operator dependency and the fact that 5–10 % of patients cannot be examined because of the absence of a bone window or of no initial flow.

Nuclear Imaging

Radionuclide brain perfusion studies are costly, but correlate well with cerebral angiography. Delayed images are usually definitive for the presence or absence of cerebral blood flow. The advantages of cerebral perfusion scintigraphy are the direct visualization of perfusion of the cerebral cortex and brainstem, and hence brain viability because the radiopharmaceutical is taken up by grey and white matter in proportion to blood flow. It is tolerant of metabolic aberrations and pharmacologic intoxicants. The radiopharmaceuticals used in scintigraphy have no deleterious effects on potential donor organs. It is not affected by electrical interference, and the presence of skull defects does not preclude its use.

Table 18.3 Criteria allowing a the diagnosis of cerebral circulatory arrest by transcranial ultrasound

Oscillating flow with a net flow of 0 or systolic spikes found bilaterally in any cerebral artery
Systolic spikes <200 ms duration, peak systolic velocity <50 cm/s, no flow signal during the remaining cardiac cycle
The diagnosis established by the intracranial examination must be confirmed by the extracranial bilateral recording of the common carotid, internal carotid and vertebral artery. Complete absence of flow may not be reliable owing to inadequate transtemporal windows
Absence of a large craniectomy defect or ventriculostomy is mandatory as they interfere with the development of ICP

Radionuclide angiography is limited by being prone to technical failure as a result of inadequate bolus injection of the radiopharmaceutical when a non-brain binding agent such as diethylenetriaminepentaacetic acid (DTPA) labeled with ^{99m}Technetium is used. Brain-specific agents like ^{99m}Technetium-hexamethyl propyleneamine oxime (HMPAO) are advocated now because their interpretation is far less dependent on the quality of the bolus. Lack of visualization of the brain on delayed images could conceivably be caused by improper preparation or instability of the radiopharmaceutical. Flow images will help to confirm lack of brain blood flow when the brain is not visualized on delayed images using ^{99m}Tc-HMPAO. Radionuclide angiography carries an up to 25 % likelihood of showing persistent viable spots of brain tissue in clinically brain-dead patients.

Teaching Points

1. The diagnosis of brain death is primarily a clinical one.
2. Imaging can be indicated when the clinical tests are thought to be unreliable or it is impossible to carry them out.
3. Cerebral angiography is the gold standard. It is conclusive if the flow in the posterior circulation ceases at the foramen magnum and at the petrosal portion of the carotid artery in the anterior circulation.
4. CT angiography, transcranial Doppler or nuclear imaging offer alternatives but each have a number of limitations.

Part V
Chest Imaging

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Chapter 19
Hypoxia and the General ITU Patient

Caroline A. McCann and Nigel Scawn

Clinical Problem

A 45-year old lady with no relevant past medical history is admitted to ICU via the emergency department. She gives a history of cough since about 4 weeks and increasing shortness of breath since 5 days. She says she stopped smoking 5 years ago. On arrival in the ED her oxygen saturation on room air was 85 % but improved to 92 % with high flow oxygen through a facemask. On admission to the ICU she desaturates further. After a brief trial of non-invasive ventilation she is intubated and ventilated. She requires an FiO_2 of 1.0 and high airway pressures to maintain a PaO_2 of 48 mmHg.

Hypoxemia is a condition where low oxygen partial pressure in the blood leads to deranged cell function in peripheral tissues. Satisfactory hemoglobin oxygenation depends on adequate alveolar ventilation, diffusion from the alveoli into the pulmonary vasculature, and delivery of oxygenated blood by the circulation into cells.

Admitting patients with worsening respiratory function and increasing shortness of breath despite oxygen insufflation is a common occurrence for any intensivist. Arriving at a diagnosis swiftly in order to initiate the appropriate therapy can involve a number of imaging modalities.

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Imaging Techniques

The chest x-ray is the initial screening study in this scenario. It may identify disease of the lung parenchyma (infection, aspiration, inflammation, edema or tumor) or of the pleura (pneumothorax, or pleural effusion) and provides limited cardiac assessment. If the chest x-ray is normal, equivocal or non-specific early computed tomography is of great value in establishing accurate diagnosis to direct treatment in the deteriorating or critically ill patient. Computed tomography with intravenous contrast medium enables accurate assessment of the pulmonary arteries to evaluate for acute or chronic pulmonary embolism as well as enabling better evaluation of the lungs, heart and pleural space. CT can also be used to guide drainage.

Hypoxia Related to Neuromuscular Disease

This should be suspected if a patient's central respiratory drive or respiratory muscle power is diminished. This may or may not be obvious and the past medical history is important. Possible causes include central nervous system compromise due to infarction, hemorrhage, trauma or drugs, abnormalities of the thoracic cage, muscular weakness or neurogenic paralysis, metabolic or nutritional causes and endocrine disturbances.

Imaging of the chest may be unremarkable or show sequelae of the underlying condition and/or the respiratory complications. CT or MRI brain may highlight abnormalities compromising the respiratory center.

Hypoxia Related to Atelectasis or Collapse

The terms atelectasis and collapse are used interchangeably. Lobar and segmental de-aeration is generally referred to as collapse while the process in subsegmental areas is often called atelectasis. There are several mechanisms:

Obstructive or Resorptive Atelectasis

This is the most common type and results from resorption of air from the alveoli. It happens when communication between the distal airspaces and the trachea is interrupted, often due to mucus plugging or bronchial neoplasm. Other causes include extrinsic airway compression, post traumatic or inflammatory airway stenosis or intra-luminal foreign body.

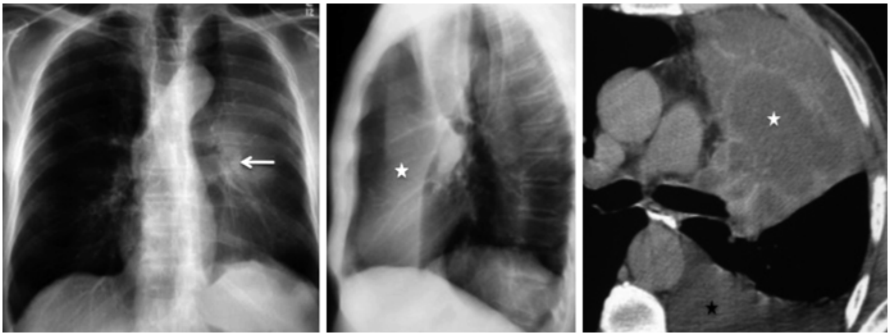

Fig. 19.1 A 57-year-old male smoker with haemoptysis. Frontal CXR (*Far left*): There is a veil like opacity in the left upper lobe (*arrow*) with volume loss as evidenced by hilar retraction, rib crowding and mediastinal shift. The collapsed lobe (*white star*) is demarcated by the major fissure on the lateral film (*mid panel*). Axial CT image (*far right*) demonstrates a necrotic mass extending from the left hilum (*white star*). Also note the left pleural effusion (*black star*)

Compressive or Passive Atelectasis

This can be caused by any entity occupying space within the thorax that compresses the lung and actively forces air out of the alveoli, or allows the lung to retract due to its intrinsic elastic recoil, e.g., pneumothorax, pleural effusion, bulla or mass.

Cicatrisation

This generally results from scarring/fibrosis where there is reduced lung compliance and lung destruction. It is often associated with bronchiectasis.

Discoid or Plate (Linear) Atelectasis

This form of atelectasis can result from insufficient surfactant when the alveoli collapse and adhere to each other preventing re-expansion. It usually has a band/line shape and can be caused by hypoventilation, ARDS as well as hyaline membrane disease. In adult patients it most commonly occurs with hypoventilation following surgery with poor post-operative analgesia.

In lobar collapse, the most important initial radiological feature is decreased volume of the affected lung enabling differentiation from consolidation. Other important signs include displacement of fissures, crowding of bronchovascular bundles, ill-defined heart or diaphragmatic borders, elevation of the hemidiaphragm, displacement of hila or mediastinum, and compensatory hyperinflation of adjacent lobes (Figs. 19.1, 19.2 and 19.3). More specific signs depend on the location of the

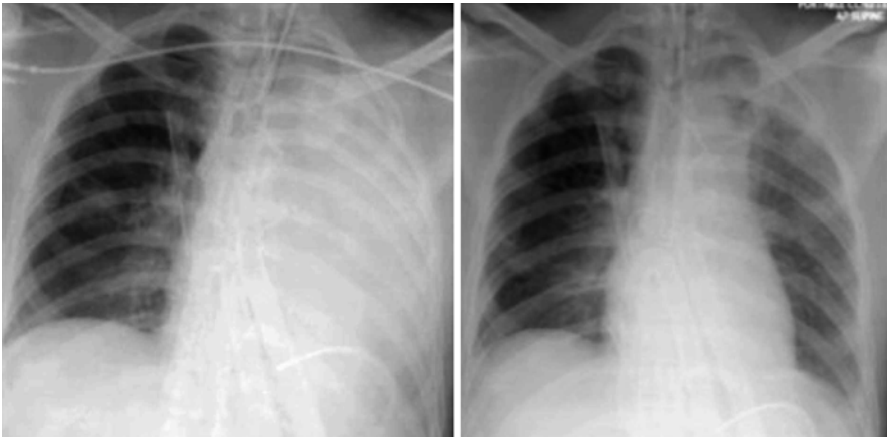

Fig. 19.2 Chest radiograph shows volume loss in the left upper lobe with an apical cavity with 'air crescent sign' (*arrow*) containing an intracavitory body (*star*) with adjacent pleural thickening. CT confirms findings typical of an aspergiloma (*star*)

Fig. 19.3 There is a triangular opacity behind the left heart (*white arrow*) indicative of left lower lobe collapse

affected lobe. While in longstanding obstructive atelectasis volume loss is marked early on in the setting of mucoid impaction volume loss may be less prominent.

Hypoxia Related to Pleural Disease

Pneumothorax

A pneumothorax is an air collection in the pleural space between parietal and visceral pleural layers. It may occur spontaneously or is associated with trauma or intervention. On an erect CXR, the pleural air usually collects apically and the

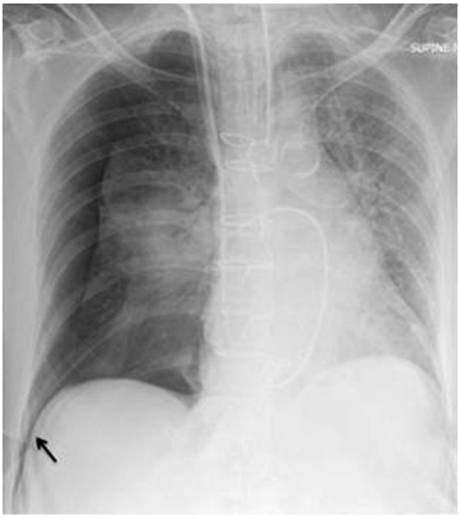

Fig. 19.4 Supine pneumothorax: Air tracks upwards in the supine position and presents as the deep sulcus sign (*black arrow*) rather than a typical apico-lateral lack of lung markings on an upright image. Also note the flattening of heart contour, increased rib spacing, increased lung volume and the collapsed lung with contralateral mediastinal shift

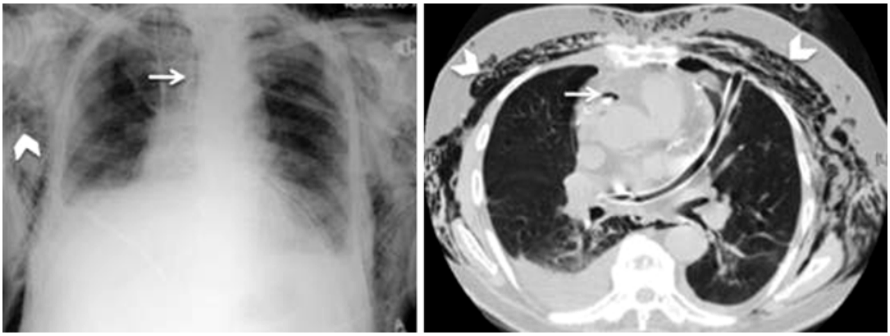

Fig. 19.5 Pneumomediastinum: Chest radiograph (*left*) in a 60-year-old male following cardiac surgery shows a linear area of right paratracheal radiolucency (*white arrow*). There is also extensive bilateral subcutaneous air (*arrowhead*). CT thorax (*right*, *arrow*) confirms the pneumomediastinum and surgical emphysema

visceral pleural lung edge is seen medial to the chest wall. On a supine film, the air within the pleural space will rise and be distributed beneath the anterior chest wall, making it more difficult to see. Useful signs to look for include: a sharply outlined diaphragm, the deep sulcus sign (Fig. 19.4), hyper-lucent right upper quadrant, air in the costophrenic or cardiophrenic sulci, and a sharply defined cardiac outline. There may be associated pneumomediastinum and subcutaneous emphysema as seen in Fig. 19.5. If there is difficulty in diagnosis, a lateral decubitus film or horizontal shoot through film will more accurately enable visualization of the anterior air. A pitfall in radiographic interpretation is the "pseudo-pneumothorax," which occurs when a skin fold is mistaken for a lung edge (Fig. 19.6). To distinguish between a skin fold and a true pneumothorax features to look for are continuation

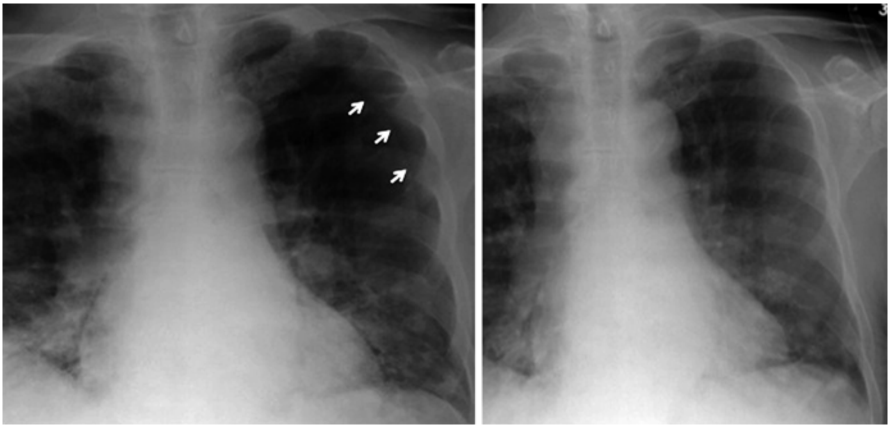

Fig. 19.6 Skin fold mimicking a pneumothorax: The left lung is outlined by a sharp edge (*white arrows*). Note that the lung peripheral to this edge is not hyperlucent, a clue that there is no pneumothorax. Redundant skin folds can give this appearance particularly on a supine film but changing patient position to an upright film (*right*) often differentiates it from a true pneumothorax

of the line outside the chest, bilateral appearances, and the presence of peripheral lung markings.

A loculated pneumothorax occurs usually as a result of attempted drainage of a simple pneumothorax but is also seen in patients with pre-existing pleural adhesions following inflammatory disease. Loculated pneumothoraces and severe emphysematous changes or bullous disease can have very similar appearances, occasionally making it impossible to differentiate between them. If there is clinical doubt a CT should be performed to guide percutaneous drainage as inadvertent cannulation of a bulla in an intensive care patient can have catastrophic consequences.

Tension Pneumothorax

Tension pneumothoraxes are an important reversible life threatening cause for obstructive shock most often associated with trauma or mechanical ventilation. A tension pneumothorax should be suspected in mechanically ventilated patients with acutely increasing central venous pressure and circulatory failure, particularly when risk factors such as chronic obstructive pulmonary disease or ARDS are present. In positive-pressure ventilated patients the risk of an unrecognized pneumothorax progressing to a tension pneumothorax is high. On CXR a tension pneumothorax is characterised by contralateral mediastinal shift, and ipsilateral flattening of heart contour, increased rib spacing, and depression of the hemidiaphragm. There may be associated collapsed lung. In a fulminant tension pneumothorax, findings are likely to change little with position. Of note, mediastinal shift can present on a CXR in the absence of a tension pneumothorax and vice versa. If the clinical suspicion of a

Table 19.1 Common causes for pleural effusions in critically ill patients

Infective para-pneumonic effusions
Cardiac failure (usually bilateral)
Neoplastic (metastatic pleural dissemination, mesothelioma, bronchogenic tumour invading pleura)
Thromboembolic disease
Pancreatitis (typically left sided)
Multiorgan failure typically with hypoalbuminemia
Aggressive fluid resuscitation and subsequent fluid overload
Connective tissue disorders
Infection post thoracic intervention

tension pneumothorax is high in a patient in shock it has to be treated immediately with emergency needle thoracotomy without waiting for imaging. However, performing a CT after the clinical situation has stabilized may help identifying the cause and associated pathologies such as subcutaneous emphysema, pleural collections, pneumomediastinum, pneumopericardium, or fractures.

Pleural Effusion

A collection of fluid in the pleural space is common in the critically ill, occurring in over 60 % of patients in some series. Immobilised patients are at risk for developing atelectasis and reactive effusions. Infection of the pleural cavity can result from surgery, trauma, or lung infection. Depending on the pathology underlying the effusion, the fluid can be a transudate, exudate, pus, blood or chyle. It is important to note that the radiographic appearance does not correlate with the type of fluid. Common causes for pleural effusion are listed in Table 19.1.

Simple effusions accumulate in gravity dependent areas and are therefore found basally on an erect CXR. The initial sign is blunting of the costophrenic angle. As the effusion expands the fluid obscures the hemidiaphragm and causes underlying lung collapse. These effusions usually have a concave upper surface, which is higher laterally and adopts a meniscal shape (Fig. 19.7). Contralateral mediastinal displacement may occur in large effusions. The lateral radiograph is more sensitive and can detect 100 ml of fluid whereas a minimum of 300 ml is required to cause blunting of the costophrenic angle on a PA radiograph.

Many critically ill patients are imaged and managed supine or semi-supine. In this position the appearance of a pleural effusion is altered, as the dependent areas are the paravertebral gutters. Radiographic signs include homogeneous increased density over the involved hemithorax with fluid capping the ipsilateral lung apex. A pleural effusion may be missed until it is large on supine radiographs, particularly when there is symmetrical disease or significant atelectasis

The effusion may be misdiagnosed as pulmonary consolidation or collapse. However, with the latter pathologies, normal bronchovascular markings tend to be obliterated, there may be air bronchograms or shift of the hila or mediastinal

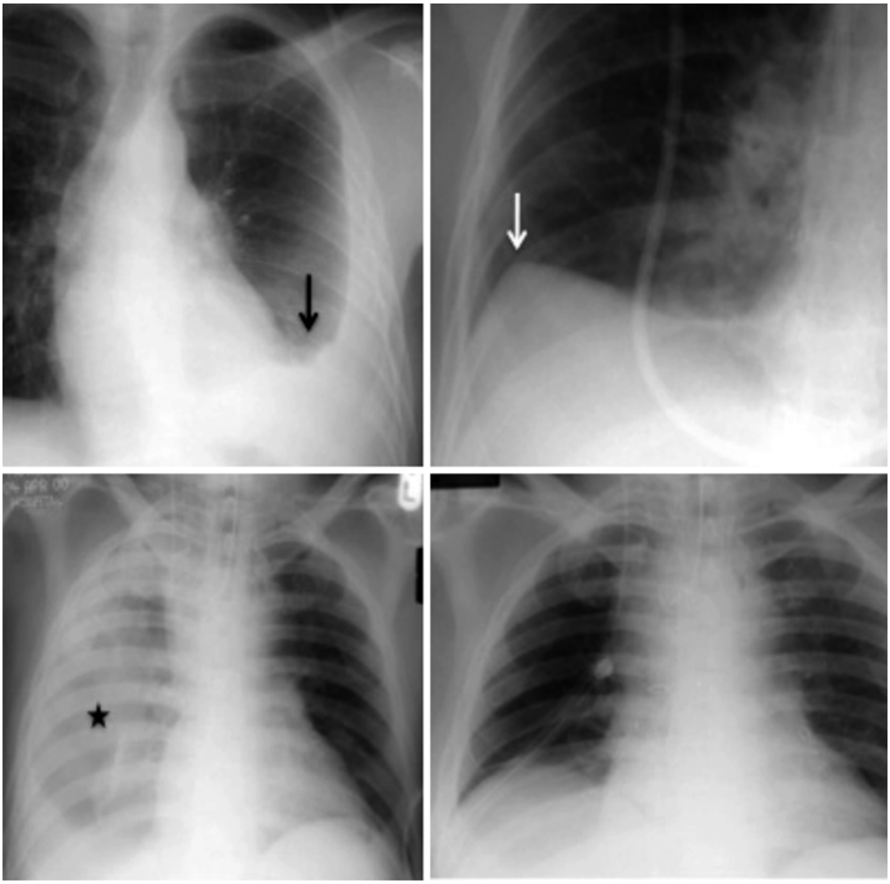

Fig. 19.7 Simple pleural effusion. *Top left* is a moderate left effusion with meniscus sign (*black arrow*); *top right* is a right subpulmonic effusion (*white arrow*). *Bottom* images show a supine effusion (*black star*) pre (*left*) and post (*right*) chest drain insertion

structures. However, consolidation without air bronchograms or collapse with minimal volume loss may be difficult to distinguish from or coexist with a pleural effusion on a supine radiograph.

Pleural fluid may be restricted in its movement due to the constituents of the fluid or altered anatomy. In the presence of such loculation gravitational rules are not obeyed and fluid may accumulate in non-dependent areas. Loculated effusions appear as homogeneous areas of opacification on the CXR. The appearance depends on the orientation of the collection relative to the x-ray beam; if the beam is tangential the image will be well defined, it will be poorly defined when seen en face. Appearance may also be influenced by the precise location of the fluid, e.g., when fluid tracks into the fissures and becomes encysted, giving the phenomenon of a "pseudotumor" (Fig. 19.8). An atypical appearance of pleural fluid also raises the

Fig. 19.8 Complex pleural effusion. *Top panel* shows a rounded well-defined opacity in right costophrenic angle that is proven to be of uniform fluid attenuation on CT *(white star)*. Appearances are that of a loculated fluid collection, giving rise to a "pseudotumor." *Bottom left* is a case of mesothelioma with irregular nodular pleural masses (*black stars*) and loculated effusion and *bottom right* is a loculated effusion with pleural thickening and enhancement (*white arrow*) and air pockets secondary to an empyema. There is a pleural fluid collection (*star*) with air fluid level (*black arrow*) and pleural thickening (*white arrow*) in keeping with an empyema

possibility of non-simple or viscous fluid, such as pus or blood, occupying the pleural space. If there is an empyema, it is usually clinically apparent but definitive diagnosis is gained from aspiration or drainage of purulent fluid with deranged biochemistry and positive microbiology. Loculation and air within the collection are signs concerning for empyema. However, recent intervention or the presence of a bronchopleural fistula should not be forgotten as potential causes of pockets of air within the collection. On CT, pleural thickening and enhancement can be seen, with separation of the parietal and visceral pleura, known as the "split pleura sign." The collection is usually lentiform in shape whereas an intrapulmonary abscess is more rounded or spherical.

On ultrasound, simple collections are anechoic. In complex cases, there may be echogenic debris or septa. Ultrasound is valuable not only in characterizing but also in guiding aspiration or drainage of pleural collections.

Hypoxia with Lung Parenchymal Opacification on CXR

There are numerous causes of parenchymal lung disease that can cause patients to present to the intensive care unit with hypoxia. Clinical history including speed of onset, presence of pre-existing lung disease, risk factors, comorbidities and drugs play an important role, as do clinical examination and laboratory findings.

Cardiogenic (Hydrostatic) Pulmonary Edema

The majority of intensive care staff will be familiar with this form of pulmonary edema usually caused by pulmonary venous hypertension secondary to left ventricular failure or mitral valve disease. Radiographic changes are apparent at symptom onset and resolve rapidly with treatment, in contrast to ARDS. CXR findings of cardiogenic pulmonary edema can be characterized by interstitial or airspace disease or a combination of the two. Thickening of interstitial structures by pulmonary interstitial edema results in an indistinct appearance of vessels and airways (peribronchial cuffing), as well as ground glass opacification in the perihilar regions. Thickening of more peripheral interstitial structures gives rise to Kerley lines. Pulmonary alveolar edema is caused when fluid spills into the alveoli generating the classical appearance of symmetrical bilateral airspace opacities that predominate in the mid and lower zones. Bilateral pleural effusions and cardiomegaly are also common (Fig. 19.9). While the diagnosis is frequently clinically apparent CT may be helpful in characterizing disease, assessing severity, complications, and possibly the cause when there is clinical doubt.

Non-cardiogenic Pulmonary Edema

This type of edema is characterized by injury to the capillary endothelium, allowing fluid to leak into the interstitium. The causes are multifactorial and include aspiration, trauma, inhalational trauma, drowning, drugs and burns. The diffuse alveolar damage can result in respiratory failure and clinically present as Acute Respiratory Distress Syndrome (ARDS), which is discussed in more detail in Chap. 24. Radiographically, the edema has a more peripheral distribution, the heart size is normal and the vascular pedicle (i.e., the mediastinal width at the level of the SVC and left subclavian artery) is not widened, as the circulating volume is normal.

Acute Interstitial Pneumonia (AIP)

This acute, aggressive form of idiopathic interstitial pneumonia is characterized by diffuse alveolar damage. The disease differs from the chronic interstitial pneumonias by a sudden onset and a rapid course. It deserves mentioning due its shared

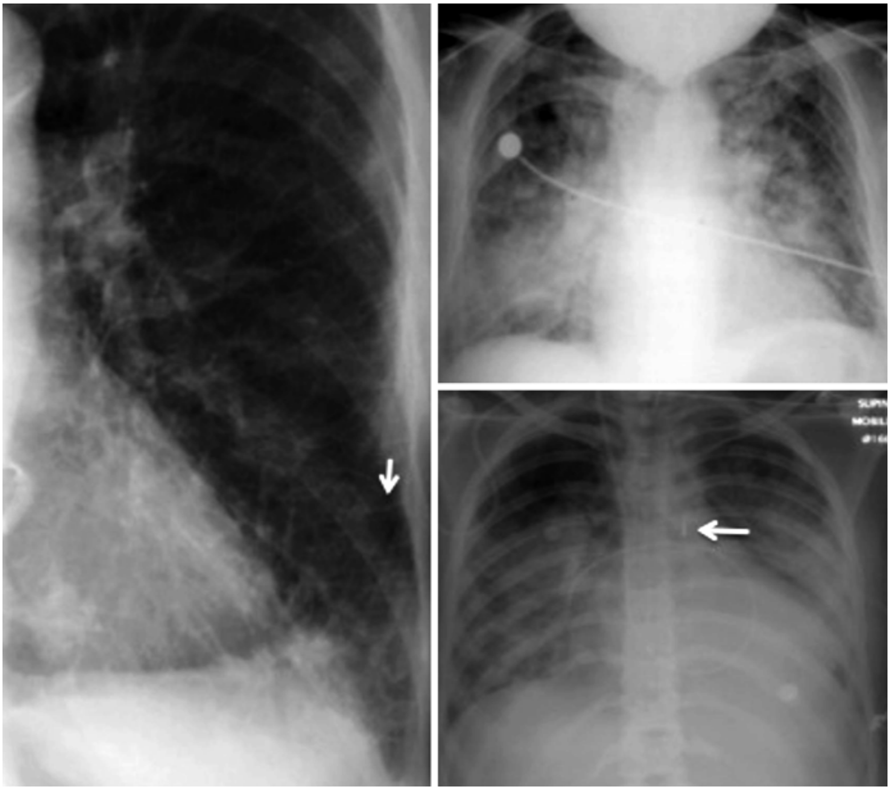

Fig. 19.9 Pulmonary edema. *Left panel* demonstrates the lower zone septal thickening (*white arrow*), the so-called Kerley B lines. *Top right* shows bilateral peri-hilar alveolar opacification and *bottom right* is progression of alveolar opacification and development of pleural effusion in keeping with worsening pulmonary oedema. Patient has now got an IABP catheter, the tip of which is projected below the aortic knuckle (*white arrow*)

clinical and histological features with ARDS. Patients have a history of cough, fever and dyspnea that rapidly progresses causing respiratory failure often requiring mechanical ventilation. Imaging findings include ground glass opacities and consolidation. Reticulation and honeycombing, as seen in the chronic interstitial pneumonia, is less common. If fibrosis does develop, it does not progress once the acute incident has resolved.

Chronic Obstructive Pulmonary Disease (COPD)

Emphysema, chronic bronchitis, bronchiectasis and asthma all cause obstructive lung disease. They may be difficult to differentiate clinically and physiologically as they share obstruction to expiratory airflow as common pathophysiology.

Fig. 19.10 Emphysema on CXR. *Left* CXR is of a patient who has a left single lung transplant. The right lung shows overexpansion with disorganised broncho-pulmonary markings. Also note the enlarged proximal pulmonary vasculature. *Right* CXR is from a patient with alpha-1 antityrpsin deficiency. The emphysema is predominantly affecting the basal segments

Emphysema

This common feature of COPD is defined as permanent enlargement of the air spaces distal to the terminal bronchioli accompanied by destruction of their walls, but without obvious fibrosis. Centriacinar emphysema is the commonest form, occurs in smokers, and affects the upper lobes predominantly. Panacinar emphysema compromises the lower lobes usually, and occurs in alpha-1 antitrypsin deficiency (Fig. 19.10).

Radiographic signs include hyperexpanded lungs with flatted diaphragms, increased anteroposterior diameter of the chest and narrowing of the transverse cardiac diameter and bulla formation.

None of these signs is diagnostic alone, but the more of them are present, the more likely that there is emphysema. High-resolution CT is used for visually assessing the severity and distribution of emphysema, but also to quantify the percentage of diseased lung, sometimes with a view to surgical intervention.

Asthma

This manifestation of COPD is characterized by small airway inflammation and reversible small airway obstruction. Between attacks, the CXR may be normal. Common findings are those mentioned above in emphysematous patients because

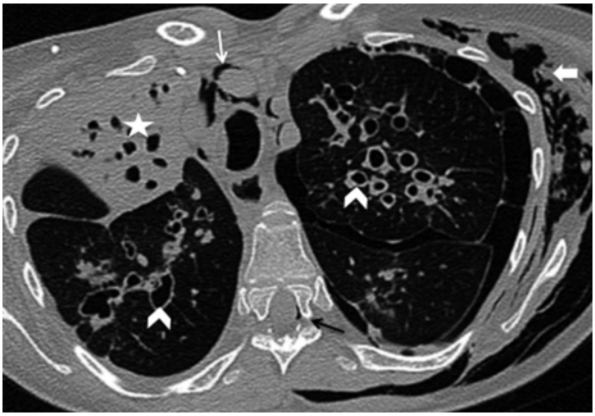

Fig. 19.11 A 18 year old male with cystic fibrosis and increasing shortness of breath. Axial CT image on lung windows demonstrates a left sided pneumothorax, extensive surgical emphysema (*block white arrow*), pneumomediastinum (*thin white arrow*) and pneumorrhachis (*black arrow*). Note the marked cystic bronchiectasis (*chevron*) and partial collapse of the right upper lobe (*white star*)

of the air trapping. However, there may also be bronchial wall thickening and focal scarring from previous episodes of infection. Atelectasis caused by mucus plugging may occur and differentiating this from consolidation is important to avoid unnecessary antibiotics. Complications, such as pneumonia, secondary allergic bronchopulmonary aspergillosis and alveolar rupture leading to pneumomediastinum or pneumothorax may develop (Fig. 19.11).

Bronchiectasis

This irreversible disease is characterized by dilatation of bronchi with three subtypes: cylindrical, varicose and cystic according to the morphological shape of dilatation. If localised previous TB or prior infection may have been the cause. More generalized bronchiectasis with an upper lobe predominance is seen in cystic fibrosis (CF). CXR findings include linear "tramtrack" opacities representing dilated airways, bronchial wall thickening, scarring, and volume loss. "Ring shadows," representing dilated airways seen end-on, are common and may contain air or fluid levels. Localized bronchiectasis tends to be peripheral, whereas if there is a central distribution CF, allergic bronchopulmonary aspergillosis (ABPA) or acquired bronchial obstruction should be considered. Aspergillus colonisation of bronchiectatic air spaces or other structural lung disease may lead to the development of an aspergilloma (Fig. 19.12).

Pulmonary Hemorrhage

Pulmonary hemorrhage is relatively uncommon and can present in isolation or as one feature of a multisystem disorder. Causes include the autoimmune diseases, thromboembolic disease, trauma, bleeding diathesis, drugs, ARDS, and infection.

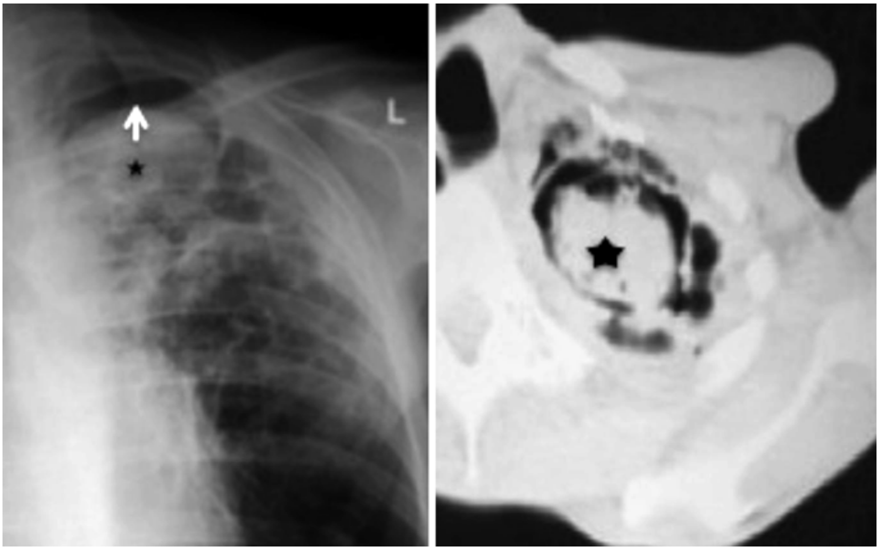

Fig. 19.12 Chest radiograph shows volume loss in the left upper lobe with an apical cavity with air crescent sign (*arrow*) containing an intracavitory body (*star*) with adjacent pleural thickening. CT confirms findings typical of an aspergiloma (*star*)

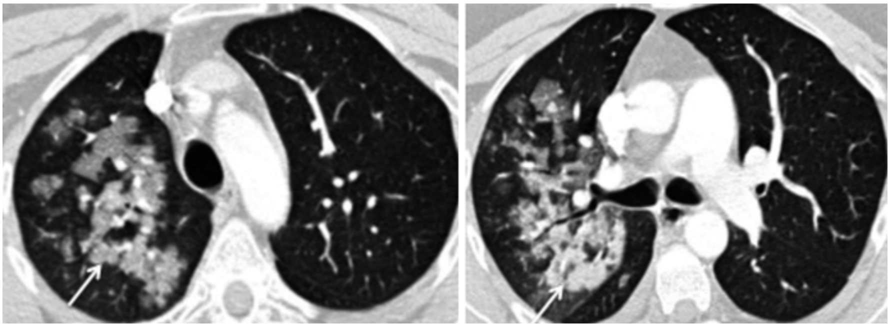

Fig. 19.13 A 51 year-old male with Wegners syndrome presented with acute haemoptysis. Axial CT images on lung windows demonstrate rather dense right-sided consolidation and ground glass opacification (*white arrow*) due to pulmonary haemorrhage. The left lung is clear

Typical radiographic features include uni- or bilateral airspace opacities or consolidation, but nodules and cavities may also feature depending on the cause (Fig. 19.13). The airspace change may be difficult to distinguish from infection or pulmonary edema without appropriate history or a drop in hemoglobin levels. If the opacities develop quickly and are associated with hemoptysis, pulmonary hemorrhage should be considered. Once active bleeding has stopped the opacities usually improve within 2–4 days, which is in between the resolution interval times of edema and infection. Recurrent episodes may result in scarring or fibrosis. If bleeding is life threatening and due to a focal cause, a bronchial angiogram with a view to do

Table 19.2 Disease pattern associated with common pulmonary malignancies

Nodule or mass	Adenocarcinoma, large cell carcinoma
Atelectasis or consolidation	Squamous cell carcinoma
Hilar enlargement	Squamous cell carcinoma, small cell carcinoma
Mediastinal mass	Small cell carcinoma, large cell carcinoma
Pleural effusion or thickening	Mesothelioma

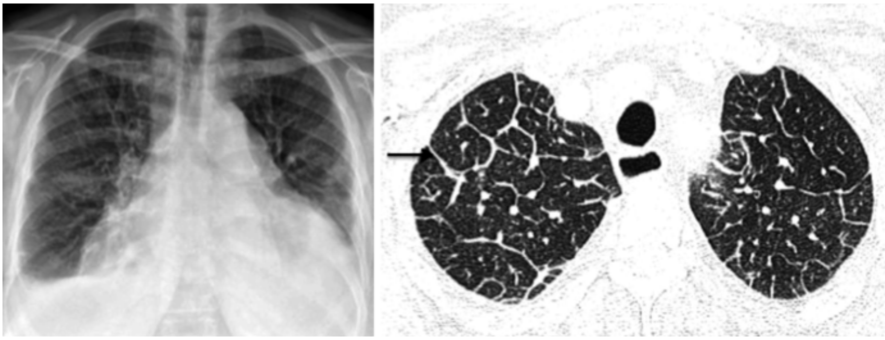

Fig. 19.14 A 49 year-old female patient with progressive breathlessness and history of breast carcinoma. On the CXR, there is enlargement of cardiac silhouette due to pericardial effusion, bilateral pleural effusions, larger on the right and septal thickening, most prominent in the right upper zone due to lymphangitis cacinomatosis. Axial HRCT confirms the upper zone interlobar septal thickening (*black arrow*) in keeping with lymphangitis carcinomatosis

embolization may be considered. A CT with intravenous enhancement obtained during an episode of active bleeding may be valuable to identify the likely cause and act as a roadmap for subsequent embolization if dilated systemic vessels are seen.

Pulmonary Malignancy

Patients with lung cancer may be admitted to the ICU following attempted curative surgical treatment but it is important to recognize that lung cancer is common and may precipitate admission before the diagnosis is established. As survival rates remain poor it can be important for the intensivist the recognize the general patterns of different types of malignancies in order to proceed to further imaging and tissue sampling in order to establish the diagnosis (Table 19.2).

One third of lung cancers present as a nodule, which may have an ill-defined, irregular or spiculated margin. Occasionally they can cavitate with a thin or thick wall. Consolidation or atelectasis is seen in up to 50 % of cases. Mediastinal or hilar lymph node involvement is seen radiologically in up to 35 % of cases but surgical specimens suggest it is more like 50 %. Small cell and squamous carcinoma spread to hilar nodes. A pleural effusion is seen in 5–15 % of patients at presentation. Patients with lymphangitis carcinomatosa may have septal lines, which can mimic pulmonary edema or other interstitial disease (Fig. 19.14).

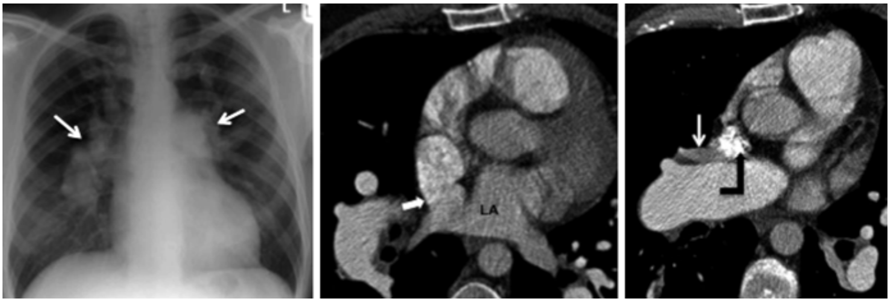

Fig. 19.15 A 45-year old female with dyspnoea and pulmonary hypertension on echo. There is mild cardiomegaly and marked enlargement of proximal pulmonary arteries (*white arrows*) on the CXR. Axial CT image (*middle*) demonstrates a sinus venosus type atrial septal defect (*block white arrow*). *LA* left atrium, *Far right* CT image shows anomalous drainage of right superior pulmonary vein (*white arrow*) in to the SVC (*curved black arrow*)

Hypoxia Related to Cardiovascular Disease

Left ventricular failure and acute thromboembolic disease are common causes of hypoxia and are described in Chap. 25.

Intracardiac shunts are often associated with hypoxemia, particularly when increased pulmonary pressure has led to a right to left shunt. In addition to the generic findings of pulmonary hypertension, the imaging features depend on the type of defect and the direction of the shunt. Transthoracic echocardiography is the first line test to investigate suspected shunts. Cardiac MRI is complementary to echocardiography and is now the gold standard for non-invasive functional assessment including shunt quantification. The cardiovascular anatomy is well delineated on CT, but the limitations of radiation and relative lack of functional data precludes its routine use as the primary modality for shunt demonstration. In reality, CT is commonly performed in patients with non-specific cardiorespiratory symptoms and may identify previously occult congenital heart disease even on ungated studies when carefully scrutinized (Fig. 19.15). The presence of the generic signs of pulmonary hypertension should lead to a systematic search for a cause including a thorough cardiac evaluation.

Teaching Points

1. Initial imaging by chest radiograph is able to exclude some life-threatening conditions and may help to guide initial decision-making.
2. CT is the modality of choice to arrive at a diagnosis and to direct interventions.
3. Pulmonary malignancies can follow specific patterns, which should arouse a high index of suspicion when encountered in undiagnosed patients with respiratory distress.

Chapter 20
Persistent Hypoxemia Despite Intervention

Alice Veitch

Clinical Problem

A 48-year-old smoker is admitted to the ICU after a complex open repair of an abdominal aortic aneurysm. The surgery was complicated by significant blood loss and subsequent hemodynamic instability. The patient is intubated and ventilated as well as on inotropes and vasopressors when he arrives from the operating room. He also has multiple lines and drains in situ. A pulmonary artery catheter was inserted just before transfer to the ICU. He is stable and blood gases show adequate gas exchange and low oxygen requirement. Shortly after admission to the ICU, the patient becomes increasingly hypoxic despite ventilator adjustments and increasing the FiO_2.

There are a multitude of reasons why invasively monitored post-surgical patients in the ICU may suffer from hypoxemia. These include pre-morbid state and comorbidities, as well as peri-operative and procedural complications.

Imaging Techniques

A plain chest radiograph will help identify readily treatable conditions and complications such as pneumothorax, hemothorax, or lung collapse. CT is used as a second-line test when the diagnosis is not clear or cannot be evaluated on CXR. Bedside echocardiography may also be required to exclude pericardial and myocardial pathology.

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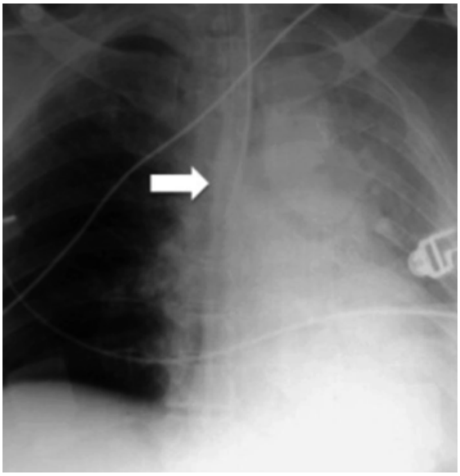


Fig. 20.1 The mal-positioned endotracheal tube tip is within the right main bronchus (*block arrow*) with resultant collapse of the left lung

Hypoxia Related to Tubes and Lines

Patients requiring treatment in intensive care commonly have multiple lines and are subject to frequent interventions. These are often important and even life saving; however, they are not without certain risks.

Endotracheal Tube

The majority of patients requiring intensive care treatment in the immediate post-operative period have an endotracheal tube in situ. Tubes have radiopaque markers identifiable on plain film and their position will vary with the degree of neck flexion and extension. The tip of the endotracheal tube should lie within the trachea at least 2 cm above the carina. Endotracheal tubes are misplaced in approximately 10 % of patients. The most commonly seen malposition is an endobronchial intubation, when the endotracheal tube tip lies within the right main bronchus often leading to contralateral (left) lung collapse (Fig. 20.1). Malposition of the tube within the esophagus should be recognized clinically as it leads to acute hypoxia and cardiac arrest.

Trauma to the trachea from tube placement may lead to glottis and tracheal edema, and in extreme cases rupture. On CXR, the trachea should maintain smooth lateral margins as bulging may represent over-dilatation or tracheal wall edema. A chest radiograph following tracheostomy placement has to be scrutinized for the presence of mediastinal hematoma, which may be seen as widening of the mediastinum on CXR, and presence of mediastinal air.

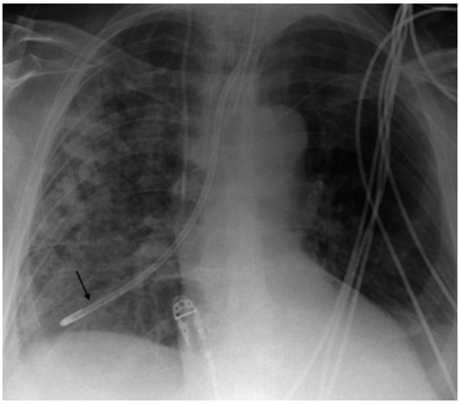


Fig. 20.2 The malpositioned nasogastric tube lies within the right main bronchus (*arrow*) and requires immediate repositioning. Patchy air space shadowing within the right lung reflects aspiration pneumonia

Mechanical Ventilation

Mechanically ventilated patients are unable to clear respiratory tract secretions and are therefore at higher risk of mucus plugs, which lead to areas of lung collapse. Mechanical ventilation can cause barotrauma and patients may develop pneumothorax, pneumomediastinum, surgical emphysema or interstitial emphysema.

Nasogastric Tubes

These are commonly placed in ICU patients for nutritional or drainage purposes. Nasojejunal tubes are placed in patients with poor pyloric function. The nasogastric tube tip should lie below the left hemi-diaphragm, distal to the gastro-esophageal junction with all the side holes within the stomach. Malposition of the tube within the bronchi must be recognized when reviewing the plain film in order to avoid administration of medication and fluids into the lungs (Fig. 20.2). It has to be remembered that in some critically ill patients the stomach may be displaced in the thoracic cage and above the diaphragm. In these cases plain AP and lateral X-ray can easily diagnose the problem.

Central Venous Lines

Indwelling catheters for monitoring and drug administration purposes should be positioned so that the tip is in the proximal SVC. Pulmonary artery catheters should lie with the tip in the proximal pulmonary artery. Invasive lines carry an associated risk of pneumothorax or hemothorax, which usually occur during insertion, and these

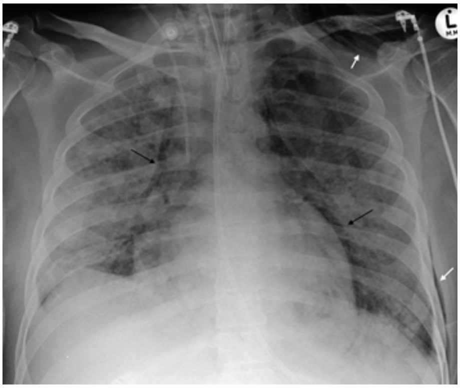


Fig. 20.3 An endotracheal tube, nasogastric tube and right internal jugular line are in situ. There is increased lucency around the heart and mediastinum (*black arrows*) in keeping with a pneumomediastinum. The left lung appears more lucent than the right in the supine position, suggesting an associated pneumothorax. There is subcutaneous emphysema seen in the left supraclavicular region and the left chest wall (*white arrows*)

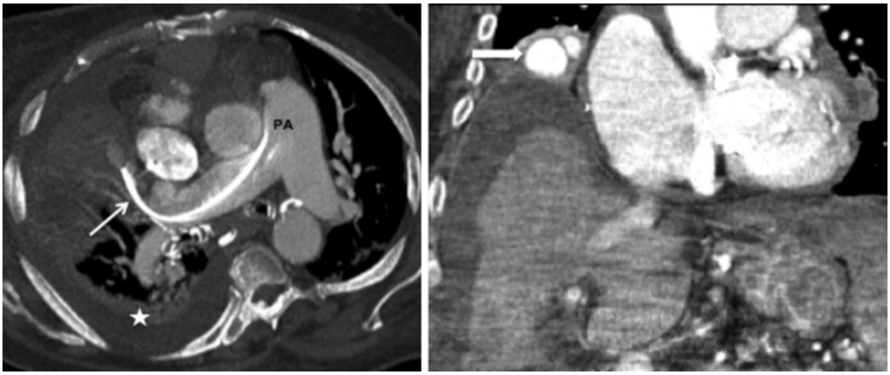


Fig. 20.4 (*Left*) The Swan Ganz catheter tip is too distal and lies within the segmental pulmonary artery (*PA*) (*thin arrow*). Right pleural collection (*star*). (*Right*) The patient went on to develop pulmonary artery aneurysm (*block arrow*)

complications should be looked for on the post-procedural plain film. Associated pneumomediastinum imposes as lucency surrounding the mediastinum and a continuous diaphragm visible on CXR (Fig. 20.3), while surgical emphysema can be seen as air within the soft tissues. Invasive lines are also a potential source of septic emboli, which may be seen on CXR as multiple irregular opacities with central cavitation.

Central line malposition is easily diagnosed on plain radiography. Inadvertent carotid cannulation, carotid and jugular antegrade position, migration into contralateral jugular vein position have all been described. It is important to remember that the malpositioned venous catheter in a large vein could still be used for sampling, monitoring, and drug infusions.

Pulmonary artery catheters are also easily visualized on plain radiography. The complications associated with these are divided into complications with central venous cannulation (common to other central venous access), malposition (right atrium, right ventricle), pulmonary artery rupture and formation of a false aneurysm (Fig. 20.4). If the pulmonary artery rupture is non-fatal a CXR is likely to demonstrate opacification around the affected pulmonary artery, representing a combination of pulmonary hemorrhage and pseudoaneurysm.

Chest Drains

Drains may be inserted to treat pleural collections of fluid, pus, blood or air. The optimal position of the drain tip within the pleural space depends on the underlying pathology – usually superiorly for a pneumothorax and inferiorly for fluid collections. All side holes have to be within the space, and a poorly positioned tube may lead to failed drainage and continued symptoms. Chest drain insertion may lead to a hemothorax if an intercostal vessel is damaged during insertion. Typically an extrapleurally contained hematoma of varying size can be found.

Malposition of chest drains is not uncommon. It includes pulmonary intraparenchymal, intraesophageal, intracardiac, intraperitoneal, intrahepatic, transgastric, and extrapleural location. Malposition is usually readily diagnosed on CXR but some patients may require CT. Using image guidance or insertion by an experienced operator reduces the prevalence of such malposition.

Hypoxia Related to Pleural Disorders

Pneumothorax

This is one of the most frequently encountered pathologies when reviewing chest radiographs of ICU patients. The term pneumothorax refers to free air in the pleural space. Air may be introduced by leakage from the lung, or breach of the chest wall from an external source. Imaging features suggestive of tension pneumothorax are described in Chap. 19.

Pleural Fluid Collections

These include transudative and exudative effusions, hemothorax, chylothorax and empyemas. In the erect position, a free-flowing pleural fluid collection will be seen as an opaque meniscus but when the patient is supine, the fluid is distributed posteriorly resulting in homogenous shadowing throughout the affected hemithorax (Fig. 20.5). A volume of approximately 200 ml of fluid or more can be seen on radiographs, and a large collection can displace the mediastinum contralaterally. A chest ultrasound may be required to help distinguish between pleural fluid, hematoma and lung tissue. Features of the different kinds of pleural fluid collections are outlined in Table 20.1.

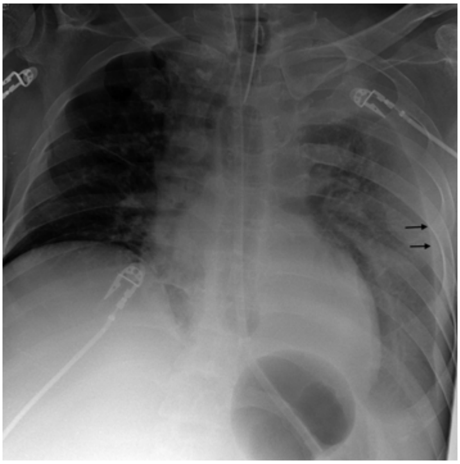


Fig. 20.5 An endotracheal tube and nasogastric tube are seen. The left lung is diffusely opacified and a pleural collection is delineated peripherally within the left hemithorax (*black arrows*). Appearances of this large left pleural fluid collection reflect the supine position of the patient

Table 20.1 Features of pleural fluid collections

	Causes	Radiological features
Hemothorax	Vascular access	May occur with pneumothorax or alone
	Trauma	
	Surgery	
Chylothorax	Trauma	Disrupton of thoracic duct above T_5/T_6 – left chylothorax
	Surgery	Disrupton of thoracic duct below T_5/T_6 – right chylothorax
Empyema	Infection	Typically septated or loculated
	Trauma	US can demonstrate complexity and loculation, identify fibrin strands and echogenic elements
	Surgery	Contrast CT gives detailed delineation of the collection, usually surrounded by thickened enhancing visceral and parietal pleura
	Pneumonia	Gas suggests infection, recent drainage or a fistula

Broncho-Pleural Fistulas (BPF)

A BPF may occur following lung resection surgery, trauma or barotrauma, as well as recurrent infection and infarction. The communication between the bronchial tree and pleural space leads to a persistent air leak and empyema. CXR will demonstrate a pneumothorax and fluid level (Fig. 20.6). CT, preferably as a thin section protocol, can demonstrate the fistula and its underlying cause in the majority of cases. A chest drain is the usual first-line management, but the fistula may require surgical intervention if it does not close with conservative management.

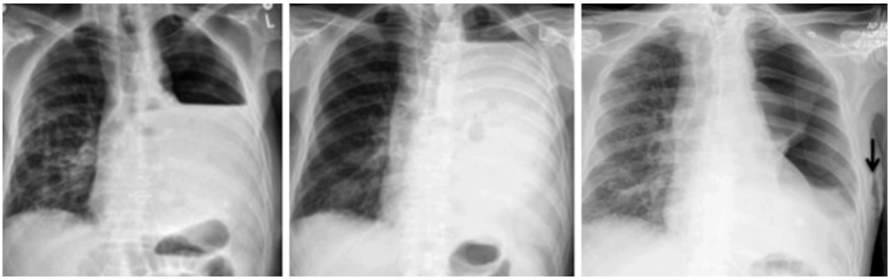
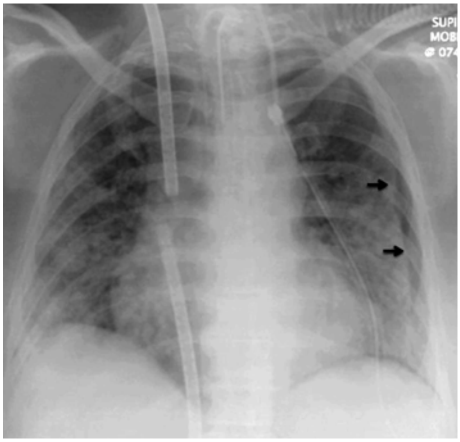


Fig. 20.6 Serial CXRs from a 70-year old male patient post left pneumonectomy for lung cancer. Far *left* radiograph is from Day 3 and shows the pneumonectomy space to be half filled with fluid; The *middle* film is from Day 15 and shows increasing fluid level; Far *right* is from Day 37 and shows a marked drop in the fluid level in keeping with bronchopleural fistula. Also note the lack of expected ipsilateral mediastinal shift with pneumonectomy and the new onset surgical emphysema (*arrow*)

Fig. 20.7 A 40 year-old patient with H1N1 pneumonia on ECMO with difficulty in ventilation. The CXR shows bilateral widespread but non-specific alveolar opacification and a left sided pneumothorax (*black arrows*)



Hypoxia with Lung Parenchymal Opacification on CXR

When assessing a CXR with parenchymal shadowing, it is helpful to bear in mind the possible spectrum of underlying alveolar abnormality. The alveoli may contain fluid, blood, pus, protein or cells, all resulting in a consolidation pattern on CXR (Fig. 20.7). Other clues including time course of CXR changes and associated features such as presence of effusions, cardiomegaly, air bronchograms, and distribution of disease may help to differentiate the diagnoses. Where possible, films should be evaluated with reference to the previous imaging.

Pneumonia

Chapter 24 provides more detailed discussion of the various types of pneumonic processes and their imaging. Pneumonia following pulmonary aspiration of stomach contents mostly affects the dependent lung segments in supine patients – usually posterior or apical segments of the lower lobes or middle lobe. The initial findings of sterile chemical pneumonitis often progress into patchy bronchopneumonic infiltrates or segmental consolidation on the CXR.

Lung Contusion

Contused lungs are regularly seen in trauma patients even in the absence of visible chest injury. Lung contusion is characterized by the presence of parenchymal blood and edema and occurs post-trauma or at the site of surgical access. It is usually seen as an area of focal consolidation on CXR, appearing several hours after the insult and beginning to resolve after 3 days. CT demonstrates non-segmental consolidation often with sub-pleural sparing. A pneumatocyst (air-filled parenchymal cyst) may be associated with contusions and lacerations, and the majority of these resolve over several weeks. Occasionally resolution of parenchymal hemorrhage following contusion will reveal a well-circumscribed opacity representing hematoma at a site of laceration.

Lung Collapse

Collapse generally occurs secondary to bronchial obstruction, which in ventilated patients can result from mucus plugging, infection, inadequate ventilation or incorrect tube placement. The chest radiographic findings of lung collapse include:

- opacification of the involved lobe with marked volume loss
- possible deviation of the trachea or mediastinum towards the lesion, or fissural distortion and
- loss of clarity of the adjacent interfacing structures, such as the diaphragm or the cardiomediastinal border.

Collapse of each lung lobe has a typical radiological appearance (Table 20.2). The affected lobe should re-inflate with appropriate management of the underlying cause (Fig. 20.8).

Table 20.2 Typical radiological appearance of collapse of different lobes

Right upper lobe	Raised distorted horizontal fissure and hilum
Right middle lobe	Loss of the right heart border
Right lower lobe	Partial loss of right hemi-diaphragm
Left upper lobe	Veil-like opacity over the upper and mid-zone
Left lower lobe	Sail-like density behind the heart

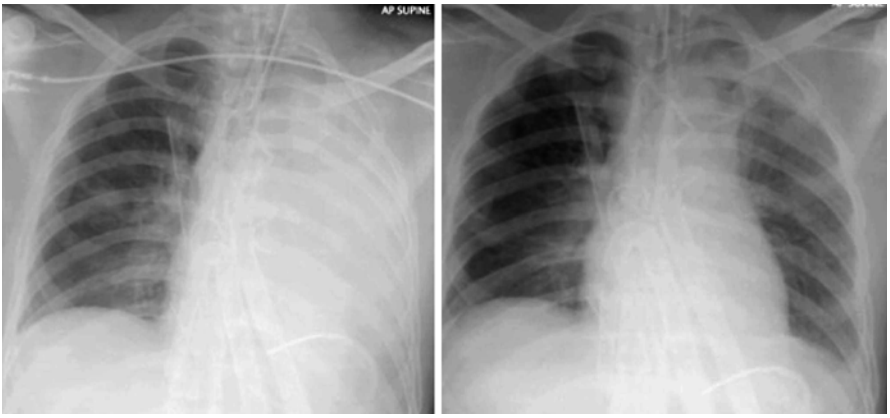


Fig. 20.8 A 60-year old ventilated patient with sudden onset of desaturation. *Left* CXR shows complete collapse of the left lung, likely due to mucus plugging. *Right* CXR demonstrates good inflation of the left lung post bronchoscopic intervention

Lung Transplantation

Lung transplant recipients develop specific complications that can cause hypoxia in the immediate postoperative period. Reperfusion edema occurs early and resolves over a few weeks. This is pulmonary edema in the absence of another cause and is thought to arise from denervation and ischemia of the lung. Hyperacute and acute rejection both cause acute alveolar damage with diffuse ground glass appearance on CT.

Pulmonary Edema and Hemorrhage are discussed in Chap. 19.

Hypoxia from Circulatory or Mediastinal Events

Embolic disease – such as pulmonary thromboembolism, air embolus and fat embolus – causes hypoxia. Air emboli sometimes occur following line placement as an iatrogenic complication, rarely after open trauma or diving accidents. Air bubbles cause microvascular obstruction of the pulmonary vessels leading to hypotension and tachypnea. The CXR can show interstitial edema and an echocardiogram is likely to confirm air within the right heart chambers. Air embolus, fat embolus following long bone fracture and amniotic fluid embolus may all result in acute lung injury. Embolic disease is discussed in more detail in Chap. 25.

Hematoma within the mediastinum can occur following trauma, aortic injury, intervention or surgery and can compress the airway. CXR may reveal a widened mediastinum but this is an unreliable finding on supine imaging and the anatomy will be better delineated on contrast enhanced thoracic CT.

Phrenic nerve or diaphragmatic injury may occur following trauma or surgery, such as hiatus hernia repair. A raised hemidiaphragm without an evident cause on imaging raises concern about the diagnosis. Positive pressure ventilation can mask this finding. Patients with a raised hemidiaphragm may require CT evaluation with 3D reformatting to look for a diaphragmatic rupture, and dynamic ultrasound studies to assess appropriate diaphragmatic movement with respiration.

Teaching Points

1. Evaluate the CXR thoroughly, including the lines, catheters and tubes in situ, and taking into account the position of the patient at the time of imaging.
2. Consider the type of intervention the patient has undergone and therefore the complications that should be specifically looked for.
3. Review imaging in series with the previous films as temporal lung changes may reveal the most likely underlying diagnosis.

Chapter 21
Hypercarbia and Difficulties in Mechanical Ventilation

Anu Balan

Clinical Problem

A 66-year old patient with no known pre-operative lung pathology is recovering from a severe chest infection after total hip replacement. He has been ventilated for over 2 weeks and has a tracheostomy in situ. He is slowly being weaned from the ventilator with good gas exchange and increasing lung compliance. He is able to transfer from bed to chair and progressing well with rehabilitation, spending increasing amounts of time separated from the ventilator. Suddenly his gas exchange acutely deteriorates, and it becomes increasingly difficult to achieve adequate ventilation due to rising airway pressures leading to refractory hypercarbia and hypoxia.

Hypercarbia is defined as abnormally high CO_2 partial pressure in arterial blood. CO_2 is 20 times more soluble in blood compared to O_2, and hence undergoes faster transfer at the pulmonary capillary level. Thus hypoxemia is the common presenting pathophysiological sign in most respiratory disorders. However, in some cases hypercarbia may be the presenting problem. Unlike hypoxia, which leads to rapidly deteriorating cellular function, hypercarbia often develops slowly, and mild hypercarbia is not associated with end organ damage or worse outcome. The main reasons for hypercarbia encountered in patients in Intensive Care are summarized in Table 21.1.

Treating hypercarbic patients, with or without hypoxemia, whose lung compliance is diminished is challenging and relies heavily on imaging to achieve an accurate diagnosis and to monitor treatment.

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Table 21.1 Main causes of hypercarbia

Physiological reason	Clinical condition
Abnormally high CO_2 production	Catabolic state
Hypoventilation	Unadjusted ventilator settings
	Drugs
	Respiratory muscle weakness
	Reduced respiratory drive
Ventilation/perfusion mismatch	Lung collapse
	Atelectasis
	Pulmonary embolism
	COPD
Alveolar/capillary barrier pathology	Interstitial pneumonia
	ARDS
	Pulmonary fibrosis
	Barotrauma

Imaging Techniques

The portable chest X-ray is the initial screening tool and may identify lung parenchymal causes of hypercarbia but given the supine acquisition may not be a sensitive test. Since pulmonary embolism is on the differential diagnosis contrast enhanced CT is the gold standard imaging technique permitting comprehensive assessment of mediastinum, pleural space, lung parenchyma and pulmonary vasculature.

Central causes of reduced respiratory drive resulting in hypercarbia may be drug induced, which will often be clinically apparent. Neuropathy or myopathy is usually diagnosed on clinical grounds. Imaging using chest radiograph or CT may identify features of phrenic nerve injury and malignant or compressive causes.

Following neurological evaluation brain imaging may be required to exclude a central cause for hypoventilation. While MRI is the reference standard for detecting brainstem disease, brain CT may be the initial test in view of access and safety. This does not preclude subsequent MRI if clinical suspicion is high.

Barotrauma

Barotrauma is a common complication of mechanical ventilation. There is evidence that it may occur in all mechanically ventilated patients but only presents as a clinical problem in approximately 10–20 %. Barotrauma is a consequence of alveolar distension in the context of prolonged ventilation with high airway pressures. Although most commonly occurring in patients with ARDS, barotrauma can become a problem in any mechanically ventilated patient (Fig. 21.1). Manifestations of barotrauma are mostly subtle. If patients become increasingly difficult to ventilate clinicians should look out for radiological signs such as subcutaneous emphysema, pneumopericardium, pneumomediastinum, and uncommonly pneumoperitoneum.

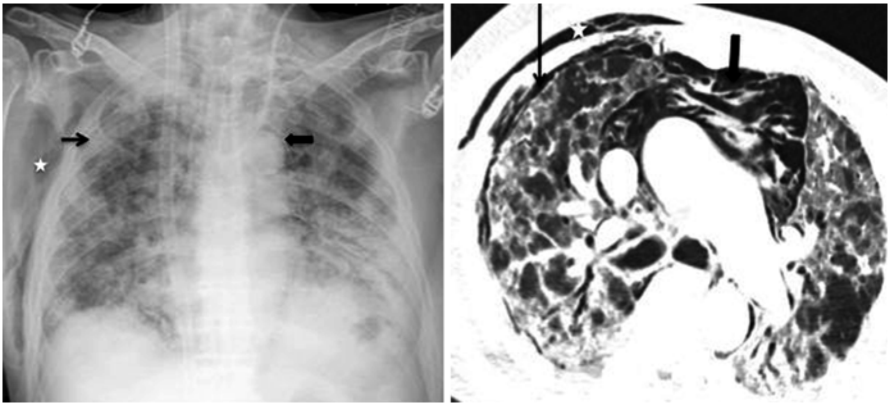

Fig. 21.1 A 55-year old female with respiratory failure on ECMO with difficult ventilation. Chest radiograph (*left*) shows widespread bilateral alveolar opacification with a subtle right pneumothorax (*thin black arrow*), pneumomediastinum (*thick black arrow*) and right lateral chest wall surgical emphysema (*white star*). The severity of the complications is more evident on the CT (*right*) allowing for better characterisation of the extent of the pneumomediastinum

The subtle signs range from the perivascular, non-branching lucencies of pulmonary interstitial emphysema to subtle pneumothoraxes. Pneumothoraces have been reported as occurring in less commonly recognized distributions such as the anteromedial, posteromedial, and subpulmonic pleural recesses, because alveoli in the nondependent portions of the lungs are more susceptible to overinflation and rupture. The chest radiograph may show lucency over the hemidiaphragm, giving it an unusually 'crisp' outline, and also within the costophrenic angle giving the 'deep sulcus sign' (Fig. 21.2a). CT imaging can be very useful in the detection of pneumothoraces that are 'occult' on the supine radiograph, and also to determine the position of loculated, anterior or basal pneumothoraces prior to intercostal drain placement (Fig. 21.2b). It is important to remember that small pneumothoraces can cause severe hemodynamic or respiratory compromise.

Insertion of an intercostal drain on ICU might not be straightforward in view of limited access and possible adhesions. Drains should ideally be placed under CT guidance at the time of the diagnostic CT.

The presence of a pneumothorax is often a manifestation of the underlying lung disease and its severity, particularly in ARDS.

Bronchospasm

A prolonged expiratory phase, wheeze and increased peak airway pressures or decreased tidal volumes characterize bronchospasm during Positive Pressure Ventilation (PPV). Narrowed airways and prolonged expiration can result in impaired emptying of alveoli during expiration and hence hypercarbia.

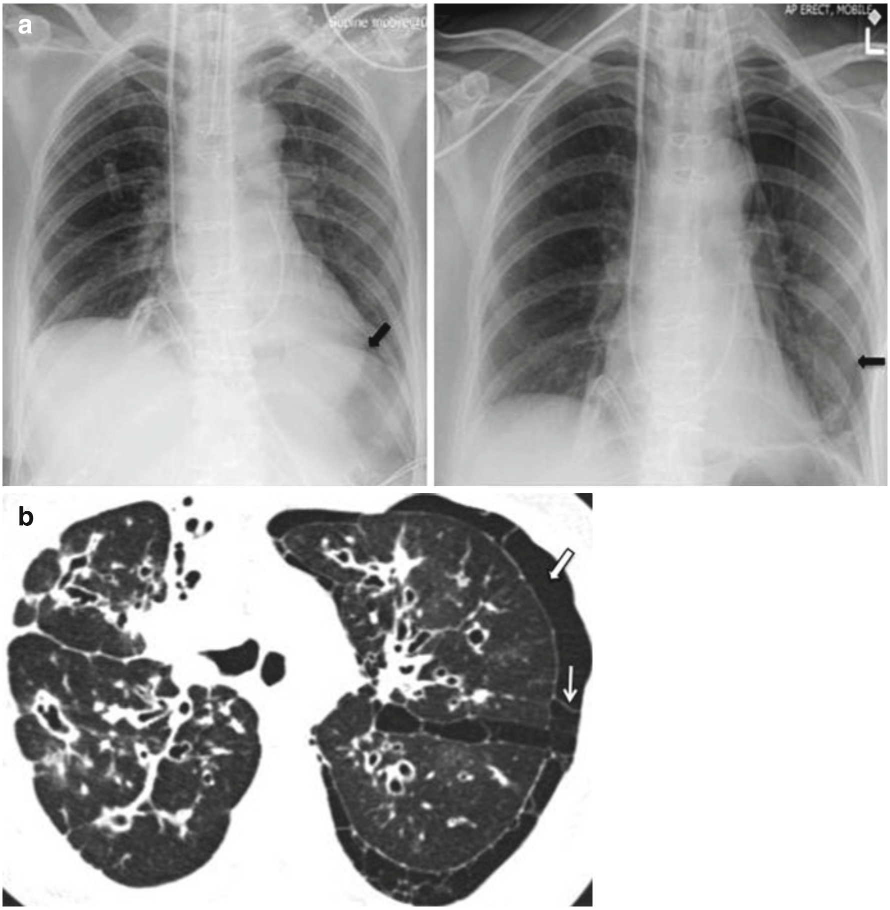

Fig. 21.2 (**a**) Supine pneumothorax: Serial chest radiographs on a 65 year-old ventilated female. *Left panel* shows abnormal lucency over the left hemidiaphragm with a resultant “crisp” outline (*block arrow*), and deepening of the costophrenic angle due to a supine pneumothorax. This was missed but subsequently picked up following a repeat erect film (*right*) where the basal pneumothorax is obvious. (**b**) Axial CT in a 20 year-old male demonstrating extensive bilateral cystic and varicose bronchiactasis due to cystic fibrosis with a complex left pneumothorax (*block arrow*) containing internal septations (*thin arrow*). Even small pneumothoraces may require drainage when there is such poor respiratory reserve and is generally safer when performed under CT guidance

In cases of severe bronchospasm, the wheeze may be quiet or absent and similarly, breath sounds may be reduced or absent. Unless rapidly corrected this can be life threatening. It is important that reversible, mechanical causes that can mimic severe bronchospasm such as a kinked tube, blocked airways (mucus plugging, cuff herniation), a misplaced endotracheal tube (endobronchial or esophageal intubation) or occlusion in the breathing circuit are ruled out quickly. Other potential causes of wheeze include pulmonary edema, aspiration of gastric

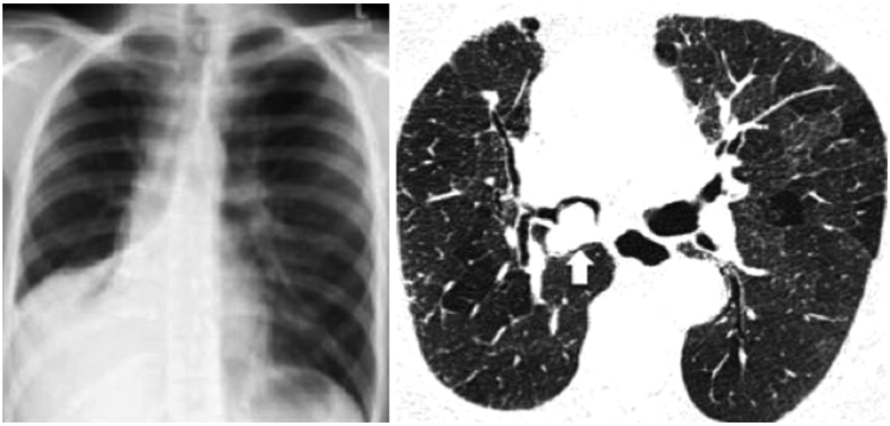

Fig. 21.3 A 35 year-old female with history of "asthma" had evidence of recurrent right-sided collapse on chest radiographs with spontaneous improvement (*left panel* shows right middle and lower lobe collapse). Axial CT thorax confirmed the presence of an endobronchial soft tissue lesion (*thick, white arrow*) within the bronchus intermedius that was histologically proven to be carcinoid

contents, pulmonary embolism, tension pneumothorax and foreign body in the tracheobronchial tree (Fig. 21.3). When bronchospasm is suspected it is important to use a CXR and review for adequate placement of the ET and NG tubes, assess for lobar collapse if mucus plugging is suspected, and suspect pulmonary edema in the face of acute deterioration with corresponding radiographic perihilar alveolar interstitial opacity.

Large and Small Airway Disease

Diseases that narrow the trachea and main bronchi can be divided into conditions external to the airway and those intrinsic to the airway. The latter will be divided into focal and diffuse processes. External causes include fibrosing mediastinitis and thyroid goiter. Intrinsic causes can be a focal stricture with numerous etiologies, or diffuse as in conditions such as amyloid, polychondritis or Wegener's granulomatosis.

Radiography has limited use as stenoses may be identified but further characterization is difficult. In children, inspiratory and expiratory CXR may demonstrate air trapping if a main bronchus is occluded (often by a foreign body). CT is excellent in assessing location and extent of stenosis, particularly in areas that are inaccessible to the bronchoscope or where there are multifocal stenoses. Additional mediastinal pathology can also be demonstrated (Fig. 21.4). Expiratory images are useful in diagnosing tracheomalacia.

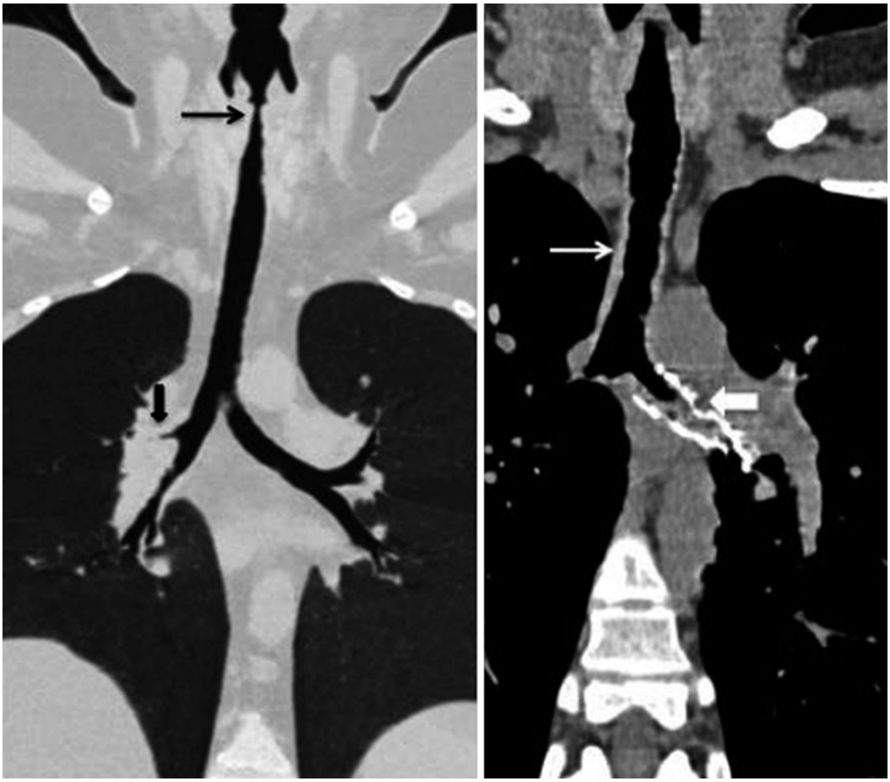

Fig. 21.4 Coronal CT reformats in two different patients with Wagener's Granulomatosis and multifocal airways disease. *Left panel* shows high tracheal (*thin arrow*) and right segmental bronchial (*thick, black arrow*) stenoses. *Right panel* demonstrates tracheitis as evidenced by soft tissue thickening around the trachea (*thin arrow*) and re-stenosis of a left bronchial stent (*thick, white arrow*)

Parenchymal Lung Disease

Idiopathic usual interstitional pneumonitis (UIP) is a progressive and usually fatal disease. Although generally a steadily progressive disease, some patients may present with an acute onset and rapid deterioration. Imaging can be very helpful in determining the extent of the disease and partially guide decision making about intubation or prolonging mechanical ventilation once initiated. The radiographic changes include reticulation predominantly in peripheral and basal segments. CT shows patchy mostly peripheral, subpleural and bibasilar reticular opacities in predominantly the posterior segments. Traction bronchiectasis and honeycombing is invariably present (Fig. 21.5a, b). When reviewed by a specialized radiologist the diagnostic accuracy of CT for UIP has been reported to be as high as 90 %.

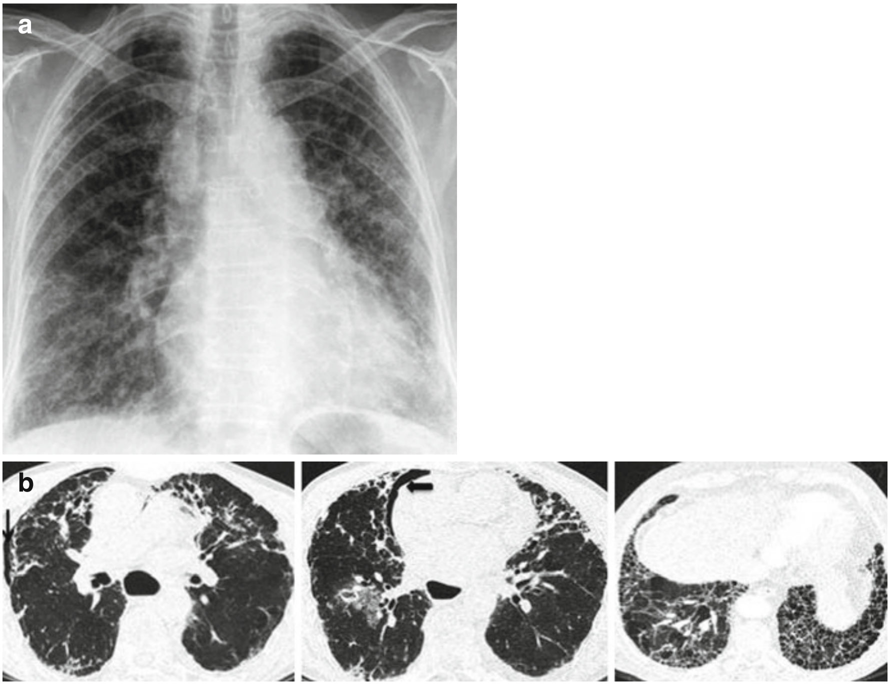

Fig. 21.5 (**a**) Chest radiograph in a 65 year old with widespread bilateral interstitial fibrosis. (**b**) High resolution CT thorax in the same patient during an acute admission better demonstrates the subpleural reticulation, traction bronchiactasis and basal honeycombing characteristic of usual interstitial pneumonitis complicated by small right lateral (*thin black arrow*) and anteromedial (*thick black arrow*) pneumothoraces

Teaching Points

1. Ventilated patients can suddenly deteriorate due to ventilator-associated complications, such as barotrauma.
2. Quickly reversible mechanical causes of hypercarbia can mimic severe bronchospasm.
3. If airway stenosis is the suspected cause of hypercarbia an urgent CT should be requested, as chest radiograph is unlikely to have enough diagnostic yield.

Chapter 22
Persistent Chest Pain

Deepa Gopalan

Clinical Problem

A 55-year-old female with a 6-h history of acute chest pain is admitted to the ICU. The pain is diffuse, but located mainly in the upper part of her chest. She was previously fit and well, in full time employment as an auxiliary in a large catering business. She claims not to have time to do regular exercise and smokes about 40 cigarettes a day. Her pain does not respond to nitrate spray. She is slightly breathless, her blood pressure is raised to 165/95 mmHg, and her heart rate is 115 bpm. After a bolus of Morphine 7.5 mg i.v. her pain settles.

Several syndromes may present as difficult to treat chest pain. The main differential diagnoses include myocardial infarction, aortic dissection, aortic aneurysm, severe aortitis/aortic ulcer, hemopericardium and extrapericardial tamponade as well as esophageal disease such as reflux.

Acute aortic syndrome (AAS) encompasses a heterogeneous range of conditions that have a common set of signs and symptoms. Strictly speaking, the spectrum is comprised of penetrating aortic ulcer, intramural hematoma, and aortic dissection but can be expanded to include traumatic transection and ruptured atherosclerotic aneurysm. AAS in a non-traumatic context has a male preponderance with hypertension being the most common risk factor. However a high index of suspicion should be maintained in patients with underlying genetic risk factors such as connective tissue diseases like Marfans and Ehlers-Danlos as well as aortopathy associated with bicuspid aortic valve and vasculitides.

AAS is characterized by abrupt onset of pain in the chest, back, or abdomen and is most severe at the time of onset as opposed to the gradual increasing pain of acute coronary syndrome (ACS). AAS pain is often described as tearing or ripping but in

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case of an aortic dissection can be sharp and stabbing. It can be migratory as the dissection extends along the vessel or involves other organs. On examination, a new aortic regurgitant murmur or pulse deficit may be detected.

Since all diseases manifesting as AAS are potentially catastrophic with significant early and late mortality, prompt diagnosis and early intervention are crucial.

Imaging Techniques

Imaging is mandatory for definitive diagnosis of AAS. The first test in a patient with acute chest pain tends to be a chest radiograph. However this is neither sensitive nor specific to exclude the presence of an AAS. Computed tomography (CT), magnetic resonance (MR) and transesophageal echocardiography (TEE) have all been shown to have high diagnostic accuracy but in clinical practice, CT is the most commonly used modality for a variety of reasons. It is non-invasive, and readily available in most institutions. With its excellent isotropic spatial resolution, CT can rapidly and robustly provide exquisite anatomical detail of the thoraco-abdominal aorta and branch vessels with the possibility of being able to image the coronary arteries if needed. TEE can furnish vital bedside information but is invasive, user dependent and may miss abdominal segments. MR is non-invasive but very time consuming with the limitations discussed in Chap. 4 and 13.

If the initial imaging is negative or equivocal in the presence of high clinical index of suspicion for AAS, a second modality should be considered to prevent further delay.

Penetrating Aortic Ulcer (PAU)

This is a focal atheromatous plaque that penetrates through the internal elastic lamina in to the aortic media. Deep erosion can precipitate intramedial dissection and hemorrhage, pseudoaneurysm formation or aortic rupture.

On imaging, the majority of penetrating ulcers are seen in the descending thoracic aorta often with extensive atheromatous disease. The ulceration may be at a single site or at multiple locations. It is characterized by a focal contrast medium filled outpouching from a thickened aortic wall, with irregular margins and overhanging edges (Fig. 22.1). The calcified intima may be dislodged internally when there is associated intramural hematoma.

The natural history of penetrating aortic ulcers is uncertain. Asymptomatic patients may have atheromatous aortic lesions that are indistinguishable from PAU.

Fig. 22.1 A 60 year-old male, known to have severe peripheral vascular disease with chest pain. There is a focal outpouching from the aortic arch (*arrow*) with overhanging edges in keeping with a penetrating ulcer

Hence, most units tend to take a conservative treatment approach. Persistent pain, hemodynamic instability or aortic rupture requires active intervention either by surgery or endovascular stent graft placement.

Intramural Hematoma (IMH)

IMH accounts for 10–20 % of AAS and is characterized by rupture of the aortic vasa vasorum and extravasation of blood into the intramedial or subadventitial compartments either spontaneously or secondary to blunt trauma. Unlike dissection, there is no entrance tear and the process is confined within the aortic wall with no direct communication with the aortic lumen.

An unenhanced CT dataset is very valuable in the diagnosis of IMH. The fresh thrombus will be seen as a crescent shaped or circular thickening of the aortic wall (>7 mm). The thrombus will appear hyperdense (Hounsfield unit 60–70) compared to the unenhanced blood. This smooth area will not show any enhancement on the subsequent CT with intravenous contrast medium and there will be no demonstrable intimal flap (Fig. 22.2). IMH can also be differentiated from mural thrombus by luminal displacement of the calcified intima in the former whilst the latter lies outside the calcification.

IMH is a dynamic process and has a variable clinical course with regression seen in about 10 % of cases. There seem to be differences in the natural history between Asian and Caucasian patients. In the western population, IMH involving the ascending aorta (type A-IMH) has a greater risk of rupture or dissection.

Another acute complication of IMH is the development of saccular pseudoaneuysms, commonly in the distal aortic arch. Many studies have established predictive factors for IMH progression that include a Type A location, maximal aortic

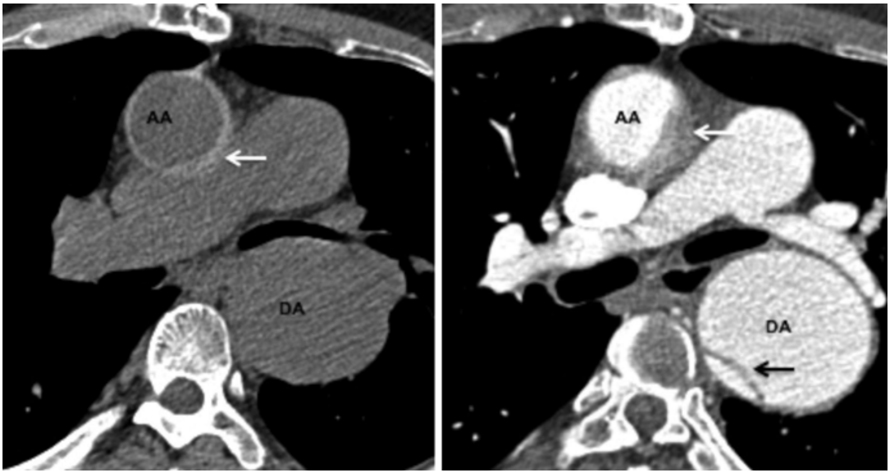

Fig. 22.2 A 70-year old hypertensive male with acute chest pain. *Left panel* is unenhanced axial CT image demonstrating crescentric high attenuation (*arrow*) in the ascending aorta (*AA*). *Right panel* is the corresponding post IV contrast medium image with non-enhancing intramural hematoma (*arrow*). The descending aorta (*DA*) is aneurysmal and has a focal dissection flap (*black arrow*)

diameter of greater than 50 mm, IMH thickness greater than 16 mm and severe luminal compromise. The presence of significant pleuro-pericardial effusions, penetrating ulcers and persistent pain are other perilous signs.

Aortic Dissection (AoD)

Dissection is the most common cause of AAS. Acute dissection generally occurs within 14 days of onset of pain. Dissection is the result of intimal laceration and longitudinal splitting of the aortic media, giving rise to an entrance tear and an intimomedial flap forming a double-barrel aorta. The blood-filled space within the delaminated medial layer is the false lumen.

The Stanford classification divides the dissection in to Type A for ascending aortic involvement and Type B for intimal tears of descending aorta distal to left subclavian artery. However, arch dissection without involvement of the ascending aorta is also labeled as Type B. An alternative classification is the DeBakey system based on the origin of the intimal tear and the extent of the dissection. A Type I tear originates in the ascending and propagates to the arch and descending aorta. Type II is confined to the ascending aorta. Type IIIa is limited to descending thoracic aorta whilst Type IIIb propagates distally below the diaphragm (Fig. 22.3).

Chest radiograph may show mediastinal widening, abnormal aortic and cardiac contours, displacement of aortic calcification and pleuro-pericardial effusions. It is important to remember that a chest x-ray cannot exclude the presence of aortic dissection, as it may be normal in up to 40 % of patients.

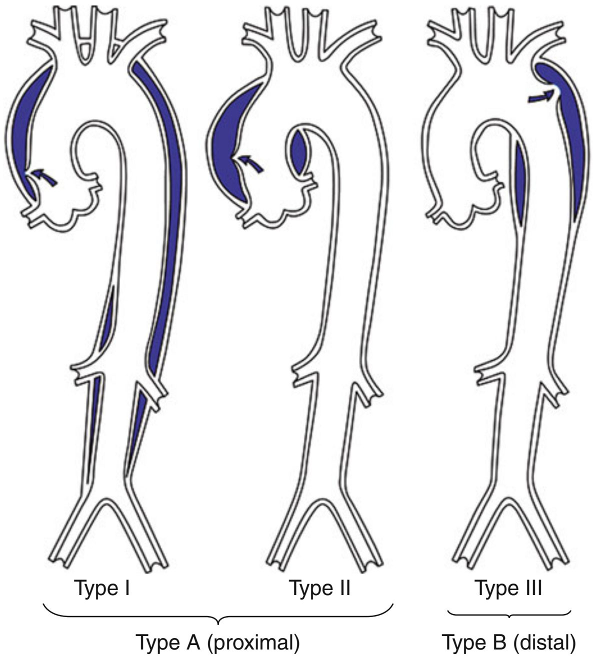

Fig. 22.3 DeBakey and Stanford classification of aortic dissection (Used with permission from Larsen R. Thorakale Aortenaneurysm. Heidelberg: Springer Science+Business Media, 2012)

CT is invaluable in delineating the extent of dissection, branch vessel involvement and evaluation of end organ damage and associated complications. The addition of ECG gating to image acquisition helps eliminating false positive diagnoses of mural flaps in the proximal aorta, particularly the aortic root, which can occur as a result of a motion artifact. In addition, gated studies allow for assessment of coronary arteries.

The initial unenhanced CT will be able to demonstrate IMH or high attenuation thrombus in the false lumen. When the dissection has been complicated by aortic rupture, a high-density fluid collection may be present in the mediastinum or the pleuro-pericardial space in keeping with hemorrhage.

Post contrast CT can identify the entrance tear in most patients. It is usually seen along areas of greatest hydraulic stress such as the right lateral wall of the ascending or in the proximal descending aorta near the ligamentum arteriosum. A distal re-entrance intimal tear may also sometimes be identified. The true lumen is usually smaller and narrower with high-velocity laminar flow and exhibits continuity with the undissected aorta and left ventricular outflow tract. The false lumen tends to be bigger with thinner walls, has slower velocity resulting in a turbulent flow pattern and may even be partially or fully thrombosed with delayed opacification (Fig. 22.4). The pressure difference between the two channels can result in compression of the true lumen. Multiple thin strands of the incompletely separated media with similar attenuation to the dissection flap can sometimes be seen within the false lumen resulting in the "cobweb sign." Another CT indicator of false lumen is the "beak sign" produced by the wedge of hematoma that cleaves a space for the propagation of the false lumen.

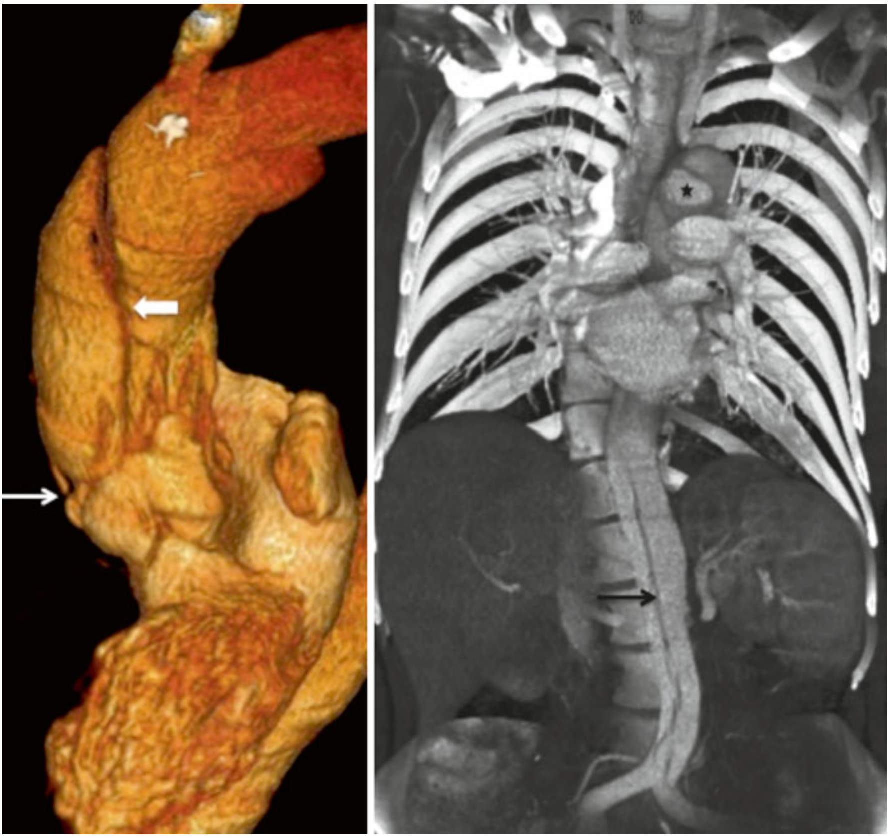

Fig. 22.4 Volume rendered CT images in two patients with type A (*left panel*) and Type B (*right panel*) dissection. In the first patient, the dissection flap in the ascending aorta (*block white arrow*) involves the ostium of right coronary artery (*thin white arrow*). In the second patient, the dissection involves the descending and abdominal aorta down to the bifurcation (*black arrow*). The true lumen in the descending thoracic aorta (*black star*) is smaller and shows better enhancement whilst in the abdominal aorta the differential enhancement between the two lumina is less evident

Active extravasation of contrast medium or a periaortic hematoma is an ominous sign of rupture. Other perilous complications include aortic insufficiency, acute myocardial ischemia, neck vessel occlusion and resultant neurological sequelae, cardiac tamponade and malperfusion syndromes (Fig. 22.5). Such complications are more common with Type A dissection and hence this generally requires emergency surgical intervention whilst Type B is usually suitable for medical management. However, when Type B dissection is associated with hemodynamic instability, aneurysmal widening of the descending aorta of >6 cm, visceral or peripheral vascular malperfusion or distal embolization, active intervention in the form of surgery, endovascular stent placement or fenestration should be considered.

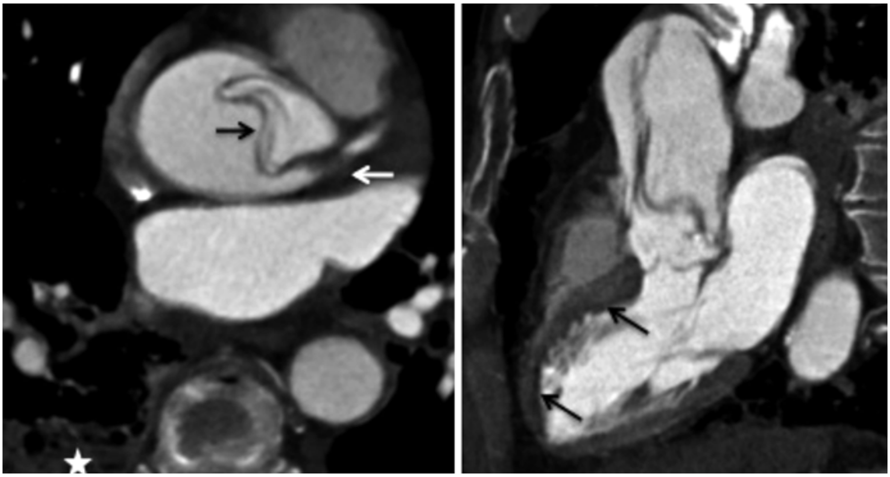

Fig. 22.5 Axial CT images from a 55-year old female with complex Type A dissection. *Left panel* shows the flap in the aortic root (*black arrow*) with thrombus in the left main coronary artery (*white arrow*). *Right panel* is a left ventricular outflow tract view demonstrating the extent of the flap as well as the perfusion defect in the anterior wall of the left ventricle (*black arrows*) due to acute myocardial ischemia. *White star* corresponds to small right pleural effusion with basal consolidation

Acute Traumatic Aortic Injury (ATAI)

ATAI is usually sustained from deceleration or crush injury and is associated with substantial morbidity and mortality. Traumatic vascular injury is discussed in Chap. 39.

Thoracic Aortic Aneurysm (TAA)

TAA is an indolent process and is often asymptomatic and diagnosed as an incidental finding. It has diverse etiology ranging from atherosclerosis and hypertension to genetic predispositions such as connective tissue disease like Marfans, Ehlers-Danlos, bicuspid aortic valve and vasculitides like Takayasu's and Giant cell arteritis. Pseudoaneurysms are narrow-necked saccular protrusions that occur as a consequence of trauma or often mycotic infection (Fig. 22.6). Location, size and etiology impact on the clinical outcome.

With increasing size of the aneurysm, patients develop symptoms related to compression of adjacent structures such as superior vena cava, trachea, esophagus and recurrent laryngeal nerve. Proximal aortic dilatation involving the valve and ascending aorta can be complicated by aortic regurgitation and heart failure. Acute onset of severe neck, chest or back pain may portend aortic leak, rupture or dissection.

Fig. 22.6 A 27-year old patient with previously undiagnosed bicuspid aortic valve and coarctation presented with clinical features of infective endocarditis. Sagittal CT image elegantly demonstrates the pseudoaneurysm in the post-ductal coarctation (*white arrow*). There is also an aortic root abscess (*black arrow*)

The risk of rupture increases when the aneurysm reaches certain "hinge points" which are around 6 cm in the ascending and 7 cm in the descending aorta. Increasing age, smoking and hypertension accelerate this process.

Surveillance imaging is usually performed with echocardiography, CT or MR. However, in an acute setting, CT is the most appropriate imaging modality, particularly when there is clinical suspicion of rupture and it becomes mandatory to define the precise anatomy of the aneurysm and its relationship to adjacent structures prior to definitive treatment.

TAAs can rupture into the mediastinum, pleural or pericardial space, adjacent airway or esophagus. A peripheral crescent of high-density within the thrombus of an aneurysm on pre-contrast CT is a sign of acute or impending rupture. Enhanced CT may demonstrate active extravasation of contrast medium from the aortic lumen. An area where the contour of the posterior aorta is difficult or impossible to delineate and the posterior aorta follows the contour of the spine characterizes the "draped aorta sign." Focal discontinuity in circumferential wall calcification is more commonly observed in unstable or ruptured aneurysm (Fig. 22.7). Fistula formation is rare but can result in communication with the bronchi or the esophagus. Mycotic aneurysms have an irregular lobulated appearance and may contain eccentric thrombus with surrounding periaortic inflammation.

Aortitis

Systemic autoimmune diseases such as Takayasu's and Giant cell arteritis and Behçet's disease can cause large vessel aortitis. Although they may be accompanied by systemic manifestations like fever or inflammatory syndrome, the presentation can be variable.

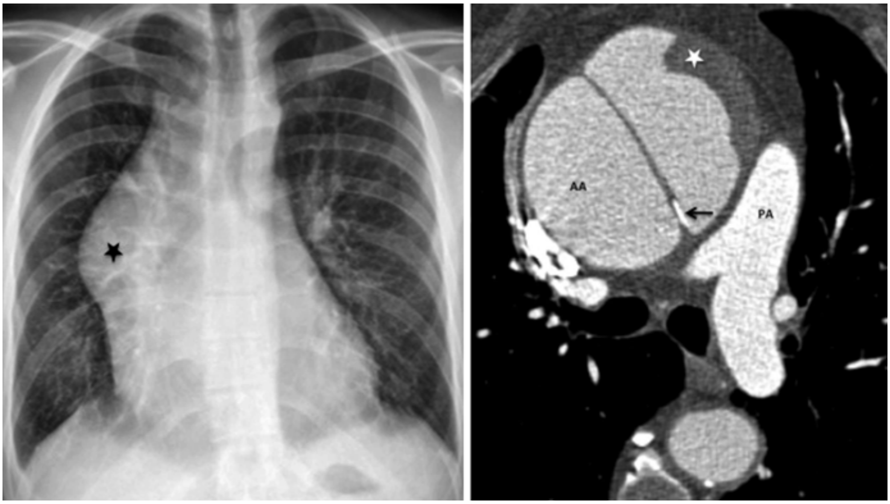

Fig. 22.7 A 60-year old female hypertensive with known aortic aneurysm presented with acute severe chest pain radiating to the back. Dilated ascending aorta (*black star*) on the chest radiograph (*left panel*). Axial CT (*right panel*) shows the ascending aortic (*AA*) aneurysm with a dissection flap and displaced calcification (*black arrow*) and antero-lateral thrombus (*white star*). Also note the compression and displacement of the pulmonary artery (*PA*)

In the initial stage, the aortitis is characterized by circumferential wall thickening and enhancement of the aorta and involved branches. Involvement of the aortic root can result in annuloaortic ectasia or aortic regurgitation. Chronic manifestations include aneurysmal dilatation, mural calcium deposition and vascular stenoses. Complications include aortic dissection or rupture. CT, MR and Positron emission tomography (PET) play complimentary roles in the diagnosis and follow up. Steroids and immunosuppressive therapy form the mainstay of medical treatment that needs to be continued even after surgical intervention.

Teaching Points

1. D-Dimers have excellent sensitivity but only moderate specificity for AAS as it cannot differentiate it from other causes of chest pain such as pulmonary embolism.
   If the initial imaging is negative in the presence of high clinical index of suspicion for AAS, a second modality should be performed without further delay.
2. Although MR is superior to CT in differentiating acute intramural hematoma from atherosclerotic plaque and chronic intraluminal thrombus, it is not an appropriate test in acutely unwell patients with hemodynamic compromise.
3. Chest x-ray cannot exclude the presence of aortic dissection as it may be normal in up to 40 % of patients.
4. A peripheral crescent of high-density within the thrombus of an aneurysm on pre-contrast CT is a sign of acute or impending rupture.

Chapter 23
Mediastinal Masses

Devinda Karunaratne

Clinical Problem

A 68-year-old patient who has previously been fit and well has recently been diagnosed with Lymphoma. She is now being admitted to the Intensive Care Unit after becoming acutely unwell. She is very short of breath, tachypneic, her peripheral oxygen saturation is 86 % on high flow oxygen administered via a facemask. In the last few hours she has started to develop some hemoptysis. Apart from a tachycardia of 130 bpm she is hemodynamically stable on admission and denies any chest pain. She finds it very difficult to talk in full sentences.

It is decided that she needs initial stabilization before further imaging is requested to rule out the presence of a mediastinal mass causing compressive signs and to identify the cause of hemoptysis.

In an ideal situation evaluation and risk assessment of these patients will include mode of clinical presentation, radiological investigation, pulmonary function tests, fibre-optic bronchoscopy (FOB) and echocardiography. However, some of these may not be possible in the critically ill patient.

Presenting features in a patient with mediastinal mass depend upon the pressure effects on the surrounding structures. These can compress the major airways, cardiac chambers and mediastinal vessels due to direct involvement or as a consequence of the primary disease, pleural or pericardial effusion. Symptoms include dyspnea, cough, stridor and orthopnea. Compression of the heart and great vessels may lead to cyanosis, syncope, and dysrhythmias. Superior vena cava (SVC) syndrome is characterized by engorgement of the veins of the neck, upper arm and chest wall.

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The natural history of mediastinal masses varies from those that are asymptomatic (often benign) to those with aggressive symptoms (invasive neoplasm). In infants, children and adolescents the most common lesions are lymphomas, neurogenic tumors, and germ cell tumors. In adults, invasive malignancies with conglomerate lymph node masses and lymphoma are reported to be the most common mediastinal masses. While lesions arising in the posterior mediastinum typically do not cause airway obstruction, invasive malignancies do not respect mediastinal boundaries.

Intensivists generally encounter mediastinal masses in the antero-superior mediastinum, the most common lesions include lymphomas, thymoma, teratoma/germ cell tumor and benign lesions like cystic hygroma and retrosternal thyroid goiter.

Imaging allows for review of mediastinal masses, preoperative evaluation and risk assessment, and various measures utilized for airway and cardiovascular management.

Imaging Techniques

Chest radiograph (CXR) is a basic study and is readily available even under emergency conditions. It may be helpful in diagnosing and localizing pneumonia, acute or chronic airway compromise, most bronchogenic cancers, or pleural diseases, i.e., pneumothorax, hemothorax or large effusions.

Computed tomography (CT) of the chest provides more accurate and detailed information about the anatomical relationship of the mediastinal mass to neighboring structures and its effects on the tracheobronchial tree. It can quantify the degree of airway compression, which is not always obvious on the CXR. It is especially useful for the evaluation of main and lobar bronchi. The measurement of the tracheal diameter, tracheal cross-sectional area, mediastinal thoracic ratio (MTR) and mediastinal mass ratio (MMR) can be used to identify patients at risk of airway compromise. The degree of tracheobronchial compression identified on CT predicts airway difficulty and obstruction. In anticipation of upper airway compromise, the chest CT should be extended to include high neck from the base of skull. Intravenous contrast medium is vital; an arterial phase study is adequate. In some cases a 40–60 s delay is helpful to demonstrate venous structures.

Ultrasound imaging of the upper airway in critically ill patients offers a number of advantages compared with competitive imaging techniques or bronchoscopy. It is portable, widely available, repeatable, relatively inexpensive, and pain free. One of the important disadvantages is operator dependency. Ultrasound can be used for pre-intubation assessment, endotracheal tube placement, verification of tube position (CXR is more widely utilized), extubation outcome as well as guided percutaneous tracheostomy. Ultrasound is more commonly used in assessing the vasculature.

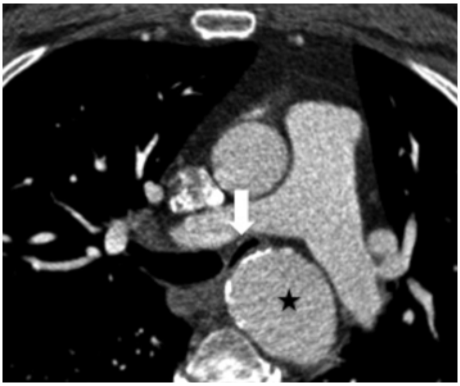

Fig. 23.1 ECG-gated Cardiac CT on a 45 year-old male patient with history of childhood road traffic accident shows an incidental aortic pseudoaneurysm (*black star*), presumed secondary to previous undetected transection. This is causing severe compression of the left main bronchus (*block arrow*)

Airway Compromise

Mediastinal masses can present with a wide array of airway related symptoms. They can include anything from freedom of airway compromise to severe dyspnea either caused by the disease itself or by sequelae of disease process, such as mucus plugging or severe bronchopneumonia.

Patients with large mediastinal tumors and seemingly normal airways may develop airway obstruction when lying supine or after induction of general anesthesia (Fig. 23.1). Sometimes, a life threatening compression can occur even after an uneventful endotracheal intubation. Performing an emergency tracheostomy to relieve obstruction is likely to prove futile in these cases, as the airway compromise may be distal to the tube.

As obtaining a secure airway is vital, prompt diagnosis and early intervention are crucial.

In the presence of severe symptoms of cardiorespiratory compression such as, positional dyspnea, stridor, orthopnea, syncope, and SVC syndrome the induction of general anesthesia may be fatal. In high-risk patients with mediastinal mass, irreversible cardiorespiratory collapse can occur with as little as the use of a sedative or simply by putting the patient in a supine position. It is also possible that tracheobronchomalacia due to prolonged compression by a mediastinal mass may potentiate the airway collapse, especially after tracheal extubation (Fig. 23.2). Therefore, airway management in patients with large mediastinal masses with or without direct airway compromise poses a difficult challenge to the intensivists.

Venous and Arterial Compromise

Tumors may invade the heart, pericardium and great vessels by means of lymphatic or hematogenous dissemination, local extension, or, more uncommonly, via the transvenous route. Tumors that are most likely to involve the heart and pericardium

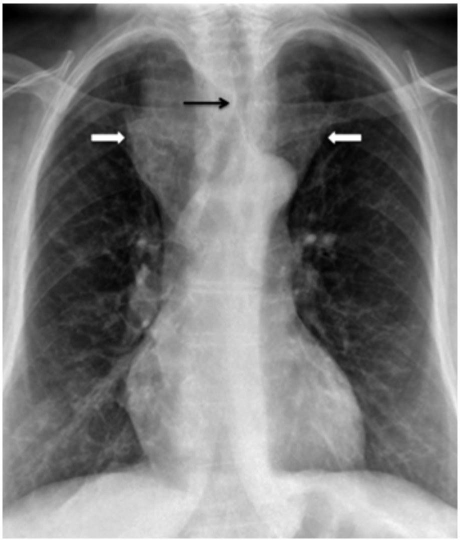

Fig. 23.2 A 65 year-old female with a large anterior mediastinal mass secondary to retrosternal thyroid goiter (*white block arrows*) and resultant compression of the trachea (*black arrow*)

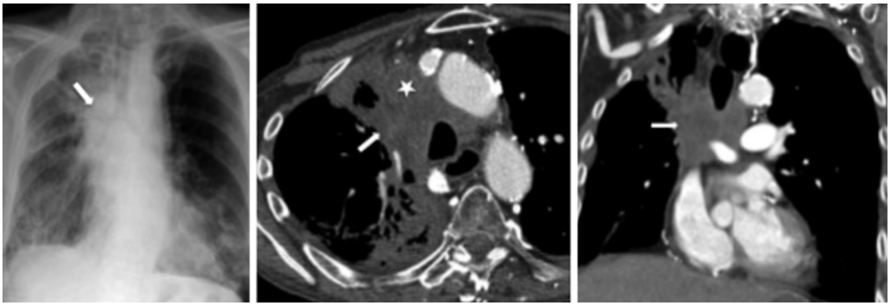

Fig. 23.3 A 55-year old female with small cell lung cancer. CXR (*far left*) shows a large right-sided mediastinal mass (*block arrow*) with obliteration of right paratracheal stripe. Axial (*middle*) and Coronal CT images demonstrate the large necrotic mediastinal mass (*block arrow*) with invasion and occlusion of the superior vena cava (*white star*)

include cancers of the lung, breast cancer, lymphoma, and melanoma. Metastases to the heart and pericardium can manifest as a lung mass or mediastinal mass with direct invasion of adjacent structures such as the heart, as a central mass extending into the left atrium via the pulmonary veins, as pericardial effusion and nodularity, or as myocardial lesions.

Profound hypoxia may also occur due to compression of great mediastinal vessels in the presence of patent airways. Severe symptoms of cardiorespiratory compromise can be due to right ventricular outflow tract or pulmonary artery compression.

The SVC is vulnerable to extrinsic compression and obstruction because it is thinwalled, its intravascular pressure is low and its anatomical position which is confined by lymph nodes and other rigid structures (Fig. 23.3).

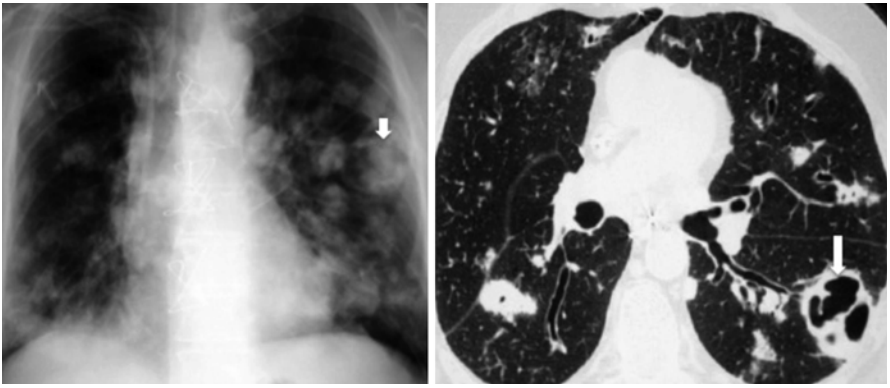

Fig. 23.4 CXR and CT on a 30 year-old male intravenous drug abuser with multiple bilateral septic infarcts. The largest of the cavities in the left lung (*block arrow*) has intracavitary soft tissue and air, proven to be aspergillus

Hemoptysis

This serious, potentially life-threatening complication can be due to airway erosion by tumors or pulmonary hemorrhage. Pulmonary artery injury or aneurysm formation secondary to Swan Ganz catheter manipulation is one of the uncommon iatrogenic causes of hemoptysis.

Diagnostic studies for massive hemoptysis include CXR, bronchoscopy, contrast enhanced CT of the chest and the gold standard 'selective angiography'. In patients with massive hemoptysis, the work-up is usually performed both to find the cause of the bleeding and to localize its site.

Fibreoptic bronchoscopy (FOB) is readily available and can be performed in patients too unstable for transfer to the CT scanner. Bronchoscopy has been considered to be a primary method for diagnosis and localization of hemoptysis. FOB has been proven to be efficacious in evaluating central bronchial lesions. A vasoactive drug can be applied locally during bronchoscopy to control bleeding.

Bronchoscopy has some disadvantages in the diagnosis and localization of massive, active hemoptysis. It can be difficult to localize the bleeding site because of excessive blood in the bronchi and endobronchial therapies are not effective in most cases of massive hemoptysis. The risks of bronchoscopy include possible airway compromise, delay in definitive treatment, and hypoxemia.

Contrast CT has been shown to be of considerable value in diagnosing bronchiectasis, vascular lesions, eroding aspergilloma, and bronchogenic carcinoma in patients with massive hemoptysis (Fig. 23.4). A major advantage of CT over other imaging modalities is the ability to exclude other causes of bleeding, i.e. mimics of hemoptysis, from nasopharynx and gastrointestinal tract and provide a vascular road map. The argument for performing a CT prior to bronchoscopy or embolization is to localize the pulmonary lobe in which bleeding is suspected and

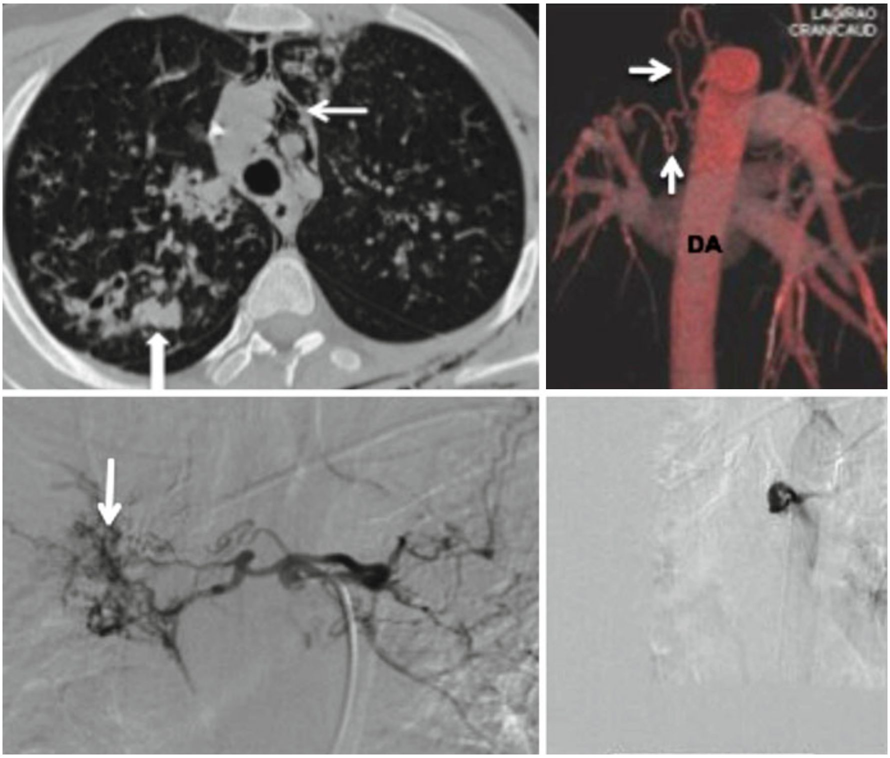

Fig. 23.5 A 18-year old male cystic fibrosis patient with hemoptysis. CT (*top left*) demonstrates widespread bronchiectasis with focal area of hemorrhage in the right lung (*block arrow*) and pneumomediastinum (*thin arrow*). Volume rendered technique CT image (*top right*) elegantly demonstrates the enlarged bronchial collaterals (*thin arrows*) arising from the descending aorta (*DA*). Catheter angiography was performed to identify the culprit lesion (*white arrow*) (*bottom left*) that was subsequently successfully embolised (*bottom right*)

identify enlarged bronchial or non-bronchial collateral vessels (Fig. 23.5). Knowing the potential site for bleeding permits intervention such as embolization to be focused and performed in a safe and efficient manner. CT and bronchoscopy are not competitive but complementary tools for assessing and managing patients with hemoptysis, and indeed, the combined use of bronchoscopy and CT does yield the best results. Angiographic findings in massive hemoptysis include neovascularity, hypertrophic and tortuous bronchial arteries, shunting into the pulmonary artery or vein, bronchial artery aneurysm, and extravasation of contrast medium. Determination of which arteries are to be embolized should be based on a combination of CT, bronchoscopy, and angiographic findings together with clinical correlation.

Table 23.1 Common causes of pericardial effusion

Iatrogenic causes	Disease related causes
Myocardial or coronary perforation after Pacemaker or ICD lead implantation	Ascending aorta dissection
Central line placement	Uremic or infective pericarditis
Percutaneous coronary intervention	Post myocardial infarction
Post cardiac surgery	

Pericardial Effusion

This is probably the most common manifestation of pericardial disease. Echocardiography is the test of choice for the diagnosis of pericardial effusion, although serial chest radiographs that show suspicious cardiac enlargement and contour (in consideration with the above clinical context) are also useful as a baseline investigation. The most common causes of pericardial effusions with or without tamponade physiology are listed in Table 23.1. In a patient who has had prior radiation therapy, the pericardium may appear thickened and nodular, mimicking metastatic disease.

CXR and echocardiography cannot reliably delineate fluid composition. On CT, blood or effusions associated with hypothyroidism will have a high attenuation, serous fluid a water density, and chylous fluid may have a low attenuation. As well as delineating the density of the fluid, associated pericardial thickening/enhancement, malignancy and any significant pulmonary disease such as sarcoid or TB can be demonstrated. CT also enables evaluation of the size of the effusion and provides indirect evidence of any hemodynamic effect. Distortion of the right ventricular (RV) free wall and RV compression suggests significant hemodynamic compromise. Large effusions can accumulate over time with no evidence of tamponade, so size alone should not be used to indicate hemodynamic significance (Fig. 23.6).

Pericarditis

It may be difficult to distinguish between constrictive pericarditis and restrictive cardiomyopathy as both conditions have restricted ventricular filling leading to an increase in diastolic pressure and equalization of atrial and ventricular pressures in all four cardiac chambers. The causes of constriction include cardiac surgery, previous radiation, infection, uremia, connective-tissue disease and malignancy. CT features that suggest constriction include pericardial calcification, thickening of >4 mm, dilatation of systemic veins, tubular configuration of right ventricle, leftward septal bowing, hepatomegaly and ascites (Fig. 23.7). An important caveat is that neither pericardial thickening nor calcification are diagnostic unless the patient is symptomatic. Constrictive pericarditis generally presents with very non-specific symptoms. Table 23.2 summarizes the most common features.

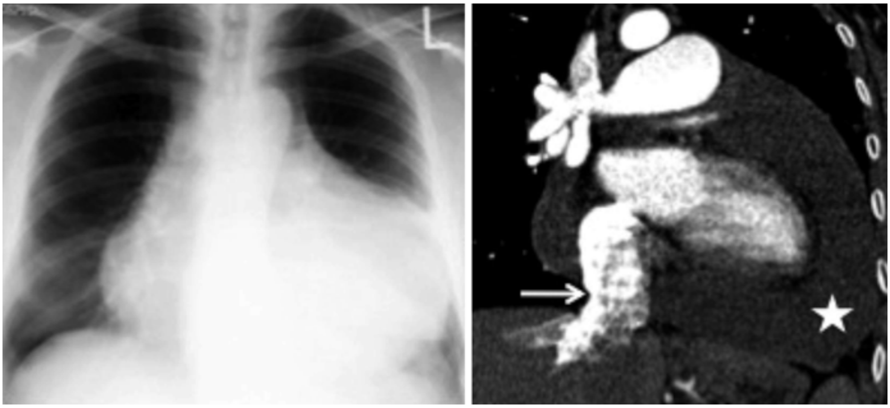

Fig. 23.6 A 53-year old female with breast carcinoma presented with worsening dyspnea. The cardiac silhouette is enlarged with a globular shape on the CXR. Coronal contrast enhanced CT confirmed pericardial effusion (*white star*) that was large and circumferential with dilated systemic veins (*arrow*)

Fig. 23.7 A 49-year old male patient with constrictive pericarditis. The pericardium is thickened (*white thin arrow*) with focal calcification (*block arrow*). There are bilateral pleural effusions (*white star*)

Table 23.2 Common symptoms associated with constrictive pericarditis

Cardiac symptoms	Tachycardia
	Palpitations
	Dyspnea
	Lower extremity swelling
Abdominal symptoms	Abdominal swelling
	Abdominal discomfort
	Nausea
	Right upper quadrant pain
General symptoms	Fever
	Diaphoresis
	Easy fatigability

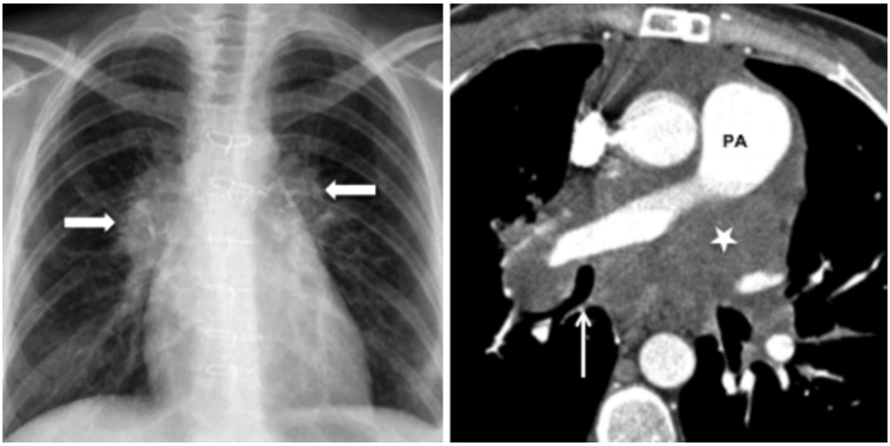

Fig. 23.8 A 67 year-old male patient with history of CABG was found to have bilateral hilar enlargement (*block arrows*) on a follow up radiograph. Axial enhanced CT image demonstrates a large mediastinal mass (*white star*) that that is causing extrinsic compression of the pulmonary artery (*PA*) as well as the right segmental bronchus (*thin arrow*). This was histologically proven to be lymphoma

In the acute phase echocardiography is better suited to demonstrate changes associated with constrictive pericarditis.

Acute myopericarditis can occur as a result of infection (viral, tuberculosis) or complication of myocardial infarction. The inflamed pericardium may demonstrate enhancement on CT and may also be accompanied by effusion and thickening.

Extrinsic Compression of Pulmonary Vasculature

Any enlarged structure adjacent to the pulmonary arteries or veins can theoretically cause compression and lead to subsequent hypoxia and pulmonary hypertension (PH). It usually results from bronchial carcinoma or hilar/mediastinal lymphadenopathy. Patients tend to present with symptoms associated with the underlying disease process but the imaging features of pulmonary vascular compression can mimic thromboembolic disease (Fig. 23.8). CT is pivotal in determining potential surgical resectability and the type of appropriate surgery. Tumors extending around >180° of the circumference of the pulmonary artery are generally regarded as inoperable. While in lung cancer the main influence on survival is the tumor itself, in chronic diseases such as sarcoidosis the development of PH has a significant impact on prognosis. Patients with sarcoidosis associated PH have poor functional status, and are likely to require listing for lung transplantation. Fibrosing mediastinitis can also extrinsically compress pulmonary vessels with subsequent PH. Other appearances include unilateral or asymmetric narrowing of the arteries. Ipsilateral Kerley B lines and peripheral wedge-shaped consolidation may occur in arterial or venous infarction.

Mediastinal Appearances in Critically Ill Patients Following Cardiothoracic Surgery

Median Sternotomy

The main complications are mediastinitis and rebleeding. Up to 20 % of patients with bleeding complications are picked up radiologically. Rebleeding usually occurs in first 24 h. CT is the best modality to show complications like dehiscence, abscess, mediastinitis, and sternal osteomyelitis. Dehiscence or mediastinitis may be asymptomatic or present with nonspecific symptoms such as chest pain, cough and fever. They usually don't occur before 10–14 days after operation.

Thoracotomy

Complications to follow thoracotomy include atelectasis, air leak, pleural effusions, pulmonary hemorrhage and hemothorax, and infection. Potentially fatal complications include pulmonary embolism, lobar torsion, cardiac herniation, pneumonia, respiratory failure and ARDS. Normally there is ipsilateral mediastinal shift after pneumonectomy with varying degrees of fluid in the pneumonectomy space. With contralateral or no mediastinal shift or descent of the air fluid level on the side of the pneumonectomy on serial studies one must consider bronchopleural fistula, hemorrhage or empyema in the pneumonectomy space.

CXR still remains a vital tool for screening. However, computed tomography will assist in problem solving with greater specificity.

Imaging Post Surgery or Chemoradiotherapy

It is important to be aware of normal, benign findings that occur after surgery and/or chemoradiation therapy, and to distinguish such findings from those indicative of recurrent disease. For example, following a pneumonectomy, the ipsilateral hemithorax normally fills with organized fluid, appearing as low attenuation material on CT. The presence of a mass within the low attenuation material is suggestive of tumor recurrence. Post-radiation pulmonary necrosis is an uncommon, severe complication. It manifests as cavitation within a fibrotic background lung parenchyma. Such an appearance may simulate recurrent disease.

CT is able to delineate esophagitis. Its most common appearance is esophageal thickening.

Radiation-induced lung disease (RILD) unfortunately is common. In the acute phase, RILD typically manifests as ground-glass opacity or increased attenuation or as consolidation; in the late phase, it typically manifests as volume loss, scarring, and traction bronchiectasis. Awareness of the atypical manifestations of RILD can be useful in preventing misdiagnosis with infection, recurrent malignancy, radiation induced tumors, and lymphangitic carcinomatosis.

Overall prognostic evaluation of these patients based on clinical and radiological assessment is useful for immediate and intermediate prognostic outcomes, particularly when admitted to ICU with complications or unrelated disease.

Mediastinal Infection

Infective processes in the mediastinum a rare cause of sepsis and shock and can present as a mediastinal mass. Infection should be considered especially in patients following cardio-thoracic surgery, suspected esophageal perforation or even in those with retropharyngeal or neck infections. Please see Chap. 24 for more detail.

Teaching Points

1. CT allows for review of mediastinal masses, optimizes preoperative evaluation, risk assessment, anesthetic management, and enables various measures to be utilized for airway and cardiovascular management in these patients.
2. Progressive cardiac enlargement on serial chest radiographs is suspicious for pericardial effusion and should be confirmed by echocardiography.
3. It is important to differentiate constrictive pericarditis and restrictive cardiomyopathies, as pericardial stripping is a potential cure for the former condition.

Chapter 24
Sepsis of Thoracic Origin

Caroline A. McCann and Reena Dwivedi

Clinical Problem

A previously fit and well 27-year-old man is admitted to ICU from the Emergency Department. He gives a 1-week history of malaise and cough. He does not smoke and denies the use of recreational drugs. He became increasingly unwell over the course of the previous night, since the early hours of the morning he is feeling short of breath. He has a non-productive cough. He is tachycardic with 145 bpm and hypotensive; his ECG shows he in atrial fibrillation. His respiratory rate is 40 breaths per minute; his peripheral oxygen saturation is 80 % with 5 l O_2 through a facemask. On auscultation a few crackles can be heard and both bases are very quiet.

Multi-organ organ dysfunction is a feature of severe sepsis. Persistent hypoperfusion and inadequate tissue perfusion induced by infection results in septic shock. This is an important cause of considerable morbidity and mortality in critically ill patients. Ageing population and antibiotic resistance have resulted in increasing incidence of sepsis. A range of microorganisms including bacteria, viruses, fungi and protozoa can be the causative factor. The underlying immune status and associated co-morbidities also play an important role in determining the outcome. Whatever the organism or site of infection, a high clinical index of suspicion and early diagnosis is vital to enable rapid institution of appropriate treatment.

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Imaging is inaccurate in discriminating between various organisms. Its main functions are to:

- initially demonstrate the location of the infection
- monitor the response to treatment and to identify any potential complications.

Imaging Techniques

The chest radiograph is a useful screening tool in patients with sepsis of suspected thoracic origin. Lobar or multifocal bronchopneumonia may be readily identified but in early disease the chest x-ray may be insensitive. While the chest X-ray may identify cavitation in TB or multifocal cavities in septic emboli these changes may be subtle and better characterized on CT. Either reactive pleural effusions or infected empyemas are frequently encountered on plain film and may require intervention. Similarly in the patient post thoracic or cardiac surgery infected pleural or mediastinal collections are not uncommon. While the chest X-ray is a useful first line assessment tool if infected mediastinal collection is a concern CT is considerably more sensitive and specific in making this evaluation. In the immunocompromised setting the chest X-ray remains the standard screening tool but as progression of disease may be rapid early CT to detect occult disease is required in undiagnosed persisting sepsis.

When the chest X-ray identifies disease which requires further characterization, when the differential diagnosis includes mediastinal sepsis or pulmonary embolus, or when the cause of cardiovascular collapse or respiratory symptoms is unclear CT is a valuable problem solving tool. The use of intravenous contrast material may be relatively contraindicated in the setting of renal impairment but often the clinical need of the patient will necessitate intravenous contrast administration with relevant hydration. CT enables comprehensive assessment of the lungs, proximal airways for debris or tumor, pleural space, mediastinum, pulmonary vasculature, bones and upper portion of the abdomen. It also permits image guided intervention particularly for difficult to access or partly gas containing collections which can be difficult to assess with ultrasound.

Ultrasound is ideal for image guided pleural drainage and aspiration. Its portability makes it the first line technique for this purpose in ICU patients.

Fluoroscopic procedures such a water-soluble contrast swallow may be used to evaluate suspected esophageal perforation. However, by the time patients are admitted to the ICU CT is typically the safest method to make this assessment.

Pulmonary Infection

There are three subtypes of pneumonia depending on the radiological and pathological appearances: lobar, interstitial and bronchopneumonia. The key finding is consolidation, which appears radiologically as increased lung opacification resulting in obscuration of the underlying vessels. This usually indicates that the alveolar

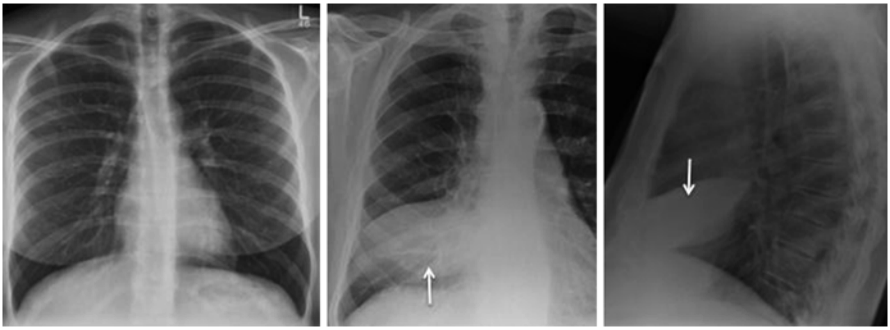

Fig. 24.1 Silhouette sign: *Left panel* is a normal chest radiograph demonstrating the "silhouette" sign. The mediastinum, heart and diaphragm are sharply delineated against the aerated lung. Frontal (*middle*) radiograph in a different patient shows obscuration of the right heart border due to consolidation (*white arrow*) in the immediately adjacent lung (right middle lobe). On the lateral film (*right panel*) the consolidation (*white arrow*) has a straight margin as it abuts the fissure

space is filled with fluid, cells, blood, pus or tissue. The appearance can vary from small ill-defined shadows to large air-space opacities, which may be localized or involve multiple lobes.

When localizing consolidation radiographically, the "silhouette sign" is useful (Fig. 24.1). This refers to the mediastinum, heart and diaphragm being visualized against aerated lung by a sharp edge. When a part of lung lying adjacent to these structures becomes non-aerated, the outline of that structure will become indistinct or invisible. If consolidation has a straight margin, then it most likely abuts a fissure.

Lobar Pneumonia

This is the most common manifestation of a community-acquired pneumonia and typically results from a pneumococcal (*Streptococcus pneumoniae*) infection after airborne transmission. The localized inflammatory reaction causes the exudate to spill into the adjacent alveoli. This process spreads from the distal air spaces via the pores of Kohn, and may progress to occupying a whole lobe. As the central air-spaces are patent despite the distal ones being compromised, the typical radiographic appearance is an air bronchogram without significant volume loss. In patients with a potential malignancy, a central obstructing lesion needs to be considered as being suspicious (Fig. 24.2).

Bronchopneumonia

This is the result of the inflammatory exudate localizing around inflamed airways but respecting septal boundaries. Some acini are involved while others are spared. The exudates initially originate around the terminal and respiratory bronchioles

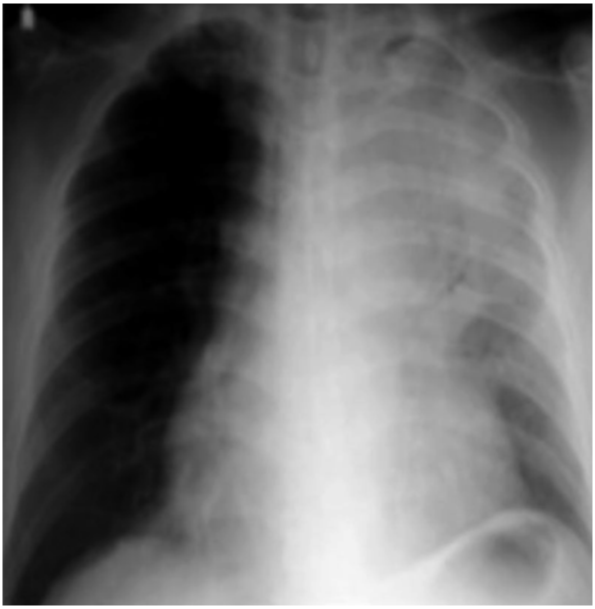

Fig. 24.2 Lobar pneumonia. Homogeneous consolidation involving left upper lobe with multiple air bronchograms and no volume loss

Fig. 24.3 Broncho-pneumonia. There are ill-defined nodular opacities with patchy inhomogeneous consolidation involving several lobes

rather than the distal airspaces in lobar pneumonia. Several foci of infection usually develop resulting in the radiographic appearance of multifocal nodular or patchy consolidation. Air bronchograms and volume loss are usually absent. Numerous organisms can result in bronchopneumonic patterns (Fig. 24.3).

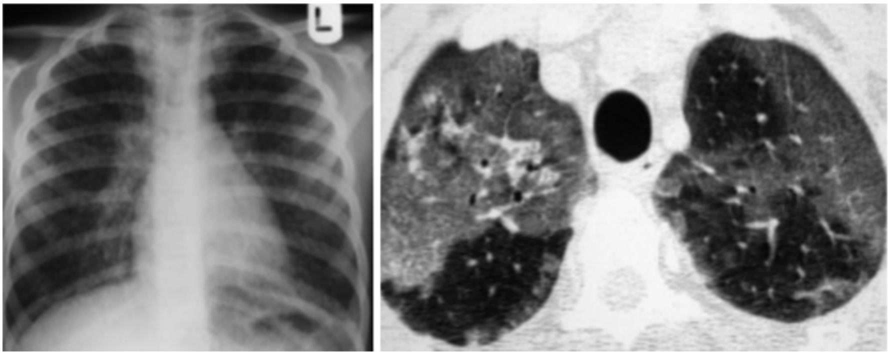

Fig. 24.4 Interstitial pneumonia. CXR shows subtle ground glass and fine reticular pattern. These features are more readily appreciable on the HRCT where there are patchy bilateral centrilobular opacities

Interstitial Pneumonia

This predominantly involves the supporting interstitium between the airspaces/alveoli. Bronchial and bronchiolar walls become infiltrated and edematous with further extension from the peribronchial tissues into the interlobular septa. The inflammatory process can also progress into the terminal air spaces and alveoli. The usual radiographic appearance is a reticulonodular pattern reflecting the compromised peribronchial and interstitial tissue. The infective organisms tend to be viral or *Mycoplasma pneumoniae* (Fig. 24.4).

Cavitating Pneumonia

This often rapidly spreading, destructive process is usually caused by *Staphylococcus aureus*, gram-negative bacteria, fungal infections or *Mycobacterium tuberculosis*. Pneumatoceles may mimic cavitations and are defined as air cysts more than 1 cm in size and a wall thickness of less than 4 mm (Fig. 24.5a, b). If there is co-existing emphysema with bullae, consolidated lung can give a similar appearance to cavitation.

Ventilator-Associated Pneumonia (VAP)

VAP is the most common healthcare associated infection in ICU and may account for up to half the antibiotic use. It occurs in up to 30 % of ventilated patients, its incidence is quoted as 5 cases per 1,000 ventilator days. It carries a mortality of 9 %.

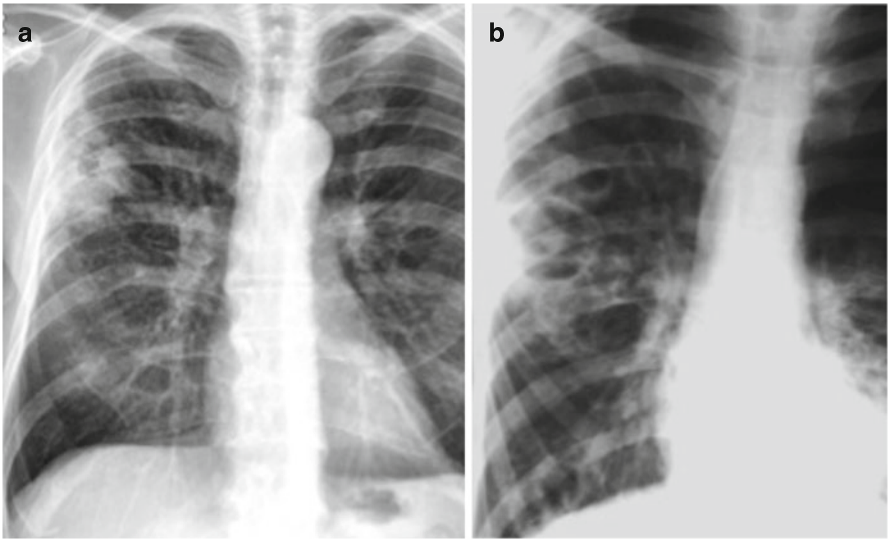

Fig. 24.5 (**a**). *Left* image is from a 52 years old male with history of alcohol excess, presenting with pyrexia. There is a thick walled cavitating lesion in the right upper lobe due to Staphylococcus aureus pneumonia. (**b**) Pneumatocle, approximately 4 weeks after the initial film

In the absence of a consensus definition it is generally accepted that VAP is a clinical diagnosis. Table 24.1 details the criteria for diagnosis as proposed by the Centre for Disease Control and Prevention.

CXR has poor specificity for the diagnosis of VAP. No single radiographic sign has diagnostic accuracy better than 68 %. However, according to studies, certain signs if present can be helpful. The presence of an air bronchogram is probably the best predictor of VAP and has a specificity of 96 %. Other useful signs include:

- rapid cavitation of consolidation signifying necrotizing pneumonia, especially if progressive,
- an air space process abutting a fissure (specificity of 96 %).

In one study of surgical patients, 26 % of pulmonary infiltrates were detected by CT but not by portable chest X ray. In the face of unexplained clinical deterioration and seemingly stable serial radiography, or in situations where it is difficult to detect new consolidation, e.g., ARDS, CT scanning has an important role to play in diagnosis of VAP.

Acute Respiratory Distress Syndrome (ARDS)

ARDS is a form of pulmonary edema from increased capillary permeability but not associated with compromised cardiac function, together with respiratory failure associated with increased lung stiffness. There are several causative factors, the

Table 24.1 CDC criteria for diagnosis of VAP

Radiological signs	2 or more serial chest X-ray with at least 1 of New or progressive and persistent infiltrate Consolidation Cavitation
Microbiological criteria	At least 1 of Positive blood culture not related to any other source of infection Positive sputum culture from lavage or protected specimen brushing >5 % of cells with intracellular bacteria on direct microscopy of gram-stained lavage fluid Histopathological evidence of pneumonia
Clinical signs	At least 1 of Temperature >38 °C White cells >12,000 or <4,000 Altered mental status in patients >70 years without any other recognized cause
Other signs	At least 2 of New onset of purulent sputum or change in character of sputum Increased respiratory secretions New onset of cough, dyspnea or tachypnea Rales or bronchial sounds Deteriorating gas exchange Increased O_2 requirements

Table 24.2 Common causes of ARDS

Direct injury to the lungs	Toxic inhalation Aspiration Near drowning Pneumonia Lung contusion
Indirect injury to the lungs	Sepsis Trauma Burns Massive blood transfusion Drug overdose Pancreatitis Cardio-pulmonary bypass

most common of which are summarized in Table 24.2. The mortality rate associated with ARDS is high and can approach 50 %. Early identification on imaging can guide decisions regarding the need for ventilatory support or other support such as extracorporeal membrane oxygenation (ECMO).

A CXR can be abnormal within 12–24 h of symptom onset, with multiple patchy airspace opacities bilaterally. These appearances can be differentiated from cardiogenic pulmonary edema by their peripheral predominance, whereas with heart failure changes are typically more centrally distributed. Also with ARDS, the heart will remain normal in size with no upper lobe diversion or septal lines. If there is a

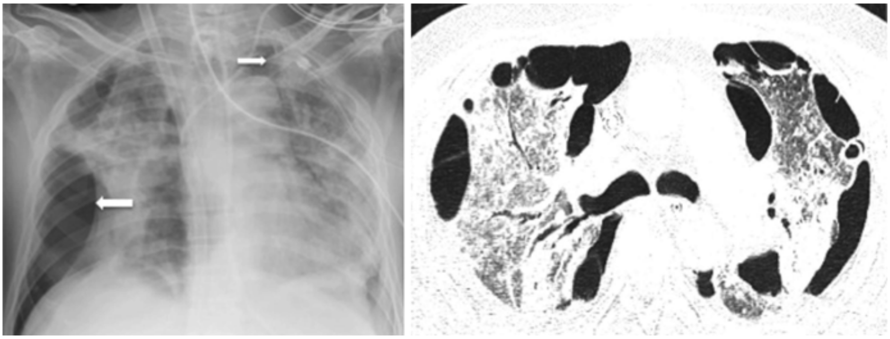

Fig. 24.6 CXR and a selected HRCT image to show parenchymal changes of ARDS. Also note the left pneumothorax (*thin arrow*) with multiple adhesions and surgical emphysema. Note also the well defined lung edge with no lung markings lateral to it in keeping with loculated pneumothorax (*block arrow*)

significant pleural effusion or a focal area of opacification, this may indicate superimposed pneumonia complicating the ARDS.

Portable CXRs on the ITU may show potential complications in ARDS, such as pneumothorax and pneumomediastinum (Fig. 24.6), where positive pressure ventilation is used.

If treated appropriately a slow improvement should be noted on CXR over a time course of about seven days. The opacified areas resolve leaving a coarse pattern of linear and sometimes tiny nodules (reticulonodular). This pattern should improve over several months. However, if it persists ARDS organizes as irreversible pulmonary fibrosis.

An abdominal radiograph can be performed when there is a possible intra-abdominal source of infection, or if bowel obstruction or perforation is being considered. In the ICU setting this can be performed in supine or decubitus position.

For suspected biliary pathology, an ultrasound scan of the upper abdomen may be useful. A thick walled gallbladder with pericholecystic fluid indicates acute cholecystitis. This may or may not be related to a stone. A dilated CBD suggests biliary obstruction.

CT scanning can image multiple areas of the body. Although altered mental status is common in sepsis, patients demonstrating any neurological signs should undergo a CT head to assess for a cerebral abscess or increased intracranial pressure. Infarction may be seen in cases where there has been prolonged suboptimal cerebral perfusion.

Pulmonary Abscess

These lesions develop from localized consolidation where necrosis has occurred and a cavity forms. Causative organisms include Staphylococcus aureus and Klebsiella pneumoniae, but fungal infection and post-primary TB should also be considered. Abscess formation can also occur secondary to esophageal pathology, such as carcinoma or achalasia, and consequent aspiration.

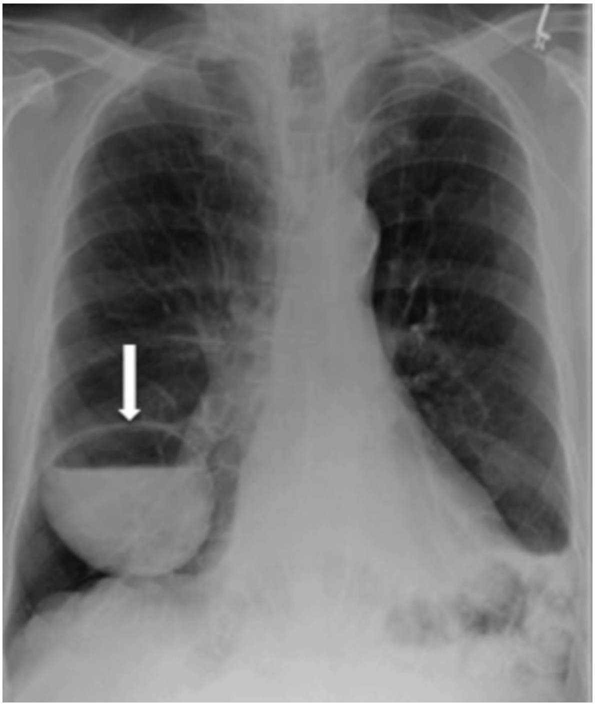

Fig. 24.7 There is a large rounded thick walled cavity with air fluid level (*block arrow*) in the right lower lobe in keeping with a lung abscess

The typical CXR appearance is an intraparenchymal lesion, predominantly spherical with irregular walls often with an air-fluid level (Fig. 24.7). The lung bases are most commonly involved. Usually previous CXRs show consolidation as a precursor for abscess formation. If the lesion is located close to the periphery, an acute angle is formed with the pleural surface. This is in contrast with a pleural empyema, which creates an obtuse angle on CXR.

Tuberculosis (TB)

The majority of cases is caused by *Mycobacterium tuberculosis*; the remainder by atypical strains, mainly *Mycobacterium kansasii* and *Mycobacterium avium-intracellulare*.

When a patient becomes infected, this usually remains initially subclinical in most cases. Only 10 % of initial infections develop clinical disease. Of the quiescent cases, about 10 % will re-activate, when the immune system is compromised for whatever reason. TB can be a multi-system disease resulting in a wide range of radiological appearances. These include not only lung parenchymal changes but also skeletal disease such as osteomyelitis, and involvement of the visceral organs and systemic node enlargement.

The difference between "primary" TB and "post-primary/reactivated" TB is related to the difference in degree of previous exposure and immune status.

Radiological features associated with primary TB include ill-defined opacities and consolidation, unilateral hilar or mediastinal lymphadenopathy, occasional cavitation, and tree in bud opacities. In post-primary TB, when there is a strong cell mediated immune response to the organism, radiological features include apical and posterior upper lobe/superior lower lobe distribution, ill-defined opacities/consolidation, lymphadenopathy (less commonly than in primary), tree in bud opacities, frequent cavitation, bronchiectasis, and miliary nodules. Miliary disease is the most specific feature in distinguishing between primary and post primary disease but is insensitive. Cavitation with an air/fluid level is highly suggestive of active disease in reactivated TB. The key to appropriate management is identifying whether the radiological changes represent active disease.

Active TB can be variable in CXR appearance, usually commencing with ill-defined patchy opacification. Nodules can progress to thick-walled cavitatory lesions. Some cases develop a unilateral pleural effusion, which may progress to empyema.

CT appearance of active TB shows airspace consolidation, predominantly in the lung apices. Cavities with air-fluid levels may be associated with this. Such foci can result in multifocal bronchopneumonia through endobronchial spread of organisms. Hemoptysis can occur when a cavity erodes into a pulmonary arterial branch forming a Rasmussen aneurysm.

Sometimes following resolution of TB infection cavities can become colonized by fungus, particularly Aspergillus fumigatus, resulting in a mycetoma. Mediastinal and hilar lymph node enlargement may be demonstrated, as may evidence of previous TB infection, such as calcification involving the pleura and upper lobe parenchyma.

Hematogenous spread of TB results in disseminated miliary TB with involvement of many organ systems. The miliary CXR appearance classically shows diffuse tiny nodules of 2–3 mm diameter randomly distributed throughout both lungs but with lower lobe predominance where perfusion is better. Symptoms are usually pronounced and often precede radiological appearances (Fig. 24.8a–d).

Sequelae of TB are commonly seen. These include a Ghon focus, which is asymptomatic and noted on CXR as a small calcified pulmonary nodule, associated with calcified hilar nodes. Upper zone fibrosis and calcification is an indicator of healed disease. Serial imaging will confirm disease inactivity.

Mediastinal Infection

Mediastinal infections are rare, but can be a cause of severe and difficult to treat sepsis. There should be a high index of suspicion especially in patients following cardio-thoracic surgery, suspected esophageal perforation or even in those with retropharyngeal or neck infections (Fig. 24.9).

Esophageal perforation can occur as a result of carcinoma, intervention (endoscopy with dilatation or biopsy, transesophageal echocardiography), and penetrating

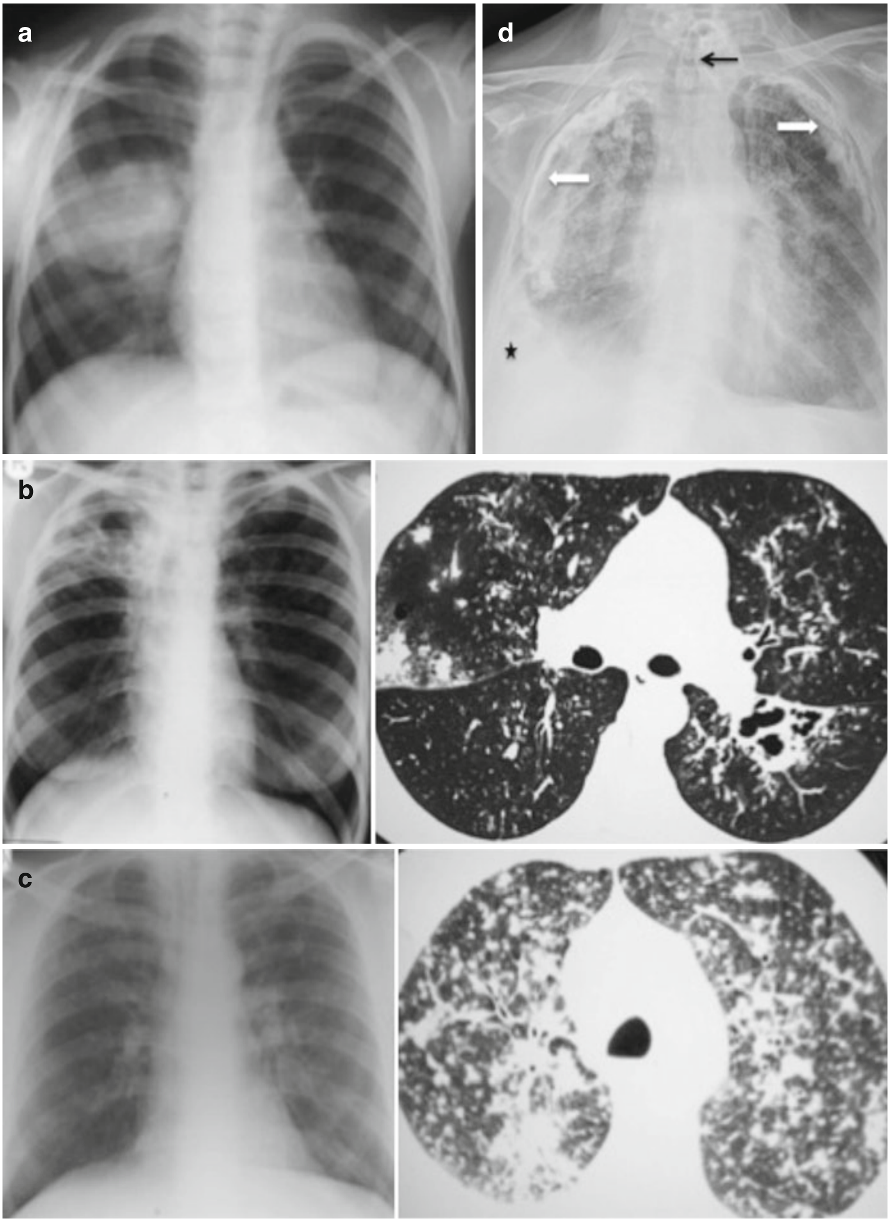

Fig. 24.8 (**a**–**d**) Series of images demonstrating various forms of TB. (**a**) Dense consolidation in right mid zone with bulky right hilum in primary disease. (**b**) Cavitating lesions in right upper and left lower lobes, the latter has developed on the CT taken 2 weeks after the CXR in post primary disease. (**c**) Miliary TB characterised by innumerable randomly distributed micronodules in both lungs. (**d**) A 75 year-old female patient with respiratory failure. There is a tracheostomy (*black arrow*) and moderate right pleural effusion (*black star*) on a background of marked bilateral pleural calcifications (*white block arrows*), a chronic squeal of TB empyema

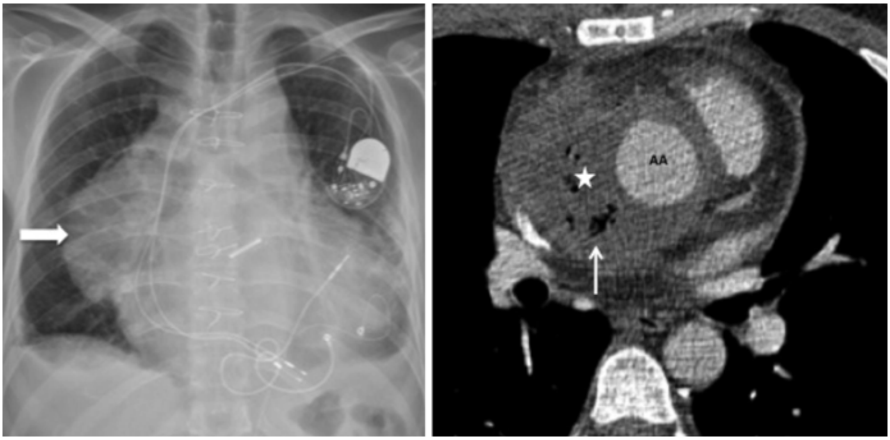

Fig. 24.9 A 67-year old patient developed fever with chest pain 1 week after complex cardiac surgery. CXR shows widening of mediastinal silhouette (*arrow*). Intravenous contrast medium enhanced CT demonstrates a large mediastinal collection (*white star*) with locules of air (*white arrow*), intimately related to the ascending aortic (*AA*) interposition graft. Appearances are those of mediastinal abscess

chest trauma. Also, following a significant episode of vomiting, spontaneous perforation can occur typically described as a tear at the left postero-lateral wall of the distal esophagus, known as Boerhaave syndrome.

The most common CXR findings include widening of the superior mediastinum and a pleural effusion. Other signs that have been described include pneumomediastinum with air outlining the left side of the mediastinum and around the mediastinal vessels. Air can extend into the subcutaneous tissues of the neck. Air-fluid levels may be seen within the mediastinum. With Boerhaave's syndrome, a left sided hydropneumothorax and/or pneumoperitoneum may be present.

Contrast enhanced-CT is the preferred modality where mediastinal infection is suspected. It can be used for initial diagnosis, guiding treatment and determining prognosis. In patients with suspected esophageal perforation, water-soluble oral contrast medium can be given in addition to intravenous contrast material. Signs on CT include bulging of the mediastinal contours, extraluminal air (around the esophagus), and infiltrative changes within the mediastinal fat, which appears "hazy" in contrast to the homogeneous low density of normal regions of fat. A focal low attenuation fluid collection with an enhancing wall suggests abscess formation.

Fat infiltration and mediastinal fluid can be common in post-operative patients who have had a midline sternotomy. Assessing infection in this group can be difficult with progression/resolution of changes to fluid collections and fat infiltration over a matter of days or weeks being key. Points that favor infection include low attenuation fluid collections with wall enhancement persisting more than 14 days post-operatively. At less than 14 days, a post-operative hematoma can be included in the differential diagnosis. Other complications to look out for include bony destruction (suggesting osteomyelitis), empyema, sub-phrenic abscess and jugular venous thrombosis.

Left lower lobe consolidation with associated pleural effusion can be seen in patients following Boerhaave's syndrome. An esophageal tear can be delineated on water-soluble contrast swallow showing by a bright track (high attenuation) of contrast medium passing from the esophageal lumen into the mediastinum.

Prognosis can be varied and is largely dependent on the cause of mediastinal infection and time taken to establish the diagnosis. Patients with esophageal perforation tend to have a worse outcome. Radiographically, there are certain features that can help to assess prognosis. Diffuse infiltrative changes within mediastinal fat can suggest extensive infection with mortality rates of up to 50 %. In contrast, abscess formation may indicate improved prognosis. For example, small focal abscesses can be treated with antibiotic therapy alone, while large abscesses can be amenable to percutaneous or surgical drainage.

Teaching Points

1. Radiological findings of sepsis often lag behind clinical findings, especially in the presence of dehydration.
2. If there was chest trauma or severe vomiting prior to the episode of sepsis, assess for acute mediastinitis. Contrast enhanced CT can be tailored to assess for esophageal leak with the use of oral contrast.
3. The role of imaging in ARDS is to differentiate it from pulmonary edema and provide a serial assessment of progress of the course of days or weeks.

Chapter 25
Cardiogenic and Non-cardiogenic Shock

Kristian Havmand Mortensen and Deepa Gopalan

Clinical Problem

A 75-year-old male has been admitted at the Emergency Department (ED) with rapidly worsening shortness of breath. He is not known to have any relevant past medical history apart from having been a life-long smoker. On physical examination he is obtunded but rousable and appears to be in pulmonary edema, SaO_2 is 90 % on 15 l of O_2 via a rebreathe mask. His blood pressure is 100/55 mmHg, he is in sinus rhythm, but tachycardic at 138 bpm. He says that he has not passed any urine in the last 24 hours. The ED staff are asking for help in form of a quick transfer to ICU.

As the potential final common manifestation of a plethora of diseases, shock related to diseases within the chest is a frequent cause for emergency admissions to intensive care units. Prognosis is often grave with high risk of unrecoverable multi-organ failure and ultimately death. Outcome is highly dependent on early commencement of specific therapy to relieve the causative lesion as well as more general resuscitative measures correcting the shock syndrome in order to restore adequate organ perfusion and oxygen delivery.

Until a patient has been stabilized, advanced imaging apart from surveillance echocardiography plays little role in the initial diagnosis of severe circulatory failure.

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Imaging Techniques

Though not defining the presence of shock, imaging is often advantageous at an early stage in the declining trajectory towards manifest shock. This above all includes echocardiography for the assessment of cardiac output, systolic and diastolic ventricular function, regional myocardial wall motion abnormalities, heart valve function and morphology as well as excluding cardiac tamponade. The combination of clinical assessment and echocardiography will often help guide the diagnosis toward one of two forms of shock:

- Cardiogenic shock with adequate or raised left atrial filling pressure in the context of reduced heart pumping action, or
- Non-cardiogenic shock, where atrial filling pressure is abnormal on a backdrop of normal cardiac function.

This distinction may in many instances prove somewhat artificial in a clinical setting with diverse co-exciting factors often involved in precipitating, exacerbating and maintaining circulatory failure in the same patient.

The chest X-ray (CXR) despite the limitations often imposed by supine imaging remains helpful either in assessing for marked cardiomegaly or interval changes in heart size or configuration. For example globular cardiomegaly of rapid onset is suggestive of pericardial effusion. Pulmonary interstitial and alveolar edema accompanying left ventricular failure are readily apparent on chest X-ray in most cases. In contrast to this, CXR is insensitive to pulmonary embolism and acute myocardial disorders. In this setting CT is a valuable imaging modality for problem solving. CT pulmonary angiography is sensitive in detecting and quantifying pulmonary embolism and contrast enhanced CT is sensitive in detecting pericardial thickening or effusion as well as evaluating cardiomegaly and patterns of chamber enlargement. Using cardiac gating both coronary as well as precise delineation of the thoracic aorta can be performed. CT can also be used to guide aspiration or drainage of pleural or pericardial collections. Cardiac MRI is not the optimal environment for the ICU patient particularly those with shock with bedside echocardiography and CT being preferred cross sectional techniques.

Cardiogenic Shock

Cardiogenic shock is a medical emergency characterized by reduced cardiac output and inadequate tissue perfusion due to cardiac dysfunction. The most common causes for cardiogenic shock are summarized in Table 25.1.

As this constitutes an emergency with a very high mortality rate ranging from 50 to 80 %, early diagnosis and institution of appropriate treatment are pivotal to improving the prognosis. In the majority of cases, myocardial revascularization by

Table 25.1 Common causes of cardiogenic shock

Acute myocardial infarction (MI)
Hibernating or stunned myocardium
Mechanical complications of MI
Papillary muscle rupture
Interventricular septum rupture
Left ventricular free wall rupture
Acute valvular regurgitation
Acute myocarditis
Septic cardiomyopathy
Myocardial contusion
Cardiac tamponade
Decompensated cardiomyopathies

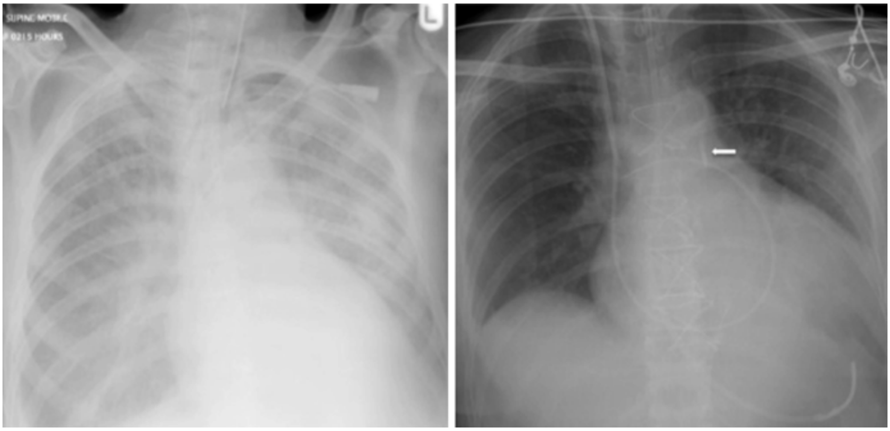

Fig. 25.1 CXR from two different patients with cardiogenic shock. The *left panel* shows the CXR of a 60-year old male presenting with severe hypotension and respiratory distress requiring intubation. There is pulmonary edema as evidenced by widespread bilateral alveolar opacifcation and supine pleural effusions. The *right panel* shows that of a 75-year old patient who underwent treatment for shock post-cardiac surgery with good improvement in the radiographic appearances. Intra-aortic balloon pump catheter tip is projected immediately below the aortic knuckle (*block arrow*). Patient also has right jugular line, pulmonary artery flotation catheter and a nasogastric tube

percutaneous angioplasty or coronary bypass grafting will be required and hence transfer to a tertiary referral center may be necessary.

An important role of the CXR is to exclude alternative causes of shock such as a tension pneumothorax. It can also be used to assess severity of left ventricular failure which is characterized by features including cardiomegaly, redistribution of pulmonary blood flow to the upper lobes or signs of interstitial and alveolar edema, and bilateral pleural effusions (Fig. 25.1). Pulmonary interstitial edema is characterized by peribronchial cuffing, with thickening of interlobar fissures and development of interlobular septal lines or Kerley B lines which are short, 1–2 cm peripheral horizontal lines in the mid and lower zones. Opposed to this, pulmonary alveolar edema is characterized by bilateral alveolar opacification usually with a perihilar distribution. The CXR also permits checking the position and complications relating to placement of indwelling lines. It can be used to confirm the position of the intra-aortic balloon pump used for initial stabilization of patients with cardiogenic shock. The proximal balloon tip should ideally be in the descending thoracic aorta, about 1–2 cm distal to the origin of the left subclavian artery (Fig. 25.1).

Although non-invasive, EGG-gated cardiac CT is not an appropriate diagnostic tool to exclude acute coronary syndrome (ACS), particularly in the setting of cardiogenic shock. Catheter coronary angiography is the definitive tool for diagnosis of coronary disease with the possibility, where appropriate to angioplasty and stent to restore coronary blood flow. However, when alternative conditions such as pulmonary embolism or aortic dissection are being entertained as the potential cause of hypotension, CT can be used to solve the diagnostic conundrum. Once the patient's condition has stabilized, Cardiac MRI can help to estimate the extent of myocardial scarring and viability.

Cardiac Tamponade

Cardiac tamponade is a potentially fatal clinical syndrome caused by compression of the cardiac chambers secondary to collection of fluid, blood, pus, air, or tissue within the pericardial space. The rise in intrapericardial pressure results in compromised diastolic filling and reduction in cardiac output. The rate of accumulation is more relevant than the size or content as the pericardial compliance is generally poorer with rapid collection.

The diagnosis of tamponade should be entertained in all patients with unexplained cardiogenic shock or pulseless electric activity. The common causes of tamponade are summarized in Table 25.2.

Table 25.2 Common causes of cardiac tamponade

8–10 % of patients with acute Stanford type A dissection of the thoracic aorta develop cardiac tamponade secondary to hemopericardium caused by aortic rupture
Penetrating or blunt trauma
Acute myocardial infarction with free wall rupture
Dressler syndrome
Malignancy
Poorly controlled anticoagulation
Uremia
Heart failure
Infection such as tuberculosis and HIV
Chest wall radiation
Iatrogenic injury secondary to procedural complications following pacemaker insertion, coronary intervention or cardiac surgery
Cardiopulmonary resuscitation

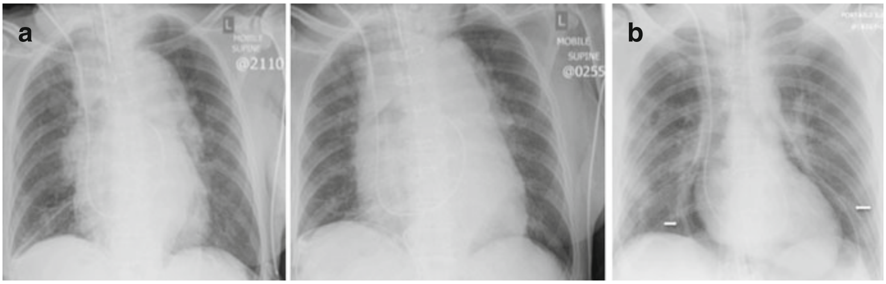

Fig. 25.2 (**a**, **b**) CXR from two different patients with pericardial tamponade. (**a**) A 67-year old male patient who had increasing cardio-mediastinal silhouette on post surgical serial chest radiographs. (**b**) Another post cardiac surgery patient with pneumopericardium (*block arrows*)

Table 25.3 CT features in keeping with cardiac tamponade

Pericardial effusion causing compression and straightening of the right heart chambers
Interventricular septal bowing
Distension of systemic veins
Reflux of contrast medium in to the inferior vena cava, hepatic and azygos veins
Compression of the coronary sinus and periportal edema

Echocardiography is the imaging modality of choice for diagnosis and assessment of the severity of hemodynamic compromise. CT plays a secondary role to echocardiography and should be considered only if the latter is equivocal or in cases of suspected hemorrhagic effusion, pericardial thickening or calcification.

Rapidly increasing cardiac size on serial CXRs is usually due to pericardial effusion (Fig. 25.2a). However, when the tamponade is due to pneumopericardium, there may be a marked reduction in the size of the cardiac silhouette with sharp outlining of the pericardium by radiolucent air on either side (Fig. 25.2b).

CT features are relatively non-specific: Table 25.3 shows the spectrum of findings that should raise the suspicion of tamponade. The attenuation value of the fluid on an unenhanced CT can help in the differentiation of the pericardial contents. Simple serous effusion has a uniformly low attenuation value whilst hemorrhagic, malignant and infective collections demonstrate higher valves. CT can differentiate fluid from thickened pericardium although MRI is superior. Nodular pericardial thickening and enhancement is suspicious for pericardial malignancy (Fig. 25.3). CT demonstration of the extent and severity of pericardial calcification is also useful, particularly when considering treatment options.

Needle pericardiocentesis can be successfully performed using echocardiographic or CT guidance. Surgical intervention is preferable in malignant collections, clotted hemopericardium or recurrent tamponade.

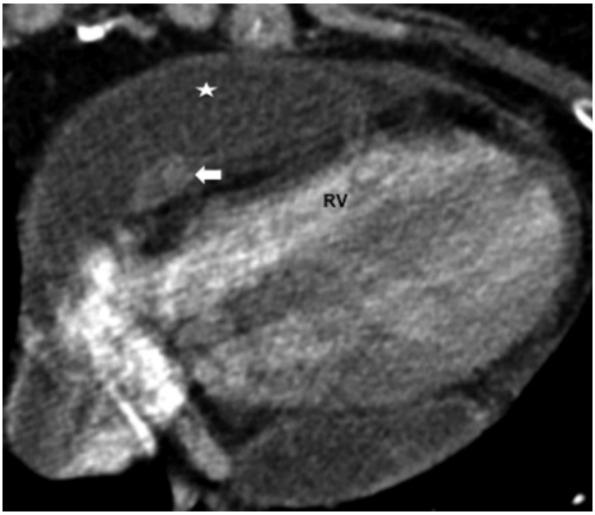

Fig. 25.3 Axial CT in a 50-year old female patient with breast carcinoma. There is a loculated complex pericardial effusion (*white star*) with abnormal thickened and enhancing pericardial wall and a metastatic nodule (*block arrow*). This is causing tamponade with compression of the right ventricle (*RV*), which has assumed a tubular configuration suggesting pericardial constriction

Non-cardiogenic Shock

Circulatory shock with, at least initially, preserved cardiac function can be separated into different forms that include hypovolemic, distributive, obstructive and endocrine shock syndromes. For diseases within the chest, distributive and obstructive shock syndromes are especially relevant with less frequent occurrence of hypovolemic and very rarely endocrine forms. The principal distributive form of shock involved in diseases of the chest includes sepsis, which is discussed in Chap. 24.

Obstructive Shock

In obstructive shock the mean arterial pressure, falling urine output and progressive lactate acidosis fail to recover with fluid delivery, vasoconstrictors or inotropes during resuscitation. Cardiac function is, at least initially, normal but filling is impaired. Immediate relief of the obstruction is pivotal for outcomes with imaging forming a cornerstone in making the diagnosis.

Table 25.4 gives an overview over the most common intrathoracic causes of acute obstruction of normal flow as a result of abnormal preload or afterload in the setting normal cardiac function.

Other conditions may also alter after- or preload and cause shock, but in most cases there will be an element of primary cardiac failure precipitating circulatory failure. The latter includes conditions such as acute valvular dysfunction or pulmonary hypertensive crises.

Table 25.4 Intrathoracic causes of obstructive shock

Restrictive pericardial processes (*tamponade*)
Raised intrathoracic pressure (*pneumothorax*)
Intracardiac mass (*atrial thrombus or tumor*)
Extracardiac mass (*superior vena cava superior syndrome*)
High pulmonary resistance to flow (*pulmonary embolus*)
Increased aortic resistance to flow (*dissection of the thoracic aorta*)

Pulmonary Embolus

Intensive care patients are at higher risk of thromboembolism within the pulmonary arteries due to immobilization, surgical intervention, and major medical illness. Pulmonary embolus (PE) presents as shock in 5–10 % of affected patients. The definitive imaging modality in this setting for correct and timely diagnosis is a CT pulmonary angiography. If the clinical suspicion for a pulmonary embolus is high on the backdrop of circulatory failure, triaging with low specificity D-dimer measurement or assessment for deep venous thrombus formation is irrelevant and will only delay time to appropriate treatment.

CXR may help to exclude conditions mimicking a PE such as pneumothorax, pneumonia and cardiac failure. However, radiographic findings are insensitive and of poor specificity even with major, central acute PE. CXR may be normal or show non-specific features including cardiomegaly (notably right heart dilatation), pleural effusion, elevated hemidiaphragm, pulmonary artery enlargement, atelectasis and consolidation. Features suggestive of PE without infarction include the Westermark sign (regional oligemia) and the Fleischner sign (distended central pulmonary artery). Infarction is uncommon (<10 %) due to collateral bronchial arterial and retrograde pulmonary venous flow. The "Hampton's hump" suggesting infarction is a wedge shaped peripheral opacity. The blunted apex points towards the feeding vessel and the base sits against the pleural surface. Surrounding hemorrhage may obscure it in the initial stage but as the hemorrhagic component resolves, the hump becomes more obvious. Infarcts resolve over weeks to months but usually leave scarring or pleural thickening. Due to this non-specific nature of the CXR it will never exclude an acute PE, especially not in patients with preexisting cardiac or lung disease.

CT has a sensitivity and specificity that approaches 100 % for detection of large central pulmonary artery emboli. If a good quality CT study has been performed, no further imaging for central pulmonary embolism as a cause of shock is needed. Multidetector CT scanners provide superior image quality to single detector scanners through faster imaging and more optimal triggering for opacification of the pulmonary artery. The presence of a central clot is reliably diagnosed as a filling defect of the pulmonary artery. The timing of the CT has to be optimized for good pulmonary artery opacification, and an embolus cannot be excluded from non-contrast studies or a suboptimally contrast enhanced study. EGG gating allows for assessment of biventricular function. Besides depicting arterial filling defects, CT can also elucidate important prognostic features that assist in the assessment of the

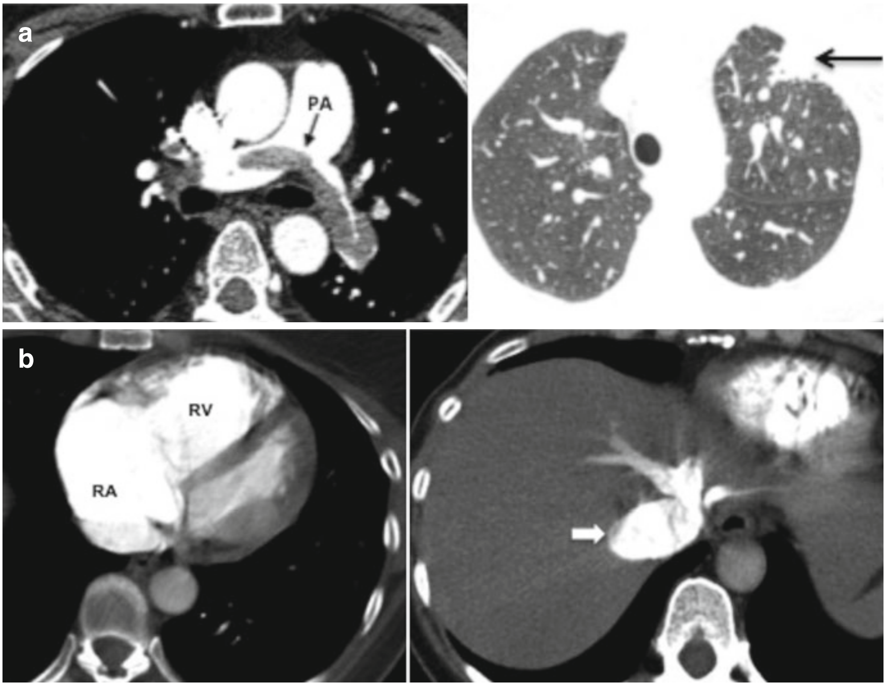

Fig. 25.4 (**a**, **b**) Selected CT images from a contrast enhanced angiographic examination of a 40-year old female patient who presented with shock secondary to extensive pulmonary emboli. (**a**) *Left panel*, mediastinal window. The pulmonary artery (*PA*) is dilated with a saddle embolus (*black arrow*). *Right panel*, lung window. There is a peripheral wedge shaped infarct in left upper lobe (*black arrow*). (**b**) There is marked dilatation of right atrium (*RA*) and right ventricle (*RV*) and reflux of contrast medium in to the inferior vena cava and hepatic veins (*block arrow*)

Table 25.5 Radiological signs of right heart strain

Enlargement of main pulmonary artery and right sided cardiac chamber dilatation
Leftward bowing of the interventricular septum due to suprasystemic right ventricular pressures
Tricuspid regurgitation detected by contrast medium reflux into the inferior vena cava
Systemic venous congestion of the inferior vena cava, hepatic veins and azygos vein
Various extents of pulmonary hemorrhage or infarction with ground-glass appearance or consolidation
Pleural effusions

hemodynamic severity (Fig. 25.4a, b). See Table 25.5 for the radiological features associated with severe right heart strain.

Echocardiography may assist in the diagnosis of an obstructive central PE when a patient is too unstable for transport or CT is unavailable. Transthoracic echocardiography can in some patients directly confirm the presence of embolus in very proximal main pulmonary arteries or the right heart chambers (≈5 % will have visible right atrial thrombus). Transesophageal echocardiography can provide more direct visualization of embolus in the main and proximal right and left pulmonary arteries with a sensitivity of 90 % but the shocked and non-intubated patient may not tolerate the required mild sedation, and there is a risk of aspiration, esophageal

Fig. 25.5 Axial CT in a 58-year old patient with ischemic cardiomyopathy. Following the insertion of a left ventricular assist device (LVAD) as a bridge to transplant, patient became haemodynamically unstable with drop in hemoglobin. There is a high attenuation haematoma (*white star*) anterior to the aortic conduit of the LVAD (*arrow*). This is causing compression of the right ventricle (*RV*) that has a sigmoid configuration. There is also a pericardial effusion (*black star*); the fluid attenuation is lower than the hematoma. Also note the left lower lobe atelectasis (*4 pointed white star*)

injury and bronchospasm. As a whole, echocardiographic findings have up to 50 % sensitivity and 90 % specificity for pulmonary embolism.

Ventilation-perfusion scanning, pulmonary angiography and MRI have no place in the diagnosis of thromboembolic disease in the shocked patient.

Hypovolemic Shock

Non-hemorrhagic loss of circulating blood volume due to external losses or interstitial shift is not common in diseases of the chest. In contrast, the more common hemorrhagic variety of oligemic shock presents more frequently as a result of diseases within the chest.

This may occur after penetrating or even blunt chest trauma. Hemorrhage from any large systemic or pulmonary artery or vein may cause shock. If this is involving structures such as the pulmonary arteries, the heart, and the thoracic aorta there is a high risk of immediate death. Patients who reach an ICU are more likely to have experienced an initial contained bleeding episode, and shock may be a late representation of renewed hemorrhage.

CT is the diagnostic study of choice. With unenhanced and contrast enhanced imaging triggered for the arterial phase, this modality allows differentiation between active and contained hemorrhage with good delineation of the extent of hemorrhage, hematoma and affected compartments (Fig. 25.5).

Ultrasound may assist in assessment of a hemothorax, and transthoracic echocardiography may diagnose proximal aortic dissections. Transesophageal echocardiography more optimally visualizes the thoracic aorta but opportunity to perform this investigation is often limited in the shocked patient. However, these ultrasonic modalities are not able to assess for active and contained bleeding in the same exhaustive manner as CT. Of course, transthoracic echocardiography has a central role in bedside assessment for tamponade.

CXR may also depict a hemothorax with blunting of costophrenic angles being the earliest sign or there may be diffuse opacity projected over the lower lungs. A mediastinal hematoma may present with free, partial or contained hemorrhage from any mediastinal vein or artery. The radiographic signs include widening of the mediastinal shadow with or without airways displacement, poorly defined contours or increased width of the thoracic aorta, and thickening of the right paratracheal stripe. The presence of these signs may alert to the presence of a mediastinal hematoma but they are by no means specific. Their absence has poor negative predictive value particularly when the limitations of supine CXR are taken into consideration.

Endocrine Shock

The role of chest disease to endocrine shock is marginal, and principally pertains to secondary aspects such as precipitation of an Addisonian crisis in abrupt withdrawal of steroid treatment for inflammatory thoracic disease. Imaging has little relevance in resolving such diseases that rely mainly on medical history.

Rare neuroendocrine tumors such as pheochromocytomas and paragangliomas can occur within the chest. If these tumors are suspected to be the cause of shock syndrome, symptomatic resuscitation with circulatory recovery precedes appropriate imaging. Biochemical markers of neuroendocrine tumors play an important role in diagnosis. CT can confirm the presence of a mass. ^{131}I–labeled MIBI scintigraphy may be needed if there is a strong clinical suspicion and negative CT.

CT contrast medium administered in pheochromocytoma has been reported to precipitate crises, though the risk is debated. Nevertheless, this adverse effect should be kept in mind and where there is biochemical suspicion of pheochromocytoma appropriate pharmacological prophylaxis should be considered before undertaking contrast-enhanced CT.

Teaching Points

1. The most common cause of cardiogenic shock is acute myocardial infarction and is usually seen with larger anterior infarcts, older population and diabetics. However, small infarcts can also precipitate shock in the presence of pre-existing left ventricular impairment.
2. Cardiac CT is not an appropriate tool for investigation of acute coronary syndrome, particularly in unstable cases.

3. Tamponade should be entertained in all patients with unexplained cardiogenic shock or pulseless electric activity. Bedside echocardiography is the imaging modality of choice, and treatment should not be delayed by further imaging with CT.
4. Even small pericardial effusions can cause tamponade if accumulation is rapid due to lack of adaptive pericardial stretching.
5. CXR may be normal even when there is extensive acute pulmonary embolism.

Part VI
Abdominal Imaging

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Chapter 26
Post-operative Abdominal Wall Cellulitis

Amir H. Davarpanah, Andrew W. Lischuk, Syed A. Jamal Bokhari, and Lewis J. Kaplan

Clinical Problem

A 42-year-old man is admitted to the ICU after attempted laparoscopic sigmoid colectomy for repeated episodes of diverticulitis. The procedure needs to be converted to an open approach due to multiple adhesions. After repeated episodes of contact with the healthcare system over the last 2 years, he received double cover for staphylococcus aureus as peri-operative surgical site infection prophylaxis. The total OR time was 7 h. He has a history of COPD related to alpha1-antitrypsin deficiency disease and fails an extubation attempt at the end of the case. He is reintubated and sent to the ICU for management of his acute respiratory failure.

On POD#2 he is noted to complain of abdominal pain that is increased compared to POD#1; a 6 cm zone of cellulitis is noted around the midline laparotomy incision but no purulence is expressible. He does not do well on a spontaneous breathing trial due to high minute ventilation leading to fatigue. His WBC increases to 19.7 from 12.1 and his urine output decreases as well despite being net positive by 2.2 L over the last 24 h. The abdominal wall cellulitis is unexpected and the port

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sites that are remote from the midline incision are uninvolved. Since there is no purulent drainage the surgeon is loath to open the wound.

Abdominal wall cellulitis early during the post-operative course gives rise to several concerns and is different from late appearing abdominal wall cellulitis. The main worry is whether the patient is developing a necrotizing soft tissue infection (NSTI), in particular with *Clostridium perfringens*, although Group-A *Streptococcus* has also been described as a cause early after surgery. Group-B *Streptococcus* infections are more common after gynecologic procedures. A NSTI is a surgical emergency and multiple laboratory scoring systems have been elaborated to help differentiate a necrotizing from a non-necrotizing soft tissue infection. Surgical exploration is often the best way to rule in or out such a NSTI. For those with clear signs of surgical sepsis or unexpected septic shock exploration may be life saving.

Other major concerns are whether the cellulitis is related to an underlying undrained infected fluid collection resulting from a hematoma or an anastomotic leak. A missed intestinal injury can present with a similar picture.

Imaging Techniques

Imaging has a large role to play in early detection of postoperative wound infections, defining the extent of the disease and looking for complications. Recognizing these early is important as patients may deteriorate rapidly if left untreated.

The two main questions that need to be answered are those of the presence of an NSTI and the integrity of the gastrointestinal track. Due to the early time frame after a laparotomy, pneumoperitoneum on CXR might simply be related to the operation and not provide any diagnostic value. More often than not the patient's condition will not allow an upright X-ray anyway.

When the diagnosis is not clear a CT scan will be more helpful in these situations. Several CT scoring systems have helping to differentiate between necrotizing and non-necrotizing infections have been developed.

Currently, several imaging modalities are available for wound management and evaluation of the extent of soft tissue infection.

Radiography

Due to its cost and ready availability the plain radiograph has been the most widely used imaging tool to evaluate for postoperative retained foreign bodies. Radiographic findings for soft-tissue cellulitis and abscess are nonspecific and include soft-tissue swelling and displacement of fat. Radiographs are valuable for detection of soft-tissue gas, which is considered one of the most specific findings for necrotizing fasciitis (Fig. 26.1a, b). However, this may also be a late finding, with a reported sensitivity of only 17 % in one series. Presence of pneumoperitoneum in the post-operative period is a common and nonspecific finding with a prevalence of 87 % on

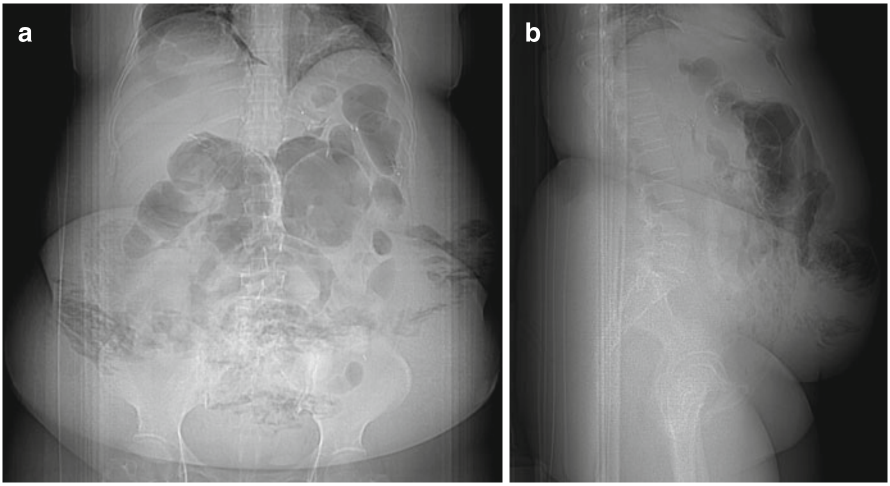


Fig. 26.1 (**a**, **b**) A 44-year-old woman post hysterectomy and salpingo-oophorectomy. Postop day 4, presented with abdominal pain. Anterior (**a**) and lateral (**b**) scout views from CT scan show extensive subcutaneous gas within the anterior abdominal wall, consistent with necrotizing fasciitis

CT and 53 % on radiograph 3 days after surgery, which drops to 50 and 8 % respectively 6 days after surgery.

Ultrasound

Ultrasound is easily available and does not involve transporting or moving a potentially unstable patient. It can help to differentiate between cellulitis and an abscess within the superficial soft tissue. Cellulitis typically causes increased subcutaneous tissue echogenicity with hypoechoic strands of edema, whereas the ultrasound appearance of abscess is usually a hypoechoic or anechoic soft tissue mass with a surrounding echogenic rim and hyperemia (Fig. 26.2). It may be difficult to delineate the depth of infection and exclude involvement of the deeper structures. Recently, there has been a growing interest in using ultrasound for evaluation of suspected radiolucent foreign bodies.

Computed Tomography

CT scan is the modality of choice and the most extensively used imaging tool for evaluation of soft tissue infections. It also is the most reliable imaging tool for the detection of deep infections such as abscesses.

CTs can delineate the anatomic site of involvement by demonstrating increased subcutaneous fat attenuation and edema as well as asymmetric fascial thickening

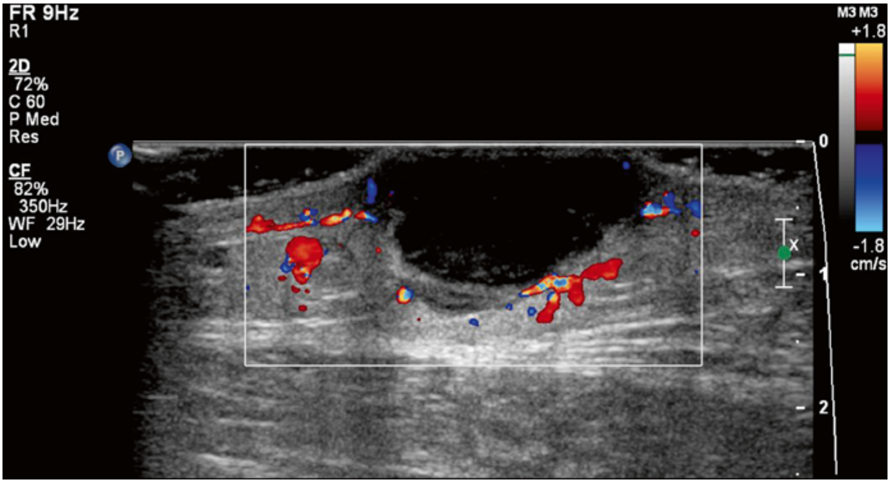


Fig. 26.2 Ultrasound image of a patient post surgery shows an anechoic fluid collection that contains isoechoic debris just beneath the anterior abdominal wall in the right lower quadrant with adjacent hyperemia consistent with an abscess

Fig. 26.3 A 54-year-old patient post ventral hernia repair. The axial CT image through the pelvis shows subcutaneous edema and extensive areas of high attenuation within anterior abdominal wall subcutaneous fat, compatible with cellulitis but without deeper extension or abscess formation

(Fig. 26.3). Using contrast-enhanced CT, a soft tissue abscess can be distinguished from an uncomplicated fluid collection by means of peripheral enhancement and higher attenuation (Fig. 26.4). Unlike ultrasound, which is suitable for superficial soft tissues, CT scanning has the advantage of being able to evaluate deeper structures and the extent of surrounding inflammation, loculated collections, abscess formation (Fig. 26.5a, b) and complications such as osteomyelitis and myonecrosis. Besides, CT is more sensitive than plain film for the detection of soft-tissue gas and both radiopaque and radiolucent foreign bodies.

Fig. 26.4 A 43-year-old woman post ventral hernia repair. The axial non-enhanced CT image demonstrates extensive subcutaneous edema with a focal fluid collection and an air-fluid level in the left periumbilical subcutaneous fat (between *arrowheads*), suggestive of an abscess, but no evidence of intraabdominal extension

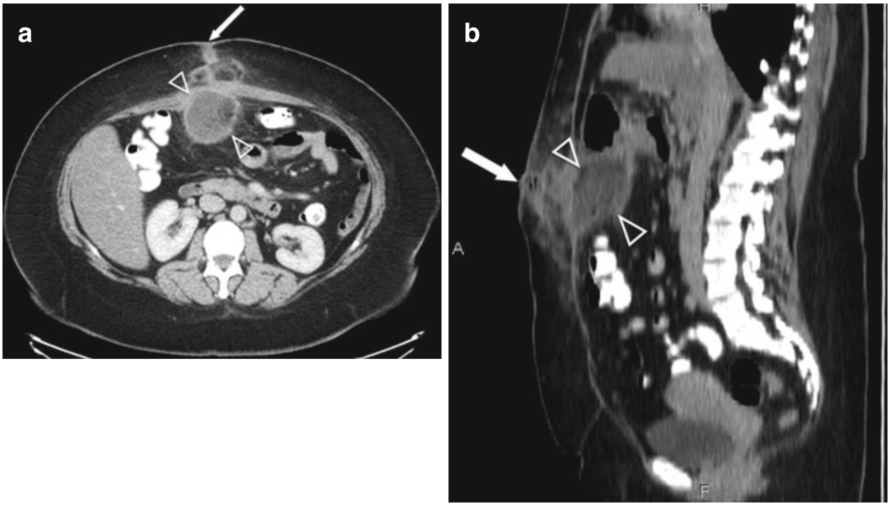


Fig. 26.5 (**a**, **b**) A 40-year-old patient post distal pancreatectomy and splenectomy for cancer, with new-onset fever. Axial (**a**) and sagittal (**b**) CT images show a midline round fluid collection with rim enhancement (*arrowheads*) in the mid abdomen at the region of the pancreatic surgical bed extending to the anterior abdominal wall and incision site, where soft tissue stranding is also visualized (*arrow*). Drainage confirmed an intraabdominal abscess

The presence of soft tissue gas, fascial thickening and enhancement as well as muscle involvement are the features of soft tissue necrosis due to infection with gas-forming organism (Fig. 26.6a, b). Early diagnosis in this case is vital because urgent surgical debridement is necessary. One distinguishing feature of necrotizing fasciitis is sparing of the superficial epidermis, which is not characteristic of cellulitis and postoperative changes. In case of doubt serial CT exams are helpful

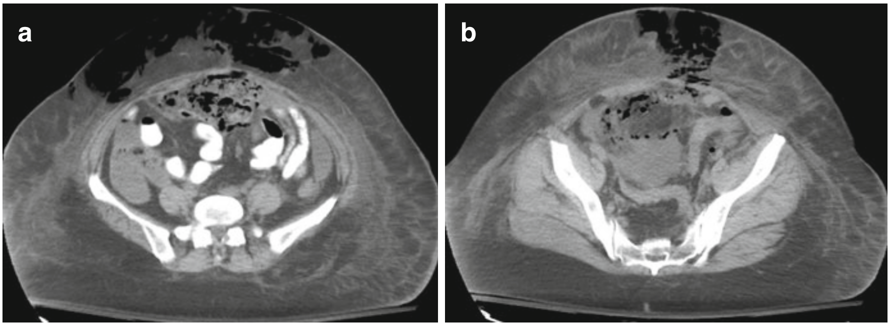
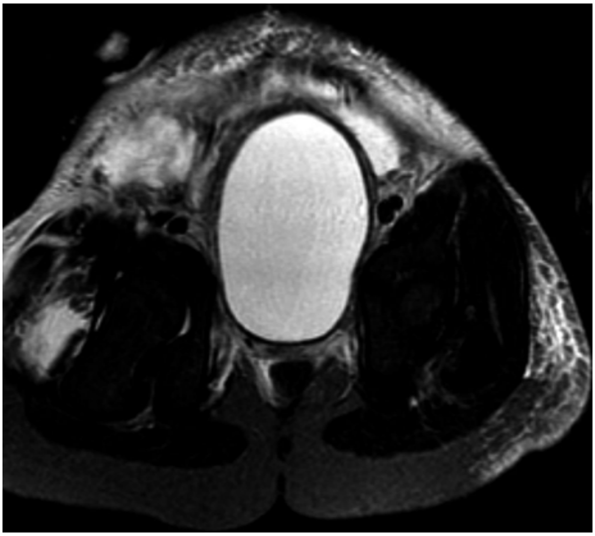


Fig. 26.6 (**a**, **b**) Axial CT images of the same patient shown in Fig. 26.1 show extensive subcutaneous necrotizing fasciitis (**a**) involving the majority of the anterolateral abdominal wall bilaterally with gas and debris extending from the abdominal cavity (**b**)

Fig. 26.7 Axial T2-weighted image of a patient who developed cellulitis after abdominal surgery, showing extensive anterior abdominal wall edema



to identify postoperative changes, which typically show steady resolution in the absence of infection.

Magnetic Resonance Imaging

MRI is more sensitive in depicting soft-tissue infections, thanks to its superior tissue contrast. MRI findings of soft tissue infection include subcutaneous thickening, focal fluid collections with intermediate to low signal on T1-weighted images, high signal intensity of subcutaneous tissue and superficial fascia on T2-weighted images, and peripheral enhancement after contrast administration (Fig. 26.7). MRI is also considered the technique of choice for detecting soft tissue infection due to its higher soft-tissue contrast and sensitivity for soft-tissue fluid and its multiplanar capabilities. However, the differentiation of subcutaneous emphysema from calcifications or foreign bodies on MRI is challenging.

The sensitivity of MRI for detection of necrotizing fasciitis is reported to be 89–100 % with specificity of 46–86 %. The MRI findings include deep fascia involvement and thickening with high signal intensity on T2-weighted images and contrast enhancement, although they are not pathognomonic for necrotizing fasciitis. It has to be noted that the involvement of deep structures does not proof necrotizing fasciitis as much as the lack of involvement is not enough to exclude it.

Teaching Points

1. Early diagnosis of postoperative wound infections is imperative for starting the appropriate therapy.
2. Radiography is useful for identifying retained surgical foreign bodies but has a low-yield for detection of subcutaneous gas.
3. Ultrasound can differentiate between cellulitis and an abscess within the superficial soft tissue, however it has a limited use for evaluation of the deep extension of the infection.
4. CT is the most widely used and the modality of choice for this purpose. Though not as accessible as CT, MRI has the highest sensitivity for detecting soft tissue infection and fluid collection, due to its superior tissue contrast.

Chapter 27
Post-operative Trans-Abdominal Wall Succus Entericus or Stool Drainage

Amir H. Davarpanah, Garry Choy, Syed A. Jamal Bokhari, and Lewis J. Kaplan

Clinical Problem

A 27 year-old previously healthy female undergoes an urgent decompressive laparotomy for secondary abdominal compartment syndrome following resuscitation from H1N1 pneumonia and respiratory failure. She does relatively well and after four abdominal washouts has her abdominal wall primarily closed on post-operative day (POD) #8 (ICU day #12). She remains on the ventilator but is slowly weaning from mechanical support. She is receiving nutritional support via total parenteral nutrition and slowly increasing enteral alimentation via nasojejunal catheter.

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On POD#17 (ICU day #21) the nurse notices a new 4 cm abdominal wall cellulitis and large volume greenish, slightly malodourous drainage from the midpoint of the anterior abdominal wall incision.

Observing enteric drainage through the abdominal wall rarely gives any information about the etiology of the discharge. The questions that need to be answered are:

- Is there a subfascial abscess?
- Is there only one point of egress from the bowel?
- What is the location of the site(s) of the leakage?

If there is an abscess, it is important to know if the collection is amenable to percutaneous radiologic catheter-based drainage to establish a controlled fistula. Re-operation in the early post-operative period is likely to result in an inadvertent enterotomy due to intestinal inflammation and the vascularity of adhesions rendering plane identification difficult. Therefore, a temporizing measure to allow inflammation to settle is desirable in these situations. Additionally, understanding whether the fistula is proximal or distal to the ligament of Treitz will assist with planning nutritional support and fluid management. Distal fistulas often permit luminal nutrition and fluid maintenance while proximal ones generally require enteral support.

Imaging Techniques

Answering these essential questions relies almost exclusively on imaging. The etiology of the fistula is often both discovered and characterized on imaging studies. Imaging can also yield diagnostic information such as complications including deep abscess formation and can characterize the extent of associated inflammation.

Radiography has a limited role in directly demonstrating bowel pathology in patients with suspected enterocutaneous fistula. Nevertheless, it may help to identify free air, bowel obstruction, or gas-containing collections.

Ultrasound

Ultrasound has the advantage of being inexpensive and portable, but only plays a limited role in the evaluation of most enterocutaneous fistulas. It usually requires a corroborative study for confirmation of any findings. If visualized on ultrasound, enterocutaneous fistulas usually appear as a hypoechoic tract adjacent to the bowel and arising in the area of bowel wall thickening. Using this sonographic appearance, sensitivity of 87 % and specificity of 90 % was achieved for detection of enterocutaneous fistulas in a study focused on complications of Crohn's disease (Fig. 27.1). Another potential benefit of ultrasound is the detection of associated complications such as abscess collections within the superficial soft tissues. Ultrasound may be limited in the presence of significant bowel gas, ileus or overlying surgical incisions and dressings.

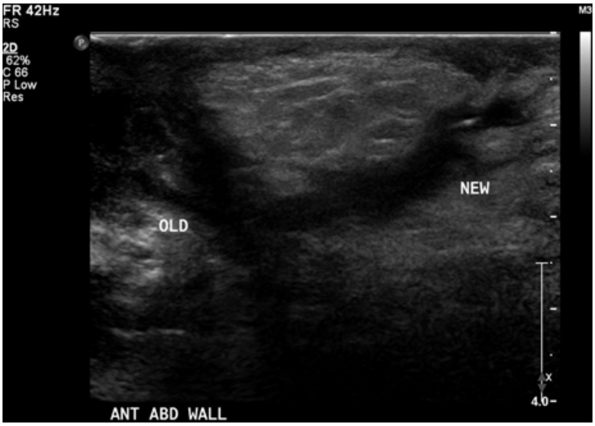

Fig. 27.1 Abdominal ultrasound in a 34-year-old male with history of Crohn's disease and enterocutaneous fistula in the mid-abdomen. This patient presented with new drainage of pus from a new skin site, with ultrasound demonstrating two fistulous tracts to the skin surface with pus drainage, compatible with enterocutaneous fistulas

Fig. 27.2 Plain film image of a fistulogram in a 23-year-old male with history of gunshot wound to the abdomen and ileostomy depicting an enterocutaneous fistula communicating with the jejunum and antegrade flow of the contrast towards the ileostomy site. The contrast opacification pattern suggests the fistula arising from the mid jejunal loops, proximal to the ileostomy. Of note, the image also shows the patients hand; he was asked to hold the catheter firmly during injection of the contrast

Fistulogram

Traditionally, fistulography has been the most rapid and widely used technique in the evaluation of communication between the skin opening and bowel or abdominal cavity (Fig. 27.2). During fistulography, the external skin opening is cannulated, followed by injection of a water-soluble contrast agent under fluoroscopic guidance to delineate the fistulous tract. Multiple fluoroscopic images are usually obtained in various obliquities by moving the patient in different positions to allow for dependent drainage and improved visualization. Using this thorough technique the location of the fistula, length of the tract and extent of the bowel wall

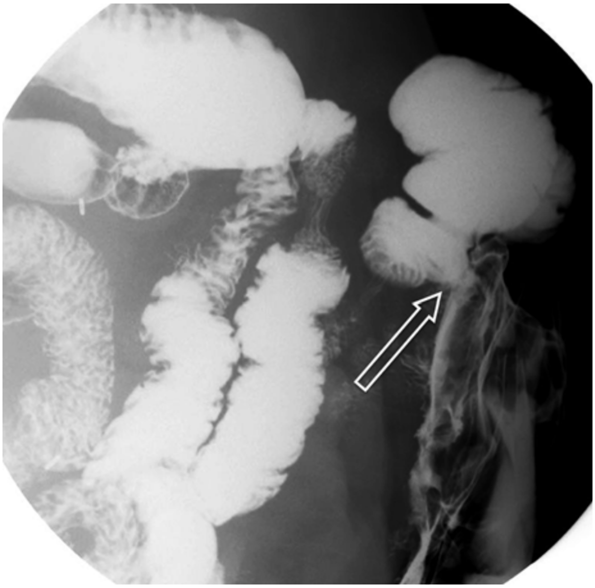

Fig. 27.3 Small bowel follow-through in a 43-year-old male who had undergone multiple operations for Crohn's disease including an ileostomy. Note the contrast delineating the fistulous tract (*arrow*) to the skin surface filling an ileostomy bag

disruption can be adequately evaluated. Water-soluble agents such as Gastrografin have the advantage of rapid absorption within the peritoneal cavity while causing minimal inflammation. However, Gastrografin usually provides less mucosal detail compared to barium. Therefore, a water-soluble iodinated contrast agent is often injected initially, followed by barium if no extravasation is seen and additional detail is required. While a cost-effective and efficient diagnostic test, a fistulogram may still fail to provide detailed information regarding contained abscess collections, exact location of the fistula in the GI tract, or additional bowel pathology proximal or distal to the fistula. Fistulography is also contraindicated in patients with sepsis, as the technique may result in bacteremia. If the result of fistulogram is inconclusive, additional imaging studies such as a small bowel follow-through, CT, or MRI can be performed.

Small Bowel Follow-Through

The location of the fistula along the GI tract may be identified using an intraluminal enteric contrast agent. Enterography also provides more detailed information regarding the intestinal tract and intraluminal causes of enterocutaneous fistula (Fig. 27.3). The small bowel follow through involves drinking the contrast material or giving it via a feeding tube and obtaining serial films as the contrast moves through the intestinal tract. Typically, barium is used to provide satisfactory opacification of the bowel. In patients with concerns over bowel perforation it should not

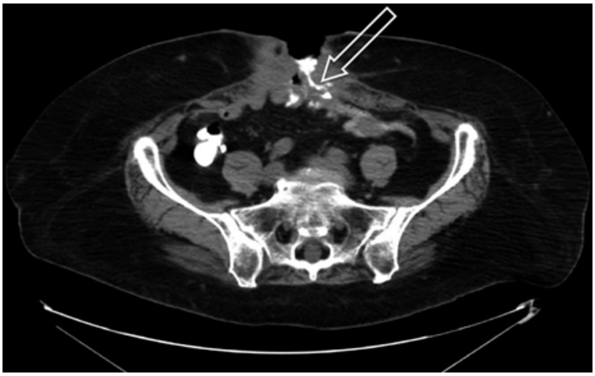

Fig. 27.4 Axial CT image of 73-year-old female with a history of ulcerative colitis, post partial colectomy and left colostomy. She developed an enterocutaneous fistula and abdominal wall abscess. The *arrow* points to the tract that leads to the left colon

be used unless a bowel leak has been definitively ruled out. While an effective test, traditional enterography is a time-consuming procedure that might cause considerable patient discomfort.

Traditional CT and CT Enterography (CTE)

Although a fistulous connection from the bowel or any potential intraabdominal collection to the skin can be shown using fistulography, CT is mostly used as a complementary exam in order to definitively characterize abscess collections and to guide percutaneous drainage. The advantage of CT imaging lies in the identification of extraluminal pathology, such as intraabdominal abscesses, bowel obstruction, and inflammation (Fig. 27.4). Traditional contrast-enhanced CT utilizes "positive" (high density) contrast materials such as dilute barium or water-soluble iodinated solutions to opacify the small bowel. However, CT enterography can also be performed using "negative" (low density) contrast, such as water or VoLumen®, which provides additional information concerning the mucosa surrounding the fistulous tract. CT has low sensitivity for detection of small abscesses.

MR Enterography (MRE)

Magnetic resonance imaging is a promising tool for the evaluation of enterocutaneous fistulas, which does not expose patients to ionizing radiation. Taking advantage of high signal intensity of fluid on T2-weighted sequences, MRI can identify the fistula tract between bowel wall and other structures such as muscle and hollow viscera with high sensitivity. MR imaging can provide functional and real-time information, which has advantages when evaluating fistulous tracts (Fig. 27.5).

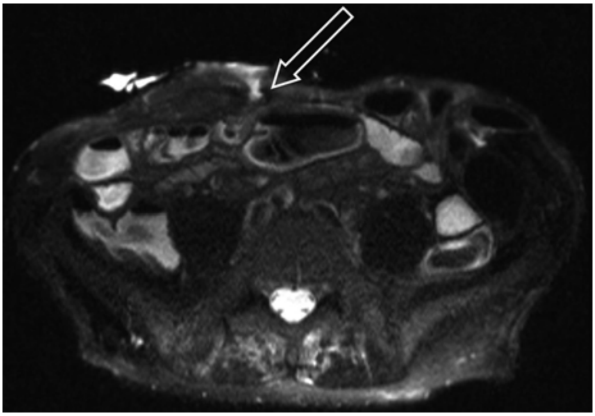

Fig. 27.5 This axial MR enterography image demonstrates an enterocutaneous fistula (*arrow*) in a patient with a history of extensive bowel surgery for diverticulitis

Teaching Points

1. Fistulography is the most direct method for defining the fistulous tract.
2. Cross-sectional imaging and small bowel follow-through provide complementary information that allows comprehensive evaluation of the fistulas and associated complications, such as bowel obstruction and abscesses.

Chapter 28
Abdominal Distension and Feeding Intolerance

Susan C. Williams, Edward Lineen, and Gary H. Danton

Clinical Problem

A 55 year-old woman with severe COPD was admitted to the ICU after a laparotomy and ileocecectomy for intestinal obstruction due to intussusception. She is unable to be extubated in the operating room and requires ventilator management. At 72 h it becomes clear that she has a concomitant pneumonia and is unlikely to rapidly liberate from mechanical ventilation. A nasojejunal feeding catheter is placed for enteral access. The patient has a distended abdomen with a mildly increased intra-abdominal pressure of 12 cm H_20 pressure. When enteral feeding is started at 20 ml/h the patient develops significant reflux after NG drainage had previously been low (mean daily drainage is 800 cc/24 h).

Whenever there is unanticipated distension or tube feeding intolerance in an ICU patient there must be concern about obstruction, extrinsic compression, leak, abscess or other cause of intra- or extra-abdominal sepsis. Post-operative and unoperated critically ill patients share many of the same conditions that can result in abdominal distension or intolerance of enteral feeding, including abdominal compartment syndrome, calculous or acalculuous cholecystitis, intestinal ischemia, ileus, internal hernia, and a wide variety of other causes. The panoply of available tests may be winnowed using readily available elements of history and physical examination.

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The prominent critical dilemma in the post-surgical patient with abdominal distention and feeding intolerance is whether the bowel is obstructed. If the index of suspicion is high the questions of whether it is a functional or mechanical obstruction and where is the location of the obstruction needs to be addressed. If there is no bowel obstruction the diagnostic question turns towards the location and cause of the suspected ileus. The definitive cause of abdominal distention and feeding intolerance may be due to a variety of factors that include mechanical or functional small or large bowel obstruction, adynamic/paralytic ileus, or sepsis from a variety of causes including both intra- and extra-peritoneal etiologies.

Imaging Techniques

Radiographic studies play an important role in determining the etiology, evaluating for complications, and in monitoring resolution once the cause has been treated. The main differential in a patient with abdominal distention is distinguishing stomach, small or large bowel obstruction from ileus.

The initial radiographic examination for evaluation and triage of patients with abdominal distention is the plain abdominal film. However, abdominal radiographs are diagnostic in only 50–60 % of cases and are only highly sensitive in high-grade obstruction. Radiographic findings are equivocal in 20–30 % and normal or nonspecific in 10–20 %. In these equivocal or nonspecific cases, if high-grade partial or complete SBO is suspected an immediate surgical evaluation should be performed.

Computed tomography is the imaging modality of choice to confirm the diagnosis of small bowel obstruction and to identify its cause. It is part of the standard preoperative evaluation of SBO, with a sensitivity of 90–96 %, specificity of 96 %, and accuracy of 95 % for high-grade obstruction. CT assesses severity and cause of the obstruction and is the best modality for determining which patients would benefit from conservative management and close follow-up and which patients would benefit from immediate surgical intervention. If the initial radiograph or CT is inconclusive the differential diagnoses of low-grade, partial SBO or of an ileus should be considered and an imaging technique with increased sensitivity and specificity for distinguishing between the two has to be selected. Functional studies can reveal subclinically obstructed segments.

Small Bowel Obstruction

Small bowel obstruction (SBO) is a clinical condition in which the normal transit through the small bowel is disrupted secondarily to mechanical or functional obstruction. It is a common cause for surgical admission, representing 20 % of all admissions for acute abdominal pain. Small bowel obstruction is often diagnosed late, or misdiagnosed, resulting in significant morbidity and mortality. An accurate

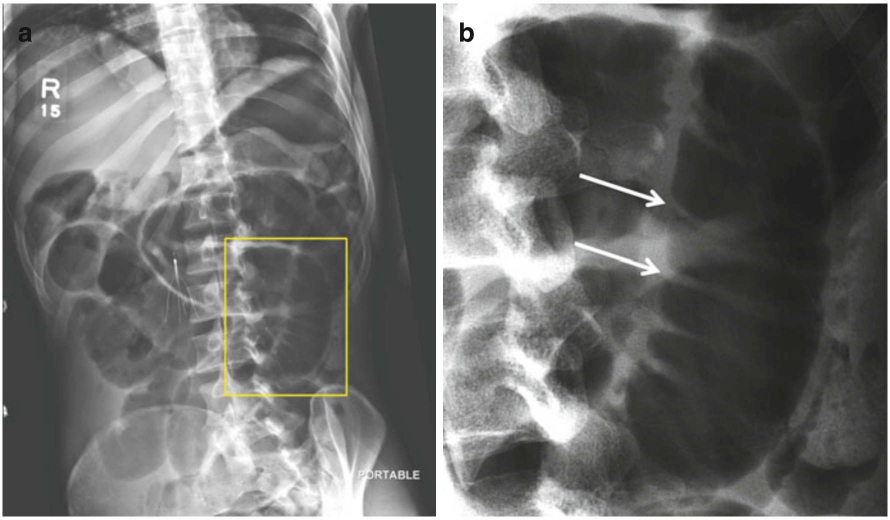


Fig. 28.1 Abdominal x-ray (**a**) shows features of small bowel obstruction with grossly distended gas filled small bowel loops. The expanded panel (**b**) shows valvulae conniventes (*white arrows*) traversing the full width of the bowel loops confirming it as small bowel

and early diagnosis of obstruction, determination of its severity, site, and cause as well as the assessment of the presence of strangulation is required to optimize outcome.

The most common cause for small bowel obstruction is postoperative adhesions. More than 67 % of open abdominal surgical patient's develop adhesions and more than 5 % of all postoperative open abdominal surgery patients will develop small bowel obstruction at some point in their lifetime. Other, less common cases of small bowel obstruction include incarcerated external or internal hernias, malignancy, inflammatory disorders, intussusception, and gallstone ileus.

In the past the limited recognition of strangulation led to the old surgical paradigm when confronted with small bowel obstruction was to "never let the sun set or rise on an obstructed bowel." In current practice adjunctive imaging has enhanced the initial evaluation and management of small bowel obstruction. In fact, many conditions resolve with nonsurgical treatment. Advanced imaging can help exclude complicated SBO, which is associated with high mortality rates. This has allowed a paradigm shift where early surgery is now performed less often allowing for a more selective approach.

On supine plain films the small bowel can be identified the linear folds traversing the circumference of the bowel lumen, also known as valvulae conniventes (Fig. 28.1a, b). Small bowel dilatation is defined as a wall-to-wall diameter of greater than 3 cm. A small bowel diameter exceeding 50 % of the caliber of the largest visible large bowel loop is consistent with the diagnosis of a high-grade small bowl obstruction. Occasionally, bowel loops are fluid filled making the diagnosis of bowel obstruction challenging on radiograph. In these cases SBO may be suspected

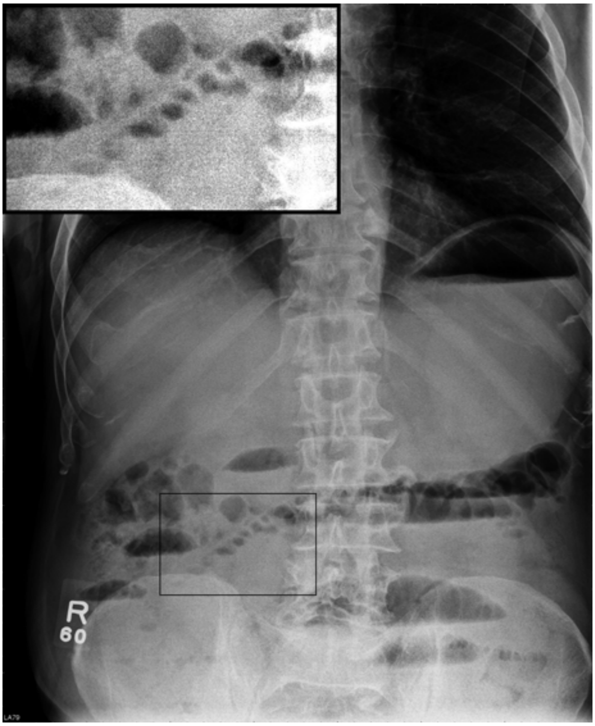


Fig. 28.2 Erect abdominal x-ray shows multiple air-fluid levels in the central abdomen aligned in a linear fashion (see *e* expanded panel) – the “string of pearls” sign if small bowel obstruction

because of the increased density within the abdomen. This is sometimes referred to as the “pseudotumor sign”, when the abdomen looks as if there are multiple subtle areas of increased density. These areas correspond to fluid filled bowel loops.

Distended air-filled loops may lay in a tiered or stepladder pattern on upright or lateral decubitus views as the air rises to form a series of short air-fluid levels. When these air-fluid levels are horizontally or obliquely oriented, it is known as the “string of pearls” sign (Fig. 28.2). Air- fluid levels see at differing heights within the same bowel loop (“Stepladder” air fluid levels) on upright positioning indicate small bowel obstruction, particularly in the early stages. In a high-grade, prolonged small bowel obstruction there may not be differential air-fluid levels or any air filled loops at all as the bowel becomes filled with fluid (Fig. 28.3). Variable amounts of air are present in the colon, depending on level, grade and duration of the obstruction. If the small bowel is distended and fluid-filled while the colon is collapsed small bowel obstruction must be suspected. Upright or lateral decubitus radiographic views are essential when evaluating for obstruction because distended small bowel loops containing mostly fluid are not well visualized on supine radiograph.

Ultrasound is not commonly used for SBO because air reflects sound waves creating a “dirty shadowing” that obscures the view of adjacent bowel loops. Repositioning the patient on their side and imaging from a more dependent portion of the abdomen may help identify fluid filled loops because air rises and the probe will be closer to the fluid-containing portion of the bowel. When the bowel

Fig. 28.3 Featureless abdomen with paucity of bowel gas resulting from fluid-filled distended small bowel loops in a patient with high-grade, prolonged small bowel obstruction

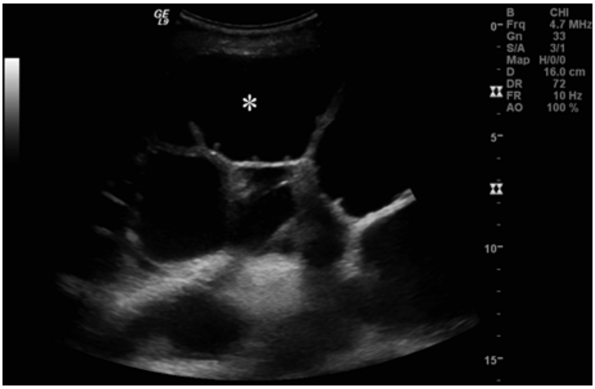


Fig. 28.4 Abdominal ultrasound in a patient with multiple markedly distended anechoic small bowel loops (note valvulae connavientes) in a patient with small bowel (*asterix*) obstruction

is near completely fluid filled a small bowel obstruction can be diagnosed because of the number and size of fluid filled bowel loops (Fig. 28.4). Ultrasound is limited in determining the cause of obstruction. Adhesions, the most common cause of mechanical SBO, are not detected with this method.

The main CT finding in small bowel obstruction is markedly distended fluid and sometimes gas filled loops proximal to the point of obstruction as compared to the nondilated bowel distal to the obstruction (Fig. 28.5a, b). A potential pitfall

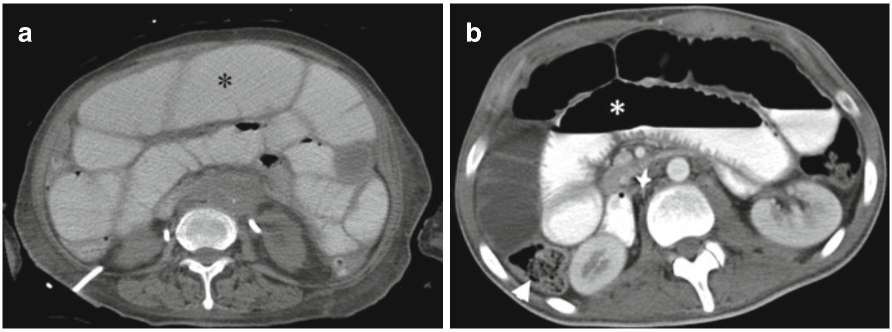
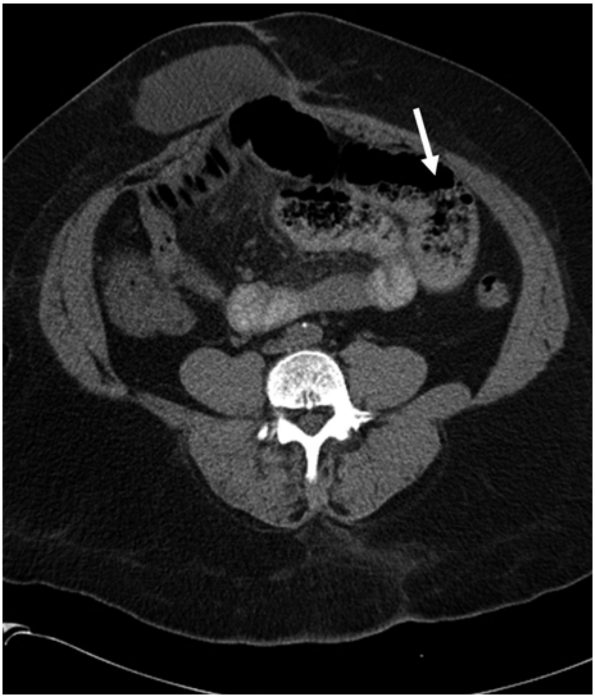


Fig. 28.5 Selected CT images show markedly distended fluid filled small bowel loops (*asterix*) (**a**, **b**) in contrast to the more normal caliber ascending colon (*arrowhead*) (**b**) in keeping with small bowel obstruction

Fig. 28.6 CT image shows mottled gas admixed with fluid in the small bowel (*arrow*) – the "small bowel feces" sign – is a definitive CT finding for small bowel obstruction



is the normal appearance of a collapsed descending colon, even in a patient with adynamic ileus. Bowel obstruction should not be diagnosed in this setting unless an obstructing lesion is visualized at the splenic flexure or there is distension throughout the bowel proximal to the splenic flexure. The "small bowel feces" sign is a definitive CT finding for small bowel obstruction. It is seen when a slowly transiting *succus entericus* becomes overgrown with bacteria and partially dehydrated creating the appearance of feculent contents mixed with gas bubbles within dilated small bowel (Fig. 28.6).

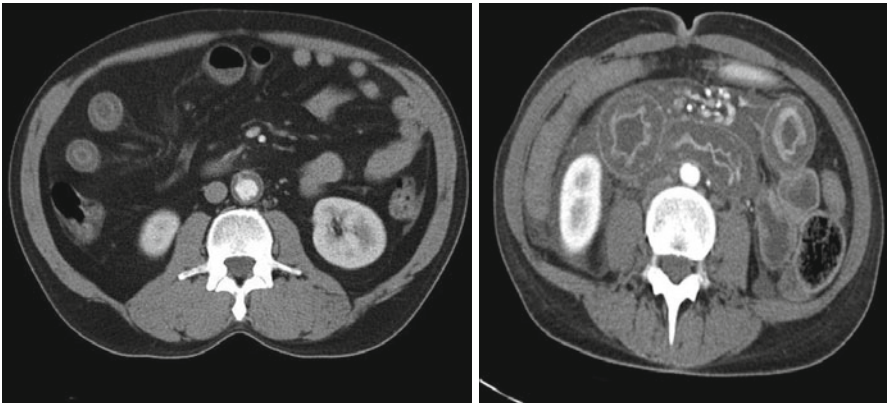


Fig. 28.7 CT images obtained during intravenous contrast enhancement show concentric rings of high and low attenuation of the bowel wall – the target sign – a feature seen in ischemic bowel

Contrast-enhanced, multidetector CT imaging is the method of choice to evaluate for complications of obstruction such as intestinal ischemia or contained perforation. Oral contrast is optional and is often discouraged as the fluid naturally accumulating in the bowel makes the loops easy to visualize. Giving oral contrast to patients with bowel obstruction may lead to vomiting and aspiration. The appearance of the bowel wall on i.v. contrast-enhanced CT changes as it progresses from ischemia to infarction. When obstruction is complicated by strangulation and ischemia, CT demonstrates circumferential thickening of the bowel wall (>3 mm) and may contain a target or halo appearance.

The target sign (Fig. 28.7) describes three concentric rings of high and low attenuation of the bowel wall. It is seen when an ischemic injury starts at the mucosa and extends progressively through the wall to the serosa and is formed by inner and outer layers of high attenuation surrounding an edematous central area of decreased attenuation. It is best visualized during a late arterial or early portal venous phase of IV contrast enhancement. Poor enhancement of the bowel wall along its mesenteric border suggests ischemia whereas poor or absent mucosal enhancement with thinning of the bowel wall provides evidence of bowel infarction. Most strangulated obstructions, such as incarcerated hernias or volvulus, are closed loop obstructions where both afferent and efferent limbs are involved. They have a U-shaped or C-shaped configuration on axial CT with a "beak" sign at the site of torsion seen as fusiform tapering of a dilated bowel loop (Fig. 28.8a, b).

Fluoroscopic and CT enteroclysis require placing a nasojejunal tube for directed contrast administration. Direct injection of contrast distends the bowel and will clearly identify an area of functional and mechanical obstruction.

The use of water-soluble contrast material versus barium depends on the question to be answered. If there is concern of obstruction, barium is optimal as it is inert, does not draw fluid across the mucosal barrier and thus does not exacerbate

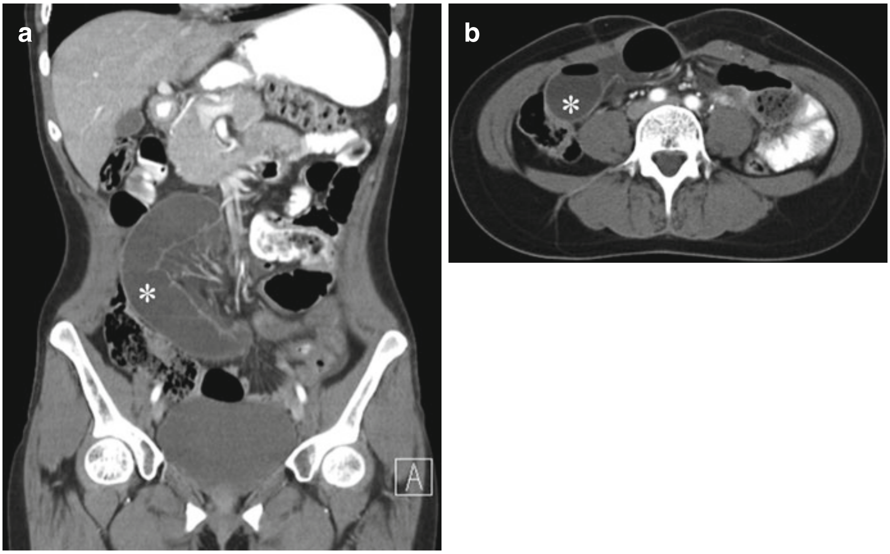


Fig. 28.8 Axial (**a**) and coronal (**b**) CT images show fusiform tapering of a dilated bowel loop (*asterix*) with C-shaped configuration and a "beak" sign at the site of torsion

the distension of the bowel. A single contrast enema with either barium or water-soluble contrast material is sometimes ordered to rule out the possibility of colonic obstruction. If there is the potential for perforation barium should be avoided due to the risk of chemical peritonitis. The viscid barium will trap bacteria leading to multiple abscesses and is rather difficult to evacuate from the peritoneal space. In these circumstances water-soluble contrast is the medium of choice. Occasionally the hygroscopic nature of water-soluble contrast will relieve fecal impaction by hydrating inspissated stool, leading to fecal content evacuation.

Large Bowel Obstruction

Large bowel obstruction composes approximately 20 % of intestinal tract obstructions and may be due to malignancy, fecal impaction, sigmoid or cecal volvulus as well as hernia, adhesions, and ischemic stricture. Fecal impaction is the one of the most common etiologies of large bowel obstruction in elderly and bedridden patients. Plain radiographs should be the initial study of choice with the intent of looking for markedly dilated large bowel loops. Although quoted measurements vary, dilatation of the colon should be suspected when its diameter exceeds 6 cm while dilatation of the cecum occurs when it exceeds 9 cm in diameter. Usually the large bowel and cecum are dilated much more than 6–9 cm when obstructed and the massive dilation is readily apparent (Fig. 28.9). The large bowel can be

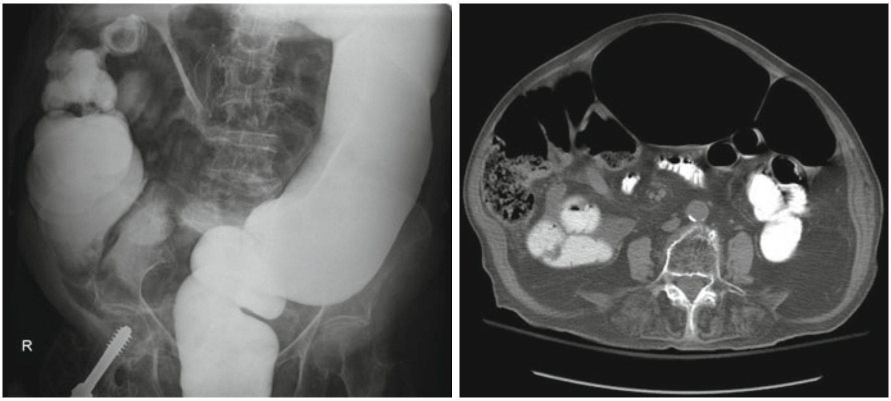


Fig. 28.9 Large bowel dilatation shown on contrast enema on CT

differentiated from small bowel in part by the peripheral location and more definitively by lack of valvulae conniventes; instead, the large bowel has haustra that extend only part way across the lumen of the bowel.

Abdominal radiographs are often diagnostic of large bowel obstruction, demonstrating dilation of the colon from the cecum distally to the point of obstruction. The cecum dilates to the greatest extent, irrespective of the site of large bowel obstruction. When the ileocecal valve is competent the colon is unable to decompress into the small bowel and progressive distention of the cecum occurs. If the ileocecal valve is incompetent, the colon can decompress into the small bowel and dilation of the small bowel will occur. The risk of cecal perforation is reduced with an incompetent ileocecal valve. The cecum is at highest risk of perforation as it is the most distensible part of the bowel and has the thinnest wall.

CT scanning shows masses or collections that are pressing on the colon. Areas of peristalsis can give the appearance of an obstruction when there is none. To avoid false results or inconclusive studies, filling the CT with rectal contrast is an option. This helps to identify areas of obstruction and exclude false positives from peristalsis since the latter does not usually prevent contrast from passing through the colon.

Ileus

Post-operatively, gastrointestinal motility is impaired, especially colonic activity. An ileus develops when gastrointestinal peristalsis is absent or ineffective and there is no physical obstruction to the passage of luminal contents of the bowel. "Physiologic" ileus revolves spontaneously within the first 2–3 days after surgery and is often related to a combination of inflammatory mediators released from the site of injury, inhibitory neural reflexes and electrolyte imbalances. If normal gastrointestinal motility has not returned after postoperative day three the diagnosis

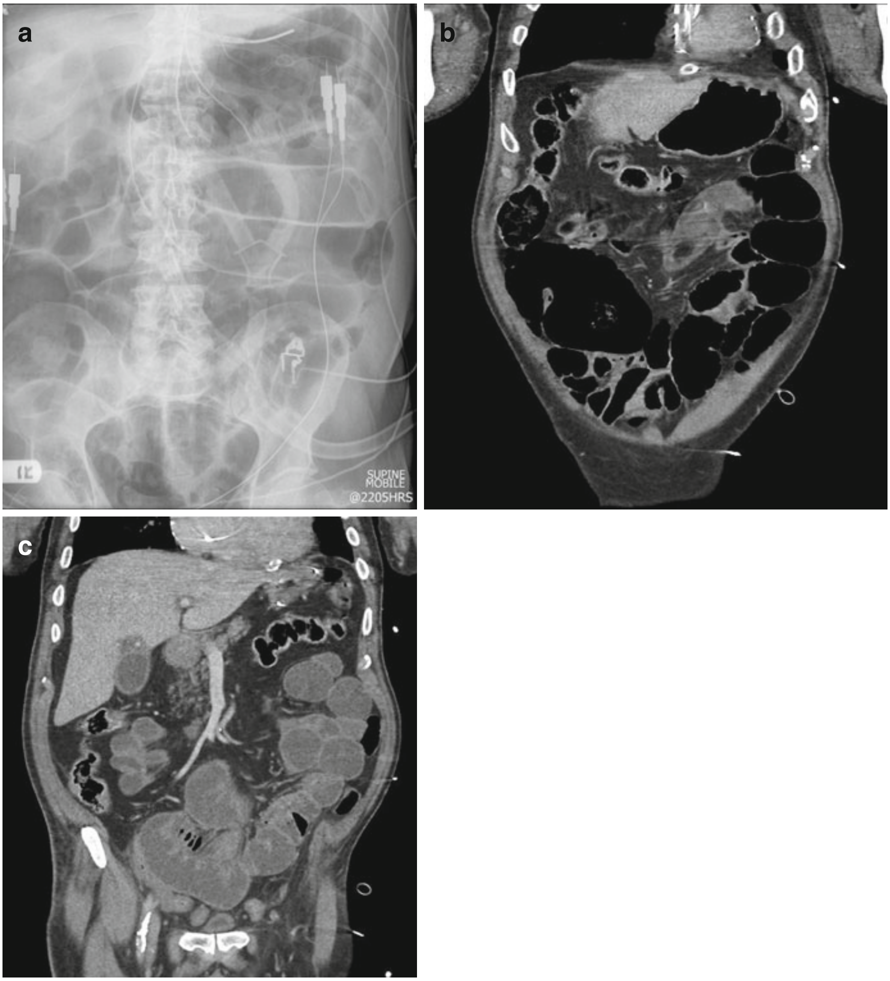


Fig. 28.10 (**a**) Abdominal X-ray in a patient 2 days following cardiac surgery shows dilated gas filled small and large bowel loops. (**b**, **c**) CT during IV contrast medium administration shows dilated small bowel loops and caecum which are partly fluid and gas filled. There is no obstructive lesion and no abrupt transition point consistent with ileus, which resolved spontaneously

of postoperative adynamic ileus or paralytic ileus should be explored and an early post-operative obstruction has to be excluded. Generally, the small-bowel is the first to recover (0–24 h postoperatively), followed by the stomach (24–48 h), and then the colon (48–72 h). Delayed gastrointestinal motility leads to difficulties with refeeding with the effective duration of ileus mainly dependent on the return of motility to the left colon.

On abdominal radiography, diffuse and uniform gaseous distention of the small and large bowel in proportion to each other without a demonstrable point of obstruction can help differentiate generalized ileus from obstruction (Fig. 28.10a–c).

However, the ileus can also affect an isolated segment of bowel due to an adjacent acute inflammatory process. This localized loop of bowel is referred to as a "sentinel loop" as its position can suggest the underlying diagnosis. As an example, a focal dilated loop of bowel in the mid-abdomen may be indicative of pancreatitis. Differential air-fluid levels in the same loop of bowel may be seen in early ileus, although this is not typical. A paralytic ileus is classically referred to as dysmotility of the small bowel but it can selectively affect the stomach or colon. Determining of which portion of the gastrointestinal tract is involved is important as management may depend on the affected site.

Gastroparesis

An ileus of the stomach is referred to as gastroparesis. Patients predisposed to developing gastroparesis include diabetics and patients who have undergone certain surgical procedures, most commonly after pancreaticoduodenectomy (Whipple procedure) or post vagotomy. Post-operative gastroparesis occurs in up to 57 % of patients after a Whipple procedure. Exclusion of mechanical obstruction is important. In the setting of the critically ill patient, endoscopy is preferred to exclude gastric ulcers, tumors or bezoars.

Colonic Ileus and Toxic Megacolon

Colonic ileus or colonic pseudo-obstruction is a disproportionate distention of the large bowel without obstruction. It often accompanies an acute inflammatory process, abdominal surgery or the use of antipsychotic medication. However, it can also occur after extra-abdominal surgery, such as after orthopedic procedures. Its incidence was reported in one study as 1.3 % after hip replacement surgery and 1.2 % after spinal procedures. It is more common in elderly patients with multiple medical comorbidities.

Toxic megacolon is characterized by extreme dilation (>6 cm) of all or a portion of the colon combined with systemic toxicity. Patients present with progressive abdominal distension, fever, and clinical signs ranging from sepsis to severe septic shock. The risk of spontaneous perforation is high and mortality is progressive with perforation and septic shock requiring surgical intervention. Common causes of toxic megacolon include pseudomembranous colitis due to *Clostridium difficile*, ulcerative colitis, Crohn colitis, and ischemic colitis. Plain abdominal films demonstrate distension of the colon with absent haustra. Dilation of the transverse colon up to 15 cm in diameter can occur. On CT, the wall of the distended colon is thin and has a nodular contour. Intramural gas may be identified. Contrast enema is absolutely contraindicated because of the high risk for perforation.

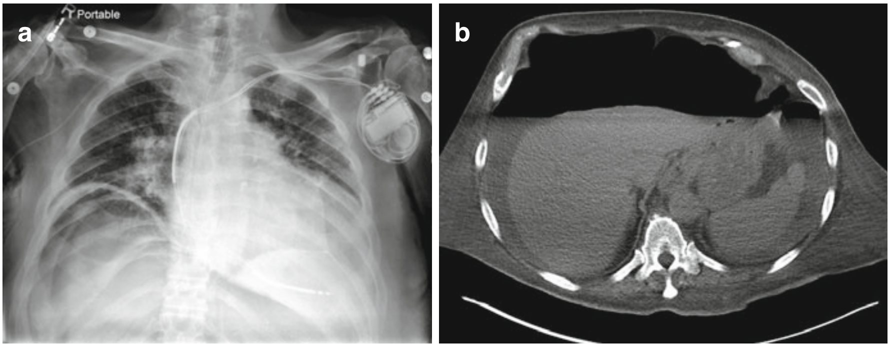


Fig. 28.11 Pneumoperitoneum (**a**) on erect CXR with extensive free air beneath the right hemidiaphragm in a patient with perforation. CT (**b**) confirms extensive pneumoperironeum and free fluid in the abdomen

Pneumoperitoneum and Peritonitis

Major causes of pneumoperitoneum (Fig. 28.11a, b) with peritonitis include a perforated viscus from a gastric/duodenal ulcer or from the colon (toxic megacolon) and penetrating trauma. Major causes of pneumoperitoneum without peritonitis include recent abdominal surgery or laparoscopy; a postoperative pneumoperitoneum usually clears within 3–7 days. Failure of progressive resolution or an increase in the amount of air present suggests intestinal disruption but may also stem from a necrotizing soft tissue infection of the abdominal wall or the retroperitoenum (with rupture into the peritoneal space). A pneumoperitoneum is best demonstrated in upright projection as air underneath the diaphragm. Upright chest radiographs are highly sensitive for free air. In ideal conditions as little as 1 mL can be detected. Free air under the diaphragm is best visualized on the right as the liver offers a distinct outline between the air and soft tissues. On the left, free air can be confused with endoluminal gas within the stomach or splenic flexure. If it is impossible to obtain an upright chest or abdominal film, a lateral decubitus film may be used. It has to be remembered, though, that movement of air is not rapid and its percolation to the highest point of the abdominal cavity may take 10–20 min.

On supine radiographs the findings of pneumoperitoneum include an area of increased lucency over the liver, evidence of gas on both sides of the bowel wall (Rigler sign), gas outlining the falciform ligament (falciform ligament sign), and gas outlining the peritoneal cavity (“football sign”) which is more commonly seen in children. There are certain conditions that mimic free intraperitoneal air and can lead to the mistaken diagnosis of pneumoperitoneum. These include loops of bowel interposed between the diaphragm and liver, linear atelectasis of the lung base being mistaken for the diaphragm, subpulmonic pneumothorax on supine radiograph, or dilated loops of bowel giving the appearance of both sides of the bowel wall being visualized, also known as a pseudo-Rigler’s sign. Small amounts of extraluminal gas can be difficult to determine on CT and may be confused with intraluminal gas.

Foreign Body

Foreign bodies may be ingested or inserted, result from penetrating trauma, or be left behind from surgery. Retained bullets and shotgun pellets may lead to abscess formation or much more rarely, lead intoxication. Retained surgical sponges are a dreaded complication of surgery. They may be asymptomatic, cause an abscess or generate a granulomatous response.

CT is utilized to determine the exact position and associated complications of foreign bodies and serves to help plan their removal. Wooden foreign bodies are not visualized on plain radiographs; CT demonstrates wooden foreign bodies as high attenuation. Sponges are usually detectable on radiographs because of a radiopaque string-like marker. CT scans of a retained operative sponge may demonstrate a soft tissue mass commonly laced with air bubbles.

Abscesses and Infection

Abscesses in the peritoneal cavity are most commonly associated with surgery, trauma, pancreatitis, intestinal ischemia or intestinal perforation. Abdominal radiographs may demonstrate a soft tissue mass, collection of extraluminal gas, localized or generalized ileus, elevation of the diaphragm, pleural effusion and changes at the lung bases. CT may demonstrate a loculated fluid collection with internal debris or fluid levels. Gas within the fluid collection is a strong indicator of abscess formation. The fascia adjacent to the abscess is typically thickened and there may be fat stranding due to inflammation. When imaged using i.v. contrast there often is rim enhancement of the abscess wall due to local hyperemia. Ultrasound classically demonstrates a focal fluid collection that contains echogenic fluid, floating debris and septations. It is worth remembering that anechoic fluid collections may also be infected. Gas within the collection is evidenced by echogenic foci producing comet-tail or reverberation artifacts. CT or US guided aspiration confirms the diagnosis and allows for percutaneous catheter drainage. Collections that are unable to be accessed (i.e., do not have a window for safe passage of a needle, guidewire and catheter) may require surgical drainage.

Teaching Points

1. Postoperative abdominal distention and feeding intolerance can be caused by a variety of factors including small or large bowel obstruction, adynamic/paralytic ileus, perforated viscus causing pneumoperitoneum, peritonitis and abscess formation.

2. Radiographic studies play an important role in illuminating the etiology of abdominal distention and feeding intolerance.
3. Imaging allows the evaluation of complications, planning of management and monitoring the resolution of the underlying cause of abdominal distention and feeding intolerance.

Chapter 29
New Onset of Fever and Leukocytosis

Michael L. O'Neill, Anthony M. Durso, Edward Lineen, and Gary H. Danton

Clinical Problem

A 44-year-old male undergoes an uncomplicated laparoscopic hand assisted right hepatectomy for the management of hepatitis C associated hepatocellular carcinoma. He does well for the first day in the ICU. During POD #2 he develops a high fever and his previously normal white cell count rises to 18.2. His breathing appears labored and he requires intubation and mechanical ventilation for hypercarbic and hypoxemic respiratory failure. His abdominal incisions at each port site are clean but his hand port site has a 1 cm zone of erythema; his post-intubation CXR demonstrates clear lung fields and an appropriately positioned oral endotracheal and orogastric tubes. His sputum is thin, readily suctioned and white without foul odor.

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Table 29.1 Common sources of sepsis

Pulmonary	Gastrointestinal	Genitourinary	Miscellaneous
Atelectasis	Colitis	Urinary tract infection	Malignancy
Pneumonia	Obstruction	Pyelonephritis	Drug reaction
Empyema	Perforated viscus	Renal abscess	Deep vein thrombosis
Pulmonary embolism	Peritonitis	Cystitis	Sinusitis
	Cholecystitis	Urethritis	Dural sinus thrombosis
	Cholangitis	Prostatitis	Osteomyelitis
	Pancreatitis	Gynecological	Discitis
	Abscess		Catheter related bloodstream infection
			Wound infection

He has previously received one pre-operative and two post-operative doses of surgical site infection prophylaxis with a cephalosporin.

Fever and leukocytosis are not uncommon after surgery or in the intensive care environment. However, when they are accompanied by evidence of systemic illness detailed investigation is warranted. A primary concern is the abdomen. However, other potential sources, such as pneumonia, catheter related bloodstream infection or drug reactions must not be forgotten (Table 29.1).

Imaging Techniques

The choice and sequence of initial imaging techniques to investigate suspected abdominal sepsis must largely be tempered by a focused differential diagnosis surmised by a careful history, physical examination, and analysis of the initial laboratory data. Guided by the patient-specific differential diagnosis, an imaging modality is then selected. Four of the five classic "Ws" of post-surgical pyrexia may help guide decision-making:

- Wind – Atelectasis (Chest Radiograph)
- Wound – Wound infection or post-operative collection (Focused Ultrasound or Contrast enhanced CT)
- Water – Urinary tract infection (Urinalysis +/− Renal Ultrasound, followed by CT if still concerned about renal abscess or collection)
- Walking – Deep Venous Thrombosis (Lower Extremity Ultrasound)
- What Did We Do – Drugs, heating blankets etc. (no imaging available apart from clinician's eyes and vigilance).

In this day and age much emphasis has been placed on the early utilization of the various cross-sectional imaging modalities (US, CT, MRI). However, the plain film remains a useful initial diagnostic imaging modality. Particularly in intubated and ventilated ICU patients, sepsis of pulmonary origin is high on the list of potential differential diagnoses (see Chap. 24).

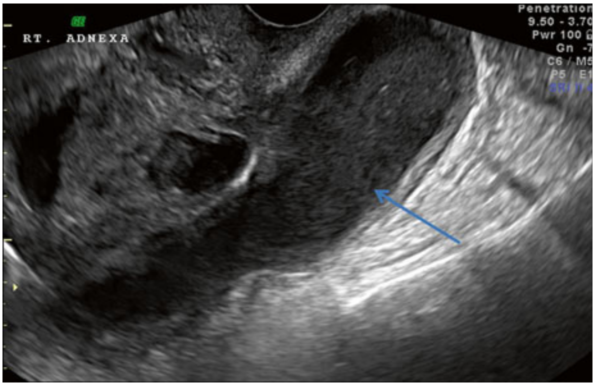

Fig. 29.1 Transvaginal grayscale ultrasound image in a 44 year old with fevers demonstrates a large tubular loculated echogenic collection in the right adnexa (*blue arrow*), which represents a pyosalpinx or a tubo-ovarian abscess. Normally, the fallopian tube is not a well-imaged structure, unless filled with fluid (Hydrosalpinx) or pus (Pyosalpinx) as in this case

Ultrasound is easily performed at the bedside, provides a good overview of common pathologies and can guide the need for further imaging. It is also useful for picking up some of the less common sources of sepsis (Fig. 29.1). Computerized Tomography (CT) remains the preferred imaging modality for intra-abdominal infections in many ICU settings across the world. Various complementary applications can often be employed with the obtained data set, such as 3D volume-rendered reconstructions of various anatomic structures. As the data set is obtained quickly, often in a matter of seconds, it suffers less from motion artifacts commonly seen in MRI or Nuclear Radiology studies. CT can also be utilized for image-guided procedures in addition to diagnostic indications.

Scintigraphic studies are used in extremely rare circumstances in ICU patients. They have a role in cases where other modalities have failed to yield a diagnosis, mainly when looking for an infective focus (Fig. 29.2a, b). These studies are cumbersome and slow and they require the patient to be returned to the Nuclear Medicine Suite on more than one occasion (e.g., delayed Gallium Scan Images at 4 and 24 h to confirm absence of infectious source).

Urinary Tract Infections

They are thought to be the most common overall source of ICU fever and are often catheter-related. It is possible that the incidence of catheter-related urinary tract infections has been overestimated because many studies do not distinguish between asymptomatic bacteriuria and a genuine urinary tract infection. If unrecognized they may progress to pyelonephritis but urosepsis is the ultimate endpoint that needs to be prevented. The diagnosis is typically made clinically in conjunction with laboratory. The role of imaging is typically to exclude more advanced infections of the urinary tract or their complications, such as advanced cystitis, pyonephrosis and both emphysematous and non-emphysematous pyelonephritis. Ultrasound provides the first line test, followed by CT (Fig. 29.3).

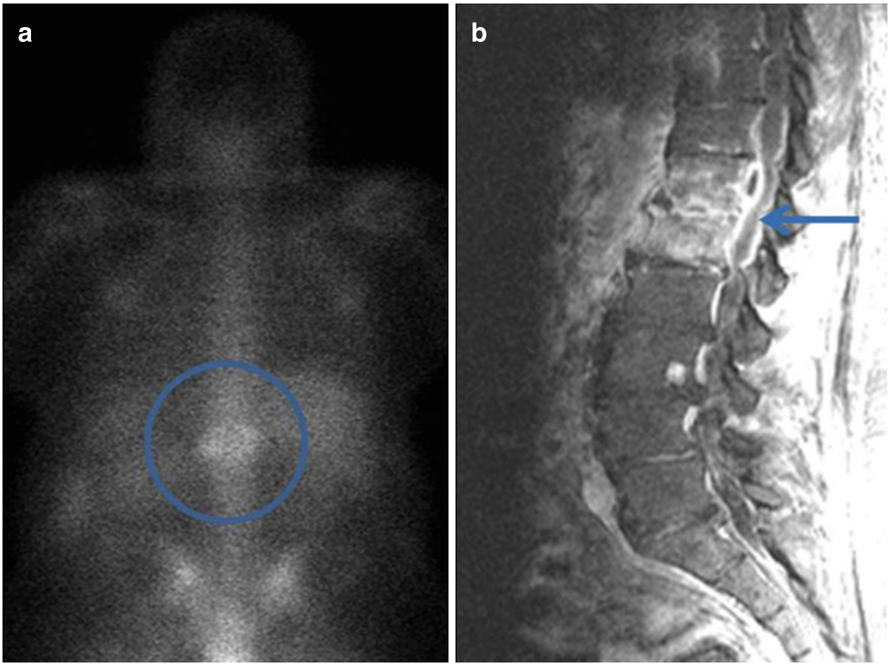

Fig. 29.2 Osteomyelitis/discitis in an iv drug abuser with fevers and leukocytosis of unknown source. The Gallium-67 scan (**a**) shows the radiotracer accumulating in the T12-L1 region (*blue circle*). The T1-weighted post-contrast MRI image (**b**) demonstrates a robust enhancement of the vertebral bodies, disc, and paravertebral soft tissues (*blue arrow*) consistent with osteomyelitis and discitis

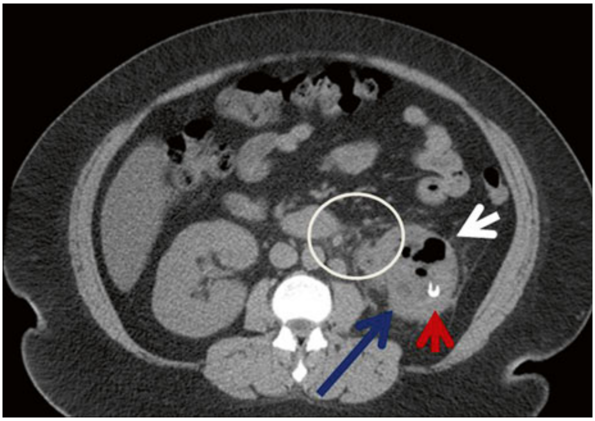

Fig. 29.3 Axial non-contrast CT images through the mid-abdomen at the level of the kidneys demonstrate multiple pockets of gas within both the renal collecting system and the parenchyma (*white arrows*) as well as adjacent stranding and mild adenopathy within the anterior pararenal space (*white circle*), in keeping with an emphysematous pyelonephritis. Also noted are vague areas of relative hypoattenuation within the parenchyma at multiple levels (*blue arrows*) representing pyelonephritis and underlying renal abscesses. Note the multiple calculi (*red arrow*) within the collecting system, likely playing a causative role

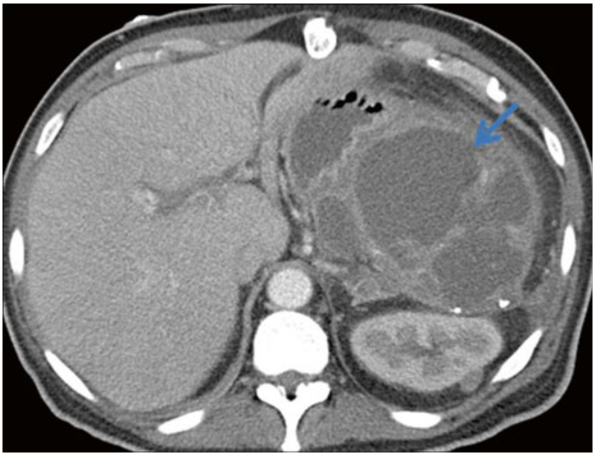

Fig. 29.4 This axial iv contrast enhanced image of a 62 year old male with abdominal pain and history of chronic pancreatitis demonstrates a large loculated upper abdominal collection, consistent with abscess or less likely a pseudocyst (*blue arrow*). A pseudocyst is expected to have fewer inflammatory changes and thinner walls

Post-operative Abdominal Infections

Deep Abdominal Abscess

Persistent abdominal pain, focal tenderness, a persistent paralytic ileus in addition to fever and leukocytosis are suggestive of a deep abdominal abscess (Fig. 29.4). They are not uncommon following abdominal surgery but may also occur for a variety of other reasons.

In supine patients deep fluid collections commonly collect in the pelvis and under the diaphragm. These sites are therefore predisposed for abscess formation. Localized abscesses tend to form in close relationship to the affected intra-abdominal viscus.

Ultrasound may give some idea about the presence of free fluid and any bigger collections. However, only CT can help to distinguish between abscess, hematoma, seroma, or other benign peritoneal collection as well as guide drainage, if indicated. The interpretation of post-operative images can be very tricky because non-infected serous collections are a physiological reaction to the operative trauma.

Furnishing the imaging request with adequate clinical detail and a discussion with the radiologist prior to sending the patient to the imaging suite are important when CT guided, percutaneous drainage appears to be an option. If the radiology staff have ample warning that an intervention is likely to take place delays can be minimized.

Clostridium Difficile Colitis

Clostridium difficile colitis is one of the most common healthcare-associated infections and is commonly carried in up to 20 % of hospitalized patients, and up to 40 % of patients in long-term care facilities. Clinically, it often manifests with multiple episodes of watery diarrhea, abdominal pain, fevers, and leukocytosis. Toxic megacolon

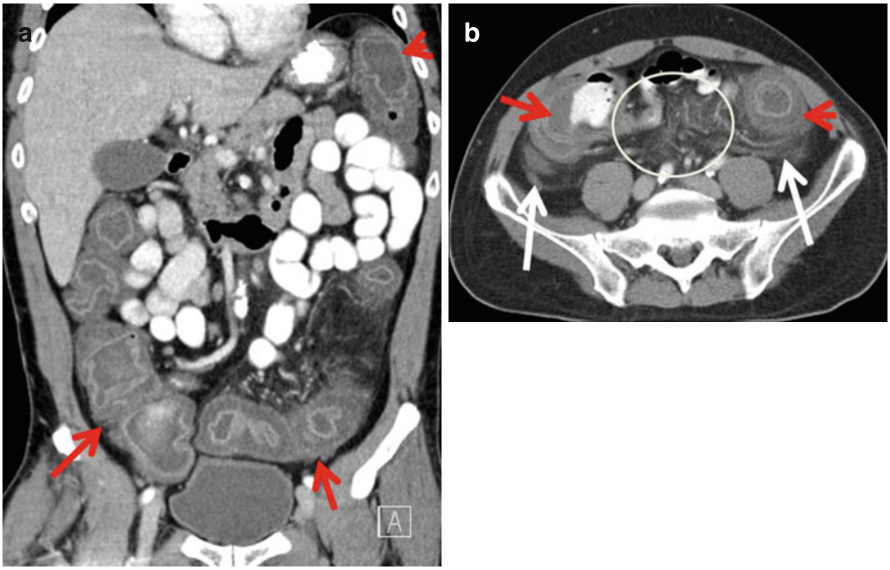

Fig. 29.5 Axial (**a**) and coronal (**b**) iv contrast enhanced CT images demonstrate diffuse marked colonic wall thickening and mucosal enhancement (*red arrows*) with adjacent mesenteric stranding (*white arrows*, *white circle*), which can be seen with severe acute colitis. Note that similar imaging findings can be seen in severe cases of colitis from other infectious etiologies as well as non-infectious etiologies, as in Ulcerative Colitis, or less likely in infiltrative neoplastic processes such as lymphoma

(see Chap. 28) and fulminant colitis are the dreaded complications that need prompt diagnosis and treatment. CT can be a useful tool in this setting to demonstrate signs of colitis (Fig. 29.5a, b), such as thumbprinting, colonic wall thickening and mild dilatation as well as more advanced complications, such as massive dilatation (>7 cm), perforation, pneumatosis intestinalis, and portal venous gas. Abdominal radiography is often useful as an initial evaluation, although insensitive for early colitis.

Acalculous Cholecystitis

Acalculous Cholecystitis is an important cause of fever in ICU patients. The high-risk populations, including post-operative patients, the immunosuppressed, diabetics and those with atherosclerosis, are frequently seen in intensive care. Acalculous cholecystitis is estimated to represent approximately 10 % of all cases of cholecystitis. Ultrasound remains the first-line examination (Fig. 29.6) and specific imaging signs include absence of demonstrable calculus, in addition to other signs, which are somewhat similar to those seen in the calculous variety. They include thickening of the gallbladder wall (>5 mm) with pericholecystic fluid, a positive Murphy's sign induced by the ultrasound probe, failure to visualize the gallbladder,

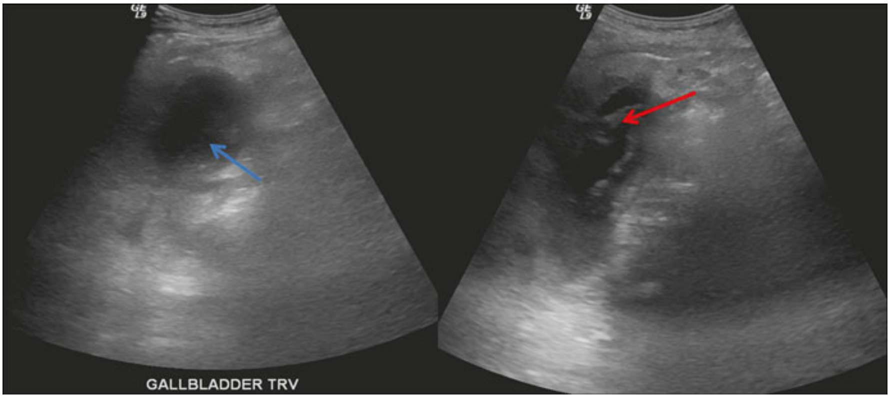

Fig. 29.6 Acute Cholecystitis. Axial (*left panel*) and sagittal (*right panel*) of right upper quadrant gray scale ultrasound images in a 56 year old male with right upper quadrant pain and fever demonstrates gallbladder wall thickening of 0.43 cm (*red arrow*), well above the normal maximum of approximately 0.2–0.3 cm and pericholecystic fluid (dark area above the *red arrow*) in keeping with an acute cholecystitis. Note the intraluminal echogenic material, which probably represents sludge (*blue arrow*)

emphysematous cholecystitis with gas bubbles arising in the fundus of the gallbladder (also known as the champagne sign) and in advanced cases, perforation of the gallbladder with associated abscess formation. CT can also be a useful adjunct in advanced or equivocal cases, for peri-operative planning, or for image-guided drainage.

Non-infectious Causes of ICU Fever

Although fever in ICU patients is generally caused by an infection, clinicians need to be aware of non-infectious causes of fever particularly when the initial imaging in inconclusive. Most are diagnosed in the laboratory, however some can be amenable to imaging. The broad categories are summarized in Table 29.2.

Thrombophlebitis

Thrombophlebitis often results from endothelial trauma and inflammation resulting from the presence of intravascular catheters. Clinically, there is mild tenderness and erythema over the venous access site. In non-complicated cases, spontaneous remission can be observed shortly after removal of the catheter. Involvement can be somewhat more extensive in cases of PICC line-related thrombophlebitis, due to the increased venous length involved.

Table 29.2 Causes of non-infectious fever

Malignancy	Lymphoma
	Renal cell Ca
	Carcinomatosis
Granulomatous disease	Sarcoid
	Inflammatory bowel disease
Connective tissue disease	Rheumatoid arthritis
	Lupus
	Arteritis
Vascular disease	Phlebitis
	Thrombosis
Neurological	Subarachnoid hemorrhage
	Intraventricular hemorrhage
	Tumor
Drug reactions	
HIV	

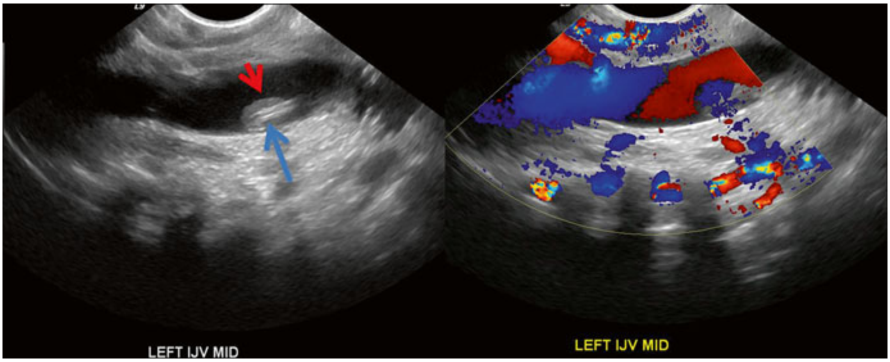

Fig. 29.7 Gray scale (*left panel*) and color Doppler ultrasound image (*right panel*) of the left neck of an ICU patient with a central venous catheter in place demonstrate an eccentrically located intraluminal echogenic focus within the left internal jugular vein at the mid-portion, which represents a thrombus (*red arrow*). Note the presence of the linear intraluminal echogenic focus (*blue arrow*) associated with the thrombus, which represents the patient's central line. The color Doppler image demonstrates turbulent blood flow in the area of the thrombus

Occasionally thrombophlebitis may progress to its suppurative subtype. It characterized by persistent bacteremia 72 h post catheter removal, intraluminal thrombus or pus and evidence of perivascular inflammation.

The imaging diagnosis of thrombophlebitis can be well demonstrated by ultrasound as the soft tissue manifestations of hyperemia and swelling, i.e. as extravascular color signal and soft tissue thickening. Thrombosis may or may not be associated with thrombophlebitis. The expected ultrasound findings of vascular thrombosis include intraluminal echogenic material (Fig. 29.7), lack or paucity of color flow on Doppler images, and most specifically the lack of compressibility of the vessel when compressed with the ultrasound probe.

Heterotopic Ossification

Heterotopic ossification, also known as myositis ossificans, is characterized by the development of dystrophic soft tissue calcifications, typically in an area previously affected by trauma, surgery, burns, or infection. While many cases are mild, severe cases may be seen in which fever as well as significant erythema, swelling, warmth and tenderness are noted. The associated morbidity can be high. Imaging findings on radiography can include irregular cloud-like ossifications within the soft tissues, often giving a characteristic appearance. Nuclear Medicine Tc-99 MDP bone scan may demonstrate increased localization of the radiotracer in the involved soft tissues, further confirming the diagnosis.

Teaching Points

1. Most infectious causes of fever within the abdomen need prompt diagnosis and treatment.
2. CT is mainly used for imaging and may provide a tool for treatment at the same time.
3. Good communication between the ICU and Radiology are important to choose the right imaging tool and to allow a possible intervention to be planned adequately.
4. Despite being slow and involving several transfers to the imaging suite, nuclear medicine offers an option to find a suspected infective focus if all other diagnostic results have been inconclusive.

Chapter 30
Acutely Decreased Hemoglobin

Christine C. Toevs and Paul R. Klepchick

Clinical Problem

A 67 year-old otherwise healthy woman has undergone a TAH/BSO, omentectomy, diaphragm stripping and periaortic lymph node resection for ovarian cancer. She arrives to the ICU intubated with appropriate vital signs, on no cardiovascular support. Her coagulation profile is normal, an initial Full Blood Count shows an Hb of 104 g/l with a platelet count of 218×10^3. A post-op bladder pressure is 12 mmHg. Her pelvic JP drain that is on bulb suction has sero-sanguineous drainage of 75 cc after 4 h.

At 5 h post-op her heart rate increases, her pulse pressure narrows and her urine output falls below 0.5 cc/kg/h and is a more dark yellow, appearing concentrated. A repeat Hb is measured to be 72 g/l. The JP drainage remains serosanguineous. The bladder pressure is rechecked and is now 18 mmHg. Since the source of her decreased hemoglobin is not apparent by JP drainage assessment immediate surgical re-exploration is considered inappropriate.

The first concern is hemorrhage from the operative site – a concern that is difficult to embrace since the predominant thought often is "it was dry when I closed." Contrary thinking requires recognizing that there may have been a technical error.

Nonetheless, in the absence of large volume fluid resuscitation operative site hemorrhage is the most common cause of acutely post-op decreased hemoglobin. It should be ruled out first as the cause of postoperative decrease in hemoglobin. The second concern is whether any collection is accessible for drainage. Imaging should be chosen appropriately in order to answer these two questions.

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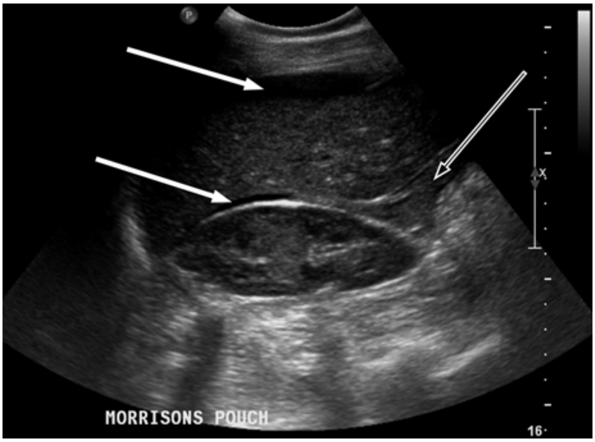

Fig. 30.1 Longitudinal transabdominal ultrasound image of the right upper quadrant shows hypoechoic hemorrhage (*arrows*) anterior to the liver and in the hepatorenal fossa. Hyperdense acute hemorrhage (*open arrow*) is also seen in the hepato-renal fossa

Imaging Techniques

Operative site hemorrhage or bleeding from surrounding structures must be ruled out as a cause of postoperative decrease in hemoglobin. However, any lengthy diagnostic testing battery to evaluate a source of bleeding could cause delay of definitive treatment and might cause serious harm to the patient. Bedside ultrasound by the intensivist or radiologist is a good first step in evaluating the abdomen for free fluid that in the immediate postoperative period is most likely to be blood (Fig. 30.1). The use of further imaging should be guided by patient stability. Contrast enhanced CT permits identification of the extent and location of hematoma and active bleeding sites and angiography permits intervention where surgical re-exploration is not appropriate.

Ultrasound

Ultrasound is highly sensitive in detecting free peritoneal fluid in the abdomen or pelvis (Fig. 30.1). It is portable, inexpensive, and provides the opportunity for diagnostic aspiration or therapeutic drainage of collections and is therefore well suited to the ICU setting. Ultrasound may be limited due to dressings, bowel gas or patient body habitus and is less sensitive in detecting retroperitoneal hematoma.

Plain Radiograph

If the patient had a central venous catheter (CVC) placed in the internal jugular vein or the subclavian vein preoperatively, a CXR will evaluate for a hemothorax as a

Fig. 30.2 The axial unenhanced CT image shows hyperdense fluid (*arrow*) in the extra-peritoneal pelvis surrounding a surgical drain (*open arrow*). Note extrinsic compression of the decompressed urinary bladder (*B*)

potential source of blood loss. Another very rare complication after CVC placement is cardiac tamponade. Although clinical signs will likely lead to patient instability long before a change in labs, the CXR may show a change in heart size or shape, leading one to suspect a problem. Use of ultrasound guidance for placement of these catheters has decreased the complications but does not eliminate them.

There is no indication for an abdominal plain film (flat plate or upright) in the evaluation of postoperative decrease in hemoglobin or suspected postoperative intraabdominal bleeding. Sitting the patient up or putting them in a lateral position carries a high risk of further hemodynamic destabilization. Plain films of the abdomen allow for evaluation of pneumoperitoneum or intraluminal air. They are not helpful for the evaluation of extraluminal blood.

Computed Tomography

In the acute setting CT is useful for the detection of a large number of post-operative complications, including bleeding, perforation, abscess, fluid collections, wound dehiscence, bowel obstruction and anastomotic leak. If the location of bleeding is unrelated to the surgical site and is away from the drains, such as the retroperitoneum or the abdominal wall, a CT can guide the diagnosis and save valuable time (Figs. 30.2 and 30.3). CT assessment of fluid attenuation also allows for differentiation between ascites (0–20 HU) and blood (30–70 HU) in the peritoneal cavity. Acute intraabdominal bleeding can mimic ascites on a postoperative CT, particularly in the presence of profound anemia and large-volume crystalloid resuscitation. Narrow CT window settings (window center = 70; window width = 300) facilitate visualization of a fluid-fluid level with more dense dependent sedimented red blood cells. This finding, known as the "hematocrit effect," was initially described in anticoagulated patients but is also useful for detecting subtle hemorrhage (Fig. 30.4).

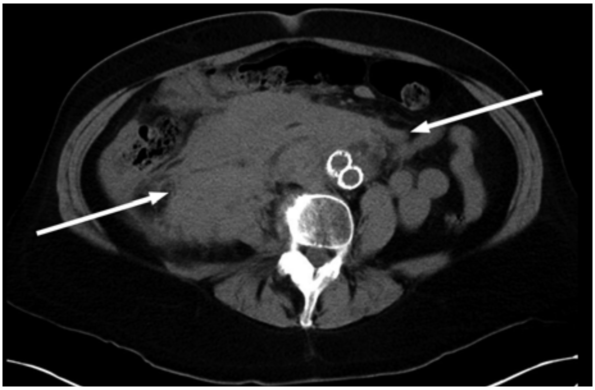

Fig. 30.3 This patient developed tachycardia, hypotension and anemia following endovascular repair of abdominal aortic aneurysm. The axial unenhanced CT image shows hyperdense retroperitoneal hemorrhage (between *arrows*) expanding the retroperitoneal space

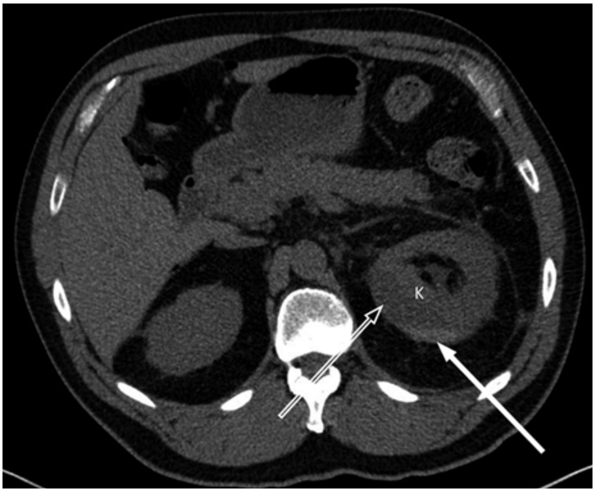

Fig. 30.4 The axial unenhanced CT demonstrates subtle left perinephric hemorrhage with hyperdense sedimented red blood cells (*arrow*). The less dense component of the hemorrhage (*open arrow*) is nearly isodense to the kidney (*K*)

CT scans with the intent to look for acute bleeding are ideally done with i.v. contrast medium. This may reveal the site of active extravasation of contrast, allowing for localization of the bleeding source. A CT scan without contrast will show fluid collections and hematomas. Identification of the most dense hematoma (known as the "sentinel clot") is useful for determining the site of hemorrhage in CT scans performed with and without IV contrast (Fig. 30.5). Although the risk for developing a contrast-induced nephropathy is increased in hypovolemic patients the potential benefits far outweigh the risks.

Although oral contrast medium is preferable to distinguish bowel from blood or other surrounding structures, most surgeons would prefer not to administer oral contrast in the setting of a fresh anastomosis. Also, oral contrast should ideally be given at least 1 h before the CT scan is performed, introducing a suboptimal delay. CT maintains a high sensitivity for detecting postoperative hemorrhage in these settings even when oral contrast material is an absolute or relative contraindication.

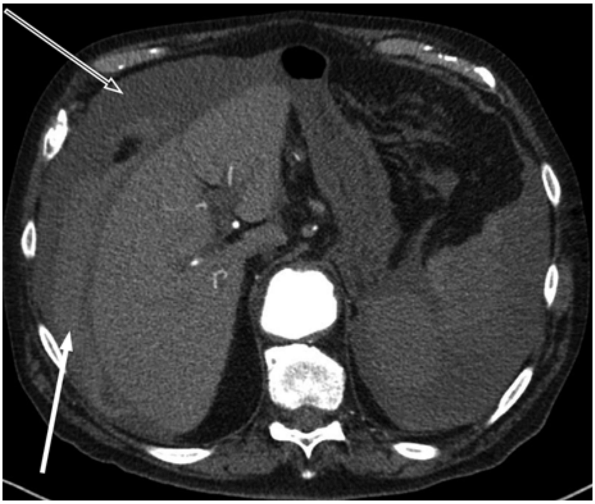

Fig. 30.5 The axial contrast enhanced CT shows hyperdense hemorrhage (*arrow*) adjacent to the liver. The more hypodense fluid (*open arrow*) in the upper abdomen is a combination of ascites and hemorrhage

Angiography

If bleeding can be demonstrated, angiography has the advantage of diagnostic and therapeutic interventions. However, in the immediate postoperative period, an acute decrease in Hb may be from a site not accessible by angiography, such as the mesentery, omentum, raw surfaces of the retroperitoneum or the surgical bed. Angiography generally is more successful in addressing bleeding when the site of the bleeding is suspected, such as a splenic injury after trauma or pancreatic bleeding several days after a Whipple procedure.

Tagged RBC Scan

Although a tagged RBC scan can detect a slow rate of bleeding, its primary use is for intraluminal GI bleeding that has not been localized. The study takes approximately an hour. For a postoperative patient, who may have a significant intraabdominal bleed and might be hemodynamically unstable a long study in nuclear medicine does not provide the optimal diagnostic tool.

MRI

An MRI of the abdomen is useful in the evaluation of complex liver, biliary and pancreatic pathologies. Although MRI has high sensitivity and specificity for detecting hemorrhage, in the acute setting, MRI is less useful due to the length of the study and relative hostility of the MRI environment to intensively monitored and supported patients.

Teaching Points

1. Time is of the essence when blood loss into the abdominal cavity is suspected.
2. Bedside ultrasound is the first line investigation when there is a high index of suspicion that there is free fluid present in the abdomen. Often this gives enough of an overview to plan any therapeutic interventions.
3. If further investigations are required CT with or without i.v. contrast offers the best diagnostic yield. It can also provide a therapeutic solution if percutaneous drainage of a collection is required.

Chapter 31
Acute Kidney Injury

Dirk C. Johnson and Michele H. Johnson

Clinical Problem

A 54 year-old man undergoes an uneventful open infra-renal AAA reconstruction and is admitted to the ICU postoperatively to be transferred to the floor the following day. His indwelling urinary catheter is removed on the second postoperative day. On POD #3 he acutely becomes short of breath, develops chest pain and his oxygen saturation drops to 84 % on 100 % FIO_2 non-rebreather. An ECG reveals atrial fibrillation, which is new. He is transferred back to the ICU after receiving furosemide 40 mg IV for presumed volume overload.

A portable chest x-ray reveals signs consistent with pulmonary edema and he is intubated for increased work of breathing and impending fatigue. Laboratory tests demonstrate acute kidney injury with a near tripling of his serum creatinine, which was normal on admission. A freshly placed bladder catheter drains 2 cc of dark urine with a bladder pressure of 12 mmHg.

AKI is often a toxic phenomenon in the ICU related to sepsis, and has been well described in the post-operative setting. Pre-renal etiologies have been equally well characterized. The etiology is often more readily established after structural causes including arterial inflow, venous outflow or ureteric or bladder outflow obstruction have been ruled out. Slowly dwindling urine flow starting with normal flow for the initial 48 h argues against bilateral ureteric injuries but does not exclude unilateral events.

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Operative technical factors should be entertained as a potential cause of AKI. Cardiac surgery (8–11 %), vascular surgery (15–46 %), hepatic transplantation (48–94 %), hepatic resection (15 %) and gastric bypass (8.5 %) procedures demonstrate increased incidences of AKI compared to other operations (1 %).

Imaging Techniques

The primary concern must be differentiating primary ureteric injury (ligation, laceration, division) and extrinsic obstruction (hematoma) from non-ureteric causes of AKI.

A long-standing tenet of managing acute renal failure is to identify and relieve obstructions to urine flow. To this end renal ultrasonography has been an almost reflexively used diagnostic tool when a patient has a rising serum creatinine or is oliguric and does not respond to plasma volume expansion. As the terminology has shifted from renal insufficiency or dysfunction to AKI, so too has the existing dogma with regard to renal imaging. Specific obstructive uropathy risk assessments are available for patients with medical diseases but not for the postoperative patient. Clinical factors should guide imaging studies including anatomy at-risk in the surgical field, anesthetic techniques, blood loss, intravascular volume status, preexisting conditions, and patient demographics.

Given the anatomy of gynecologic and urologic operations such as a TAH/BSO or robotic prostatectomy, concern for obstructive uropathy is reasonable – but toxic nephropathy is still far more common. Operations focused more superiorly in the retroperitoneum such as laparoscopic adrenalectomy for pheochromocytoma may predispose to direct renal injury from trauma, venous outflow obstruction or pedicle distortion leading to ischemia from locally compressive fluid collections, such as a hematoma.

Plain abdominal radiography can be useful in identifying nephrolithiasis and possibly the size and location of kidneys. Little or no information is gleaned from plain radiographs for either intrinsic or extrinsic causes of AKI.

In the acute setting, MRI adds little information over CT, requires more time to perform, and is less ideal than CT scanning in all but the pregnant patient where MRI has a distinct advantage in avoiding fetal exposure to ionizing radiation.

Ultrasound

This modality can be useful to identify dilatations along the entire length of the urinary tract from the renal pelvis to the bladder. The presence of hydronephrosis should raise suspicion of obstruction. The level of the potential obstruction is mostly suggested by the laterality as well as the presence of a transition point (Fig. 31.1a, b). Ultrasound evaluation can be used to guide placement of a urinary collecting system

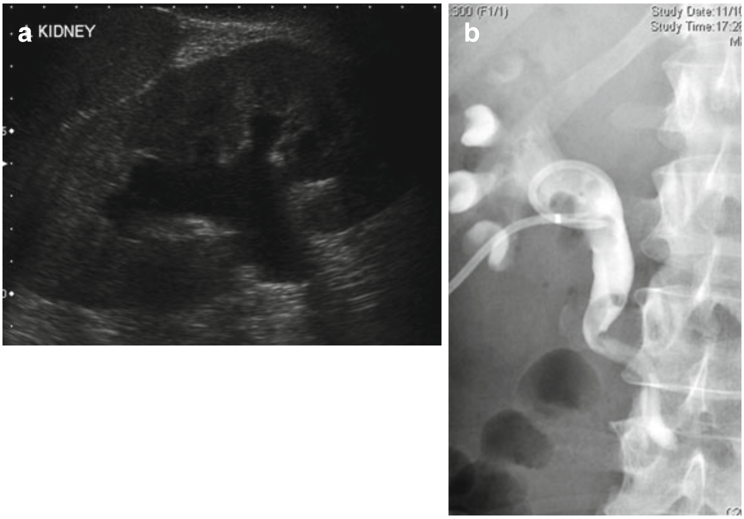

Fig. 31.1 (**a**) Ultrasound of right kidney shows dilated pelvicalyceal system in keeping with hydronephrosis. (**b**) Fluoroscopic image following insertion of a percutaneous nephrostomy shows contrast medium within the decompressed pelvicalyceal system

for decompression, such as a percutaneous nephrostomy catheter. If identified promptly, however, complete obstruction may have only caused mild hydronephrosis at that point, especially in the hypovolemic patient with diminished renal perfusion and therefore low urine generation. Thus, repeated examination by ultrasound is common to assess interval changes in size ureter, renal pelvis and kidney. While ultrasound is safe and repeatable, its effectiveness is compromised in patients who are clinically severely obese, have gaseous abdominal distension, large volume ascites or significant retroperitoneal fluid collections.

Doppler ultrasonography can be used to evaluate renal blood flow to exclude hypoperfusion or venous congestionas a cause of AKI. It has to be remembered though, that renal blood flow is reduced in both prerenal and intrarenal AKI, limiting the diagnostic utility of Doppler ultrasonography in patients with AKI.

Computed Tomography

Standard intravenous nonionic iodinated contrast medium used for CT is potentially nephrotoxic (see Chap. 12) and should be avoided whenever possible to minimize compounding existing renal insults. CT without intravenous contrast material can identify dilation in the renal collecting system and may be helpful in evaluating for obstruction in patients where sonography is technically limited. It may also help to identify other extra-renal conditions, such as an intra-abdominal abscess (see Chap. 29), which may be associated with AKI. Non-contrast enhanced CT may

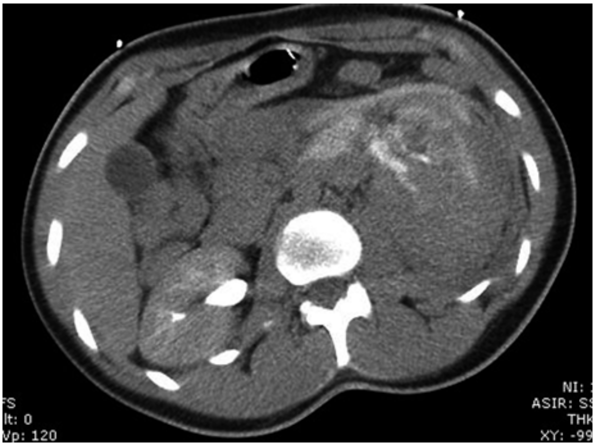

Fig. 31.2 CT of blunt injury induced left renal contusion with expanded left kidney with poorly defined adjacent fat and high linear areas of attenuation in the renal parenchyma and adjacent soft tissues consistent with acute intra-renal hemorrhage

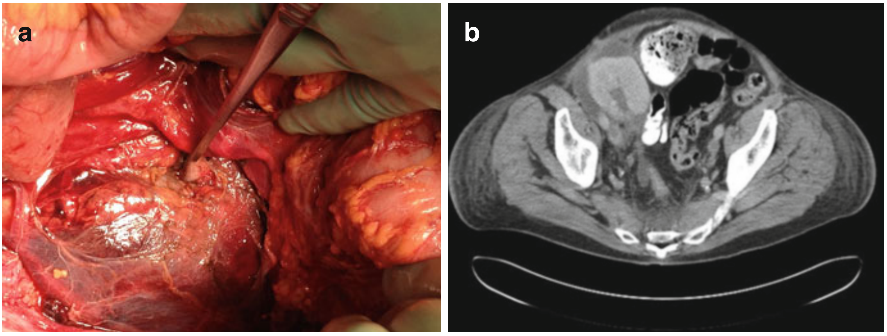

Fig. 31.3 (**a**) Intraoperative photograph of gunshot wound induced renal pelvis through and through laceration. This patient had a rising creatinine, oliguria, and a normal ureter on ultrasound. (**b**) CT following a renal transplant shows low attenuation fluid surrounding the transplant kidney in the right iliac fossa in a patient with ureteric leak and urinoma

be invaluable in planning operative intervention by providing information about the peritoneal as well as retroperitoneal anatomy. CT can readily identify direct renal injuries and their sequelae including intra-renal hemorrhage, renal contusion and surrounding hematoma (Fig. 31.2). Missed injuries such as a renal pelvis injury (Fig. 31.3a, b), which will not show any ureteral dilatation because the ureter is decompressed, show up as urinoma on CT.

Intravenous Pyelography (IVP)

Nephrotoxic, iodinated i.v. contrast is required to obtain these images. IVP should therefore be avoided.

Teaching Points

1. Acute kidney injury can have a huge number of different causes, ranging from sepsis to post-operative mechanical compression or injury.
2. In most patients ultrasound will provide sufficient information about the urinary system, from the renal pelvis to the bladder, to exclude obstruction or compression.
3. Doppler ultrasound may help to identify hypoperfusion as being causative of AKI.
4. CT provides anatomical information of the peritoneal cavity as well as the retroperitoneal space and can help to plan surgical intervention.
5. Where possible, contrast media should be avoided in patients with developing AKI.

Chapter 32
Acute Gastrointestinal Luminal Hemorrhage

Allan S. Philp and Paul M. Kiproff

Clinical Problem

A 75-year-old male is admitted following a fall with a small traumatic brain injury and an acetabular fracture, both of which are nonoperative. His past history is notable for coronary disease, hypertension, diabetes and obesity. His medications include metoprolol, clopidogrel and insulin. His mental status is improving but on day 3 he develops melena and has a drop in his hemoglobin from 11 to 9 together with hypotension and tachycardia.

The initial efforts to resuscitate and stabilize the patient need to go hand in hand with trying to establish a diagnosis early in the course of events. The patient should also be made NPO immediately for possible interventions, and in the cases of brisk bleeding with shock, altered neurological status or upper GI bleeding with hematemesis, consideration should be given to intubation and airway protection.

Most melena originates proximally in the GI tract, although it can occasionally be from right-sided colonic sources. Most hematochezia or clotted blood in the stool generally is from lower GI sources. However, it is worth remembering that very brisk upper GI bleeding can result in this as well. The most common causes of GI bleeding are summarized in Table 32.1.

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Table 32.1 Common causes of GI bleeding

Upper GI tract	Erosion ulcer
	Variceal bleeding
	Mallory-Weiss tear
	Vascular lesions
	Neoplasms
Lower GI tract	Diverticular disease
	Angiodysplasia
	Neoplasms
	Colitis
	Benign anorectal lesions

Imaging Techniques

Since endoscopic localization and control of luminal bleeding has become the mainstay of management, a gastroenterology evaluation should be obtained early in the course of bleeding. However, endoscopic techniques only work if the bleeding lesion can be adequately visualized. Urgent colonoscopy has been shown to identify a bleeding site in only 13 % of patients and a probable bleeding site in 67 % despite adequate colon preparation.

Catheter-directed angiography has been shown to have high sensitivity and 100 % specificity for upper and lower GI bleeding, however it is dependent on the presence of bleeding. When present, bleeding rates as low as 0.5 ml/min can be detected.

CT angiography has shown promising results with sensitivity and specificity for detecting and localizing GI bleeding of over 90 %.

If cirrhosis and variceal bleeding is a consideration, then LFT or bedside ultrasound to assess for ascites might also be useful.

Barium studies have no role for acute GI bleeding investigation (upper or lower) and will only obscure details at endoscopy, place the patient at risk for aspiration, and consume valuable time.

Upper GI Bleeding

Upper endoscopy is the therapy of choice in these cases, offering both diagnosis and treatment options, and should be employed early in the course. If non-variceal bleeding is identified various ways to stop the bleeding, such as epinephrine injection, thermal coagulation, or hemoclip application, have all been utilized. Angiography with embolization can be used as an adjunct (Fig. 32.1a, b). When angiography is used for therapy the options include embolization, which is not necessarily intended to be permanent (Gelfoam or similar) or efforts at permanent closure with either mechanical agents (microcoils) or chemical agents (such as polyvinyl alcohol, NBCA glue, etc.). Infusion of a constrictive agent such as vasopressin can also be

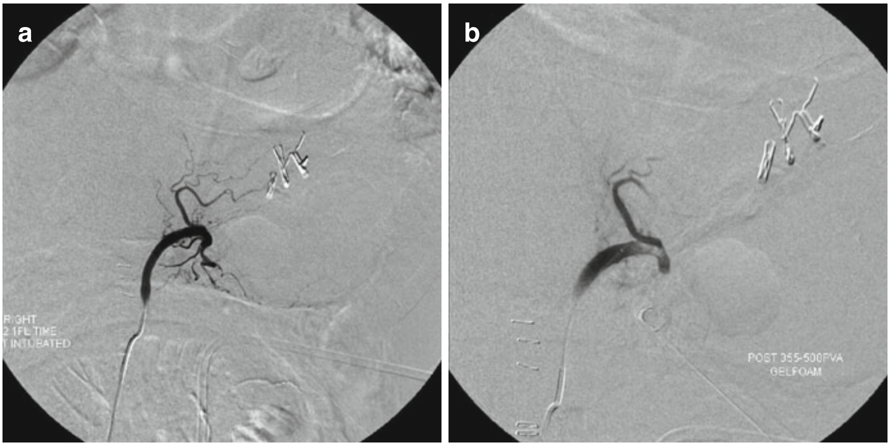

Fig. 32.1 (**a**) Catheter directed angiography interrogating ongoing gastric bleeding. (**b**) Cessation of bleeding after Gelfoam embolization

delivered intra-arterially via this route, but seems to be associated with higher failure rates and has the additional potential complications of local tissue necrosis or systemic effects such as myocardial ischemia.

CT angiography demonstrates active bleeding as hyperattenuating extravasation of contrast medium into the bowel lumen. If the contrast fills the entire lumen an entire hyperattenuation loop can be seen. The diagnosis of GI bleeding is best made by comparing the CT angiography images with a previously obtained, unenhanced study.

Surgical intervention should be reserved for those that either fail other less invasive management or have had a localizing study.

If neither endoscopy nor imaging endoscopy can reveal a bleeding source, a tagged RBC scan can be helpful (Fig. 32.2).

Lower GI Bleeding

Colonoscopy continues to be the mainstay of therapy in lower GI bleeding, and offers the same selection of therapeutic interventional options as discussed above. Angiography with embolization can also be performed for therapy or localization, and like upper GI bleeding can be used to deliver either blockage agents or intra-arterial vasopressin (Fig. 32.3a, b).

Whereas it was previously believed that colonic embolotherapy would serve to arrest hemorrhage, allow for resuscitation, and then mandate resection, sufficient experience has been garnered to disprove these suppositions. Embolizing the bleeding vessel can serve as definitive therapy without resection. It does require careful observation for more than anticipated tissue ischemia and subsequent

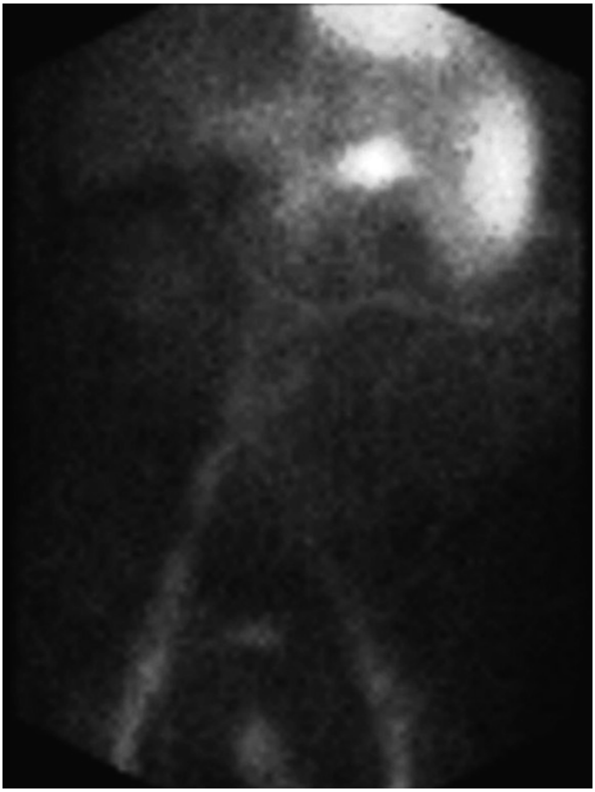

Fig. 32.2 Ongoing duodenal bleeding with gastric reflux

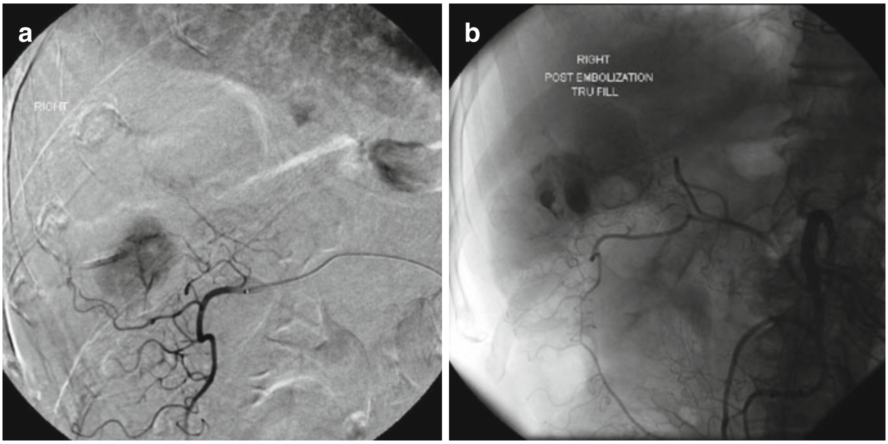

Fig. 32.3 (**a**) Blush from distal right colic artery. (**b**) No extravasation after embolization

perforation. If sepsis or peritonitis become evident after embolization an operation to remove the ischemic and possibly perforated segment might be necessary. If the patient remains stable but suffers from rebleeding repeat endoscopy or angiography are reasonable. If the lesion has been identified and the patient becomes unstable immediate surgical intervention is most appropriate. This is also true of cases where repeated non-surgical therapy has failed to offer full control of hemorrhage.

Nuclear medicine studies for bleeding localization can also be very useful, since colectomy is optimally performed anatomically and localization to right, mid, or left colon can often be enough information to allow the best operation to be performed. Hemodynamic instability and ongoing hemorrhage may preclude localization and subtotal colectomy may be lifesaving.

Variceal Bleeding

Variceal hemorrhage occurs in a challenging patient population, as the systemic impact of cirrhosis cannot be overstated. Specific to GI bleeding, these patients often exhibit refractory coagulopathy and thrombocytopenia that requires aggressive blood product resuscitation as well as clotting adjuncts.

Balloon tamponade does not offer good definitive or long-term control but can be used to temporize while other measures are being instituted. There are a number of devices available, but all depend on first securing the airway before inserting a large diameter orogastric tube equipped with high volume balloons designed to be secured on traction to compress the gastro-esophageal junction and sometimes esophagus as well. Most have suction ports distally and some offer a port proximal to the balloon to evacuate swallowed and pooled oropharyngeal and esophageal secretions. The mainstay of acute hemorrhage control in these cases remains endoscopy, with either sclerotherapy or banding of the bleeding vessels.

The TIPS procedure (transjugular intrahepatic portosystemic shunting) is an interventional radiographic procedure which has offered reasonable success in cases of acute hemorrhage refractory to a combination of endoscopic and pharmacologic approaches or in cases of initial stabilization followed by rebleeding. It involves passage of a needle and wire across the hepatic parenchyma. The wire guides placement of a stent connecting the inflow and outflow of the liver, resulting in a drop in portal pressures and subsequent variceal decompression (Fig. 32.4a–d).

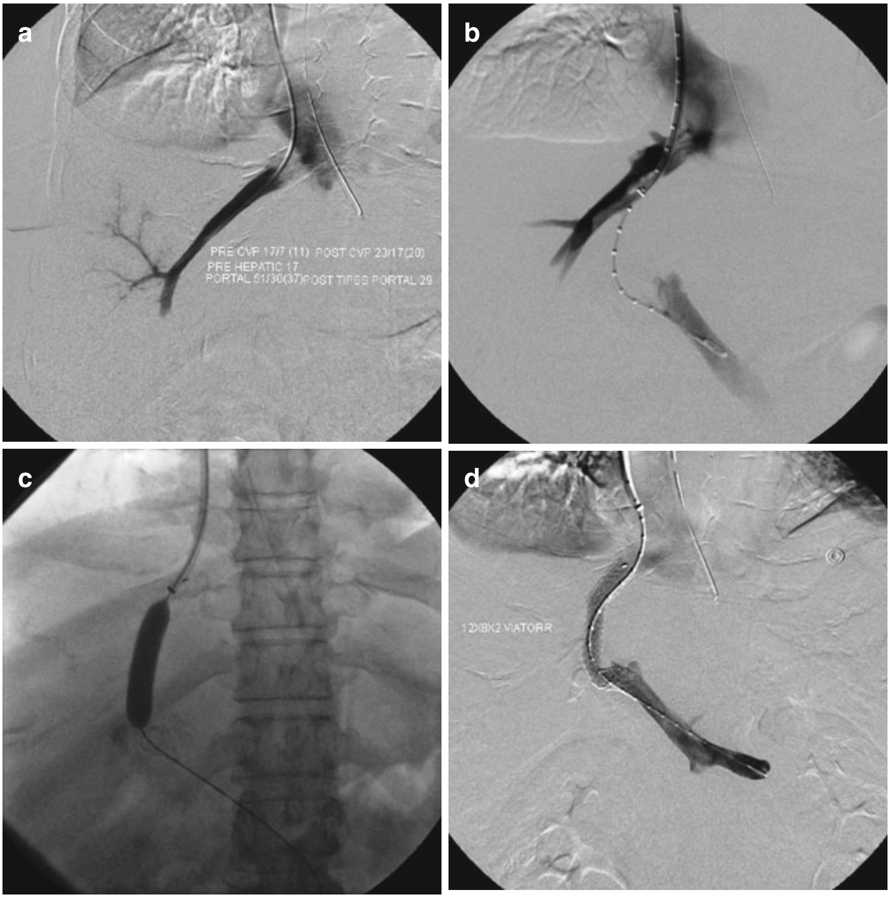

Fig. 32.4 (**a**) Hepatic vein access for TIPS. (**b**) Crossing liver for TIPS. (**c**) Dilating tract for TIPS. (**d**) TIPS stent in place

Teaching Points

1. If possible upper and lower endoscopy with a combination of injection, thermal coagulation, or hemoclip application provides the first line therapeutic intervention.
2. Transcatheter embolization is an option if endoscopy fails to identify and stem the bleeding.
3. CT angiography is a useful tool to identify the bleeding area in preparation for a surgical intervention.
4. Unusual bleeding sources may require a more complex workup. A combination of endoscopy, nuclear medicine studies and angiography will demonstrate a source in the majority of instances.

Chapter 33
Intra-abdominal Hypertension

Amir H. Davarpanah, Syed A. Jamal Bokhari, and Lewis J. Kaplan

Clinical Problem

A 26-year-old man is involved in a high-speed motor vehicle crash. He arrives in the ED intubated and hypotensive. A FAST ultrasound exam is positive for free fluid and he is rapidly taken to the OR. A grade III liver laceration and a grade IV renal laceration are noted in conjunction with multiple small bowel contusions and mesenteric lacerations. His liver is packed, the kidney is resected and a small bowel mesenteric laceration is repaired. After 1.5 h in the OR, he is cold, coagulopathic and acidotic. He is packed with ten laparotomy pads and a temporary abdominal wall closure is placed. He is transported to the ICU for metabolic resuscitation and rewarming. He has been oliguric during the operation and an indwelling urinary catheter has so far filled with 5 ml of dark yellow urine. Immediately post-operatively the bladder pressure is 12 mmHg.

At 7 h post-op he is still hemodynamically unstable and anuric despite receiving 6 l of lactated Ringer's solution and over 40 units of blood products. His bladder pressure has risen to 26 mmHg and he is becoming increasingly lactacidotic.

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The first concern is whether or not there is intra-abdominal hypertension. In an appropriately sedated patient it is unlikely that abdominal wall muscular tone is contributing to the measured bladder pressure. Therefore, one can reasonably assume that this is the correct diagnosis and there is a surgical emergency.

Primary intra-abdominal hypertension can result from hemorrhage, visceral edema, a combination of both or rapid accumulation of ascites. In the trauma patient or in the emergency general surgery patient hemorrhage and visceral edema clearly dominate and generally require surgical management. Unstable patients should undergo rapid surgical exploration and delay is associated with untoward outcomes. Angiographic control may be utilized after decompression and repacking if there is bleeding away from the surgical drains that might be amenable to angiographic control.

Thermally injured patients as well as those with extra-abdominal disease who require large volume resuscitation may rapidly accumulate ascites and develop a secondary abdominal compartment syndrome. This group of patients can regularly be managed with a percutaneous catheter to drain ascites. A third group of patients who may be managed without operation are those who have gaseous distension of their GI track, in particular the colon, who might be managed with transanal catheter decompression with or without colonoscopic decompression.

Imaging Techniques

When dealing with these patients the intent is to rapidly identify if the patient's intra-abdominal hypertension is primary or if it is secondary to large volume ascites or severe gaseous colonic distension.

The diagnosis of intra-abdominal hypertension is almost always made clinically at the bedside with intravesical pressure measurement and not on the basis of the imaging findings. However, imaging can help to exclude a surgical emergency, identify the underlying etiology and guide treatment. If time permits imaging might be helpful for determining the severity of the condition and for identifying potential complications, particularly in trauma patients and those with liver transplantation, bowel obstruction, pancreatitis, or peritonitis. It cannot be stressed enough that if a patient is unstable or there is clear evidence of abdominal injury immediate surgical exploration without imaging is necessary. However, if provided with a detailed clinical history the early identification of imaging signs, even though not very specific, may allow the radiologist to suggest the diagnosis of this life-threatening condition that requires emergent surgical decompression.

Radiographs

Although radiography has a limited role in demonstrating signs of intra-abdominal hypertension, it often is the initial test to be ordered and may help to evaluate bowel gas pattern, particularly colonic gaseous distension, and to identify free air,

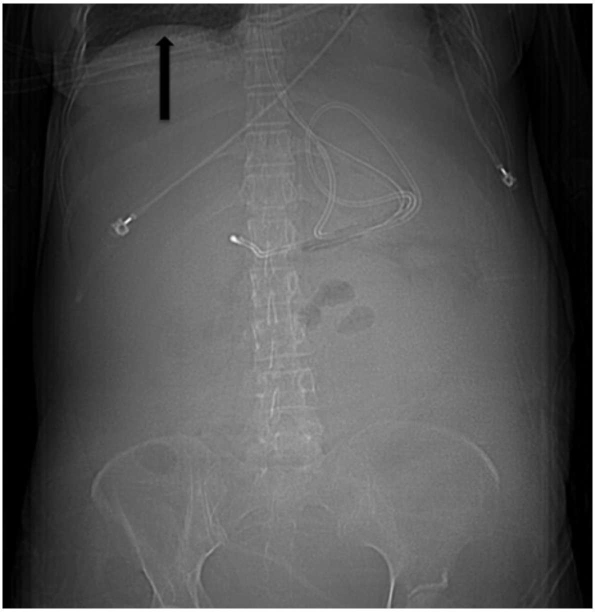

Fig. 33.1 Radiograph of a gasless abdomen and elevated right hemidiaphragm (*black arrow*)

bowel obstruction, pneumatosis or gas collections. Once colonic distension with gas has been excluded, most of the other plain film findings of intraabdominal hypertension are related to increased intraperitoneal or retroperitoneal fluid accumulation. These signs are usually nonspecific and include diffusely increased density of the abdomen, paucity of bowel gas, medial displacement of bowel and bulging of the flanks. An elevated diaphragm has been described as a sign of increased intraabdominal pressure (Fig. 33.1).

Ultrasound

Ultrasound cannot rule intra-abdominal hypertension out. However, a useful indicator of increased intraabdominal pressure is elevated Resistive Index, a measure of the resistance to blood flow through arteries. A linear resistive index response to increasing pressure has been described in the renal and hepatic arteries (Fig. 33.2). Evaluation of the morphology and the flow through the inferior vena cava (IVC) and the portal vein may allow for indirect estimation of intraabdominal pressure as well as intravascular volume status and responsiveness to fluid resuscitation. Ultrasound may be very useful for detection of intraperitoneal free fluid, especially large volume ascites, which can be managed at the bedside with directed catheter-based management. Although the reported false negative rate of intra-abdominal free fluid detection is more than 15 % this is more pertaining to small volumes of fluid. Bowel gas and obesity make US studies difficult.

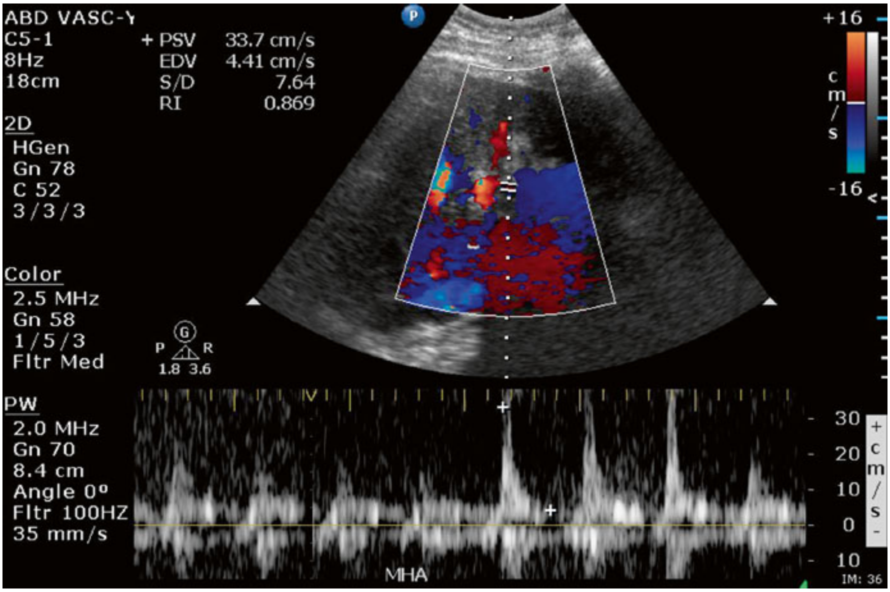

Fig. 33.2 This Color Doppler study of a 48-year-old man who underwent orthotopic liver transplantation shows decreased diastolic flow and high resistive index in the main hepatic artery. Further follow up demonstrated rising intraabdominal pressure secondary to hemoperitoneum

Computed Tomography

In general, CT is a fast and noninvasive diagnostic tool for evaluating patients with clinical suspicion of abdominal hypertension. Its role is obviously limited to the stable patient able to tolerate a trip to the Radiology Suite. An increasing ratio of maximum anteroposterior to the transverse dimension measured on serial CT scan has been described as positive round belly sign and is worrisome for abdominal hypertension (Fig. 33.3a–c). An exact cutoff value of 0.8 for this ratio has been advocated but is very controversial. Other common CT findings include collapsed inferior vena cava and renal veins (Fig. 33.3b, c), the presence of a hemoperitoneum (Fig. 33.3a, c), an increase in the size ascites on serial CT studies as well as new bilateral inguinal herniation and increased bowel wall thickening or enhancement. It should be noted that none of the aforementioned individual CT signs are sensitive or specific for abdominal hypertension and are seen in multiple other conditions such as hypovolemia, multiorgan failure and shock, which may coexist with and contribute to or even precipitate intraabdominal hypertension.

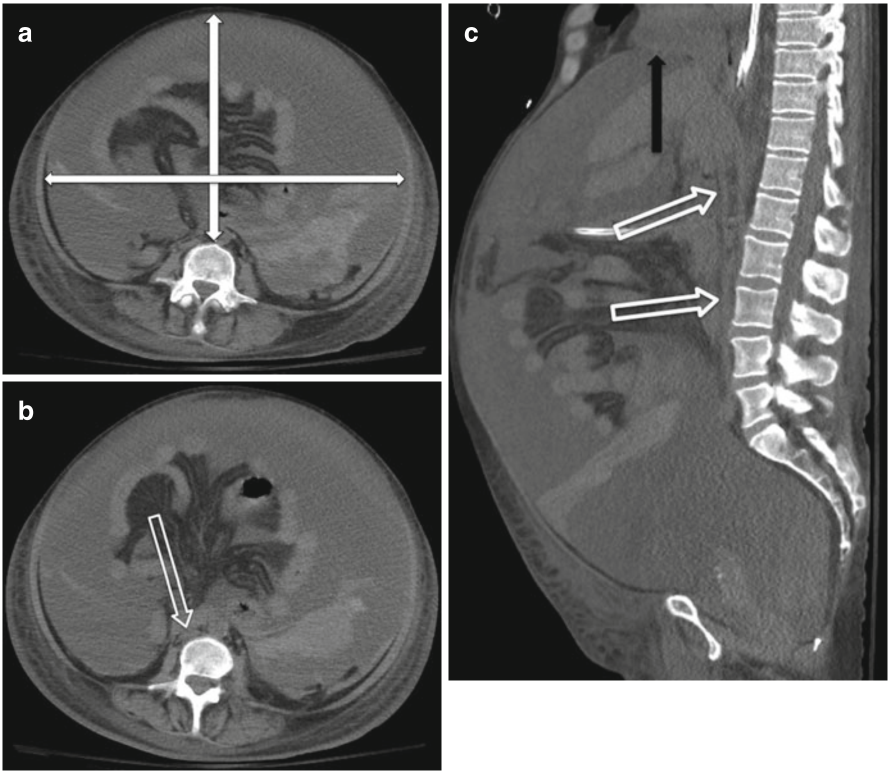

Fig. 33.3 Non-contrast CT was performed due to renal failure, which shows high-attenuating peritoneal fluid, consistent with hemoperitoneum and increased AP-to-transverse dimension ratio (*double-headed arrows*) of 0.7 (**a**). The axial (**b**) and sagittal (**c**) images show collapsed inferior vena cava (*open arrows*). An elevated right hemidiaphragm can also be seen (*black arrow*) (**c**)

Teaching Points

1. Ultrasound can help identify patients who can be managed by catheter decompression.
2. The Resistive Index and Doppler Flow imaging through the IVC can give some guidance to the presence of intra-abdominal hypertension and can estimate the pressure.
3. Serial CT imaging can help identify intra-abdominal hypertension caused by increasing ascites.
4. There are no diagnostic imaging findings but in combination with the appropriate clinical indicators, imaging may be helpful in recognizing the possibility of increased intraabdominal pressure and in subsequent monitoring.

Chapter 34
Large Volume Diarrhea

Julie Mayglothling and Yang Tang

Clinical Problem

A 54-year-old man with a past medical history of hypertension is admitted for elective complex ventral hernia repair. Post operatively, he is NPO with an NGT in place and is receiving maintenance. He is slow to progress and is diagnosed with a post-operative ileus. On post-op day six, the patient begins to have copious watery diarrhea. He complains of mild diffuse abdominal aching, but his abdomen is soft, minimally but diffusely tender and not distended. His surgical incision is without erythema.

Diarrhea is a common problem in ICU patients, with an estimated incidence of up to 40 %. Common noninfectious etiologies include enteral feeding, hypoalbuminemia, bowel ischemia and medication, while *Clostridium difficile* colitis is the most common infectious cause of diarrhea in the ICU. For those with hemodynamic instability, toxic megacolon, or ischemia with or without perforation, subtotal colectomy is the operation of choice (Figs. 34.1 and 34.2).

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Fig. 34.1 Intraoperative photograph of colon resection for *C. difficile* associated disease

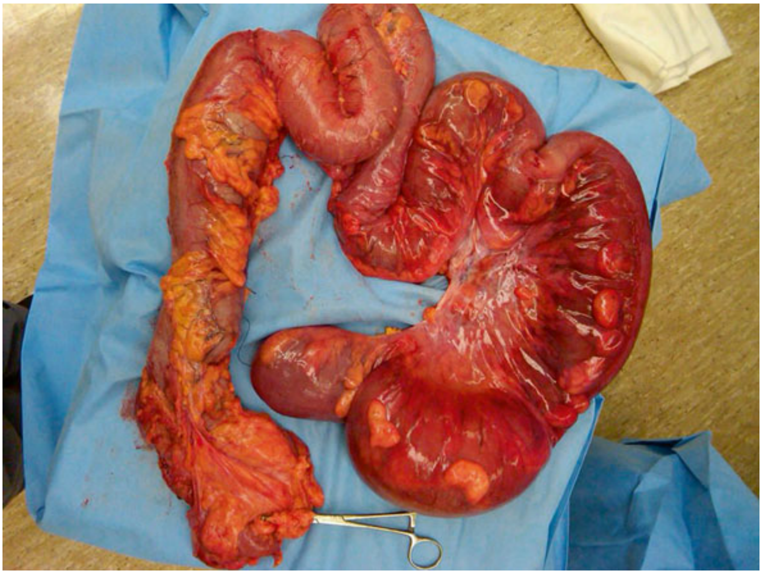

Fig. 34.2 Resected specimen of total abdominal colectomy for *C. difficile* induced toxic megacolon

Imaging Techniques

Abdominal imaging modalities especially plain radiographs and computed tomography (CT) are widely used to establish the cause and monitor treatment response in these patients. Plain radiograph can be quickly performed at bedside and is usually the initial modality to be used.

Abdominal X-Ray

Upright abdominal radiograph can detect intra-abdominal free air as little as 1–2 mm^3. It is also valuable to assess the intestinal gas pattern and distinguish generalized postsurgical adynamic ileus from mechanical obstruction, although both the sensitivity and specificity are limited in many cases due to portable technique and difficulty of maintaining upright position by many ICU patients. Plain radiography can also detect large amount of ascites, pneumatosis and severe bowel wall thickening, although the sensitivity and specificity are both far inferior to CT scan. Serial radiographs are valuable to monitor the progression/resolution.

Computed Tomography

CT is the primary imaging modality in diagnosing abdominal emergencies and postsurgical complications. The CT imaging features of *C. difficile* colitis include colonic wall thickening (>4 mm) and nodularity, pericolonic fat stranding, trapping of contrast material between thickened folds (accordion sign) and ascites. *C. difficile* colitis may manifest as diffuse colonic involvement (pancolitis), right sided, left sided, or even segmental thickening. Of note, these CT features are not specific to *C. difficile* colitis and may be noted in other colitides, although the accordion sign, colonic wall thickening >10 mm, pancolitis and the presence of ascites are more commonly seen with *C. difficile* colitis.

The sensitivity of CT in diagnosing *C. difficile* colitis varies among several studies from 50 to 61 %. However, it is clear that CT scan abnormalities are absent in a significant number of patients with minor symptoms. Nevertheless, CT is useful in distinguishing *C. difficile* colitis from other infectious, ischemic, or inflammatory bowel disease and is also valuable in assessing the response to treatment and detecting associated complications such as toxic megacolon and perforation. It is not uncommon that CT is the first test to suggest the diagnosis of *C. difficile* colitis in patients who are otherwise not clinically suspected to have the diagnosis.

CT can also demonstrate other postoperative complications such as internal/external fistula and is the test of choice for intra-abdominal abscesses.

Magnetic Resonance Imaging

MRI has been increasingly used for abdominal imaging and is the modality of choice of many liver, pancreaticobiliary, and, in particular, retroperitoneal diseases and masses. MRI has been used in inflammatory bowel disease and has an established role in pregnant and pediatric patients with abdomino-pelvic emergencies.

However, MRI has very limited role in evaluating routine postoperative complications due to inferior spatial resolution, longer acquisition time, sensitivity to motion artifacts and compatibility issues with monitoring equipment used in intensive care units.

Teaching Points

1. Clostridium difficile colitis is the most common cause of infective diarrhea on the ICU with potential life threatening complications.
2. Plain abdominal X-ray is the initial imaging test but is insensitive and nonspecific. Contrast medium enhanced CT is the preferred test for patients with severe symptoms to evaluate for presence, extent, possible cause and complications of colitis.
3. Appropriate infection control should be followed in patients with unexplained diarrhea.

Part VII
Trauma Imaging

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Chapter 35
Blunt Abdominal Trauma

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Clinical Problem

A 35-year-old woman was the restrained, front-seat passenger in a motor vehicle accident. There was minimal intrusion into the vehicle after being "T-boned" on the driver's side. She was brought into the trauma bay normotensive but tachycardic, on 6 L of supplemental oxygen via facemask. She was alert, able to answer questions and follow commands. She complained of abdominal pain, back pain, and left knee pain.

In the trauma room such patients need to be examined with focus on primary survey and initial resuscitation, an evaluation of the need for further resuscitation, and secondary survey with the aim of establishing the definitive diagnosis and triaging. If unstable, the primary survey has to target airway, breathing and circulation in order to stabilize the patient prior to triage and transfer to the operating room, the radiology suite or the intensive care unit. If stable, the clinician must proceed with further resuscitation and the secondary survey. This should include a thorough examination of the patient as well as a focused, but complete, history. On physical examination signs for overt trauma must be thoughtfully but efficiently evaluated; for example, lap-belt ecchymoses or the "seat-belt sign" is an important indicator

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for potential intraperitoneal hollow organ injury. Findings on physical examination of the abdomen can be misleading, especially in the obese patient, patients with distracting extra-abdominal injury, or patients who are neurologically altered. Radiologic examination is frequently very helpful in these patients.

Imaging Techniques

Historically there has been some controversy as to which radiologic tests must be performed or are recommended in the stable and unstable patient. Computed tomography (CT) has largely supplanted other imaging modalities due to its combination of accuracy, speed and universality. CT is not without its pitfalls; for example, hollow viscus injury remains notoriously difficult to identify in the absence of pneumoperitoneum. While there are few randomized, double-blinded trials to provide Level I evidence for various radiologic modalities, the American College of Radiology (ACR) has issued appropriateness criteria for the imaging of patients with blunt abdominal trauma.

In unstable patients who are rapidly deteriorating or only transiently respond to resuscitative measures, definitive operative treatment must not be delayed for imaging studies. If operative capabilities are not available the patient should be transferred to the nearest Level I trauma facility with accompanying intravenous fluid and blood products. The imaging that may still be appropriate in that case include chest and pelvis radiography and targeted ultrasound of the chest, abdomen and pelvis according to the ACR guidelines.

In the case of a stable patient, the highest yield imaging examination is a contrast-enhanced CT of the abdomen and pelvis. The initial evaluation may also include radiography of the chest, abdomen (Fig. 35.1a, b) and pelvis, although sensitivity for solid organ injury, hollow viscus injury or vascular injury is poor. Focused assessment by sonography for trauma (FAST) examination is an adjunct for assessment in the stable trauma patient. The advantages of the FAST examination include its portability, speed, reproducibility and non-invasiveness. Similar to diagnostic peritoneal lavage, the FAST examination relies on the notion that clinically significant abdominal injuries are associated with hemoperitoneum. The main disadvantage of FAST is its poor specificity and suboptimal sensitivity. Additionally, FAST is operator dependent, often requiring an experienced practitioner to yield useful information. Intraperitoneal fluid in the upper quadrants of the abdomen and pelvis are presumed to be hemorrhage unless the patient has known ascites (Fig. 35.2). A FAST is able to detect collections greater than 400 ml. However, it cannot help determine the source of the hemorrhage and has limited utility in the obese patient or patients with subcutaneous emphysema or retroperitoneal hemorrhage from pelvic fractures. FAST is associated with a high 15 % false negative rate.

Computed tomography is routinely used to evaluate the viscera and vasculature in hemodynamically stable patient with an equivocal examination, fluid on the FAST examination ("positive FAST"), in patients with distracting extra-abdominal injury or suspicion of multiple trauma. Trauma CT can evaluate the entire torso in

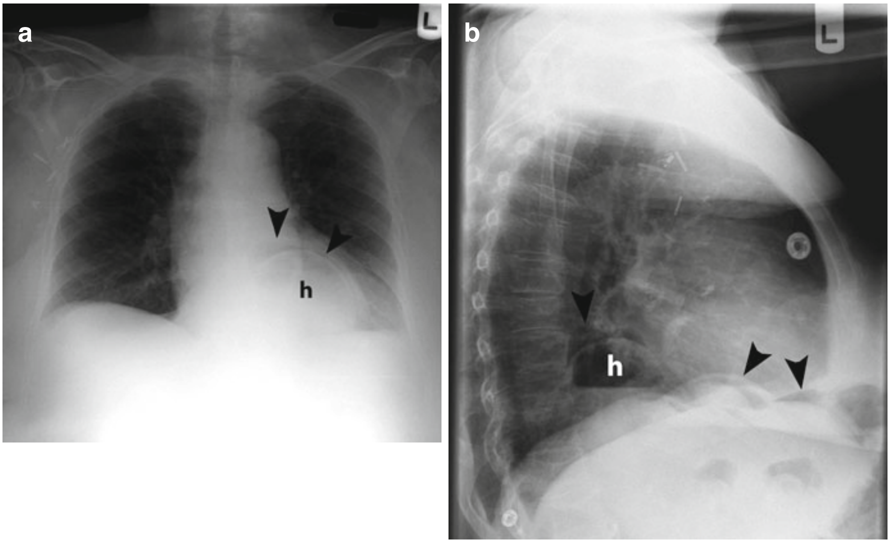

Fig. 35.1 Free intraperitoneal air. AP (**a**) and lateral (**b**) chest radiographs show linear lucencies (*arrowheads*) under the diaphragm due to free intraperitoneal air. Note that some of the free air extends above a large hiatal hernia (*h*). Laparotomy revealed a gastric rupture

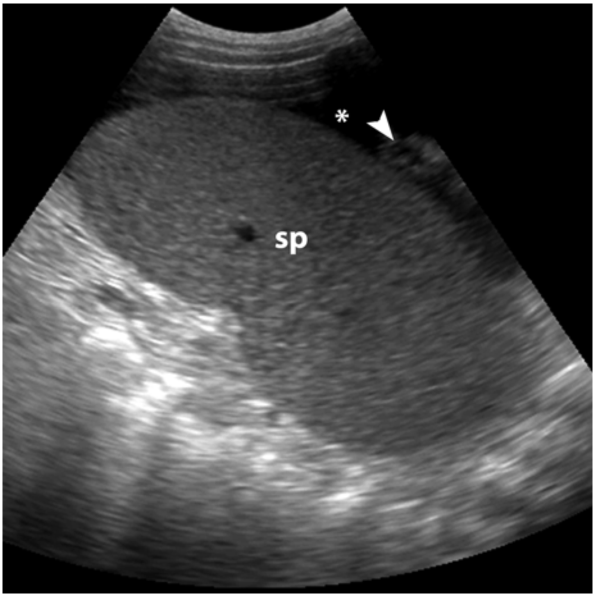

Fig. 35.2 Free fluid and hemoperitoneum on Focused Assessment by Sonography for Trauma (FAST) examination. Ultrasound image of the left upper quadrant demonstrates fluid (*asterisk*) and a small amount of hematoma (*arrowhead*) adjacent to the spleen (*sp*) due to a small splenic laceration

less than 1 min. The protocol consists of helically acquired images obtained after intravenous contrast injection. Multi-planar and three-dimensionally reconstructed images can be created rapidly. Intraperitoneal and retroperitoneal extra-luminal gas due to perforation is much more readily demonstrated by CT than by radiography. In the hemodynamically stable patient with unexplained free intraperitoneal fluid, bowel wall thickening, mesenteric fat stranding or free air, the sensitivity of CT as a diagnostic modality is greater than 90 %.

Most trauma CT examinations are performed during the portal venous phase of IV enhancement, as this represents the time of peak parenchymal enhancement of the abdominal viscera. In some institutions, a biphasic examination of the upper abdomen is performed in conjunction with a chest CT so that arterial and portal venous phase images are acquired. This is done in an attempt to increase the sensitivity for detection of vascular injuries and active hemorrhage. An ill-defined focus, or "blush," of extravasated contrast indicates the source of bleeding and can direct a subsequent angiographic study.

Early angiography has been shown to be a helpful tool for diagnosing and managing liver, kidney and splenic injuries. Angio-embolization can be performed if active bleeding or a pseudoaneurysm are identified. Compared to sites of active hemorrhage, pseudoaneurysms are well-defined round or ovoid enhancing structures, which enhance strongly during the arterial phase but fade (or wash-out) on the venous phase of imaging.

Evaluation of Solid Organ Injury

CT can accurately diagnose parenchymal injury to the solid organs, such as the liver, spleen and kidney. The injury can be graded in order to tailor further therapy. The most important acute imaging findings are the presence of contrast extravasation, pseudoaneurysm and intraparenchymal or perivisceral hematoma. Assessment of these may contribute to the decision if a patient is suitable for angio-embolization or will benefit from an immediate surgical intervention. Patients with high-grade injury, contrast extravasation, and pseudoaneurysm are not automatically disqualified from non-operative management (NOM). However, they remain at high risk of requiring future intervention. If the hemorrhage persists or the patient becomes unstable and remains so despite resuscitation and angio-embolization, an urgent laparotomy is the appropriate course of action.

Hepatic Injury

The liver is the most commonly injured abdominal organ in bunt trauma accounting for nearly 5 % of all abdominal trauma admissions. Most common etiologies include motor vehicle collisions, pedestrians struck by vehicles, and

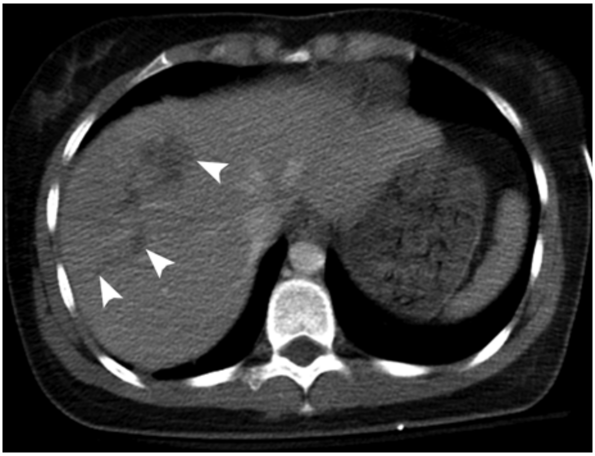

Fig. 35.3 Liver laceration. Contrast-enhanced computed tomography (CT) reveals an irregular defect (*arrowheads*) in the right hepatic lobe due to a laceration

falls. Blunt force results in parenchymal and hepatic vascular injury. A common type of hepatic parenchymal injury is the laceration, which can appear as a linear or stellate low density ("hypoattenuating") defect (Fig. 35.3). Peripheral lacerations, which involve the hepatic capsule, can result in a variable amount of hemoperitoneum. Bleeding from many lacerations will tamponade within the liver, fill the parenchyma with heterogeneous hematoma and will not result in a hemoperitoneum. Small lacerations usually heal spontaneously while deep lacerations (>3 cm) are associated with a higher risk of bleeding, bile duct injury and biloma.

Any patient with a blunt abdominal trauma, hemodynamic instability or a FAST study that shows hemorrhage warrants urgent laparotomy. However, nearly 80 % of patients with hepatic injury can be successfully managed non-operatively by a surgeon. Those who fail NOM usually do so within 24–48 h of injury. Angioembolization is indicated for ongoing hepatic hemorrhage requiring transfusion of 4 units of red blood cells (RBC) in 6 h or 6 units of RBCs in 24 h. There are no specific studies examining follow-up imaging modalities for asymptomatic patients. The American College of Surgeons Committee on Trauma recommends repeat imaging by bedside ultrasonography in patients with complex hepatic injury. Although the decision when to re-image depends on the patient's clinical status and grade of injury, some studies have indicated that the optimal time period is between 7 and 10 days after initial presentation. In asymptomatic patients, most trauma centers obtain a repeat CT to evaluate for development of a pseudoaneurysm in high-grade hepatic injury. Additional post-discharge imaging is usually conducted around 4 weeks from the initial injury. Patients with right upper quadrant fluid collections or presenting with a clinical deterioration, including worsening examination, abdominal pain, worsening liver function tests, and unexplained fever should undergo CT to evaluate for a biloma, abscess, necrosis or ongoing hemorrhage.

Fig. 35.4 Pancreas laceration. Contrast-enhanced computed tomography (CT) shows a low density linear defect in inferior aspect of the pancreatic neck (*arrowhead*) due to a small laceration. Note a small amount of hemorrhage (*arrow*) between the posterior margin of the pancreas and the splenic vein (*sv*)

Pancreatic Injury

Diagnosing a pancreatic injury is challenging in most circumstances. Knowledge of the mechanism of injury and a high degree of suspicion for pancreatic injury are essential to an early diagnosis. A missed pancreatic duct injury has dire consequences for the patient. Worsening abdominal exam with increasing pain, elevated amylase or an amylase level that does not normalize should prompt evaluation of the pancreas for a ductal injury. In the hemodynamically unstable patient requiring laparotomy the diagnosis is usually made in the OR. In the hemodynamically stable patient who does not have any indication for laparotomy, CT can help to identify a pancreatic parenchymal injury. Pancreatic lacerations appear as low-density defects on CT. They are more common in the pancreatic neck and proximal body due to the fulcrum effect of the lumbar spine on the pancreas during a rapid deceleration injury (Fig. 35.4). Since the pancreas lacks a capsule and fat intercalates between the parenchymal acini, lacerations can be difficult to detect on the initial CT. Important secondary signs of pancreatic injury include the findings of fluid between the pancreas and the splenic vein, peripancreatic fat stranding, retroperitoneal hematoma or fluid and fluid in the lesser sac. Parenchymal hematoma may manifest as focal or diffuse glandular enlargement or increased density, while contusion typically appears as a region of poor contrast enhancement. CT has a reported sensitivity and specificity of 70–80 % in detecting a pancreatic injury.

In cases where the mechanism of trauma gives rise to a high degree of suspicion of a pancreas duct injury it is important to monitor the patient clinically. Many institutions request a repeat CT with pancreatic protocols 8–24 h after the initial injury to assess for any pancreatic contusion or fluid collection. CT is not sensitive enough to detect ductal disruption, although suspicion should increase when lacerations are deep (>50 % of the anteroposterior thickness of the pancreas). The time from injury to treatment of a ductal injury is critical in ensuring the best outcome for the patient. If possible a suspected ductal disruption is best evaluated by endoscopic retrograde

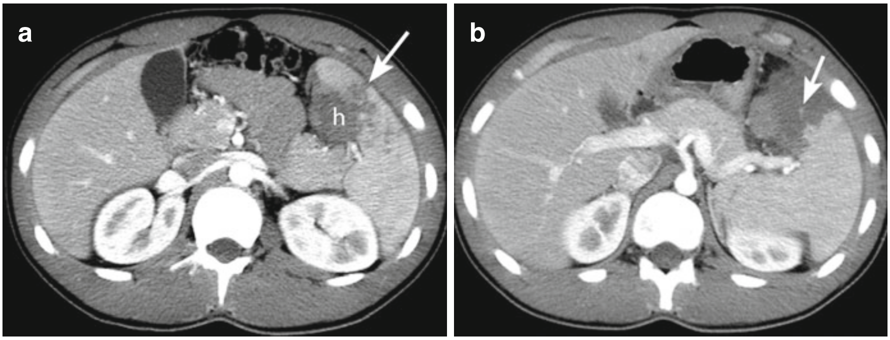

Fig. 35.5 Spleen laceration and bleeding. (**a**) Contrast-enhanced computed tomography (CT) shows an irregular parenchymal defect (*arrow*) consistent with a laceration. Note the adjacent hematoma (*h*). (**b**) More superiorly, there is a small focus of active contrast extravasation (*arrow*) due to arterial hemorrhage

cholangiography (ERCP), which has the advantage of being diagnostic as well as therapeutic if a stent can be deployed across the injury.

Splenic Injury

The spleen is the second most commonly injured organ in blunt abdominal trauma. Similar to hepatic injury patterns, most splenic injuries in blunt abdominal trauma result from motor vehicle collisions, pedestrians struck by vehicles or falls. The imaging findings for splenic injury are similar to those described for the liver. Hemodynamic instability along with a positive FAST should indicate the need for an emergent laparotomy. Splenic injury identified on CT must be given an injury grade based on the AAST injury grading scale. CT findings must specify if there is any contrast extravasation (splenic blush contained within the parenchyma or spillage of contrast into the peritoneum), the amount of intra-abdominal hemorrhage (bleeding confined to the splenic fossa or extension into the pelvis), and the presence of pseudoaneurysms (Fig. 35.5a, b). Hemodynamically stable patients without any overt signs of peritoneal bleeding or another indication for an urgent laparotomy can be treated with NOM. Patients with low-grade injury where contrast is confined to the splenic parenchyma and who are otherwise stable may be considered candidates for NOM instead of immediate angio-embolization. If low to high-grade injury is present stable patients can be treated with angiographic embolization. The patient with a high-grade injury typically presents with hemodynamic instability and often requires operative management with splenorrhaphy or splenectomy.

Follow-up imaging has not been rigorously examined and there is little consensus about the use of follow-up imaging. More extensive or complex injuries may require repeat CT imaging to evaluate progression and complications. Some centers opt to obtain a follow-up biphasic abdominal CT to evaluate for the development of

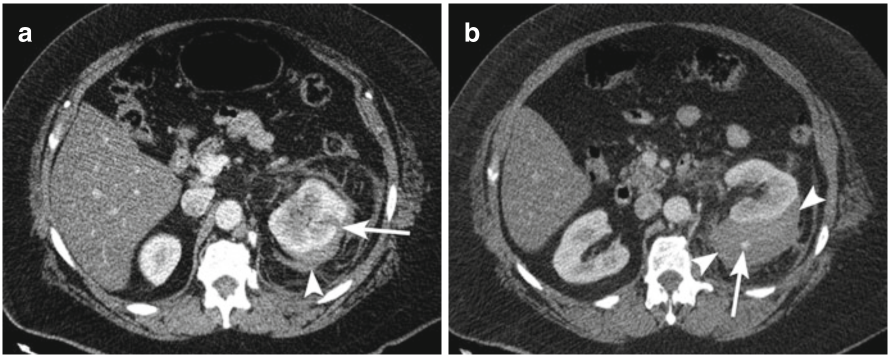

Fig. 35.6 Kidney laceration and bleeding. (**a**) Contrast-enhanced computed tomography (CT) demonstrates a linear defect (*arrow*) through the lateral renal cortex consistent with a laceration. Note the surrounding hematoma (*arrowhead*) in the perinephric space. (**b**) More inferiorly, there is a focus of active arterial hemorrhage (*arrow*) into the perinephric hematoma (*arrowheads*)

pseudoaneurysms. Patients at high risk for delayed complications, such as those involved in contact sports, should undergo CT in 6 weeks from injury to assess for complete resolution of the injury. Ultrasonography is an alternative methodology for follow-up of lesions.

Renal and Ureteral Injury

Although hematuria is the usual manifestation of kidney trauma, it is poorly correlated with the degree of parenchymal injury. CT imaging is the recommended modality for evaluation of kidney injury. It has to be remembered that most trauma CT examinations are performed during the portal venous phase. However, the kidneys typically enhance in the later corticomedullary or early nephrographic phases. This timing will allow assessment of the vessels and the renal parenchyma for contusions, lacerations or hematomas (Fig. 35.6a, b). In select cases, excretory phase imaging can be obtained after an 8–12 min delay from the time of the contrast injection. The excretory phase images will allow evaluation of the renal collecting systems, ureters and bladder for extravasation of contrast material (Figs. 35.7 and 35.8). Excretory phase images are especially helpful in patients with perinephric hematoma and fluid since it is impossible to differentiate extravasated non-opacified urine in this setting. Low-grade injuries are usually managed non-operatively. Follow-up imaging 24–48 h after the initial CT to evaluate for urine extravasation is recommended for patients with high-grade injuries. Urinary extravasation may take several weeks to resolve. US is an appropriate alternative to CT to assess these fluid collections during follow-up.

Ureteral injury is rare and is best diagnosed during excretory phase imaging in a stable patient. Although the CT is not the optimal method for detecting ureteral injury, contrast extravasation is diagnostic.

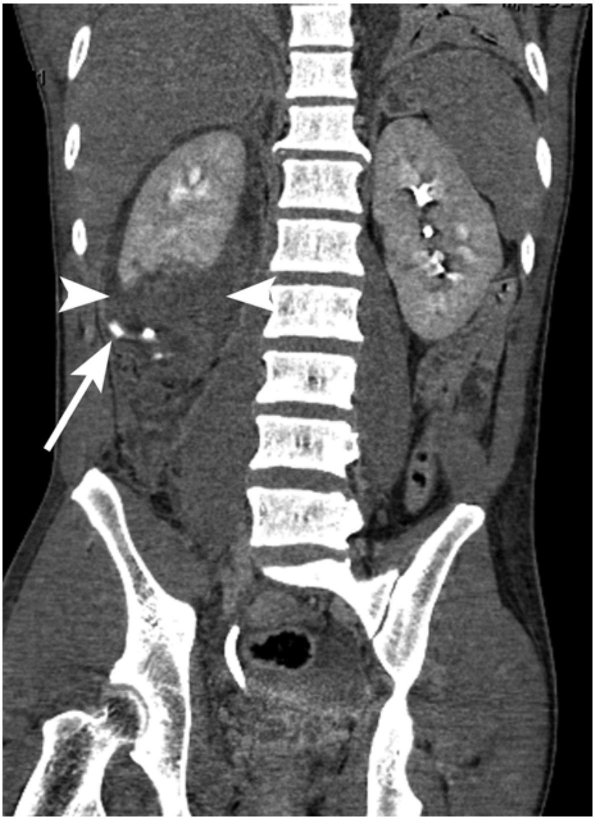

Fig. 35.7 Ureteropelvic junction injury. Coronal computed tomography (CT) image obtained during the excretory phase shows extravasation of excreted contrast (*arrow*) into a hematoma (*arrowheads*) in the inferior perinephric space. The inferior pole of the right kidney has been lacerated and obscured by the hematoma

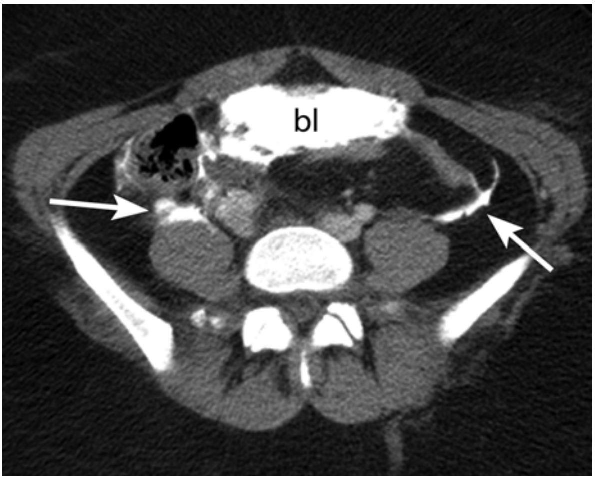

Fig. 35.8 Bladder rupture. Computed tomography (CT) cystogram shows contrast in the bladder lumen (*bl*) and extravasation of bladder contrast (*arrows*) into the extraperitoneal spaces

Hollow Viscus Injury

A thorough physical examination of the abdomen can give valuable clues to any hollow organ injury. Signs include any specific patterns of ecchymoses, such as from the use of seatbelts, or a distended or rigid abdomen. A FAST exam does not usually detect hollow viscus injury and cannot distinguish between a solid organ and hollow viscus injury. Specific CT signs of bowel injury include identification of a full-thickness tear and extravasation of ingested oral contrast material. Less specific, but more sensitive signs include focal mural thickening, irregular mural enhancement, free intraperitoneal fluid and mesenteric stranding adjacent to the segment of injured bowel. According to guidelines endorsed by the American College of Surgeons, a patient with a negative CT and a benign abdominal examination is usually observed. No further diagnostic work-up is required. However, the patient must be closely observed as an initial negative imaging study can be associated with a 12–13 % chance of undiagnosed hollow viscus injury. The exact location is rarely known and can only be diagnosed and treated further during a laparotomy.

Retroperitoneal intestinal injury may present as free air confined to the retroperitoneum. This usually stems from a duodenal perforation. The patient can present as stable with a moderately concerning abdominal examination. In this case, it is appropriate to admit them for close observation, fluid resuscitation, and serial abdominal examinations. An upper gastrointestinal examination with use of water-soluble oral contrast material can be obtained for further evaluation. The stable patient usually recovers over several days as the injury seals itself off. The unstable patient requires operative intervention.

Pelvic Organ Injury (Urinary Bladder, Urethra)

Bladder injury is usually caused by blunt abdominal trauma and is not regularly associated with a pelvic fracture, though the risk increases with disruption in the bony pelvic ring. Patients usually present with gross hematuria. Any disruption can be identified on a retrograde CT cystography or a plain film cystography. Indications for cystography include blunt trauma with a pelvic ring fracture accompanied by gross hematuria (>30 RBCs per high-power field (hpf)). CT cystography has a 90 % sensitivity and 100 % specificity, and is reliable in detecting the location of bladder disruption, including bladder neck injuries. Bladder injuries are treated nonoperatively if extraperitoneal, and operatively if intraperitoneal. Extraperitoneal injury is reassessed 10-days after the initial injury with a repeat CT cystography.

A urethral injury can present with blood at the urinary meatus. It is best evaluated with retrograde urethrography (Fig. 35.9).

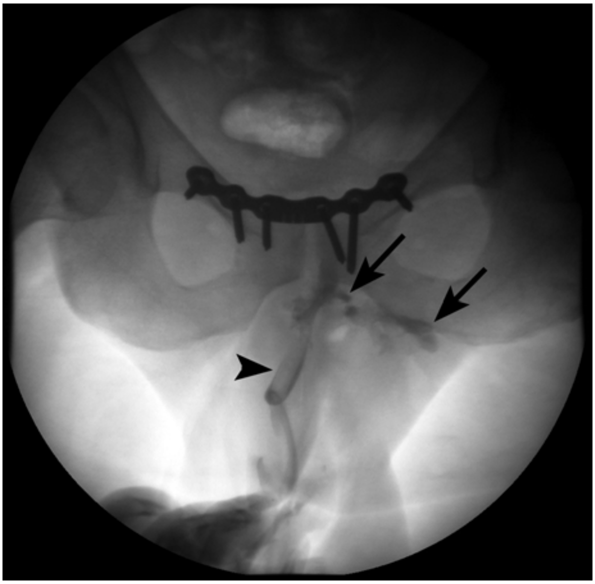

Fig. 35.9 Urethral injury. Image obtained during retrograde urethrogram shows contrast opacifying the penile urethra (*arrowhead*) and extravasating (*arrows*) from the bulbous portion of the urethra into the perineum

Mesenteric Injury

The mesenteric vasculature is best evaluated with contrast-enhanced CT. Findings may or may not be associated with apparent bowel trauma. Mesenteric injury is suspected in patients whose CT findings include intra-peritoneal active contrast extravasation, mesenteric hematoma, infiltration of the mesentery, mesenteric tear with internal hernia or beading and abrupt termination of the mesenteric vessels.

Vascular Injury

Nearly 25 % of all patients with serious abdominal injury can present with an additional intra-abdominal vascular injury. Compression and shearing mechanism usually result in major trauma to the abdominal aorta, inferior vena cava or parenchymal vasculature. Traumatic abdominal aortic dissection is very rare but associated with a 75 % morality rate without swift treatment. Injury is suspected based on the mechanism of trauma and hemodynamic stability. Intra-abdominal vascular injury is often diagnosed in the unstable patient during emergent laparotomy. In the relatively stable patient, a FAST exam can be helpful by finding free intra-peritoneal fluid, as will occur in a major vascular injury. If the suspicion of an abdominal vascular injury is high but the initial FAST examination is negative, a subsequent CT, which is 100 % sensitive, is recommended. CT has the additional advantage of assisting with planning for endovascular stent graft repair if necessary. Angiographic examination is the imaging modality of choice in the stable trauma patient with suspected serious abdominal vascular injury based on CT findings.

Teaching Points

1. Examination of the abdomen in the setting of blunt trauma is necessary but may not provide critical information regarding the degree of abdominal injury, especially in the obese patient.
2. The selection of imaging modality depends on the clinical stability of the patient.
3. FAST is most informative in experienced hands as it is highly operator dependent. Its utility is greatest in the unstable patient.
4. CT is the imaging modality of choice in the stable patient.
5. Definitive operative or angiographic treatment must not be delayed in the unstable patient in order to obtain imaging studies.

Chapter 36
Penetrating Abdominal Trauma

Matthew T. Heller and Samuel A. Tisherman

Clinical Problem

A 26 year-old male presented to the trauma service after sustaining a gunshot wound to the abdomen. Due to hemodynamic instability, the patient proceeded immediately to the operating room for exploratory laparotomy. The patient underwent a small bowel resection and repair of a liver laceration. Following surgery he is admitted to ICU where he remains unstable. There is concern about ongoing bleeding or yet unidentified injuries.

While the initial evaluation of all trauma patients focuses on the immediate recognition of acutely life-threatening injuries during the primary survey, a complete secondary survey becomes critically important in assessing the hemodynamically stable patient's injuries and facilitating triage. The physical examination helps to identify entrance and exit wounds providing an estimate of the bullet trajectory and potential organ injury. However, estimation of wound trajectory is an insensitive method of determining the extent of injury and the need for surgical intervention. The finding of a mismatch between entrance and exit sites implies bullet retention and increases the likelihood of internal injury.

Patients sustaining a gunshot wound to the abdomen may have a variable hemodynamic presentation, ranging from stable to complete cardiovascular collapse. In the past, all patients presenting with an abdominal gunshot wound were evaluated with emergent laparotomy regardless of their hemodynamic status. Use of emergent

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laparotomy remains standard practice in those patients presenting with cardiovascular compromise, which is unresponsive to resuscitation efforts, or clear evidence of generalized peritonitis on examination.

Hemodynamically stable patients presenting with posterior penetrating injuries can pose a diagnostic challenge. The physical examination of the retroperitoneum can be difficult due to vague signs and symptoms since there are no peritoneal signs associated as with the typical acute abdomen. Hematomas can become quite large before they cause symptoms. In addition to the non-specificity of the physical examination, there are fewer ancillary tests to evaluate the retroperitoneum compared to the peritoneal cavity.

Imaging Techniques

While diagnostic peritoneal lavage (DPL) and, more often, Focused assessment by sonography for trauma (FAST) ultrasound scanning have proven to be useful adjuncts to the physical examination, they do not provide a highly sensitive, global evaluation of the peritoneal cavity, retroperitoneum, vascular, soft tissue and bony structures. CT has emerged as the procedure of choice for further assessment. It provides a highly sensitive evaluation of all abdominal and pelvic structures in a matter of minutes. It offers the option of an added chest scan if a thoraco-abdominal injury pattern is suspected.

Abdominal Injuries

In addition to the technical ease of performing a CT examination, the sensitivity and specificity of image interpretation is critical in the management of the hemodynamically stable victim of a penetrating injury, often from a gunshot. An initial important step in interpretation is identifying the tract created at the time of injury. In patients with a tangential injury (Fig. 36.1a, b), the body wall tissues are breached but the fascial layers of the peritoneum or retroperitoneum are intact, surgical intervention is usually not undertaken. These patients can be managed non-operatively with local wound care and pain control. If the trajectory traverses the fascial layers, the solid viscera, bowel and mesentery the tract needs to be thoroughly evaluated for lacerations, hematomas and active hemorrhage. The finding of a solid visceral laceration without active hemorrhage can often be managed non-operatively, with clinical, laboratory and imaging follow-up. If active extravasation is detected, angio-embolization provides an alternative to surgery.

The presence of extraluminal gas can be confusing, as it may be introduced at the time of assault or may be due to a bowel injury. Since a focal disruption in the bowel wall is rarely seen on CT, these patients may benefit from repeat imaging after ingestion of a water-soluble oral contrast agent if no laparotomy or laparoscopy is undertaken.

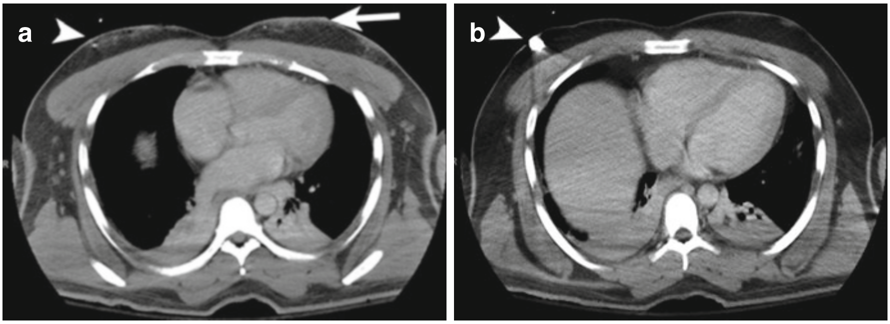

Fig. 36.1 A 23 year-old male presents with pain after sustaining a gunshot wound to the upper abdomen. (**a**) Post contrast computed tomography (CT) shows the tract of the bullet; the bullet entered the subcutaneous tissues in the left upper quadrant (*arrow*) and traveled tangentially to the right upper quadrant (*arrowhead*) without traversing the fascial layer. (**b**) Immediately inferiorly, the bullet (*arrowhead*) is lodged in the subcutaneous tissues of the right upper quadrant

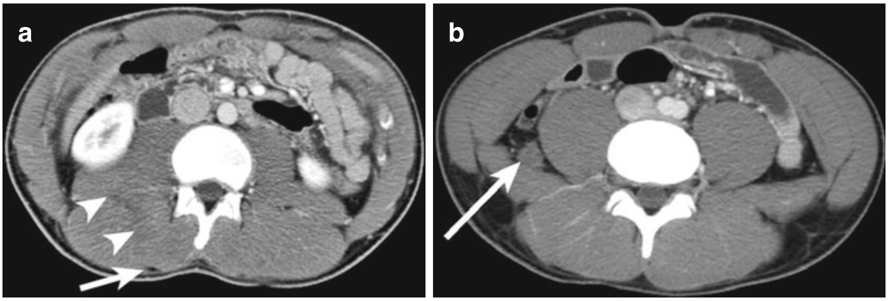

Fig. 36.2 A 20 year-old male sustained a stab wound to the right flank during assault. (**a**) Contrast-enhanced CT shows the stab wound entry site (*arrow*) and the tract (*arrowheads*) through the posterior musculature. (**b**) More inferiorly, there is a small hematoma (*arrow*) between the psoas and quadratus lumborum muscles. The retroperitoneal viscera were intact

Posterior Injuries

CT provides an efficient, global view of the abdomen. The field of view should be chosen to include the entirety of the peritoneum, retroperitoneum, bony structures, adjacent soft tissues and skin surface. Inclusion of the skin surface is important as it may provide the first clue in identifying the site of injury. Generally, a focal site of skin disruption or subcutaneous gas indicates the entrance site of the penetrating object. After identifying this, the adjacent soft tissues and retroperitoneum in the trajectory of the penetrating injury need to be evaluated. Surgical exploration can usually be avoided in patients with penetrating wounds confined to the superficial tissues or sparing the retroperitoneal viscera, only causing a small hematoma (Fig. 36.2a, b). The triage of the patient largely depends on a CT performed according to proper protocol.

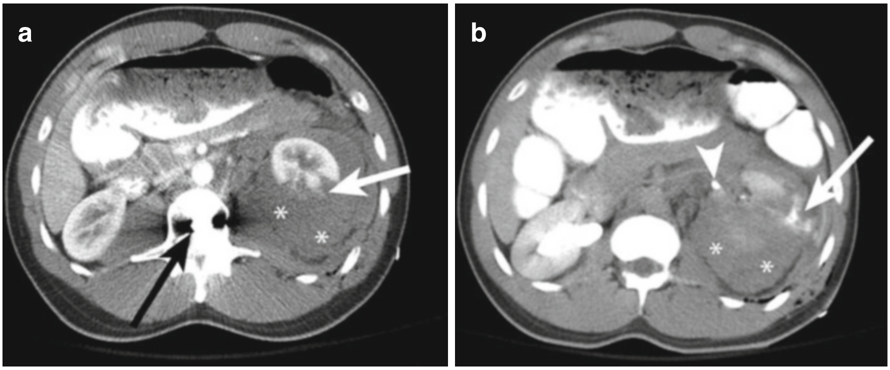

Fig. 36.3 A 58 year-old male sustained a gunshot wound to the left flank. (**a**) Contrast-enhanced CT shows laceration (*white arrow*) of the left kidney and complex fluid (*asterisks*) in the perinephric space. A bullet fragment (*black arrow*) is lodged in the vertebral body. (**b**) Excretory phase image shows contrast in the ureter (*arrowhead*) and extravasating (*arrow*) into the complex perinephric fluid (*asterisks*) due to disruption of the collecting system

Unless contraindicated, the CT should be IV contrast medium enhanced. While a non-contrast CT can identify the site of penetrating injury, provide a rough estimate of its depth, and detect a retroperitoneal hematoma, the lack of contrast medium renders the examination suboptimal. Particularly, the depth of a penetrating injury and the number and depth of renal lacerations may be severely underestimated. More importantly active hemorrhage and pseudoaneurysms cannot be diagnosed. Determination of active hemorrhage is a critical finding, as either angioembolization or surgical intervention is usually indicated. Additionally, the use of intravenous contrast medium may allow characterization of the retroperitoneal fluid. In the presence of peri-nephric fluid or suspected hematoma the acquisition of delayed phase imaging during the excretory phase is crucial for accurate assessment of retroperitoneal injury. Extravasation of contrast during the excretory phase indicates disruption of the renal collecting system, renal pelvis or ureter. When correlated to coronal reformatted images, the site of the leak can often be identified, which helps with interventional planning (Fig. 36.3a, b).

Instillation of water-soluble rectal contrast should always be considered if disruption of the ascending or descending colon is clinically suspected. The CT finding of retroperitoneal fluid or hematoma abutting the colonic wall is a non-specific finding which may be due to the extension of a remote retroperitoneal injury, colonic serosal injury or colonic disruption with leakage of contents. Similarly, extra-luminal gas could have been introduced by the penetrating injury or from a colonic tear.

Patients After Immediate Surgery

Some patients will require immediate surgery following the primary survey. After the initial stabilization in the operating room a whole-body CT should be considered to evaluate the extent of the abdominal injuries and to detect occult injuries that

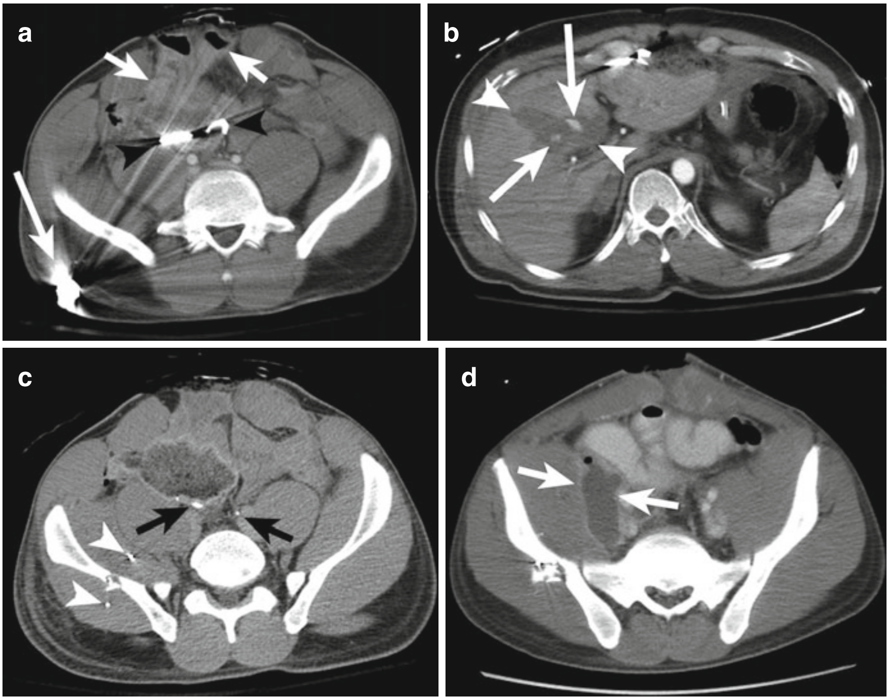

Fig. 36.4 A 26 year-old male presented to the trauma service after sustaining a gunshot wound to the abdomen. The patient underwent bowel resection and laser coagulation of liver lacerations. (**a**) Post-operative computed tomography (CT) shows the bullet fragment (*long white arrow*) in the right gluteal musculature, laparotomy pads (*black arrowheads*) at the root of the mesentery and thickened, clumped small bowel (*short white arrows*). (**b**) More superiorly, there is active hemorrhage (*arrows*) within a hepatic laceration (*arrowheads*). (**c**) Delayed phase image shows contrast within the normal ureters (*black arrows*) and shrapnel (*arrowheads*) adjacent to the fractured right iliac bone. (**d**) One week later, an abscess (*white arrows*) has developed

are not evident during physical examination or surgery. Non-displaced fractures of the sternum, ribs, spine and pelvis may not be diagnosed during the initial radiographic survey due to suboptimal patient positioning or artifact. In the advent of multidetector CT and use of isotropic voxels the generation of multi-planar, reformatted images is standard practice in most major trauma centers. This facilitates the diagnosis of in-plane fractures, which may be inapparent when viewed only on the axial images. Similarly, the diagnosis of diaphragmatic injuries using only axial CT images could prove to be challenging since the diaphragm parallels the image plane. Diaphragmatic injuries are diagnosed with greater ease when viewed in an orthogonal plane.

Post-operative hemodynamic instability should prompt a body CT. Non-contrast enhanced studies can reveal an occult site of acute blood loss which was not apparent in the operating room; examples include intramuscular, inter-fascial or retroperitoneal hematomas. Contrast-enhanced studies can reveal active hemorrhage as ill-defined foci of extra-luminal contrast. The images obtained help to guide surgical re-exploration or percutaneous embolization (Fig. 36.4a–d). Including the lung bases or entire chest in the CT evaluation allows assessment of the pericardium and identification of a large effusion and/or hemopericardium with deformation of the cardiac chambers suggesting cardiac tamponade.

A common imaging pitfall encountered in the post-operative patient is the presence of pneumoperitoneum. While it may be reflexive to regard free air as a sign of bowel perforation, caution must be used since the free air may have been introduced during surgery. Bowel wall thickening is a relatively common, nonspecific finding, which is usually due to post-operative edema, shock bowel or third-spacing of fluid. Attributing bowel wall thickening to ischemia or infection is usually erroneous in the post-operative setting.

Teaching Points

1. Patients with hemodynamic instability or evidence of diffuse peritonitis on examination require exploratory laparotomy and generally do not benefit from pre-operative imaging studies.
2. In the hemodynamically stable patient who has sustained an abdominal gunshot wound or other penetrating trauma, evaluation with contrast-enhanced CT is the most efficient means of injury assessment and triage.
3. These patients can often be managed non-operatively, especially when the CT reveals tangential injury, bowel integrity and no active hemorrhage.
4. For hemodynamically stable patients presenting with posterior penetrating trauma, CT with oral, rectal and intravenous contrast material provides a sensitive evaluation of retroperitoneal injury.
5. Acquisition of delayed CT images during the excretory phase provides a non-invasive means of evaluating the kidneys, ureters and bladder for a traumatic leak without the need for additional contrast material.
6. CT evaluation of the post-operative patient is important to assess the extent of injuries, the surgery site and potential delayed complications.

Chapter 37
Pelvic Trauma

Samuel A. Tisherman and Omar Almusa

Clinical Problem

An 18-year-old male was involved in a motorcycle crash. He was intubated at the scene for combativeness. His initial heart rate was 120 with a blood pressure of 80/50, prompting fluid resuscitation at the scene. Upon arrival in the Emergency Department, he remained hypotensive. His chest radiograph was normal. The radiograph of his pelvis revealed complex pelvic fractures, including diastasis of the pubic symphysis, bilateral superior and inferior pubic rami fractures, and right sacro-iliac joint disruption.

The initial assessment of a patient with a suspected pelvic injury should follow standard trauma guidelines. After assuring an adequate airway and adequate ventilation, adequacy of circulation becomes the most important priority. Bleeding from severe pelvic trauma can be life threatening.

Imaging Techniques

Since hemorrhage is far and away the most common cause of hemodynamic instability in trauma patients, fluid resuscitation and a simultaneous search for the source of bleeding should proceed expeditiously. The most common sites for internal

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hemorrhage are the chest, abdomen, pelvis and long bones. Therefore, in addition to a rapid assessment by physical examination, adjuncts to the primary survey include anterior-posterior chest and pelvis radiographs, and the focused assessment with sonography for trauma (FAST). Because of the mechanism of injury leading to severe pelvic trauma, intra-abdominal solid organ injuries are commonly also found in these patients.

Computed tomography of the pelvis should be obtained as soon as the patient is stable. Ideally, this study should be performed with thin section images (1.25 mm or thinner if appropriate radiation reduction is available). Technological advances in CT technology have enabled easy representation of images in many orthogonal planes. Depiction of the pelvis in axial, sagittal and coronal planes is now considered the imaging standard and improves diagnostic accuracy. CT allows for excellent detection of bony injuries and enables 3-D rendered imaging to assist management planning for orthopedic operative reconstruction. Plain radiographs, such as Judet views, may be helpful with certain injury complexes.

Hemorrhage Control

Getting the bleeding associated with complex pelvic trauma under control is not straightforward. The first intervention is to attempt to tamponade the hemorrhage by placement of a circumferential binder on the pelvic ring. If there is not a high level of concern for intra-peritoneal hemorrhage, pre-peritoneal packing can be very effective. In more desperate situations ligating an internal iliac artery might be necessary. If possible, rapid external fixation of the pelvis can help provide tamponade for the bleeding.

Angiographic Embolization

This can provide a good alternative for patients who have evidence of ongoing hemorrhage from the pelvis but are not unstable enough to mandate an operative approach.

Angiography should also be considered if active extravasation of contrast into the pelvis can be seen on CT. The CT diagnosis is made when an amorphous blush of contrast that does not conform to the expected path of vascular branches can be seen (Fig. 37.1a). Extravasation may be suspected on unenhanced images in the presence of intramuscular hematomas. Some trauma institutions recommend multi-phase contrast images of the pelvis, however, the value of acquiring an arterial and conventional "venous" phase of imaging must be weighed against the total radiation dose.

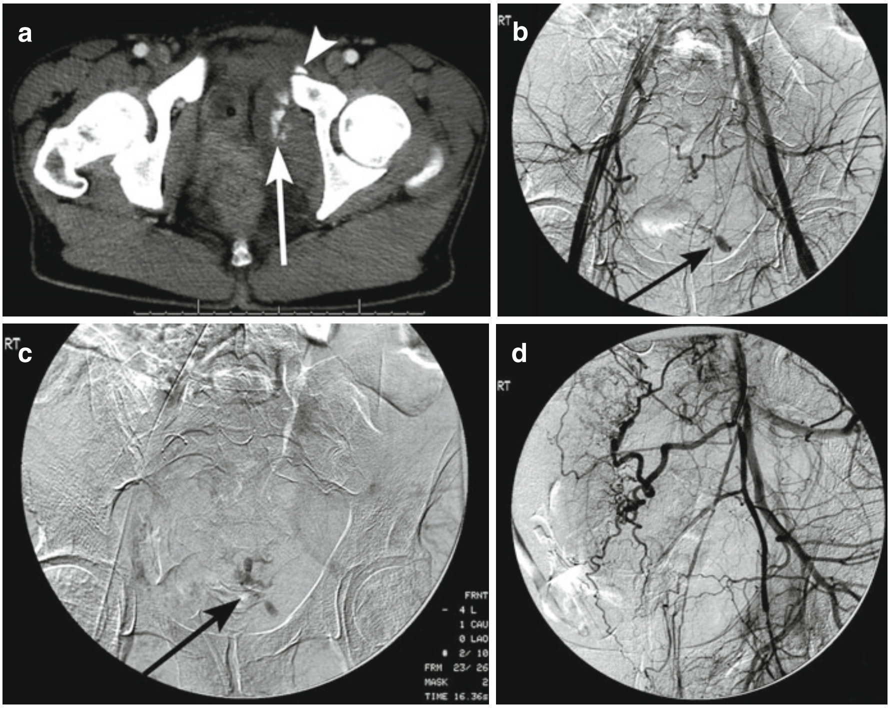

Fig. 37.1 A 42 year-old female presents after motor vehicle accident. (**a**) Post-contrast computed tomography (CT) images of the pelvis performed during the arterial phase shows focal active hemorrhage (*arrow*) in the left obturator internus muscle and fracture of the adjacent superior pubic ramus (*arrowhead*). (**b**) Arterial phase image during angiography shows the site of active bleeding (*arrow*) from the left obturator artery. (**c**) On the delayed phase, more extravasated contrast (*arrow*) has accumulated. (**d**) After selection of the left obturator artery and infusion of Gelfoam slurry, a repeat angiogram shows that the bleeding has stopped

The sources of active extravasation may be either arterial or venous. With arterial injuries, the most common sources are the internal iliac artery branches. With selective catheterization (Fig. 37.1b, c) hemostasis may be achieved with embolization coils or gel foam (Fig. 37.1d).

Associated Injuries

Patients with significant pelvic trauma rarely have isolated pelvic fractures. Genito-urinary injuries are particularly common with injuries to the pubic symphysis or pubic rami. In a male, a urethrogram should be performed prior to

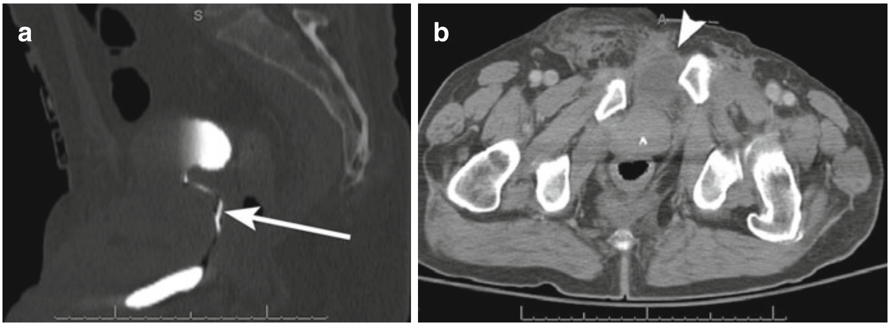

Fig. 37.2 A 74 year-old male presents after sustaining pelvic trauma. (**a**) Sagittal image of the pelvis during the excretory phase shows contrast filling the urinary bladder and stretching of the urethra (*arrow*), but no extravasation of contrast (type II injury). (**b**) Axial computed tomography (CT) image shows traumatic bladder extrophy (*arrowhead*) and diastasis of the pubic symphysis

placement of a Foley catheter, particularly if blood is noted at the meatus or scrotal or perineal hematomas are identified (Fig. 37.2a, b). A cystogram should also be obtained once the Foley is placed, which can be done with plain radiographs or CT. It is important to be aware that subtle bladder ruptures may be missed if the volume of injected contrast is too small. CT cystography is far superior in the detection of subtle injuries and is preferred compared to conventional cystogram if the clinical circumstances allow. In order to prevent streak artifact the contrast dose should diluted about 1:10 in saline when performing a CT cystogram.

Findings of bladder rupture on conventional or CT cystogram are similar. In case of an extraperitoneal rupture contrast will be visualized surrounding the bladder, extending into soft tissues and the retroperitoneal space. The contrast is mostly anterior to the bladder (in the space of Retzius) and superior, at the level of the umbilical ligament. Contrast, which is superior to the dome and, by extension, superior to the umbilical ligament, indicates an intraperitoneal bladder rupture. The contrast will often outline bowel within mesenteric folds. Occasionally, bladder ruptures can be complex with both intra- and extra-peritoneal components (Figs. 37.3a–c and 37.4a, b).

Injuries to the female reproductive tract should be evaluated with a thorough pelvic examination. Rectal injuries also need to be considered, particularly if the CT demonstrates bony fragments near the rectum. Digital rectal examination may reveal blood or bony fragments. Rigid proctoscopy is the best procedure to more completely evaluate the integrity of the rectum.

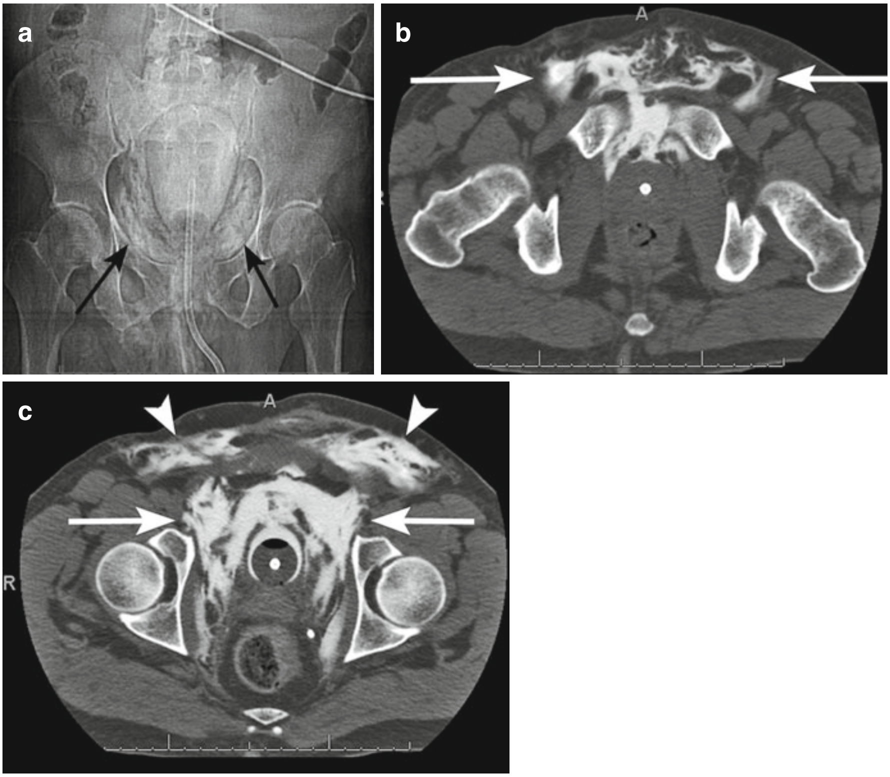

Fig. 37.3 A 51 year-old male presents after motor vehicle collision. (**a**) Pelvic radiograph after infusion of contrast into the urinary bladder shows extravasation of contrast (*arrows*) into the perivesicular tissues, consistent with extra-peritoneal bladder rupture. (**b**) Image obtained during computed tomography (CT) cystoscopy shows contrast material (*arrows*) extravasated into the perivesical tissues, consistent with bladder rupture into the extraperitoneal space of the pelvis. (**c**) More inferiorly, the extravasated contrast material dissects through the extraperitoneal space of the pelvis in the "molar tooth" configuration (*arrows*), characteristic of extraperitoneal bladder rupture. Contrast also extends along the anterior pelvic wall (*arrowheads*)

Teaching Points

1. Severe pelvic trauma can cause severe, life-threatening hemorrhage.
2. Control of hemorrhage from pelvic injuries can be accomplished by circumferential binding of the pelvis, angio-embolization, pre-peritoneal packing, or ligation of the internal iliac artery.

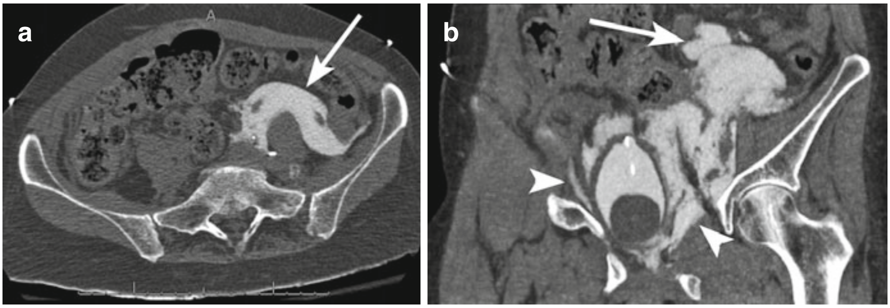

Fig. 37.4 A 66 year-old female presents after motor vehicle collision. Axial (**a**) and coronal (**b**) computed tomography (CT) images during CT cystogram show extravasated contrast from the bladder filling the perivesical spaces (*arrowheads*) of the extraperitoneal compartment of the pelvis and extending around small bowel in the inferior peritoneal cavity (*arrow*)

3. CT imaging is the mainstay for evaluating the specific injuries within the pelvis.
4. CT cystography requires sufficient bladder distension to detect small tears or ruptures. Bladder ruptures may have multiple components (intra- and extra-peritoneal).
5. Associated injuries to the genito-urinary system and rectum need to be considered.

Chapter 38
Chest Trauma: Blunt Aortic and Cardiac Trauma

Mara B. Antonoff, Melissa E. Brunsvold, and Amar Shah

Clinical Problem

A 25-year-old restrained driver of a motor vehicle involved in a head-on collision was admitted to the intensive care unit with multiple complex extremity fractures, sternal fracture, and scattered trunk abrasions and ecchymoses. A left-sided chest tube was placed in the trauma bay for pneumothorax. The patient continues to complain of chest pain. He has been hemodynamically stable after fluid resuscitation, except for mild persistent tachycardia.

Blunt chest trauma may result in serious and potentially life threatening injuries to the heart and great vessels. Greater than two-thirds of all thoracic aortic injuries are consequent to motor vehicle crashes (MVC). Aortic injury occurs in approximately 1.5–2 % of all MVC's, but accounts for up to 15 % of MVC-related deaths. The majority of such injuries are fatal at the scene of accident.

Cardiac contusion is exceedingly uncommon in the injured patient, but it is the most common cardiac injury associated with blunt trauma. Its mechanism usually requires extreme blunt force, often with a significant head-on component. While a

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variety of mechanisms have been described, the most common cause of myocardial contusion is deceleration in a motor vehicle crash, followed by falls, animal kicks, industrial crushing injuries and assaults.

Imaging Techniques

If the index of suspicion for a blunt chest trauma is high and the patient survives to a trauma center imaging is required very early on to rule out life-threatening injuries. Volumetric helical computed tomography angiography with appropriately timed intravenous contrast has become the gold standard for diagnosing and characterizing injuries to the aorta and other great vessels. Transesophageal echocardiography (TEE) may additionally be helpful in evaluating the thoracic aorta. While sensitivity and specificity have been reported as high as 100 %, these tend to be variable among reports and are notably operator dependent. A unique advantage of TEE in evaluating the aorta lies in its portability. TEE may be used intraoperatively during a trauma laparotomy or at the bedside in the ICU. If negative, CT angiography is still recommended once the patient is stable enough for the study in order not to miss more subtle injuries.

Blunt Aortic Injury

This is an imprecise term used to describe a range of injuries to the aorta. Patients who survive to hospital typically have a tear of the intima or of intima and media. The integrity of the aorta is, at least temporarily, maintained by the adventitia. The most widely accepted mechanisms for aortic injury are those of high-velocity abrupt deceleration or massive blow to the anterior chest. In the setting of rapid deceleration the most frequent location of an aortic tear occurs just distal to the takeoff of the left subclavian artery, at the level of the ligamentum arteriosum. The aorta just proximal to the ligamentum arteriosum is more mobile and can forcefully swing away from the fixed distal portion. The resulting shear stress causes aortic disruption.

Up to one-third of patients brought to hospitals with traumatic aortic injuries have minimal, if any, external evidence of injury to the chest. Clinical findings that should lead the practitioner to consider aortic injury include sternal instability, heart murmur between the scapulae, unequal extremity blood pressure readings and flail chest on the left. Hypotension is not usually caused by the aortic injury; patients with aortic injuries significant enough to cause hemorrhagic shock tend not to survive to hospital.

A number of features have been described on chest radiographs as being associated with blunt aortic injury (Fig. 38.1, Table 38.1). None of these findings are particularly sensitive or specific for aortic injury. While such findings may raise

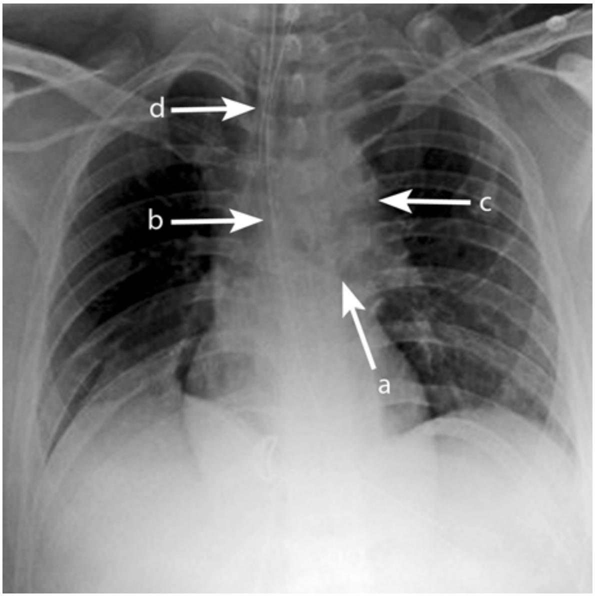

Fig. 38.1 Chest radiograph demonstrates typical findings associated with aortic injury: downward displacement of the left mainstem bronchus (*a*), right sided displacement of the esophagus with nasogastric tube shifted to the right of midline (*b*), widened superior mediastinum and ill-defined aortic knob (*c*), trachea and endotracheal tube shifted to the right of midline (*d*)

Table 38.1 Plain chest film features associated with aortic injury

Widened mediastinum
Prominent or obliterated aortic knob
Trachea deviated to the right
Esophagus deviated to the right
Left main bronchus depression
Hemothorax
Loss of aorto-pulmonary window
Left apical cap

one's index of suspicion, plain chest radiography cannot serve as a definitive diagnostic modality.

CT imaging is the reference standard for diagnosing aortic injury (Figs. 38.2 and 38.3). With modern scanners and higher resolution output, the sensitivity and negative predictive value of CT in evaluating the integrity of the thoracic aorta approaches 100 %. Further, the wide availability, speed, safety, and ease of interpretation make CT more attractive than formal angiography. The CT findings associated with aortic injury are summarized in Table 38.2. Despite the numerous strengths of the CT in evaluating aortic injuries, its sensitivity and specificity can vary among centers and radiologists. Potential pitfalls in imaging the thoracic aorta, including failure to distinguish true intimal injuries from anatomic variants—such as ductus diverticulum—and pulsation artifact, are minimized with experienced image interpretation.

Prior to recent improvements in CT imaging, catheter aortography was long held as the gold-standard test for aortic injury. Its role is now fairly limited, as it requires considerable investment of time and cost, and it is more invasive than CT

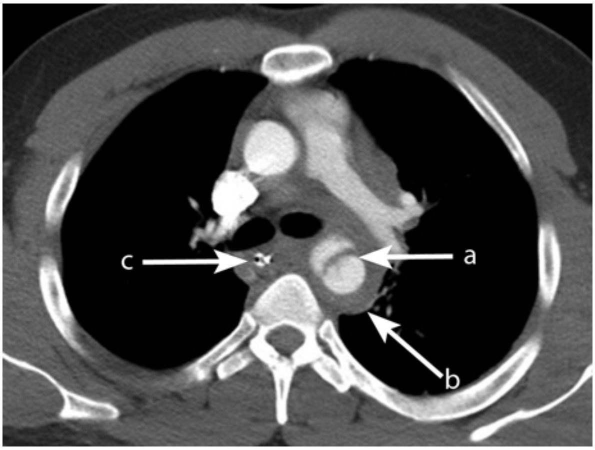

Fig. 38.2 Multi-detector computed tomography (CT) angiogram demonstrating: pseudoaneurysm distal to the aortic isthmus (*a*), surrounding mediastinal hemorrhage (*b*), rightward displacement of the esophagus (*c*)

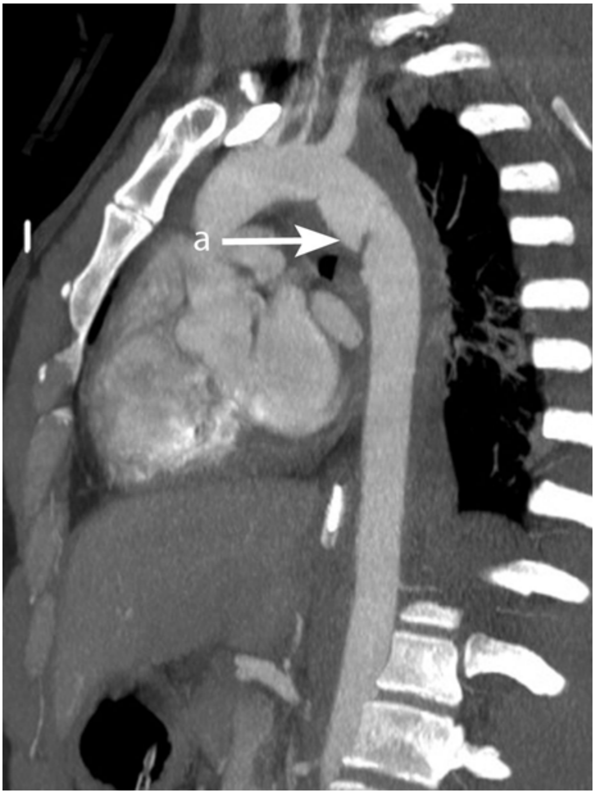

Fig. 38.3 Sagittal Maximum Intensity Projection (MIP) image demonstrates pseudoaneurysm and intima injury, just distal to the aortic isthmus at the level of the ligamentum arteriosum (*a*)

evaluation. However, its utility should not be forgotten, along with its near 100 % sensitivity and specificity. While it is no longer considered the reference-standard examination, there may be circumstances in which catheter aortography can be

Table 38.2 CT features associated with aortic injury

Extravasation of contrast
Filling defects
Para-aortic hematoma
Mural thickening
Vascular intimal flaps
Mural thrombi
Pseudoaneurysm
Contained rupture
Abnormal aortic contour
Sudden change in aortic caliber

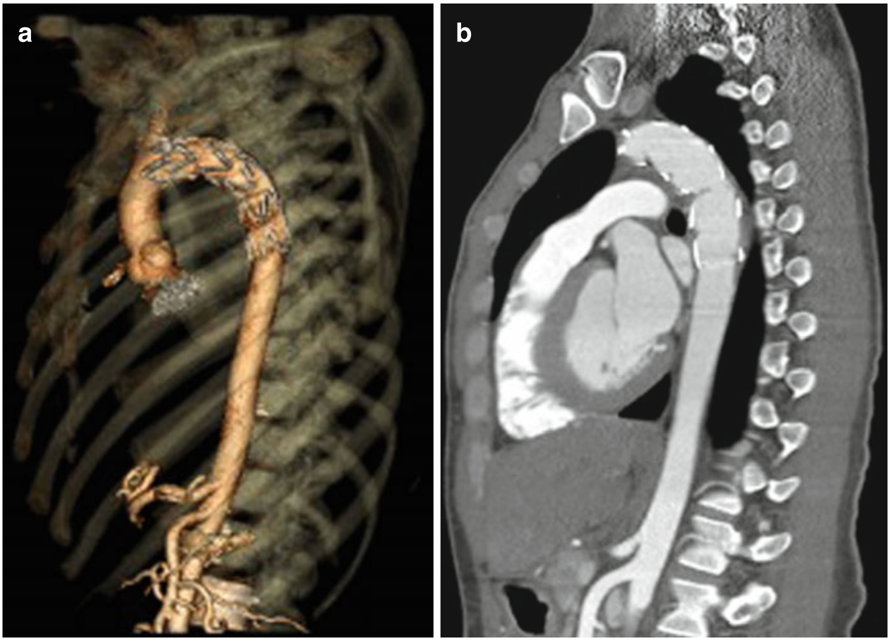

Fig. 38.4 Postoperative imaging of a successful endovascular stent graft bridging the site of aortic injury, including: (**a**) volume rendered image; (**b**) sagittal Multiplanar Reformatted (MPR) Image

useful. Aortography should be considered when a patient is already undergoing catheter-based angiography, such as pelvic angio-embolization. Angiographic, endovascular management of the aortic injury is now commonly employed (Fig. 38.4a, b).

Intravascular ultrasonography, performed by threading a high-frequency ultrasound transducer through a large arterial sheath, allows acquisition of real-time circumferential images of the aorta. While this technique requires further development and standardization, there are data to suggest that intravascular sonographic evaluation may be more specific than catheter-based contrast aortography among patients with equivocal CT findings. However, at present, this technique is limited due to its cost, invasiveness, and paucity of data. As further developments proceed, this strategy may have a role in future approaches to evaluating patients with potential aortic injuries.

Minimal Aortic Injuries (MAI)

This term refers to a classification of small intimal tears and intramural hematomas, the discovery of which have led to recent controversy with regard to subsequent requisite management. These small, sub-centimeter intimal injuries have been identified with greater frequency as CT resolution has improved. MAI were probably under-recognized during the era of catheter angiography as the primary diagnostic modality.

MAIs tend to appear as small luminal defects, intimal flaps, or intramural collections, usually without any associated pseudoaneurysm or mediastinal hematoma. A range of treatment strategies have been suggested for patients with these small injuries, varying from imaging surveillance to endovascular therapy to more invasive operative intervention. While it appears safe to observe subcentimeter lesions, this remains an ongoing area of interest and investigation.

Blunt Cardiac Injury

High-pressure forces may be inciting factors for severe, immediately life-threatening injuries, including ruptures of the cardiac free wall or intraventricular septum, valvular cusps, or chordae tendinae. More often, and with less dramatic findings, these forces may result in myocardial contusion. The most common anatomic location injured is the right ventricle, due to its placement in the anterior mediastinum. The diagnosis of cardiac contusion requires the presence of:

- an appropriate mechanism
- chest wall tenderness or pain
- demonstration of early arrhythmia or signs of heart failure.

One should have a high index of suspicion based on the mechanism of injury. Additional clinical settings that may raise concern include the young trauma patient with unexpected arrhythmias and the older trauma patient with angina unresponsive to nitroglycerin.

The diagnosis of myocardial contusion can be difficult. Confirming the diagnosis in a stable patient may not be critical, as it does not change management. Electrocardiography tends to be nonspecific. A number of potential arrhythmias have been described, the most common of which is sinus tachycardia – which is a common finding in the trauma population at large. Cardiac enzymes may or may not be abnormal, and trending of CK and troponin levels is of unclear utility.

In patients with normal electrocardiogram and normal chest x-ray, no further cardiac imaging is generally recommended, as the combination of these two studies has adequate negative predictive value. If concerns about heart failure continue to exist echocardiography is the most useful imaging study, as it can demonstrate wall motion abnormalities and valvular injury. Evidence does not support the use of this tool for routine screening.

Teaching points

1. Findings on chest x-ray concerning for aortic injury include: widened mediastinum (>8 cm), prominent or obliterated aortic knob, tracheal deviation, depressed left mainstem bronchus, hemothorax, and loss of aortopulmonary window. Presence of these findings mandates CT for further characterization.
2. Contrast-enhanced spiral CT serves as the current standard for evaluating the thoracic aortic. One should look for evidence of extravasation of contrast, filling defects, associated para-aortic hematomas, mural thickening, vascular intimal flaps, mural thrombi, and pseudoaneurysms.
3. While the management of subcentimeter intimal lesions continues to evolve, such findings are increasing in frequency with improved CT resolution. Minimal aortic injuries should be noted, with consideration given to treatment or surveillance options.
4. Cardiac contusion can be difficult to diagnose with imaging modalities. Evaluation should be focused on physiologic parameters, with the use of echocardiography reserved for functional evaluation in the presence of clinical abnormalities.

Chapter 39
Vascular Trauma

Amir Awwad and Samuel A. Tisherman

Clinical Problem

A 47-year-old female was admitted to the Emergency Department after being involved in a high-speed motor vehicle crash as a restrained driver. She is awake, alert and hemodynamically stable. On examination, her right knee is swollen and unstable. Her right foot is cold with no palpable pulses.

Mechanisms of peripheral vascular trauma include both penetrating and blunt trauma, with penetrating being much more common. Penetrating trauma can lead to complete transection, causing either hemorrhage or thrombosis from vessel spasm. Re-bleeding may occur as the blood pressure is raised. Partial transections tend to continue to bleed. The location of the injury is usually readily evident from the path of the penetrating object.

Blunt trauma typically leads to a stretch injury to the vessel. The intima, and sometimes the media, of the vessel are disrupted, exposing the underlying tunica externa, which is very thrombogenic. Thus the presentation may be vascular occlusion and resultant ischemia, rather than hemorrhage. If thrombosis does not occur, the injury may lead to an intimal flap, pseudoaneurysm or arterio-venous fistula. Specific orthopedic injuries are associated with specific vascular injuries, such as popliteal artery injury secondary to knee dislocation, brachial artery injury in supracondylar humeral fracture or subclavian artery injury in clavicular fractures. Blunt trauma can also lead to direct vessel disruption by bony fragments.

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Table 39.1 Imaging signs of vascular injury

Penetrating injury	Contrast extravasation or false aneurysm formation
	Adventitial or medial tear without an intimal injury
	Blood flow deviation due to large hematoma, or vascular spasm
Blunt injury	Caused by vascular compression and stretching
	All vascular layers tear can occur, as well as an intramural hematoma
	Dissection, occlusions or vessel rupture in severe injuries
Blunt aorta injury	Blunt aortic trauma is fatal in ascending aorta (die at scene of accident)
	Signs of mediastinal hematoma on chest radiograph or scout CT view
Hepatic and splenic injury	(CT diagnosed) Extravasation point or blush of contrast overlying/ surrounding the organ
Renal injury	(CT diagnosed) Angiography not always indicated unless persistent hematuria, or contrast extravasation on delayed imaging (e.g. plain KUB)
Pelvic injury	Pelvic fractures associated with massive blood loss (venous injury).
	Arterial injury can also occur with extravasation, pseudoaneurysm and AV fistula formation
	Angiography can show persistent bleeding following pelvic fracture stabilization/fixation
Extremity injury	Direct limb trauma or dislocation (e.g. the popliteal artery)
	Angiography can show dissection, occlusion or disruption in blunt injury
	Extravasation, pseudoaneurysm or AV fistula formation in penetrating

Clinical evaluation of the patient at risk for vascular injury begins with obtaining a detailed clinical history, including the mechanism of injury, blood loss at the scene, and pre-hospital vital signs. The initial assessment of the trauma patient should include examination for hard signs of vascular injury. Soft signs of vascular injury include a history of blood loss at the scene, hypotension, and a small, non-pulsatile hematoma. Since ischemia can cause neurologic dysfunction distal to the injury, a thorough neurological examination of the injured extremity is critical. Comparing physical examination and ankle-brachial indices with the contralateral, non-injured side is very helpful. Further evaluation may be indicated when only soft signs are present. In general, though, the absence of hard signs rules out surgically important injuries.

Imaging Techniques

The presence of active hemorrhage or a large, expanding, pulsatile hematoma necessitates immediate intervention, usually by operative exploration or angiography. For patients with multilevel trauma, urgent arteriography, preferably in the operating room or in the interventional radiology suite, is indicated. Absent distal pulses or other signs of distal ischemia (pain, paresthesia, pallor, paralysis, poikilothermia) as well as the presence of a palpable thrill or audible bruit, should also prompt urgent vascular imaging.

Duplex imaging can be useful, though it is typically not available in a timely fashion for evaluation of trauma patients. It may help for post-operative follow-up, however. The options for acute vascular imaging include computed tomographic angiography (CTA) and conventional arteriography. Specific signs of injury (Table 39.1) should be sought. Although arteriography has been the gold standard,

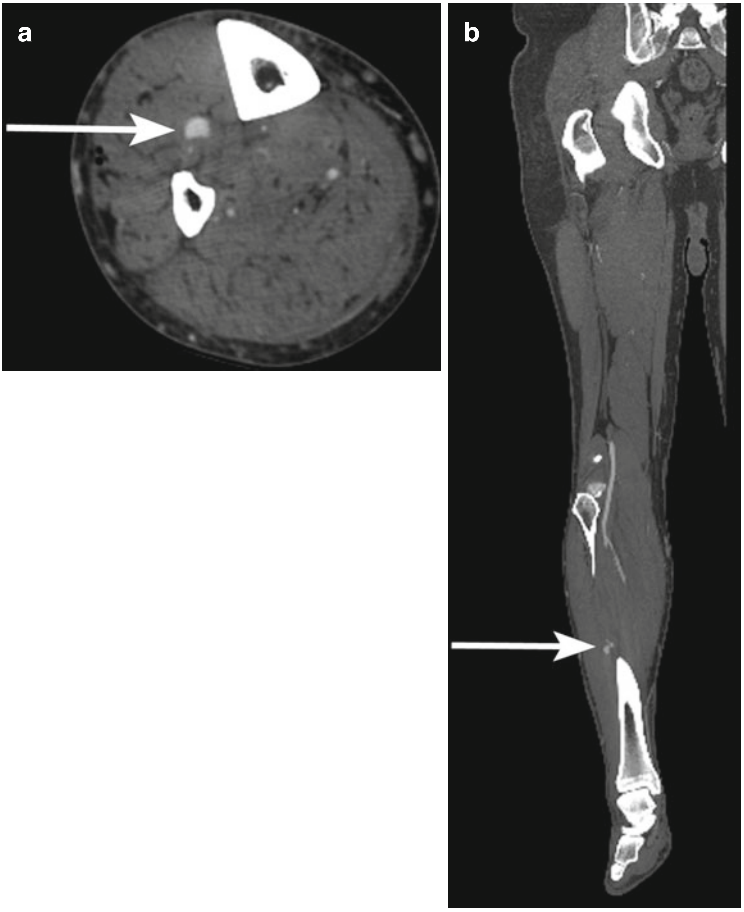

Fig. 39.1 A young patient suffered a gunshot wound to the leg. Axial (**a**) and coronal (**b**) images from a computed tomography angiogram reveal extravasation of contrast (*arrows*) from the anterior tibial artery

it is more invasive and requires greater expertise. There is increasing evidence for the accuracy of CTA. Therefore, the best practice in vascular trauma imaging is most likely the development of a multidisciplinary protocol by the local trauma center, based upon available facilities, expertise and clinical demands for vascular and non-vascular trauma.

Computed Tomographic Angiography

The availability of CTA has increased and it has become standard in most tertiary trauma centers (Fig. 39.1a, b). CT consoles and picture archiving and communication systems (PACS) can complement CTA images of a trauma patient with automatic generation of a series of multi-planar reconstructions (MPR) for bony, visceral or vascular injuries in 3 dimensional planes.

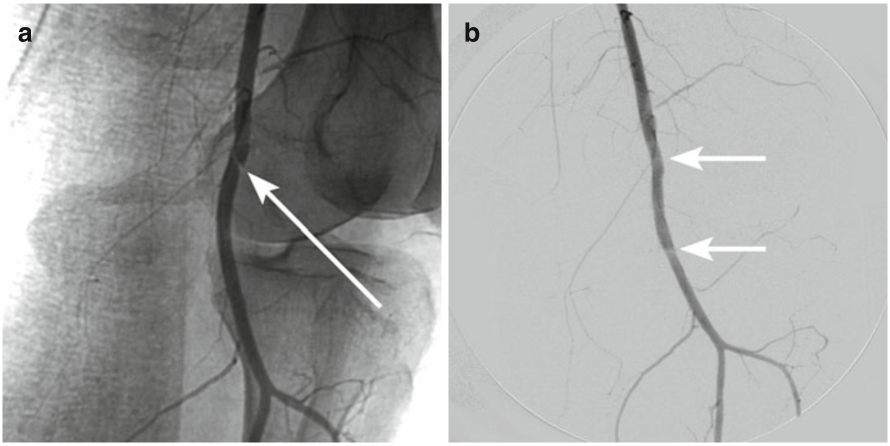

Fig. 39.2 A patient was involved in a motor vehicle collision and suffered a posterior dislocation of the knee. (**a**) Angiography revealed an intimal tear (*arrow*) of the popliteal artery. (**b**) A stent (*arrows* denote stent margins) was successfully placed across the injury

Arteriography

Although mostly supplanted by CTA this modality should be considered in patients who clinically have evidence of vascular trauma, either hemorrhage or ischemia from thrombosis, and who are considered for endovascular intervention to manage the injury. Although unstable patients should be taken to the operating room immediately there still may be a role for a radiologic approach if the necessary expertise and equipment is available.

Patients with a therapeutic angiographic option have to be referred for arteriography in a timely fashion. Direct consultation with the interventional radiologist is critical. Once the indications for an angiographic intervention is established, the study can aid in choosing the best method for managing the injury, i.e., preserve an organ or salvage an acutely ischemic limb, by embolization or stent-grafting (Fig. 39.2a, b).

The key steps for safe vascular embolization include:

- Angiographic imaging with excellent quality
- Identifying the point of vascular injury and the collateral pathways
- Continuous fluoroscopy during and after embolization

The choice of embolic agent depends upon whether permanent or temporary occlusion is required. Permanent agents that cause mechanical occlusion include coils and balloons. Particular agents that provide temporary occlusion include polyvinyl alcohol, Gelfoam, and autologous blood clots. Liquid agents, such as adhesives and sclerosants, can also be used.

Solid organ injuries can cause life-threatening hemorrhage. Unstable patients need operative exploration. The trend has been to attempt non-operative management in the great majority of patients, depending on the grade of injury on CT and clinical stability. Some of these patients may still exhibit evidence of active hemorrhage. Arteriographic approaches may allow splenic or renal salvage, or assist with management of complex liver injuries. Non-operative management protocols often include follow-up CTA to rule out development of pseudoaneurysms or arterio-venous fistulas. No specific or routine imaging follow up is usually recommended following successful arteriographic embolization.

Teaching Points

1. Unstable patients should undergo immediate operative intervention.
2. Hard physical examination findings of vascular injury in patients with penetrating injury typically mandates operation
3. Absence of hard signs of vascular injury excludes most surgically significant injuries.
4. Patients with blunt injury or complicated penetrating injury may require angiography in the operating room before exploration
5. Vascular injuries detected by CTA in stable patients require urgent referral for arteriography and selective embolization or stent-grafting.

Chapter 40
Traumatic Brain Injury

Vikas Agarwal and Samuel A. Tisherman

Clinical Problem

A 23-year-old male was an unrestrained driver involved in a high-speed motor vehicle crash. At the scene, he had bilateral decorticate posturing and his eyes opened in response to painful stimulation. He did not vocalize. His heart rate and blood pressure were normal. He was intubated and transported to the nearest Level I trauma center.

Traumatic brain injury (TBI) is classified in several different ways. The first distinction is between blunt (closed), penetrating (open), or blast trauma. Second is the severity of the injury, most useful for blunt trauma. Classification is typically based upon evaluation of the Glasgow Coma Scale (GCS). Mild is defined as GCS 13–15, moderate as 9–12, and severe as <8. Third is the location of the intracranial injuries, e.g. intra-axial vs. extra-axial (epidural, subdural, subarachnoid hemorrhage). At the neuronal level, primary injury is defined as damage that occurs at the moment of impact. Secondary injury refers to the damage sustained as a consequence of physiologic responses to the initial injury, most importantly cerebral ischemia due to multiple factors, including hypotension, hypoxia, inadequate cerebral perfusion pressure, and intracranial hypertension. All of these factors have important implications for outcome from TBI.

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Imaging Techniques

Conventional radiographs of the skull have little to no role in the evaluation of patients with TBI and have been largely supplanted by CT. They may occasionally be used to evaluate position of penetrating objects or radiopaque foreign bodies.

Computed tomography without contrast medium is the most important imaging modality for initial assessment of patients with TBI. It is widely available, fast and compatible with life support devices. CT can accurately identify the presence of hemorrhage, herniation, hydrocephalus, fractures and radiopaque foreign bodies. Liberal use of head CTs seems justified given the potential consequences of undiagnosed brain injury. The one drawback to the use of CT is the associated radiation exposure, which can become significant, as trauma patients typically require multiple initial scans and might require serial follow-up examinations.

Magnetic Resonance Imaging is generally not utilized in the evaluation of patients with TBI in the acute setting. MRI has relatively long imaging times and is incompatible with many devices utilized in the acute management of trauma patients. It is relatively insensitive for detection of acute subarachnoid hemorrhage (SAH). MRI imaging is best suited for use in the subacute and chronic assessment of patients with TBI as a problem-solving tool in cases where the CT does not explain the neurologic findings.

Skull Fractures

Fractures have been described as linear, depressed and basilar (Fig. 40.1). Depressed skull fractures are commonly associated with injury involving the underlying brain parenchyma. Basilar skull fractures are important to recognize since they can be associated with injury to vascular structures (internal carotid artery, transverse and sigmoid sinuses, cavernous sinuses), the cranial nerves and the middle/inner ear structures. Fractures involving the temporal bone are now classified as "otic capsule sparing" and "otic capsule involving."

Epidural Hematomas

An epidural hematoma (EDH) is present in 1–4 % of patients with TBI. The epidural space is located between the dura and the calvarium and can accumulate extravasated blood from injured blood vessels, most commonly arteries (85 %), such as the middle meningeal artery. An underlying fracture is present in more than 90 % of cases. Typically, EDHs appear as biconvex, hyperdense, extra-axial collections on non-contrast enhanced CT examinations (Fig. 40.2). They do not cross suture lines except at the level of the sagittal suture, where the dura does not invest the suture due to the presence of the superior sagittal sinus. Unlike subdural

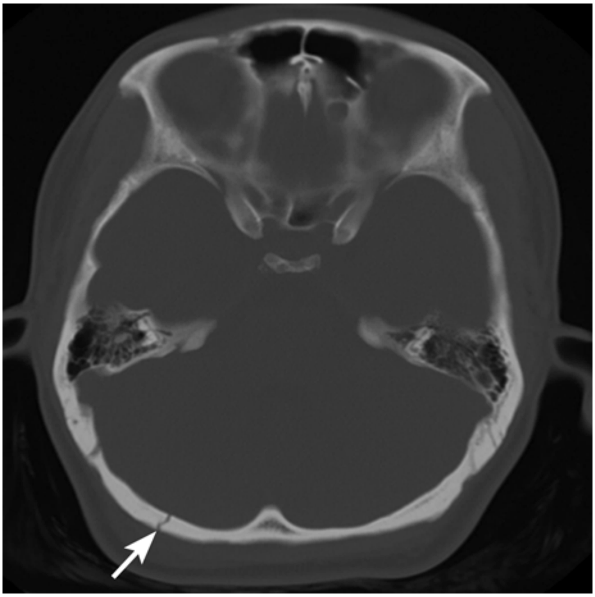

Fig. 40.1 Non-contrast enhanced head computed tomography (CT) in a patient after motor vehicle collision displayed in bone algorithm shows fracture through the right occipital bone (*arrow*)

Fig. 40.2 Small epidural hematoma along the posterior left temporal lobe causing mass effect on underlying brain parenchyma (*arrow*)

hematomas (SDH), an EDH can cross dural reflections such as the falx cerebri or tentorium cerebelli. Mixed density or heterogeneous EDHs have been shown to have a worse prognosis than more homogenous EDHs, due to the presence of active bleeding with hypodense areas representing unclotted blood; this has been termed the “swirl sign” (Fig. 40.3).

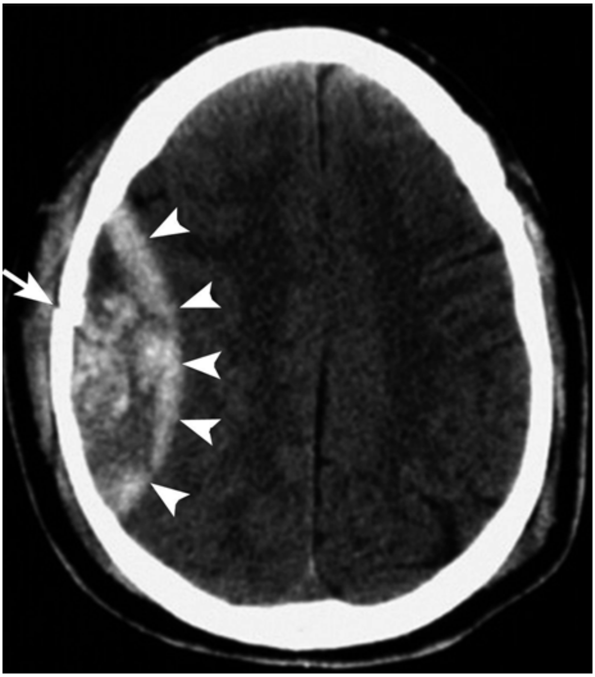

Fig. 40.3 Non-contrast enhanced head computed tomography (CT) in a patient after a motor vehicle collision demonstrates a high density, biconvex epidural hematoma (*arrowheads*) deep to the parietal skull fracture (*arrow*). Areas of hypodensity within the epidural hematoma are likely related to areas of active bleeding

Following decompressive craniectomies, small EDHs remote from the surgical site may dramatically increase in size. This is thought to relate to release of a tamponade effect generated by preoperative elevated intracranial pressure.

Subdural Hematomas

Ten to twenty percent of patients with TBI will present with a subdural hematoma. The subdural space is a potential space located between the inner meningeal layer of the dura and the arachnoid mater. As opposed to EDHs, the majority of SDHs are venous in origin, the result of traumatic injury to bridging cortical veins that traverse the subdural space. They are less frequently associated with skull fractures compared with EDHs. The majority of SDHs are supratentorial and occur along the cerebral convexities, tentorium cerebelli or falx cerebri. On non-contrast CT they appear as crescentic extra-axial collections that cross suture lines and often span an entire hemisphere. Internal characteristics of SDHs on CT however vary based on whether they are acute, subacute or chronic. Acute SDH (<1 week) are typically homogenously hyperdense (Fig. 40.4). In patients with underlying anemia, acute SDHs can appear iso- or hypointense. Like EDHs, if there is active bleeding, acute SDHs can also appear heterogeneous.

Over time, subdural blood breaks down and cellular elements are removed causing a progressive decrease in attenuation. Subacute SDHs (1–3 weeks) often have

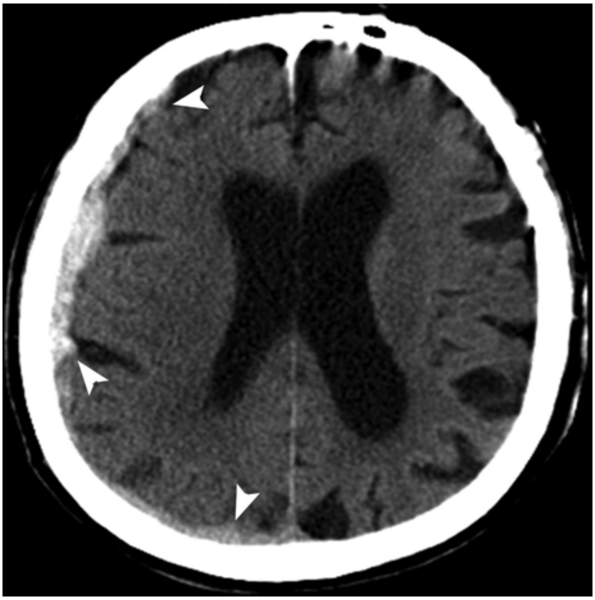

Fig. 40.4 Non-contrast enhanced head computed tomography (CT) in a patient after a fall shows a subdural hematoma (*arrowheads*) along the right convexity causing mild mass effect on underlying right cerebral hemisphere with sulcal effacement. High density suggests more acute blood products

internal density on a spectrum that includes an isodense phase. The isodense collection can be difficult to recognize on non-contrast medium enhanced CT (Fig. 40.5). Clues to the presence of an isodense SDH include white matter buckling, medial displacement of the gray-white junction and presence of a mass effect (midline shift, sulcal effacement, compression of ipsilateral ventricle). As the collection ages, it will eventually become homogeneously hypodense. Chronic SDHs (>3 weeks) can sometimes contain adhesions and membranes, producing multiple compartments.

Subarachnoid Hemorrhage

Subarachnoid hemorrhage (SAH) results from tearing of small cortical vessels, extension of intraparenchymal hemorrhage (IPH) into the subarachnoid space or extension of intraventricular hemorrhage (IVH) via the fourth ventricular outlet foramina. It is present in approximately 11 % of patients suffering TBI. Traumatic SAH can lead to vasospasm as well as development of communicating hydrocephalus.

On non-contrast CT, acute SAH appears as areas of high attenuation within the subarachnoid spaces, which include the basilar cisterns and sulci (Fig. 40.6). Occasionally the only clue to presence of SAH is sulcal effacement. As SAH ages it can be increasingly difficult to detect on CT. Magnetic resonance imaging, in particular Fluid Attenuated Inversion Recovery (FLAIR) and/or gradient echo (GRE) T2* sequences, is more sensitive for detection of subacute and chronic SAH.

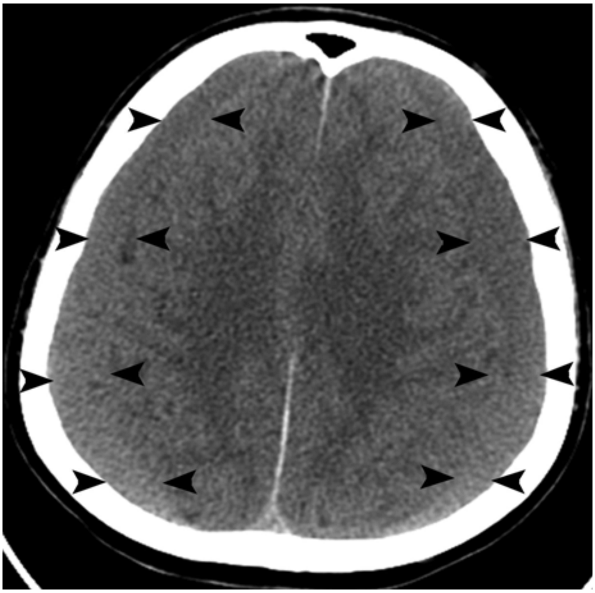

Fig. 40.5 Non-contrast enhanced head computed tomography (CT) in patient several weeks after fall shows intermediate density, crescent shaped collections (*arrowheads*) overlying both cerebral hemispheres consistent with subacute subdural hematomas. As the blood products become reabsorbed, the hematomas become isodense to normal gray matter and may be difficult to visualize. Note the presence of balanced mass effect on both cerebral hemispheres

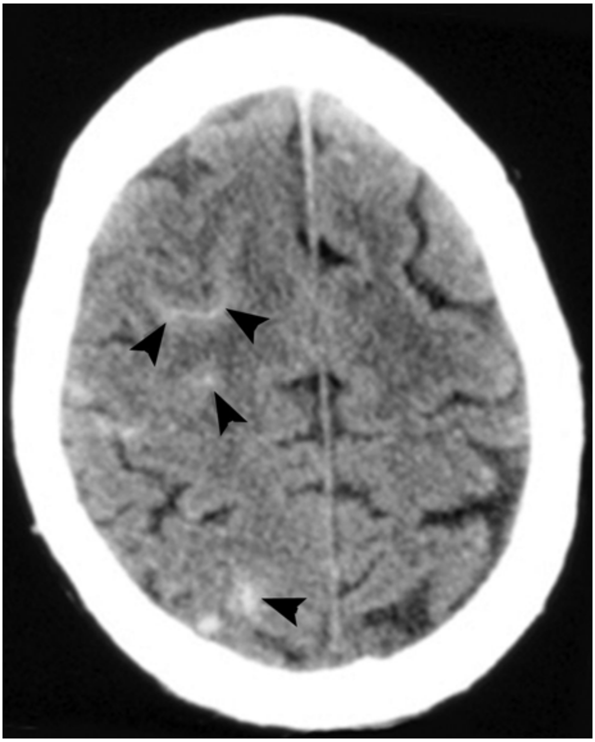

Fig. 40.6 Non-contrast enhanced head computed tomography (CT) in a patient following head trauma with high density blood (*arrowheads*) filling the sulci over the right hemisphere consistent with subarachnoid hemorrhage

Intraventricular Hemorrhage

Intraventricular hemorrhage (IVH) results from tearing of subependymal veins along the surface of the ventricles, extension of IPH or SAH into the ventricular system or from a direct penetrating injury. IVH is relatively uncommon, occurring in approximately 1–2 % of patients suffering TBI. It is usually seen in the setting of severe TBI and is therefore associated with a poor prognosis. IVH appears as high-density material within the ventricular system on non-contrast enhanced CT. Most commonly, this is seen as a fluid-fluid level within the dependent portion of the occipital horns of the lateral ventricles.

Cerebral Edema

Inflammation around areas of contusion and the loss of cerebral auto regulation with subsequent cerebral hyperemia are the main causes of cerebral edema in TBI. On non-contrast enhanced CT, cerebral hyperemia is seen as the presence of a mass effect with relative preservation of gray-white matter differentiation.

Over time, cerebral hyperemia may progress to cerebral edema, which can be divided into two major categories:

1. Vasogenic edema due to disruption of the blood-brain barrier and accumulation of extracellular water;
2. Cytotoxic edema due to intracellular water accumulation.

Both forms can co-exist in patients with TBI. Vasogenic edema is typically more prominent in white matter and cytotoxic edema more prominent in gray matter. Non-contrast CT demonstrates compressed ventricles, effaced sulci/cisterns and loss of gray-white differentiation (Fig. 40.7a, b).

Cerebral Contusions or Intraparenchymal Hemorrhages

These represent areas of the brain parenchyma that have suffered direct trauma with the rupture of small intraparenchymal blood vessels and represent the most common forms of intra-axial injury in TBI patients. They occur primarily in the cortex but can extend into the underlying subcortical white matter and are often associated with the site of direct impact, usually beneath a depressed skull fracture. A coup contusion develops from transient inbending of the calvarium but does not have to be associated with a fracture. It can occur under the site of impact or in areas of the brain located near bony protuberances on the inside surface of the calvarium, under the frontal and temporal lobes, and on the roof of the orbit. Contrecoup contusions occur 180° opposite the site of the initial head impact.

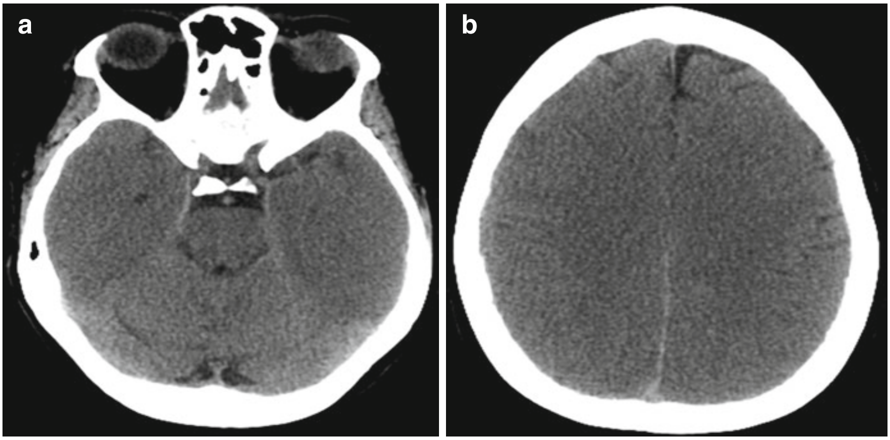

Fig. 40.7 (**a**, **b**) Non-contrast enhanced head computed tomography (CT) in a patient 24 h after a motor vehicle collision shows diffuse loss of gray/white matter interface with sulcal and basilar cistern effacement consistent with diffuse cerebral edema. Note that the cerebellum is spared and appears brighter than the cerebral hemispheres

Acute contusions can be subtle on initial non-contrast CT exams. They appear as patchy, ill-defined areas of low attenuation in one of the common locations described above. As the contusion evolves, vasogenic edema develops and it takes on the more classic appearance of solitary or multiple focal areas of low or mixed attenuation with or without tiny areas of increased density representing petechial hemorrhage ("salt and pepper" appearance). Frank hemorrhagic transformation or coalescence of petechial hemorrhages into a hematoma is not uncommon after 24–48 h (Fig. 40.8a–c). Contusions are far more conspicuous on MR imaging.

Diffuse Axonal Injury

Diffuse axonal Injury (DAI) results from rotational acceleration/deceleration forces that exceed the elastic stretching limit for an axon. The result is a spectrum of changes to the axon that depends on the severity of the injury. In the acute phase, injury leads to edema and demyelination. Eventually, disconnection of the axon can occur resulting in fiber loss (Wallerian degeneration). The initial non-contrast enhanced CT appears normal in the vast majority of the patients subsequently proven to have DAI (50–80 %). Delayed CT scanning

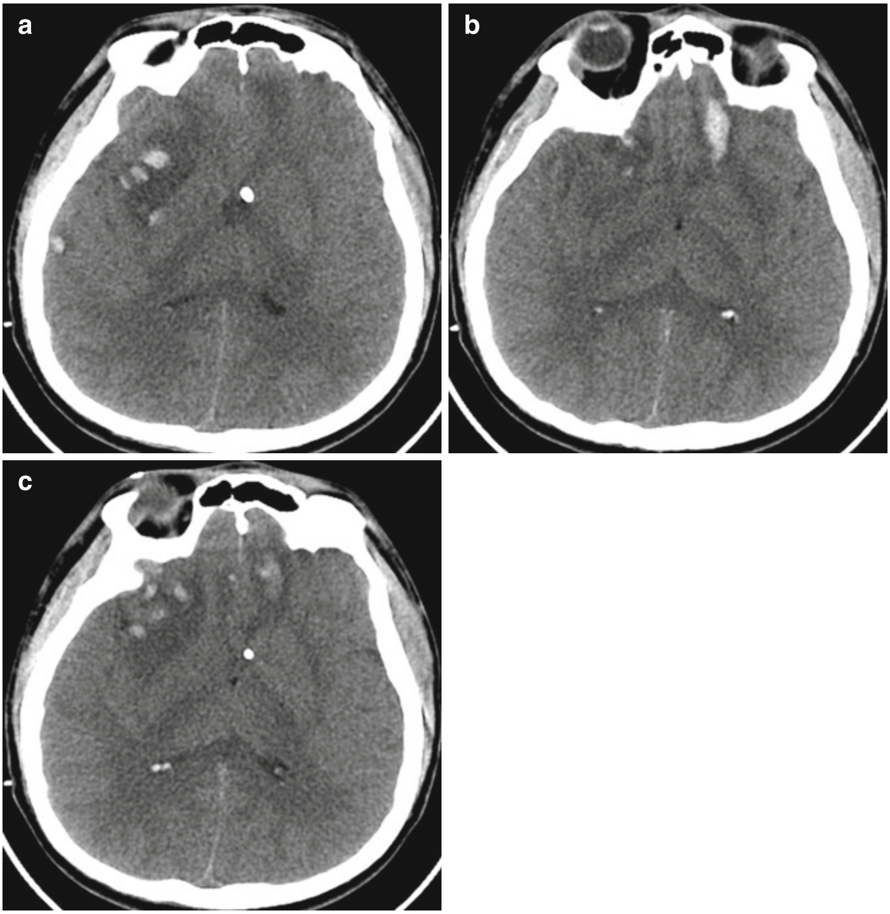

Fig. 40.8 (**a**–**c**) Patient involved in a motor vehicle collision. Non-contrast enhanced computed tomography (CT) demonstrates hemorrhagic contusions anterior inferior frontal lobes as well as right temporal lobe. Note surrounding edema resulting in mass effect. A ventriculostomy catheter is in place

may show areas of petechial hemorrhage in characteristic locations (gray-white matter junction, corpus callosum, dorsolateral midbrain) (Fig. 40.9a, b). Unfortunately false negatives with CT are not uncommon (30 %). Therefore, if there is clinical concern for DAI, an MRI should be obtained as soon as is feasible (Fig. 40.10a–c).

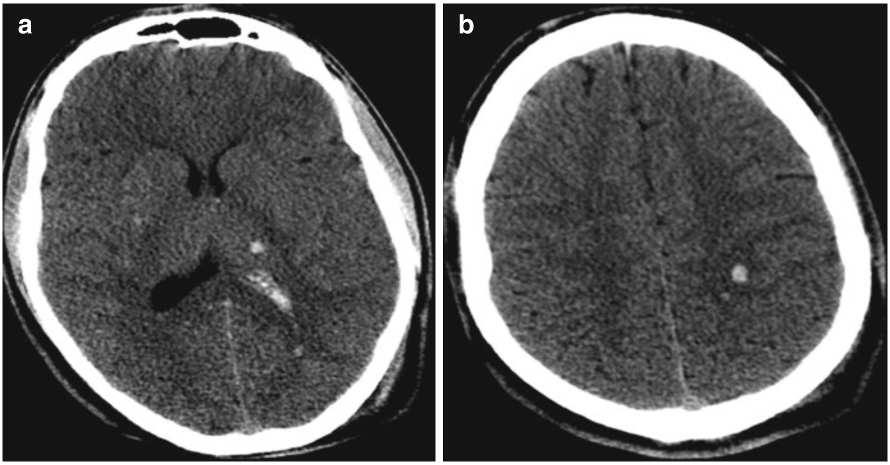

Fig. 40.9 (**a**, **b**) A young patient involved in a high speed motorcycle accident. Multiple images from non-contrast enhanced computed tomography (CT) demonstrate multiple scattered small foci of hemorrhage at the gray-white junction and left thalamus. The overall pattern favors diffuse axonal injury (DAI)

Cerebrovascular Injury

This entity includes a spectrum of pathologies, including vessel dissection, pseudoaneurysm formation, complete transection or occlusion. Concern about a vascular injury should be raised when there is a bony injury adjacent to a vessel. CT angiography is often the initial imaging modality of choice because of its non-invasive nature. If this study demonstrates an injury or the study is equivocal, formal angiography, which can be both diagnostic and therapeutic, may be indicated. Because of the associated risk for pseudoaneurysm formation, CT angiography is often performed after penetrating head injuries.

Laceration of an artery adjacent to a vein can lead to a traumatic arteriovenous fistula (AVF). The classic example is the carotid cavernous fistula (CCF) which results from an injury to the internal carotid artery (ICA) adjacent to the cavernous sinus. Since symptoms related to the CCF (proptosis, ophthalmoplegia with vision loss and facial pain) often present in a delayed fashion, the presence of skull base fractures involving the carotid canal should raise suspicion. CT or MRI may demonstrate lateral bowing of the cavernous sinus, dilated superior ophthalmic vein, stranding of the retrobulbar fat, enlarged extraocular muscles and proptosis. Conventional catheter angiography demonstrates early filling of the cavernous sinus during the arterial phase with early venous outflow, most commonly into the superior ophthalmic vein.

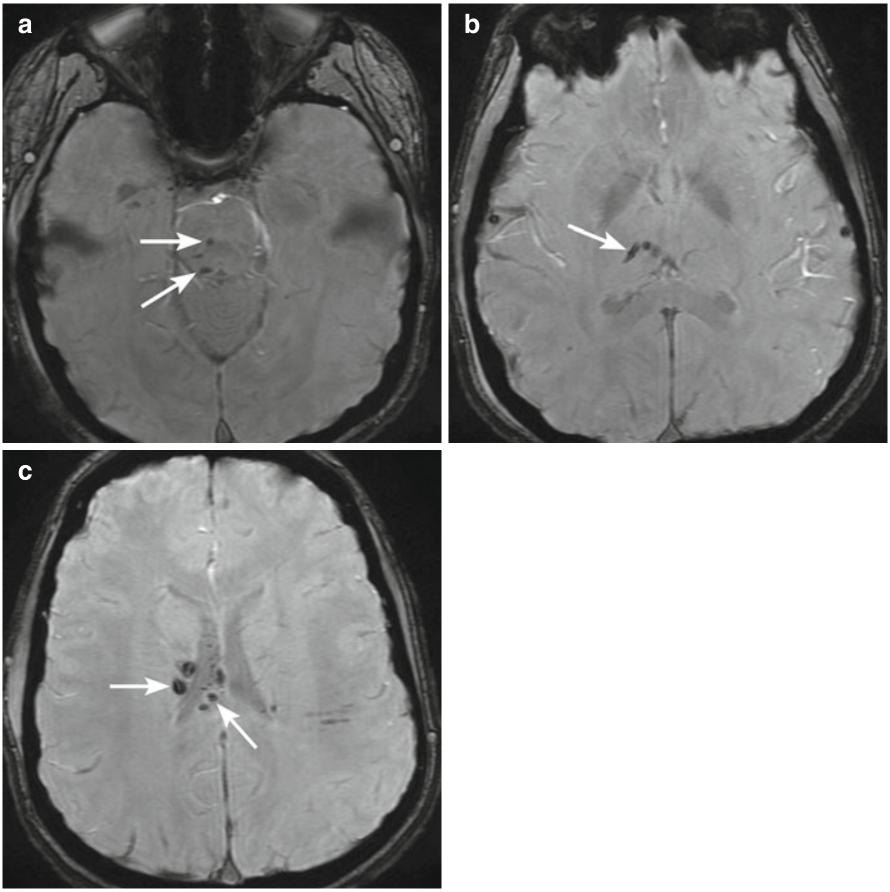

Fig. 40.10 (**a**–**c**) A young patient involved in a high speed motor vehicle collision. Gradient echo images demonstrate areas of susceptibility (*arrows*) involving the right aspect of the pons, periaqueductal gray matter, right thalamus and corpus callosum in a pattern consistent with diffuse axonal injury

Teaching Points

1. CT imaging of the brain is critical to the initial management of patients with TBI.
2. Classification of TBI includes mechanisms (blunt, penetrating, or blast), severity (mild = GCS 13–15, moderate = GCS 9–12, severe = GCS ≤8), and location of intra-cranial injuries (EDH, SDH, SAH, IPH, IVH, or DAI).
3. Angiography (either CT angiography or catheter angiography) is important for patients with injuries near the intracranial vessels.
4. MRI is not usually helpful acutely, but can be useful for fully evaluating the scope of brain damage after the acute phase.

Chapter 41
Spinal Cord Injury

Rajiv R. Shah and Samuel A. Tisherman

Clinical Problem

A 19-year-old male was ejected from the back of a pick-up truck in a sharp turn. Eyewitnesses say that he landed on his head. On admission to the trauma center he is slightly obtunded but orientated. He is hypotensive and bradycardic. He is not able to move his legs and had decreased rectal tone. His biceps strength is normal but there is a significant triceps weakness bilaterally. He has no sensation below the clavicle.

Spinal cord injury (SCI), though uncommon, causes significant morbidity and mortality. Most patients are young adults, predominately males. Patients with SCI frequently have concomitant traumatic brain injury. The primary mechanism of SCI is direct trauma, either with or without underlying spondylosis. Motor vehicular collisions and falls are the causes of nearly 70 % of the cases. Other causes include violence (primarily gunshot wounds), sports, and recreational activities. Less commonly, SCI occurs from vascular compromise, usually from arterial disruption, arterial thrombosis or hypoperfusion.

The initial injury is caused on a neuronal level by the impact or compression. Secondary injury is caused by inflammation, hypoperfusion or ischemia. Consequently, early management of the patient with SCI is focused on prevention of hypoxemia and hypotension.

Neurologic deficits are classified as either complete or incomplete cord syndromes. Complete cord injury results in the complete loss of motor and sensory function below the traumatic lesion. Incomplete cord syndromes are more variable.

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The central cord syndrome typically involves cervical lesions resulting in motor weakness that is greater in the upper extremities, particularly distal muscle groups, than lower extremities. Dysthesias are common in the upper extremities. In the anterior cord syndrome, there is loss of motor function, pain and temperature sensation, with preservation of proprioception, vibratory sense, and deep pressure sensation below the level of the injury. The Brown-Sequard syndrome is due to a hemisection cord injury, resulting in both ipsilateral motor and proprioreception loss with contralateral pain and temperature sensation loss.

SCI may cause loss of sympathetic tone below the level of the injury leading to neurogenic shock, particularly in complete injuries involving the cervical or upper thoracic spine. Hypotension worsens outcomes, but it is not clear that artificially increasing blood pressure to supranormal levels improves outcome.

Patients may also suffer spinal shock resulting in spinal cord dysfunction below the level of the injury lasting 24–72 h. Final evaluation of the severity of injury should await resolution of spinal shock.

Cerebrovascular injury in patients with SCI may occur as a result of direct trauma or by a stretch injury to the vessel. The indications for imaging in patients with SCI remain controversial. Patients at particular risk are those with cervical injuries, subluxation, and fractures of the transverse foramen. Although early screening of patients at risk seems appropriate, the best imaging modality is not as clear. CT angiography and MR angiography have been utilized. The gold standard remains formal angiography.

Imaging Techniques

The American Spinal Injury Association (ASIA) Classification of SCI involves a detailed examination of the patient to determine the level and severity of the injury. ASIA classification should not be determined until other life-threatening injuries have been addressed and spinal shock has resolved.

Computed Tomography

A CT of the entire spine should be obtained during the initial assessment of the patient with suspected SCI to evaluate the bony anatomy. The scan should be performed with a multi-slice, helical scanner utilizing adequately thin slices to provide high-resolution sagittal and coronal reconstructions.

Magnetic Resonance Imaging

MRI is the modality of choice for evaluation of the spinal cord and ligaments. It is useful in identifying location of cord injury, degree of cord compression, and establishing whether there is presence of hemorrhage within the cord. Standard imaging protocol involves T1, T2 (Fig. 41.1) and Gradient echo (Fig. 41.2) images.

Fig. 41.1 Magnetic Resonance Imaging sagittal T2 through the cervical spine demonstrating traumatic disc protrusions (*solid black arrow*), long segment cord edema (*open arrow*), focal cord hemorrhage, and extensive posterior cervical soft tissue edema (*white arrow*)

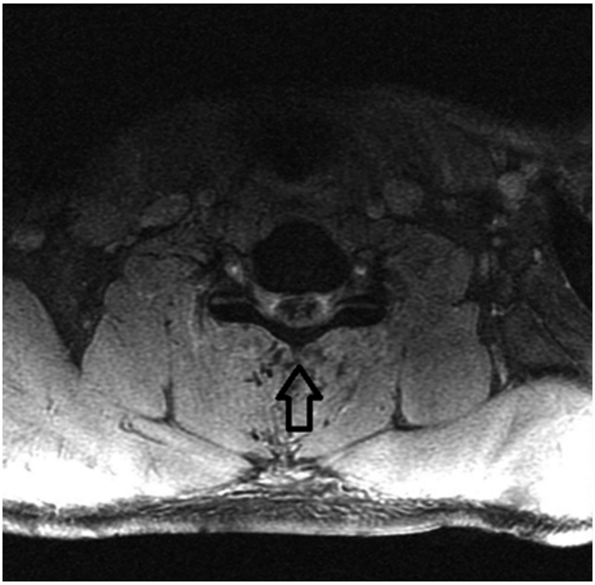

Fig. 41.2 Magnetic Resonance Imaging axial Multiple Echo Recombined Gradient Echo (MERGE) 2D through the cervical spine demonstrating gradient susceptibility in the cervical cord confirming hemorrhage (*open arrow*)

The advent of MRI use in SCI evaluation has led to the revision of the classic spinal cord injury without radiographic abnormalities (SCIWORA) to the more aptly termed SCI without neuroimaging abnormality. Patients with this presentation have a better prognosis than those with radiologic abnormalities. Of the patients with radiologic abnormalities, the presence of hemorrhagic contusions portends the worst prognosis.

Advanced MR neuro-imaging techniques such as diffusion, functional and spectroscopy have further expanded evaluation of cord injury. Diffusion weighted imaging can acutely demonstrate axonal loss. Diffusion tensor imaging shows promise in delineating the white matter tracts affected as well as their response to treatment. Functional imaging allows for correlation between a specific function and cordal anatomy while spectroscopy allows for evaluation of the cord biochemistry in patients with SCI.

Teaching Points

1. High resolution CT with sagittal and coronal reconstructions of the entire spine should be the initial examination of choice.
2. MRI should be used to evaluate the spinal cord and to help prognosticate the severity of SCI.
3. Angiography is indicated for patients at risk for cerebrovascular injury.

Chapter 42
Neck Injury

Graciela Bauzá, Ryan T. Fitzgerald, and Vikas Agarwal

Clinical Problem

A 19-year-old male was involved in an altercation during which he suffered a stab wound to the neck, just anterior to the sternocleidomastoid muscle on the left. On arrival in the Emergency Department he is awake and alert, neurologically intact. His vital signs are normal. Examination of the neck reveals a 2 cm long stab wound without active hemorrhage, expanding hematoma, or crepitus.

The neck is a small area where vital structures are in close proximity. Injuries to the neck often extend into the skull base or chest. The severity of injury varies depending on the mechanism, with gunshot wounds typically causing more damage than stab wounds. Neck trauma is classically divided into three zones (Table 42.1). Imaging and management is guided by the location of the injury.

Patients with penetrating trauma to the neck who are hemodynamically unstable or display hard signs of vascular injury (expanding neck hematoma, arterial bleeding, bruit, pulse deficit) or aerodigestive tract injury (respiratory distress, crepitus, subcutaneous emphysema, hoarseness, hemoptysis, dysphagia) should undergo emergent neck exploration in the operating room. For stable patients, imaging is

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Table 42.1 Zones of neck injury

Zone 1	Clavicles and suprasternal notch to inferior aspect of cricoid cartilage
Zone 2	Cricoid cartilage to angle of mandible
Zone 3	Angle of mandible to skullbase

often invaluable for determining the extent of injury and further testing required, thus facilitating optimal patient management and guiding operative intervention.

Imaging Techniques

Computed tomography angiography (CTA) has become the modality of choice in the workup of hemodynamically stable patients with suspected vascular injury in the neck (i.e., carotid, jugular, vertebral vessels). As a result, the rate of surgical neck exploration, particularly negative exploration, has decreased over the past decade. Advantages of CTA include wide availability of multi-detector CT equipment capable of increasingly rapid scan times and reported sensitivity and specificity of 100 and 97 % respectively for the detection of clinically significant vascular and aero-digestive injuries to the neck. There is no difference in approach between penetrating and blunt trauma as long as the patient is stable.

Magnetic resonance imaging (MRI) and MR angiography (MRA) may also play a role. The advantages of MRI/MRA include improved detection of small infarctions and diffuse axonal injury compared to CT/CTA. Additionally, for patients suspected with cervical cord injury, MR assessment of the extra-cranial cerebral vasculature may be included among the sequences acquired during a single (although prolonged) imaging session. Studies evaluating the relative sensitivity and specificity of CTA versus MRI/MRA for the detection of carotid and/or vertebral artery dissection have been unable to show conclusive superiority of one modality over the other. The choice of imaging modality is typically based upon patient, availability, and equipment factors.

Vascular Trauma

Vascular injuries are among the most important of all potential injuries in the neck to recognize and treat expediently due to the high mortality with major arterial injury. Traditionally, Zone II injuries were often explored regardless of hemodynamic status in large part because of the relative ease of accessibility. Injury to Zones I and III required imaging confirmation of a vascular and/or aero-digestive tract injury due to poor exposure and difficulty in control of hemorrhage if the skull base or chest were involved. Mandatory operative exploration without clear injury in hemodynamically stable patients led to many negative explorations. Currently, selective operative management in hemodynamically stable patients has become standard. When evaluating neck injuries it is important to keep in mind that external wounds are not necessarily representative of the full extent of injury given that metallic and/or bone fragments may be deflected or otherwise travel along unknown trajectories through the soft tissues of the neck.

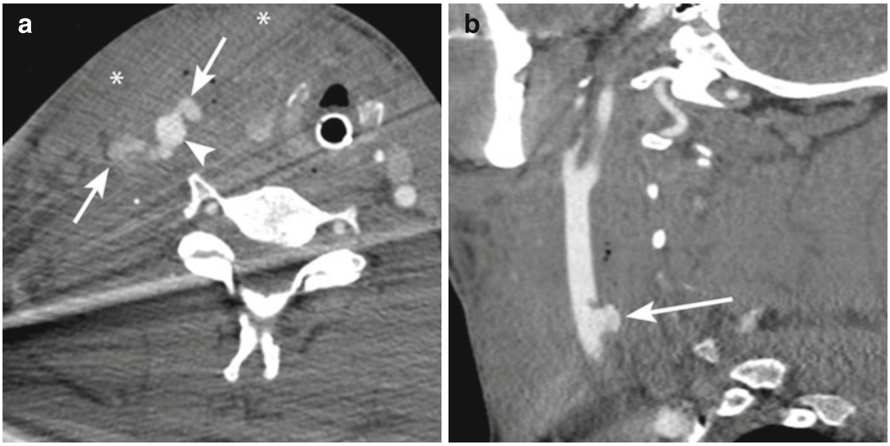

Fig. 42.1 Axial (**a**) and sagittal (**b**) images from a computed tomography angiogram (CTA) of a patient with a gunshot wound to the right neck. There is injury to the anterior and posterior aspects of the right common carotid artery (*arrowhead*) with active extravasation of contrast (*arrows*) consistent with active bleeding and associated large hematoma (*asterisks*). Note small amounts of streak artifact from bullet fragments

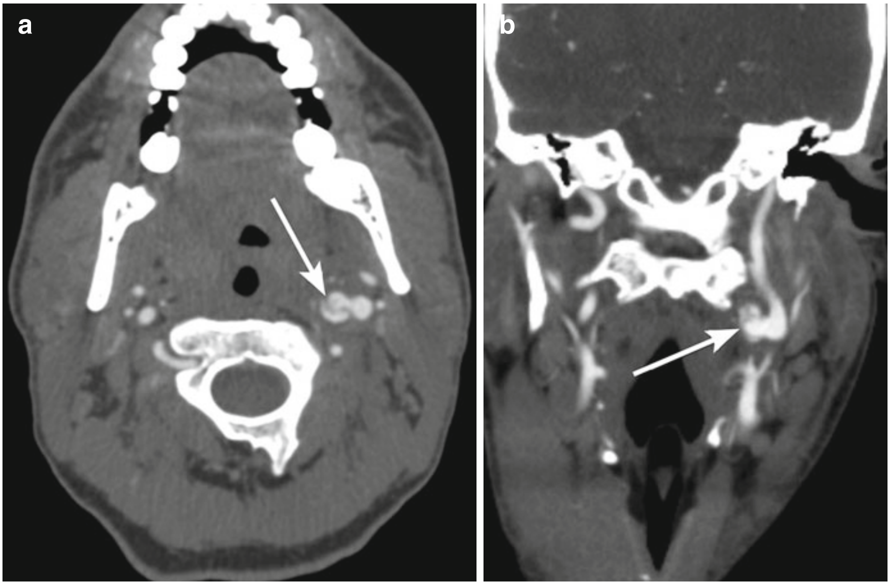

Fig. 42.2 Axial computed tomography angiogram (CTA) image (**a**) in a 26-year-old male with a history of blunt trauma reveals a 1 cm pseudoaneurysm (*arrow*) along the medial aspect of the left cervical internal carotid artery. A coronal CTA image (**b**) demonstrates a broad-based connection between the ICA lumen and pseudoaneurysm. Mixed attenuation indicating contrast mixed with thrombus is seen within the body of the pseudoaneurysm (*arrow*)

Both penetrating and blunt trauma may result in vascular injury in the neck (Figs. 42.1a, b and 42.2a, b). Even in the absence of penetrating trauma, blunt cerebrovascular injury may occur in over 1 % of patients sustaining significant blunt

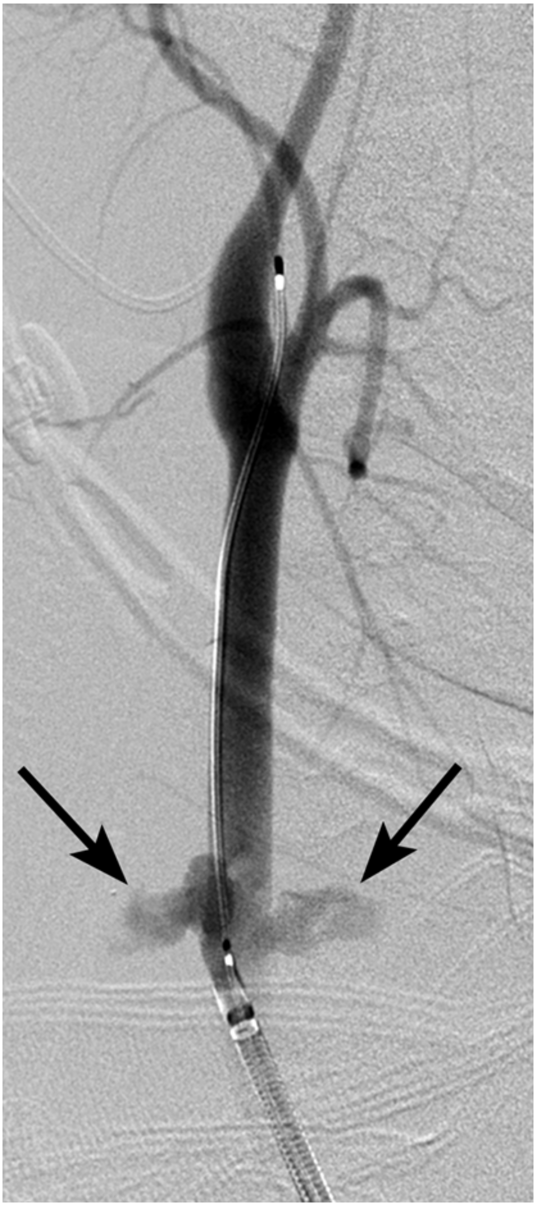

Fig. 42.3 Catheter angiography confirming contrast extravasation (*arrows*) as seen on CTA in Fig. 42.1

trauma and should be considered whenever patients exhibit neurological deficits without explanatory findings on brain imaging, major facial trauma or basilar skull fracture, cervical spine fractures, cervical bruit, high energy mechanism with neck flexion extension, near hanging, neck hematoma or "seat belt sign." Evaluation for vascular injury in patients with neck trauma begins with CT angiography.

Conventional angiography (Fig. 42.3) is now mainly utilized for cases with equivocal or discrepant results on CTA/MRA or for those in which high pre-test

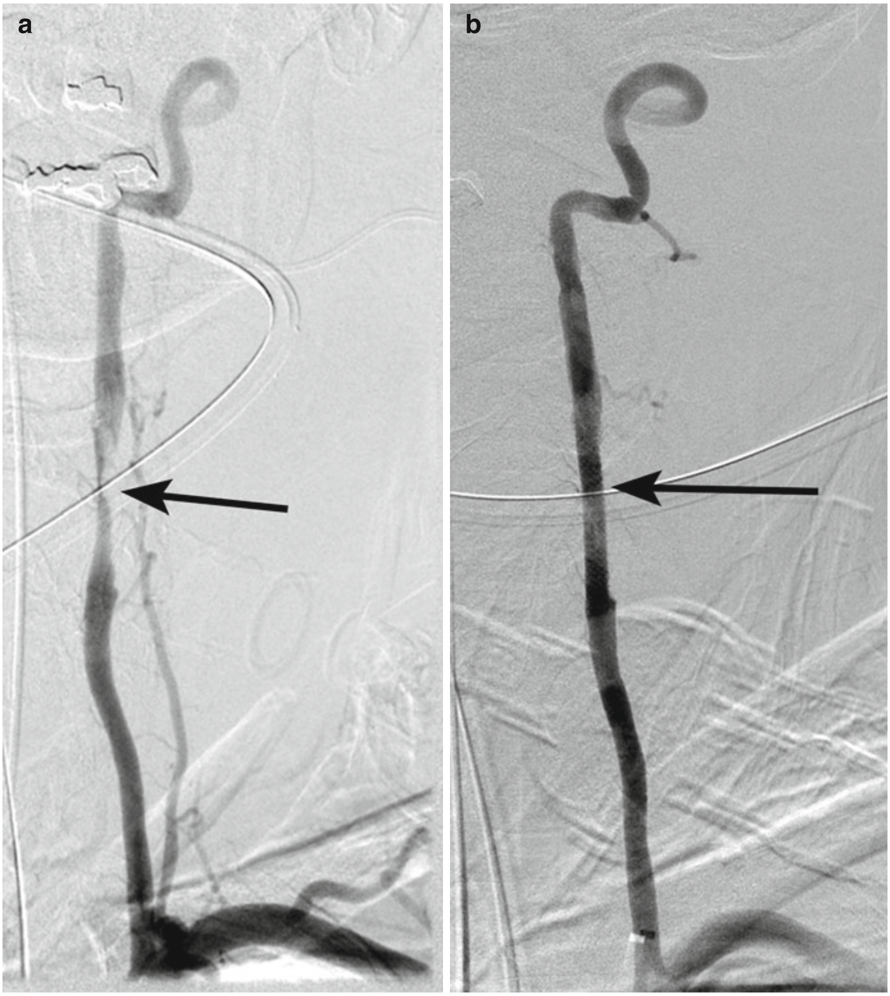

Fig. 42.4 Young patient involved in a motor vehicle collision. (**a**) Catheter angiography demonstrates dissection of the left vertebral artery (*arrow*). (**b**) Repeat angiography following successful placement of a stent graft (*arrow*)

suspicion for injury requiring endovascular intervention demands expedient evaluation and treatment (Fig. 42.4a, b).

Trauma to the Aero-Digestive Tract

The aero-digestive tract in the neck includes oropharynx, nasopharynx, hypopharynx, larynx, cervical esophagus and the trachea above the thoracic inlet. All these structures are susceptible to both blunt and penetrating trauma. Clinicians may be alerted to these injuries by the presence of crepitus in the neck on examination, dysphagia, odynophagia, or by the detection of subcutaneous emphysema on initial screening studies such as plain radiographs or CT of the cervical spine. Fractures involving the first to third ribs and posterior sterno-clavicular dislocation have been associated with aero-digestive tract injuries. When such an injury is suspected, CT examination of the neck and chest with intravenous contrast should be considered to localize of the site of the aero-digestive tract disruption. Contrast-enhanced CT provides assessment for potential associated vascular lesions. Patients with suspected aero-digestive tract injury who exhibit signs of airway compromise should proceed directly to intubation and bronchoscopy with evaluation of larynx as well as esophagoscopy.

Traumatic Laryngeal and Cervical Tracheal Injuries

This pattern of injury has to be considered when extra-luminal gas is seen on initial screening radiographs. Other potential signs include respiratory distress, hemoptysis, stridor, dysphonia, and loss of laryngeal prominence or hyoid elevation on exam. Ensuring control of the airway, potentially requiring the use of bronchoscopy, is the initial goal in the patient experiencing respiratory distress after sustaining a neck trauma. In some cases, fibreoptic intubation or even surgical tracheostomy may be required. Imaging evaluation should only be sought after the airway is adequately controlled. High-resolution CT is the modality of choice for the assessment for laryngeal injury, including laryngeal dislocation, fracture or hematoma (Fig. 42.5a–c). However, direct visualization has to be considered if the clinical suspicion for laryngeal injury persists following a negative CT exam.

Esophageal Injury

Esophageal injury must be ruled out within 24 h as morbidity increases exponentially with missed injuries and surgical management becomes more complex. Assessment for injury to the hypopharynx and cervical esophagus is inherently challenging in patients requiring ICU care due to their inability to cooperate with contrast esophagography, which is commonly the study of choice for investigation of potential esophageal injury. For trauma patients with penetrating neck injuries, CT without oral contrast medium may be able to demonstrate an injury to the esophagus (Fig. 42.6a, b).

If a patient is co-operative enough to undergo a contrast fluoroscopic exam caution with the use of contrast agents is important. Due to the potential for fibrosing mediastinitis after barium extravasation through a thoracic esophageal defect, water-soluble agents such as gastrograffin are used initially. However, water-soluble contrast medium can cause chemical pneumonitis if aspirated into the lungs. Given the improved sensitivity of thicker barium-based agents over water-soluble contrast, some would suggest proceeding with barium esophagography if no evidence of extravasation is seen with initial water-soluble swallows.

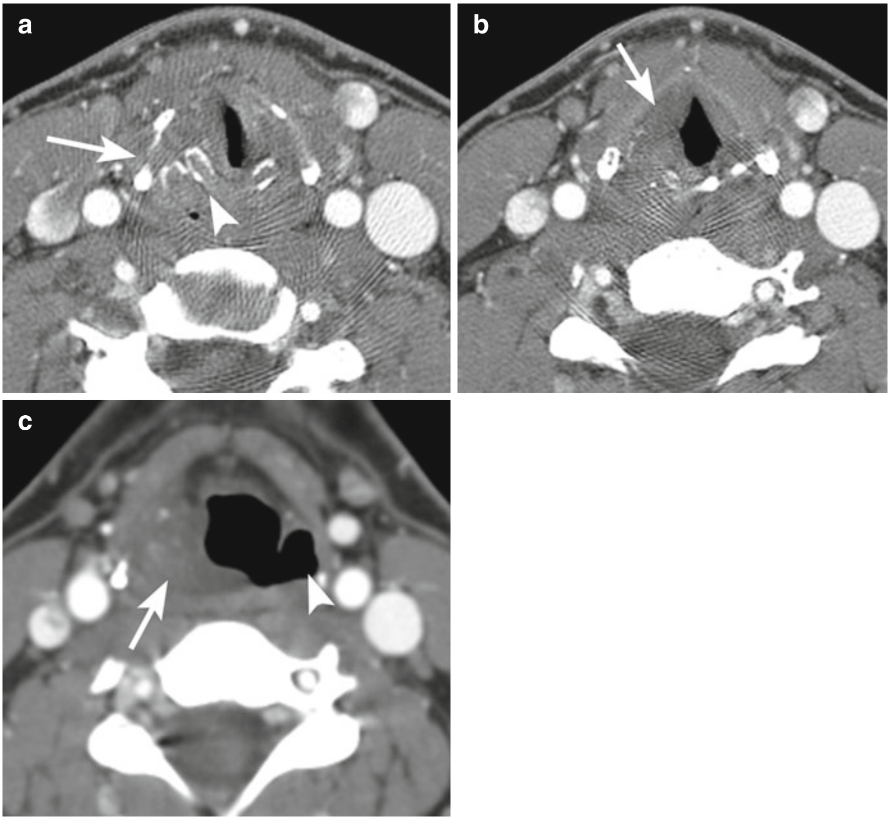

Fig. 42.5 Contrast enhanced computed tomography (CT) examination of a patient struck in the neck with a baseball demonstrates: (**a**) Fractures of the right cricoid (*arrowhead*) and thyroid (*arrow*) cartilages with medial displacement and anterior displacement of the right arytenoid cartilage. (**b**) Soft tissue swelling and hemorrhage involving the true and false cords which extends up to the right aryepiglottic fold (*arrow*). (**c**) There is obliteration of the piriform sinus (*arrow*) and mild mass effect on the right side of the airway, which remains patent. The left piriform sinus is normal (*arrowhead*)

In intubated and ventilated patients endoscopy allows for the detection of hypopharyngeal injuries that are notoriously difficult to identify via contrast esophagography as well as injuries of the cervical esophagus. Sensitivity of endoscopy may be as high as 100 %. Endoscopy provides the added benefit of being done at the bedside or in the operating room.

Cervical Spine Injury

Fracture, dislocation, and/or cervical cord injury occurs in 3–4 % of major trauma victims and may be predicted by age >65 years, male sex, GCS <15, LeFort facial fractures, and certain high risk injury mechanisms. Non-enhanced CT of the spine

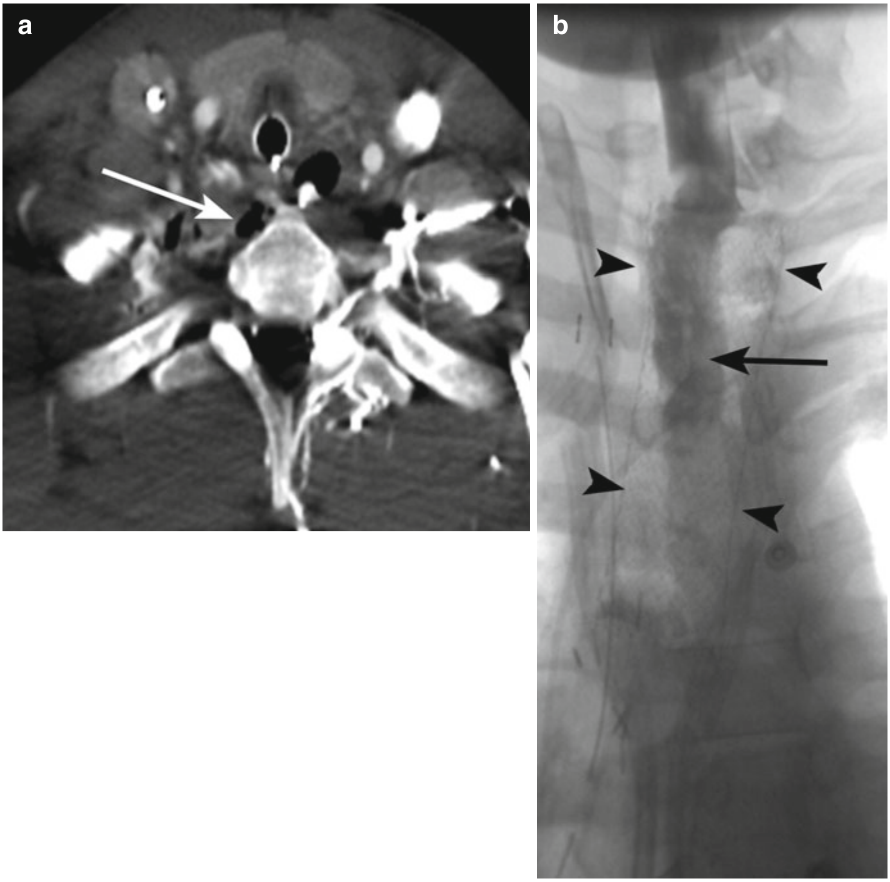

Fig. 42.6 A young patient suffered a gunshot wound to the neck. (**a**) Initial trauma chest computed tomography (CT) demonstrated evidence of proximal posterior esophageal injury with gas and contrast (*arrow*) extending along the right apical pleural space and right neck into the supraclavicular fossa. (**b**) The patient was subsequently taken for emergent esophageal stenting. Post-procedure swallow study shows operative changes related to esophageal stent (*arrowheads*) placement and contrast material in the esophageal lumen (*arrow*) with no evidence of residual leak

is the current gold standard assessment tool to exclude cervical spine injury following trauma, as the sensitivity of plain radiography is far inferior to that of CT.

Debate continues regarding the most appropriate management of the obtunded patient or of those otherwise unable to be cleared by neurological examination after a negative cervical spine CT. Multiple groups have reviewed the utility of MRI scans in obtunded patients and concluded that it is not required on a routine basis in these patients. The risk of missing an unstable cervical spine injury with the current generation of CT scanners appears to be negligible. Further, in patients with a negative admission cervical spine CT, MR very rarely yields results that change management. Until conclusive data provided by large series is available, decisions regarding the merits of MR in the setting of a negative CT scan may be determined in large part by institutional and individual physician preferences.

Teaching Points

1. CT angiography offers the most expedient and readily available imaging modality for assessment of potential vascular injury in the neck for hemodynamically stable patients.
2. Advantages of MR angiographic assessment for vascular injury include concurrent evaluation of the brain and spinal cord, but at the cost of increased scan time and greater difficulty with simultaneous monitoring and management of a critically ill patient.
3. CT may facilitate localization of aero-digestive tract injury in many cases. However, endoscopy remains the gold standard and should be the initial strategy in patients with an unstable airway.
4. Negative CT of the cervical spine excludes unstable cervical spine injury. The role of MR assessment for potential injuries not detectable by CT remains much debated.

Chapter 43
The Pregnant Trauma Patient

Jason L. Sperry and Matthew T. Heller

Clinical Problem

Twentynine-year-old female at 22 weeks gestation was involved in a motor vehicle collision. She had an altered mental status with GCS 7. She was intubated at the scene. En route she developed hypotension (SBP <90 mmHg) and heart rate increased to 125 bpm. Fluid resuscitation was initiated and her hemodynamics improved.

The more active lifestyle, the increased number of women in the work force, and the higher exposure to domestic violence and abuse in our society today, place pregnant women at significant risk for traumatic injury throughout gestation. The most common mechanism is motor vehicle collision, which is usually responsible for over half of all trauma events during pregnancy. The remainder is divided almost equally among falls and interpersonal violence, or assault. The incidence of trauma increases as women approach the later stages of gestation, primarily the late 2nd and 3rd trimesters. A majority of these pregnant trauma patients are minimally injured. This is due, in part, because women are more likely to present to the hospital after a potentially injurious event because they are pregnant, rather than because they are injured. Despite this, it has been shown that even with minor maternal injuries, there is increased risk of poor fetal outcome in the acute setting and throughout the remaining pregnancy.

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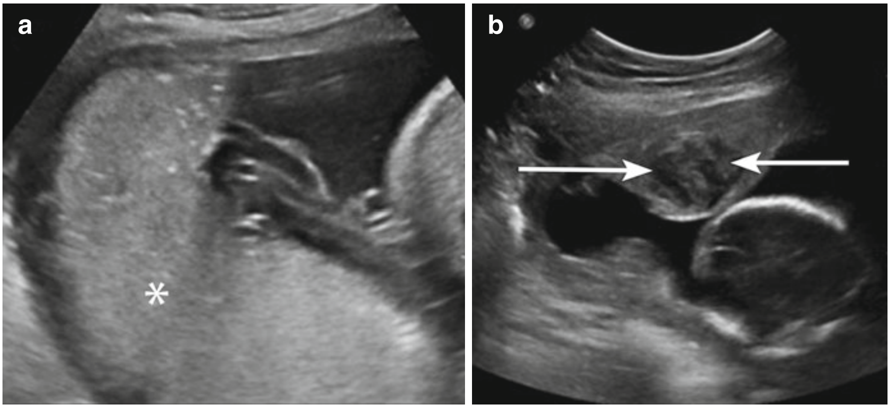

Fig. 43.1 (**a**) Transverse image from a pelvic ultrasound (US) shows a normal-appearing placenta (*asterisk*). (**b**) In a different patient, the US shows a focal hemorrhage (*arrows*) within the placenta due to focal abruption

Fetal Monitoring

All pregnant women with a potentially viable fetus (i.e. able to survive in an extra-uterine environment), defined by a gestational age of 24 weeks or greater, should undergo continuous cardiotocographic monitoring (CTM). This consists of measuring simultaneous fetal heart rate and uterine contractions of the mother. CTM remains the most widely used modality for evaluation of the fetus, and is considered the "gold standard" for fetal assessment following injury. Multiple studies have shown that fetal morbidity and mortality can occur even in women without apparent injury. The objective of the monitoring period is to identify premature labor, placental abruption, and fetal distress for which an urgent intervention is needed. Less than 5 % of fetal deaths following maternal injury are due to direct injury to the fetus while up to 70 % are due to placental abruption. In addition to physical examination, ultrasound (US) (Fig. 43.1a, b) is important for evaluating the fetus and uterus for potential complications. CTM may identify fetal distress from placental abruption before changes in physical examination are evident.

Women with no apparent significant injury, without concerning physical examination findings such as vaginal bleeding or uterine tenderness, who have a normal 6 h CTM tracing without evidence of contractions or abnormal fetal heart rate variability, can be safely discharged from the hospital. An extended period of CTM for 24 h is required If:

- any monitoring abnormality is identified during the initial monitoring
- the mother requires admission for management of her injuries
- the mother requires general anesthesia
- the mother is clinically considered to be at high risk for fetal complications based on history or mechanism of injury.

Also, direct trauma to the uterus can cause release of decidual lysosomes and arachidonic acid metabolites that can result in uterine contractions and can induce premature labor and pre-term delivery.

Trauma Management in Pregnancy

Despite two individuals being at risk, the first and primary goal in treating a pregnant trauma victim is maternal stabilization. Achieving maternal wellbeing offers the best chance for preventing fetal morbidity and mortality. Simple measures like preventing hypotension through compression of the vena cava by placing pregnant patients greater than 20 weeks gestation in the left lateral decubitus position throughout resuscitation will help decrease potential fetal problems.

Early obstetric consultation should be obtained while initial resuscitation and assessment are occurring. A full obstetric history should be included along with the usual history and physical examination. An estimation of gestational age derived from the history and by accessing fundal height is an important factor in the decision regarding early delivery if needed. In addition to the trauma physical examination, a pelvic examination is required to rule out factors associated with fetal or placental injury, such as vaginal bleeding, ruptured membranes, or a bulging perineum.

Screening

Assault or interpersonal violence effects up to 20 % of all pregnant women sometime during gestation, though perhaps as few as 4–10 % of cases present for medical care. Such violence is commonly associated not with just a single event, but rather multiple episodes are the norm (Fig. 43.2). Violence occurs across all races and

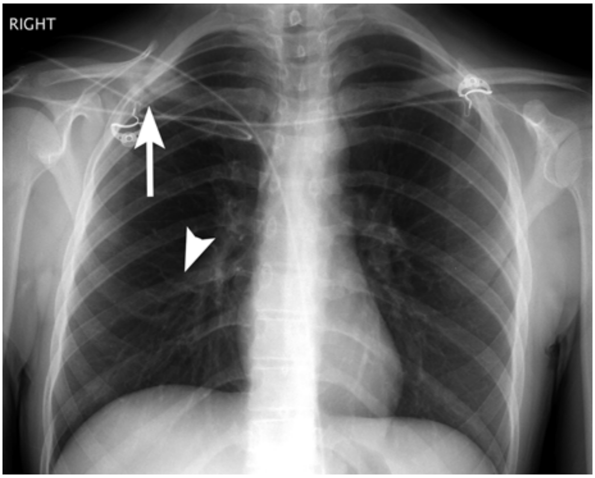

Fig. 43.2 Chest radiograph shows an acute, non-displaced rib fracture (*arrowhead*) and a healed clavicle fracture from possible prior domestic abuse

Table 43.1 Interpersonal violence screening questionnaire

Have you been kicked, hit, punched or otherwise hurt by someone within the past year?
Do you feel safe in your current relationship?
Is there are partner from a previous relationship who is making you feel unsafe now?

socioeconomic levels. Its been shown that abused mothers are twice as likely to begin their prenatal care in the third trimester. Women who report a history of abuse are at increased risk of poor fetal outcome. Interestingly, women who decline to be interviewed for interpersonal violence have even higher rates of fetal complications. Because a single trauma admission may be the only chance to pick up these types of events before a serious maternal or fetal injury may occur, screening using a validated three question questionnaire is currently recommended and included in advanced trauma life support (ATLS) recommendations (Table 43.1.) Interpersonal violence should be considered when:

- the injuries appear to be inconsistent with the history,
- the patient has a history of depression, substance abuse, self-abuse or suicide attempts,
- the patient blames herself for the injuries,
- the partner seems controlling and tries not allow the patient to be examined without him,
- the patient has had frequent visits.

Imaging Considerations for the Pregnant Patient

As in other trauma scenarios, imaging plays a major role in the diagnostic assessment of the pregnant trauma patient. Choosing the proper imaging examination to evaluate the pregnant patient can pose a dilemma for the clinician who is trying to facilitate prompt diagnosis while balancing radiation dose. Although imaging modalities that do not use ionizing radiation, such as US and magnetic resonance imaging (MRI), are strongly preferred when possible, their limitations can be substantial. The availability, speed and reliability of computed tomography (CT) are advantageous, but CT is associated with significant radiation exposure. Plain radiography and angiography are additional potential sources of ionizing radiation used in this setting. Although there are theoretical risks of fetal carcinogenesis, congenital malformations and mental retardation, there is no documented risk at current exposure levels commonly associated with diagnostic imaging. The risk of abnormality is considered to be negligible at 50 mGy or less. Practice guidelines for imaging the pregnant patient are based on the guiding principle that the mother's health is the most important factor for fetal survival and favorable outcome. Therefore, concerns regarding fetal radiation dose exposure should not delay or preclude radiologic evaluation in trauma patients requiring accurate and prompt diagnosis.

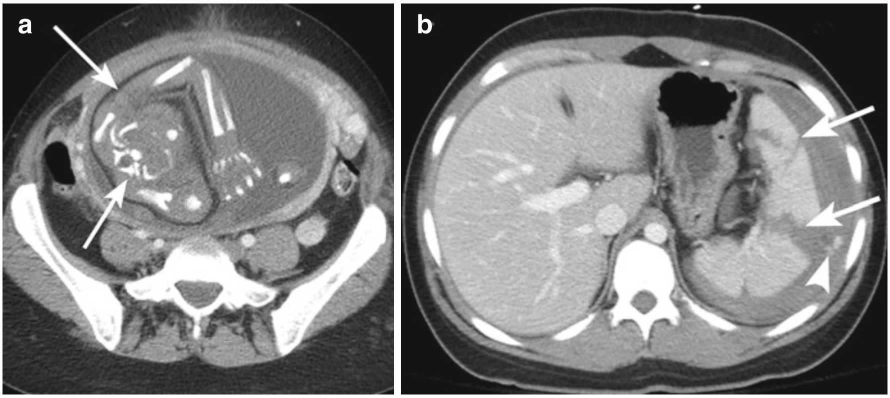

Fig. 43.3 (**a**) Post-contrast computed tomography (CT) of the pelvis shows a fetus within the gravid uterus (*arrows*). (**b**) More superiorly, there are multiple splenic lacerations (*arrows*) and focal active hemorrhage (*arrowhead*) with peri-splenic hematoma

Ideally, an attempt should be made to initially image mother and fetus with a modality that does not require ionizing radiation if possible. US provides appropriate first-line imaging, if necessary allowing rapid triage. The Focused Assessment by Sonography for Trauma (FAST) is considered to be positive when a significant volume of intra-peritoneal fluid or a pericardial effusion is present. However, the finding of a small amount of pelvic free fluid is less specific than free fluid elsewhere in the abdomen. Unfortunately, drawbacks of using US include operator dependence and suboptimal performance compared to body CT (Fig. 43.3a, b). Overall, the sensitivity and specificity of US for detection of abdominal injury in the pregnant patient are 61–86 % and 98–100 %, respectively. However, US is notoriously insensitive for detection of most pancreatic, renal, retroperitoneal, mesenteric and bowel injuries.

After the mother has been stabilized, US can be used to evaluate the fetus and placenta, since placental abruption is one of the most critical diagnoses to make in the pregnant trauma patient and a leading cause of fetal demise. Although US is the imaging modality of choice in this setting, its accuracy for determination of placental abruption is estimated to be only 50 %. US findings of abruption include visualization of separation of the placenta from the uterine wall, identification of retroplacental hematoma and echogenic amniotic fluid due to hemorrhage. In addition to placental evaluation, US allows rapid assessment of fetal anatomy, heart rate and biometry.

If the initial US is negative, consideration may be given to MRI evaluation of the abdomen and pelvis in an attempt to avoid radiation. However, there is no literature support for emergency use of MRI to evaluate the abdomen and pelvis in pregnant patients. Despite the exquisite soft tissue contrast resolution of MRI, its use in the pregnant trauma patient is often impractical due to examination length, patient comfort and potential difficulty monitoring patients. Additionally, although there is no definitive evidence that MRI harms the fetus, potential concerns related to acoustic exposure and tissue heating have been raised. However, the American College of Radiology (ACR) advocates use of MRI if the imaging results are of direct benefit to the mother or fetus. Otherwise, elective maternal MRI examinations should be postponed until after pregnancy.

In most trauma cases an imaging modality that uses ionizing radiation, such as CT or radiography, may be chosen if the benefits of the information obtained from the scan outweigh the risks to the mother and fetus. CT is primarily used to assess for maternal injuries, but theoretically CT can also assess placental and fetal trauma. The CT appearance of such injuries is highly variable and may not be readily recognized prospectively.

The spectrum of CT findings of abdominopelvic trauma in pregnant patients is similar to that of the non-pregnant population. However, retroperitoneal hemorrhage is more common in pregnant patients due to the increased blood flow associated with pregnancy. Additionally, the liver, spleen and bladder are more susceptible to trauma due to their displacement by the gravid uterus. Maternal injuries more commonly associated with fetal demise include penetrating trauma, significant head injury and pelvic and acetabular fractures. In the setting of maternal stabilization, the most common cause of fetal demise is placental abruption. Placental abruption is due to shear forces between the uterus and the placenta. It is characterized on CT by uteroplacental separation, retroplacental hematoma or devascularization of a portion of the placenta shown as a nonenhancing region. The accuracy of CT in the diagnosis of placental abruption is unknown. In some instances, retroplacental clot can not be distinguished from uterine thickening or contraction, resulting in a false negative CT. Conversely, chronic infarctions, venous lakes and chorionic villa indentations may be confused with acute pathology in some cases. It is therefore very important to always correlate imaging findings with fetal monitoring.

Technical Considerations

When deciding to use ionizing radiation, physicians involved in the care of the pregnant patient should strive to minimize radiation according to the principle of ALARA (As Low As Reasonably Achievable) without compromising the diagnostic quality of the examination. This principle accounts for deterministic and stochastic effects of radiation. Deterministic effects occur when a defined threshold of radiation exposure is reached; general examples include organ malformations and impaired neurologic development. In contrast, stochastic effects are not dose dependent and may occur after any level of radiation exposure; examples include childhood malignancies such as leukemia and lymphoma. In the first 14 days after conception, the only risk of radiation exposure is pregnancy loss; however, it should be noted that doses used for diagnostic medical imaging have not been associated with such an effect. Radiation reduction is most critical between 2 and 15 weeks of gestation, as this timespan encompasses organogenesis (2–8 weeks) and is the most radiation sensitive period for the fetus. Effects associated with radiation exposure during this period include stunted growth, mental retardation, alterations of organogenesis, increased risk of malignancy and miscarriage. During organogenesis, the estimate for the approximate threshold dose for induction of these untoward events is greater than 100 mGy. The estimated threshold dose for mental retardation in fetuses between 9 to 15 weeks is also greater than 100 mGy. Comparatively, the estimated absorbed fetal dose from maternal CT is substantially less. Although much knowledge regarding the effects of radiation dose on the fetus has been gleaned from experimental animal studies and atomic bomb survival data, no specific safe threshold for radiation exposure has been determined. However, fetal doses below 50 mGy (5 rad) have not been proven to cause fetal malformations or to increase the risk of abortion, while fetal doses between 50 to 150 mGy (5–15 rad) may have potential detrimental effects. In practice, the fetal dose during CT is influenced by multiple factors such as CT scanner settings, maternal body habitus, ability to provide pelvic shielding and distance of the fetus from the center of the beam. Estimates of fetal dose from a maternal head CT are felt to be less than 0.1 mGy (0.01 rad) since the fetus is remote from the epicenter of the CT beam. Conversely, CT of the maternal abdomen and pelvis may incur a fetal dose of approximately 17–35 mGy (1.7–3.5 rad). While it is not possible to measure the fetal dose directly, effective dose calculations have resulted in estimated it to be 7.3–14.3 mGy/100 mAs (0.73–1.4 rad/100 mAs) during simulations. With newer CT technology, the patient's radiation dose can reduced through image reconstruction techniques and the use of dose modulation calculations based on the patient's weight and body habitus.

The typical CT protocol for pregnant patients with suspected abdominopelvic trauma consists of acquiring 5 mm images through use of helical technique. Multiplanar reformatted images are reconstructed from the original scan data. Additional excretory phase images can be obtained approximately 10 min after injection of intravenous contrast material in those patients suspected of sustaining renal collecting system rupture or to assess for active hemorrhage into a hematoma if the initial scan is inconclusive. Diluted contrast material can be instilled into the bladder through a Foley catheter if CT cystography is required to assess for bladder injury in the presence of hematuria, pericystic hemorrhage or pelvic fractures near the bladder. Excretory phase imaging and CT cystography are only used in select patients, as the additional scans will increase maternal and fetal radiation dose.

When imaging the pregnant patient, the use of intravenous contrast material must also be considered carefully. For CT, iodinated contrast material administered intravenously will cross the placenta, but is not teratogenic or mutagenic. The Food and Drug Administration considers iodinated contrast material a Class B drug and its use depends on evaluation of the risk/benefit ratio. On the other hand, intravenous gadolinium based contrast agents for MRI are considered a Class C drug by the FDA and have been shown to cause growth retardation and congenital malformations at high doses in animals. Although no definitive adverse effects have been reported in human fetuses, the ACR guidelines and most radiology departments do not advocate use of gadolinium based contrast agents in pregnant patients.

Teaching Points

1. Providing optimal care for the mother is critical to assure the best outcome for both mother and fetus. Initial assessment of the pregnant trauma patients should follow standard trauma protocols.
2. Early fetal monitoring and obstetric consultation is important after the fetus has reached the point of potential viability, even if the trauma seems minor.
3. A modality that does not use ionizing radiation is preferred for the initial imaging examination.
4. The inherent limitations of these examinations and the need for prompt diagnosis make CT the highest yield examination in many cases.
5. The risks of radiation are small compared to the risk of missed or delayed diagnosis in a pregnant trauma patient.

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